The International Center for Tropical Agriculture (CIAT, its Spanish acronym) is one of 16 food and environmental research organizations known as the Future Harvest centers. The centers, located around the world, conduct research in partnership with farmers, scientists, and policymakers to help alleviate poverty and increase food security while protecting the natural resource base. The Future Harvest centers are principally funded through the 58 countries, private foundations, and regional and international organizations that make up the Consultative Group on International Agricultural Research (CGIAR).

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Agropastoral systems

Maize with pastures.
(Photo taken by
Dennis Friesen)

Rice crops.
(Photo taken by
Mauricio Antorveza)

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Agropastoral Systems for the Tropical Savannas of Latin America

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Prologue

For us to describe the importance of the Latin American tropical savannas in this prologue would only be an echoing of the points already made in the excellent work carried out by the authors of this publication. However, we must mention the enormous expectations the international community has for the use of this region—one of the few areas in the world available for immediate growth in food production. A great challenge thus exists in preserving natural resources while ensuring the sustainability of agricultural and livestock production.

Throughout the 20 chapters of this book, the authors clearly describe their experiences, the potential of agropastoral systems, and the future opportunities for exploiting this ecosystem efficiently and sustainably while preserving its natural resources. The scientific contributions of the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) and the Centro Internacional de Agricultura Tropical (CIAT), together with the efforts of national research programs in Bolivia, Colombia, and Venezuela, have awakened great interest in the international scientific community.

The authors' analyses indicate that integrated agricultural and livestock systems do exist that have good economic prospects for farmers while guaranteeing the sustainability of natural resources for future generations. We therefore believe that investing in research on this ecosystem is justified, and call upon the international community to analyze the information presented by this volume and continue supporting institutional efforts directed toward tropical savannas.

To conclude, we thank the researchers whose dedication and efforts have made possible a publication that, undoubtedly, will serve as reference for the region. The sum of their efforts and interest in collaborative work has produced results that will improve the living conditions of rural populations.

Clayton Campanhola
President, EMBRAPA

Joachim Voss
Director General, CIAT

Preface

The tropical savannas of Latin America represent one of the last major land areas with potential for agricultural production. With an area of over 250 million hectares they are equivalent to the world's area of irrigated crop land. As world population continues to grow the demand for food will increase and, because the productivity of some crops is reaching a plateau, there will be increasing pressure to bring any remaining lands into agricultural production. Thus it seems inevitable that more of the savanna lands will be exploited. Lessons from the experience in the Brazilian *cerrados* suggest that crop monocultures and pastures are not sustainable under current practices. The estimated rate of land degradation in the *cerrados* is between 2%-4% per year. The causes of degradation of crop lands include soil compaction and erosion losses from inappropriate management practices, a rapid loss of soil organic matter, weed infestation, pest and disease problems. Pastures degrade from a lack of maintenance fertilization, poor grazing management, weed, pest and disease infestations.

Farmers, agri-businesses and research institutes are reacting to these problems by searching for, and developing, new improved production systems. In Brazil and in other countries with savannas, these innovations include no-till and minimum tillage systems, integrated crop-livestock systems and agropastoral systems.

This volume reviews the research, progress, and prospects of agropastoral systems in the region. The body of work results from the establishment of an agropastoral network in 1992 and the subsequent workshops held in Brazil (1993), Venezuela (1994), Bolivia (1995), and Colombia (1996). Experiences with agropastoralism from Brazil, Bolivia, Colombia, and Venezuela are reported together with a summary of the achievements and constraints to the further adoption of this promising land use system. The book is the English version of the original Spanish version entitled "Sistemas Agropastoriles en Sabanas Tropicales de América Latina", edited by E.P. Guimarães, J.I. Sanz, I.M. Rao, M.C. Amézquita, and E. Amézquita. Since the first publication (1999), the book has been re-edited to mention recent advances and a new chapter (Chapter 19) on new perspectives of the *cerrados* has been included.

This volume should be of use to farmers, researchers, extension workers, and policy makers who are interested in achieving improved environmentally sound production systems for the acid soil savannas of Latin America and elsewhere.

Support for this publication has come from EMBRAPA and CIAT together with the Managing Acid Soils Consortium which forms part of the CGIAR Systemwide Program on Soil, Water and Nutrient Management.

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PART I

Agropastoral Research in the Tropical Savannas of Latin America

CHAPTER 1

Research on Agropastoral Systems: Background and Strategies

*R. R. Vera**

Contents

Abstract

This chapter briefly describes the context in which agropastoral research in the neotropical savannas is developed. First, it summarizes the latest trends in land use, and the role these have in increasing the proportion of basic agricultural products such as grains, oils, meat, and milk. The increase of staples is closely associated with increased human intervention in the savannas, which has led to a debate on the need to make compatible agricultural land use with the conservation of natural resources. The definition of agropastoral systems in the savannas is analyzed. The role that the Centro Internacional de Agricultura Tropical (CIAT), Colombia, plays in research on agropastoral systems and its relationships with national and other international institutions are discussed. Reference is made to the agreement made with the Programa Cooperativo de Investigación y Transferencia de

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Tecnología para los Trópicos Suramericanos (PROCITROPICOS) on the distribution of responsibilities and work among all institutions participating in this type of research.

Resumen

Se analiza brevemente el contexto en que se desarrolla la investigación agropastoril en las sabanas neotropicales. Inicialmente se resumen las tendencias recientes en el uso de los recursos de tierras y el papel que cumplen en el suministro de una proporción creciente de productos agrícolas y pecuarios básicos tales como granos, oleaginosas, carne y leche. Este fenómeno está estrechamente asociado con una 'antropización' creciente de las sabanas, por lo que se debate la necesidad de compatibilizar su uso agropecuario con la conservación de los recursos. La definición de sistemas agropastoriles en el contexto de las sabanas es objeto de análisis y se discute el papel que el Centro Internacional de Agricultura Tropical (CIAT), Colombia, desempeña en la investigación sobre sistemas agropastoriles y su relación con instituciones nacionales y otras internacionales en estas funciones. En este contexto se hace referencia al acuerdo dentro del marco del Programa Cooperativo de Investigación y Transferencia de Tecnología para los Trópicos Suramericanos (PROCITROPICOS) en relación con la división de responsabilidades y labores entre todas las instituciones interesadas en este tipo de investigación.

Introduction

The Agropastoral Research Network for the Savannas works to promote research on agropastoral systems for savannas and regions that have transformed into savannas. This research operates within the conceptual framework of sustainable agriculture, and recognizes the reality of massive human intervention in these ecosystems.

The neotropical savannas of South America cover about 250 million hectares in Bolivia, Brazil, Colombia, Guyana, and Venezuela, and are connected with other important biomes, such as the Amazon Basin and the Chaco Region of Bolivia, Paraguay, and Argentina (Figure 1). Because of this proximity and, partly, because some of the soil resources are similar, the technology developed for the use of these savannas has influenced agronomic and land use practices applied in these other ecosystems. An example of the degree of anthropogenic intervention in the savanna agroecosystem is the fact that more than 12 million hectares are devoted to annual crops, many of which, such as maize and soybean, require high levels of external inputs, such as agrochemicals, energy, and management.

This region, as mentioned before, is physically connected with other ecosystems of the subcontinent. For example, the area under soybean in 1994-1995 extended 20 million hectares: from the northern limit of the *cerrados*, in the State of Mato Grosso (Brazil), passing, in an almost uninterrupted form, to temperate and subtropical pastures in Argentina and Uruguay, crossing large areas of the Chaco. With variations in input use and crop varieties, the agronomic technology

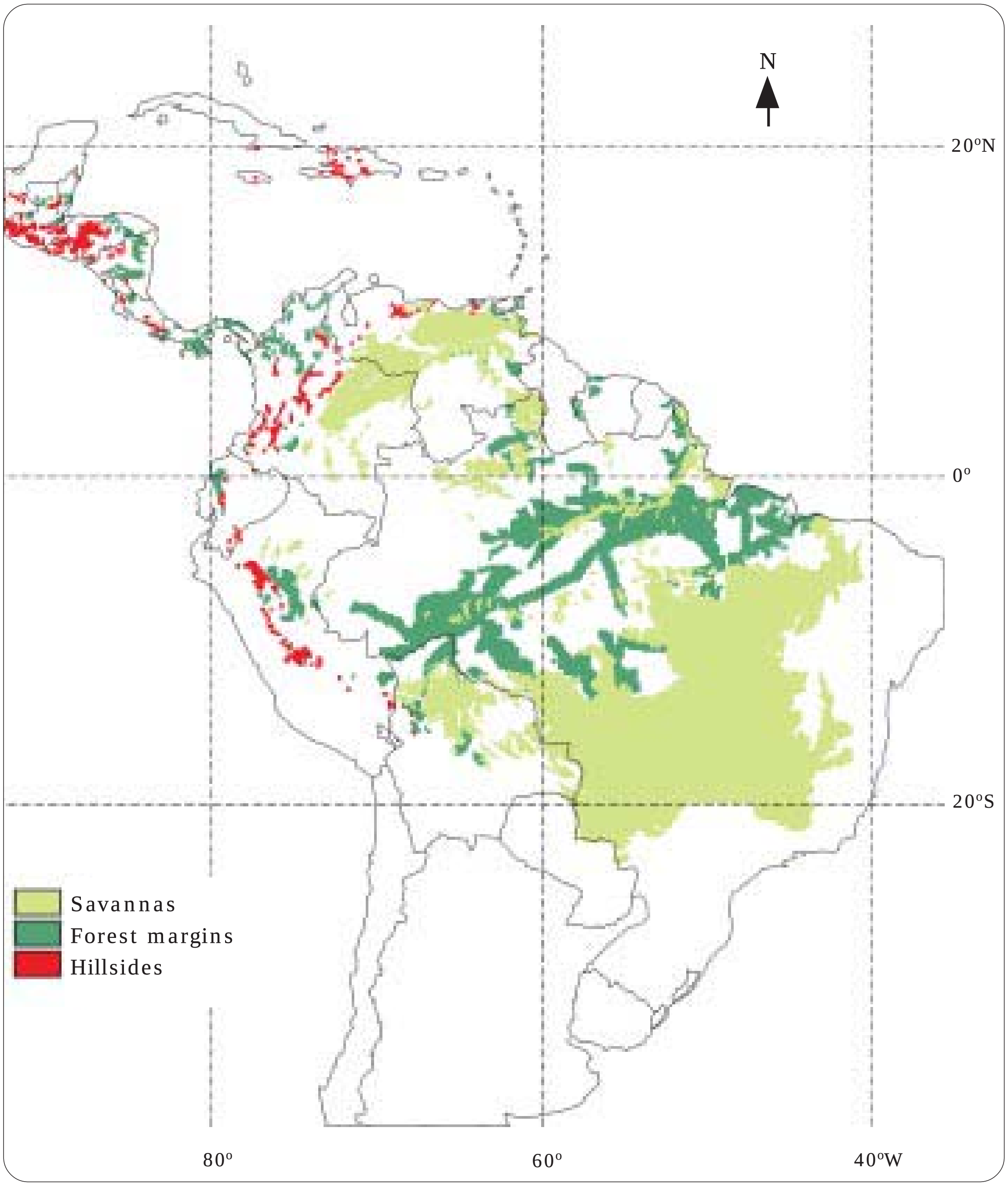

Figure 1. The neotropical savannas, and some bordering ecosystems, found north of the Chaco Region (Bolivia, Paraguay, and Argentina).

SOURCE: CIAT, Land Management Unit, 1992.

is similar throughout this area. Thus, between 30 and 50 million hectares have been converted into monocropped pastures. Other smaller, but still important, areas have been converted into plantations of timber and fruit trees, sugarcane, and African palm, among others.

Such massive agricultural and livestock exploitation of the savannas has meant that, in less than 30 years, the contribution of the natural ecosystem to agricultural production increased from practically zero to values ranging between 20% and 90%, according to country.

Similar percentages are found for the livestock sector. For example, in 1994-1995, about 40% of the national herd of Brazil was maintained in the *cerrados*. Moreover, some countries, among them Bolivia, consider that areas of natural savannas and their derivatives constitute a safety valve for land tenure problems and natural resource degradation in very fragile ecosystems such as the Amazon forest or highly intervened areas such as the high Andean Region. As a consequence, we can foresee a continued growth in human intervention, although, perhaps, at a somewhat slower rate than in recent years.

The challenge then is to face these realities and to contribute, through the generation of technology, to the development of an agricultural and livestock sector that can maintain high levels of productivity, while minimizing environmental risks. From the research point of view, we must quantify the costs and benefits inevitably involved in any modification of natural systems, thereby contributing scientific facts to the debate on development and ecology that arises with ever greater intensity in our modern society. This contribution of agricultural and livestock research, to both the development of the savannas and scientific debate requires adjustments and modifications in institutional research models, as well as in the personal preparation and mental attitude of each individual involved in this process. Within this context, CIAT's role is briefly reviewed here. Also examined are some implications of this experience and the connections with the agropastoral network that functions informally in Latin America.

CIAT in Natural Resources Management

As is well known, CIAT is a research center that focuses its activities on a limited number of commodities: rice, cassava, beans, and tropical pastures. This is a common model in national and regional institutions. From this beginning, a reasonably successful research strategy has evolved whereby, on the one hand, research continues to be based on germplasm development of the traditional commodities and, on the other, research is now conducted on natural resource management for the three largest agroecosystems: mid-altitude hillsides, forest margins, and savannas. These last two constitute the research focus of CIAT's Tropical Lowlands Program.

Research on natural resource management implies first recognizing that, in some regions or subregions of the agroecosystems of interest, while the commodities whose germplasm is being improved can be very important, others also exist that surpass them in importance, from both the economic point of view and their environmental impact. The native vegetation and the soybean and maize crops particularly illustrate these considerations in the case of the savannas.

Such research on the use and preservation of natural resources is complex and requires the support of numerous institutions. For this reason, CIAT does not intend to be self-reliant in any agroecosystem and, as other international centers of the Consultative Group on International Agricultural Research (CGIAR), CIAT works toward implementing collaborative research with other institutions, be these governmental, regional, national, or private. Similarly, CIAT attempts to provide a base for operations or a platform for the activities of other international centers in the region. For example, in 1995, the following institutions used CIAT for their regional operations: CIMMYT, IPGRI, IIMI, IFPRI, ICRISAT, IFDC, CIRAD, and JIRCAS.

The CGIAR is now creating, on a continuous basis, and in contrast to the situation of the recent past—when each Center was more or less self-reliant—global programs and projects. These are rapidly established and involve several centers, as well as varied institutions. Very recent examples of these initiatives include the Global Program on Genetic Resources, the Livestock Program —including the Tropileche Project initiated by institutions from Costa Rica, Peru, ILRI, and CIAT—and the Soil, Water and Nutrient Management Program.

This series of developments in recent years implies that CIAT should continue evolving its mandate and acquire a broader vision that transcends crops and traditional commodities if it is to honor the term “Tropical Agriculture” in its name.

It is within this general context that research on the sustainable management of natural resources in the savannas ecosystem is based.

Research on Agropastoral Systems

The concept of agropastoral systems for the savannas

As previously indicated, the savanna ecosystem is increasingly contributing to the production of annual and perennial crops, and livestock. Historically, the agricultural and livestock sectors have evolved independently, with very little spatial or temporal integration between them at the farm level. This suggested one of the more important research foci for the sustainability of at least soil resources in the savannas: the development of systems that integrate these two sectors, that is, of agropastoral systems.

The concept of agropastoral systems cannot be limited to orthodox rotations between annual crop systems and forage production systems for ruminants. This is because the rotation of crops and pastures is not always the optimal solution, and a much broader and more comprehensive interpretation is needed to include not only situations such as the aforementioned, but also others that make capturing the potential synergism between crops, pastures, and other components possible (Spain 1993). Indeed, most farms have a variety of soils and topographies with different capacities for use. Some sections of a farm are therefore adequate for continuous agriculture, or for at least for one long sequence of crops, while other areas, usually poorer, are best reserved for perennial pastures or forest plantations. Consequently, the integration of these components into real production systems has both temporal and spatial dimensions. As Spain (1993) indicated, without a doubt, planned rotations of crops and pastures maximize the synergism between them. However, these same forms of land use and other resources can be highly complementary, without necessarily occupying the same physical space. For example, the use of wastes and byproducts from cropping activities for animal feed supplementation during dry periods constitutes another form of integration. Organic fertilizers (faeces and urine) from confined animals can be used to increase or recover numerous properties of cropped soils. These two examples demonstrate a spatial integration of various components.

Research approach to agropastoral systems for the savannas

Agropastoral research tends to follow two, mutually complementary, approaches:

1. The goal is to overcome limitations or problems already identified. As examples, we cite those that relate to the physical and biological degradation of soils subjected to monocropping, even when given high-level applications of fertilizers; and the well-known, but little documented, process of pasture degradation.

2. The search for opportunities and generation of innovative systems for those cases that have specific niches. Examples include the selection and identification of new germplasm for ground cover, such as legumes in no-tillage systems and tree plantations; or the development of new crops adapted to acid soils and their incorporation into existing production systems.

Within this panorama, basic, applied, or adaptive research is required. The Agropastoral Network includes institutions that cover this broad range of complementary activities. The division of labor has been well identified in projects such as the PROCITROPICOS savanna project. In this project and, generally within all research projects on natural resource management of the savannas, CIAT prefers to concentrate on strategic research, that is, research directed toward developing a mechanistic understanding of the processes under study, be they biophysical or socioeconomic. Table 1 shows the agreement signed in 1994 on the division of responsibilities, which could be implemented provided each planned activity is funded.

Strategic research is frequently believed to be synonymous with research on biophysical processes, but equally important is socioeconomic research. Such research is also important in the sense that it is the humans who make decisions on the use and management of natural resources. The processes behind a farmer's decision making also need to be understood, even when designing new technologies.

Consequently, research on both agropastoral systems and other complex systems, has a series of requirements (Taylor 1990). These are

Table 1. Distribution of responsibilities among the institutions involved in agropastoral research, agreed to by PROCITROPICOS in 1994 for its savannas project.[a]

Institution	Technology transfer	Information and documentation	Training	Validation on farm	Applied research	Germplasm	Strategic research
National	++	++	++	++	++	++	++
Private sector	++	++	++	++	++	—	—
CIAT	—	+	+		+	++	++
PROCITROPICOS	—	—	++	++	+	—	—
FAO and national institutions	++	+	++	—	—	—	—
CIRAD	—	—	++	++	—	—	+

a. + = involved; ++ = highly involved.

(1) multidisciplinary teams;
(2) holistic analysis (Seré and Vera 1990) and experimentation within the production system or farm, which involves documenting the systems by means of case studies, surveys, on-farm monitoring, and participatory experimentation with new alternatives and prototypes; (3) more mechanistic long-term research, outside and inside the experiment station; and (4) both analytical and synthetical research approaches.

In practice, synthetical research can operate in different ways, depending on the objective. Thus, the synthesis can take the form of one or more prototypes of agropastoral systems, which ideally should be evaluated in a participatory way on farm. Knowledge of agropastoral systems can also be synthesized and assumptions even based on it. This is done through the use of mathematical simulation models, either to investigate *a priori* alternative hypotheses or to evaluate their feasibility, economically or otherwise. Ideally, the prototypes and the simulated models should be developed in a more or less parallel manner and should interact with each other.

Research components: problems of scale

Finally, savanna research involves problems of scale. The design of prototypes for sustainable agropastoral systems that combine crops, native savannas, planted pastures, and other uses in space and/or in time must be supported by, and should benefit from research underway on their different components. Such research is frequently carried out on a smaller scale. Thus, for example, aspects of nitrogen recycling should be evaluated with isotopes in small plots or even under greenhouse conditions. Problems of scale in extrapolating from one level to the other are evident. Similarly, opportunities for generalizing and extrapolating research results on prototypes, or generalizing about demands for research, depend on analyses at other scales of land resources. This requires the analysis of thousands and, sometimes, millions of hectares, as has occurred for the *cerrados* in Brazil (Jones et al. 1992) and is being done for other regions.

It is at these more inclusive levels where the consequences of intensified use of the savannas should be examined. Aspects to be considered should include the sedimentation and contamination of major rivers, loss of biodiversity or opportunities for conservation in selected areas, and the economic impact on the development of both region and bordering areas. Smith et al. (1997, 1998) present some examples of this type of aggregate analysis. Again, as well as in the cases previously cited, the need for multidisciplinary and interinstitutional collaboration is marked.

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CHAPTER 2

Managing and Conserving Acid Savanna Soils for Agricultural Development: Lessons from the Brazilian *Cerrados*

*A. S. Lopes**, *M. Ayarza***, and *R. J. Thomas***[1]

Contents

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Abstract

Acid-soil savannas represent most of the remaining land suitable for agricultural development in the world. These marginal lands have low inherent productivity for agriculture and are susceptible to rapid degradation. The vast Brazilian *cerrados*, opened up about 30 years ago, today supply a significant portion of the country's agricultural commodities. Monocrops of either grains or pastures are proving unsustainable under today's conditions, and alternative production systems that incorporate improved production technologies and conservation of natural resources are being developed and implemented. No-tillage, minimum tillage, and integrated crop/livestock systems are proving successful in terms of farmer adoption. However, to ensure that, over the long term, these marginal savanna lands are being developed in a sustainable manner, we need to understand the principles and functioning of these systems; appreciate the social, cultural, and economic aspects involved; promote a favorable policy environment; and seek a clearer understanding of sustainability and its measurement. In this article, we review the lessons learned from the *cerrados* experience. Future research should seek to develop (1) alternative crop options that tolerate acid soils, (2) better understanding of water and nutrient cycles, (3) principles of soil organic matter and crop residue management, and (4) improved biological management of soil fertility.

Resumen

Los suelos ácidos de las sabanas tropicales constituyen gran parte del área disponible para la expansión de la frontera agrícola en el mundo. Estos suelos han sido generalmente considerados marginales debido a su baja fertilidad natural y a su susceptibilidad a una rápida degradación. Las vastas áreas de los Cerrados brasileños, abiertos hace 30 años, hoy responden por una considerable proporción de la producción agrícola del país. Sin embargo, los sistemas de monocultivo, tanto de especies anuales como de especies forrajeras perennes, han mostrado poca sostenibilidad bajo las actuales condiciones de manejo. Los nuevos sistemas desarrollados e implementados incorporan tecnologías de producción y de conservación de los recursos naturales; entre ellos, los de cero-labranza, labranza mínima y los sistemas integrados de agricultura-ganadería están siendo exitosos en términos de su rápida adopción por los productores. No obstante, es necesario conocer mejor los principios y el funcionamiento de estos sistemas con el fin de determinar su conveniencia en términos de sostenibilidad en el largo plazo. Los desafíos que aún persisten para asegurar el desarrollo sostenible de las sabanas incluyen aspectos económicos, sociales y culturales. Además, es necesario implementar una política ambiental adecuada y un mejor entendimiento de la sostenibilidad y de la forma de medirla. En este artículo se revisan las lecciones aprendidas de la experiencia del desarrollo de la agricultura en los Cerrados brasileños. La futura investigación debe incluir el desarrollo de otras opciones de cultivos con tolerancia a la acidez en el suelo, un mejor entendimiento de los ciclos del agua y de los nutrimentos, el desarrollo de los principios de manejo de la materia orgánica y de los residuos de los cultivos y del manejo biológico de la fertilidad del suelo.

Introduction

The burgeoning world population, growing at a rate of about 1.4% (about 84 million people) per year, places heavy demands on the existing agricultural resource base and will exert increasing pressure to exploit any remaining lands with potential for agriculture. At the same time, there is increasing awareness of the need for careful stewardship of the world's existing agricultural lands, already suffering significant degradation (Scherr and Yadav 1996).

About 50% of the world's savannas are found in Latin America: in the vast savanna areas of Brazil (207 million hectares), Venezuela (28 m hectares), Colombia (17 m hectares), Bolivia (14 m hectares), and Guyana (4 m hectares), totaling 270 m hectares. Constituting one of the last agricultural frontiers (Borlaug and Dowswell 1994), the sum of these areas exceeds the current worldwide area of 255 m hectares under irrigated agriculture (Brown et al. 1998).

The Brazilian savannas or *cerrados* are the largest and most developed savannas in Latin America. Before the mid-1960s, the *cerrados* were used mostly for extensive cattle ranching on native pasture of low carrying capacity. During the 1970s, exotic pastures, mainly *Brachiaria* species, were introduced but, because of inappropriate management (including lack of maintenance fertilizer), as much as 50% of the estimated 50 million hectares of these initially lush pastures degraded to some degree (Macedo 1995; Spain et al. 1996).

The region began seeing the gradual introduction of grain crops, coffee, fruit crops, and reforestation (Lopes 1996b). Soybean was the main grain crop, followed by maize. However, inadequate management and tillage practices meant that these monocrops proved as unsustainable as pastures, suffering increased pest and disease problems and soil fertility decline (Spehar and Sousa 1995). As both monocrops and introduced grass pastures became increasingly unsustainable under current practices, alternative systems emerged, such as agropastoral, silvoagropastoral, perennial cropping, and minimum and no-tillage systems.

In this article, we describe and review the lessons learned during the development of the *cerrados*, highlighting the constraints and the technological and management options to overcome them. Such lessons, together with a better understanding of the driving forces behind land use change, could serve as valuable background for the exploitation of other similar areas in both Latin America (Smith et al. 1997) and indeed certain parts of Africa (Sánchez 1997).

Constraints to Agricultural Production

Soil acidity and nutrient status

Most *cerrado* soils are highly weathered Oxisols (46%), Ultisols (15%), or Entisols (15%), with limitations for crop production in terms of their low inherent soil fertility. Lopes and Cox (1977) surveyed 518 topsoil samples collected in central Brazil, from under natural vegetation, which covers 33% of the *cerrados*. Of the soil samples, 48% had a pH (water) of less than 5.0, and 50% had a pH between 5.0 and 5.9. This indicates that these soils are predominantly acid, and emphasizes the need for adequate liming as the first management practice for cultivating species that are not acid-soil tolerant.

Nutrient deficiencies

Organic matter. Levels of organic matter (OM) in *cerrado* soils range from 70 to 660 g/kg, that is, from medium to high for these soils. Under monoculture, where conventional tillage and lime and fertilizers are used, OM mineralizes rapidly and is consequently depleted very quickly, reaching low levels within 5-6 years or less, especially in sandy soils. Silva et al. (1994), for example, found that losses of OM in the top 15-cm layer in West Bahia under soybean monocropping were 80%, 76%, and 41% of the initial values in soils with <150, 150-300, and >300 g/kg of clay, respectively. The authors suggested that the half-life of soil OM was 2.1, 2.3, and 2.9 years, respectively.

Phosphorus. Phosphorus is the most deficient nutrient in the *cerrados*, that is, 90% of samples in the Lopes and Cox (1977) survey had less than 2 mg P/dm^3. The problem is compounded by the high P-fixing capacity of these soils (Leal and Velloso 1973).

Nitrogen and sulfur. Malavolta and Klieman (1985) suggested that only 32% of *cerrado* soils are N deficient. These authors calculated an annual availability of N at 135 kg/ha, assuming a medium level of total N at 90 g/kg and a mineralization rate of 5% per year. However, water stress, low pH, and generalized nutrient deficiencies limit mineralization. Therefore, large responses to N applications have been observed for a range of crops in this region (Britto et al. 1971; Coqueiro et al. 1967; Cunha et al. 1980; Grove et al. 1980; Lobato et al. 1972; Magalhães et al. 1978; Reis et al. 1974).

Sulfur deficiency tends to be pronounced over time as a result of considerable losses by annual burning of the natural *cerrado* vegetation and the use of concentrated fertilizers, which usually do not contain S. Several experiments have shown positive responses to S in these soils (Coqueiro et al. 1967; Couto and Sansonowicz 1983; Couto et al. 1988; Mascarenhas et al. 1967; McClung and Quinn 1959; Miyasaka et al. 1964). Couto and Ritchey (1986) suggested a rate of S at 15-30 kg/ha per year to supply the needs of most cultivated crops, although a level of 10 mg/dm^3 seems adequate for crops.

Exchangeable cations Ca and Mg, CEC, and Al saturation

Most *cerrado* soils have extremely low levels of exchangeable Ca and Mg. The Lopes and Cox (1977) survey indicated that 96% of samples had less than 1.5 cmol Ca/dm^3, and 90% could be classified as low in exchangeable Mg (<0.5 cmol Mg/dm^3). Most of these soils have less than 0.4 cmol Ca/dm^3 and less than 0.2 cmol Mg/dm^3, emphasizing the importance of Mg and dolomitic lime in savanna production systems for correcting soil acidity and supplying sufficient Ca and Mg to crops.

Most of the soils sampled by Lopes and Cox (1977) had between 0.25 and 1.0 cmol Al/dm^3 (medium level), and only 15% were considered high in Al. However, because Ca and Mg levels were extremely low, exchangeable Al was the dominant cation in these soils, even when exchangeable acidity levels were not high. The effective CEC (the sum of Al + Ca + Mg + K) was low, with most soils having less than 4.0 $cmol/dm^3$.

Such extremely low levels of effective CEC reflect the high degree of weathering of *cerrado* soils. Few negative charges exist at the natural pH values, which, together with the low levels of basic cations, result only in a small reserve of nutrients for cultivated crops. Exchangeable Al occupies most of the effective CEC, hence Al saturation is high. The productivity of most cultivated crops sensitive to Al^{3+} decreases in soils with more than 20% Al saturation. Most *cerrado* soils have more than 40% Al saturation, a level at which most cultivated plants suffer from Al toxicity (Kamprath 1967).

Micronutrients

Because few studies report on micronutrients, farmers adopt an “insurance” strategy for rates of application. Recommended rates at kg/ha are 6 for Zn, l for B, 1 for Cu, and 0.25 for Mo, broadcast every 4-5 years. One quarter of this rate is recommended for annual distribution in the furrow (CFSG 1988).

Lopes and Cox (1977), however, tentatively suggest 1 mg Zn/dm^3 as a critical level for *cerrado* soils. Most samples analyzed had Zn levels between 0.5 and 0.8 mg Zn/dm^3, indicating that this micronutrient is a limiting factor for the growth and development of many crops in these soils.

Although research related to Cu availability is still incipient, good yields in several crops in the region have been observed without use of Cu fertilizers (Galrão and Mesquita Filho 1981; Perim et al. 1980). Some studies suggest a critical level of 0.8 mg Cu/dm^3.

Induced deficiencies of manganese are common because of over-liming and/or inadequate depth of incorporation. By using 5.0 mg Mn/dm^3 as the critical level, Cox and

Kamprath (1973) observed that only 37% of the samples were below this value. This suggests that most of these soils are well supplied with extractable Mn. Similarly, *cerrado* soils are also well supplied with extractable Fe.

Boron (B) can be limiting in sandy soils with low OM content. McClung et al. (1961) observed increases of 80% to 90% in cotton yield. Silva and Andrade (1982) observed yield increases and reductions in male sterility in wheat as a result of B additions. Deficiencies in these cases seem related more to the high demand of certain crops (cotton, coffee, cauliflower, cabbage, and other brassicas) than to low natural availability (Galrão and Mesquita Filho 1981; Perim et al. 1980). A level of 0.5 mg B/dm^3, extracted by hot water, can be used as an approximate critical level (Lopes and Guilherme 1990; Sousa 1989).

With respect to Mo, most experiments have shown negative responses (Britto et al. 1971; França et al. 1973; Freitas et al. 1972; Mikkelsen et al. 1963). However, Couto et al. (1988) observed that the use of Mo increased dry matter yield in pasture grasses associated with leguminous species. Adequate liming of these soils seems to liberate sufficient Mo for most crops, if adequate amounts of the latter are present in the soil.

Problems of Mn and Fe toxicity are restricted to small areas that are usually associated with continuous and excessive rainfall and/or poor local drainage conditions.

Water stress

A major constraint to food production under nonirrigated agriculture in the *cerrados* is the high probability of dry spells or *veranicos* during the rainy season. Duration, period, and number of *veranicos* during a given year can be variable. Calculating from climatic data over 42 years, Wolf (1975) suggested that *veranicos* of 8 days' duration occur 3 times a year. He also concluded that only 1 year in every 13 has an adequate distribution of rainfall.

The problem is further aggravated by the low water-retention capacity of these soils. Reichardt (1985) estimated that the average storage would be 6.9 mm H_2O/10 cm of soil depth in sandy soils, whereas for other soil texture classes, it would be 11.1 mm H_2O/10 cm. He suggested that, if soil physical properties were homogeneous with depth, soil water lost by evapotranspiration at a rate of 6 mm/day, soils contained less than 180 g clay per kg, and a crop had roots that explored only the top 30-cm layer, then, after 4 days of no rain, the given crop would have no water available (Table 1). Even clayey soils behave similarly to sandy soils in terms of water retention (Reichardt 1985).

Another important factor related to water stress in *cerrado* soils is the presence of chemical barriers that restrict root penetration of most cultivated crops. These natural chemical barriers are the result of Al toxicity and low exchangeable Ca down the soil profile. Ritchey et al. (1984) indicated that root development is restricted when exchangeable Ca is less than 0.15 cmol/dm^3 in the subsoil and when Al saturation is close to 80%.

Soil compaction

In the *cerrados*, annual tillage operations with disk plows and heavy tandem disks have resulted in compacted soil layers that drastically reduce root penetration. Such compaction at depths between 10 and 15 cm limits the absorption of water and nutrients from the subsoil,

Table 1. Available water storage for *cerrado* soils in central Brazil with sandy and loamy sand texture classes (<180 g/kg).

Soil depth (cm)	Maximum storage (mm)	Residual storage (mm) after n days without rainfall and evapotranspiration of 6 mm/day							
		n = 2	n = 4	n = 6	n = 8	n = 10	n = 12	n = 14	n = 16
0 – 10	6.9	0	0	0	0	0	0	0	0
10 – 20	13.8	1.8	0	0	0	0	0	0	0
20 – 30	20.7	8.7	0	0	0	0	0	0	0
30 – 40	27.6	15.6	3.6	0	0	0	0	0	0
40 – 50	34.5	22.5	10.5	0	0	0	0	0	0
50 – 60	41.4	29.4	17.4	5.4	0	0	0	0	0
60 – 80	55.2	43.2	31.2	19.2	7.2	0	0	0	0
80 – 100	69.0	57.0	45.0	33.0	21.0	9.0	0	0	0
100 – 120	82.8	70.8	58.8	46.8	34.8	22.8	10.8	0	0
120 – 140	96.6	84.6	72.6	60.6	48.6	36.6	24.6	12.6	0

SOURCE: Adapted from Reichardt (1985).

making the crops much more susceptible to water stress during the *veranicos* in the rainy season.

Stoner et al. (1991) studied an Oxisol with 430 g clay per kg and which had been cultivated with a heavy tandem disk for 10 consecutive years. They found a high compaction level (Cone index of 1.4 MPa), compared with native savanna soil (0.4 MPa; Figure 1). Additional soil tillage with disks in the 11th year aggravated the compaction problem, with MPa levels reaching 1.4 and 1.8.

Knowledge of clay content is essential for identifying areas with greater or lesser susceptibility to soil compaction and likelihood of restricted root development for different crops. Surface soil samples with 160, 530, and 700 g clay per kg were artificially compacted to give bulk densities of 1.0, 1.1, 1.2, 1.3, and 1.4 g/cm^3. The samples were then evaluated in relation to root development for seedlings of maize, soybean, wheat, and common bean (Stoner et al. 1991). The roots of all four species showed normal development in the sandier soils (160 g clay per kg), even at the highest bulk density of 1.4 g/cm^3. In the clayey Oxisol (530 g clay per kg), roots also penetrated all bulk densities (from 1.0 to 1.4 g/cm^3), but in the very clayey Oxisol (700 g clay per kg), root penetration was severely restricted in all four species.

Restricted root development was greatest for common bean, followed by maize, wheat, and soybean in that order. The most problematic soil was the very clayey Oxisol, which impeded bean root penetration under humid conditions, when its bulk density was 1.1 g/cm^3, a level frequently observed in farm fields (Stoner et al. 1991). The main conclusion of this research was that the higher the clay content, the more susceptible soil was to compaction and the more root development was restricted.

Soil erosion

Excessive tillage operations with disk equipment, even in level areas of the *cerrados*, lead to loss of soil structure and the formation of compacted soil layers at 10 to 15 cm deep. These can result in reduced water infiltration and

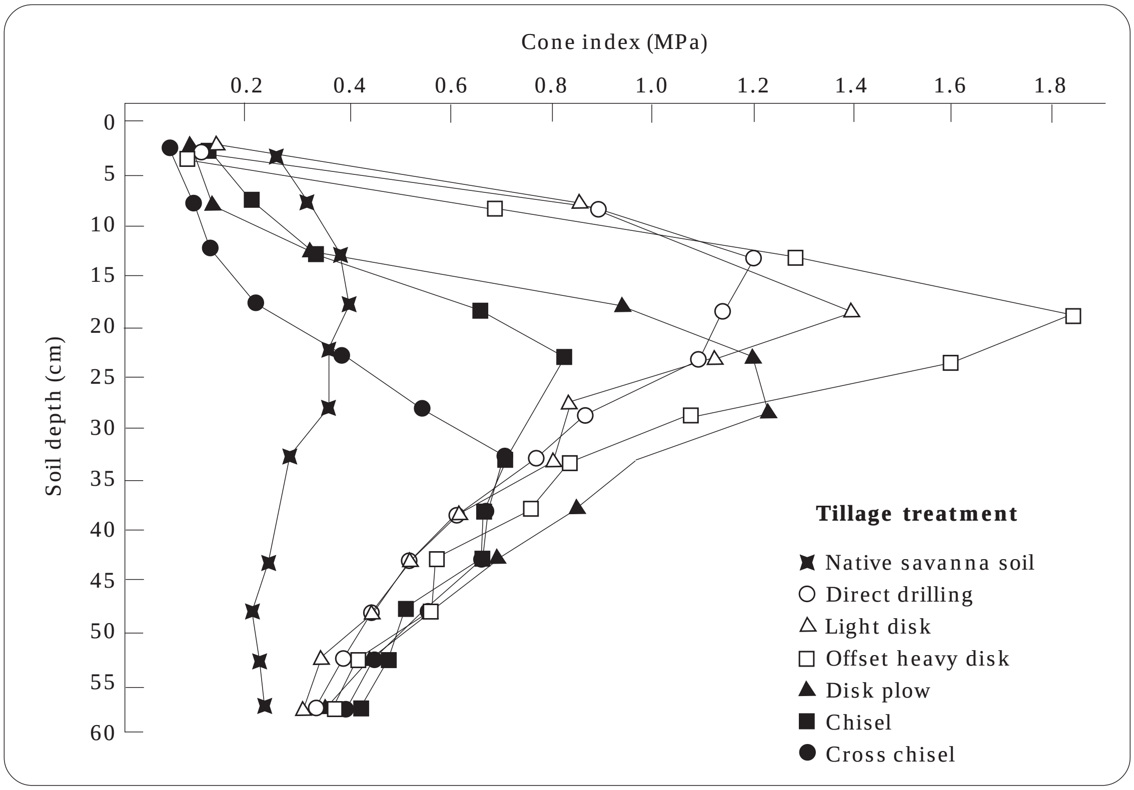

Figure 1. Mechanical impedance profiles of six tillage treatments on a Typic Haplustox with 430 g clay per kg and which had received 10 years of disk tilling, Minas Gerais, Brazil, compared with native savanna soil conditions (after Stoner et al. 1991).

considerable soil loss by run-off and erosion.

Rainfall erosivity, as characterized by the index EI_{30} (kinetic energy of rainfall in 30 min), is intense in the *cerrados*, increasing the breakdown of surface soil aggregates, sealing the soil surface, reducing infiltration, and increasing run-off (Dedecek et al. 1986; Resck 1992). Losses of soil and water in a Dark Red Latosol (Oxisol) with a 5% slope were higher for bare soil and maize under conventional tillage than for soybean under no-tillage and pasture (Table 2). These findings emphasize the need to maintain soil cover and avoid long periods of bare soil as a first step toward reducing erosion in the *cerrados*. Even in this

Table 2. Loss of soil and water under different soil covers and tillage systems for a Dark-Red Latosol (Oxisol) with a 5% slope (data averaged across 6 years), Brazilian *cerrados*.

Parameter	Conventional tillage				No-tillage (soybean)	Pasture
	Bare soil	Maize	Rice	Soybean		
Erosivity index at 805 t/ha per mm per hour, then:						
Soil loss (t/ha)	53	29	8	9	5	0.1
Rainfall at 1243 mm, then:						
Water loss (mm)	293	264	257	180	168	15
Infiltration (%)	76	79	79	86	87	99

SOURCE: Dedecek et al. (1986).

Dark Red Latosol, which was considered as highly resistant to erosion according to the erodibility evaluation by the authors, soil losses from erosion under no-tillage were 5 t/ha (Resck 1996).

Technologies for Alleviating Soil Acidity and Low Fertility

Liming

Benefits. Several papers have summarized the positive effects of using lime in the *cerrados* (Lathwell 1979; Lopes 1983; Miranda et al. 1990). Goedert (1987) and Lopes (1983) suggest that liming:

- Corrects soil acidity
- Reduces Al toxicity
- Increases the inherent low levels of Ca and Mg
- Increases biological activity
- Improves the efficiency of fertilizer applications with macronutrients
- Increases the pH dependent charges and, consequently, the “effective” CEC
- Diminishes P-fixing capacity by precipitating exchangeable Al as $Al(OH)_3$
- Stimulates increased root development at depth, depending on the rate, depth of incorporation, and time after application.

The average rate of lime applications used in this region is 3 t/ha (ranging from 1 to 5), and incorporation is as deep as possible, using disk plow or tandem disk harrow (usually 0-20 cm depth). This procedure is usual for establishing annual grain crops, perennial crops, and some pasture species.

When micronutrient deficiencies are adequately corrected, additional benefits can be obtained by using high rates of lime that will result in pH values of more than 6.0. These values are usually achieved with the “increasing base saturation” method (Raij and Quaggio 1997). Independent of the method used, these rates must be corrected according to the lime’s relative power of total neutralization (RPTN), which includes the $CaCO_3$ equivalent and reactivity of the lime. The residual effects of these rates may last from 3 to 5 years.

Liming in minimum or no tillage systems. The concept of liming in minimum or no tillage agriculture differs from that used with conventional tillage. Before initiating minimum or no tillage, an adequate rate of lime needs to be used to increase base saturation of CEC at pH = 7.0 to 70%. Lime should be incorporated as deep as possible and targeted to increase the residual effect by using a coarser lime (Lopes and Guilherme 1994). After this preparatory period, one third or half of the lime requirements can be applied in clayey and sandy soils without plowing (Lopes 1996a).

Ameliorating subsoil acidity. The existence of chemical barriers (Al toxicity and low exchangeable Ca) means that only a small volume of soil can be explored by the root system. This situation can be corrected in two ways: (1) deeper lime incorporation and possible applications of phosphate fertilizer, and (2) downward movement of Ca and Mg through the soil profile. The first practice is limited by the high costs of deeper lime incorporation, and the second by the slow vertical movement of Ca and Mg.

Gypsum, a byproduct of phosphoric acid production, has been promoted as an ameliorator of subsoil acidity (Raij 1988). The most direct effects of gypsum on subsoil, after broadcast application on the soil surface, is an increase of Ca and a reduction in exchangeable Al down the soil profile. Rooting depth increases, with beneficial implications in terms of water and nutrient use in the subsoil.

Several studies have estimated gypsum applications for specific soil conditions. Lopes (1983) developed the first guidelines for applying gypsum to ameliorate the rooting ambient in the subsoil when exchangeable Ca is ≤ 0.3 cmol/dm^3, and/or exchangeable Al is ≤ 0.5 cmol/dm^3, and/or Al saturation is $\geq 30\%$ of the effective CEC. It should be stressed that these parameters (Ca, Al, and Al percentage) must be evaluated not only in the surface soil layer (0-20 cm), but also at depths of 20-40 and 40-60 cm, and at 60-80 cm for perennial crops (Lopes 1983, 1986).

Rates of gypsum depend on soil texture, level of organic matter, proportion of Ca in relation to other cations, and crop species (Lopes and Guilherme 1990; Sousa et al. 1992).

Phosphorus capitalization

Increasing P supply by fertilizer application in soils with extremely low levels of extractable P and high P-fixing capacity has been crucial for achieving adequate and economic yields over the short term. The importance of an adequate "buildup" of P via phosphate fertilizer applications can be observed in Figure 2. Research has indicated that, with adequate rates of phosphate applications, yields of wheat, soybean, and maize can more than double yields on low rates of maintenance fertilizer (Wagner 1986).

Several experiments have been conducted in the *cerrados* to evaluate methods, sources, and application rates of P fertilizer (Goedert 1983; Lathwell 1979; Lopes 1983; Sánchez and Salinas 1981). For opening up new areas of the *cerrados* to grain crop production, Lobato (1982) and Lopes (1983) have recommended broadcasting phosphate fertilizer at "buildup" rates, followed by band applications of maintenance fertilizer. To achieve good yields for 3 to 4 years after clearing the area, the commonest method is to "buildup" soil P content by applying 1.5-2.0 kg P/ha per 10 g clay per kg, followed by normal annual applications of maintenance P fertilizer (Lopes 1983).

Considerable research has been conducted in the last 20 years to compare the effectiveness of Brazilian phosphate rock with triple superphosphate and Gafsa phosphate rock (Lopes 1996c). Goedert and Lobato (1984), studying a clayey Oxisol at the Centro de Pesquisa Agropecuária dos Cerrados, Planaltina, DF, showed that Brazilian rocks have a low agronomic efficiency index (AEI) (Table 3). However, for an *Andropogon* grass, cultivated for 3 years after annual crops, the AEI percentage of these Brazilian phosphate rocks, except Catalão, was considerably higher. The high AEI percentage for Gafsa phosphate, triple superphosphate, and thermophosphate-Mg is a good indication that these P fertilizers are adequate sources for "buildup" of P capital in the *cerrados*.

In recent years, the coarser commercial products of a few highly reactive phosphate rocks (North Carolina, Arad, Daouy, and Gafsa) have been compared with powdered products.

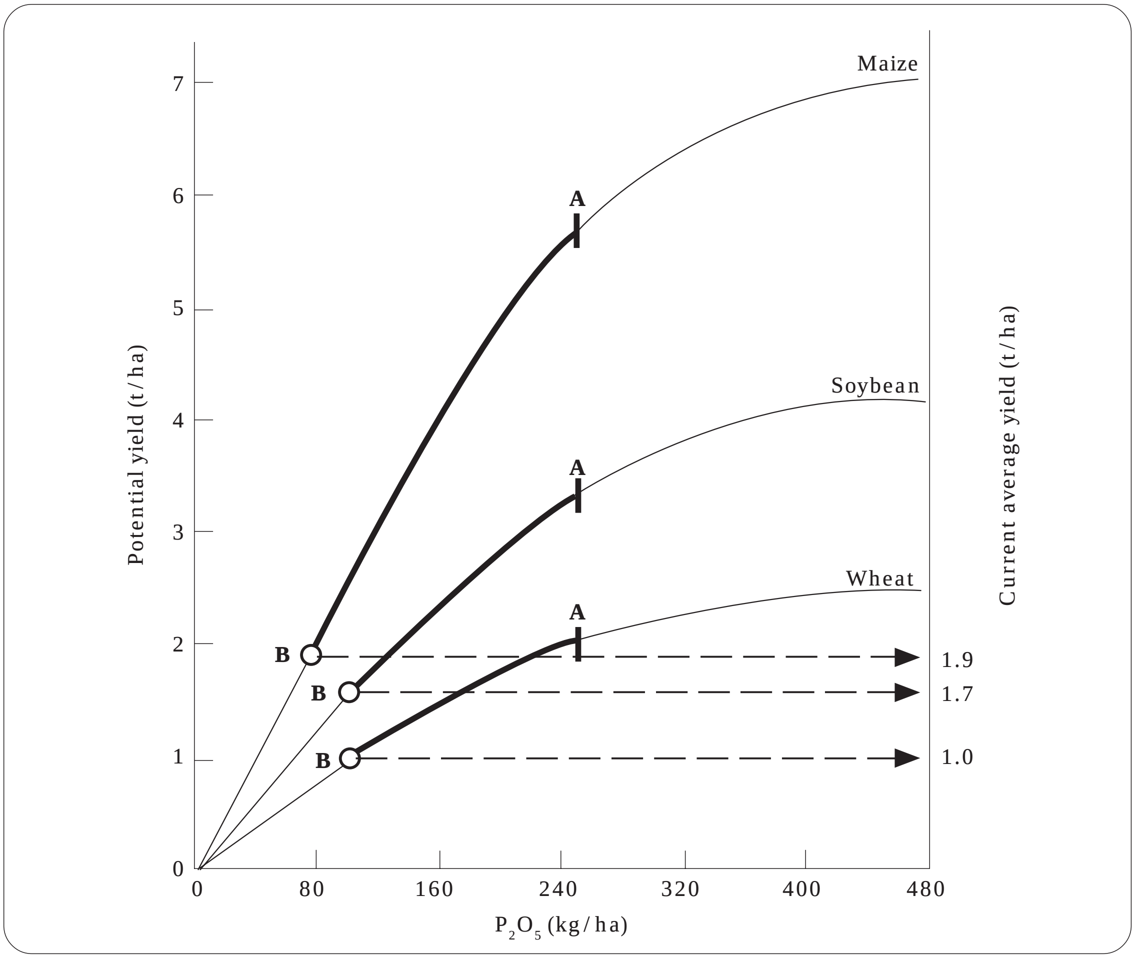

Figure 2. Potential (A) and average production (B) for maize, soybean, and wheat as a function of "building up" phosphate levels under rainfed conditions in the central *cerrados* of Brazil (after Wagner 1986).

Table 3. Agronomic efficiency index (%) of phosphate fertilizers in a clayey Oxisol under *cerrado* vegetation in central Brazil, calculated by P absorption data over 5 years with annual crops, followed by 3 years with *Andropogon* pasture.

Phosphate fertilizer	200 kg total P_2O_5/ha			800 kg total P_2O_5/ha		
	Annual crops	*Andropogon* sp.	Total	Annual crops	*Andropogon* sp.	Total
Triple superphosphate	100	100	100	100	100	100
Hyperphosphate (Gafsa)	93	110	104	106	106	106
Thermophosphate-Mg	92	142	113	110	119	114
Thermophosphate-IPT	45	84	60	88	98	92
Pirocaua[a]	76	97	87	81	84	82
Araxá[a]	27	69	41	47	74	58
Patos[a]	45	81	59	56	91	70
Abaeté[a]	21	86	43	47	71	56
Catalão[a]	8	36	17	26	43	33

a. Brazilian phosphate rocks.

SOURCE: Goedert and Lobato (1984).

Preliminary results indicate that, for highly reactive phosphate rocks, both commercial (coarser) and finely ground are adequate for building up P levels in these soils when they are broadcast and incorporated through tillage into the surface soil (Table 4).

"Buildup" of potash levels

Although response is not as common or as pronounced as those obtained with lime and P, potash fertilizers, applied at adequate rates, are needed to ensure medium to high yields.

A corrective broadcast application of potash fertilizer is recommended for soils with more than 200 g clay per kg soil and low exchangeable K. For soils with less than 200 mg clay per kg soil, complete correction is not recommended because the low CEC in these soils can lead to an accentuated loss of K by leaching (Sousa 1989).

Corrections can also be made gradually through annual applications of K_2O at rates higher than those recommended for maintenance, applied in the planting furrow. Tillage operations in successive years (plowing and disking) mix the residual K in the plow layer, resulting in an adequate level of exchangeable K in the plow layer being developed within 4-5 years (Sousa 1989).

The recommended rates for total and gradual "buildup" of soil potash content for soybean crops in the *cerrados* as a function of clay content and K availability is presented in Table 5. Adaptations of these recommendations

Table 4. Agronomic efficiency index (%) of triple superphosphate (TSP), North Carolina phosphate rock—commercial (NCC), and very finely ground NCC (NCG), broadcast and banded, for soybean in a clayey Oxisol.

Year	Broadcast[a]			Banded[b]		
	TSP	NCC[c]	NCG[d]	TSP	NCC[c]	NCG[d]
1992	100	63	96	100	30	42
1992/93	100	138	112	100	96	91
1993	100	167	114	100	108	77
Average	100	123	107	100	78	70

a. 160 kg of total P_2O_5/ha broadcast in the first year.
b. Average of 40 and 80 kg of total P_2O_5/ha banded every year.
c. NCC: 80% with a diameter between 0.15 and 0.42 mm.
d. NCG: more than 70% with a diameter of less than 0.075 mm.

SOURCE: Adapted from Rein (1994).

Table 5. Rates of K_2O (kg/ha) recommended for total and gradual "buildup" of soil potash content for soybean in the Brazilian *cerrados*.

Interpretation	Level of exchangeable K (mg/dm^3)		"Buildup" with K_2O at kg/ha	
	Clay < 200 g/kg	Clay ≥ 200 g/kg	Total if clay ≥ 200 g/kg	Gradual
Low	<15	<25	100	70
Medium	16-30	26-50	50	60
Good[a]	>30	>50	0	0

a. After achieving this level, the rate of K_2O maintenance fertilizer is 20 kg/t of soybean produced per hectare.

SOURCE: Adapted from Sousa (1989).

can be made for other crops in the region. The main source of K in Brazilian agriculture is KCl.

Land Management Systems

Native pastures

Until 30 years ago, the commonest land use system in the *cerrados* was that of cattle raising on native pastures. The main management practice was an annual burning, to eliminate dry, unpalatable, native pasture at the end of the dry season and to stimulate the growth of more palatable new material. The two main factors responsible for the low forage quality and animal performance under these conditions were a lack of soil humidity during the dry season and low soil fertility.

Improved pastures

In newly cleared *cerrados*, introduced pastures were usually established after a pioneer crop of upland rice, using low rates of lime and fertilizers. Today, about 48 million hectares of improved pastures are estimated as being planted with exotic grasses introduced from Africa, such as *Brachiaria* and *Andropogon* spp. (Macedo 1995). Despite the low native soil fertility, the resulting pastures are lush and productive during the first years after planting (Spain et al. 1996). However, pure-grass pastures often decline in productivity after 4-10 years of grazing, the effect being faster on sandy soils (Boddey et al. 1996; Macedo 1995). More than 50% of this area of improved grass pasture in the *cerrados* is estimated as experiencing some degree of degradation (Macedo 1995). The decline in animal and grass productivity is followed by invasion of unpalatable weed species and the appearance of bare areas in the sward. Often, termite populations and number of mounds increase markedly (Boddey et al. 1996).

The causes of pasture degradation are numerous and complex (Spain et al. 1996). However, N deficiency is a major factor. Pure-grass pastures under intensive grazing pressure usually become deficient after 2-3 years (Spain et al. 1996) as N is lost from the system by volatilization, leaching from urine spots, and immobilization in stable OM pools formed from grass residues in the soil (Ferreira et al. 1995). Lack of applications of maintenance fertilizers and pest and disease pressures have also been mentioned as important causes of pasture degradation.

The use of legume-based pastures can reverse the rapid decline of soil fertility and can contribute to improved forage quality and availability in the dry season (CFSG 1988). Adapted legumes and grasses are now becoming available and should result in more persistent and productive pastures. However, a key factor for persistent grass/legume pastures is appropriate grazing and maintenance fertilizer management (Thomas 1995).

Annual crops—conventional tillage

Monocropping of annual crops in the *cerrados*, considered as moderately successful, contributes about 28% of total grain production in Brazil, 43% of soybean, 3% of wheat, 14% of common bean, and 9% of sugarcane. However, the system of extensive monoculture is often accompanied by inappropriate tillage operations, mainly too many passes of the disk plow, which result in decreased productivity, increased production costs, and soil degradation through OM loss, soil compaction, and erosion. Additionally, weed invasion and pest and disease problems exacerbate productivity losses.

Rainfed annual crops—minimum and no tillage systems

Probably more important than the "*cerrado* revolution" that occurred in the 1970s is the "no-tillage revolution" that started in the 1980s in Brazil and spread rapidly in the 1990s. In 1980, the no-tillage system was applied to 150,000 ha in Brazil, increasing to 1 million hectares in 1990, then to almost 10 million hectares in 1998. Today, about 2 million hectares of annual grain crops in the *cerrados* are cultivated with no-tillage techniques (Landers 1995).

The first attempts to apply no-tillage in the *cerrados* failed because the hot and dry winter did not allow the development of traditional winter crops. A variant was developed in which a cover winter crop was absent. Instead, minimum tillage was used to plant crops into perennial grasses. The main advantage of this technology was the possibility of using conventional planters, leaving the soil surface loose and easy to plant (Scaléa 1996).

A major breakthrough in the evolution of the two tillage systems was the introduction of a *safrinha* that consisted of planting a second crop into the residues of the main crop in the same year. This strategy improves financial returns, enhances the production of sufficient crop residues to be left on the soil surface, and reduces rates of herbicide use. Besides these effects, a *safrinha* can improve forage availability for livestock during the dry season and increase nutrient recycling by bringing nutrients to the surface that are normally susceptible to leaching (Landers 1995).

A second major breakthrough, which improved no-tillage in the *cerrados*, was the introduction of African millet *(Pennisetum typhoides)*. This plant is highly resistant to drought, is adapted to low-fertility soils, and has a high capacity to produce green material. African millet requires little water, compared with other crops, and has a rooting system that can penetrate into high-Al, low-Ca subsoils, thereby facilitating deep nutrient capture and recycling (Table 6). Furthermore, millet is easy to establish and manage. It produces vigorous seeds and can be planted using any of several methods such as rows, broadcasting, and even aerial sowing. Millet resists diseases and pests, is an excellent animal feed, and has low risk of becoming a weed species (Scaléa 1995).

Although minimum and no tillage systems are recent for the *cerrados*, several variations of these systems

Table 6. Quantity of macronutrients recycled by several crops in the Brazilian *cerrados*.

Crop	Dry matter (t/ha)	Nutrients recycled (kg/ha)				
		N	P_2O_5	K_2O	Ca	Mg
Millet	12.0	206	60	350	53	32
Soybean	4.0	42	11	64	35	26
Wheat	3.5	34	11	58	7	4
White oat	2.5	18	16	60	13	3

SOURCE: Scaléa (1995).

have already developed (Landers 1995). These variations are as follows:

No-tillage, hay as a winter crop. Before initiating no-tillage, soil fertility must be "builtup", an activity that, under conventional tillage, normally takes 3-4 years. The next step is to generate a large amount of hay as a winter cover crop. In some cases, seed is planted into the cut hay of the preceding crop. A nonselective herbicide is applied in winter to eliminate weeds before planting.

The most promising combinations for achieving adequate hay for the summer planting include planting millet with the first summer rains, followed by planting of the main crop with no tillage, and generating hay with maize, millet, sorghum, or other crop (*safrinha*) after the main crop. For farmers more interested in soybeans, a deep plowing and adequate soil "buildup" in the first year and crop cycles of soybean + sorghum (or millet) for several years are recommended. Using this system for 4 consecutive years, soybean yields of more than 4 t/ha have been obtained (Seguy et al. 1995). These yield levels are similar to those from the world's better soils.

No-tillage, no winter fallow. This system is characterized by the absence of a second crop (*safrinha*) after the main rainy season crop. In this situation, weeds, mostly grasses produced from seeds of the same year, are the main hay producers. This option is efficient when the weed species are easy to control. This system has been used in Santa Helena de Goiás, State of Goiás, to plant no-tillage maize and soybeans on weed winter fallow hay on clayey soils with high fertility for more than 5 years. After allowing the weeds to remain as fallow during the winter (dry period), the weeds are left to germinate and are controlled with herbicides.

No-tillage, living cover crop. Under this system, crops are planted into a living legume cover crop. This system requires the control of the legume regrowth with herbicides (e.g., 2,4-D) during the first 40 days of maize development. Then paraquat can be used. Perennial soybean (*Glycine javanica*), kudzu (*Pueraria phaseoloides*), *Centrosema* spp., siratro (*Macroptilium atropurpureum*), and *Arachis pintoi* have been used with relative success. The cycle ends when a grass/legume pasture is established. Calopo and siratro have been planted into rice hay and used later as forage crops for beef cattle.

No-tillage and conventional tillage on the same farm. This system is practiced when planting has been substantially delayed and weed germination is high in areas already prepared, using conventional soil preparation methods. Tandem disking and leveling are substituted by herbicide use when the area to be planted exceeds farm capacity. The farmer selects areas with predominant grass-weed infestation to obtain more hay for protection against erosion and reduce further weed germination.

The main advantages of this combined system are reduced production costs and the avoidance of preparing wet soil, and thus of damaging soil quality and ultimately the environment. Under this system, conventional planters can be used because the soil is well prepared and loose.

Intermittent no-tillage. Surface compaction due to machinery transit under humid conditions, or weed infestation that is difficult to control can both contribute to a reversion to conventional tillage practices. Surface compaction is easily eliminated with minimum tillage by chisel plowing to a depth of 20-25 cm. However, no tillage sometimes has to be combined with deep plowing (Landers 1995), such as in the following situations:

- When a crop like rice is very sensitive to small changes in soil compaction (Seguy et al. 1995)
- When persistent weeds and pests must be controlled economically
- When precautionary measures must be taken against disease propagation through the hay, and in cases where disease epidemiology either requires this procedure or is not clear
- To eliminate soil compaction resulting from excess machinery trafficking in moist soil, especially in the cases of silage production and irrigation
- To dilute the effect of high rates of lime applied to the soil surface

Minimum tillage. This system represents disturbance of a minimum level to the cover crop and soil, leaving as much hay as possible on the soil surface. When used in combination with pre-planting chemical weed control, minimum tillage represents an intermediary option between conventional and no-tillage. This system is suitable for erosion control where no compacted layer is present, and represents a preliminary step toward adopting no-tillage. Landers (1995) discussed variations of minimum tillage.

Irrigated annual crops —minimum and no tillage systems

Some farmers use minimum and no tillage systems with annual crops under irrigation. The main difference with rainfed conditions is security against water stress during *veranicos* in the rainy season, and the elimination of the deleterious effects of the dry season. Under irrigated conditions, with two or more crops per year, considerable quantities of hay can be generated.

Continuous use of no-tillage under irrigation requires higher levels of technical knowledge and experience, with detailed attention to:

- Soil humidity when operating machinery
- Crop successions to prevent pest buildup
- Close monitoring of soil and nutritional levels for plants
- Selection of herbicides and other cultural practices that prevent problematic weeds reaching harmful levels
- Prevention of residual effects of pesticides in the cropping sequence

Perennial crops

Perennial crops occupy about 2 million hectares of the *cerrados*, and include banana, coffee, rubber, citrus fruits, cashew, pineapple, mango, avocado, passionfruit, Barbados cherry, and soursop (*Annona muricata*). Forestry is mainly pine and eucalyptus. Coffee is grown on about 1 million hectares, mainly in the southern State of Minas Gerais (Spehar and Sousa 1995).

Integrated crop/pasture systems

In more recent years, considerable research has been invested on crop/pasture rotations as an integrated system. This integrated approach could contribute more to the ecological and economic sustainability of crop and livestock production systems in the humid and subhumid tropics than any other single innovation. If this integrated approach can also be combined with minimum or no tillage of annual crops in the system, we could expect a much improved and sustainable system.

The advantages of crop/pasture rotations (ley farming) derive mainly from the potential synergism between the annual and perennial components of the system (Lal 1991; Saleem and Fisher 1993; Spain et al. 1996). Each component has problems alone but most can be solved by rotating crops with pastures. Vera et al. (1992), Thomas et al. (1995), and Spain et al. (1996) cite the following advantages:

- Enhanced soil fertility
- Increased biological activity
- More efficient nutrient cycling
- Enhanced soil physical properties
- Controlled weeds, pests, and diseases
- Improved feed quality and availability in the dry season
- More effective soil and water conservation and use
- Economically more resilient than other production systems

The argument for crop/pasture rotations in the *cerrados* is strengthened by the presence of extensive areas of degraded pastures, most of which are on arable soils in areas also being exploited for grain production. At the same time, many grain farmers are facing increased production costs and declining yields as soils degrade through soil compaction, weeds, pests, and diseases.

Several technologies concerning crop/pasture rotations were developed and have been used extensively by farmers in the *cerrados*. One is the "*barreirão* system" (Kluthcouski et al. 1991; see Chapter 15 of this book). This was developed by farmers to establish pastures with a pioneer crop of upland rice. Other options include maize, sorghum, and millet with pastures (Kluthcouski et al. 1991; Oliveira et al. 1996). Advantages include:

- Reduced requirements for machinery
- Correction of acidity according to needs of the given plant species
- Reduction of termite mounds and weeds
- Reduction of water stress risk
- Extended growth of forages during the dry period
- Partial or total return on investment over a short period
- Ease of implementation if machinery and technical support are available

Trials on reversing pasture degradation by integrating grain crops, mainly soybean, have been conducted by the Fundação Mato Grosso para Pesquisa e Difusão de Tecnologias Agropecuárias of the Brazilian State of Mato Grosso do Sul. This comprises the integration of degraded pastures (*Brachiaria decumbens, B. brizantha, Panicum maximum* cv. Tanzania, and *P. maximum* cv. Mombaça) and annual crops, mainly soybean, under no-tillage. In addition, several combinations of commercial crops, green manures, and perennial pasture species have been used to implement crop rotations in an integrated crop/livestock system. A summary of this technology is described by Broch et al. (1997), and a series of studies involving the evaluation of herbicides for the desiccation of these pasture species is available (Borges and Bordin 1996, 1997a, 1997b; Carneiro and Borges 1994, 1995; Paiva and Borges 1995).

As this Brazilian state lies in the southern temperate region of the country, we can extrapolate the use of cover crops to southern parts of the *cerrados*. A series of practical extension publications are available, giving guidelines to the appropriate management of these crops in this region (Hermani et al. 1995; Pitol and Salton 1989; Pitol et al. 1998; Salton and Cichelero 1988; Salton et al. 1995).

A highly successful example of crop/livestock integration was developed in Santa Terezinha Farm, near Uberlândia, State of Minas Gerais (Ayarza et al. 1993). Briefly, beef cattle production, which was the Farm's only activity in 1978, has gradually been replaced by crop/pasture rotations. The main rotation system consists of 2 years of soybean, followed in the third year by maize planted simultaneously with pasture grass. After harvesting the crop, the pastures are ready for grazing and remain green throughout the dry season, thus supplementing forage availability for the herd during the most critical period of the year (May to September). As soil fertility improved as a result of fertilizer applied to crops, the hardier grasses —*B. decumbens, B. ruziziensis*, and *B. humidicola*—were replaced by improved but more demanding grasses such as *P. maximum* (cvs. Vencedor, Tanzania, and Centenario) and *B. brizantha* cv. Marandu.

The control of pastures to plant crops was initially achieved by conventional tillage, plowing at the end of the rainy season. The farmer is now moving toward planting crops directly into chemically controlled degraded pastures. His goal is to take advantage of the improved soil fertility and minimize tillage operations.

The main advantages of the rotation system used at Santa Terezinha Farm can be seen in the increased carrying capacity of the pastures (Table 7), improved soil structure, and increased grain yields.

Despite the significant achievements at Santa Terezinha Farm, the introduction of high-quality forage species that are more demanding in terms of fertility and management is leading to a rapid decline in pasture productivity. In particular, N deficiency is causing rapid degradation of *P. maximum* pastures.

The Challenge of Achieving Sustainable Production Systems

The opening up of the *cerrados* for crop and livestock production has clearly shown that even marginal soils can be successfully incorporated into production by using appropriate management and technology. The adoption of these technologies has resulted in substantial gains in production, with substantial increases predicted from further exploitation of the potential area (Table 8). However,

Table 7. Changes in pasture area over time at the Santa Terezinha Farm, Uberlândia, MG, Brazil, as consequence of the introduction of crops and crop/pasture rotation.

Year	Planted (ha) pastures[a]	Pastures after crops (ha)	Total area (ha)	Herd size	Stocking rate (animals/ha)
1983	1014	0	1014	1094	1.1
1984	970	0	970	1069	1.1
1985	858	60	918	1025	1.1
1986	647	80	727	804	1.1
1987	521	176	697	862	1.2
1988	293	296	589	821	1.9
1989	205	377	582	846	1.4
1990	115	493	608	892	1.4
1991	15	632	647	891	1.4
1992	0	412	412	1150	2.8

a. Pastures planted after clearing *cerrado*.

SOURCE: Ayarza et al. (1993).

Table 8. Current production of cereals and meat in the *cerrados*, and two scenarios for potential food production using available technology in (1) the area already occupied, and (2) potential areas of the *cerrados*.

Activities	Area (× 10^6/ha)	Productivity (t/ha per year)	Production (× 10^6 t)
Current production of cereals and meat			
Crops (rainfed)	10.0	2.0	20.0
Crops (irrigated)	0.3	3.0	0.9
Meat	35.0	0.05	1.7
Total	45.0	—	22.6
Scenario 1			
Crops (rainfed)	20.0	3.2	64.0
Crops (irrigated)	5.0	6.0	30.0
Meat	20.0	0.2	4.0
Total	45.0	—	98.0
Scenario 2			
Crops (rainfed)	60.0	3.2	192.0
Crops (irrigated)	10.0	6.0	60.0
Meat	60.0	0.2	12.0
Perennial crops	6.0	15.0	90.0
Total	136.0	—	354.0

SOURCE: Macedo (1995).

the apparent lack of long-term sustainability of these systems has led to a series of alternative management options that are thought to be more appropriate for meeting today's and tomorrow's needs.

As with all new technologies and management options, some difficulties and obstacles to their widespread adoption in other areas arise. These result from three fundamental viewpoints:

1. *Social, economic, and cultural aspects* at both farmer and community levels can hinder the required changes in thinking and/or adoption of more sustainable management practices

2. A *favorable policy environment* is needed for the transitional periods of technological change

3. *Standardization* of sustainability concepts and quantifiable parameters of sustainability is essential.

Below we briefly discuss these points.

Social, economic, and cultural aspects

A better understanding of the driving forces behind land use change at the farm and other levels is required to ensure that new technological and management options are appropriate, and are acceptable to farmers. For example, the conventional wisdom that farmers will not adopt resource management technologies that require long-term investment needs re-examination following the finding that soybean farmers in the *cerrados* do invest in no-tillage systems for erosion control and longer term benefits (Smith et al. 1998). In this case, the private sector played a major role in the diffusion of no-tillage systems.

The concept of integrated crop/livestock systems appears to be sound from the economic and ecological aspects. However, over 60% of farmers surveyed in three watersheds of the State of Minas Gerais only planted pastures in areas they considered unsuitable for crops (Smith et al. 1998). These examples emphasize the need for better communication and collaboration among farmers, researchers, and policy makers. The recent emphasis on the need for "farmer first" and "farmer participatory research" approaches within the research community is a welcome sign that progress is being made. The American Society of Agronomy's publication of a book on no-tillage agriculture by a Chilean farmer and based solely on his experiences (Lamarca 1996) is another indicator of a willingness to break down traditional barriers between the scientific community and agricultural practitioners.

Favorable policy environment

Just as the opening up of the Brazilian *cerrados* was stimulated by governmental programs and subsidies, so too will new technologies and management options require more favorable policy environments to be successful. "Magic bullet" remedies are rare, especially when dealing with the complexities of sustainable agriculture. Better dialog among farmers, researchers, extension workers, and policy makers is essential and requires much more effort from the agricultural research community.

Standardizing sustainability concepts and their quantifiable parameters

Among the several definitions of sustainable agriculture is the widely accepted one from FAO (1989): "Sustainable agriculture should involve the successful management of resources for agriculture to satisfy changes in human needs while maintaining or enhancing the quality of the environment and conserving the natural resources". The key issue in this definition is the quality of the environment, which, in terms of this paper, is soil quality. According to Eswaran et al. (1993), the aspects of soil quality that are important for sustainable agriculture are many but can be reduced to ten:

- Water-holding capacity
- Nutrient-retention capacity and cation exchange capacity
- Nutrient availability, pH, base saturation, and P and K availability
- Nutrient fixation
- Chemical constraints, including acidity, sodicity, and salinity
- Physical constraints, including low hydraulic conductivity, permeability, high bulk density, and crusting
- Effective soil volume, that is, depth to root-restricting layer, stoniness, and structure
- Surface tilth
- Erodibilty
- Water-logging

Until and unless such soil quality standards are established, monitoring soil degradation will always be difficult and, consequently, so will evaluating the effects of management. From the viewpoint of sustainable agriculture, soil quality standards provide a basis for evaluating changes in soil conditions due to management, tools for monitoring changes, a basis for legislating soil stewardship, a means of signaling potential problems to trigger research or development activities, and criteria for evaluating sustainable agriculture (Eswaran et al. 1993).

For the specific case of the *cerrados*, many of the possible quality patterns (chemical, physical, biological, and others) are not yet quantified on a scientific basis to give sufficient support for discussions concerning directions for sustainable management. Not only do we need to further develop scientific parameters, but we must also relate them to parameters that farmers can use and understand. More efforts must be made to document farmers' knowledge and perceptions of soil quality. Science and local knowledge need to be brought together to develop land quality monitoring systems that can be implemented and interpreted by the land users themselves.

Conclusions and Recommendations for Further Research

Research, teaching, and extension

Considerable research has been conducted in the last 3 decades to solve the problems of inherent low soil fertility, high soil acidity, P-fixing capacity, Al toxicity, and low Ca availability in the subsoil, problems that limit root development in the *cerrados*. The basis for the chemical management of these soils has been established through relatively high rates of lime and fertilizer application. This knowledge allowed the incorporation of millions of hectares into the agricultural-livestock-forestry production sector, transforming marginal land into highly productive land.

Most research findings were adequately transferred to a significant number of farmers in the form of practical bulletins and other extension mechanisms that led to a revolution in terms of soil fertility management. However, this revolution has been seriously questioned in recent years as being inadequate in terms of medium- to long-term sustainability of these soils. Most research on the evaluation of sustainability loss has involved classical parameters such as decreased soil OM, intensified soil erosion, and the formation of compacted layers. We need to establish "early warning" indicators, biological indicators, and integrative indicators that incorporate chemical, physical, and biological parameters that will gauge system productivity, resilience, and sustainability. Integrative indicators should be based primarily on the indicators that farmers use.

The search for more sustainable systems of cropping, animal husbandry, and forestry on these soils has led to intensive efforts to introduce minimum and no tillage systems for grain crop production in the region, sometimes integrated with improved pastures. The observed increase in minimum and no tillage systems in the last decade, reaching almost 30% of the grain crop area in 1997 in the *cerrados* is evidence of a change in thinking among the region's farmers.

Although considerable efforts have been made in research, teaching, and extension to develop and diffuse better technologies in the region by various national and international institutions, the true "explosion" in technology implementation was more a result of efforts by farmers themselves. Farmer-to-farmer communication and farmer cooperatives were the main driving forces behind the transfer and adaptation of the experiences obtained in the southern temperate region in Brazil.

The good results obtained at farm level from the integration of grain crops with improved pastures is strong evidence that this integration is not only feasible but highly recommendable for achieving more sustainable production systems.

Improved pastures, mainly with *Brachiaria* species, comprise, by far, the land use that has most extensively replaced native *cerrado* vegetation. The fact that about 50% of improved pastures already show some level of degradation is of major concern. Policy incentives are needed to stimulate adoption of crop/pasture systems or other means of intensifying production.

Perennial crops represent a minor cropping system in the region, compared with grain crops and improved pastures. Several perennial crop systems (coffee, rubber, and fruit trees), and reforestation with pines and eucalyptus constitute some of the successful experiences on large farms in the region. Integrated systems that involve perennial crops with annual crops and/or improved pastures are only beginning to receive attention from researchers with respect to sustainable production on these soils.

The higher average yields for several crops obtained by good farmers in the region, compared with the average yields for the region as a whole, is strong evidence that considerable technology information is available and is already being used by the best farmers. In this sense, it appears much more important to develop strategies that would ensure farmers have access to and would implement these technologies, and discourage opening up of new areas of poorly productive native *cerrados*.

Extrapolating findings to other regions

The knowledge gained over 30 years of experience of soil and crop management in the *cerrados* could be of invaluable help in the opening up of other similar areas in Latin America and Africa with acid soils that are highly weathered, of low-fertility, and with high P-fixing capacity. However, careful analysis of the biophysical and socioeconomic factors of these similar areas is essential before any effort is made to transfer the "*cerrado* technology". The use of relatively high amounts of inputs such as lime and fertilizers and the favorable policies and subsidies available in Brazil at the time of the "opening up" of the *cerrados* are unlikely to be repeated elsewhere. In addition, most farmers in tropical savanna areas do not have ready access to inputs and machinery, especially in Africa. Recent changes toward minimum and no tillage systems with reduced inputs and improved efficiency in Brazil are, however, relevant to other savanna areas.

This knowledge needs to be incorporated into a strategy that combines the selection of crop species tolerant of the constraints of acid soils with the definition and application of agroecological principles. The latter involves technologies of integrated pest management (IPM) and integrated nutrient management (INM). An example of INM involves the use of grass/legume pastures to improve P acquisition and cycling in pasture and crop/livestock systems in the Colombian savannas (Friesen et al. 1998; Oberson et al. 1999). As well as improving P cycling, the legume component brings other benefits such as increased N input and cycling via biological fixation, and increased soil organic matter (Fisher et al. 1994; Thomas et al. 1995). Increasing soil organic matter will be important for improving the productivity of acid soils if large inputs of fertilizers are not to be used. Not only will it help reduce Al toxicity, soil OM can improve the physical, chemical, and biological parameters of soil (Coleman et al. 1989).

Efforts to characterize the climates and soils of potentially similar areas should be increased, particularly as details of these parameters are not yet available for many tropical areas (Richter and Babbar 1991). Each potentially similar area will have its own particular set of socioeconomic and biophysical characteristics that need to be understood at the local level. The development of a set of technological and management principles has emerged from the *cerrado* experience. These can be used to produce simple decision-support tools for the available production options but they must be firmly grounded in local experience to become relevant and significant.

Topics for further research in the savannas

Based on our experiences in the *cerrados*, we list below topics that require further research on the improved management of acid-soil savannas:

1. Development of more crop options, such as sunflower, quinoa, pigeon pea, and multipurpose legumes, with better stress adaptation in terms of water stress, soil acidity, and nutrient acquisition.

2. Understanding the fate of herbicides and the environmental risks of increased use with increasing use of minimum and no tillage systems.

3. Quantifying water and nutrient flows and cycles in the improved production systems to improve nutrient-use efficiency and reduce

costs by less use of machinery and chemical inputs (e.g., the role of plants such as forage legumes in acquiring unavailable P sources).

4. Understanding soil OM management in the improved production systems, such as optimization of immobilization and mineralization, the role of the physical nature of soil organic matter, and decomposition and nutrient release.

5. Stubble and residue management—is it science or art? Farmer knowledge needs to be collated and related to scientific principles.

6. Studying soil biological factors, for example, nutrient cycling of P and N, mycorrhizae and rhizobia, agrochemical residues, soil structure, and pests and diseases.

7. Policies addressed at potential problems in nutrient cycles, such as nutrient mining, return of nutrients to the land, scales involved on-farm, off-farm, and urban areas.

8. Addressing the issue of helping small-scale (versus large-scale) farmers.

9. Improving farmers' access to information on crop options (especially higher value crops), postharvesting technologies, agroprocessing, and market opportunities.

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To save space, the following commonly used acronyms are not written out in full:

CPAC	Centro de Pesquisa Agropecuária dos Cerrados (of EMBRAPA)
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária

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CHAPTER 3

Concepts and Strategy of Participatory Research in the PROCITROPICOS-Savannas Project

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Contents

Abstract

The agricultural and livestock production systems in the Latin American savannas need improving. Taking into account the prevailing

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agroecological and socioeconomic characteristics, the PROCITROPICOS-Savannas Project is promoting soil use and management technologies. To ensure that these technologies are socially acceptable, environmentally sustainable, and profitable, a systemic and holistic approach, based on participatory research, is adopted. This approach requires interdisciplinary activity and the integration of researchers, extension workers, and farmers. Research first begins with a diagnosis of current farming systems on targeted farms, followed by participatory research to adjust and validate new technologies in traditional agroecosystems. Not only will linkages between technology generation and synthesis, validation, and transfer to users be improved, but feedback will also be provided for thematic research aimed at technological development. Through participatory research, the “gap” between the generation of technological innovations and their adoption is expected to narrow. At the same time, the participation of local, national, and regional entities in rural development policies is expected to increase.

Resumen

Las características agroecológicas y socioeconómicas prevalentes en la región de las sabanas latinoamericanas demandan del Proyecto Sabanas-PROCITROPICOS la promoción de tecnologías de uso y manejo del suelo socialmente aceptables y ecológicamente sostenibles y rentables, con el fin de mejorar los sistemas de producción agrícola y pecuaria. Dichas acciones se realizan a través del enfoque sistémico y holístico aplicado al manejo sostenible de los suelos de sabanas. La estrategia planteada es la investigación participativa, cuya aplicación exige el avance de conocimientos basados en acciones interdisciplinarias y en la integración sectorial involucrando investigadores, extensionistas y productores. El trabajo se inicia con el diagnóstico de la realidad de los sistemas de producción en fincas de referencia, seguido de investigación participativa destinada al ajuste y validación de innovaciones tecnológicas en los agroecosistemas tradicionales. Además de promover la mejor articulación en las actividades de generación-síntesis, validación y transferencia de tecnología hacia los usuarios, la estrategia planteada proporcionará información de retorno para la investigación temática tendiente al desarrollo tecnológico. A través de la investigación participativa se espera disminuir el ‘vacío’ existente entre la generación y la adopción de innovaciones tecnológicas planteadas para el manejo sostenible de los suelos de sabanas, además de ampliar la participación de los agentes locales, nacionales y regionales en las políticas de desarrollo rural.

Introduction

The prevalent agroecological and socioeconomic characteristics of the Latin American savannas provide numerous challenges of generating, adjusting, validating, and disseminating technologies for soil use and management. Not only should these technologies improve and stabilize agricultural and livestock production, they must also be ecologically sustainable, profitable, and socially acceptable while reducing climatic and marketing risks in production systems based on both annual mechanized crops and pastures (IICA and PROCITROPICOS 1994).

Theoretical Framework

Conservational management of tropical soils

Conservational management of tropical soils involves a set of practices and processes in the use of soils and crops, which, if adequately combined, could sustain productive capacity and also increase the economic efficiency of long-term production systems (Nademan 1991). This concept involves integrating working the land with diversifying its use through the rotation and sequential management of crops, including pastures, and through the use of cover crops (Figure 1).

In the tropical and subtropical soils of Latin America, tilling is conventionally done with disk implements, especially the heavy harrows that, even though producing more work for less fuel, cause the most damage to the soil. Direct seeding over plant residues (i.e., zero tillage) is more effective in protecting soils against erosion and degradation. However, this practice usually has high initial costs, represented by investments in machinery and weed control and also demands that farmers have a high degree of technical knowledge and managerial organization. In addition, if the crop sequence is not the most suitable, this practice favors a higher incidence of pests and weeds. For these reasons, direct seeding continues to be practiced only by the most skilled and progressive farmers in terms of technical, administrative, and financial skills, even in those areas with the highest levels of adoption.

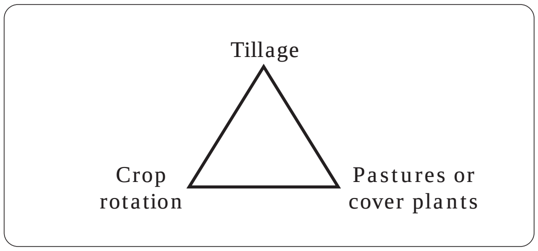

Figure 1. Components of integrated soil management, PROCITROPICOS-Savannas Project.

Minimum tillage is an option that is intermediate to the two processes mentioned above and lacks many of the previously cited drawbacks. However, disadvantages include risks of greater incidence of weeds and initial difficulties in establishing crops in recently cleared areas or in very heavy soils. Currently, the possibility of combining tilling practices is being considered as a more effective alternative for the proper management of tropical soils (Benítez 1991; Plá Sentis 1991).

Crop rotation not only preserves soils, but also contributes to the biological control of weeds and pests, better organization of farm work, better use of invested capital, and reduction of risks from climatic changes or price fluctuations. However, rotation should be flexible and should take into account variations in climate and soils, marketing opportunities, and farmers' interests and resources. That is, "recipes" for crop rotation should not be sought for, but the knowledge and options that facilitate adjustments to each new situation should be collated and disseminated (Gutiérrez 1991a; Viegas and Machado 1990).

Pastures constitute an efficient alternative way of reducing degradation in tropical soils after clearing. However, the concept still prevails that pastures should be established only in lands of poor quality. Under such conditions, if the natural resources are sufficient and favorable, the livestock agroecosystem can maintain itself over at least a significant period of time, accompanied by a reduced demand for capital. If grass becomes scarce because of drought, degraded soil, or other reasons, then management consists of reducing the stocking rate per unit area, thus, resulting in a production system of low sustainability where the animal population has to be reduced to a point where the system's profitability and economic stability are compromised. However, prolonged or inadequate use of pastures leading to overgrazing almost always results in problems of soil compaction, degraded fertility, and weeds that compete with the grasses or are toxic to livestock.

The foregoing arguments illustrate the advantages of establishing adequate pasture management programs that seek to rehabilitate soils through resting and periodic rotations with annual crops. With such programs, operations can be carried out to loosen the soil through heavy tilling, control weeds, apply amendments and fertilizers, and replace existing grasses with others of better quality.

The growing value assigned to lands and products of animal origin justifies a better use of soils to compensate for the capital investments in livestock raising. Under such circumstances, the success of agricultural and livestock production systems will depend on:

1. The recognition that grasses, as components of an agroecosystem, are cultivated plants and, accordingly, require proper management for their establishment and maintenance at satisfactory levels of profitability and sustainability.

2. Taking into account the role of pastures and their interactions with other components of agricultural and livestock production of the entire farm (Muzilli 1993a).

Latin American research shows the importance of including cover crops in rotation systems for better soil conservation and weed and pest control. One disadvantage of this system is the uncertainty that still prevails on the selection, establishment, and management of suitable cover plant species. Other questions arise on the additional costs for the periodic occupation of the land, requiring that the net earnings margins of the activities involved be compensated by increases in their profitability. Thus, the interaction between cover crops and other activities should permit soil protection without compromising the economic profitability of the production systems being used (Gutiérrez 1991b).

The three components mentioned act through a complex interaction of effects in space and time. This has been proved through experiments carried out under different conditions in tropical and subtropical South America.

Despite accumulated experience, questions still persist on the suitability of technologies offered, especially in areas where agricultural development is still expanding. These concerns refer to the adaptation of tilling practices and of the spatial and chronological arrangements of crops and pastures under different agroecological and socioeconomic conditions. Understanding of the advantages of incorporating cover crops into soil management practices, particularly in rotations with food crops and pastures, is still scarce.

Under such circumstances, the need to adapt and disseminate conservational management practices is evident. These must be appropriate to (1) the different agroecological and socioeconomic conditions of tropical and subtropical Latin America, and (2) reversing soil degradation while not compromising the profitability of production systems based on intensive land use, whether this constitutes mechanized annual crops or pastures.

A systemic and holistic approach to soil management

A systemic and holistic approach to the sustainable management of savanna soils requires that:

1. The land is used according to the most appropriate criteria of agricultural capacity.

2. Increased efficiency in using rainwater.

3. Soil tillage practices promoting continuous exposure of soil to erosive climatic actions are restricted.

4. Short-cycle crops that are more efficient in using available water and soil nutrients are cultivated, and that these are combined with medium- or long-cycle species that help preserve natural resources.

5. Diversified cropping systems are designed to guarantee continuous productivity through the rational exploitation of natural, technological, and socioeconomic resources.

Integrated soil management requires consideration of all agroecological and socioeconomic variables, from the selection of farm plots according to their suitability for different agricultural and livestock use to the selection of technological practices and processes that simultaneously maximize the cost-to-benefit ratio and conservation of soil and water, while minimizing environmental deterioration.

The most adequate strategy appears to be the farming systems approach, as applied to the generation, validation, and transfer of technologies to intermediary and end users, these being extension workers and farmers, respectively. The application of agricultural and livestock research according to this approach depends on the progress of knowledge through interdisciplinary activities. It also requires the integration of different sectors through a participatory effort that directly involves researchers, farmers, and extension workers.

Thus, the adoption of the systemic approach (i.e., integrating activities in production units) and the holistic approach (i.e., the process seen as a whole) in research and technology transfer will permit a more global perception of the problems and solutions related to the sustainable use and management of soil. It will also strengthen the integration of efforts among public and private entities dedicated to the agricultural development of a given region or country.

So that agroecosystems can be modified, activities must first be based on understanding the reality of farming systems as practiced by farmers (i.e., research must be conducted on the farms themselves), followed by on-farm research (adjustment and validation of technological innovations in the farm setting). Such research will result in accumulated scientific knowledge and experience that, combined with users' logic, can lead to research for the farm and hence to modified agroecosystems. Under this strategy, research on farming systems will be responsible for identifying demands and, subsequently, for verifying and transferring outputs of specific research, either by component or by category. The programs of topic-related research will, in their turn, generate and contribute to technological innovations that will be adjusted, validated, and incorporated into agroecosystems (cropping systems) and traditional farming systems. For this reason, farming systems research does not confront or replace topic-oriented research; on the contrary, it enriches and complements it (Muzilli 1988; 1993b).

Participatory Research Strategy

Experiences acquired in the region led to the proposal of the 1994 IICA/ PROCITROPICOS-Savannas Project for development in Bolivia, Brazil, Colombia, and Venezuela. The idea was to fill the gap that obviously exists between the generation of innovations and their adoption, indicating a need for changes in technology-transfer strategies. Human and financial resources are also lacking, limiting the implementation of technology validation and transfer to different domains of recommendation. Greater aggressiveness and complementarity of efforts from public institutions involved in research and rural extension is also needed to broaden the adoption of available technological options.

Research and rural extension typically suffer from isolated over-assessment of both the philosophy and theoretical framework of activities. Thus, the principal objective of delivering technological advances to farmers is lost. Under these circumstances, the possibility of advancing rural development in savanna areas will depend on the articulation of research, rural extension, and technical assistance, and on whether this is achieved with the active participation of users, especially farmers.

Such concerns justify implementing efforts, participatory in nature, to promote better coordination in the generation and synthesis of activities, and technology validation and transfer to final users. Additionally, this approach provides effective mechanisms for stimulating research on technological development, based on new problems and demands that could arise from the very same activities carried out in conjunction with technical assistance agents and farmers. These premises have led the Savannas Project to propose a participatory research strategy, involving a series of activities, whose stages are described below and in Figure 2.

Diagnosis

The Project’s goals in diagnosis are to:

1. Identify different homogeneous agroecological zones (AEZs) and the respective domains of recommendation (DORs) existing in each zone.

2. Become familiar with the predominant farming systems (PFSs) and technologies used by the farmers in the different DORs.

3. Identify the problems and analyze the causes and effects that restrict the productivity, profitability, and sustainability of the PFSs.

4. Make a prognosis of possible technological changes capable of contributing to the solution of problems diagnosed, based on the available technological options.

Characterizing agroecological zones. The AEZs are relatively homogeneous in terms of natural and

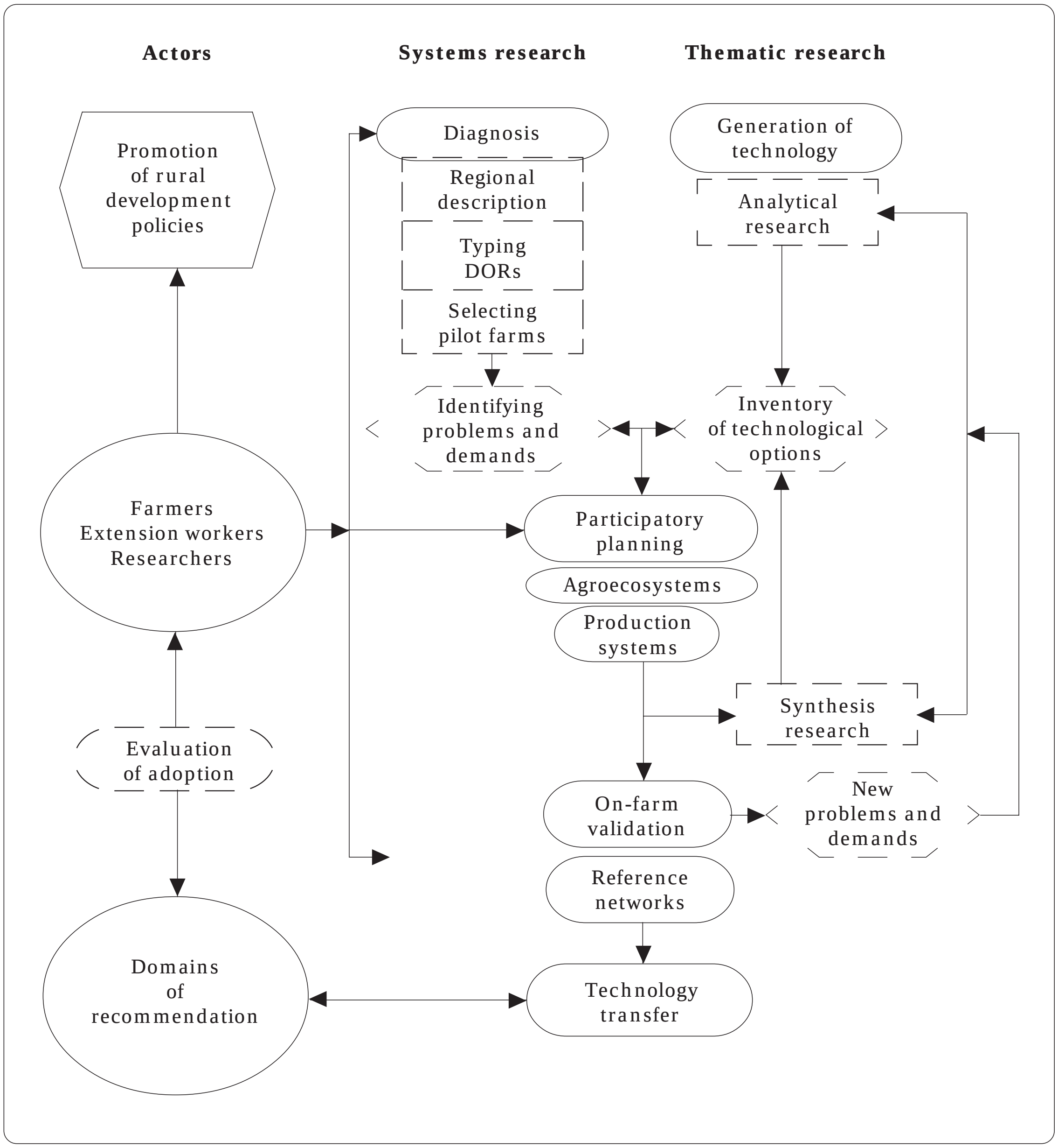

Figure 2. Strategies for technology research and transfer in production systems, PROCITROPICOS-Savannas Project.

socioeconomic resources, so that production activities show or can show single behavior.

To orient later stages of research on farming systems, characterization will be done through the collection, processing, systematization, and analysis of the set of descriptive secondary data on natural resources and socioeconomic aspects. The former include climate, soil, toposequences, and vegetation, while the latter include land use and tenure, evolution and forms of community organization, and the agricultural production profile. Another fundamental aspect to characterize is regional infrastructure, that is, the set of factors external to the production units that are related to production activities. These include domestic and external markets (supply and demand), lines of specific credit, comparative advantages (costs), market structure and channels, labor supply, agrarian structure, and standardization of land use.

The information provided by secondary data should be complemented and expanded through field visits to identify, delimit, and select the AEZs of interest.

"Typing" domains of recommendation. The DORs constitute homogeneous strata of farming systems (production units or farmer groups) with similar agricultural and socioeconomic characteristics, problems, agricultural potential and, accordingly, feasible for collective study, and likely to adopt the same technological innovations.

Within an AEZ, each farm or production unit is unique. However, to orient the diagnosis of farming systems, they can be grouped according to similar characteristics that correspond to the profile of the DORs.

The "typing" stage will aim to group these production units, using a series of variables for classification. These include the nature and availability of draft power, labor relationships used in the production unit, availability and intensity of capital use, and predominant agroecosystems (for agricultural and livestock production activities) in terms of gross production value. In addition, the most important variables should be considered: the types of cropping and livestock production systems, main sources of income, and farmers' technological management of the resources and factors needed for production. As a result, during "typing", the PFS profiles will be known in terms of resource use—land, work, and capital—and predominant production activities (agroecosystems) in the production units.

To execute this stage, in addition to workshops with farmer groups, formal surveys or informal probes can be carried out on reference farms in the targeted area, whether this is the municipality, community, or microwatershed.

As well as grouping similar farming systems and identifying the representativeness of each predominant type, the "typing" of the DORs will help formulate preliminary hypotheses that will orient the diagnostic definition and its implementation through the sampling of production units.

Formulating the diagnosis. This process consists of describing and analyzing the organizational framework and dynamics, restrictions and opportunities, and the technical profile of the PFSs and their respective agroecosystems (for production activities), as basic elements for:

1. Identifying and ranking the demands, purposes, and aspirations that condition farmers' decision making when managing resources and production activities.

2. Predicting possible technological options that can be offered in a compatible manner with the current situation of different DORs.

From farms chosen at random to represent the DORs of interest, data should be collected on (1) forms of land use and occupation; (2) the technological processes used in agricultural and livestock production; (3) the availability of resources and production practices; and (4) the farmers' aspirations, priorities, and restrictions.

Special attention should be given to the use and management of land resources, that is, systems of land use; equipment and machinery use; tillage, seeding, and harvest; use of fertilizers and pesticides; water management; pest and weed control; crop rotations and sequences, management of pastures and animals; and management of mulching with harvest residues.

Using this diagnosis as a basis, technicians can identify and understand the problems and demands expressed by users. Technicians should begin by analyzing the technological problems perceived as the most significant by farmers. Other problems exist that farmers may not always recognize, but which the technicians should be able to recognize and offer alternatives for their solution. Comparing such alternatives with the problems detected, hypotheses can be formulated about the use of production resources.

The fact that farmers do not follow practices that technicians consider as being the best does not necessarily mean that a problem exists. Instead, under the given circumstances and aspirations, the farmers may be using available resources in the most logical and efficient way. Accordingly, before deciding that they are facing an unperceived problem, technicians must consider the dynamics of operating and managing a production unit as a system, which can be determined by monitoring reference farms.

The diagnosis can be formulated through surveys, workshops with farmers, and case studies. In all cases, samples will be taken at random, using a list of representative farmers from each DOR of interest, thus helping to consolidate the diagnosis of each DOR separately.

Participatory planning. The diagnosis of problems and demands should be made and analyzed in formal workshops, with the participation of researchers, local agents for technical assistance and rural extension, representative farmers from the respective DORs, and representative members of community organizations and local political classes.

On the basis of cause-and-effect analysis, priorities will be established and available innovations selected from the bank of technological options provided by research experience, which should be compatible with the practical experiences of both farmers and technicians working in the area.

The participatory planning should lead to the design of prototypes or physical agroecosystem models for validation on reference farms. It should also enable verification of users' reactions to suggested prototypes. The final decision for their execution will be made with the consensus and acceptance of all collaborators responsible for the reference farms where validation will be carried out.

When the technological offer does not permit prognosis, based on traditional agroecosystems, of the interactive effects of technological innovations likely to be incorporated into the modified prototypes, then participatory planning will help provide feedback to new proposals for topic-oriented research through synthesis (multifactorial) or analytical experiments.

Some basic rules that researchers and technicians should follow during participatory planning are:

1. Within an optimistic setting, be prepared and motivated to offer innovations that may make users more aware, that is, emphasize

solutions rather than problems, obstacles, or failures.

2. Avoid imposing opinions during discussions. Farmers should be placed in the role of local technicians, where their practical experience is respected in the analysis and discussion of proposals.

3. Be unafraid of criticism or rejection of the proposed innovations. Under such circumstances, the technician or researcher should clarify to the users that they are dealing with options to be tested, that these may or may not be better than the technologies in current use, and that the objective is to receive opinions on the proposed innovations.

The Savannas Project has established that validation proposals resulting from participatory planning should be based on the following principles:

1. Agroecological sustainability, which will be reached by combining cropping systems with pastures, and including species that will rehabilitate or preserve the soil in diversified farming systems.

2. Economic profitability, by exploiting a combination of alternatives that will produce financial income in the short, medium, and long term.

3. Sociocultural acceptability, that is, taking into account the logic behind traditional technological processes and avoiding the introduction of abrupt changes into the area's social values.

Under the conditions prevailing on reference farms, the physical models of agroecosystems are validated as follows:

Agroecosystems with annual crops. Models of this type simulate cropping systems with mechanized or semi-mechanized crops. These are adjusted to the crop species, times, densities, and processes of planting and management that are compatible with the equipment and facilities available on the farms. The aims are to (1) avoid the removal, excessive disaggregation, and compaction of the soil, and the destruction of residues from previous crops during tillage; (2) promote cropping systems, including the use of cover crops to favor nutrient recycling and soil protection; and (3) introduce alternatives of improved crop varieties, times, densities, and methods of planting and weed control.

Agroecosystems with pastures. This group of models considers only pastures, or their combination with agricultural production. The models may aim to (1) replace pastures of low nutritive quality or infested with weeds and pests with pastures of higher forage quality; (2) place pastures in association or in sequence with seasonal crops to improve soil conditions, control weeds, and reduce costs of pasture rehabilitation; (3) offer residues and forages as supplementary feed to livestock in periods of pasture scarcity and during pasture rehabilitation; and (4) promote agrosilvopastoral systems through the rotation of pastures with seasonal crops intercalated with tree species and shrubby forage plants to provide shade, windbreaks, supplementary feed, and wood.

Agroecosystems with seasonal crops and crops in association. These systems are more appropriate for small and medium-sized farms where production activities are diversified and where planting and management are manual or semi-mechanized. Under such situations, the objectives should be to (1) diversify agricultural production through rotation and sequential management of seasonal crops; (2) promote the use of cover crops in association systems for soil protection, weed control, nitrogen input, and nutrient recycling; and (3) reduce soil removal and burning of residues of previous crops.

Agroecosystems with perennial crops. Promoted for small and medium-sized farms, and areas unsuitable for mechanical manipulation, this group of systems aims to (1) diversify agricultural production through agroecosystems with multiple strata, associating seasonal and perennial crops; (2) establish the rotation of seasonal crops and cover crops between alleys of arboreal crops to improve nutrient recycling and nitrogen input; and (3) control weeds, pests, and diseases, and protect the soil against erosion.

Given that pastures occupy large areas and cattle raising is a common activity in the savannas, those researchers who are specialized in these activities should be directly involved as members of multidisciplinary teams in charge of research. Most existing projects have not always been able to achieve this objective.

Synthesis, validation, and transfer of technologies

The purpose of validation on reference farms is to introduce, adjust, and verify technological innovations considered as feasible for changing traditional practices in farming systems under the conditions of the represented DORs. Under these conditions, the impact of the proposed changes should be evaluated in the context of the production units (i.e., the network of reference farms) as a whole.

However, in areas where information is limited, synthesis research will have to be conducted to combine and integrate technological processes and components that cannot yet be easily incorporated into validation plots. In addition, such activities can be used as a showcase for technological options, to support the training of local technicians, and to act as reference point for designing future validation plots. For example, for the conservational management of soils, synthesis research may comprise multifactorial trials that integrate tillage with rotations of crops and pastures, with or without cover plants. The plots should be sufficiently large to permit mechanization and the measurement of predictive parameters of agroecological sustainability, through a precise and controlled monitoring. Complementary or satellite and topic-related trials can also be conducted in smaller plots to verify the isolated effect of certain technological components.

Synthesis research can be carried out on private farms, representative of the DORs (reference farms or “satellites”), using experimental designs that make possible (1) comparisons and measurements related to research, and (2) support for specific activities for technology transfer such as field trips and technical tours. The foregoing aims to determine progress and to confirm the applicability of the technological options to other production units of the same DOR. However, we are dealing with large-scale trials that are based on a complex experimental design, usually long term, and demanding in the use of equipment and labor at planting times. Thus, it will not always be feasible to carry out experimental verification of the selected technologies under the agroecological and socioeconomic conditions of farms.

As an alternative, synthesis research can be carried out in its own experimental fields, located in areas with agroecological conditions that are representative of those of the DOR of interest. This will facilitate the measurement of agronomic parameters that simulate certain financial indicators. However, because the socioeconomic representation may be compromised, the innovations will have to be validated on reference farms to minimize this type of problem and to consolidate the socioeconomic monitoring.

Because the physical models being proposed are managed and evaluated with the active participation of users and with the resources and working methods available on farm, the design of validation plots should be simple and flexible. This will permit the introduction and adjustment of new techniques and processes in accordance with the progress of synthesis research and the particular circumstances of each DOR.

During “planning” workshops, users will be consulted and motivated to propose changes in the models according to their experiences, purposes, and circumstances. Additionally, they should be motivated to cooperate with and participate actively in the management of the proposed activities.

Indicators for monitoring, from the selection and description of the plots to the consolidation of validation tests, will involve edaphoclimatic, technological, and financial parameters that are internal and external to the reference farm. These parameters should be sufficient to evaluate the impact of technological innovations with regard to their agroecological sustainability, economic profitability, and sociocultural acceptability.

After duly adjusting the innovations and validating them with cooperating users, the validation plots will serve as demonstration plots for technology transfer. The innovations will be shared with other users of the same DOR in events such as technical tours, field days, and workshops. To achieve this, use is made of information and clarifications offered by cooperating users, who will explain to their neighbors all the procedures and experiments they have done to arrive at the validated prototypes.

The technical assistants and extension workers who participated in the work, from diagnosis to validation, will be responsible for organizing dissemination activities, with due support from the researchers. Later, the adoption of the transferred innovations should be evaluated, with the help of the users, through interviews and surveys to measure their impact.

Progress in Validation in the Savannas Project

The methodology for validation used by the Savannas Project is that which is proposed in this document. In the following examples, the activities and progress that can be achieved from the first year of validating cropping systems on reference farms are demonstrated.

Validation methods for reduced tillage for mechanized annual crops in rotation with cover plants

The predominant cropping system of a farm located in an integrated zone of southern Santa Cruz, Bolivia, is based on monocropping cotton during the rainy season, followed by fallowing in the dry season. Land preparation is traditionally carried out at the beginning of the rainy season, using conventional tillage, with up to three passes with a heavy harrow and four passes with a leveling harrow.

A 2-ha plot was selected to establish validation activities. A previous diagnosis of the loamy-sand soil profile showed deficiency of organic matter, disaggregation of the upper layer, and presence of a compacted layer at 17 to 26 cm deep. These conditions led to low sustainability of the cropping system being practiced, high incidence of weeds and pests, reduced productivity, and increased production costs. The crops' water-use efficiency was low, because of restricted root development. Wind erosion was aggravated by the scarcity of plant cover in the dry period, when strong winds occur in the area.

Given this situation, a proposal was made to replace traditional tillage with minimum plowing of the soil, using a chisel plow to a depth of 35 cm. This would permit at least 30% of the soil being covered with crop residues during the cotton crop, followed by rotation with cover plants to reduce weeds, balance pest populations, and protect the soil during the dry period. Because farmers expected to direct seed, the crop rotation system shown in Table 1 was proposed for validation.

Between 1995 and 1996, when the first cotton crop was grown, the principal benefits of the modified agroecosystem, compared with those of the traditional system, were a better vegetative development of the cotton crop's aerial parts and roots, delay in weed invasion, and increased crop productivity.

Validation methods for pasture rehabilitation and management in milk-producing systems

The predominant activity in the State of Anzoátegui (Eastern Savannas of Venezuela) is dairying. For the study, a typical farm of this area was chosen. The farmer used *Brachiaria decumbens* pastures over periods of 4 to 5 years. Traditional management consisted of intensive grazing at 2 head/ha for 10 days, followed by mowing, then 20 to 30 days of rest. On diagnosis, the soil profile showed restricted root development below 40 cm. According to the farmer's experience, the most frequent problems were soil compaction from trampling by the animals, high incidence of weeds, and patches of bare soil caused by low seed germination.

The pasture—rehabilitation system to be validated involved establishing a 1-ha plot where the land was conventionally prepared with one pass with a harrow. A legume (*Stylosanthes capitata*) was planted, applying fertilizers

Table 1. Crop rotation proposed by farmers of an integrated area in southern Santa Cruz, Bolivia, PROCITROPICOS-Savannas Project.

Period	Crop	To produce	Planting method
Oct-May	Cotton	Fiber	Vertical tillage
June-Sept	Sorghum	Grain and crop residues	Vertical tillage
Oct-Dec	Sorghum or crotalaria	Crop residues	Direct seeding
Jan-Apr	Sunflower	Grain	Direct seeding
May-Aug	Sorghum	Grain and crop residues	Direct seeding
Oct-May	Cotton	Fiber	Vertical tillage

at rates determined by soil analysis. As a result, grass roots developed adequately and a favorable biological activity in the soil profile to as deep as 40 cm was observed. The *B. decumbens* pasture presented excellent vegetative development, as the legume germinated and became established.

The farmer, on his own initiative, established another 1-ha plot nearby, which was subjected to an intermediate level of management, consisting of one pass with a harrow, half the fertilizer application recommended for the validation plot, and a replanting of *B. decumbens*.

The productive capacity of these pastures was evaluated by measuring the daily milk production. To evaluate the financial results of the different agroecosystems being monitored, the farm manager daily recorded the farm's costs and income.

Validation alternatives for pasture rehabilitation in semi-extensive livestock systems

The "cerrados" of the Central High Plains. The reference farm in this case was located in the municipality of Paraúna, Goiás, Brazil. On this farm, a semi-extensive livestock production predominated, in which small plots were cultivated to maize for silage to feed the dairy herd during the dry seasons. *Brachiaria decumbens* predominated, being established in 100-ha fields. Grazing was continuous throughout the rainy period and fertilizers were not applied. This type of management led to degraded pastures, reducing biomass production and increasing the incidence of ants, termites, and weeds. Overgrazing led to the development of bare soil areas, which, unprotected from strong rains, resulted in reduced percolation of water and, ultimately, in high runoff erosion. During dry periods, biomass production was insufficient to feed the herd, resulting in low weight gain, reduced milk production, and increased animal mortality.

The plot selected as a validation unit carried a 10-year-old *B. decumbens* pasture of low productivity. The plot's soil characteristics are listed in Table 2. Jointly with the farmer and the local technical assistants, the following crop systems were validated: a plot of only *B. decumbens* (control); rice, millet-sorghum, and maize/*B. brizantha* (S1); rice, millet-sorghum, maize/*Panicum maximum* cv. Tanzania (S2); rice/*B. brizantha*, using the *barreirão* system (see Chapter 15, this volume) (S3); and maize for silage/*B. brizantha* (S4). In the modified systems, land preparation consisted of one pass with a heavy harrow in the dry period (August), followed by one pass with a moldboard

Table 2. Characteristics of the soil profile at a farm in the municipality of Paraúna, Goiás, Brazil, PROCITROPICOS-Savannas Project.

Characteristics	Soil depth (cm)			
	0-3	3-18	18-25	25+
Texture	Sandy	Sandy	Loamy sand	Sandy
Aggregates	Small	Small	Medium	Medium to large
Stability	Cohesive	Hard	Weak	Weak
Internal porosity	Scarce	Scarce	Moderate	High
Compaction	Absent	Present	Moderate	Absent
Presence of roots	Abundant and diffuse	Moderate and diffuse	Moderate and diffuse	Fine and scarce
Biological activity	Present	Present	Intense	Moderate

plow plus another with a leveling harrow at the beginning of the rainy season. Lime was also applied to reduce soil acidity. At planting, the annual crops received fertilizers at rates determined by soil analysis.

Yields of the first year of cropping were 2.88 (system S1), 2.76 (S2), and 3.04 t/ha (S3) for rice; and 13.8 t/ha (S4) for the green biomass of silage maize. The millet-sorghum, which was established after the annual crops, produced 1.27 (system S1) and 1.62 t/ha (S2) of dry matter (DM); *B. brizantha*, 3.09 (system S3) and 2.5 t/ha (S4) of DM; and *B. decumbens* alone (the control), 0.69 t/ha DM.

In this case, the modified systems were found to be superior in DM yield, especially when planting *B. brizantha* after rice in the *barreirão* system. Similarly, the upland rice crop was estimated to be most profitable under the *barreirão* system (Table 3).

Table 3. Financial profitability of three farming systems, PROCITROPICOS-Savannas Project.

Components	Agroecosystem[a] (value/ha in R$[b])		
	S1	S2	S3
Variable costs	270.60	270.60	270.60
Gross income	480.00	460.67	506.70
Gross margin	209.40	190.07	236.10

a. S1 = rice, millet-sorghum, and maize/ *Brachiaria brizantha*; S2 = rice, millet-sorghum, and maize/*Panicum maximum* cv. Tanzania; S3 = rice/*Brachiaria brizantha* (*barreirão* system).

b. 1996 exchange rate: R$1.05 = US$1.00.

The "cerrados" of north-central Brazil. The plot selected as the validation unit was located at "Comag" Farm, in the municipality of Uruçuí, State of Piauí, Brazil. The plot had a pasture of *Andropogon gayanus*, established 4 years before, after 2 years of upland rice cropping without fertilizer applications. Traditional management consisted of intensive grazing during the rainy period (3 to 4 months) with a high stocking rate, rest in the dry period, and grazing again at the beginning of the rainy season. The pastures were totally degraded, with a high incidence of weeds. Under this type of management, useful pasture life on the property is about 4 years.

The management systems evaluated were *A. gayanus* under traditional management (S1); simultaneous seeding of rice and *B. brizantha*, using a moldboard plow (*barreirão* system, S2); simultaneous seeding of rice and *B. brizantha*, using a heavy harrow (S3); planting *A. gayanus* over a rice crop (S4); and planting *B. brizantha* over a soybean crop (S5).

Table 4 presents the financial outcomes of the annual crops between 1995 and 1996. The traditional system (S1) received no income in the first year, producing a negative gross margin. In system S2 (*barreirão*), upland rice production was sufficient to amortize the annual investment plus the variable costs, giving a gross margin of R$18.62[1]. The gross income from rice corresponded to 50% of the overall value—investment plus variable costs—to rehabilitate the *B. brizantha* pasture, whose yield was 32 t/ha. System S3 is a variation, proposed by the farmer, of the *barreirão* system, resulting in the farmer's gross income being sufficient to amortize the variable costs during the first year, leaving a gross margin of R$114.70 per hectare. However, the green biomass yields (18.5 t/ha) of the pasture were lower than those obtained in system S2, mainly because of the reduced number of roots under the soil layer tilled by the heavy harrow. In system S4, the gross income from rice corresponded to 81% of the overall

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[1] 1996 exchange rate: R$1.05 = US$1.00.

Table 4. Profitability of farming systems validated in the municipality of Uruçuí, State of Piauí, Brazil, PROCITROPICOS-Savannas Project.

Components[a]	System[b]				
	S1	S2	S3	S4	S5
Investments[c] (R$/ha)	0	142.60	0	130.70	142.60
Variable costs (R$/ha)					
Inputs	20.00	144.45	140.95	189.45	248.20
Operational costs	52.74	54.33	76.69	60.34	36.96
Total	72.74	341.38	217.63	380.49	427.76
Gross income					
Grain yield (sacks/ha)	0	25	23	40	23
Value (R$/ha)	0	360.00	332.40	570.00	293.58
Gross margin	(72.74)	18.62	114.77	189.51	(134.18)
Amortization[d] (%)	0	50	100	81	35

a. 1996 exchange rate: R$1.05 = US1.00.

b. S1 = traditional; S2 = rice/*B. brizantha* with moldboard plow; S3 = rice/*B. brizantha* with heavy harrow; S4 = planting over rice; S5 = planting over soybean.

c. Values equal 25% of land adaptation costs (to be amortized in 4 years).

d. Relative proportion of the total investment value (4 years) + total variable costs (1st year).

value (investments + variable costs) needed to rehabilitate the pasture, giving a gross margin of R$189.51 per hectare in the first year. Finally, in system S5, soybean yields were low, because of late planting and the limited effect of lime applied in the first year, resulting in a negative gross margin. The gross income corresponded to 35% of the overall value (investments + variable costs) needed to rehabilitate the pasture.

Once prototypes are validated through farm field plots, they can be used as demonstration units to disseminate technologies. Cooperating farmers explain their experiences concerning the advantages and limitations of each prototype to their neighbors.

Expected Results

The expected outcomes of applying the strategy of participatory research proposed for the Savannas Project are:

1. To adjust, validate, and disseminate processes of land use and management that are appropriate to the agroecological and socioeconomic conditions of the Latin American savannas.

2. To help close the gap existing between generating technological innovations proposed for managing savanna soils and their adoption by facilitating mechanisms for coordination between researchers, extension workers, and farmers.

3. To expand the participation of local, national, and regional agents in policy making for sustainable rural development. That is, the principal actors involved in technological development—farmers, technical assistance agents, and researchers from the public and private sectors—are encouraged to integrate and exchange their experiences.

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CHAPTER 4

Sustainability Indicators: Edaphoclimatic Parameters and Diagnosis of the Cultural Profile

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Contents

Abstract

In this chapter, those soil and climatic parameters related to the sustainability of agropastoral systems are analyzed, together with their significance as indicators of "soil quality" in the systems' different phases. A production system's sustainability should be evaluated in terms of soil type and ecosystem over a specified period of time, and under typical

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biophysical, economic and social constraints. Under these criteria, the historical analysis of rainfall behavior by statistical and probabilistic methods, helps to make correct decisions on the application of practices of crop production and soil conservation such as tillage, irrigation and drainage to maintain or increase productivity. Tropical soils should be managed in such a manner to develop an arable layer that favors root growth because the physical, chemical or biological constraints are controlled. Fertility status of the soil surrounding plant roots must be assessed to evaluate the impact of agricultural production systems on that soil and on the environment as a whole. The loss and accumulation of organic matter are two key processes in improving sustainability of agricultural production systems because organic compounds are closely related to soil quality factors such as structure, available water, nutrient cycling and biological activity. Indicators that take into account the dynamics of organic matter and nutrient reserves should therefore be developed and assessed. To determine if there have been significant changes in soil quality, sustainability indicators must be observed and evaluated over several years. Mechanistic models constitute powerful tools for integrating knowledge on production systems and sustainability, to overcome limitations of scale and site specificity by simulating crop growth or ecosystem functions within certain climate-soil-plant-man relationships and permit to study the sequences of management over several seasons.

Resumen

En este capítulo se presenta un análisis de los parámetros edafoclimáticos relacionados con la sostenibilidad de los sistemas de producción y se discute cuáles de ellos podrían funcionar como indicadores apropiados de la ‘calidad del suelo’ en las diferentes fases de desarrollo de los sistemas agropastoriles. La sostenibilidad de un sistema de producción se debe evaluar dentro del concepto de un tipo de tierra y de un ecosistema específico, en un período de tiempo definido y dentro de las limitaciones físicas, económicas y sociales que normalmente ocurren. El análisis histórico del comportamiento de las lluvias por métodos estadísticos y probabilísticos es una herramienta de gran utilidad en la toma de decisiones sobre la conveniencia o no, de la aplicación de prácticas para el manejo productivo y la conservación de los suelos, entre ellas: el tipo de labranza, la aplicación de riego y la construcción de drenajes. El objetivo principal a tener en cuenta en el manejo de suelos tropicales es el de construir una capa arable, entendiendo por ello la obtención de una capa favorable para el crecimiento de las raíces de las plantas, de tal manera que no se presenten mayores limitaciones físicas, químicas o biológicas. La calidad del suelo en la zona de raíces puede ser evaluada utilizando parámetros sensibles que permitan concluir sobre el impacto de los sistemas de producción agrícola en el recurso suelo y en el ambiente. Es necesario contar con indicadores de calidad que tomen en consideración la dinámica de las propiedades físicas del suelo y de las reservas orgánicas de los nutrimentos. Los procesos de pérdida y acumulación de materia orgánica son básicos para lograr la

sostenibilidad de los sistemas de producción agrícola, ya que los compuestos orgánicos están estrechamente relacionados con la estructura, el potencial de agua aprovechable, el reciclado de nutrimentos y la actividad biológica. La evaluación de indicadores de sostenibilidad y su observación pueden requerir de varios años para determinar si ha habido o no cambios significativos en la calidad del suelo. La utilización de modelos mecanísticos constituyen una herramienta poderosa para integrar los conocimientos en sistemas de producción, venciendo las limitaciones de escala y de especificidad de sitios. Existen varios tipos de modelos o familias de modelos que simulan el crecimiento de cultivos dentro de la relación clima-suelo-planta-hombre; estos modelos tienen la capacidad de simular secuencias que permiten la evaluación de efectos de varias estaciones.

Introduction

As the world's population increases, the soil, a basic natural resource, is increasingly under pressure as demand for food, fuel, and fiber grows. Most of this pressure occurs in tropical and subtropical developing countries where soils usually have fewer nutrient reserves and where more extreme temperatures and rainfall than in temperate regions accelerate the processes of soil degradation over larger areas. Agricultural production systems, therefore, must be adapted to the edaphoclimatic conditions of these ecosystems to reach the production levels demanded by growing populations without causing long-term degradation of the soil resource on which production depends.

The sustainability of agricultural production systems depends on maintaining or improving the physical, chemical, and biological characteristics of the soil as a basic resource. Accordingly, the development and evaluation of alternative production systems requires the long-term study of productivity involving quantification of the impact of agricultural systems and soil management practices on important properties and processes related to agronomic productivity and environmental quality (Lal 1994). The sustainability of a production system should be evaluated within the concept of a given land type and ecosystem, over a specified period, and within the physical, economic and social constraints of that specific region (Dumanski 1993). A system that is sustainable under certain socioeconomic and edaphoclimatic conditions may not necessarily be so under other conditions.

In this chapter, we analyze the edaphoclimatic parameters related to the sustainability of agropastoral production systems, and discuss those parameters that might function as appropriate indicators of "soil quality" in the systems' different phases of development.

Soil-climatic Relationships and Agricultural Production

Agricultural production and productivity depend on the behavior, intensity, balance, interactions, and interdependence among climate, soils, plants and man (Figure 1). To determine the type of crop that can be successfully developed within a given agroecological area, we need to identify, define and quantify the climatic and soil characteristics that could act as constraints to crop productivity. Through appropriate soil and crop management, we must achieve the best dynamic balance among these factors to obtain the maximum yields under a given natural environment (Amézquita 1989).

Cultural practices should be focused in such a way that they maximize photosynthesis in a given site and soil. This can be achieved if the factors controlling photosynthesis such as light, temperature, water, nutrients, air and mechanical support are optimized. Under open field conditions, controlling light intensity and temperatures is not possible, but factors related to soils are amenable to be managed and improved so that they may be optimized for maximum productivity and for sustainability.

Under field conditions, the water used by plants is supplied by rain. Figure 2 shows the general characteristics of precipitation as well as its use and implications for appropriate soil management. For example, the parameter "quantity" of rainfall leads to quantitatively defining hydric balance according to the plants' specific water requirements and hence to crop selection. The parameter "intensity" of rainfall leads to calculating the kinetic energy of rainfall that causes soil erosion and to plan for the need for soil conservation. The combination of the parameters "duration", "quantity", and "intensity" of precipitation is related to flood control and to the design of suitable soil tillage systems for better water storage and use in the soil profile. Finally, the frequency of these rainfall attributes permits the calculation of the probability of repeating similar maximum or minimum events within a period of time, to design systems for soil and water conservation, and collection and storage of runoff for electrical energy purposes (Harrold et al. 1976).

The historical analysis of rainfall behavior by probabilistic statistical methods is highly useful for decision making on the desirability of applying

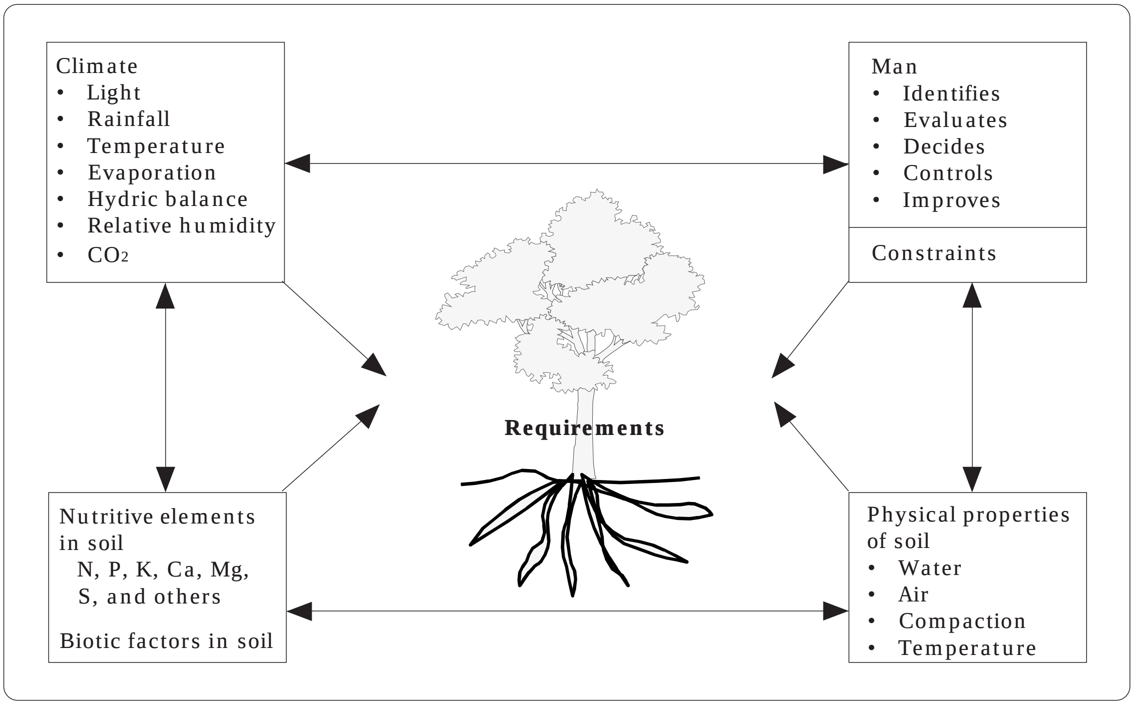

Figure 1. Agricultural production factors, and their inter-relationships.

practices for production management and soil conservation including tillage, irrigation, and drainage. By working with monthly, weekly and daily probabilities, we can estimate the quantities of rain to be expected and, hence, calculate hydric balances. Such calculations allow us to plan for irrigation and drainage systems, and design tillage and soil management practices that improve soil profiles in areas where intensive production systems are being practiced (Amézquita 1974; Ortotani and Camargo 1987).

Figure 3 presents the probability of receiving certain amount of rainfall in a 1-week period at the Carimagua Research Center, Eastern Plains of Colombia, based on 20 years of consecutive data. It can be seen from the figure that rains reliably occur from weeks 16 to 43. For example, in week 21, rains are assured because the probability of their occurring is equal to 1, and the certainty that between 70 and 250 mm will fall is 80%. Figure 4 shows the probable behavior of rainfall, that is, when a given quantity can be expected to fall and when the expected precipitation will be equal to or more than 25 mm amount of water which is required for evapotranspiration in a week, during the growing season. Between weeks 18 and 40, with a probability higher than 70% it is expected to have rainfalls above 25 mm, thus exceeding the weekly rainfall requirements.

The study of rainfall intensity in terms of energy and the prediction of rainfall distribution are indispensable for programming soil erosion control practices using the erosivity (R) factor of the Universal Soil Loss Equation (Wischmeier and Smith 1978).

The study of hydric balances is also useful for planning agronomic practices when based on both historical climatological analyses and soil physical characteristics such as those related to soil water storage, rooting depth, compaction, formation of surface crusts, aeration capacity and infiltration. Knowledge of the soil profile's properties before and during the agricultural cycle is also fundamental for the best use of land and soil management.

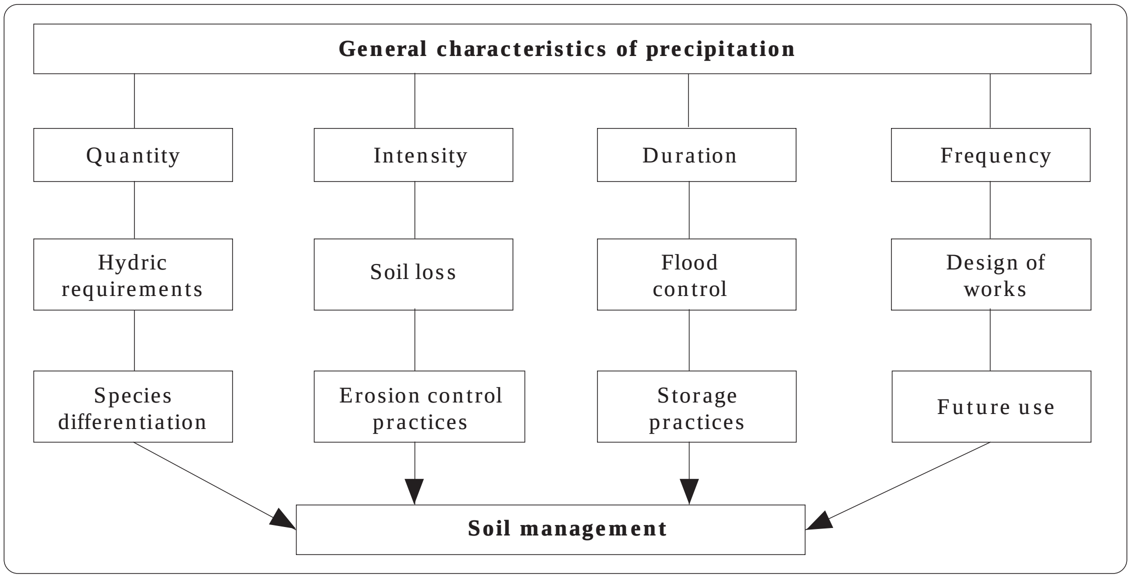

Figure 2. Relationships between precipitation and the management of soil as resources of agricultural production.

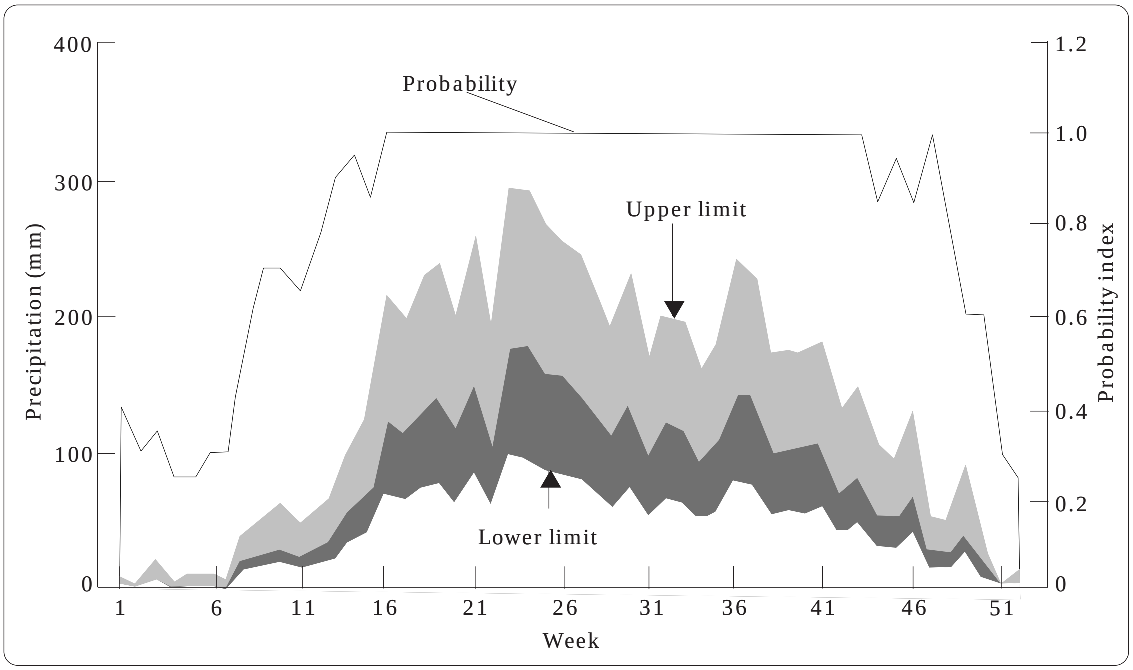

Figure 3. Probability of rainfall and confidence intervals (to 80%) of weekly precipitation in Carimagua, Colombia (20 years of data).

Relationships between Soil Physical Properties and Plant Nutrition

Roots, being geotropic develop in the soil and create a unique environment in which numerous chemical, physicochemical and biological reactions occur continuously and simultaneously. These reactions determine the soil's capacity to provide the necessary nourishment for plants.

The dynamics of water and nutrient absorption by plants is influenced by the behavior of the solid, liquid and gaseous phases of the soil which are governed by thermodynamic laws. These laws determine the magnitude, intensity, quality and opportunity for nutrient supply and for ion exchange at the soil-solution-root interfaces, processes by which the plants are nourished. Table 1 shows the factors that affect the transformations that an essential element undergoes when becoming a nutrient (Amézquita 1991). To be absorbed by a plant, a nutritive element that already exists in the soil must come into contact with that plant's roots. Such contact occurs through (1) *interception by roots* as they grow and come into contact with the element that is present in the soil; (2) *mass flow*, when the nutrient moves simultaneously with the water that is being absorbed by the plant between field capacity and wilting point, obeying hydraulic potential gradients created by evapotranspiration; and (3) *diffusion*, when the element moves across very short distances in a stationary aqueous phase, passing from a region of high concentration to another of low concentration very close to the root's surface (Barber 1984; Malavolta et al. 1989).

A close relationship also exists between these three processes and the soil pore size distribution. Interception occurs basically through macropores (>60 µm); mass flow through mesopores (60-0.2 µm); and diffusion through micropores (<0.2 µm). The proportions of the different pore sizes, relative to each other, is affected by tillage. Over-tillage may decrease macropores and increase meso and micropores (Figure 5) (Amézquita 1994; Greenland 1979).

The absorption of water and nutrients and their subsequent transport within the plant depend on there being sufficient water in the soil to guarantee normal transpiration, and sufficient and timely supplementation of nutrients to the plant, both in quantity and in quality, to avoid any limitation to photosynthesis due to low supply of water and nutrients. Normally, under field conditions, the requirements for timely transportation of water within the soil-plant-atmosphere continuum are not fulfilled (Reichardt 1985). In these cases, transpiration, which should balance the environmental evaporation demand, is constrained by the soil's limited capacity for water storage. This limitation is influenced by such factors as a reduction in hydraulic conductivity as stored soil moisture

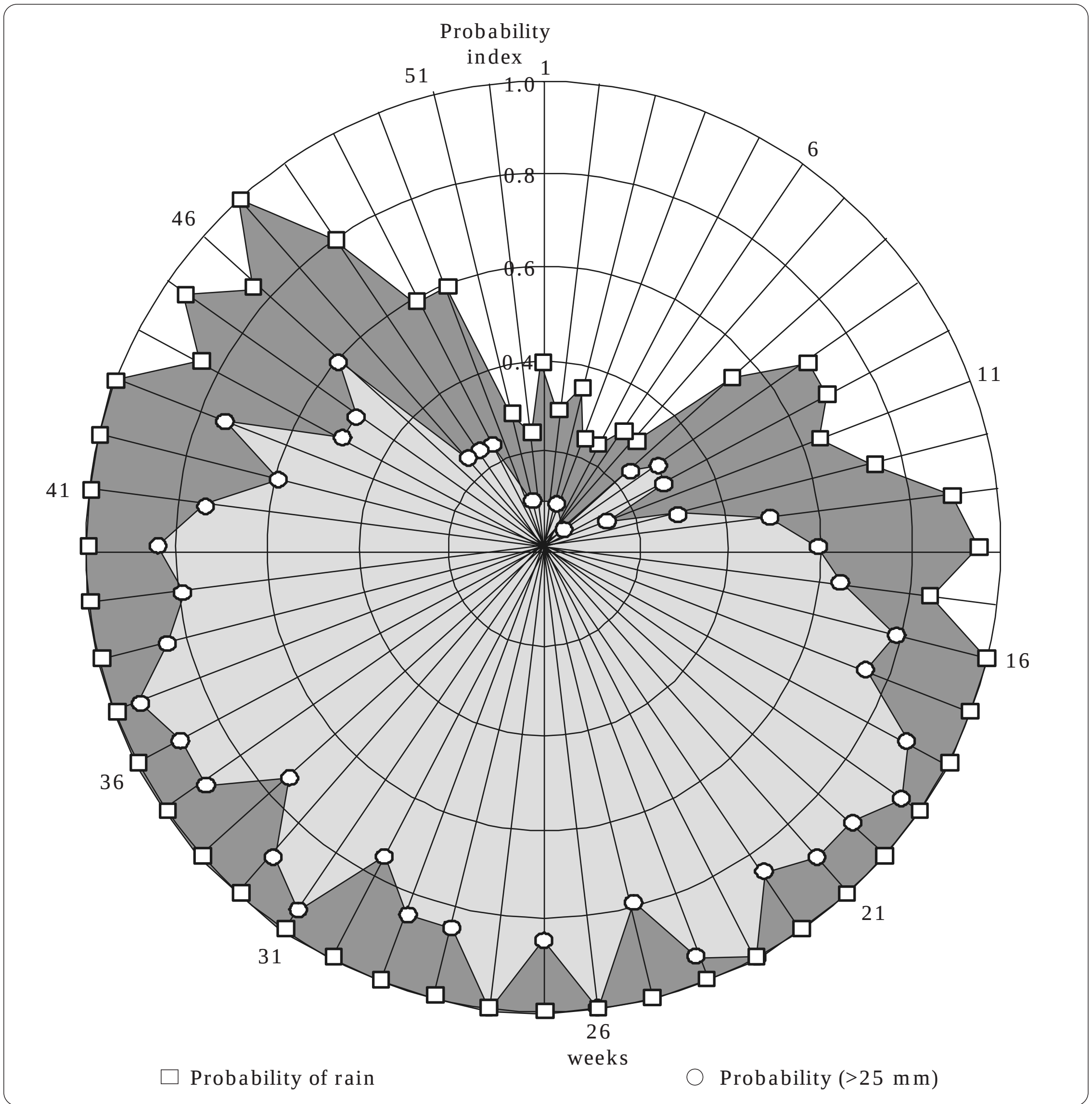

Figure 4. Weekly probability of rainfall at Carimagua, Colombia (20 years of data).

Table 1. Factors that influence the processes of plant nutrition, and the soil physical properties affecting them.

Factor	Process or property involved:	Contact with root surfaces affected by:	Uptake and use by plants affected by:
Organic matter	Cation exchange capacity	Movement of nutrients in solution; Distribution of soil pores	Presence and availability of nutrients and water
Soil texture	Organic matter mineralization Soil structure	Root growth; Root penetration	Osmotic potential of roots
Water potential	Soil moisture Rainfall Aeration	Mass flow; Diffusion	Turgor potential of roots
Structure	Aeration Temperature	Pore size distribution; Thermal diffusion	Oxygen pressure
Aeration	Temperature	Macroporosity	Temperature
Erosion	Erodibility		

diminishes, root distribution and permeability, the plant's capacity for water conduction, and the contraction of roots when atmospheric demand is excessive and the soil is unable to conduct the water at this required speed. Within a scheme of productive soil management, all these factors must be included and optimized through timely and well-focused management practices.

Adequate and timely supplementation of nutrients in quantity and quality can also be limited by factors such as low availability of nutrients, the absence of one or more of them, low solubility, ionic antagonism, low moisture content, deficiency in root distribution, and low capacity of soil aeration.

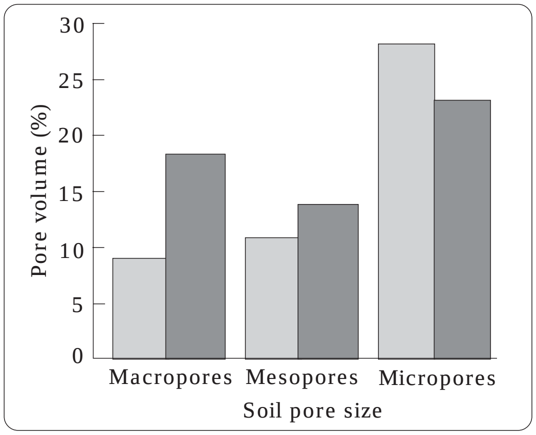

Figure 5. Distribution of soil pore size in the top 2.5 cm of soil under native savanna (□) and continuous cultivation (■), Matazul, Eastern Plains of Colombia.

The previous discussion shows that, to adequately nourish a plant, both climatic and edaphological factors needs to be considered. The latter include chemical and biological factors that affect nutrient supply, and physical factors that affect supplies of water and air.

For continuous and adequate plant nutrition, edaphic management should consider the following factors:

- Presence and availability of essential nutritive elements
- Water capillarity suction in the soil
- Aeration in the rhizosphere
- Mechanical resistance to root penetration
- Soil temperature

Demands created by these factors can be handled by applying fertilizers (for essential nutrients) in accordance with local requirements of crops and soils, and by ensuring adequate distribution of soil pores, especially macro- and mesopores, which regulate aeration, root growth, mass flow, and nutrient diffusion (Amézquita 1994).

The Soil Cultural Profile

From the edaphological viewpoint, the arable soil profile refers to that volume of soil that can be exploited by plant roots. It is made up of a series of soil layers developed through the actions of cultivation tools, roots, and those factors that resist intervention by humans or the environment (Gautronneu and Manichon 1987).

The construction of a cultural layer is the principal objective that underlies the management of tropical soils. This consists of developing a growth layer in which roots will not suffer physical, chemical, or biological limitations, thereby permitting adequate plant development. Once a consistent and productive cultural layer is obtained, sustainable agriculture can be carried out. Tilling and the application of chemical amendments and fertilizers, combined with adequate biological management of the soil, are constructive practices that will prevent soil degradation.

A good cultural soil profile is characterized by:

- Sufficient availability of essential nutritive elements so that plants do not suffer deficiencies;

- A high capacity to store and transmit sufficient water to roots, thereby preventing moisture stress;

- Possession of sufficient air space to permit root respiration and nutrient absorption;

- Easy root penetration, thereby permitting them to explore an adequate volume of soil for water and nutrients; and

- A range of temperatures that favor the physicochemical reactions that contribute to the availability and absorption of nutrients and water.

Soil research is successful when it leads to the understanding of how the previous factors can be controlled through management practices that also tend toward an integrated improvement of the soil to ensure its ability to sustain plant growth and agricultural production.

Soil Factors and Assessing Sustainability

Evaluating the sustainability of agropastoral systems

Soil richness can be evaluated by considering the quality of the rhizosphere (Dumanski 1993). Biophysical factors that determine soil quality in the rhizosphere and, consequently, affect agricultural production include bulk density, hydraulic properties, fertility, nutrient availability, and the presence of toxic elements. Indices to evaluate the impact of agricultural production systems on soil resources and the environment can be based on observations of one or more of these factors. However, sustainability indices are viable only if they take into account sensitivity to changes in management and to variability across time and space (Lal 1994), and are easy to measure. Lal (1994) has suggested the following temporal scales for evaluating sustainability indicators:

- One to several cycles for evaluating physical, chemical, and biological soil properties in any association of soils and farms

- 5 to 20 years for soil erosion and fertility reduction in hillsides and watersheds, and in any association of soils and farms, respectively

- One to several cycles for soil compaction and acidification in upland farm plots and soil association, respectively

Definitions of sustainability should also include concepts on reversibility and irreversibility in biophysical and economic terms.

Physical and hydrological factors

Physical properties of tropical soils that are subjected to changes in soil and crop management over time include soil structure, aggregate stability, bulk density and pore size distribution. Hydrological properties include hydraulic conductivity, water retention and rate of infiltration. Signs of structural degradation and erosion include compaction, crust formation and sealing, infiltration and leaching, and runoff.

The inadequate and indiscriminate use of disc harrows on fragile soils in those flat areas where intensive agriculture is possible accelerates soil degradation and, therefore, reduces the sustainability of production systems. Thus, there is a need to develop relatively less destructive tillage methodologies for sustainable soil management.

Chemical and fertility factors

The chemical processes affecting the sustainability of agricultural systems include soil acidification, nutrient reduction, and loss of organic matter (OM). These three major classes of chemical processes are summarized in the following list:

Soil property	*Class of processes*
Acidity	Acidification
pH	Mineral weathering
Total acidity	Nutrient transformation
Exchangeable aluminum	Organic matter mineralization
	Patterns of absorption of ions by plants
	Leaching
Nutritive factors	Nutrient status
CEC	Export through crops
Exchangeable cations	Recycling
Capacity for P adsorption	Fertilizer application
Availability of P and S	Mineralization
Organic and inorganic N, P, and S	Leaching
	Fixation
Organic matter content	Loss/retention of carbon
Total organic C content	Mineralization/oxidation
Pools of mobile and stable C	Humification
	Stabilization/fixation

Soil acidity is determined mainly by the soil's mineral composition which in turn is related to the degree of weathering. Soils dominated by low activity clays such as kaolinite and by iron and aluminum oxides and hydroxides have a low cationic exchange capacity (CEC) and are often highly saturated with exchangeable aluminum. Soil acidity can be increased through certain agricultural practices. Soil preparation promotes the oxidation of OM, which is accompanied by the production of hydrogen ions. Similarly, some fertilizers—particularly those that contain reduced nitrogen such as urea and ammonium sulfate—generate hydrogen ions during nitrification. Crops that present acidic patterns of nutrient absorption, such as legumes, also produce acidity.

In soils strongly dominated by low activity clays, CEC is found on surfaces of variable charge. Consequently, the principal effect of increasing soil acidity is the loss of capacity for cation retention. Under conditions of leaching, the cations liberated from surfaces of variable charge move downward through the soil profile accompanied by anions either applied as fertilizers (mainly NO_3^-, Cl^-, and SO_4^{-2}) or produced during the mineralization of OM. Under such conditions, lime application may have relatively low residual value, especially when it is accompanied by high doses of fertilizers.

Essential to understanding soil acidity is that, at least under conditions where precipitation is greater than evapotranspiration, natural and agricultural production systems promote increased acidity at variable intensities, unless adequate corrective measures are taken. Consequently, agricultural systems, especially those developed on highly weathered soils with weak buffering capacity, require regular monitoring of soil acidity. Acidity indicators include pH, exchangeable aluminum, and total acidity. Different crops and pastures often have variable degrees of acidity tolerance. This fact leads to two very important consequences: first, different crops require different levels of lime application; and second, those production systems based on low levels of lime will necessarily be limited to those components that can tolerate the given levels of soil acidity.

Nutrient status. The highly weathered soils of the humid tropical ecosystems of South America are low in total and available nutrients. Improving crop germplasm for tolerance of low soil fertility permits an increased use of such soils. However, to sustain an acceptable level of agricultural production, external applications of soil amendments and fertilizers are needed. Without these applications, using adapted germplasm alone will generally lead to a greater exploitation of the system's resource base and, thus, to reduced levels of soil nutrients.

Moreover, the ability of these soils to retain nutrients under leaching is very low, except for phosphorus, because of their low CEC. Accordingly, nutrient application should be carefully managed and balanced, so that excessive application does not result in contamination of ground water and rivers. Balanced plant nutrition requires that the relationships between crop needs, nutritive levels in the soil, and fertilizer applications be well defined. Usually, these relationships are specific to locality and crop. However, if they are defined within a certain range for given associations of soil and crop, they can also lead to significant improvement in nutrient-use efficiency.

In soils with low reserves of mineral nutrients, the organic reserves of P, N, and S play a significant role. Soil P fractionation studies show significant increases in the reserves of the mobile form of this nutrient when it is applied to the soil. Conventional analyses for P do not adequately reflect the state of this nutrient, nor the degree of recycling within the system (Friesen et al. 1997; Oberson et al. 1999). New indicators must therefore be developed and evaluated to take into account the dynamics of the organic reserves of nutrients.

Loss of organic matter. The accumulation and loss of OM are basic to the sustainability of upland agricultural production systems because organic compounds are closely related to factors of soil quality, that is, structure, available water, nutrient recycling, and biological activity. Under cultivation, total OM content declines. Attempts to recover reductions with high applications of crop residues and other types of organic biomass have had little success. The active or mobile OM fractions may comprise a more sensitive indicator of soil quality than total OM content. This hypothesis is supported by Gijsman and Thomas's (1995) finding of a high correlation between structural stability and soluble organic carbon in a Colombian Oxisol.

Biological factors

Through their diversity and populations of species, and their activities, soil fauna and flora play a significant role in the maintenance and improvement of soil quality. They can affect soil processes by modifying the soil's structure, water flow and leaching, and by incorporating organic residues. They also affect nutrient recycling through biological N_2 fixation, and by changing the balance of organic carbon and nutrients through mineralization, oxidation, and immobilization

Macrofauna are involved in fractionating and incorporating organic residues, and their conversion to OM. Consequently, macrofaunal activity has a significant influence on both soil structure and nutrient recycling. Their populations and their dynamics are strongly influenced by soil management practices. For example, Decaëns et al. (1994) observed that, in the Eastern Plains of Colombia, macrofauna populations increase under improved pastures whereas, under annual cropping systems, they tend to decline (Figure 6).

Soil microfauna also plays a major role in nutrient recycling and carbon dynamics. Microbes are responsible for the mineralization and immobilization of nutrients in OM. Consequently, these soil attributes can also serve as indicators of the system's recycling and "health" (Oberson et al., 2001).

Estimating Sustainability through Modeling

As previously indicated, to evaluate sustainability, the study of indicators may require several years to demonstrate significant changes in soil quality. Observations of the effect of resource management are often locality specific, which makes extrapolating to other sites difficult. In addition, the high cost of long-term experiments to evaluate sustainability issues excludes many management options. However, these limitations can be addressed using mechanistic modeling techniques.

The factors that determine whether an agricultural system is sustainable are numerous, complex, and interactive. Mechanistic models are useful for integrating knowledge of

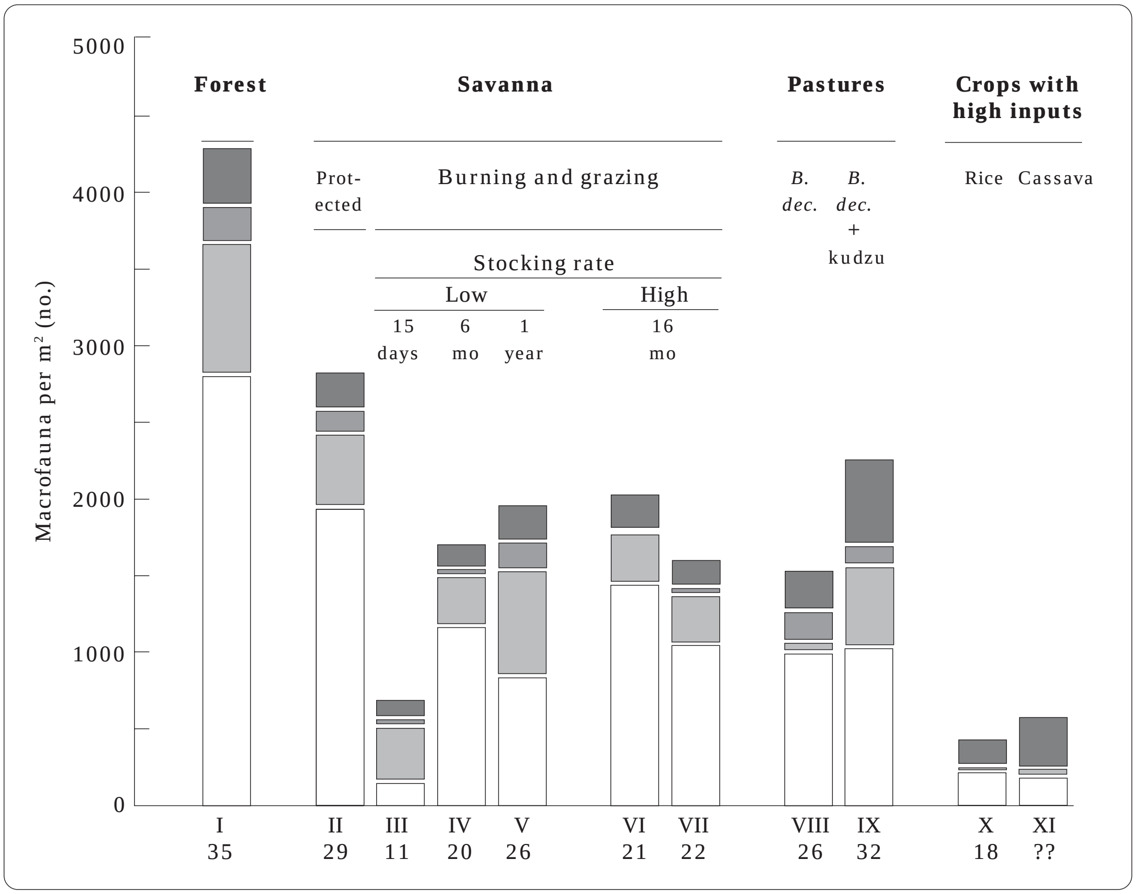

Figure 6. Distribution of density and biomass of soil macrofauna under different management systems in the Eastern Plains of Colombia (after Decaëns et al. 1994). *B. dec.* = *Brachiaria decumbens*; kudzu = *Pueraria phaseoloides*; roman numbers = management system code; arabic numbers = number of taxa; ▨ = earthworms; ░ = ants; □ = termites; ■ = other invertebrates.

production systems, and overcoming limitations of scale and site specificity. These models focus on (1) quantitative characterization; (2) understanding the processes that operate at various levels within production systems; and (3) the effects that climate, soil properties, and management practices have on them. Several types, or families, of models are available to simulate crop growth or ecosystem functioning within the soil-water-atmosphere system. These models have different attributes or approaches, depending on the objective for which they are applied.

Natural resources research at CIAT has focused on the use of two models to integrate research on the development of sustainable production systems for the acid soils of tropical lowlands. These models are DSSAT family of models for crop production (Tsuji et al. 1994) and the CENTURY model for soil OM (Parton et al. 1987). The first DSSAT models simulate the growth and development of a range of important crops (cereals, grain legumes, roots, and tubers) under different climatic conditions and water and nutrient limitations (currently, N only, but P submodule is being developed). These models have the sequential capacity to evaluate effects over several seasons. CENTURY is oriented toward the dynamics of the nutrients C, N, P, and S, and was originally developed for the extensive natural pastures of North America. The evaluation of this model at CIAT for the Oxisols of the South American savannas revealed several weaknesses, owing to low P availability in the savanna soils (Gijsman et al. 1996).

The use of models in evaluating sustainable systems of land management is limited by, among other factors, an absence of technical knowledge that would permit the prediction of long-term effects or the importance of subtle processes. In addition, the understanding of some processes, their complexity and interactions is incomplete, leading to oversimplifications that can result in erroneous conclusions when applied over the long term. Models are useful for exploring the possible effects of new methods or alternative land uses, assessing trends, and comparing the effects of alternative strategies.

Conclusions

To identify the best options for crop productivity in the agricultural sector, it is critical to know the behavior of the climatic factors (precipitation, temperature, solar radiation, relative humidity, etc.) that affect the rate of net photosynthesis. These factors determine the climatic productivity potential of a given area. Once the climatic behavior is well understood, the soil characteristics that influence the fertility status of the soil (through the determination of sensible indicators), must be also studied and understood. This will help to determine appropriate soil management options to fit the climatic component, in order to reach the maximum productive capacity of a crop or an agricultural system under a given agroecological environment. Fulfilling these needs is crucial to achieve profitable and sustainable agriculture.

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PART II

Methodological Aspects of Agropastoral Research

CHAPTER 5

Planning and Designing Agropastoral Trials

*M. C. Amézquita**

Contents

Abstract

Research on agropastoral systems in Latin American savannas is more complex than single-component research, because it involves research

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on various, individual, components such as soil, one or more short-cycle crops, one or more pastures, and animals. Certain methodological aspects of agropastoral trials such as different research phases and objectives, and the planning and design of experiments to be conducted in each phase must therefore be studied in depth if results are to be comparable and extrapolable to the countries of the Agropastoral Research Network for the Savannas: Bolivia, Brazil, Colombia, Guyana, and Venezuela. This paper discusses some methodological aspects related to research hypotheses for the well-drained tropical savannas. Different phases of agropastoral research are identified and the methodological aspects that should be considered when planning and designing trials are discussed. These aspects include hypotheses, experimental factors, control treatments, types of experimental design, response variables, and duration of experiments. Concepts and recommendations are offered for planning and designing different trials within the Agropastoral Research Network.

Resumen

La investigación en sistemas agropastoriles en las sabanas tropicales de América latina, a diferencia de la investigación en cultivos de ciclo corto, en pasturas o en suelos per se, presenta complejidades adicionales que exigen complementar y compatibilizar los resultados obtenidos mediante la investigación en componentes individuales como el suelo, uno o más cultivos, una o más pasturas y el hato ganadero. Es, por tanto, necesario profundizar en aspectos metodológicos de este tipo de investigación, con el fin de hacer comparables y extrapolables los resultados que se generen en Bolivia, Brasil, Colombia, Guyana y Venezuela, países que conforman la Red de Investigación Agropastoril para las Sabanas. En este artículo se presentan aspectos metodológicos partiendo de las hipótesis de investigación relevantes para el ecosistema sabana tropical bien drenada. Se identifican las distintas fases de la investigación agropastoril y sus objetivos y se analizan aspectos relacionados con la planeación y diseño de los ensayos, entre ellos: hipótesis experimentales, factores experimentales, tratamientos control, tipo de diseño experimental, variables de respuesta y duración del período experimental. También se ofrecen conceptos y recomendaciones para la planeación y diseño de investigación en la Red Agropastoril.

Introduction

Benefits from agropastoral systems

The potential for pasture, crop, and agropastoral systems for sustainable agricultural production of the savanna and rainforest-margin ecosystems has been recognized by several researchers (Goodland 1980; Toledo et al. 1989; Vera et al. 1993; Zeigler and Toledo 1993). Research has shown that associating and rotating pastures with crops offer economically viable alternatives to traditional cropping in the bi-seasonal tropical savannas of Laos (Southeast Asia; these savannas had previously been forested, then slashed and burned) (Shelton and Humphreys 1972; Thomas and Humphreys 1970); the Brazilian *Cerrados* (Kluthcouski et al. 1991); and the Colombian savannas (CIAT 1994a, 1994b, 1994c; CIMMYT 1994; Sanz et al. 1994a, 1994b; Vera et al. 1993). The last group of savannas is often characterized by high costs of improving pastures, pastures degraded by extensive grazing, and soil compaction and degradation caused by continuous monocropping.

The agropastoral system technology offers the following alternatives for solving the above-mentioned problems: (1) establishment of improved pastures associated with crops through use of minimum inputs that do not demand high capital investments; (2) renewal of degraded pastures through rotation or association with annual crops; and (3) pasture rotation systems with grain legumes or grain-and-forage legumes as green manure to reduce deterioration of soil by permanent monocropping.

Objectives of research on agropastoral systems, and methodological needs

Zeigler and Toledo (1993) defined the objectives of conducting research on agropastoral systems for the Latin American savannas. They are assembling germplasm of pastures and crops adapted to and productive under savanna conditions, and identifying and using the most appropriate management options.

In the agropastoral system, the perennial component should contribute to long-term improvement of soil, whereas the annual component should ensure the fast and economic establishment of perennial components, thereby offering an attractive alternative to the farmer. This objective became possible with the development of rice, maize, and sorghum germplasm adapted to the acid and low-fertility soils of the savanna ecosystem (CIMMYT 1993; INTSORMIL 1993; Sarkarung and Zeigler 1989). Research started in 1983, when germplasm of grasses and forage legumes adapted to this ecosystem was developed and made available through work performed by the International Tropical Pastures Evaluation Network (RIEPT, its Spanish acronym) (Pizarro 1983, 1992; Toledo et al. 1983).

Research complexity

Research on agropastoral systems is highly complex, and characterized by:

1. The study of multiple components: the soil and its management; the crop and its germplasm options and management practices for a synergistic and nonantagonistic effect when associated with pastures; the pasture, its germplasm options and combinations, and management; the animals and their type and condition; and the farmer's socioeconomic environment. All these components should be analyzed independently, and for their interactions with the system's other components.

2. Being long term, given that the objectives are to increase the productivity of a system with a perennial component (the pasture), and to improve the soil quality over the long term.

3. Having a multidisciplinary nature, which requires, among other things, research specialists for soils, crops, pastures, animals, and biometrics. The integration of all these researchers' multidisciplinary orientations is essential if the work to succeed.

The methodological aspects of agropastoral trials must therefore be explored in greater depth, and include the different phases of research, their respective objectives, and the planning and design of experiments for every phase.

The following section aims to define standard methodologies so that results generated in the countries participating in the Agropastoral Research Network for the Savannas can be compared and extrapolated. The overall objective of the chapter is to analyze these methodological aspects and to make recommendations for the Network's participants.

Research Phases

Research on agropastoral systems is structured as five phases that respond to the particular needs of their components, as follows:

1. Research on the plant component (crop or pasture) and research by discipline. This research may include successive phases of research on agropastoral systems, with or without animals. Although most trials are conducted on experiment stations, those on agropastoral systems may also be carried out on farms, according to the trials' objectives.

2. Establishment of pastures with crops.

3. Pasture reclamation, using crops.

4. Pasture/crop rotation systems.

5. Technology validation trials in commercial systems.

Table 1 summarizes the principal differences and methodological similarities between research by component and discipline (Phase 1) and research on agropastoral systems (Phases 2-5).

Research on the crop and pasture component (i.e., plant component) aims to develop short-cycle crops and pastures adapted to acid soils and to identify promising materials for assembling agropastoral production systems for the savannas. These systems can be pastures with crops, pasture/crop rotations, or short-term monocropping.

The planning, design, and implementation of research on the crop component are similar to those of traditional research on short-cycle crop improvement. However, at certain stages, the evaluation of promising crop lines should be carried out in association with pastures.

One example is the strategy that CIAT and the Colombian Corporation for Agricultural Research (CORPOICA, its Spanish acronym) developed for upland rice in agropastoral systems for the well-drained savanna ecosystem. The strategy consisted of:

1. Evaluating potential rice parents under monoculture and in association with pastures.

2. Managing all stages of selecting and identifying promising rice lines under monoculture.

3. Evaluating the promising lines in association with pastures to identify those that do not adversely affect the pasture's development and do not reduce their own yields when grown in association.

4. Identifying crop management practices for the association that would benefit both components.

Table 1. Characteristics of research by component and discipline versus those of research on agropastoral systems.

Criterion	Research Phase 1		Central research on agropastoral systems (Phases 2-5)		
	Research by crop component	Research by discipline	Pasture establishment and renewal	Pasture/crop rotations	Validation of technology in commercial animal-production systems
1. Objective	Evaluate and select: 1. Adapted, productive, and compatible crop lines in association with pastures 2. Crop management practices that are in synergy with the pasture	Evaluate and identify the best management practices for soils, weeds, and pests that would guarantee optimal productivity of both crop and pasture, while improving the soil resource over the long term	Evaluate and recommend the best associations in terms of their success in establishing and/or renewing pasture	Evaluate and recommend alternative systems that incorporate components that reduce or correct soil degradation and are economically attractive to farmers	Promote the better associations and rotations to commercial animal-production systems
2. Place of implementation	Experiment station	Experiment station	Experiment station	Experiment station or farm	Farm
3. Experimental factors	Multiple factors 1. Land preparation method 2. Types and rates of fertilization applied to the crop 3. Method of sowing the crop 4. Method of sowing the pasture 5. Lines or genotypes, among others	Multiple factors, according to research discipline	One factor Type of pasture/crop association + controls	Two or three factors 1. Application levels of Ca + control 2. *Alternative systems:* monoculture, crop rotation, legumes as green manure, local control 3. Duration of rotation	One factor Associations or rotations (best options) + local control
4. Experimental unit	Small plot 20-25 m^2 (monoculture) 30-40 m^2 (association)	Small plot	Intermediate plots (approx. 1-2 ha)	Large plots (10-20 ha)	Large fields (20-30 ha), according to animal production system
5. Experimental period	Short (1 crop cycle)		Intermediate duration (from 4-12 months after harvesting the crop) to evaluate success under grazing	Long (3-5 years)	Long (1-5 years, depending on animal production system)

(Continued)

Table 1. (Continued).

Criterion	Research Phase 1		Central research on agropastoral systems (Phases 2-5)		
	Research by crop component	Research by discipline	Pasture establishment and renewal	Pasture/crop rotations	Validation of technology in commercial animal-production systems
6. Experimental design	Disciplinary research: complete, incomplete, and augmented multifactorials, replicated in space, in RCB, split, sub-, and sub-sub-split plots. Selection of crop varieties: RCB and RIBD (lattice and Alpha designs)		RCB or split plots with 2-3 replicates and 3-3 associations + control per replicate	RCB, with 2-3 replicates and 3-6 treatments per replicate	Designs possibly not replicated within the farm, but farms can represent replicates, e.g., one agropastoral system per farm
7. Response variables	1. *Soil:* physicochemical 2. *Crop:* germination, yield components, production 3. *Pasture:* germination, production over several stages of the crop	1. *Soil:* physicochemical 2. Incidence of pests and diseases; incidence of weeds, depending on discipline 3. Crop and pasture production	1. *Soil:* physicochemical, over time 2. Final crop production 3. Pasture biomass available before and after grazing 4. Stocking rate, liveweight gain	1. *Soil:* physicochemical, over time 2. Final production of each crop, pasture biomass available before and after every cycle 3. Carrying capacity of system in each overall cycle 4. Total system productivity over cycles	1. *Soil:* initial and final characterization 2. Total production of each component and of the integrated system 3. Profitability for farmers

To identify rice lines that would be promising agropastoral system components, successive trials with traditional designs are carried out, that is, preliminary yield trials (randomized complete block [RCB] design with 20 to 40 lines and 3 replicates), advanced or regional trials (RCB design with 5 to 10 lines and 3 replicates), and commercial trials (RCB design with 1 to 2 lines and 3 replicates). In these trials, the lines are evaluated under monoculture and in association with pastures in plots averaging 25 and 36 m^2, respectively, using as control the varieties Oryzica Sabana 6 and Guarani Sabana 10, which are both adapted to acid soils.

However, at the International Maize and Wheat Improvement Center (CIMMYT, its Spanish acronym), the selection and identification of maize materials for acid soils are carried out under monoculture. The final product (e.g., variety Sikuani, adapted to and productive in acid soils) is delivered as a component for agropastoral research systems (CIMMYT 1994).

In another section of this chapter, other experimental designs for selecting and identifying promising crop lines are dealt with in greater detail.

Research on the pasture component aims to identify forage grasses and legumes, and their promising associations, for agropastoral systems in the savanna ecosystem. The experimental methodology used is the one suggested and implemented by RIEPT during 1979-1994 in multilocational trials types A and B for sole species (Toledo et al. 1983) and trials types C and D for sole species or associated under grazing conditions (Paladines and Lascano 1983; Pizarro 1992). The potential for producing these species has been determined over the long term in commercial-scale meat and dual-purpose systems on experiment stations or farms, where the experimental plot corresponded to fields, which measured from 20 up to 30 ha, and the experimental period varied from 1 to 6 years (CIAT 1978-1991).

Research by discipline, for example, pathology, entomology, physiology, or weeds, focuses on specific problems that affect the crops and pastures whether in association or in rotation. Soil research aims to identify those cultivation, fertilization, and management practices that would guarantee the long-term sustainability of the agropastoral system.

Basic research on agropastoral systems evaluates crops and pastures under conditions of association and rotation, and the best options, by component, that result from the research. For this purpose, improved techniques for managing soil, pests, weeds, and timing are applied, together with those methods for sowing crop and pasture recommended by disciplinary research. The socioeconomic impact can be evaluated through complementary research before and after the technology is adopted.

Planning and Design

Experimental hypotheses

In the preliminary phase (Phase 1), hypotheses are related to the specific needs for research for the corresponding discipline or plant component. Research on agropastoral systems (Phases 2-5) is governed by six working hypotheses that appear in the literature:

1. The establishment of improved pastures in association with crops is quicker and cheaper than is the

traditional establishment of pasture as a monocrop.

2. Establishing improved pastures with crops does not significantly reduce crop yields.

3. When sowing the association, the minimum fertilization required for establishing the crop improves soil quality. Soil improvement persists, even after harvest.

4. A pasture can be renewed by sowing an annual crop, and can be considered renewed when it has an adequate population density and permits a level of grazing that is equivalent to that of the initial good establishment.

5. Establishing improved pastures in areas degraded by continuous monocropping improves soil quality over the long term, enabling the land to be used again for cropping.

6. The alternatives to continuous monocropping, such as crop rotation, pasture/crop rotations, and use of forage or grain legumes as green manures, correct problems of physical deterioration of soil, weed invasion, and increased pest populations, thereby contributing to the sustainability of the overall system.

Experimental design

In agropastoral system research, trials for the different phases need different experimental designs, thereby making it possible to answer the hypotheses specific to each phase. For example, Phase 1, that is, discipline-oriented research on soils, pathology, physiology, and weeds, can be carried out as short-term satellite trials in small plots on experiment stations. In this case, replicated complete, incomplete, or augmented multifactorial designs are used. These designs make it possible to prove the significance of experimental factors and their interactions. The fertilization trials represent a typical example of the use of augmented factorial designs: N × P × K × ... + controls (positive or negative).

To evaluate, select, and identify promising lines of short-cycle crops, other experimental designs, which, when adequately implemented in the field, have proven to be more efficient than the RCB design traditionally used by plant breeders. These designs belong to the family of resolvable incomplete block designs (RIBD), and are necessary when the number (≥12) of varieties being evaluated is greater than the number that a homogeneous block can accommodate, which happens frequently in this type of research. To make these situations “resolvable”, the incomplete blocks are arranged in complete replicates and the number of replicates is small (2, 3, or 4). Designs based on balanced incomplete blocks (BIB), in contrast, require very high numbers of replicates, making them unmanageable.

The family of RIBD includes the lattice square designs of k^2 (which makes possible the testing of v varieties in complete replicates of k incomplete blocks, each with k varieties); the lattice rectangular design, where $v = k \times (k + 1)$; and the lattice cubic design, where $v = k^3$ (Cochran and Cox 1957). Also belonging to this family are the Alpha designs (Patterson and Williams 1976; Patterson et al. 1978). They fill many gaps in the Cochran-Cox tables, with regard to number of varieties to test, and make possible the evaluation of, for example, those numbers of varieties that do not correspond to a perfect square, multiples of $k \times (k + 1)$, or a perfect cube, as required for the lattice designs. However, Verdooren (1998) has demonstrated that, when the number of varieties to test (*v*) is a prime, the Alpha design is equal to the lattice; but if *v* is not a prime, then the Alpha design is less efficient than the lattice.

Where trials involve establishing pastures with crops, renewing pastures with crops, or rotating pastures with crops, and using only a few, specifically selected, production systems (2 or 3 treatments), simple experimental designs are recommended. Either the RCB design or that of split plots is useful when another factor (e.g., a specific management practice for every system) is also being tested and needs to be compared with local management. These treatments are replicated on several farms and are conceived so that the responses of the components over the long term can be evaluated. Examples are found in Amézquita (1986), applied to trials for evaluating forage species under grazing conditions.

The type of experimental design per se does not represent a challenge in trials comparing agropastoral systems. Because of their long-term nature, however, there are important aspects that should be taken into account when planning, such as selecting experimental factors and their levels, identifying the most appropriate control treatments, identifying relevant response variables, and their optimal measurement techniques.

Experimental factors and treatment control

The experimental factors selected in every research phase should be relevant to the production system being studied. The levels should represent feasible management options, and should not omit the farmer's traditional management practices as the control treatment.

In Phase 1, the best materials are identified, together with the optimal soil, crop, and pasture management practices that will be used in the advanced phases. The experimental factors in this phase are multiple (Table 1). Chapter 6, this volume (*see* Tables 5 and 6), illustrates the factors that significantly affect crop and pasture performance and their contribution to the total variance of the variables analyzed in an experiment associating upland rice with pastures. This type of exploratory multifactorial trial helps identify relevant factors and their optimal levels for use in advanced research phases.

Once the best materials and soil, crop, and pasture management practices have been identified, the type of association is the principal factor that should be studied in Phases 2-5. The traditional production system should always be included as the control treatment. In trials where pastures are established with crops, the control is the traditional establishment practice. Thus, in trials to renew degraded pastures, the control would be the degraded pasture. In a trial conducted to correct problems in the soil caused by continuous monocropping or to study the use of forage legumes as green manure, the control would be the continuous monocropping.

Response variables

Throughout the different phases of agropastoral research, the researcher measures the response of soil, crop, pasture, and animals to different management practices and under different production systems. In Phase 1, the number of variables is greater, given that one objective is to identify those variables that best characterize differences among types of associations. In advanced phases, the final productivity of each component and of the total system is measured (Table 1). Box 1 gives examples of types of variables measured in the initial phases.

Experimental period and frequency of evaluation

The duration of the experimental period depends on the research phase (Table 1). For research trials on the component, crop, and discipline, the experimental period is short and usually covers only one cropping cycle. For trials on establishing and renewing pastures with crops, the experimental period is of intermediate length, covering the time from sowing the associations or crop (in the case of pasture renewals) to harvest, or it can be variable, ranging from 4 to 12 months after the crop's harvest (Sanz et al. 1994a, 1994b), by which time the pasture is considered established or renewed. An example is RIEPT's multilocational trials, where the percentage of soil covered at 12 weeks after sowing is regarded as the best indicator of the pasture's establishment (Amézquita 1986; Toledo et al. 1983).

For trials of associations of pastures with crops, the analyses carried out by Amézquita et al. (Chapter 6, this volume) confirm that this age of 12 weeks is the earliest at which success in establishing a pasture with rice can be evaluated. For trials of pasture renewal, it is also important to know when the pasture should be renewed, while ensuring a good crop yield at the same time. A valid criterion is the percentage of legumes in the pasture—20% has been determined as the minimum legume content to guarantee pasture stability (CIAT 1994a).

For trials of pasture/crop rotations, which, by their very nature, are long term, the total duration of the experimental period and of every cycle in particular, merits a more detailed study. Depending on the pasture, the crop with which it will be associated, and the site's soil characteristics, a trial of pasture/crop rotations should last 3 to 5 years (CIAT 1994c).

Recommendations

Agropastoral research is long term and multidisciplinary in nature, and has multiple components, all of which demand numerous measurements of soil, crop, pasture, and animals. It is therefore important to distinguish clearly between the objectives, scope, and methodological needs of research by component and discipline (Phase 1) versus those of research on agropastoral systems per se (Phases 2-5).

The important aspects to consider in planning trials of this type include a clear definition of progress in the research (preliminary versus advanced phases) and of the experimental hypotheses; appropriate selection of experimental factors and their levels; identification of control treatments; and selection of response variables sensitive to differences among the different systems under study.

Taking into account the advantages that research on agropastoral systems represent in the context of the Agropastoral Research Network for the Savannas, the following recommendations are suggested:

1. Conduct Phase 1, which is research by component and discipline, as short-term satellite trials at the experiment station.

2. Carry out Phases 2-5, which is research on agropastoral systems, at the experiment station or on farms.

Box 1

Variables measured in the initial trial phases in research on agropastoral systems

1. Soil

Physical: Texture (initial characterization)
Resistance to penetration (kg/cm^2)
Soil moisture (%) (gravimetric, volumetric)
Rate of water infiltration (mm/h; cm/h)
Hydraulic conductivity (cm/h; mm/day)
Aggregate stability (%)
Apparent density (g/cm^3)

Chemical: N, P, K, S, Mg, Ca, Al, Al saturation, pH, soil organic matter

Biological: Potential of mineralized N, earthworm populations, mycorrhizae infection (CIAT 1994c)

2. Crop

Establishment (germination):
Number of plants per unit area at different stages after sowing
Leaf area (cm^2/plant; m^2 of leaf area per m^2 of surface covered)
Biomass of aerial parts (g/area)
Percentage of weeds
Yield components at different stages of the crop

Production: Yield at harvest (t/ha)

3. Pasture

The following variables measured by component and in the total pasture:

Establishment (germination):
Number of plants per unit area at different stages after sowing
Coverage (%)
Leaf area (cm^2/plant; m^2 of leaf area per m^2 of surface covered)
Biomass of aerial parts (g/m^2)
Biomass of roots (g/m^2)
Botanical composition of pasture, including weeds

Production:
Forage available (total dry matter/area)
Potential for stocking rate

4. Animal production

Depending on the animal production system being evaluated (raising calves for fattening, fattening steers, breeding herds, dual purpose, or dairy), the response variables include:

Stocking rate per hectare or grazing pressure
Weight curves for young steers
Weight gain per animal and per hectare
Reproduction indexes
Milk production and quality, lactation curves

3. Define the different types of trials corresponding to Phases 2-5 in accordance with the needs of the various regions belonging to the Network, thereby avoiding duplication of efforts and resources.

4. Use, where possible, comparable experimental designs and evaluation methodologies in agropastoral experiments with common objectives.

5. Channel information generated by the Network through an efficient communication system, which would permit the analysis of results of different research phases in an integrated fashion and disseminate them among the Network's members.

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CHAPTER 6

The Statistical Analysis of an Exploratory Trial for Methodological Decision Making

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Contents

Abstract

An agropastoral experiment is typically a complex of many components, each of which demands techniques and practices requiring different management and long-term evaluations with many response variables involving soils, crops, pastures, and animals. The statistical analysis of

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results from a multifactorial, short-term, exploratory (or preliminary) trial, established according to methodological objectives, will help answer important questions on the most efficient use of resources and time during the more advanced research stages. Such an analysis will identify a reduced group of response variables for the crop and pasture, identify and prioritize experimental factors that significantly affect the development and productivity of the crop/pasture association, and determine those factors' optimal levels, which would thus suggest appropriate periods for evaluation.

Resumen

Un ensayo agropastoril exploratorio o preliminar juega un papel importante en la planeación e implementación de investigación más avanzada. El análisis de un ensayo exploratorio con objetivos metodológicos es de gran utilidad debido a la complejidad de la investigación agropastoril, caracterizada por sus múltiples componentes, que demandan técnicas y prácticas de manejo diferentes y que exigen evaluaciones a largo plazo con múltiples variables de respuesta en el suelo, el cultivo, la pastura y el animal. El presente capítulo ilustra cómo, a través del análisis estadístico de la información generada por un ensayo agropastoril exploratorio, multifactorial y de corta duración, se responden preguntas importantes que facilitan un uso más eficiente de recursos y tiempo en etapas más avanzadas de investigación. El análisis identifica un conjunto reducido de variables de respuesta del cultivo y de la pastura; y determina y prioriza los factores experimentales que afectan el desarrollo y la productividad del cultivo y la pastura bajo asociación y los niveles óptimos de dichos factores para sugerir edades de evaluación apropiadas.

Introduction

The objective of the preliminary or exploratory phase of research on agropastoral systems is to filter the external variability of these systems, delivering as a final product a set of recommendations for planning and implementing more advanced research phases. These recommendations refer to:

1. *The most appropriate management practices* for those experimental crops and pastures that will be submitted to more advanced research phases. Such practices would include methods of soil preparation, fertilizer type and rate of application when planting the crop, and planting system and density for both crop and pasture.

2. *The identification of a minimum set of response variables* to be measured in both crop and pasture. These variables should be sufficient for evaluating the effect of the experimental factors and, ideally, are not correlated among themselves.

3. *The identification of the most appropriate periods for evaluating an agropastoral system*. These periods should permit both crop and pasture to optimally express differences among treatments.

4. *The most appropriate techniques for measuring various variables* for soils, crops, pastures, and animals.

This chapter aims to illustrate, by analyzing an exploratory trial, the type of methodological questions that this type of research can answer. The case study used is a multifactorial trial of rice/pasture associations, conducted at "La Libertad" Experiment Station in the Department of Meta, Eastern Plains of Colombia.

The Trial and Its Methodological Objectives

This agropastoral experiment seeks to:

1. Identify a reduced, minimum set of response variables for crop and pasture that can quantify the effect of different experimental factors on the agronomic and productive performance of the agropastoral systems of interest.

2. Evaluate the effect of different experimental factors on the development and productivity of both crop and pasture. In particular, the evaluation will focus on the effect of soil preparation techniques; methods of applying fertilizer; planting densities for rice; and planting methods for selected pasture and rice lines, products of research by Fischer et al. (1995).

3. Study the effect of various experimental factors on soil compaction.

4. Identify optimal levels for each experimental factor for use in more advanced stages of research.

5. Identify those periods of evaluation that are most sensitive to differences among treatments.

The experiment was carried out at "La Libertad" Experiment Station in the Department of Meta, Eastern Plains of Colombia, in May-December 1994. This site is representative of the ecosystem of a well-drained savanna. The experiment began with the simultaneous planting of rice and pasture, and ended 215 days after planting (DAP).

The experimental design used was that of split-split plots with two replicates, represented by two former systems of soil preparation. Two years before the experiment began, soil was prepared with either a chisel or moldboard plow. The main plots corresponded to the six combinations of the factorial experiment (3 × 2), that is, method of preparing the soil for planting (chisel, moldboard, or harrow plow) ´ method of applying fertilizer (in the furrow or broadcast). The subplot was represented by six different associations, forming an augmented factorial design (2 × 2) + 2, that is, two planting densities for rice (17 and 34 cm) × two systems of planting pasture (in the furrow and broadcast), plus two control treatments (rice and pasture monocrops), established under the traditional planting system. The sub-subplots corresponded to three rice lines. The total number of treatments per replicate was 108 for a total of 216 experimental plots.

Statistical Analysis

To fulfill the trial's methodological objectives, the following steps were undertaken in the statistical analysis:

1. To reduce the number of response variables to a smaller set of uncorrelated variables, while ensuring their sensitivity to differences among treatments, we used the principal component

analysis (PCA), first developed by Pearson (1901) and later expanded by Hotelling (1933).

This statistical method is a multivariate technique that examines the existing relationships among a set of quantitative variables, detects correlations among the same, then reduces the initial set to a smaller, uncorrelated set. Starting with a set of n original variables, the method calculates *n* new variables, known as “principal components” (PC), that are independent of each other, and each corresponding to a linear combination of the original variables. The complete set of the *n* principal components should explain 100% of the existing variance among the original variables.

To reduce the set, this method organizes these *n* principal components in descending order, according to their variance, so that the first one has the greatest variance of all; that is, it explains the greatest percentage of the existing variance among the original variables. The second explains the second greatest percentage of variance, and so on. The last principal component explains the least percentage of variance.

Those using this technique generally select a reduced number of principal components (e.g., the first 2, 3, or 4) subjectively so that the sum of their variances is acceptably high. In many cases, the first 2 or 3 variances explain a high percentage of the total variance among the original variables.

2. From the results of the PCA, a reduced set of response variables for both crop and pasture, representing each selected principal component is chosen. This set is used to identify the experimental factors (e.g., soil compaction) that show significant effect ($P < 0.05$) on the development and productivity of the crop/pasture association. The response variables chosen are those that show the greatest coefficient in the respective principal components.

   To study the significance of the effect of each experimental factor, analyses of variance (ANOVAs) were carried out for each response variable selected. As a criterion for prioritizing the significant factors, the percentage of variance explained by each factor—result of the ANOVA—and expressed as $CM\ factor/CM\ error \times 100$, is used.

3. The optimal levels for each experimental factor for use in the more advanced phases of agropastoral research are then identified. An optimal level is identified as that which maximizes the productivity of the association and which has the best effects on soil conditions.

4. The best periods for evaluating the crop/pasture association are then identified, together with relevant criteria for quantifying success in establishing a pasture with crops.

The model used for the ANOVAs accords with the experimental design of the trial (Table 1). To test the hypotheses related to the factors of planting density for rice, pasture planting method, and their interaction, the effect of association was broken down into orthogonal contrasts, which permits testing these effects, as well as comparing the monocrops (rice and

Table 1. Model used in the analysis of variance for the experimental trial at "La Libertad" Experiment Station, Piedmont Region, Colombian Eastern Plains.

Sources of variation	df	
Replicate (previous soil preparation)	—	1
Main plot	—	5
Later soil preparation	2	—
Fertilizer system	1	—
Later preparation × fertilizer system	2	—
Trial A = replicate × main plot	—	5
Subplot: association	—	5
Rice monoculture versus associations	1	—
Pasture monoculture versus associations	1	—
Planting density for rice	1	—
Planting system for pasture	1	—
Density × planting system	1	—
Subplot × main plot	—	25
Trial B = replicate × subplot (main plot)	—	30
Rice line	—	2
Line × main plot	—	10
Line × subplot	—	10
Line × main plot × subplot	—	50
Trial C = residual	—	72
Total	—	215

pasture) against the group of rice/pasture associations.

Results

Reducing the number of variables

Principal component analyses were carried out on the response variables for rice, independent for each of four evaluation periods: 30, 60, and 90 days after planting (DAP) and at harvest (120 DAP). Likewise, analyses of these independent components were carried out for the response variables for the pasture in each of five evaluation periods: 60 and 90 DAP, at rice harvest (120 DAP), and at 45 and 95 days after harvesting (DAH) the rice. Results are given in Tables 2 to 4.

Table 2 shows that the PCA carried out on the response variables for rice at 30 and 60 DAP made possible reducing the six original variables in each case to two principal components, which together explained 80% of the existing total variance among the original variables at 30 DAP and 75% of the total variance at 60 DAP. Similarly, the same type of analysis done for the variables evaluated at 90 DAP reduced the six variables to three principal components, which together explained 81% of the total variance.

On interpreting the coefficients of each principal component (Table 2), results are seen to be highly consistent among the three periods; that is, the six original variables can be reduced to two principal components (PC1 and PC2) of equal interpretation for periods 30 and 60 DAP; and to three principal

Table 2. Reduction of the response variables for the crop before harvest, using principal component analysis, in the experimental trial at “La Libertad” Experiment Station, Piedmont Region, Colombian Eastern Plains.[a]

Response variable	Coefficients of PCs at:						
	30 DAP		60 DAP		90 DAP		
	PC1 (44%)	PC2 (36%)	PC1 (46%)	PC2 (29%)	PC1 (34%)	PC2 (33%)	PC3 (14%)
Number of plants per 2 m	0.14	0.61	0.13	0.62	0.59	-0.22	0.20
Number of tillers per 2 m	0.31	0.53	0.33	0.58	0.66	-0.05	0.06
Total leaf area/10 plants (cm^2)	0.48	-0.20	0.43	-0.33	0.14	0.59	-0.26
Total wet weight (g/2 m)	0.43	0.34	0.42	0.24	0.42	0.38	0.01
Total dry weight (g/10 plants)	0.47	-0.31	0.49	-0.26	-0.15	0.38	0.91
Leaf dry weight (g/10 plants)	0.50	-0.30	0.52	-0.21	-0.04	0.56	-0.26
Total variance explained	80%		75%		81%		

a. DAP = days after planting.
PC1, PC2, and PC3 identify the first two or three principal components resulting from the analyses by period.
For 30 and 60 DAP: PC1 = biomass; PC2 = germination.
For 90 DAP: PC1 = germination; PC2 = leaf area; PC3 = biomass.

Table 3. Reduction of the response variables for the crop at harvest, using principal component analysis, in the experimental trial at “La Libertad” Experiment Station, Piedmont Region, Colombian Eastern Plains.

Response variable	Coefficients of variables for:	
	PC1[a] (60%)	PC2[a] (18%)
Number of panicles	0.44	0.08
Panicle length (cm)	0.41	-0.45
Grains filled (no./10 panicles)	0.43	-0.39
Grain weight (g/2 m)	0.47	0.17
Dry matter weight (g/2 m)	0.44	0.22
Yield (t/ha)	0.19	0.75
Total variance explained	78%	

a. PC1 and PC2 identify the first two principal components (yield and final yield) resulting from the analyses by period.

components (PC1, PC2, and PC3) for the period 90 DAP, with interpretation being similar to the results for the periods 30 and 60 DAP.

In the case of 30 DAP, PC1 was interpreted as *biomass*, based on the magnitude of its coefficients, being characterized by high weightings for the variables leaf dry weight (weighting of 0.50), total leaf area (0.48), total dry weight (0.47), and total wet weight (0.43). PC2 was interpreted as *germination*, being characterized by a high weighting of 0.61 for the variable number of plants. In the analysis for 60 DAP, the two resulting principal components can be interpreted similarly. The analysis for 90 DAP reduced the six original variables to three principal components: PC1 interpreted as *germination*, PC2 as *leaf area*, and PC3 as *biomass*.

These results suggest the existence of correlation among the response variables for rice, measured before harvest at 30, 60, and 90 DAP, and

Table 4. Reduction of the response variables for the pasture according to coefficients, using principal component analysis, in the experimental trial at “La Libertad” Experiment Station, Piedmont Region, Colombian Eastern Plains.

Response variable[a]	Coefficients of at: PCs						
	60 days[b]		90 days[b]		0, 45, and 95 DAH[c]		
	PC1 (69%)	PC2 (19%)	PC1 (63%)	PC2 (21%)	PC1 (43%)	PC2 (25%)	PC3 (20%)
Number of plants per 2 m	0.17	0.96	-0.06	0.97	—	—	—
Leaf area/10 plants (cm^2)	0.46	-0.28	0.47	-0.16	0.32	0.69	-0.09
Wet weight (g/2 m)	0.50	-0.01	0.51	-0.02	—	—	—
TDM (g/10 plants)	0.51	-0.09	0.50	0.16	0.63	-0.16	0.04
Leaf DM (g/10 plants)	0.49	0.02	0.50	0.13	0.63	-0.15	-0.15
TDM of regrowth, 45 DAH (g/0.5 m^2)	—	—	—	—	-0.27	-0.35	0.78
TDM of regrowth, 95 DAH (g/0.5 m^2)	—	—	—	—	-0.20	0.59	0.60
Total variance explained	88%		84%		88%		

a. TDM = total dry matter; DM = dry matter; DAH = days after harvesting the rice crop.
b. days = days after simultaneous sowing of rice and pasture.
For 60 and 90 DAP: PC1 = biomass; PC2 = germination.
c. 0, 45, and 95 DAH = at harvest, and 45 and 95 days after harvesting the rice crop.
PC1 = biomass at harvest; PC2 = leaf area at harvest; PC3 = biomass after harvest.

that we could limit them, as mentioned above, to capacity for germination, capacity for biomass production, and leaf area. The most adequate period for evaluating the preharvest rice crop is the latest, that is, at 90 DAP.

At harvest, the six response variables for rice (Table 3) can be reduced to two principal components (PC1, interpreted as the component for *yield* and PC2, interpreted as *final yield*), which explain 78% of the variance found among the original variables.

Table 4 also presents the reduction of the seven response variables for pasture to two principal components for the periods 60 and 90 DAP (PC1 interpreted as *biomass* and PC2 as *germination*) and to three principal components after harvesting the rice (PC1 interpreted as *biomass at harvest*, PC2 as *leaf area at harvest*, and PC3 as *biomass after harvest*). The results are very similar to those shown in Table 2. In other words, for both pasture and crop, the variables important for evaluating are the capacity for germination, the capacity for production, and leaf area.

The results in Tables 2 and 4 suggest that, before harvest, one evaluation period—90 DAP—is sufficient for both crop and pasture. Similarly, a single evaluation period for pasture is sufficient after the crop’s harvest.

Identifying relevant experimental factors

Table 5 includes the experimental factors that significantly affected the rice crop’s performance. In order of magnitude of percentage total variance explained, these are:

1. *Type of rice/pasture association*, which explained from 8.8% to 51% of the total variance of the different response variables.

Table 5. Experimental factors that significantly affect the performance of the rice crop in the experimental trial at "La Libertad" Experiment Station, Piedmont Region, Colombian Eastern Plains.[a]

Factor	30 days		60 days		90 days		120 days, yield (t/ha)
	PN	TLW	PN	TDW	Leaf area (cm^2)	TDW	
	Percentage of total variance explained[b] and significance level						
Soil preparation							
Previous	2.4*	ns	13.6*	19.5*	19*	ns	ns
Later	ns	ns	ns	ns	30.8**	ns	ns
Association	51**	ns	12.1**	ns	ns	8.8	40.3*
Planting density for rice	40.6**	ns	11.8**	ns	ns	ns	5.2
Planting system for pasture	ns	ns	ns	ns	ns	5.3**	ns
Rice line	1.6*	3.5*	8.6**	3.6*	6.3*	ns	3.8**
Interactions	ns	ns	ns	ns	ns	ns	ns
General mean	109	1.6	58	16	247	18	2.34
SE	18	0.3	13	3	127	4	0.43
CV (%)	16.1	20	23.1	20.2	46.4	22.9	18.3

a. days = days after simultaneous sowing of rice and pasture.
PN = plant number (no./m);
TLW = total leaf dry weight;
TDW = total dry weight (g/10 plants).
b. C = 100 × SC (factor) Sc (total).
* = $P < 0.05$; ** = $P < 0.01$; ns = not significant.

2. *Previous soil preparation*, which explained from 2.4% to 19.5% of total variance.

3. *Rice line*, which explained from 1.6% to 8.6% of total variance.

4. *Later soil preparation*, which affected only leaf area.

For pasture, the factors that significantly influenced its performance were fewer (Table 6), the main one being the type of association, which explained from 5.4% to 57.9% of total variance found among the different response variables. The method of soil preparation seemed to affect pasture response only after rice harvest. The rice line used had little effect on pasture response.

The experimental factors did not significantly affect surface compaction of the soil, measured as resistance to penetration (kg/cm^2) at depths between 0 and 60 cm.

Identifying optimal levels for each significant factor

Tables 5 and 6 show that planting density significantly affects the rice crop's capacity to germinate, the best density as not affecting final yield being 34 cm between furrows. Similarly, this factor affects pasture performance only at the beginning of establishment (60 DAP) (Table 5).

The method of planting pasture (broadcast or in the furrow) affected pasture response in all periods in terms of its total dry matter production. Planting in furrows gives the best results. In contrast, broadcasting benefits the rice crop most. This is an example of an inverse effect of an experimental factor. The

Table 6. Experimental factors that significantly affected the performance of pasture in the experimental trial at “La Libertad” Experiment Station, Piedmont Region, Colombian Eastern Plains.[a]

Factor	60 days		90 days		120 days		45 days,
	PN	TDW	PN	TDM	PN	TDW	TDW
	Percentage of total variance explained[b] and level of significance						
Soil preparation							
Previous	ns	ns	ns	ns	ns	21.2	4.0**
Later	ns	ns	ns	ns	ns	4.3	5.1
Association	14.3**	24.4**	18.5**	ns	ns	5.4	57.9**
Planting density for rice	12.9**	2.6*	13.9**	ns	ns	ns	ns
Planting system for pasture	ns	21.2**	4.4*	ns	ns	4.2	57.8**
Rice line	ns	4.5	ns	ns	ns	ns	ns
Interactions	ns	ns	ns	ns	ns	ns	ns
General mean	4.5	5.3	3.2	13.8	1297	19	496
SE	2.3	1.9	1.8	5.5	410	8.4	48
CV (%)	57.6	35.9	54.4	39.7	31.6	44.3	9.7

a. days = days after simultaneous sowing of rice and pasture.
PN = plant number (no./2 m);
TDW = total dry weight (g/10 plants);
TDM = total dry matter (g/10 plants).
b. C = 100 × SC (factor) Sc (total).

* = $P < 0.05$; ** = $P < 0.01$; ns = not significant.

best method of planting the pasture is, accordingly, the one that maximizes the long-term productivity of the system, that is, the one that is of greatest benefit to the perennial component.

These results suggest that the best management practices consist in planting rice at a density of 34 cm between furrows and the pasture in the furrows (Table 7).

With respect to soil preparation methods, data in Table 8 suggest that the best practice was the use of the moldboard plow before the experiments

Table 7. Promising rice/pasture associations in the experimental trial at “La Libertad” Experiment Station, Piedmont Region, Colombian Eastern Plains.[a]

Association	Response of rice crop			Response of pasture			
	PN (90 days)	TDW (90 days)	Yield at (120 days) (t/ha)	PN (90 days)	TDW (90 days)	TDW (120 days)	TDW (120 days' regrowth)
Rice monocrop	50.2 b	18.8 a	3.0 a	—	—	—	719.4 b
Grass alone	—	—	—	—	—	—	1493.5 a
Associations[b]							
Rice 17 cm + grass broadcast	46.3 b	19.2 a	2.3 b	2.1 c	11.7 a	15.7 b	615.3 b
Rice 34 cm + grass broadcast	63.3 a	18.0 a	2.2 b	3.5 b	12.7 a	18.5 ab	609.7 b
Rice 17 cm + grass in furrow	45.5 b	17.1 ab	2.3 b	2.8 bc	16.4 a	20.6 a	691.8 b
Rice 34 cm + grass in furrow	63.0 a	15.3 b	1.9 c	4.5 a	14.4 a	21.3 a	620.4 b

a. days = days after simultaneous sowing of rice and pasture.
PN = plant number (no./2 m);
TDW = total dry weight (g/10 plants);
Values followed by the same letters in the column are not significantly different at $P < 0.05$.
b. Rice 17 (or 34) cm = rice planted at 17 (or 34) cm between furrows.

Table 8. Optimal levels for preparing the soil for the experimental trial at "La Libertad" Experiment Station, Piedmont Region, Colombian Eastern Plains.[a]

Type of soil preparation	Response of rice crop			Response of pasture	
	Leaf area at 90 days (cm^2)	TDW at 90 days (g/10 plants)	Yield (t/ha)	TDW at 90 days (g/10 plants)	TDW of regrowth, 45 DAH (g/0.5 m^2)
Previous		ns	ns		
Chisel plow	360 a			15 b	477 b
Moldboard plow	187 b			23 a	515 a
Later		ns	ns		
Chisel plow	235 ab			18 b	495 ab
Moldboard plow	425 a			19 b	470 b
Harrow plow	161 b			22 a	523 a

a. days = days after simultaneous sowing of rice and pasture.
TDW = total dry weight.
DAH = days after harvesting the rice crop.
Values followed by the same letters in the column are not significantly different at $P < 0.05$.

and the harrow plow for later preparation, as these practices benefit pasture performance, without significantly affecting final rice yield.

The best rice lines were Oryzica Sabana 6 and Line 4 (Table 9) as they maximized crop production without affecting pasture response.

Minimum period for evaluating successful pasture establishment

In the preliminary phases of establishing pastures with crops and their renovation with crops, the required minimum experimental period comprises planting the associations (or crop in the case of pasture renovation) through to crop harvest or a time after this when the pasture is considered established or renovated.

In multilocational trials for evaluating forage grasses and legumes in monoculture, the best indicator of successful establishment is considered to be the percentage soil cover at 12 weeks after planting (Amézquita et al. 1989; Toledo et al. 1983). For trials of pastures associated with crops, it is important to confirm whether this

Table 9. Best rice lines in the experimental trial at "La Libertad" Experiment Station, Piedmont Region, Colombian Eastern Plains.[a]

Line	Response of rice crop			Response of pasture			
	PN at 90 days	TDW at 90 days	Yield at 120 (t/ha)	PN at 90 days	TDM at 90 days	TDM at 120 days	TDM of regrowth at 45 DAH
Oryzica Sabana-6	53.2 ab	17.0 a	2.5 a	3.3	13.2	18.8	495.2
Line 4	56.9 a	18.9 a	2.3 a	3.0	14.7	19.7	505.7
Line 2	50.9 b	18.0 a	2.2 b	3.4	13.7	18.5	487.0

a. days = days after simultaneous sowing of rice and pasture.
PN = plant number (no./2 m);
TDW = total dry weight (g/10 plants);
TDM = total dry matter (g/10 plants).
DAH = days after harvesting the rice crop.
Values followed by the same letters in the column are not significantly different at $P < 0.05$.

evaluation period is appropriate. The response variables and earliest possible period for evaluation to quantify success in establishing or renovating a pasture must therefore be identified.

The earliest period for evaluating the establishment of a pasture is when significant correlation exists among the different indicators for establishment. Taking into account the results obtained from the PCA of the response variables for the pasture (Table 3), germination (no. of plants/2 m) and biomass production (total DM in g/10 plants) at 60 and 90 DAP of rice were used as indicators of pasture establishment.

Table 10 shows correlations between initial germination of the pasture at 60 DAP and biomass production at different periods, as well as among different data for biomass production of the associated pasture over time. These results suggest that the earliest period for evaluating successful pasture establishment is at 90 DAP, using biomass production as the indicator.

Conclusions

Statistical analyses with methodological objectives play an important role in this preliminary research phase. Based on the statistical analyses of this case study, the following can be concluded:

1. The analyses made possible the identification and prioritization of those experimental factors that significantly affected the development and productivity of the crop/pasture association. The factors that affected the development and productivity of the crop and their explanation in the total variance (shown in parentheses) were, in order of priority: type of rice/grass association (from 8.8% to 51%); previous soil preparation (from 2.4% to 19.5%); rice line (from 1.6% to 8.6%); and later soil preparation, which affected leaf area only. In the case of pasture, the principal factor was the type of association (from 5.4% to 57.9%). The soil preparation method

Table 10. Correlations among indicators of pasture establishment at different periods in the experimental trial on rice/pasture association, Piedmont Region, Colombian Eastern Plains.

Indicators of pasture establishment	Days after planting	Correlation coefficients (probability) of indicators				
		(2)	(3)	(4)	(5)	(6)
(1) Number of plants/2 m	60	0.58 (0.0001)	0.29 (0.05)	ns	ns	ns
(2) Number of plants/2 m	90		0.39 (0.007)	ns	0.32 (0.03)	0.30 (0.04)
(3) Total DM (g/10 plants)	60			0.29 (0.05)	0.42 (0.003)	0.58 (0.0001)
(4) Total DM (g/10 plants)	90				0.33 (0.02)	0.44 (0.002)
(5) Total DM (g/10 plants)	120					0.38 (0.007)
(6) Total DM (g/10 plants)	165					

seemed to affect only the response of the pasture after rice harvest. The rice line used did not significantly affect pasture response.

2. The analyses permitted the identification of the optimal levels for each significant factor. These levels can guide the planning of the more advanced agropastoral research phases.

3. The analyses identified that, for rice, 90 DAP is an appropriate period for evaluating the successful establishment of a rice/pasture association.

4. The analyses permitted the identification of a reduced set of response variables for both crop and pasture, being sufficient to evaluate the effect of the experimental factors. These were the capacity for germination, the capacity for biomass production, and leaf area.

Recommendations

This study illustrates the capacity that a small-scale exploratory agropastoral experiment has to contribute to the process of eliminating sources of variability in later and more advanced stages of research. Likewise, it is useful for clarifying, in preliminary stages, doubts that would have been very expensive to clarify at later stages. Thus, the use of both resources and time becomes more efficient.

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CHAPTER 7

Validation Plots: Characteristics, Design, Monitoring, and Evaluation

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Contents

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Abstract

On-farm validation plots, incorporating participatory research with collaborating farmers, are used to introduce, adjust, and assess the advantages of technological innovations in traditional agroecosystems. Successful technologies are then transferred to other farmers within the same domain of recommendation of a given agroecological zone. Adequate follow-up and analysis of the different variables involved must be carried out until results show that comparative advantages may be obtained in modifying existing agroecosystems. Some basic concepts and suggestions for planning validation tests are presented. Aspects related to site selection and description are highlighted. Ways for analyzing and interpreting data, and for organizing the agronomic and economic parameters that should be assessed in validation plots are also suggested. Certain procedures for evaluating the results of validation through interviews with collaborating farmers are also discussed, and a series of certain fundamental parameters are described and ranked according to the objectives and characteristics of research projects on farming systems.

Resumen

Las parcelas de validación en fincas son conducidas de forma participativa con productores cooperadores, con la finalidad de introducir, ajustar y comparar las ventajas de las innovaciones tecnológicas en los agroecosistemas tradicionales, las cuales posteriormente serán transferidas a los demás usuarios del ámbito de la recomendación en una zona agroecológica de interés. El tema requiere de un adecuado monitoreo y análisis de diferentes variables involucradas, hasta llegar a una síntesis de resultados que evidencie las ventajas comparativas de modificar los agroecosistemas existentes. En este capítulo se presentan algunos conceptos básicos y se dan algunas sugerencias en relación con la planificación de las pruebas de validación. Se destacan aspectos relevantes para la selección y descripción de los sitios de ubicación de dichas pruebas y se brinda orientación para el análisis e interpretación del registro y ordenamiento de parámetros agronómicos y económicos que se deben tomar en las parcelas de validación. Además, se busca aclarar algunos procedimientos para la evaluación de los resultados de validación mediante entrevistas con productores cooperadores y describir y ordenar un conjunto de parámetros que se consideran fundamentales, de acuerdo con los propósitos y características de los proyectos de investigación en sistemas de producción.

Introduction

Validation trials are carried out on reference farms to introduce, adapt, and compare the advantages of technological innovations proposed for changing the agroecosystems traditionally used by farmers. Such validation is done under the agroecological and socioeconomic conditions representative of the predominant farming operations in the region. This participatory research stage aims to support the planning of strategies and activities to improve productivity and profitability without compromising the sustainability of farming systems (Muzilli and Thiele 1992).

The specific objectives of on-farm validation trials are as follows:

1. To introduce and adjust technological innovations considered as appropriate for the targeted agroecological zones and adequate for the interests and conditions of the domains of recommendation (DORs).

2. To formulate physical models (prototypes) of agroecosystems and promote their validation in the predominant farming systems in the areas of interest of a rural development project.

In planning validation plots, innovations should be selected on the basis of whether farmers can easily measure the innovations' parameters and perceive the results. Changing technologies or replacing existing crops (commercial or pastures) can disrupt the farming system—the farm—as a whole, to the point of limiting the adoption of the proposed innovations. For this reason, innovations require adequate monitoring and analysis of the different variables involved to come to a synthesis of results capable of showing the comparative advantages of modifying existing agroecosystems.

Evaluation parameters normally refer to soils, crops, animals, and, above all, economic aspects. A need is thus implied for analytical procedures and criteria capable of precisely measuring the effects observed and highlighting the advantages and limitations of the proposed options.

Basic Concepts

Reference farms are units representing the farming systems under study, and each is formed by a group of production activities interacting as a single unit. An agroecosystem is a production activity on the farm, the final product of which is the result of the interaction of a set of agroecological and socioeconomic factors. It thus refers to a single commodity or set of commodities established in a plot on the farm (Bojanic 1988; Hart 1980).

According to these concepts, the agroecosystem entails all the components necessary for producing a commodity or set of commodities during a season or longer agricultural management period. In addition to soil, these components refer to the inputs, work, and capital that enter the agroecosystem, and the dynamics of their management.

Plant-production agroecosystems include crops and their management by the farmer. Management techniques include selection of species and varieties; their spatial and chronological arrangement; timings and processes of soil tillage, planting; cultural practices, inputs, and labor; harvesting; and postharvest processing. For livestock production, pastures, animals, and their management are also components of the agroecosystem.

To promote agricultural development, production activity can be considered in its most limited sense—an agroecosystem located on a farm—or broadest sense—a group of farms located in the same agroecological zone (e.g., microwatershed, municipality, or local community).

Given the purpose of introducing and validating technological innovations in zones of traditional agricultural and livestock production, implementing actions at the agroecosystem level is easier, provided that their role and interactions with other farm components are not forgotten. According to the results obtained, physical production models will be gradually integrated on the farm, then in the zone as a whole.

These validation plots should not be confused with the traditional subject-oriented, research trials conducted at farm level. Despite analysis of more than one variable being possible (multifactorial trials), such trials almost always seek to isolate the components of the study, often without considering their interactions with agroecological and socioeconomic factors that could restrict the scope of results on the farm and in the zone. In addition, the farmer's cooperation in these traditional trials is almost always limited to providing the land and some logistic facilities, without actively participating in the work.

In contrast, validation plots are planned, conducted, and evaluated with the active participation of cooperating farmers and technical assistants, using those of their own resources and labor found on the farm. At this stage of research, events should be considered as a part of a whole, placing more emphasis on the whole than on the parts and focusing the attention on the set of interrelating elements.

Selection and Descriptive Diagnosis of the Sites

Work on the on-farm validation plots should be initiated with the knowledge and characterization of the parameters related to the current situation—those that will orient and influence the introduction of innovations and their adjustment to farming systems.

The site selected for conducting a validation plot must represent the soil types and environment predominating in the area of interest. That is, the site must ensure that the results obtained can be reproduced and applied in other areas with similar environmental characteristics.

In addition, sites should be selected on farms with adequate support infrastructure and easy access for training and extension activities. The farmer should be motivated to cooperate in all stages of the work and should be kept duly informed of the use of his or her resources and production means.

Field activities must be planned at least 3-4 months in advance of the date planned for establishing the trial. For this purpose, meetings and participatory workshops should be held with cooperating farmers and other members of the targeted group. Once the collaborators have been selected, the first activity is to describe the agroecosystems existing in the plots selected for establishing the validation.

This description, initially, can be done rapidly, including only those aspects needed to identify and understand the techniques and processes being used by the farmer. Physical parameters of interest to include are climatic and soil data. Economic resources and infrastructure (availability of land, labor, equipment, tools) should also be determined, as should be external factors. These latter—supply and demand in the local market, comparative advantages of inputs and commodities, labor supply, standardization of land use, among others—can influence farmers to accept or reject the proposed innovations. In addition, the time and effective duration of agricultural management should be established according to prevalent edaphoclimatic conditions and labor availability throughout the year.

As the study develops, other descriptive elements of the environment can be added to the information base. The principal parameters for selecting and describing the sites at the beginning and throughout the trial's execution are described below.

Climate

The climatic factors limiting the development and yield of production activities must be known. Wherever possible, data related to temperature and rainfall should be compiled, which, together with information from farmers, serve to determine the adverse periods of drought and excess moisture that can occur and their relationships with production.

Soils

Plots should be located with regard to topographical sequence, and the physicochemical characteristics of their soils—texture, depth, drainage capacity, permeability, and fertility—should be determined. In addition, the state of aggregation and structural organization of soil particles should be measured where necessary, and the existing biological activity evaluated. Other data refer to the nature and density of live or dead plant cover, state of aggregation in the surface soil layer, presence of crusts or hard layers on the soil surface, and compaction in lower soil layers.

These parameters will help identify possible limitations, the agricultural suitability and potential use of the land, and the most adequate tillage methods. With this information, validation plots should be established in sites representative of the largest area of interest and where the best results of both innovations and production systems for which they are being recommended can be reproduced.

Socioeconomic information

This refers to the collection of data, both external and internal, on the availability of resources to the reference farm.

External data include:

1. Location and opportunity for marketing the principal commodities, and current prices.
2. Facilities and costs of transportation and storage for inputs and products.
3. Location and capacity for receiving, storing, and processing products.
4. Presence and activity of technical assistance services and farmer associations.
5. Forms of land tenure and prices for leasing and sale.
6. Facilities for credit and the respective interest rates.

Internal data include:

1. Type of farm in terms of size, land tenure, and plot division.
2. Seasonal availability of labor and financial resources.
3. Local availability of labor (quantity, gender, and skills).

4. Fixed and variable capital available on the farm.

5. The farmer's technical knowledge, capacity for expression, and education.

These data, especially those related to external resources, should be collected before and during the diagnosis of the farming systems, through surveys and interviews carried out jointly with the targeted group.

Production information

Aspects related to processes and production technologies should be known and detailed. During interviews held with the farmers of each DOR, data needed for characterizing typical or traditional technological knowledge involved in the production systems should be obtained. Obtaining the most detailed information on the parameters of interest will probably require technicians to become more familiar with the cooperating farmers, and these with the purposes and procedures of the work to be done. As to be expected, more details can be obtained throughout the execution of the validation trials.

Planning the Validation Plots

The design of the validation plots should be planned separately for each site, even when these are on the one farm or zone where research is being carried out. It is necessary to simulate physical models (prototypes), the components of which can be easily perceived and handled by cooperating farmers. The designs should be flexible, and the introduction of new technologies and processes should be planned in accordance with the specific conditions found on each farm, taking into account the circumstances that will determine farmers' decision making during the trial.

In the simulated physical models, simple technologies and processes should be suggested to facilitate the perception, comprehension, and acceptance by both cooperating farmers and local technical assistants. The farmers and technicians will, in accordance with their experience, directly participate in plot managements and evaluation of results.

The methodological procedures should provide a clear and detailed identification of the stages and tasks to be carried out. The technicians and farmers should be motivated to participate, from selecting the site to selecting the options to be compared, using the modified model. In addition, each farmer should be informed of, and should agree with, the activities being carried out with the resources and labor available on his or her farm.

The technicians in charge of monitoring will have the task of orienting and following up each action programmed by making formal and periodic visits at least once a week.

The physical models will be submitted to analysis and discussion in participatory workshops with the farmers of the respective DOR in each zone. In these workshops, the farmers are consulted and encouraged to propose changes in the designs in accordance with their goals and circumstances. In addition, they are invited to cooperate and share actively in the management and evaluation of the trials.

The validation plots should be sufficiently large to permit the use of the equipment and machinery found on the farms. Moreover, farmers are well known not to like monitoring and observing trials or demonstrations on small plots. For agricultural production systems, the minimum size proposed for these plots is 1000 m^2 on small farms and up to 1 ha on medium-sized and large farms. For livestock operations, the minimum size should be 1 ha on small farms and up to 3 ha on medium-sized and large farms. In addition to the validation plots, a control plot of equal size and representative of the farmer's traditional system should be available for monitoring the same data.

Validation plots normally last 2-4 years, the time needed to consolidate adjustment and validation according to the circumstances of the DORs of interest. The first year is almost always a stage of adjusting the technological innovations to the working conditions and circumstances of the reference farm.

Data Monitoring and Collection

When using simple designs that are easily managed by farmers and cooperating technical assistants, the appropriate tools for statistical analysis and evaluation and interpretation of the data obtained in the validations are not always available. In practice, on the one hand, procedures and analytical criteria for measuring observed effects need to be developed, while on the other hand, the advantages and limitations of the proposed innovations versus the farmer's traditional systems need to be identified and assessed.

When evaluating the validation trials within the Eastern Lowlands Project in Santa Cruz (Bolivia), Muzilli and Carreño (1994) took into account a minimum set of parameters for monitoring, following the scheme discussed below.

Scheme for data collection

In every agricultural management period, a field book was used to record and order the following data:

1. Trial's identity, including title or subject, location, names of the cooperating farmer and technician in charge, and agricultural management.

2. Description of the agroecosystems, including sketches of the spatial and chronological arrangements of the crops in both the traditional and proposed models. The principal characteristics of the traditional and modified models are recorded, including commodities, crop arrangements and combinations, and any changes carried out during establishment of the trials and during each period thereafter.

3. Activity timetable, where the data related to each activity carried out in the validation plots are recorded, starting with the date of soil preparation until harvest of the different crops. For every cropping period, a chronological summary of the systems was recorded to determine the period of each crop under the different models being evaluated. This information indicates the chronological arrangement of the commodities within each model during the agricultural management.

4. Data on soil fertility and physical characteristics at the beginning of the trials and every 2 years. Soil fertility is evaluated, using composite soil samples from 10-15 subsamples taken from soil layers ranging in depths from 0-10 cm to as deep as 30-40 cm.

As well as the data discussed above, agronomic and economic information should also be collected.

Agronomic information

Indices of land occupation and use. Estimates of two indices developed by Zandstra et al. (1981) on the efficiency of land use help in the calculations and later economic comparisons of the systems. These indices are:

The land surface occupation index (LSO), which estimates the area of the plots under each crop for a given period. For seasonal crops in association and planted in rows, the LSO (expressed as a percentage) can be estimated by multiplying the total number of rows by the shared distances, then dividing by the total width of the plot. For example, in a plot with a total width of 7 m, occupied by double rows of cassava that are 1 m apart and intercropped with double rows of maize that are 1.5 m apart and planted at 1-m intervals from the cassava rows, the LSO estimated for each crop will be as follows:

Cassava = 2 rows × (1 m/7 m) × 100 = 28.6% and
Maize = 4 rows × (1.5 m/7 m) × 100 = 42.9%

The free space in the plot will be 100 - (28.6% + 42.9%) = 28.5%. In the case of monocrops in sequence or rotation, the LSO of the respective crop will equal 100%.

In tree cultivation, the LSO is estimated by multiplying the number of trees in the plot by the average radius of their canopies' projection and converting the data into percentages. For example, a plot with a useful area of 20,000 m^2 (200 × 100 m) has a central row of 50 trees distanced at 4-m intervals. The average radius of canopy projection is 2.40 m, measured by sampling 15 trees at random. In this case, the LSO will be estimated as follows:

$[50 \times 3.1416 \times ((2.40)^2/20000) \times 100] = 4.52\%$

The land use index (LUI) is used to estimate the space occupied over time by the crops in the plot. It is calculated by multiplying the LSO of each crop by the number of days that the plot was occupied (from planting to harvest) and dividing the result by 365 days. Taking the example of the above-mentioned maize crop (LSO = 42.9%) and assuming an occupation period of 168 days, the LUI for this crop would equal (168 × 42.9)/365 = 19.7. For a monocrop of soybeans (LSO = 100%), planted in sequence with sorghum and whose cycle from planting to harvest is 117 days, the LUI = (117 × 100)/365 = 32.1.

Soil cover with green manures. The main purpose for including green manure as soil cover is to reduce incidence of weeds (through competition for light or through allelopathic effects), conserve moisture, and recycle nutrients, thereby improving soil fertility.

The principal parameters include the rate or rapidity of soil cover during the period of use, and the yield and quality of plant biomass. The results are subsequently correlated with the quantity of labor needed for weeding, crop yield, and availability of nutrients in the arable layer.

The rate of soil cover by green manures can be measured periodically, at intervals of 10-15 days, according to the procedure described by Arruda (1984). With the resulting data, graphs are constructed to indicate the curve of vegetative growth of the green manures over time. If the green manures are grasses or species with a creeping growth habit such as *Mucuna* sp., this method of measurement is not reliable. More recommendable for these cases is to take periodic samples to estimate the development of plants on a dry weight basis.

The biomass of green manures is measured at full flowering of the plants—the best time for cutting. Five 1-m^2 patches in each plot are chosen, and plants (leaves + stalks) within each area are cut to soil level. With these subsamples, green matter yields are determined and subsequently dry matter (DM) yields per hectare. When possible, the DM yield should be determined by drying a composite sample for 24 h in an oven set at 70 °C. To calculate nutrient recycling, nutrient content of the green manure must also be determined.

Weed incidence. This measurement determines the quantity of weeds present in the plots for later analysis and comparison with other agronomic (e.g., spatial and chronological arrangements of crops, green manure development and soil cover, and crop yields) and economic parameters (e.g., number of days and wages spent on weeding and costs of herbicides used). To measure weed incidence, a frame (50 × 50 cm) is placed at random at 10 or 20 points in each plot, depending on the heterogeneity of weed incidence. For each point, the weight of weeds is determined and, where possible, they are botanically classified or, at least, the percentage of their distribution in terms of broad and narrow leaves is determined. Evaluations can be carried out 2-3 weeks after planting the seasonal crops, before the first weeding, and at harvest. In all cases, production data should be expressed in kilograms of DM per hectare.

Development of pastures and perennial crops. To measure the development of pastures, samples of forage accumulation from aerial parts should be taken at the beginning, middle, and end of the rainy season. For pastures, two 2-m^2 plots per hectare should be isolated from grazing. Before isolation, two 1-m^2 subsamples should be harvested to measure DM production. Cutting height and intervals between cuts will depend on the characteristics of the species and their respective development. For example, creepers may be cut at 10 cm above the soil surface; semierect species, at 20 cm; and grasslike species, at 30 cm. Intervals between cuts usually vary from 25 to 35 days.

This procedure permits the carrying out of relative comparisons of productive capacity, vigor, quality, and level of production of pastures, and between plots of traditional and modified cropping systems. In rotational grazing systems, with a resting period of 28-35 days, a reference plot can be selected for making cuts to measure the cumulative forage before grazing and for standardization afterward.

The development of perennial crops should be evaluated in both dry and rainy seasons. For fruit trees, the average of data from 8-10 trees should be taken in the useful rows of every plot, relating them to plant height, and the diameter of both crown and trunk (at 50 cm from the soil surface). For timber species, measurements of the trunk's diameter, commercial height, and diameter of the crown should be taken. When the tree's height is less than the trunk's diameter of 1.30 m at chest height, the trunk's diameter should be measured at 30 cm from the soil surface. Commercial height is easily measured to an approximate height of 2 m. At greater heights, a clinometer or the geometric proportion method must be used. The diameter of the crown is measured by the projection of the shadow of the rows on the ground at mid-day. A clinometer, telescopic ruler, altimeter, hypsometer, or Biterlich relascope can also be used, depending on the availability of equipment.

Crop cycle and yield. A record should be kept of the number of days from planting to flowering and to harvest, and of the yields of the principal seasonal and perennial crops. The first parameter is useful for calculating the LUI. Yields are expressed in the units of measure used by the farmer but are subsequently converted into kilograms per hectare of processed product and are related to the LSO of the respective crop in the agroecosystem. The information on yield is fundamental for estimating the financial income according to the market prices for each crop.

Measurements with animals. Lascano and Avila (1991) suggest the following parameters for evaluating milk production in pastures: the number of days of lactation (at the beginning of every phase of measurement), daily milk production (kg/cow), and the periodic change in the cows' liveweight. For fattening livestock operations, the principal parameter is the change in animal liveweight, which should be measured at the beginning, then at certain intervals, for example, every 28 days. In livestock systems, the presence of zootechnicians or veterinarians on the multidisciplinary team in charge of monitoring the validation trials is indispensable.

Economic information

Economic and financial analyses—production costs, income, cost-benefit ratios, and profitability indices—usually provide the information that most motivates farmers in their decision making. These analyses include the following:

1. Evaluation of the benefits or financial advantages of the innovations, compared with the farmer's traditional system.
2. Verification of costs, income, and economic efficiency of the traditional system and the ones being evaluated.
3. Verification of demand for land resources, labor, and capital of each system in light of their availability (spatial and chronological) on the farm.
4. Establishment of useful indicators related to production factors (land, labor, and capital).
5. Comparison of the efficiency of modified versus traditional agricultural systems used by the farmer.

The economic study should start with data on the farmer's background, noting among other characteristics, place of origin, year of migration to the area, and experience in the specific activity and on the farm (León 1992).

Inventorying the farm's resources should be done at the beginning of each agricultural management period, and include land area and use, equipment and tools, and available infrastructure. The use of labor and inputs should be recorded weekly while the trial lasts to maintain financial control over each system. This information can be recorded on previously prepared forms or in a notebook.

During each visit, the local technician in charge of monitoring the trial should use relevant forms to obtain information from the farmer, compiling the data for later recording and organization. The most important data to be noted are the following:

1. Each activity or operation carried out during the week, since the last visit.

2. Dates of execution of each activity.

3. Category of labor (family, contracted, community), gender, and value.

4. Time used (in man-hours/category) to carry out the activity.

In addition to the use of labor, the following should be specified for each activity carried out:

1. The agroecosystem to which it corresponds.

2. Size of the respective area. If this does not correspond to a single plot or system, then the labor used for each segment must be estimated separately.

3. Types of equipment, tools, and inputs used.

Variable costs. These refer to the total expenditures on family, hired, or community labor; inputs, and services such as transportation, processing, product selection and storage, and rental of equipment, which varies according to the dimension and technical components used in each agroecosystem. Variable costs are those that most affect the values of the net income of each activity and, accordingly, the margin of profits from the farming operation. In contrast, fixed costs, represented by land, equipment, and machinery, do not undergo significant variations.

At the end of every crop cycle, the data taken for each operation are reviewed and recorded to estimate expenditures on labor as man-hours per hectare or number of days worked per hectare in each system. Similarly, spending on inputs and the investments made to establish crops and pastures are recorded. These data are then used to calculate the average fixed and variable costs (VC) and investments per year or crop cycle in each agroecosystem.

Gross income. The quantity and market value of the commodities produced, including subsistence crops, are recorded for each agroecosystem. The prices for both costs and income should refer to real or constant values and should not be subject to strong changes or variations because of inflation rates. Converting them to U.S. dollars is suggested.

Profitability of production factors. Estimates of profitability of production factors are made by taking into account the ratio between gross margin (GM)—a differentiation is made between gross income and variable costs—and each production factor used to acquire income over a given time. These indicators are used to compare the modified systems with each other and with the farmer's traditional system. Of the indicators presented by Piñare and Fuentes (1984) and Soldatelli and Machaca (1992), the most useful are the following:

1. Profitability of capital (C) is related to the circulating capital and is estimated by the GM-to-VC ratio.

2. Profitability of labor (W) is estimated by the ratios of the GMs

of the agroecosystems to the total cost of labor and services.

3. Profitability of land (L) is estimated by the value of the GM of each system with regard to the LUI.

Comparative efficiency index for agroecosystems. This useful index (CEf) compares the economic efficiency of agroecosystems studied, using ratios between the GMs of the systems concerned. Thus, this index permits evaluating the efficiency of the modified activity or system and comparing it with that of the traditional system of the cooperating farmer. It also permits comparison of levels of efficiency among the different systems proven for each DOR.

For the traditional system, CEf = 1. The modified system is more efficient when its CEf > 1. A negative CEf points to poor performance, indicating that the components should be analyzed to identify the problem site or aspect.

The final calculations for each agricultural management, consistent as to the management of field data and development of efficiency indicators, should be done in consultation with the economists, sociologists, and statisticians of the multidisciplinary team.

Evaluation with Farmers

In validation plots, the farmers are the ones who, in the end, will decide whether a new technology is useful for their purposes and conditions. This means that, although agronomic and economic evaluations are needed to technically verify the results of the on-farm trials, what will determine the suitability of a given technological innovation are the evaluations made with farmers.

The farmers’ active participation in the evaluation of validation plots enable researchers to systematize and understand farmers’ perceptions of the results obtained through the free expression of their opinions, perspectives, suggestions, and criteria.

The objective of the evaluation interviews is to hear the cooperating farmers’ spontaneous observations and analyze them as indicators. Some recommendations for technicians in charge of on-farm evaluations by farmers are as follows (Ashby 1992):

1. Be motivated to offer innovations to farmers from an optimistic standpoint, that is, visualizing solutions, not problems, obstacles, or failures.

2. Be careful not to impose opinions.

3. Be unafraid of rejection or criticisms of the proposed innovation. Under such circumstances they should make it clear that the options for testing may or may not be better than the technologies already in use and that they want to learn what farmers think of the innovations presented.

4. Be willing to place the farmer in the role of teacher, respecting his or her experience and practice.

The evaluation interview with the farmer is not a simple conversation, but a process that should include a sequence of interviews during different stages of crop development. After analyzing each interview, the farmer should be informed of the general conclusions, and future actions should be programmed. Before initiating interviews, a list should be made of the data that the technician believes are important to record, such as appropriate times for planting and managing pests and weeds.

Evaluation of the sociocultural acceptability of proposed innovations should focus on farmers' opinions, whereas agronomic and economic evaluations for estimating the agroecological sustainability and the economic profitability should be based on previously presented criteria and procedures. When both types of evaluations cannot be conducted independently, then the interview with the cooperating farmer should be carried out first, followed by data collection and field observation.

Ashby (1992) suggests using an interview format structured as follows:

1. Identify the cooperating farmer, farm's location, interviewer's name, interview date, and agroecosystem.

2. Solicit spontaneous commentary to determine the farmer's reactions and information on each point of the technology being evaluated. After the farmer spontaneously gives his or her observations, the interviewer can, through questions, seek complementary information or clarifications. The farmer's observations must be recorded as exactly as possible, using his or her own words.

3. Ask direct questions *only* at the end of the evaluation, after the spontaneous observations, and only when further details are needed on the farmer's opinions with respect to a specific observation. The responses are allocated in a specific section of the form.

4. Once the evaluation is finished, note additional observations needed to improve evaluation, including the state of crop development, climatic conditions prevalent during the cropping cycle, and incidence of pests and diseases.

As well as giving recommendations for carrying out the evaluation interviews, Ashby (1992) suggests that certain behavior should be avoided:

- Initiating an interview without explaining the objectives and clarifying the interviewee's expectations.

- Teaching and making recommendations concerning the farmer's evaluation.

- Evaluating opinions with farmers or technicians who are not likely to be potential users or who do not have relevant experience on the theme.

- Imposing personal criteria in the evaluation.

- Criticizing the farmer's criteria, discussing them, or contradicting him or her.

- Rejecting the farmer's hospitality and making unfair demands on his or her time.

- Interrupting and hurrying the farmer during the evaluation.

- Spending more time asking questions than listening.

- Ending the interview without being certain of the reasons why the farmer prefers one alternative to another.

- Interpreting the farmer's opinions and preferences without confirming his or her interpretation.

- Repressing the farmer's initiative and creativity by rigidly controlling the innovation being evaluated.

Quirós et al. (1992) recommend using three questionnaire types:

1. Open-ended, which permit a broad range of responses without suggesting what is expected.
2. Exploratory, searching for information to facilitate the comprehension of a specific fact. This type of questionnaire complements the open-ended type and is used only when more specific information is needed to better understand a farmer's opinion.
3. Clarifiying, that is, exploring in greater depth the meaning of terms used and the farmer's opinions, and aiming to stimulate the farmer's judgment and obtain more details about his or her opinions.

Leading questions, which suggest expected responses, should not be used as they restrict the farmer's free and spontaneous expression.

Once the interview is concluded, the farmer's spontaneous observations are coded. Each piece of information is assigned a positive (+) or negative (-) symbol to identify the type of opinion manifested by the farmer. This coding will help the researcher understand how and why the farmer accepts or rejects a given technology.

Ashby (1992) also points out other evaluation techniques in interviews, including:

- Evaluations to identify what the farmer accepts or rejects according to his or her opinions.
- Ranking of alternatives, destined to obtain an overall preference ranking by the farmer of the alternatives being tested.
- Ranking matrix, a technique that consists of asking the farmer to rank the various treatments based on specific parameters chosen jointly with him.
- Comparison between pairs, applied to alternatives when the subjects being compared are clearly differentiable.

At the end of every crop cycle, the technicians synthesize the principal results, summarizing the positive and negative aspects highlighted by the cooperating farmer during the evaluation interviews. By comparing the farmer's opinions with the agronomic and economic parameters selected, the degree to which the effects evaluated from the technical and scientific standpoint agree with the user's logic and experience can be determined.

Neither the farmers nor the researchers will wish to be committed on the basis of just one trial. Instead, they would want to be certain that the observed results can be repeated under other circumstances. Thus, they will try to select several promising options for future trials. In addition, two or three attractive options can be expressed. Accordingly, researchers should adopt and keep a neutral attitude and be receptive when faced with the farmer's honest criticisms.

Final Considerations

To adjust and verify the sustainability, profitability, and acceptability of technological innovations offered by agricultural research, validation plots should be established on reference farms and monitored. These plots should be planned and carried out in accordance with previously diagnosed problems and limitations and in response to the characteristics prevalent in the DOR under study and to the existence of need and interest in adopting new technologies.

The adjustments and validation of technological offers should be carried out in agroecosystems at farm level, with the active participation of cooperating farmers and with formal support from extension agents and local technical assistants.

Through adequate monitoring and evaluation, the technologies most appropriate to farmers' different objectives, needs, and areas of influence can be chosen. Accordingly, procedures and criteria must be adopted to permit the adequate recording and organization of the evaluation parameters.

Success in evaluations with farmers requires, above all, the establishment of a relationship of confidence, friendship, and respect throughout the validation process. This requires attitudes of simplicity and sincerity on the part of researchers to establish good relationships with farmers.

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CHAPTER 8

Technology Transfer: The Case of the *Barreirão* System in Goiás, Brazil[1]

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Contents

Abstract

Agricultural production systems offer a challenge to the development of strategies for technology transfer. Traditional models follow a sequence of actions for a specific theme, starting with problem diagnosis by the researcher, followed by project design and execution, and finishing with the transfer of experimental results to technical assistants. The “*barreirão* system” is broader in concept, requiring that a whole system be transferred through a major effort of validation and transfer and involving researchers, farmers, extension workers, policymakers, and cooperatives. For transfer to be successful, the word “system” is key to the farmer adopting the whole technology package, to developing machinery for plowing and planting, to obtaining financial support for

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[1] Adapted from the publication of the same name, distributed by EMBRAPA Arroz e Feijão, Goiânia, Brazil.

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the system and thus win policymakers' support, to conducting field days, and to promoting the system through communication media. The "*barreirão* system" was successful in terms of (1) costs, which were recovered through the sale of crop grains; (2) adapting a series of plows and planters for the system; and (3) funding from banks to reclaim and renew pastures. The area of reclaimed pastures grew from about 2000 ha in 1990/91 to 400,000 ha in 1993/94, thus indicating the success of the transfer strategy for the "*barreirão* system".

Resumen

Los sistemas de producción agrícola representan actualmente un reto a las estrategias de transferencia de tecnología. Los modelos tradicionales implican una secuencia de acciones que se inician con el diagnóstico del problema por el investigador, pasando por la elaboración de proyectos y la ejecución de la investigación, y terminando con el proceso de transferencia de resultados experimentales a los asistentes técnicos. La propuesta del 'Sistema Barreirão' es más amplia y requiere que todo el sistema se transfiera a través de un mayor esfuerzo en las fases de validación y transferencia propiamente dicha con la participación de investigadores, productores, políticos, cooperativas y técnicos en extensión. Para tener éxito en el proceso es necesario utilizar la palabra 'sistema' como una clave para la adopción de toda la tecnología, el desarrollo de maquinaria para preparar el suelo y sembrar, la obtención de financiamiento para el sistema y ganar el apoyo de políticos, la realización de eventos como días de campo, y la divulgación del sistema a través de los medios de comunicación. Los resultados obtenidos en el Sistema Barreirão indican que es exitoso en relación con: (1) los costos, que fueron cubiertos por la venta de los granos producidos; (2) el desarrollo de una serie de arados y sembradoras adaptados al Sistema; y (3) el financiamiento por parte del sistema bancario para la recuperación y renovación de pasturas. Con el uso de este sistema, el área recuperada de pasturas aumentó de cerca de 2000 ha en el período 1990/91 a 400,000 ha en el período 1993/94, lo cual es un indicativo de su adopción y uso por los productores.

Introduction

Technological evolution in the agricultural and livestock production sectors of developing countries is limited by several factors, including farmers' relying on experience and having a low economic capacity. This complicates technology transfer, hindering sustainable development. Historically, in tropical regions, farmers adopted new varieties at a fairly reasonable rate. In contrast, the dissemination of production systems involving practices and inputs fundamental to improving the fertility of the generally poor savannas soils is complex.

This situation becomes even more complex when there are difficulties in expanding the agricultural area at the cost of productivity. For example, 62% of Brazil's central *cerrados* is occupied by farms of more than 1000 ha, and 0.5% by farms of less than 100 ha (Teixeira et al. 1986, cited by Seguy et al. 1989). Under these conditions, increasing productivity is of utmost importance to small and medium-scale farmers. However, their deficient resources and information mean that they almost always have limited access to mechanization and use few inputs.

Although the basic philosophy of the official rural extension service is to work together with the small farmer, transferring knowledge and technologies, that interaction does not always lead to higher productivity or to a more sustainable development of agricultural regions. In addition, the low adoption of technologies by farmers discourages technical assistants to the point of their losing credibility in the eyes of their respective communities (Mussoi 1993). Moreover, the lack of adoption of technological innovations such as inputs and agricultural mechanization results in an increasing loss of competitiveness, primarily because of the relationships between prices of primary products and prices of the inputs and capital resources needed for production.

Because many farmers regard the solution to production-constraining factors as being found in the market, they are not concerned about sustaining the ecosystem's productive potential. Thus, practices such as erosion control and conservation of soil organic matter are being used less and less. Furthermore, production costs tend to be higher in tropical regions because of the need to control weeds, pests, and diseases by frequent applications of fertilizers and agrochemicals, and to adopt specific cultural practices for preparing the soil and planting crops (Kluthcouski et al. 1991). Nor are farmers motivated to invest in technology as the release of resources to finance their activities is frequently not only untimely but also inadequate. Except for new varieties and some specific technologies that cost little, technology transfer services have, so far, not made much impact on agricultural yields. For this reason, technology transfer should include a set of interrelated techniques within the framework of a given agricultural system to guarantee impact on productivity and on enhancing farmers' socioeconomic situation.

The Traditional Model for Technology Transfer

While acknowledging those factors limiting the adoption of technologies generated by research, the manner in which they are transferred is known to contribute significantly to changing farmers' mentality. It can also influence both the credit sector and the implementation of development programs generated by the policy-making sector. The usual model relating the processes of technology generation and transfer implies a sequence of actions that starts with the researcher's diagnosis of the problem at the farm level. Diagnosis is then followed by project preparation and execution of research. The sequence ends with transferring, through training or written means, experimental results to technical assistants (Figure 1), who then become responsible for disseminating the generated technology.

This model gives good results when it concerns specific themes such as the use of chemical products and planting distances, but is inadequate for disseminating agricultural systems. Its limitations include the possibility that technical assistants may not always have sufficient knowledge of the generated technology to conduct the transfer. Also, within the process of transfer, their role in diffusion is relatively isolated, even though they are also responsible for developing technologies to provide feedback to the researchers.

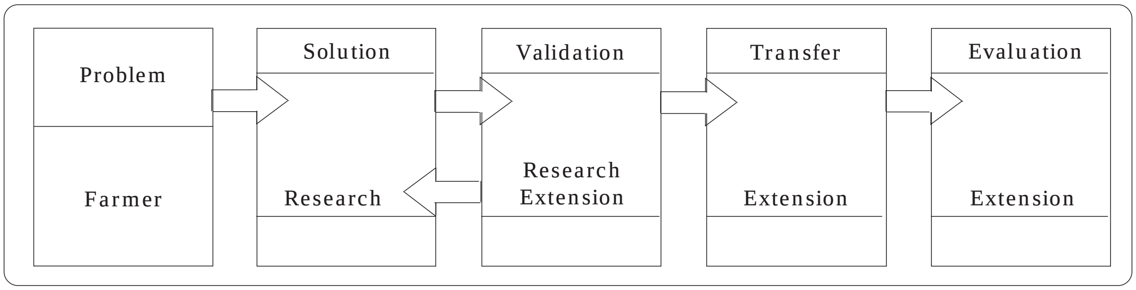

Figure 1. Flow chart of conventional technology transfer.

Technology Transfer Model for the *Barreirão* System

This system consists of a technology that includes a set of practices—advanced techniques for preparing soils, precision planting, and use of modern inputs—designed to reclaim degraded pastures through associations of forages with crops such as rice, maize, sorghum, *Pennisetum* sp., and sunflower (Kluthcouski et al., Chapter 15, this volume). Because of the interrelationships of the recommended practices, all must be applied so not to compromise the system's efficiency. For this technology, a model, different from the traditional dissemination-and-transfer model discussed above was adopted. From its conception, this alternative model has been undergoing continuous improvement during the monitoring of agricultural development.

Based on the assumption that the *barreirão* system would be transferred principally to cattlemen, the following factors were considered:

- The need to use machinery and equipment other than those traditionally used by farmers, as well as modifying those that already exist.
- The possibility that the introduction of upland rice, a pioneer crop in the implementation of the *barreirão* system, would not interest the farmer.
- The need to apply inputs in the quantity and quality as required by the *barreirão* system.
- The need to implement and monitor numerous demonstration units, thus implying a high demand for human resources, materials, and financial capital.
- The inappropriateness of some commercially available equipment to carry out the agronomic practices required by the *barreirão* system.
- Lack of credit for establishing associations of crops, including forages.
- Given the complexity of the *barreirão* system, the training of technical assistants would have to be developed beyond merely implementing a training course and producing publications.
- Almost 80% of the 130 million hectares of pastures grown in the Brazilian *cerrados* are degraded, but even so their reclamation is economically viable.

The following strategies were adopted for technology transfer:

- Refer to the generated technology as the "System" to induce adoption of all practices, and eliminate the term "upland rice", which is of low acceptability to farmers.

- Promote the *barreirão* system throughout the country through mass media, including newspapers, radio, and television.

- Agree on strategies with companies producing agricultural machinery, implements, and inputs, seeking their support in disseminating the *barreirão* system, providing equipment needed for specific activities, and implementing needed modifications in the products they already offer.

- Once the municipality and sites for the trials are selected, encourage the effective participation of technical assistance enterprises, cooperatives, and other sections of the agricultural sector in implementing and monitoring the demonstration units of the *barreirão* system.

- Invite representatives of financial entities, local and national political authorities, and agricultural insurance agencies to all promotional events concerning the *barreirão* system.

- Offer continuous theoretical and practical training to the extension workers of both official and private technical assistance networks.

With these strategies, the process of transferring the *barreirão* system was initiated in the *cerrados*, a vast region of about 200 million hectares, accounting for 25% of the country. During the first year of dissemination, several representative demonstration units were established, permitting the evaluation and comparison of conventional methods of pasture reclamation and the effects of different soil preparation techniques with the agronomic practices recommended in the *barreirão* system. From the beginning, interested farmers and, especially, technical assistants were in continuous contact with the development of the demonstration units. From the second year onward and to reduce costs, the monitoring of new units was done at the national level on large-scale private farms.

Joint multidisciplinary efforts contributed heavily to the transfer's overall success, particularly the following:

- Joint participation of biologists, economists, and extension workers.

- Effective contribution of partners in the promotion of events with policy makers and representatives of the Government and industries.

- Dedication of local technical assistants to the organization of field days.

In those areas that received no official technical assistance services, the responsibility of the activities for the *barreirão* system was assumed by technicians of local cooperatives, the municipality, or other committed institutions.

Principal Economic Results

The efficiency of the model used to transfer the *barreirão* system can be verified by the direct rates of return obtained over four agricultural years (Table 1).

Table 1. Productivity and direct rates of return obtained from the demonstration units of the *barreirão* system over four agricultural years in different municipalities and states of Brazil.

Year	Associated crop	Municipality (no.)	States (no.)	Average crop productivity (kg/ha)		Direct rate of return (average)
				Conventional system[a]	*Barreirão* system[b]	
1987/88	Rice	5	2	—	2063	—
1990/91	Rice	11	1	889	2001	1.27
1991/92	Rice	15	5	1080	2248	1.09
1992/93	Rice	8	3	—	1853	0.96
1992/93	Maize	3	1	—	3994	1.06

a. Harrow plow, and fertilizer applications of P_2O_5 at 50 kg/ha and K_2O at 30 kg/ha.

b. Moldboard plow, and fertilizer applications of N, P_2O_5, K_2O, trace elements (FTE BR 12), and $ZnSO_4$ at 12, 90, 45, 30, and 20 kg/ha, respectively.

These rates reflect the income from grain sales, which represented an immediate return on the capital employed. In this case, the return on renewed pastures was not considered, as this is determined by animal liveweight gain and increases in meat and milk production, especially during the dry period. However, the improved quality of renewed pastures increases animal productivity in terms of higher birth rates, lower mortality indices, reduced times to weaning, and higher meat yields. It also increases soil cover, which, in turn, contributes to reductions in erosion and agrochemical use.

Strategies for Disseminating Information

The *barreirão* system was implemented, and 37 demonstration units monitored, by the Centro Nacional de Pesquisa de Arroz e Feijão (CNPAF) of the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA). Another 35 units were coordinated together with the Rural Extension Service. Over time, a diverse range of dissemination media were used, including videos and documentaries for national, regional, and local television programs; and articles in journals, newspapers, agricultural bulletins, and cooperative and private enterprise reports. In addition, numerous farmers were encouraged to participate in field days set up to demonstrate the *barreirão* system. Specific groups were reached through specialized media such as conferences and training events. Consultancies and direct mailing systems were also established for farmers, private enterprises, and public institutions.

Conclusions

The principal results of the method used to transfer the technology of the *barreirão* system are highlighted as follows:

1. The area of reclaimed pastures expanded from about 2000 ha in the 1990/91 cropping season to 10,000 (1991/92), 50,000 (1992/93), and 400,000 ha in 1993/94.

2. Cultivation tools were made more efficient, including a moldboard plow with an automatic disassembly, adapted planters, fertilizers with balanced formulas, and increased number and availability of moldboard plow models.

3. The Federal Government approved adequate agricultural credit and insurance, including total coverage of costs and favoring the *barreirão* system over other cropping systems.

4. Subsidies were given to the national agricultural insurance program to reduce risks involved in monoculture.

5. Relationships were strengthened with private entities, which assumed the dissemination and transfer costs, and provided vehicles, machinery, and equipment.

6. Financial aid was obtained for research, eliminating the need for public spending.

7. Technical and policy-making leaders participated at the national level, and committed themselves to continuing the process of disseminating the *barreirão* system.

8. A national dissemination program, known as the "Green and Yellow Program", was established under the sponsorship of a group of companies to disseminate publications and provide training throughout the technology-transfer process.

9. Local and national multidisciplinary research teams were formed, involving research centers and universities.

10. Twenty-three field days were conducted in seven states, with 50 to 4000 farmers participating in each event. Extension workers, researchers, students, and representatives of the Government, banks, and private enterprise also participated.

11. The farmers demanded other technological innovations, which demand was fed back to the research process, culminating in the creation of new technologies and, consequently, strengthening the *barreirão* system.

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PART III

Crops and Forages as Components of Agropastoral Systems

CHAPTER 9

Genetic Alternatives for Production Systems in the Acid-Soil Savannas of the Colombian Orinoquia

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Contents

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Abstract

The savannas of the Colombian Orinoquia are characterized by low-fertility soils that are poor in essential nutrients, particularly phosphorus, calcium, magnesium, potassium, and sulfur. They also have low pH, high exchangeable aluminum (Al), high Al saturation, and fragile soil structure. Nevertheless, they offer certain advantages for sustainable agriculture such as abundant and adequate rainfall distribution between April and November, flat topography, and large tracts of available land. The entire region comprises about 26 million hectares, of which 53% are well drained and underused. The predominant land use is extensive cattle raising, with low technology and productivity. The efficient use of these soils requires viable and cheap technology, including crop species and cultivars that can tolerate high concentrations of Al while efficiently absorbing nutrients. Also needed are land preparation practices that increase the stability of soil aggregates and minimize erosion and runoff. The search for suitable food crop production systems is led by the Colombian Institute for Agriculture and Livestock (ICA) and the Colombian Corporation for Agricultural Research (CORPOICA), who have made progress by integrating multidisciplinary research groups. Collaborative research with international centers such as CIAT (rice), INTSORMIL (sorghum), and CIMMYT (maize) has led to the release of crop and forage species that tolerate acid soils: rice varieties Oryzica Sabana 6 and Oryzica Sabana 10; soybean variety Soyica Altillanura 2; sorghum varieties Sorghica Real 40, Sorghica Real 60, and Icaravan 1; maize variety Sikuani V-110; grass species *Brachiaria* spp. and *Andropogon gayanus*; and legume species *Arachis pintoi*, *Stylosanthes capitata*, and *Centrosema acutifolium*.

Resumen

Las sabanas de la Orinoquia Colombiana se caracterizan por tener suelos de baja fertilidad con bajos contenidos de fósforo (P), calcio (Ca), magnesio (Mg), potasio (K) y azufre (S); bajo pH, alta concentración de aluminio (Al) intercambiable, elevada saturación de Al y baja estabilidad de la estructura física. Sin embargo, estos suelos ácidos tienen algunas características que favorecen sistemas de agricultura sostenible, entre ellas: (1) abundante y adecuada distribución de lluvias entre abril y noviembre, (2) topografía relativamente plana, (3) buenas características físicas, y (4) una alta disponibilidad de tierra. La Orinoquia Colombiana comprende cerca de 26 millones de hectáreas, de las cuales el 53% son bien drenadas y subutilizadas en sistemas de ganadería extensivos en pasturas manejadas con baja tecnología y escasa productividad. Para el manejo racional de estos suelos se requieren tecnologías altamente eficientes y de bajo costo. Los componentes tecnológicos necesarios para el desarrollo de esta región incluyen especies y cultivares que toleren altas concentraciones de Al y sean eficientes en la absorción de nutrimentos. Asimismo, se requieren prácticas que incrementen la estabilidad estructural en los agregados y que disminuyan la erosión y la escorrentía del suelo. La investigación en sistemas de producción de cultivos para incorporar estas áreas a la producción de alimentos ha sido liderada por el Instituto Colombiano Agropecuario (ICA) y por la Corporación Colombiana de Investigación Agropecuaria (CORPOICA), a través de la generación de variedades con alto potencial genético y el desarrollo de prácticas tecnológicas de manejo de suelos adecuadas para la solución de los problemas edáficos. Los logros de la investigación en sistemas de producción sostenible son el resultado de la integración de los grupos multidisciplinarios. Las variedades de arroz Oryzica Sabana 6 y Oryzica Sabana 10, la variedad de soya Soyica Altillanura 2, las variedades de sorgo Sorghica Real 40, Sorghica Real 60 e Icaravan 1, y la variedad de maíz Sikuani V-110, todas ellas tolerantes a suelos ácidos han sido el resultado de la investigación cooperativa entre el ICA, CORPOICA y centros internacionales como el CIAT, INTSORMIL y el CIMMYT. Para la producción pecuaria se han desarrollado diferentes alternativas de gramíneas y leguminosas forrajeras de alto potencial genético como *Brachiaria* sp., *Andropogon gayanus*, *Stylosanthes capitata, Arachis pintoi* y *Centrosema acutifolium*, entre otras.

Introduction

The Eastern Plains of Colombia cover nearly 26 million hectares, of which 53% are located in the well-drained Orinoquia, which consists of alluvial terraces and flat dissected plateaus. Of this area, nearly 4.6 million hectares have high agricultural and livestock potential, but are currently being underused in extensive livestock systems, with pastures of poor nutritional quality.

Production in these ecosystems is limited by edaphic factors such as low soil fertility because of deficiencies in P, Ca, Mg, K, and S; high acidity; high Al saturation; and fragile soil structure. Other limiting factors, which have retarded the sustainable development of the region, are the lack of technology adoption and absence of socioeconomic studies. Nonadapted germplasm and agronomic practices that negatively affect the environment are still being used, for example, excessive tillage and use of amendments, chemical fertilizers, and pesticides. These result in high production costs, limited incentives for farmers, and low profitability and competitiveness of the products.

Despite the constraints, the region has certain advantages, including flat topography, which facilitates mechanization, and both sufficient and adequate distribution of rainfall between April and November.

Given the foregoing and considering the large agricultural and livestock potential of the Colombian Orinoquia, the Colombian Institute for Agriculture and Livestock (ICA) and the Colombian Corporation for Agricultural Research (CORPOICA) have led research in the region, using a multidisciplinary approach, to generate technologies that would permit the development of efficient, sustainable, and competitive production systems. Technology generation is oriented toward the acquisition of species and improved genotypes adapted to highly Al-saturated acid soils. The technologies sought must be efficient in using resources for production while conserving natural resources.

Alternative Crops for Acid Soils

Most crops do not tolerate the low-fertility conditions prevalent in acid soils and require the application of high doses of amendments and fertilizers for economically viable production. Taking this situation into account, ICA and

CORPOICA, together with international institutes, have developed germplasm adapted to these ecosystems, tolerant of Al, and with high production potential (Table 1).

Rice (Oryza sativa *L.*)

Research on genetic improvement of rice for the acid soils of the Colombian Orinoquia was initiated in 1982 through an ICA-CIAT Agreement. Initially, an evaluation was made of 1360 introduced materials that had been used to identify parents with high genetic potential for adaptation and reaction to diseases. Starting in 1985, through hybridizations carried out at CIAT and selection and evaluation of the resulting lines by ICA, the first rice variety, known as Oryzica Sabana 6, was developed for the acid-soil savannas.

Oryzica Sabana 6 (parents: TOX 1780-2-1-1-1P-4/Colombia 1 × M312A/IAC 47) was released in 1991 as the first high-yielding upland rice variety for acid soils. The mechanism for tolerance of this genotype for acid soils probably involves the exudation of organic acids from the roots, including citric acid. The acids establish ligands with the Al, to which they become strongly bonded, inactivating it, and, at the same time, releasing fixed P.

This improved rice variety is early maturing (110-115 days), tolerates high Al saturation (>90%), has broad leaves, thick strong stalks, and resists lodging. It has an average height of 100 cm and produces long thin grains with small white centers. Roots are characteristically deep, thereby enabling the rice plant to more easily take up water and nutrients from deeper soil layers.

Oryzica Sabana 6 is resistant to the diseases and pests prevalent in the region, thus helping to reduce or eliminate the use of agrochemicals and, hence, the risks of environmental contamination. This variety can be planted in association with grasses and legumes, permitting the establishment of an improved pasture in a short time (Leal et al. 1991).

In regional trials conducted on Al-saturated soils (81%-92%), this variety produced, on average, 3.22 t/ha; whereas the improved variety IAC 165 from Brazil, used as the tolerant check, produced 2.21 t/ha and the susceptible varieties had even lower yields (Table 2).

Another alternative was developed in 1986 for acid soils with better quality grains by crossing, at CIAT,

Table 1. Varieties of crops released for the acid soils of the Colombian Orinoquia.

Species	Variety	Tolerance of Al sat. (at %)	Agreement[a]	Year variety released
Rice	Oryzica Sabana 6	90	ICA-CIAT	1991
	Oryzica Sabana 10	90	ICA-CORPOICA-CIAT	1995
Soybean	Soyica Altillanura 2	70	ICA-CORPOICA-FFA	1994
Sorghum	Sorghica Real 40	40	ICA-INTSORMIL	1991
	Sorghica Real 60	60	ICA-INTSORMIL	1991
	Icaravan 1	40	ICA-INTSORMIL-El Alcaraván	1993
Maize	Sikuani V-110	55	ICA-CORPOICA-CIMMYT	1994

a. CIMMYT = Centro Internacional de Mejoramiento de Maíz y Trigo;
CORPOICA = Corporación Colombiana de Investigación Agropecuaria;
ICA = Instituto Colombiano Agropecuario;
INTSORMIL = International Sorghum and Millet.

Table 2. Yield of rice varieties, averaged across 18 trials, in the acid soils of the Colombian Eastern Plains, 1989-1990.

Variety	Yield (kg/ha)
Oryzica Sabana 6	3220
IAC 165	2212
Oryzica Llanos 5 (susceptible to acidity)	878

Colombia 1 × M312ND/IRAT 124/RHS 107-2-1-2TB-1-1M and from which was generated, by individual selection, Line 3 (subsequently named Oryzica Sabana 10). In trials carried out by CORPOICA at the sites of El Yopal and Puerto López and at the research centers “La Libertad” and “Carimagua” (Colombian Eastern Plains) in 1994, Line 3 produced, on average, 3.6 t/ha in three regional trials and 2.9 t/ha in four semi-commercial plantings. These yields were similar to those obtained for var. Oryzica Sabana 6 (Table 3) (Aristizábal et al. 1995).

Oryzica Sabana 10 produces more dry matter (DM) than does Oryzica Sabana 6, and has an excellent ability to compete in rice-pastures associated systems. In addition, it resists lodging, and is highly resistant to the leaf and neck blasts caused by *Pyricularia* fungi. The grain’s appearance, its length, and length-to-width ratio give this variety an additional advantage in milling, thereby improving its marketability (Aristizábal and Leal 1995).

The genetic improvement of rice for acid soils is currently oriented toward the search for well-adapted, high-yielding, early maturing, and good-quality materials that are resistant to *Pyricularia* spp. These materials should be capable of being easily introduced into integrated production systems for tropical savannas, particularly those systems in which crop rotations and associations are fundamental elements of sustainability.

Soybean (Glycine max (*L.*) *Merrill*)

In 1984, the Genetic Improvement of Soybeans for Acid Soils Program was initiated at the “La Libertad” Research Center in Villavicencio, Department of Meta, to develop genotypes tolerant of high Al saturation in the soil. Initially, 1069 accessions from the world soybean collection were evaluated (421 from Brazil, 226 from Taiwan, and 422 from other countries), as well as 407 populations between segregating and advanced lines from CORPOICA’s research center at Palmira, Department of Valle del Cauca. As a result of strong intra- and interfamily selection pressures, the first lines of soybeans

Table 3. Average yield (t/ha) of rice varieties Oryzica Sabana 6 and Oryzica Sabana 10 in regional and semi-commercial trials conducted on the acid soils of the Colombian Orinoquia.

Site	Type of trial			
	Oryzica Sabana 6		Oryzica Sabana 10	
	Regional	Semi-commercial	Regional	Semi-commercial
El Yopal	4.5	3.2	4.5	3.9
La Libertad	3.4	2.0	2.5	2.1
Puerto López	3.0	3.0	2.7	2.7
Carimagua	—	3.5	—	3.2
Average	3.6	2.9	3.2	2.9

tolerant of 70% Al saturation were obtained and given the name “Lita” (Valencia R 1994).

Line Lita 09, characterized by its good adaptation and high genetic potential, was released as ‘Soyica Altillanura 2’ as the first soybean variety for the acid soils of the Colombian plateaus. The variety was developed by ICA during its institutional division into ICA and CORPOICA in 1994. The number “2” refers to the second variety of soybean obtained in the Eastern Plains, after Soyica Ariari 1, which was developed for the favored lowlands of the Colombian Piedmont.

Soyica Altillanura 2 is the product of a simple cross between Line 109 (currently Soyica N-21) and Line 124. The first parent had, as one of its parents, plant introduction PI274954, which had tolerance of chrysomelids. The second parent had, from soybean var. Davis, genes of resistance to the fungus (*Cercospora sojina* Hara) causing frogeye leafspot. These genes were combined with genes for high-yield potential from vars. Hill and Mandarin.

Soyica Altillanura 2 characteristically tolerates as much as 70% Al saturation, and efficiently uses nutrients and water. It is therefore a promising alternative for sustainable production systems for acid-soil savannas. Other characteristics are an indeterminate growth habit, purple flowers, brown pubescence, and yellow seeds. It is early maturing (85-95 days), with 13-26 pods per plant, each with 2-3 grains (Caicedo et al. 1984).

In acid soils with 70% or more Al saturation, Soyica Altillanura 2 achieves average yields of 1.5 t/ha. In soils with lower levels of saturation, yields increase significantly (Table 4). By increasing the organic matter content in this region’s soils through crop rotation, incorporation of green manures, and efficient soil management, the harmful effects of Al can be reduced, thereby increasing the productive potential of these agroecosystems in a sustainable and competitive way.

To develop a soybean variety with greater adaptation and high yield, CORPOICA is conducting research to evaluate and select parents with high genetic potential for incorporation into hybridization experiments. Highly promising advanced lines, which are early maturing and resistant to the diseases prevalent in the region, have now been generated for acid soils.

Sorghum (Sorghum bicolor (*L.*) *Moench*)

In 1983, “La Libertad” Research Center initiated work on selecting sorghum materials tolerant of acid soils. At first, 4362 cultivars were evaluated; these had been introduced into Colombia by the International Sorghum and Millet (INTSORMIL). Under the ICA-INTSORMIL Agreement, the first varieties adapted to this ecosystem

Table 4. Yield (t/ha) of soybean varieties Soyica Altillanura 2 and Soyica Ariari 1, averaged across 15 regional trials conducted on the acid soils of the Colombian Eastern Plains.

Site	Al sat. (%)	Organic matter (%)	Soyica Alti-llanura 2	Soyica Ariari 1
Villavicencio	63	3.9	2.1	1.8
San Martín	82	3.2	1.4	1.1
Puerto López	81	6.5	1.2	0.8
Average			1.6	1.2

were obtained by selecting for early maturity, plant height, and stable yields. These varieties were released as Sorghica Real 40 and Sorghica Real 60, which, respectively, tolerate as much as 40% and 60% Al saturation in the soil (Table 1; ICA 1990).

Sorghica Real 40, derived from the introduced Serere 1, takes 59-62 days to flower, grows to 1.5-1.7 m tall, and has panicles that are 5-7 cm long and are semi-open and semi-compact. Its leaves are smooth. It performs well during both growing seasons, with higher yields in the first wet semester (Table 5).

Sorghica Real 60, derived from the introduced MN 4508, is tolerant of pests and diseases and well adapted, with stable yields in soils having 40%-60% Al saturation (Table 5). The selection of this variety was based on its early maturity and plant height (Ruíz and Rendón 1991).

Both varieties are tolerant of the principal diseases caused by *Colletotrichum* and *Gloeocercospora* fungal species found in the Colombian Eastern Plains and, although no pest problems occurred during the first semester, *Trichogramma* wasps should be released in the second to reduce attacks from the stemborers of the *Diatraea* spp.

Table 5. Yield (t/ha) of grain sorghum varieties in regional trials in acid soils, Colombian Eastern Plains.[a]

Variety	Regional trials	
	Semester A (wet)	Semester B (dry)
Sorghica Real 40	3.40	2.79
ICAIMA	0.71	2.17
Sorghica Real 60	3.22	2.99
ICA Nataima	0.53	0.89

a. The yields of Sorghica Real 40 and ICAIMA correspond to data from seven sites in semester A and 13 in B. The yields of Sorghica Real 60 and ICA Nataima were obtained at 13 sites.

SOURCE: ICA (1990).

Another alternative for acid soils is the sorghum variety Icaravan 1, obtained from the introduced IS 3071, itself native to Uganda. 'Icaravan 1' is a result of research carried out by INTSORMIL under the Agreement between El Alcaraván Experiment Station and ICA. It is well adapted to fertile savanna soils and to low-lying areas with 60% Al saturation. The growing period is 110 days, with flowering at 73 days. Plant height is 1.6 m and the panicle is semi-open, with light brown grains. It is tolerant of foliar diseases and the fungi *Fusarium* and *Curvularia*, which cause grain rot. In regional trials and commercial plantings carried out in Arauca during the second semester, yields averaged 2.48 t/ha, being equal to or slightly higher than those of the commercial var. Sorghica Real 60, used as check (Muñoz et al. 1993).

Currently, in other agreements, including that with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), CORPOICA is conducting research on both grain and feed sorghum varieties with better adaptation to acid soils than the above-mentioned varieties.

Maize (Zea mays *L.*)

ICA and the International Maize and Wheat Improvement Center (CIMMYT, its Spanish acronym), in collaboration with CORPOICA, developed the improved maize variety Sikuani V-110. This variety tolerates as much as 55% Al saturation and a soil P content as low as 8 ppm. Thus, it is recommended for planting on improved soils of the plateaus and piedmont areas in the Colombian Eastern Plains.

It resists lodging, reaching an average height of 2 m. The female flowers appear at 57 days, and harvest can be carried out 2 months later. Grains are yellow, flint shaped, with a thin floury layer. In regional trials carried out in acid soils (average pH = 4.7, 8 ppm P, and 56% Al saturation), the variety yielded 2.9 t/ha of grain, that is, 53% more than the susceptible check (Table 6). In soils with no Al-saturation problems and average-to-high fertility, yields can average 7.1 t/ha (Torres et al. 1994).

To increase maize productivity on savanna soils, the CORPOICA-CIMMYT Agreement has developed a series of hybrids with good vigor, the yields of which significantly surpass those of var. Sikuani V-110. These materials are being evaluated under different agronomic practices before release.

Agronomic management of annual crops

In addition to identifying varieties adapted to acid soils, agronomic management techniques suitable for optimizing existing resources also had to be developed. These include selecting land, soil preparation with adequate tools to minimize erosion and improve aeration and biological activity, sowing densities and timing, fertilization, and integrated pest management. Tables 7 and 8 summarize some recommendations for managing annual crops in acid soils.

Forage Grasses and Legumes

In the acid-soil savannas of the Colombian Eastern Plains, animals are

Table 6. Yield (t/ha) of maize varieties Sikuani V-110 and Tuxpeño in acid soils of different regions and nonacid soils, 1992-1993.

Variety	Acid soils		Nonacid soils (inter-Andean valleys, 5 sites)
	Colombian Eastern Plains (18 sites)	Other countries (2 sites)	
Sikuani V-110	2.93	3.11	7.14
Tuxpeño	1.92	2.67	6.45

SOURCE: Torres et al. (1994).

Table 7. Planting densities, sowing times, and vegetative growth periods of crop species and varieties for acid soils.

Species	Variety	Planting density (seed at kg/ha)	Sowing time in season:		Growth period (days)
			First semester (dry)	Second semester (wet)	
Rice	Oryzica Sabana 6	80-100	15 April-31 May	—	115
	Oryzica Sabana 10	80-100	15 April-31 May	—	115
Soybean	Soyica Altillanura 2	100	25 April-25 May	15 August-15 September	100
Sorghum	Sorghica Real 40	17	15-30 April	15 August-15 September.	117
	Sorghica Real 60	17	15-30 April	15 August-15 September	120
	Icaravan 1	12	—	15 August-15 September	110
Maize	Sikuani V-110	25	15 March-15 April		

SOURCES: Leal et al. (1991); Ruíz and Rendón (1991); Torres et al. (1994).

Table 8. Fertilization (kg/ha) recommended for acid soils in the Colombian Eastern Plains.

Species	Variety	Fertilizer					
		Lime	N	P	K	Mg	Zn
Rice	Oryzica Sabana 6	300-500	80-120	22-50	49-100	15-30	2-4
	Oryzica Sabana 10	300-500	80-120	22-50	49-100	15-30	2-4
Soybean	Soyica Altillanura 2	500-600	—	35-43	25-50	15-30	—
Sorghum	Sorghica Real 40	300-600	100	35-43	50-75	—	—
Maize	Sikuani V-110	500-700	100	43	50	—	—

SOURCES: Leal et al. (1991); Ruíz and Rendón (1991); Torres et al. (1994).

grazed on native and introduced grasses, which, being of poor-to-moderate quality, have an adverse impact on animal production. To improve this situation, ICA, CORPOICA, and CIAT have joined efforts to generate forage alternatives that are widely adapted and of good quality, and have potential for production in the region. Programs have been developed for germplasm introduction, selection, and development.

Legumes are important components of tropical pastures because they fix atmospheric nitrogen, which is used by grasses in associated systems to increase production and nutrient quality, thereby contributing significantly to liveweight gain in grazing animals. Table 9 lists promising forage species in tropical regions with acid soils.

Andropogon gayanus *Kunth cv. Carimagua-1*

Native to West Africa, this grass was introduced by CIAT to Colombia in 1973. It grows well in acid soils, cross-pollinates, and is responsive to short day length, being harvested 36-44 days after the onset of flowering. Under commercial conditions, it produces 65-125 kg/ha of clean seed.

The annual animal liveweight gain in savannas with pastures of cv. Carimagua-1 in monoculture ranges from 90 to 119 kg. By introducing legumes into these pastures, liveweight gains can reach 150 kg/year, with moderate stocking rates of no more than 2 animals/ha. At 12 weeks of regrowth, it produces 3 and 6 t DM/ha in the dry and rainy seasons, respectively (Belalcázar et al. 1995).

Stylosanthes capitata *Vogel cv. Capica*

This legume, resistant to anthracnose and adapted to acid soils, promotes good animal productivity with acceptable economic returns. Given its easy establishment and management, tolerance of prolonged droughts, and abundant seed production, it is ideal

Table 9. Forage grasses (G) and legumes (L) for acid soils.

Cultivar	Scientific name	Agreement	Year variety released
Carimagua-1	*Andropogon gayanus*	ICA-CIAT	1981
Capica (L)	*Stylosanthes capitata*	ICA-CIAT	1983
Vichada (L)	*Centrosema acutifolium*	ICA-CIAT	1987
Pasto Llanero (G)	*Brachiaria dictyoneura*	ICA-CIAT	1987
Maní Forrajero Perenne (L)	*Arachis pintoi*	ICA-CIAT	1992

SOURCES: ICA (1983, 1987, 1990).

for increasing and maintaining pasture production. Another advantage is its persistence under grazing conditions and its compatibility with grasses such as cv. Carimagua-1 (*A. gayanus*). In agronomic trials with controlled grazing and in association with the previous cultivar, it produces annually 2-3 t/ha DM. Seed yield in the pod ranges from 75-300 kg/ha if the harvest is mechanized, and 50% higher with manual harvesting. In both cases, seed purity reaches 98% and germination of the scarified seed is 95%. The crude protein content of the leaves in the dry season is 12% and in the rainy season, 18%; digestibility ranges from 55% to 60% (ICA 1983).

Centrosema acutifolium ***Benth. cv. Vichada***

This species is from the Colombian Orinoquia and was collected in the Province of Vichada in 1979. Under experimental conditions, this legume has shown to be well adapted to low-fertility acid soils, tolerant of drought, and of better quality than other legumes adapted to the region, with a potential for establishment in association with forage grasses such as *A. gayanus* cv. Carimagua-1 and *Brachiaria decumbens* Stapf. Under the conditions of the Eastern Plains, after a 12-week period of regrowth, outputs of 0.9 and 2 t DM/ha have been obtained in the dry and rainy seasons, respectively.

It is a short-day plant that reproduces by self-pollination. The onset of flowering is in mid-November and lasts 4-5 weeks, producing yields of 30-80 kg seed/ha. Protein content can reach 25% with a digestibility of 60%. After 2 years of grazing at the Carimagua Research Center, the association of *A. gayanus* cv. Carimagua-1 with this legume has produced daily liveweight gains of 670 g/animal in the rainy season and 115 g/animal in the dry season (ICA 1987b).

Brachiaria dictyoneura (*Fig. & De Not.*) ***Stapf cv. Pasto Llanero***

This cultivar is the result of an ICA-CIAT interinstitutional effort. It was evaluated and selected as an alternative for the Colombian Piedmont and plateaus of the Eastern Plains. It is native to Africa and was introduced to Colombia by CIAT in 1978.

This cultivar is characterized by its good adaptation and production in low-fertility acid soils. It is drought tolerant, and recovers after burnings. It tolerates spittlebug (*Zulia* spp.) attacks, recovering rapidly, but does not tolerate prolonged waterlogging. The cultivar spreads through stolons, runners, or caryopsids. Seeds characteristically have a prolonged latency, which is difficult to break. The plant is palatable to animals and has a good carrying capacity. In the Colombian Piedmont, the forage's production ranges from 0.6 to 0.7 t DM/ha in the dry season and from 0.9 to 1.7 t DM/ha in the rainy season.

The carrying capacity of this cultivar in pastures associated with legumes ranges from 3 to 6 animals/ha in alternate grazing systems. Annual liveweight gain is 179 kg/animal and 537 kg/ha, with a protein content of 8.6% and digestibility of 59% (ICA 1987a).

Arachis pintoi ***Krapovickas & Gregory cv. Maní Forrajero Perenne***

This cultivar, which is native to Brazil, adapts well to those tropical acid soils having a texture between loam and clay and high exchangeable Al content. It is characterized by good persistence and compatibility with grasses, and spreads readily vegetatively or by seed. Given its stoloniferous habit, it has a high carrying capacity. It is moderately tolerant of drought and is ideal as a cover crop and for erosion control in association with perennial crops. In the plateaus, this legume has produced as much as 1.4 t DM/ha per year, while in the Colombian Piedmont, it produces 3.8-5.5 t/ha. The level of crude protein in leaves ranges from 13% to 18%, from dry to rainy seasons, respectively. Average digestibility is 62%-67%. In the Colombian Piedmont, under alternate grazing and a fixed stocking rate of 3 animals/ha, annual liveweight gains on pastures alone and in association with Maní Forrajero Perenne ranged from 134 to 200 kg/animal on *B. decumbens* and from 131 to 168 kg/animal on *B. dictyoneura* (Rincón et al. 1992).

Table 10 gives some technical recommendations for managing forage species adapted to acid soils.

Production Systems

The fragility of the soils in the acid-soil savannas of the Colombian Orinoquia, the loss of structure due to inadequate land preparation practices, and soil loss by erosion require the application of conservational practices that permit the system's sustainability from both a productive and conservation standpoint. Available practices include rotation systems of annual crops with grasses and grain legumes, and associations of these crops with forage grasses and legumes for establishing improved pastures or cover crops to minimize soil losses to erosion and compaction.

The release of rice variety Oryzica Sabana 6 for use in association with grasses such as *B. dictyoneura* cv. Pasto Llanero and *A. gayanus* cv. Carimagua-1 and forage legumes such as *S. capitata* cv. Capica initiated a key stage in the development of sustainable agricultural and livestock systems for the Colombian plateaus. The rice-pasture system was proposed as an alternative for establishing improved pastures or for recovering native savannas. Available technologies include:

Selecting the field,
Preparing the land,
Using suitable implements to minimize losses to erosion and improve aeration and microorganism activity in the soil,
Using adapted crop species and varieties,
Sowing with appropriate methods and densities,
Using, at minimal rates, amendments and fertilizers,

Table 10. Planting densities and methods of sowing forage grasses (G) and legumes (L) in the Colombian Eastern Plains.

Cultivar	Density		Method	
	Seed (kg/ha)	Vegetative (t/ha)	Seed	Vegetative (distance in m)
Pasto Llanero	2-3	6-7	Broadcast or in row	0.6-0.8
Capica (L)	3-4		Broadcast	
Maní Forrajero Perenne (L)	8-10	0.5-1	Broadcast or in row	
Vichada (L)	3-4		Broadcast or in row	0.8
Carimagua-1 (G)	8-12		Broadcast or in row	

Adopting appropriate pest and disease management practices, and

Incorporating tolerant forage germplasm.

All these technologies reduce or eliminate the application of agrochemicals and conserve the environment (Leal 1994).

Experience with annual crop rotation to establish improved pastures in the acid-soil savannas of the Colombian Orinoquia indicates that increasing cultivar yields, improving soils' physicochemical conditions, and reducing establishment costs are possible. For example, var. Oryzica Sabana 6 produced 3.9 t/ha on land planted consecutively to rice, but when planted after soybean, it produced 4.2 t/ha.

Although Oryzica Sabana 6 currently represents the best genetic alternative for acid soils, when grown as a monocrop, it can result in rapid degradation of soils. Thus, crop rotation or association with forage pastures and legumes is essential for sustaining production on the acid-soil savannas of the Colombian Orinoquia.

Table 11 presents the results obtained for animal production under the rice-pasture system. Animal liveweight gains are similar to those obtained with other production technologies proposed for soils of medium-to-high fertility in the Colombian Piedmont.

With this systemic approach to research, we hope to incorporate—sustainably and economically—an extensive area of the acid—soil savannas of the Colombian Orinoquia into national production through practices of crop rotation and associations, incorporation of green manures, and rationalization in use of machinery and inputs. Multidisciplinary research projects have now been prepared to establish the comparative advantages of different crop-and-pasture production systems. With this technology, the goal is to maintain or improve the productive potential of these ecosystems to meet present needs, without affecting the well-being of future generations.

The production systems being researched in this region include the crop rotation rice-soybean-maize, using Al-tolerant varieties; the incorporation of green manures; and integration with improved pastures. In addition, the effects of different intensities of land use on the physical, chemical, and biological properties of the soil are being evaluated in these systems.

Conclusions

From this review of production systems in the acid-soil savannas of the Colombian Orinoquia, we conclude the following:

1. There currently exists a genetic germplasm base of annual crops

Table 11. Stocking rate and animal liveweight gains in pastures established in rice-grass associations at Puerto López, Colombian Eastern Plains.

Season	Stocking rate (animals/ha)		Daily liveweight gain (g/animal)	
	Andropogon gayanus	*Brachiaria dictyoneura*	*Andropogon gayanus*	*Brachiaria dictyoneura*
Rainy	2.04	1.93	835	692
Dry	1.16	1.13	546	521

and forage species for developing integrated production systems for the region.

2. A collection of appropriate technologies is available for production in accordance with the principles of sustainability and conservation of the environment.

3. Systems for rotating and associating grasses and legumes that use production resources efficiently should be adopted.

4. Regardless of the production system and species used, a cover crop should be developed to reduce soil erosion and compaction, and nutrient loss.

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To save space, the following abbreviations are used:

CORPOICA = Corporación Colombiana de Investigación Agropecuaria
ICA = Instituto Colombiano Agropecuario

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CHAPTER 10

Maize Varieties for Acid Soils

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Contents

Abstract

Maize (*Zea mays* L.) is grown throughout the world on about 130 million hectares. Of these, 60% are in developing countries where maize is both a staple food and animal feed, especially for poultry. Because demand for maize is greater than its production, developing countries import at an increasing rate of 1.5 million tons per year and, thus, urgently need to increase their maize production. Because the best lands are occupied by cash crops, marginal environments with acid low-fertility soils must be developed. Such soils can be improved by using amendments,

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complemented by planting adapted cultivars. Because the first option is usually out of reach for resource-poor farmers, the Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT), based in Mexico, in collaboration with several national agricultural research programs, has developed four maize populations that tolerate acid soils. These populations are all heterotic, two are yellow (SA-3 and SA-4), and two are white (SA-6 and SA-7). They are being improved, and are used to develop cultivars. Grain yield of cultivars already developed from these populations has increased dramatically from less than 0.4 t/ha for the cultivars used to form the base populations to 3.0 t/ha for open-pollinated cultivars, and 4.5 t/ha for hybrids. Yield of these same materials is also very high in medium to highly fertile soils, with some hybrids yielding more than 11 t/ha. One physiological mechanism found as contributing to acid-soil tolerance is the release of citric acid from roots. Also being studied are alternatives for crop management that would help improve the productivity of maize-cropping systems while preserving the environment.

Resumen

El maíz (*Zea mays* L.) se cultiva en 130 millones de hectáreas en el mundo, de las cuales el 60% se encuentran en los países en desarrollo donde es básico para la alimentación de la población humana o como alimento para animales, principalmente aves. Debido a que la demanda por maíz es mayor que el incremento en la producción, las importaciones en estos países están creciendo a un ritmo de 1.5 millones de toneladas por año, siendo urgente incrementar la producción de este cultivo. Para ello, se requerirán tecnologías que aseguren buenos rendimientos en suelos marginales, ya que las zonas de mayor fertilidad serán ocupadas por cultivos más rentables. Los suelos disponibles para la expansión de la frontera agrícola son generalmente de baja fertilidad, siendo la acidez una de sus principales características. Para aumentar la producción en estos suelos se puede mejorar la fertilidad utilizando enmiendas, o se pueden generar cultivares que crezcan en estas condiciones. Aunque la primera opción tiene algunas limitaciones prácticas para la adopción por el pequeño agricultor, ambas son complementarias. El Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT), con sede en México, conjuntamente con varios programas nacionales de investigación, han optado la segunda estrategia, o sea, la obtención de cultivares tolerantes a suelos ácidos. Para ello se formaron poblaciones base a partir de las cuales por selección se generaron, primero variedades de libre polinización y, luego, líneas sintéticas e híbridos. Se ha venido trabajando con dos poblaciones amarillas (SA-3 y SA-4) y dos blancas (SA-6 y SA-7), que son heteróticas entre sí. El incremento en rendimiento en las variedades generadas ha sido significativo, si se considera que en suelos ácidos el rendimiento de los materiales que constituyeron las poblaciones base fue menor que 0.4 t/ha, mientras que el promedio de rendimiento de las nuevas variedades de libre polinización es 3 t/ha, y el de los híbridos de 4.5 t/ha. Estos mismos cultivares tienen, también, buen rendimiento en suelos de media a alta fertilidad, existiendo híbridos que producen más de 11 t/ha. En el campo de la fisiología se está trabajando para explicar los mecanismos fisiológicos responsables de la tolerancia a suelos ácidos. En el germoplasma existente en el CIMMYT se ha identificado que la exudación de ácido cítrico por las raíces es un mecanismo de esta tolerancia. Simultáneamente se trabaja en la agronomía del cultivo para encontrar las alternativas que contribuyan al incremento de la productividad de los elementos que componen los sistemas del cultivo de maíz y, a la vez, mantengan la sostenibilidad del ambiente en el que desarrollan las actividades.

Introduction

Maize (*Zea mays* L.) is the third most important crop in the world, after rice and wheat. It is cultivated on about 130 million hectares, of which more than 60% are found in developing countries. This cereal grain, which is a staple food for millions of people in Latin America and the Caribbean, Asia, and Africa, provides 10% of protein and 8% of calories found in their diets.

The annual increase in maize production (3%) is less than that of world demand (4%), the deficit being greater in developing countries. Thus, imports by these countries grow at an annual rate of 1.5 million tons. Increasing maize production in new areas means using marginal low-fertility soils, which are subject to other types of abiotic stress. A leading cause of these soils' low fertility is acidity (i.e., low pH), which is primarily related to high aluminum saturation and low phosphorus uptake. These soils are found in the tropics, especially in savannas, which are considered as highly important for producing food in the near future. For example, on the assumption that the current per capita consumption is not increasing, we needed, at the beginning of the new millennium, about 200 million additional hectares to feed the world's population.

To use these marginal soils, appropriate technology must be developed, including modification of edaphic conditions to permit crop development and manipulation of the plant's genetic structure so that it will grow well under these conditions. CIMMYT, in collaboration with several national research programs, decided to work with the latter option to develop cultivars—both synthetic (i.e., open-pollinated) varieties and hybrids—that perform well in acid soils and thus constitute a permanent, environmentally clean, and economically feasible solution to increased food needs, as well as generate technologies that can be easily adopted by farmers.

The first part of this paper deals with the genetic manipulation of the maize plant; the second reviews the probable mechanisms responsible for the plant's tolerance, permitting it to grow in acid soils. A better understanding of these mechanisms is fundamental to obtaining greater efficiency in genetic improvement. Also being developed are genetic materials needed for marking genes and ascertaining tolerance mechanisms related to maize yield on acid soils. Finally, some advances CIMMYT made in agronomic research are presented as a fundamental complement to technology adoption by farmers in different regions of the world.

Genetic Improvement

Germplasm development

The initial step in developing maize germplasm for acid soils consists in forming basic populations for the improvement program. The first population of maize developed that was tolerant of acid soils was SA-3, with yellow semiflint grains, followed by SA-8, derived from cycle 2 of full siblings (FS) of the SA-3 population (Granados et al. 1993, 1995).

To respond to national program requirements and to future needs of hybrid production, heterotic populations were formed: two yellow (SA-4, dent; and SA-5, flint) and two white (SA-6, dent; and SA-7, flint). The methodology for forming these populations is described by Granados et al. (1995) and Pandey et al. (1995).

The current priority is to orient the improvement program toward line production, to form both synthetics (open-pollinated varieties) and hybrids. Accordingly, germplasm is being grouped into two heterotic groups: one for yellow maizes and the other for white (Narro et al. 1997). In accordance with interpopulational heterosis, populations SA-3 and SA-5 were brought together into a single population (new SA-3), and population SA-7 was joined to population SA-8 (new SA-7). Then, a program of reciprocal recurrent selection was adopted for the yellow group, including populations SA-4 and the new SA-3; and for the white group, including populations SA-6 and the new SA-7.

Germplasm improvement

Environments and selection methods. Different methods of recurrent selection have been used in the program, including modified ear-to-row (MER), FS, and selection based on S_1 families (S_1). International trials of progeny were carried out in all cases. At Palmira (Colombia), with high-fertility soils, the progenies are recombined and generated for subsequent evaluation at three or more sites within the country. The evaluations were carried out at (1) the Carimagua Research Center, on soils with 55% Al saturation and 10 ppm P (Bray-II); (2) Santander de Quilichao, under conditions similar to those of Carimagua; and (3) Villavicencio, on two soils, one with 55% Al saturation, the other with 65%, and both with 10 ppm P. In addition, where possible, the progenies were evaluated in Brazil, Indonesia, Peru, the Philippines, Thailand, and Venezuela. The selection of the best-performing progenies across sites and their recombination made possible the development of maize populations with improved tolerance of acid soils.

Once the base population was formed, the intrapopulation selection process was initiated to increase the frequency of favorable genes in each population.

Population SA-3 was submitted to an intense selection process (Granados et al. 1993) over 16 selection cycles, using the MER method (Pandey et al. 1984). The SA-8 population underwent three FS and S_1 selection cycles. Currently, a program for reciprocal recurrent selection is under way for both yellow and white populations.

Selection criteria. The principal selection criterion in the reciprocal program is high yield under both acid and fertile soil conditions. Indirect selection, which considers traits that are easier or faster to evaluate, is useful when strong genetic correlation exists between the two traits included in the selection process and when the heritability of the trait under indirect selection is greater than that of the principal trait. For population SA-3, efficiency was only 88.7% when the number of ears per plant was considered as the trait to improve yield (Pandey et al. 1994).

Selection, using nutrient solutions or pots with soil, has been less efficient in improving maize yield in acid soils than evaluating yield directly in experimental plots (Kasim et al. 1990; Magnavaca et al. 1987).

Selection gain. In each population, a variable number of selection cycles were completed. Since the mid-1970s, the selection method for the SA-3 population was MER. Subsequently, the FS and/or S_1 methods were used for all populations, including the SA-3. Another important aspect of the selection methodology used was that the evaluation of progenies and cycles was done in environments with either acid or fertile soils.

Selection progress, measured in acid soils for the SA-3 population over 14 cycles, gave an average gain of 40 kg/ha, using the MER method and 310 kg/ha (average 2 cycles) with the FS method. For the other populations (SA-4, SA-5, SA-6, and SA-7), two selection cycles were completed with the FS method, with gains of 48, 7, 119, and 185 kg/ha per cycle, respectively.

When evaluation was carried out on fertile soils, the average gain per cycle in the SA-3 population, using the MER method, was 47 kg/ha after 14 cycles and 145 kg/ha after 2 cycles with the FS method. For populations SA-4, SA-6, and SA-7, the gains were 263, 360, and 703 kg/ha per cycle, respectively. In population SA-5, yield dropped by 131 kg/ha per cycle. When interpreting such results, the number of cycles and sites where the evaluations were made should be considered.

The most important conclusions in the evaluation of selection cycles are as follows:

- The selection methodology used should permit yield increase on both acid and fertile soils. The populations that yielded best on acid soils also gave high yields on fertile soils. A similar trend was observed for lower yielding populations.

- When the selection method included progeny evaluation in trials with replicates, as occurs with the FS method, the gains per selection were greater.

- Gain per selection depended on the population under study and on the precision with which the selection and evaluation of progenies were carried out.

Cultivar development

National research programs can immediately use experimental varieties. Thus, at different sites around the world, trials are carried out with replicates to compare the patterns of those formed in the Program with the best checks available in each national program.

Since 1992, different types of trials (I, II, III, IV, and V) have been established for acid soils, where the evolution of cultivars obtained by the Program can be observed. During 1992 to 1993, acid-soil trial II was established at 24 sites: 4 in fertile soils and 20 in acid soils. The results indicated that, in acid soils, the yield of the CIMMYT-CIAT maize varieties (CIMCALIs) was slightly higher (about 2.8 t/ha) than that of the best regional checks (about 2.5 t/ha).

Trial type III was planted at 13 sites with acid soils and at 2 with nonacid soils. Across environments with acid soils, the best variety (CIMCALI) yielded 3.51 t/ha, while the best check yielded 3.67 t/ha and the var. Tuxpeño Sequía yielded 2.31 t/ha. This series of trials resulted in the release of experimental varieties by national programs in Indonesia (Antasena) and Colombia (ICA-Sikuani V-110).

Trial type IV for acid soils initiated the evaluation of eight unconventional hybrids (line × variety), together with eight open-pollinated varieties (CIMCALIs 95) and four checks (Sikuani, Tuxpeño Sequía, and two local varieties). The trial was planted at six sites with acid soils and three with nonacid soils. Results show that, on nonacid soils, the yield of the best hybrid surpassed that of var. Sikuani by 50% (Table 1). On acid soils, the yields of vars. Sikuani and Tuxpeño Sequía, and the best CIMCALI were 3.07, 2.51, and 3.18 t/ha, respectively, while the yield of the best hybrid was 4.53 t/ha.

The results of 13 type V trials (six on acid soils and seven on nonacid soils) show that the yield of the best hybrids is 50% or more than that of var. Sikuani (open-pollinated) (Table 2). On acid soils, the yield of var. Sikuani was 1.9 t/ha, while that of the best hybrid was 44% higher (3 t/ha). Stress conditions were very severe, which is why yields were very low.

What this series of results shows is that a production system that includes the maize crop as a component does

Table 1. Grain yield of maize varieties and nonconventional hybrids evaluated at six sites with acid soils and three sites with nonacid soils.

Material	Acid soils		Nonacid soils	
	(t/ha)	(%)	(t/ha)	(%)
Checks:				
Var. Sikuani	3.07	100	3.65	100
Var. Tuxpeño Sequía	2.51	82	3.86	106
Local variety 1	3.10	101	4.81	132
Local variety 2	3.64	118	5.54	152
Average for 8 CIMCALI varieties	2.47	80	2.67	73
Best CIMCALI variety	3.18	104	3.77	103
Average for 8 hybrids	3.84	125	4.70	129
Best hybrid	4.53	148	5.48	150

Table 2. Grain yield of maize varieties and hybrids evaluated at six sites with acid soils and seven sites with nonacid soils.

Material	Acid soils		Nonacid soils	
	(t/ha)	(%)	(t/ha)	(%)
Checks:				
Var. Sikuani	1.90	100	3.54	100
Local variety 1	2.11	111	5.35	163
Local variety 2	1.72	90	4.87	138
Average for varieties	2.27	119	4.74	134
Hybrids:				
Best simple variety	2.50	132	5.98	169
Best triple variety	2.74	144	5.30	150

well when the best available technology is used. The variety (or cultivar or genotype in general) is a key factor that can, in many cases, decide whether a technology is adopted or not.

Physiological Studies

Aluminum toxicity is more widely distributed in acid soils, where it is the most important constraint. The search for tolerant genotypes is thus a fundamental step for crop adaptation. For barley and wheat, adaptation to acid soils and Al tolerance are closely correlated (Reid et al. 1969), a trait that appears to be also true for maize.

Aluminum mainly affects the plant's root system, producing a toxic effect and inhibiting P and water uptake. Reduction in growth of the root system can be measured some hours after the onset of stress (Horst et al. 1992). However, other more sensitive indicators of Al toxicity exist, including callus formation in the roots (Schreiner et al. 1994; Wissemeir et al. 1987) and inhibition of the net efflux of K (Cakmak and Horst 1991; Sawasaki and Furlani 1987).

The mechanisms responsible for plants' tolerance of Al toxicity are not well known. As the effects of Al toxicity are observed primarily in the root system, a close relationship may exist between Al concentration in the root apex and the degree of root growth.

Evidence suggests that Al toxicity and tolerance are manifested in the cellular area. If true, this will facilitate the development of evaluation methods based on cell and tissue culture, thus permitting the possible development of important tools for identifying tolerance of this element on the basis of an individual plant or, perhaps, cell. This methodology would also pave the way for applying nonconventional techniques for improving the maize plant's adaptation to acid soils.

Phosphorus is another important limiting element in acid soils, and its use depends on the plant's capacity for absorbing and transporting the element to the leaf surface, and on the plant's metabolism and growth. As this nutrient scarcely mobile in the soil, plants with well-developed root systems have greater access to it. Similarly, plants with greater capacity to secrete hydrolytic enzymes and organic acids, and evolve CO_2, all of which, in their turn, increase the decomposition of organic matter, also make greater use of available P in the soil.

To identify individuals tolerant of acid soils, various evaluation techniques have been tried, taking into consideration root traits. In 1987, 17 maize populations were evaluated with different degrees of tolerance of Al toxicity, according to the net length of their seminal root (final seminal root length minus initial seminal root length). Plants were grown in nutrient solutions containing 0, 4.5, 6, or 8 ppm Al. In materials tolerant of acid soils (e.g., var. CMS-36), the length of the seminal root (19.9 cm) was double that of the susceptible materials (e.g., var. Tuxpeño Sequía = 9.9 cm), although some materials that were highly tolerant in the field did not perform better in nutrient solutions (Pandey 1991).

In the acid soils of the CIAT Carimagua and Quilichao experiment stations, the tolerance of maize genotypes of acid soils was evaluated under field conditions, in pots in the greenhouse, and in nutrient solutions (Urrea 1994). The seedlings grew for 2 weeks, during which the morphological traits used to separate susceptible and tolerant genotypes were measured. The first trial was a dialellic experiment with eight progenitors (six tolerant of and two susceptible to Al) and their possible combinations. The second consisted of the evaluation of 10 varieties, two of which were susceptible. Results suggested that the pot technique is effective for distinguishing between tolerant and susceptible genotypes. The correlations among the best traits between evaluations with the pots and yields in the field ranged from 0.45 to 0.55.

Agronomic Studies

The release of var. Sikuani by the Colombian Corporation for Agricultural Research (CORPOICA) in 1994 created the need for obtaining complementary agronomic data related to fertilization, use of amendments, and feasibility of incorporating maize into agropastoral systems. For this purpose, trials in experimental fields and on farms were initiated in coordination with national programs. Progress in these trials is reported below.

On-farm fertilization trials

In the Colombian Eastern Plains, on those farms that traditionally grew maize, two trials were established in lots where maize was traditionally planted. The soils at the experimental sites (Guacavía and Guamal) have low Al saturation, so lime was not applied. The maize variety Sikuani (five levels of N-P-K) and the local variety (high levels of fertilization, with N = 100, P = 100, and K = 120) were used. In addition, a treatment was included to represent farmers' management practices, that is, local variety planted to a density of about 40,000 plants/ha, with very low fertilization, manual weeding, and no pest control. Var. Sikuani yielded more (>3 t/ha) than the local variety, which yielded 1.9 t/ha with the farmers' technology and 2.3 t/ha with high fertilization. The largest net gain was obtained with var. Sikuani and the application, at kg/ha, of 100, 60, and 60 N-P-K, respectively (Table 3).

In the same region, var. Sikuani was also evaluated in those farm fields located in Pachaquiaro, Santa Cruz, and La Esperanza. Maize had not been planted at these sites because the high Al saturation did not permit growth of the available, but susceptible, varieties. Given that the soils had an Al saturation of more than 60%, 400 kg/ha of dolomitic lime had to be applied to reduce this level to 55%. Four levels of N-P-K were applied (Table 4). The results showed differences in yield among sites but not in the response to fertilization rates at any one site. What was most important in these trials was the yield and response

Table 3. Yield and net gains per hectare obtained with the local variety and improved maize variety ICA-Sikuani V-110 under different crop management systems, Guacavía and Guamal, Colombia, 1994.

Benefits	Local variety		Var. Sikuani	
	Farmers' management	N (100), P (100), K (120)	N (50), P (100), K (60)	N (100), P (60), K (60)
Production costs (Col$/ha)[a]	115,125	262,815	238,125	241,365
Maize yield (t/ha)	1.9	2.3	3.3	3.5
Value of maize (Col$/ha)[a]	349,100	425,500	556,750	595,000
Net profit (Col$/ha)[a]	233,975	162,685	318,625	353,635

a. 1994 exchange rate: Col$900 = US$1.

Table 4. Production (t/ha) of maize variety Sikuani with N-P-K application in farm fields, Colombian Eastern Plains, 1994.

Farm	Treatment			Site		
	N	P	K	Pachaquiaro	Santa Cruz	La Esperanza
1	100	100	120	4.58	2.62	3.07
2	100	100	60	4.27	2.45	2.68
3	100	60	60	4.10	2.85	2.98
4	50	100	60	4.01	2.02	2.20
Average				4.24	2.46	2.73
CV (%)				11.95	13.21	11.66
LSD (5%)				1.01	0.68	0.64*

* = $P < 0.01$.

to fertilization of var. Sikuani (>4.5 t/ha) in Pachaquiaro, where the level of Al saturation was 55%.

At the Carimagua Research Center (Colombian Eastern Plains), the response of the maize varieties Sikuani, CIMCALI 93 SA3, CIMCALI 93 SA6, and an experimental hybrid to fertilization with P and K (0, 40, 80, and 120 kg/ha P_2O_5 and K_2O) plus 120 kg N/ha was evaluated. In general, response to the application of K was slight, especially when applied as K_2O at 40 kg/ha (2.92 t/ha for the check versus 3.33 t/ha). In contrast, the response to P applications was greater, with yields of 1.38, 3.09, 4.17, and 4.41 t/ha, with P_2O_5 at 0, 40, 80, and 120 kg/ha, respectively (Table 5). No differences were found in the responses of genetic materials to applications of P and K.

To study the residual effect of the treatments in this trial, the same cultivars were planted on the same plots corresponding to the previous year, and N at 80 kg/ha was applied. The average yield was 2.02 t/ha versus the average mean of 3.26 t/ha for the previous year, when P and K were applied. This indicates that the investment in fertilizers is profitable if the value of the additional production (1.24 t) is greater than the cost of fertilizing, which was, at that time, a highly profitable investment in Colombia. It is likely that this profitability will be higher, to the extent that the best available technological alternatives are used in terms of

Table 5. Maize grain production (t/ha) with P and K applications on an Oxisol, Colombian Eastern Plains.

P_2O_5 (kg/ha)	K_2O (kg/ha)				Average[a]
	0	40	80	120	
0	1.52	1.54	1.27	1.20	1.38
40	2.87	3.10	3.22	3.16	3.09
80	3.45	4.47	4.18	4.58	4.17
120	3.83	4.20	5.07	4.55	4.41
Average[b]	2.92	3.33	3.44	3.37	

a. $LSD_{0.05}$ for P rate = 0.29 t/ha.
b. $LSD_{0.05}$ for K rate = 0.27 t/ha.

variety, fertilizer rates, and forms of use. In this case, no differences were observed, due to the residual effect of the K application, but there were for P: 1.46, 1.99, 2.24, and 2.38 t/ha when P was applied as P_2O_5 at 0, 40, 80, and 120 kg/ha, respectively (Table 6).

In the Colombian Eastern Plains, a trial was conducted to study the response of maize to the application of the trace elements B, Zn, Mn, and Cu at rates of 1.2, 8.8, 7.2, and 5.2 kg/ha, respectively, applied as sulfates and chelates. Results showed a clear response to applications of Zn. In the treatment containing all trace elements, the maize yield was 2.13 t/ha; when only Zn was included, it was 1.78 t/ha; and when Zn was not included, but the other trace elements were, yield was 0.29 t/ha (Table 7). No observed differences were seen between chelated and sulfate forms.

The principal results of on-farm trials carried out in collaboration with the national institutions of Colombia, Ecuador, and Peru were as follows:

- In areas of fertile lowlands and savannas of the Colombian Eastern Plains, the performance of var. Sikuani and the local variety was studied under two management technologies: recommended and traditional. The former consisted of fertilization (kg/ha) with N (100), P_2O_5 (60), and K (60); a sowing density of 50,000 plants/ha; and two applications of agrochemicals for controlling pests. The farmers' technology consisted of half of the above fertilizer rates, 37,500 plants/ha, and one application of pesticides. In both cases, herbicides were applied for weed control.

Table 6. Residual effects of P and K applications on the grain yield (t/ha) of maize cultivars, Colombian Eastern Plains.

K (kg/ha)	P (kg/ha)				Average
	0	40	80	120	
0	1.61	1.86	2.08	2.12	1.92
40	1.43	2.00	2.34	2.86	2.16
80	1.45	1.96	2.30	2.35	2.02
120	1.34	2.13	2.26	2.17	1.98
Average[a]	1.46	1.99	2.24	2.38	2.02

a. $LSD_{0.05}$ for P rate = 0.83 t/ha.

Table 7. Maize yields (t/ha) after applications of different trace elements (B, Zn, Mn, and Cu), Colombian Eastern Plains.

Treatment[a]	Yield (t/ha)
C	2.13
C - B	1.82
C - Zn	0.29
C - Mn	1.78
C - Cu	2.02
B	0.21
Zn	1.78
C - Mn	0.17
C - Cu	0.32
$LSD_{0.05}$	0.32

a. C = B + Zn + Mn + Cu
C-B = Zn + Mn + Cu - B
C-Zn = B + Mn + Cu - Zn
C-Mn = B + Zn + Cu - Mn
C-Cu = B + Zn + Mn - Cu
B = B only
Zn = Zn only

Rates were, at kg/ha, B = 1.2; Zn = 8.8; Mn = 7.2; Cu = 5.2.

- There was a significant response for both the use of technology and adoption of variety. For the traditional maize variety, the recommended technology meant an average increase of 0.7 t/ha in yield over that of the traditional technology‘, and was greater on the fertile lowlands than on the savannas.

- Similarly, the adoption of the improved variety alone—in this case

Sikuani—meant a greater yield increase in the savannas of 0.6 t/ha, and, in the fertile lowlands, of more than 1 t/ha (Table 8).

Table 9 gives the results of four trials conducted at Castilla, Grenada, Yopal, and Aimaral (all in the Colombian Eastern Plains) with var. Sikuani, a commercial hybrid, and the local variety when cultivated with the traditional and recommended technologies as described previously. Yields were higher when using the recommended technology than with the traditional practices (3.4 versus 2.2 t/ha). With the three cultivars, an average of more than 1 ton of additional of grain was obtained with the adoption of the recommended technology, although this difference was greatest when the commercial hybrid was used. In addition, the adoption of a new variety (Sikuani) or the commercial hybrid meant an increase of at least 0.6 t of maize over the local variety. This increase was greater with the commercial hybrid when using the recommended technology. The economic analysis of the impact of var. Sikuani showed a marginal rate of return of 60% over the technology used by farmers.

In Ecuador, four cultivars were evaluated in four environments with different levels of Al saturation in the Province of Napo. Variety Sikuani outyielded the two local checks: INIAP 526 (a variety for nonacid tropical soils improved by the Ecuadorian national research program), and the local cv. Tusilla. The average yield of var. Sikuani was 2.2 t/ha, that is, 48% more than the yield of the local check cv. Tusilla (at 1.49 t/ha) (Table 10).

In Peru, trials were established on farms in the Province of San Martín (Alto Mayo). Variety Sikuani and the local variety—an advanced generation of Marginal 28 Tropical, derived from CIMMYT population 28—were evaluated, using the recommended technologies and that of the farmers.

Table 8. Yield (t/ha) of two maize varieties—Sikuani and local variety—cultivated with two technologies in the fertile lowlands and savannas of the Colombian Eastern Plains.

Technology	Fertile lowlands		Savannas		Average
	Sikuani	Local	Sikuani	Local	
Recommended	3.45	2.35	2.20	1.65	2.41
Traditional	2.40	1.80	1.40	1.15	1.68
Average	2.92	2.07	1.80	1.40	

Table 9. Yield (t/ha) of two maize cultivars and a hybrid, cultivated under two technologies in farm fields, Colombian Eastern Plains.

Material	Technology[a]		Average
	Recommended	Traditional	
Var. Sikuani	3.53	2.42	2.98
Commercial hybrid	3.85	2.51	3.18
Local variety	2.93	1.82	2.38
Average	3.44	2.25	

a. $LSD_{0.05}$ for technologies = 0.34.

Table 10. Yield (t/ha) of maize cultivars in the acid soils of the Province of Napo, Ecuador.

Variety	Site				Average
	El Heno	La Punta	San Carlos	Payamino	
Improved varieties					
CIM. 93 SA5	1.00	3.01	1.80	1.58	1.78
Sikuani	1.59	3.26	1.54	2.17	2.20
Local checks					
INIAP 526	0.49	2.45	1.36	1.92	1.41
Tusilla	0.69	1.89	1.06	1.75	1.49
Best check (%)	231	133	133	113	

The principal difference between them was that farmers did not apply fertilizer, whereas, for the recommended technology, N (90) and P (90 as P_2O_5) were applied (at kg/ha). No K was applied. Results indicated that var. Sikuani (1.81 t/ha) had higher yields than did the local variety (1.22 t/ha) (Table 11).

Although different technological alternatives, cultivars, and agronomic practices were evaluated in these trials to identify maize varieties with potential in farmers' production systems, this crop should also play an important role in the management of agropastoral systems in the acid-soil savannas of tropical Latin America. Accordingly, the gradual improvement of germplasm oriented toward the search for cultivars with higher yields under these conditions will contribute to the better use of these environments. Currently, improved varieties have greater yield and better agronomic traits than do local cultivars. Evidence that hybrid vigor should be exploited to increase yields of acid-soil-tolerant materials makes it possible to accelerate hybridization to obtain useful lines for forming open-pollinated and superior hybrids for these environments. The response to P applications should also be highlighted, particularly when P_2O_5 is applied at 80 kg/ha. The high response to applications of Zn is also an important achievement that should be taken into account when formulating recommendations for production systems.

Table 11. Yield (t/ha) of two maize cultivars under two technologies, and evaluated in farm fields, Alto Mayo, Peru.

Cultivar	Technology		Average
	Recommended	Farmers'	
Sikuani	2.00	1.62	1.81
Local	1.24	1.20	1.22
Average	1.62	1.41	

Using amendments

At the CIAT Quilichao Experiment Station (Colombia), the effect of applying dolomitic lime and its interaction with P were evaluated in maize varieties Sikuani (tolerant of acid soils) and Tuxpeño Sequía (susceptible to acid soils). The effects were measured in one phase of the crop cycle and in a following crop with no P application. The Al saturation in the soil was 65%, 50%, or 35%, and P was applied as P_2O_5 at 0, 45, 90, or 135 kg/ha.

On the average, var. Sikuani produced 22% more grain than var. Tuxpeño Sequía (4.71 versus 3.87 t/ha). This difference was greater when plant stress increased with higher Al saturation or greater P deficiency. Thus, var. Sikuani yielded 80% more than var. Tuxpeño Sequía when the Al saturation was 64% and no P was applied to the soil (3.0 versus 1.7 t/ha). Both varieties responded to P applications, the response being greater with P_2O_5 at 0-45 kg/ha. At higher rates, the average yield of the varieties was 1.12 t/ha (data not shown).

To evaluate the residual effect of lime and P, the experimental arrangement from the previous trial was used without fertilizers. There was a clear reduction in yield in vars. Sikuani (by 1.68 t/ha) and Tuxpeño Sequía (by 0.89 t/ha), being more drastic in the latter as stress became more severe. However, when Al saturation was 64%, the absence of P had no negative effect. Production in this case was also greater when P_2O_5 was applied at 45 kg/ha in the previous crop. In the check without P, production was 0.68 t/ha, whereas, when P_2O_5 was applied at 45 kg/ha, it was 1.27 t/ha (data not shown).

In a sandy Oxisol of the Colombian Eastern Plains, the application of soil amendments was evaluated. Sources used were dolomitic lime (1.03 t/ha, i.e., 57% $CaCO_3$ and 35% $MgCO_3$) and Sulcamag (1.3 t/ha, i.e., 25% CaO, 12% MgO, and 8% S) for var. Sikuani. The application methods used were a handful per plant, broadcast, band application, or a combination of the last two. In addition, fertilizer was applied to every crop, at 120, 80, and 80 kg/ha of N, P_2O_5, and K_2O, respectively.

When Sulcamag was applied, average maize yield was more than double that under dolomitic lime (3.45 versus 1.59 t/ha). For Sulcamag, no observable differences were seen among application methods nor for the interaction methods × source (Table 12). The broadcast application of Sulcamag is probably the most economical alternative for the sandy soils of the Colombian Eastern Plains. When the residual effects of applying Sulcamag was evaluated, trends similar to those observed in the first trial were observed, but yields were lower.

Establishing pastures in association with maize

In the Colombian Eastern Plains, pasture establishment was evaluated, using the maize variety Sikuani as an associated crop. Treatments consisted of maize in monoculture, maize + grass, and maize + grass + legumes.

Table 12. Effect of method of applying lime and Sulcamag on first harvest of maize variety Sikuani and residual effects, Colombian Eastern Plains.[a]

Application method	Amendments			
	First year		Residual effects	
	Lime	Sulcamag	Lime	Sulcamag
Handful per plant	1.20	3.43	0.96	1.41
Band	1.36	3.00	0.76	1.30
Broadcast	1.68	3.67	0.49	1.24
Band + broadcast	2.14	3.71	0.87	1.63
Average	1.59	3.45	0.84	1.40

[a] $LSD_{0.05}$ between amendments = 0.54 t/ha.
$LSD_{0.05}$ between methods of application = 0.25 t/ha.

Table 13. Net profit per hectare of three production systems that include maize and grasses, Colombian Eastern Plains, 1994.

Variable[a]	Maize monocrop	Maize + grass[b]	Maize + grass + legume
Production costs (Col$)	380,000	416,000	670,000
Maize yield (t/ha)	2.9	3.1	2.7
Value of maize (Col$)	493,000	527,000	459,000
Value of pasture (Col$)	—	175,000	400,000
Net profit (Col$)	113,000	286,000	189,000

a. 1994 exchange rate: Col$900 = US$1.
b. + = grown simultaneously in same field.

The grass was *Brachiaria dictyoneura* Fig. & De Not. and the legumes were *Stylosanthes capitata* Vogel, *Centrosema acutifolium* Benth., and *Arachis pintoi* Krapovickas & Gregory.

Results obtained (Table 13) indicated the following:

- Maize yield changed significantly in the pasture association, whether with grass alone or with grass + legumes.

- The commercial value of the maize production covered the establishment costs of the associated pasture. This result is key to the more intensive use of pastures in the region.

- The costs of establishing the maize + grass + legume association increased because of the high cost of the legume seed and labor for sowing maize and pasture. In this trial, *A. pintoi* was planted in parallel, between every two rows of maize + grass, and at a distance of 15 cm from the maize + grass rows.

- The best net gain per hectare (US$358) was obtained with the maize/grass system.

The establishment of production systems that include annual crops and improved pastures in the acid-soil savannas of the Colombian Eastern Plains is an economically viable alternative. Native species have a carrying capacity as low as 1 animal/10 ha, with daily liveweight gains of 300 g/animal. This means an annual income of about US$110/10 ha. With improved pastures, the stocking rate can be increased to 2 animals/ha and the daily liveweight gain can reach 500 g/animal, thus increasing the annual income to US$365/ha. Taking into account that the liveweight gain can be increased between 10% and 15% on the grass-legume mixture, the farmer could obtain an annual income of US$400/ha. Consequently, this ecosystem is favorable for establishing profitable agropastoral systems, in which annual crops, improved pastures, and tree systems form parts of a production system that permits the rational and sustainable use of available natural resources.

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CHAPTER 11

Promising Germplasm for Agropastoral Systems in the Eastern Plains of Venezuela

T. Rodríguez, L. Navarro, and *D. Sanabria**

Contents

Abstract

The savannas of the Venezuelan Eastern Plains present an alternative for increasing the country's grain, meat, and milk production. However, the soils of this ecosystem suffer physical and chemical limitations that require suitable technology for sustainable exploitation. The Fondo Nacional de Investigaciones Agropecuarias is developing and adapting available technology for the region, such as introducing and evaluating forage germplasm. In 1990, a rice program was established, and several rice lines adapted to acid soils and drought have since been identified. Some of these lines are now being evaluated in association with pastures, destined for agropastoral systems. We summarize the progress made in research on these systems.

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Resumen

La explotación de las sabanas de los Llanos Orientales de Venezuela es una alternativa potencial para incrementar la producción de granos, carne y leche. Sin embargo, el ecosistema presenta suelos con características químicas y físicas que limitan su utilización; por tanto, se requieren tecnologías adecuadas y adaptadas a una explotación sostenible. El Fondo Nacional de Investigaciones Agropecuarias (FONAIAP) está trabajando para desarrollar y adaptar las tecnologías disponibles en la región; para ello ha hecho introducciones de germoplasma de forrajeras que está evaluando a través de localidades. En el caso del cultivo de arroz, desde de 1990, cuando se inició el programa arroz, se vienen identificando líneas tolerantes a suelos ácidos y sequía. Actualmente existen varias líneas adaptadas a las condiciones de suelos ácidos de Venezuela que se están evaluando asociados con pasturas en sistemas agropastoriles. Los avances de estos sistemas se resumen en este capítulo.

Introduction

The savannas ecosystem in Venezuela occupies about 26 million hectares (Ramia 1967), amounting to 29% of the national territory. About 70% of this area (18.9 million hectares) corresponds to the plains of the States of Monagas, Anzoátegui, Apure, Barinas, Portuguesa, Cojedes, Guárico, and part of Bolívar. The Eastern Plains of Venezuela, with an area of about 3.4 million hectares, occupy almost all of the State of Monagas and south central Anzoátegui. Formations found in these Plains include high plateaus, alluvial plains, valleys, and undulating terrain. The high plateaus represent 82% of the area occupied by the Eastern Plains. Characterized as piedmont plateaus, they are flat and dissected. Cattle ranching has been developed mainly in the high plateaus and alluvial plains (MARN 1982).

The climate type of the Eastern Plains of Venezuela is tropical dry forest, characterized by erratic and high-intensity rainfall, with an annual average of 1600 mm toward the northeast (two rainy periods and one dry) and of 850 mm toward the south (one rainy period and one dry). Between September and October, dry periods of 5 to 10 days have a 50% probability of occurring, and those of >10 days have a 20% probability (Caraballo et al. 1994).

The vegetation is typical savanna, comprising grasses such as *Trachypogon plumosus*, *T. vestitus*, *T. ligularis*, *Axonopus purpusii*, *A. anceps*, *A. pulcher*, *Andropogon bicornis*, and *A. selloanus*; and some shrubby species such as *Curatella americana*, *Byrsonima crassifolia*, *B. cocoolobifolia*, and *Bowdichia virgilioides*.

Plateau soils are predominantly Entisols, Ultisols, and Oxisols (Quartzipsamments, Kandiustults, and Haplustox, respectively). These areas present certain advantages for agricultural use, among them: flat topography that does not require costly investments in terrain adaptation; light and deep soils, readily permitting machinery; good drainage that facilitates entrance of equipment shortly after rain; and availability of abundant, good quality groundwater.

Caraballo et al. (1994) consider the following to be the principal limitations of this ecosystem:

1. A predominantly sandy texture in the upper horizons, which implies low content of essential nutrients such as Ca, Mg, K, and P.

2. Acid soils with a low capacity for moisture retention, which reduces the efficiency of fertilizer applications.

3. Occurrence of dry periods during any given rainy season and high capacity for evaporation due to climatic conditions.

4. Fragile soils, low in organic matter content and susceptible to hardening, runoff, and erosion by wind and water.

5. Limited root penetration as a consequence of soil acidity and low availability of nutrients in the lower soil horizons.

6. Susceptibility to compaction in the subsoil through excessive use of machinery and the presence of gravel in horizons close to the surface.

The Fondo Nacional de Investigaciones Agropecuarias (FONAIAP) carries out studies in the Eastern Plains at research centers in the States of Anzoátegui and Monagas, following a strategic plan aimed at the rational use of the savanna ecosystems. This work plan was partially initiated in 1993 and, among other objectives, aims to (1) identify the types of land use in the Eastern Plains and their limitations and causes; (2) generate technologies for crop exploitation through practices aimed at improving and conserving the soil (tillage, crop rotation); (3) select forage germplasm adapted to conditions of water stress, and acid and low-fertility soils; (4) select promising accessions of cashew and cassava, crops with high potential for exploitation under savanna conditions; and (5) evaluate the agronomic behavior of promising genetic materials under proper management practices.

Land Use

Several types of land use can be identified in the region. In the flat and undulating plateau formations, the following agricultural systems are practiced: (1) upland agriculture, with sorghum grain, cashew, beans, pineapple, maize, sweetpotato, and cassava; (2) pure-grass pastures of *Brachiaria brizantha*, *B. dictyoneura*, *B. decumbens*, and *Digitaria swazilandensis*, and pasture associations of grasses and legumes; (3) irrigated farming, with sorghum seed, passion fruit, melons, mango, watermelon, guava, and Tahitian limes; and (4) intensive forestry with species of Caribbean pine and *Eucalyptus*. This last activity has generated conflicts over land use.

Pastures and Livestock Raising

In Venezuela, about 13.2 million hectares are under pastures. Of these, about 7.6 million hectares are under native vegetation and about 5.6 million hectares under introduced species. The greatest extension of pastures is in regions with intensive and dual-purpose livestock systems, not found in the savannas. Of the total of native pastures, about 52% correspond to well-drained plains and the rest (48%) to poorly drained (Chicco and Linares 1992).

Beef and milk production constitutes an option for the country, given that large extensions of native and cultivated pastures exist that are suitable for this activity. Native pastures do not provide sufficient nutrients for animal production, especially in the dry season. Chacón and Arriojas (1989) found that the *Trachypogon*-dominated vegetation in well-drained savannas constitutes a resource of low productivity, with a daily production of dry matter (DM) between 0.4 and 20 kg/ha without burning, and between 5.8 and 22 kg/ha after controlled burning.

In the State of Monagas, 73% of the area is under native grasses of low productive capacity, but carrying 43.3% of the animal population. The remaining area (27%) is under introduced pastures (Alcalá 1990). When adequately managed, introduced grasses improve animal production and productivity, but the costs of establishment and maintenance are high, mainly because of the need to apply amendments to correct nutrient deficiencies in the soil. Even so, management problems become evident in most cases, such as excessive stocking on some farms and a surplus of biomass production in the rainy season. This situation demands the generation of strategies appropriate for pasture production and management to guarantee a forage supply of sufficient quantity and quality to meet the requirements of the animal population.

Forage Germplasm

FONAIAP and the Venezuelan Universidad de Oriente have been conducting studies at research centers in the States of Anzoátegui and Monagas to select forage legume species adapted to the conditions of the savanna ecosystem. These species must also have a high capacity for DM production during the dry season and be efficient in nitrogen fixation.

Forage germplasm has been evaluated in collaboration with the International Tropical Pastures Evaluation Network (RIEPT). After collection, agronomic evaluation, and multiplication of forage grass and legume species with potential for well-drained plains, promising materials of the genera *Brachiaria*, *Digitaria*, *Stylosanthes*, *Centrosema*, *Glyricidia*, and *Alysicarpus* were selected. These materials, unlike other species of the same genera, can adapt to the constraints caused by climatic factors and the soil's low moisture retention capacity and low nutrient contents.

In studies carried out on the Guanipa Plateau, FONAIAP found that, with nitrogen applications at 0, 37.5, 75.0, and 112.5 kg/ha, DM yields of *B. humidicola* during the rainy period were 1.38, 2.49, 3.18, and 3.89 t/ha, while in the less rainy period (September-November), outputs were 0.38, 0.47, 0.56, and 0.65 t/ha, respectively (Navarro et al. 1992). The same researchers, in a similar study on *D. swazilandensis*, found that, with the same rates of nitrogen applications, DM production in the rainy season was 1.10, 1.61, 2.08, and 2.51 t/ha, respectively. In the shorter rainy season (September-November), DM yields were 0.81, 1.17, 1.48, and 1.76 t/ha, respectively.

At present, the Anzoátegui Research Center has a germplasm bank of forage species evaluated in previous years, together with species from other national collections, CIAT, EMBRAPA, and CIRAD. Among the materials considered as promising are *Cratylia argentea*, *Centrosema rotundifolium*, *Galactia striata*, *Chamaecrista rotundifolia*, *S. humilis*, *S. scabra*, and *S. capitata*.

Cratylia (*Cratylia argentea)* establishes quickly, tolerates drought, and, after defoliation, regrows vigorously. This shrubby species has diffused rapidly among farmers for its facility to integrate into mixed production systems and protein banks. Its seed production is outstandingly high. On plots at the Anzoátegui Research Center, yields of up to 650 g/plant have been obtained (Rodríguez 1996). This trait makes Cratylia a potential alternative as a protein source for animals and an eventual substitute for *Leucaena leucocephala* (Leucaena), whose adaptation to the region's acid soils is not well defined (Sanabria 1989).

Despite having been introduced into the Eastern Plains of Venezuela more than 15 years ago, Leucaena has not been widely adopted by farmers, in contrast to *S. capitata* cv. Capica (Fariñas 1995). This latter species was introduced in the 1980s and, despite its high susceptibility to anthracnose, has high potential as forage. Lascano et al. (1994) point out that, although Leucaena can grow well under a broad variety of environmental conditions in the tropics and subtropics, it is limited in adapting to acid soils with low base saturation, such as those of the eastern Venezuelan plateau region.

Glyricidia sepium ("mata ratón"), under irrigation, produced more DM and crude protein (CP) than did Leucaena. *Centrosema macrocarpum* also has high potential as a protein source in well-drained plains, being persistent and suitable for mechanized harvesting. At the research center, it presented yields of DM at 12 t/ha per year and levels of CP at 15%, values that are comparable with those of alfalfa (*Medicago sativa*) in temperate regions (Fariñas 1995). In the mata ratón-pangola grass ecosystem, during September to December, young grazing animals attained averages of daily liveweight gains between 600 and 785 g.

Pachecoa venezuelensis, a shrubby legume belonging to the subtribe Stylosanthinae, subfamily Papilionoideae, was evaluated. It was collected for the first time in the State of Guárico, and has prospects as a protein source for sheep and goats (González 1995).

Several accessions of other herbaceous legumes are also being evaluated, including *C. rotundifolium* CIAT 5260, 5283, 5521, 5721, 25120, and 25148. In field evaluations, after 12 weeks of growth, *C. rotundifolium* accessions CIAT 25148 and 5260 were outstanding. In the well-drained plains in southern Monagas, 20 accessions of forage legumes were evaluated. *Centrosema macrocarpum* CIAT 5713 and 5224, *C. brasilianum* CIAT 5234, and *S. capitata* demonstrated the greatest potential for the area (FONAIAP 1990). Near El Tigre, at 12 weeks old, *C. macrocarpum* CIAT 5713 and 5224, *C. brasilianum* CIAT 5234, and *S. capitata* produced DM at an average rate of 0.32 and 1.2 t/ha during the dry and rainy periods, respectively (Flores 1992).

Rice Germplasm

In 1990 in Monagas, FONAIAP initiated studies with advanced rice lines sent from CIAT. These lines, tolerant of acid soils, were first evaluated in the experimental field at Santa Barbara, characterized by an annual average rainfall of 1000 mm, temperature of 26°C, soils with a pH = 5.6, and low contents of P, K, Mg, and Zn, and moderate Ca content.

Preliminary results, despite suboptimal conditions resulting from late planting, showed lines with potential for the region, including line CT7072-43-1-4-1-1-M, which produced 2 t/ha. In 1991, trials were initiated at San Agustín de La Pica, under soil conditions different from those of Monagas and with a total annual rainfall of 1300 mm. Under these conditions, lines with yields of up to 4.5 t/ha were observed, but no response was found to lime applications at 500 kg/ha (Sanabria 1994).

Fertilizer application studies showed different patterns, depending on the germplasm materials. In 53.6% of the experiments, no differences were detected between applications of P_2O_5 at 65 and 100 kg/ha, and of K_2O at 60 or 100 kg/ha. Line CT1059-3-1-M-4 showed the highest response to this fertilizer application regime, with an increase of 1.33 t/ha.

In 1993, the process of introducing and evaluating new CIAT rice lines was continued, making it possible to identify materials with potential of producing up to 7 t/ha. In 1994, research was undertaken with new rice lines at the FONAIAP-Anzoátegui field station. In these trials with introduced lines from EMBRAPA and CIAT and cultivated under conditions of extreme water deficiency, up to 1.8 t/ha were produced. The outstanding lines were the Brazilian cultivars Araguaia, Guarani, Rio Paranaíba, and Carajas, and CIAT line CT9992-22-2-4-M-16. Yields at this site, although lower than those obtained in Monagas, were considered as promising (Rodríguez 1995). Based on these results, research at Anzoátegui was expanded and, in 1995, it was also initiated at FONAIAP-Amazonas.

Research with rice germplasm and the preliminary evaluations using rice/pasture associations have awakened the interest of farmers and institutions. Consequently, relationships have been initiated with the Corporación Venezolana de Guayana, which was provided with seeds of promising materials from the Monagas studies.

Current research on upland rice indicates that:

1. Upland rice farming, cultivated with low levels of amendments, is a valid alternative in the production systems of the well-drained savannas of the Eastern Plains of Venezuela.

2. From their behavior under experimental conditions, several upland rice materials have potential for rotation in pasture systems.

3. Planting upland rice together with pastures is a practical alternative for the region, because it contributes to reduced establishment costs for the pastures and to the ecosystem's improved sustainability.

However, research must be intensified and this technology validated on farm to adjust agronomic practices and analyze economic advantages to guarantee its sustainability.

Agropastoral Systems

Farmers in the Eastern Plains of Venezuela have no tradition of agropastoral systems. Agriculture is essentially monoculture with intensive use of fertilizers, pesticides, and mechanization, whereas livestock grazing is based on native or introduced grasses. However, in recent years, with the elimination of subsidies and changes in fiscal policies, a change has occurred toward diversifying the agricultural exploitation of the region, including:

1. Simultaneous establishment of pastures with sorghum and maize crops.

2. Manufacture of multi-nutrient blocks, using harvest residues.

3. Use of maize grown on the farm as rations for dairy cows.

4. Inclusion of cassava and sweetpotato crops in animal feeds.

5. Establishment of protein banks based on forage legumes.

6. Cultivation of cashew and mango, intercropped with *Brachiaria* pastures.

Conclusions

Studies, currently being carried out in the Eastern Plains of Venezuela, are identifying forage germplasm and other crops with potential to adapt to sustainable agropastoral systems in the region. To achieve the transfer and adoption of these technologies by farmers, the collaboration of Venezuelan national institutions is needed.

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To save space, the following abbreviations are used:

CIAE	Centro de Investigaciones Agropecuarias del Estado
FONAIAP	Fondo Nacional de Investigaciones Agropecuarias

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CHAPTER 12

Potential of Agropastoral Systems for Managing Degraded Soils in Santa Cruz, Bolivia

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Contents

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Abstract

This chapter describes the most important physiographic and socioeconomic conditions of the Department of Santa Cruz, Bolivia. Soil problems under slash-and-burn (or migratory) and mechanized agricultural systems are analyzed in terms of degradation, possible solutions, and final consequences. Also highlighted is the importance of research on agropastoral systems, which integrate annual crops and pastures, whether the pastures are renewed, established, or rotated. Farmers in the region frequently plant pasture in association with either rice or maize, even though these sometimes fail as a result of poor management of specific components. The Centro de Investigación Agrícola Tropical in Santa Cruz (CIAT-Santa Cruz) has been conducting research on multistoried alley farming in which annual crops are planted in alleys, alternating with shrubby or arboreal forage legumes such as *Leucaena leucocephala* or *Flemingia congesta*. After 2 years, when the trees are established, pastures—either *Brachiaria decumbens* or *B. brizantha*—replace crops. The alleys can be diversified by planting trees of high value such as *Swietenia macrophylla* or *Schizolobium amazonicum*. Other promising trees are *Erythrina fusca*, *Samanea tubulosa*, and *Prosopis* sp. CIAT-Santa Cruz is also conducting research on the sustainable management of soils carrying annual crops and pastures. Results so far indicate that (1) soil managed with various annual crops across time and space is a promising alternative for farmers; and (2) more research must be conducted on the entire agropastoral system, including final evaluations with grazing animals.

Resumen

En este capítulo se hace una descripción general del Departamento de Santa Cruz, caracterizando sus unidades físiográficas más importantes y sus aspectos socioeconómicos predominantes. Se analizan la problemática del uso del suelo, bajo los sistemas de corte y quema (agricultura migratoria) y mecanizado, los procesos de degradación y las posibles soluciones y sus implicaciones posteriores. Se resalta, de manera general, la importancia de la investigación agropastoril, integrando cultivos anuales y pasturas, bien sea para recuperar o establecer pasturas o en programas de rotación. En la región es frecuente que los productores establezcan pasturas asociadas con arroz o maíz, aunque en algunos casos con fracasos atribuibles al mal manejo de ciertos componentes del sistema. El Centro de Investigación Agrícola Tropical en Santa Cruz (CIAT-Santa Cruz), Bolivia, está trabajando en sistemas agropastoriles multiestrato mediante establecimiento de árboles en pasturas existentes. En callejones de potreros, el cultivo anual de forrajeras durante dos ciclos y la siembra inicial de *Leucaena leucocephala* seguida de estrato arbóreo con mara (*Swietenia macrophylla*), serebó (*Schizolobium amazonicum*) y *Flemingia congesta* asociados con *Brachiaria decumbens* o *B. brizantha* al final del segundo ciclo, son opciones promisorias. En potreros se ha observado un buen desarrollo de *Erythrina fusca* (gallito), *Samanea tubulosa* (penoco) y *Prosopis* sp. (cupesí). Se presentan los resultados de investigación en cultivos anuales/pasturas que está realizando el CIAT-Santa Cruz tendientes a un manejo más sostenible de los suelos en la región. Se concluye que el uso del suelo con varios cultivos en tiempo y espacio, son alternativas promisorias para los productores y que es necesario incrementar la investigación en sistemas asociados cultivos/pasturas hasta su evaluación final con animales en pastoreo.

Introduction

The Department of Santa Cruz in eastern Bolivia occupies 370,621 km^2 and represents about one third of the national territory. According to the U.S. soil taxonomy classification, the Department can be divided into four large physiographic units: Subandina, Chiquitano Shield, Chaco Beniana Plains, and Pantanal (Cordecruz et al. 1994). Their characteristics are discussed below.

Subandina unit

This unit, occupying 7% of the Department, is found in southwestern Santa Cruz, and has a topography that includes hills, mountains, and synclinal valleys representing the last foothills of the Eastern Cordillera of the Andes. It lies between 1000 and 2900 m above sea level.

Chiquitano Shield

This unit includes northern and northwestern Santa Cruz, constituting about 65% of the Department's area. The topography is undulating, with low hills and acid soils belonging mostly to classes V and VII. The soils are of low fertility, and susceptible to leaching, although suitable for livestock and some permanent crops. Vegetation comprises semi-humid or dense dry forests. This unit contains the greatest number of protected areas under the national park system.

Chaco Beniana Plains

Encompassing the entire central region of the Department, this unit lies between the Subandina unit and the Chiquitano Shield. The Plains are grouped into subunits: in the northwest are the undulating *Yapacaní and Chore Plains*, constituting a piedmont region to the Andes. The annual average temperature is 24 °C and annual rainfall is 2000 mm. About 10% of this unit is flat (Penny nd). Farmers from valleys and high plains predominate in this unit, practicing migratory (or slash-and-burn) agriculture with rice and maize crops. In this type of agriculture, when crop yields become low, farmers move on to other areas of virgin forest, where they initiate a new cycle. The abandoned croplands are turned over to livestock production, which is economically less risky, more stable, and more "sustainable" in terms of soil use (Penny nd).

In *central Chaco Beniana Plains*, integrated and expansion areas are found, together with colonies of small farmers. These areas are suitable for intensive and extensive livestock production. The Plains carry the basins of the Grande, Piraí, and San Julián Rivers. The soils belong to classes II to IV, and are of alluvial origin. Usually, the soils are deep, with a medium texture, and are mostly loams, clay loams, and sandy loams. Other classes can be found, in accordance with slopes and depressions in the land. The soils are of recent formation, with moderate to high natural fertility (Severiche 1992). In areas with uncontrolled deforestation, drainage and leaching are significant problems. Annual average rainfall varies from 900 mm in the south to 1300 mm toward the north, with an annual mean temperature of 24 °C.

The integrated area is near the city of Santa Cruz, and is the most developed in terms of infrastructure (roads, energy, factories, and markets), but is also the most disturbed, with problems of declining fertility and soil compaction. This area is found between Grande River to the east, Piraí River to the west, Mora and Sanja Honda Rivers to the south, and Chané River to the north.

The expansion area covers about 650,000 ha. It is found east of the Grande River and was recently converted to agriculture on account of its high fertility soils (Guamán 1980, cited by Barber and Romero 1993).

The small-farmer colonies are found to the north of the integrated and expansion areas. These farmers had received between 20 and 50 ha of land from the Government and, initially, had practiced slash-and-burn agriculture. Currently, they are tending toward mechanization as a result of the opening up of the international soybean market.

In southern Santa Cruz, the alluvial *wetlands of the Bañados del Izozog* are found. These comprise sediments from the Parapetí River, and have a characteristically dry to semi-arid climate. This area is also known as the Chaco.

Pantanal unit

This physiographic unit comprises the zone where the national borders of Bolivia and Brazil meet and constitutes part of the flood plains of the Paraguay River.

Problems of Soil Use in Santa Cruz

The physiographic units of most importance to agricultural and livestock production in the Department of Santa Cruz are the Chaco Beniana Plains (primarily the northwestern—Yapacaní and Chore Plains—and central sectors—the integrated and expansion areas, and the colonies of small farmers) and the Chiquitano Shield.

The characteristics of slash-and-burn agriculture and its eventual *crisis del barbecho* (i.e., soil degradation, requiring fallowing), and of the degradation of mechanized soils have been amply described by the technicians of the Bolivian Centro de Investigación Agrícola Tropical (CIAT) and the Misión Británica en Agricultura Tropical (MBAT), also in Bolivia (CIAT/MBAT 1994). The *crisis del barbecho* creates an untenable situation for the farmer because of low crop yields, which are caused by weed invasion, soil compaction, and loss of soil fertility. We consider that alternative solutions to the *crisis* can be found in mechanization, livestock production, perennial cropping, and agroforestal systems. We hope that these production systems will allow farmers to consolidate their land lots, thus reducing possibilities of their either returning to their places of origin or migrating to urban centers to swell out the ranks of the poor.

Mechanization of small farms is possible only through the use of different strategies, and when certain economic conditions and channels of communication are achieved. With mechanization, more amendments are required and the farmer must face problems typical of this system. These include (1) soil compaction caused by use of heavy implements, particularly in soils with high contents of loam or fine sand; (2) wind erosion due to high wind speeds in the region and lack of windbreaks; and (3) crustation and surface erosion of the soil.

Livestock production is another option for the small farmer in the area and is a less risky and more stable activity. However, it can negatively affect the environment through use of inadequate germplasm, poor management, soil compaction, and loss of soil fertility.

Agroforestal systems that involve two or more crops are a recent introduction and have the potential to alleviate the *crisis del barbecho*. They are oriented toward diversifying production, reclaiming degraded fallow lands, and improve soil fertility. Associations of annual and perennial crops with tree species for livestock and forest use not only maintain productivity but also increase the value of the farms.

Agropastoral and Agroforestal Research Activities

Associations of annual crops and pastures

The association of crops such as rice and maize with pastures, whether for establishing pastures after 2 or 3 years of annual cropping or reclaiming degraded pastures is an alternative that helps solve problems caused by the *crisis del barbecho* among small farmers. In the Brazilian *cerrados* (Kluthcouski et al. 1991) and Colombian Eastern Plains (Sanz et al. 1993), upland rice has been successfully used as an association crop with pastures of *Andropogon gayanus* and *Brachiaria decumbens*, either alone or in association with forage legumes.

At CIAT, Santa Cruz, although no specific research on agropastoral systems has been carried out, information is available on the experiences of Santa Cruz farmers with planting annual crops in association with rice or maize under different strategies.

In the *chaqueado* system, after the annual planting of rice, and when the crop has attained a height of 10-15 cm, farmers sow pastures. After harvesting the cereal, the farmers leave the pastures to go to seed to permit spontaneous re-seeding. After 1 year, the pasture is completely established. However, the poor quality of available commercial seed or use of poorly adapted germplasm leads to frequent failures in this system. When farmers lack machinery and labor, neither will they establish large extensions of rice or maize in association with pastures.

Rotations of annual crops with pastures

From a technical viewpoint, the properly managed rotation of annual crops with pastures is recommended as a more sustainable system than rotations of only annual crops. This was demonstrated by studies carried out by the CIAT/MBAT Project (Barber and Navarro 1991). In this type of rotation, pastures must be managed properly, restricting stocking rates to appropriate levels to prevent degradation and permit recovery according to species and time of year.

Barber and Romero (1993) consider that the period of pasture use in the rotation system should be 5 to 8 years, before the pasture is eliminated. Recovery of soil productivity would thus be guaranteed and the costs of establishment amortized over time. After eliminating the pasture, at the end of the dry season (August-September), rotation can be initiated with the planting of annual crops for both summer (e.g., soybeans) and winter (e.g., sunflower). Crops such as these permit the use of grass herbicides during the pre- and postemergence stages, thereby guaranteeing control of pasture regrowth.

The optimal time for re-establishing pastures in annual cropping systems depends on the tillage system, being more delayed in minimum tillage systems than in conventional tillage systems. Eventually, the farmer returns to the beginning of the cycle, that is, to establishing pasture in association with an annual crop which, depending on the area, can be rice, soybeans, maize, or wheat.

Although rotating annual crops with pastures has many advantages, it can be adopted only by those farmers who have both crops and livestock, and with most (50% to 80%) of their farms under pastures. For cropping-only farms, the most important aspects to take into account for rotation are the construction of fences and availability of water and animals. Where farms only raise livestock, then the availability of farm machinery for cultivation should be considered.

Use of alleys in agrosilvopastoral systems

The CIAT/MBAT Project is carrying out various studies on agrosilvopastoral systems. One such study consists of evaluating the use of multistoried forage-producing alleys. In this case, an annual crop is initially planted parallel to the forage shrubs or trees. After 2 years, the pasture is planted, when the trees have reached an adequate size for browsing and can be harvested. Leucaena (*Leucaena leucocephala*) is useful for this purpose, provided the soil is not acid. Another alternative is *Flemingia congesta*, although its forage value is lower than that of Leucaena.

Forage alleys can be diversified by establishing trees of high commercial value such as *mara* (i.e., big leaf mahogany or *Swietenia macrophylla*), or “serebó” (*Schizolobium amazonicum*). The pasture can be *Brachiaria decumbens*, *B. brizantha*, or other grass.

At the Saavedra Agricultural Experiment Station, and in Yapacaní and San Julián, forage alleys have been established in plots currently being used by farmers (León and Adlard 1994). Although the establishment of these alleys had no agronomic problems during the first stage, it is still necessary to evaluate the costs of planting and of applying the most appropriate management practices (Johnson et al. 1995; León and Adlard 1994). At the Saavedra Station, the effect of three cutting heights on Leucaena (0.9, 1.2, and 1.5 m above the soil) is also being evaluated to determine the optimal height for grazing and cutting to produce green forage. Time and frequency of grazing the alleys depend on the state of the grass, which factor should be kept in mind.

Silvopastoral systems

The CIAT/MBAT Project is evaluating the planting of leguminous trees in existing pastures as an alternative for improving yields. This system enhances the environment for livestock by providing more shade in the fields, thereby reducing stress in the animals from excess solar radiation and encouraging higher pasture consumption. The presence of trees reduces evapotranspiration from the soil, wind speeds, and impact of raindrops. The trees also facilitate nutrient recycling because of their deeper roots and capacity to fix atmospheric nitrogen. Finally, the trees provide extra forage for browsing livestock.

The Saavedra Experiment Station has 80 ha dedicated to pastures in association with the tree species *Erythrina fusca* (‘gallito” or coral bean), *Samanea tubulosa* (“penoco”), and *Prosopis* sp. (*cupesí*, a type of mesquite) in different stages of development.

Many tree species are appropriate for multipurpose systems, but some aspects related to their establishment are not yet known (Wilkins 1995), including (1) the ideal distance between trees to prevent competition among themselves and with the pasture, and to recycle nutrients from litter; (2) the degree of tolerance trees have of trampling and browsing by livestock, and of burns; and (3) the age trees should be at livestock introduction, taking into account that pastures should be used periodically.

For Santa Cruz, data are not yet available on the impact of trees on pasture yields and livestock productivity. However, trees can be established simultaneously with annual crops, using plants from 8 months to 1 year old. When grazing begins, the trees would be 15 months old or more and able to tolerate the presence of animals.

Other systems being set up in the area are live fences with *Glyricidia sepium* and windbreaks of *L. leucocephala*.

Reducing the degradation of mechanized soils

In the area known as “integrated” central Chaco Beniana Plains, about 50% of the lands under annual crops are degraded (Barber and Navarro 1991) as a result of physical and chemical alterations in the soil. Most are now being turned over to livestock production activities. Causes for such degradation include wind erosion, accelerated mineralization of soil organic matter, extraction of nutrients by intensive monoculture without use of fertilizers, water erosion, and, above all, soil compaction. These factors are aggravated by excessive tilling, inappropriate use of implements, and natural compaction induced by heavy rains.

The CIAT/MBAT Project is evaluating various sustainable management systems for soils under annual crops, including (1) conservationist tillage systems that reduce the number of plowings and encourage the use of more appropriate agricultural implements; (2) use of green manures and amendments to correct imbalances in the soil’s chemical composition; and (3) crop rotation systems that provide large quantities of organic matter and facilitate control of weeds, pests, and diseases with minimal use of agrochemicals.

Reclaiming degraded lands under livestock and mechanized cropping systems

The Instituto Interamericano de Cooperación para la Agricultura (IICA) and PROCITROPICOS have a collaborative project of participatory research and training that involves the CIAT-Santa Cruz and farmers. Renovation of pastures cultivated simultaneously with rice or maize, using zero tillage, annual crops, and green manures, is being evaluated.

The project is in the implementation phase in four agroecological areas of the Department of Santa Cruz, three in the integrated area and one in the area of the

Chiquitano Shield. The project's strategy for action includes the following stages:

- Diagnosis, which includes regional characterization, "typing" of domains of recommendation (DOR), and selection of reference farms for carrying out validation studies.
- Participatory planning among research technicians, extension personnel, and farmers.
- Data collection and monitoring by farmers. These data refer to indicators of sustainability, profitability, and acceptability.
- Technology transfer through dissemination activities, evaluation of results, and adoption by farmers.

Conclusions

In the Department of Santa Cruz, land use systems with several crops, varied over time and space, provide a promising alternative for small farmers, because they can diversify production in a sustainable manner.

Although farmers in the region understand the advantages of the agropastoral system for establishing pastures in association with annual crops, the CIAT-Santa Cruz still needs to carry out research to validate this system and systematically demonstrate the most economic, rational, and technological use of the various factors involved in its execution. Basically, research should include the element of livestock in existing agroforestal systems. In addition, institutions involved in technology transfer and extension should adapt, validate, and disseminate existing agropastoral technology.

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CHAPTER 13

Morphological and Physiological Traits Related to the Performance of Upland Rice in Association with *Brachiaria brizantha*

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*M. P. do Carmo***

Contents

Abstract

The *barreirão* system, used in the Brazilian *cerrados*, helps reclaim degraded pastures through crop/pasture association. Grain crops provide immediate income and facilitate pasture establishment. Understanding the physiological mechanisms involved in growing

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mixtures of species will help establish criteria for genotype evaluation and improve crop management. The results of four trials at Embrapa Arroz e Feijão, Goiânia, showed that the association affects the growth parameters of both rice and pasture (*Brachiaria* sp.), decreasing rice biological yield (BY) and grain yield (GY). Under normal *cerrado* conditions, GY correlates positively with BY and negatively with pasture dry matter. The crop cycle, overall, does not correlate with yield, indicating that earliness is not detrimental to yield. Under optimal conditions of soil fertility and water availability, GY under association correlates significantly with GY under monocropping, indicating that, under good management, even cultivars susceptible to interference can yield well when in association with pasture. Nevertheless, genotypes with an intermediate growth cycle should have adaptive traits, these being found more frequently in traditional upland plant types than in modern types. The capacity to accumulate and remobilize stored photoassimilates can function as a criterion for screening desirable genotypes, although the screening methodology needs improving. Under water stress conditions, the association was found to reduce leaf rolling in rice and to increase leaf water potential, compared with the monocropping. Moreover, the water consumption of the association was not increased in relation to that of the crop alone, suggesting that the rice crop's susceptibility to water stress is not increased by the association.

Resumen

El sistema *barreirão*, utilizado en los *cerrados* de Brasil, ayuda a renovar pasturas degradadas a través de la asociación cultivos/pasturas. Los cultivos de grano son una fuente de ingresos inmediatos para el productor y facilitan el establecimiento de las pasturas. El conocimiento de los mecanismos fisiológicos involucrados en la siembra de mezclas de especies ayudará a establecer criterios para la evaluación de genotipos y a mejorar el manejo de los cultivos. Los resultados de cuatro ensayos en Embrapa Arroz e Feijão, Goiânia, mostraron que la asociación afectó los parámetros de crecimiento tanto del arroz como de la gramínea (*Brachiaria* sp.) y redujo el rendimiento biológico (RB) y el rendimiento de grano (RG) del arroz. En condiciones normales de *cerrado*, el RG se correlaciona positivamente con el RB y negativamente con la materia seca de la pastura. En general, el ciclo del cultivo no se correlacionó con el rendimiento, lo que indica que la maduración temprana no es un factor limitante para el rendimiento. En condiciones óptimas de fertilidad de suelo y de disponibilidad de agua, el RG en asociación tuvo una correlación significativa con el RG en monocultivo, lo que indica que, bajo buenas condiciones de manejo, hasta los cultivares susceptibles a la competencia pueden presentar un buen rendimiento en asociación con la pastura. Sin embargo, los genotipos de ciclo de crecimiento intermedio deben poseer características de buena adaptación, las cuales se presentan más frecuentemente en los tipos de planta tradicionales de las tierras altas que en los tipos modernos. La capacidad de la planta de arroz de acumular y movilizar nuevamente compuestos fotoasimilados de reserva puede servir de criterio para seleccionar genotipos deseables, aunque la metodología de evaluación debe mejorarse. En condiciones de estrés hídrico se encontró que la asociación redujo el enrollamiento foliar en el arroz y aumentó el potencial hídrico foliar, en comparación con el monocultivo. Además, el consumo de agua de la asociación no aumentó en relación con el consumo de agua del arroz en monocultivo, lo que sugiere que la asociación no aumenta la susceptibilidad del cultivo de arroz al estrés hídrico.

Introduction

The Brazilian savannas or *cerrados* have high potential for agricultural and livestock production. In the 1960s and 1970s, the exploitation of the region was stongly promoted, resulting in indiscriminate clearing of native areas and application of management techniques unsuitable for the region's edaphoclimatic conditions. After slashing and burning the native vegetation, soil was prepared using heavy machinery. Upland rice, considered as rustic and tolerant of the *cerrado* soils' low pH, was intensively used as a pioneer crop. After deforestation and depending on the soil's natural fertility and market prices, rice was cultivated for 2 or 3 consecutive years before improved pastures were established.

As a result of this exploitation strategy, upland rice eventually covered 4.5 million hectares of the Brazilian *cerrados*. However, this crop is susceptible to water deficits, and the introduction of other crops, such as soybeans and maize, that were more drought tolerant and more economically attractive reduced the area planted to rice to only 2 million hectares. Today, the development of new rice varieties, characterized by improved plant type and grain quality, has renewed interest in the use of upland rice in the *cerrados*.

Currently, much of the *cerrados* under pasture is degraded and reclamation is very expensive. The *barreirão* system (Kluthcouski et al. 1991) helps reclaim pastures through crop/pasture intercropping. The rice crop facilitates pasture establishment, while its grain production converts immediately into income. Understanding the physiological mechanisms involved in growing mixtures of species will help establish criteria for genotype evaluation and improve crop management.

This chapter presents the results of four experiments, carried out at Embrapa Arroz e Feijão in Goiânia, Brazil, in collaboration with the Overseas Development Administration (ODA now DFID), to study the morphological and physiological aspects of the rice/pasture association.

Physiological Components of Interference by *Brachiaria brizantha* with Rice Genotypes

During the crop seasons 1995/96 and 1996/97, two experiments were conducted on Dark-Red Latosols with degraded *Brachiaria brizantha* pastures. The basic differences between the two experimental sites were soil fertility and groundwater level, being more favorable at one. In both cases, the degraded pastures were incorporated by one pass of a moldboard plow at the beginning of the rainy season. Before planting, soil was prepared with a light pass of the plow and subsequently leveled.

In both experiments, a split-plot design with two treatments was used: rice under monoculture, and rice in association with pasture. In the first year, eight rice genotypes were evaluated. Four of these were selected for their contrasting traits for further evaluation in the second year.

During the growth cycle, leaf area index (LAI) and dry matter (DM) of separate plant parts (leaves, culms + leaf sheaths, and panicles) were determined at intervals of 12-15-days, totaling six samples per treatment. At maturity, grain yield (GY) and its components, biological yield (BY) (straw + grain), and harvest index (HI) were measured.

Effect of competition on growth of pasture and rice

Figure 1 shows the growth curve for the total DM and LAI of *B. brizantha* under monocropping and in association. The LAI values were similar for both years. The average biomass of the associated pasture at the time of rice harvest in 1996/97 was 660 g/m^2, compared with only 320 g/m^2 in 1995/96. The maximum values for pasture biomass under monocropping for the first and second years were 1700 and 1500 g/m^2, respectively.

No significant differences in the relative ability of rice genotypes to affect pasture growth were found, despite the apparent differences in their biomass under association. A major difficulty of on-farm experiments is to attain uniform plant densities. In addition to the *Brachiaria* sown, seeds of the preceding pasture are present in the soil seed bank, but are not uniformly distributed. Spatial variability of the pasture is therefore high and, consequently, coefficients of variance for the intercropping plant population is also high.

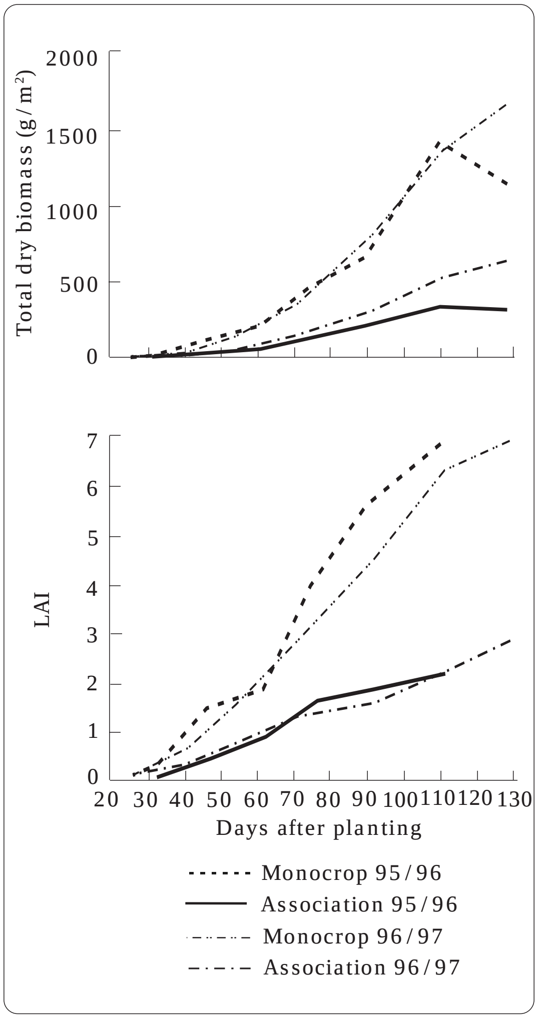

Figure 1. Evolution over 2 years of the total dry biomass and leaf area index (LAI) of the pasture *Brachiaria brizantha,* cultivated as a monocrop or in association with upland rice.

In both experiments, the association reduced rice leaf area growth and accumulation of biomass (Figure 2). The early maturing genotypes, evaluated only in the first experiment (Expt 1), reached their maximum LAI in the fourth sampling. The maximum value for intermediate-cycle genotypes was observed in the fifth sampling. As expected, leaf area growth and accumulation of dry biomass were lower in the short-cycle genotypes than in the intermediate-cycle types.

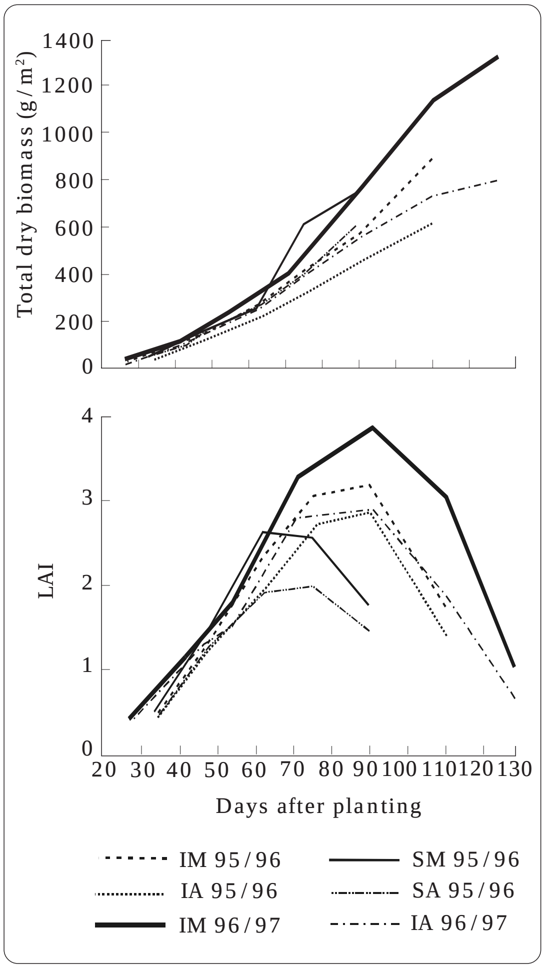

Figure 2. Evolution over 2 years of total dry biomass and leaf area index (LAI) of short- (S) and intermediate-cycle (I) rice cultivars grown as monocrops (M) or in association (A) with the pasture *Brachiaria brizantha*.

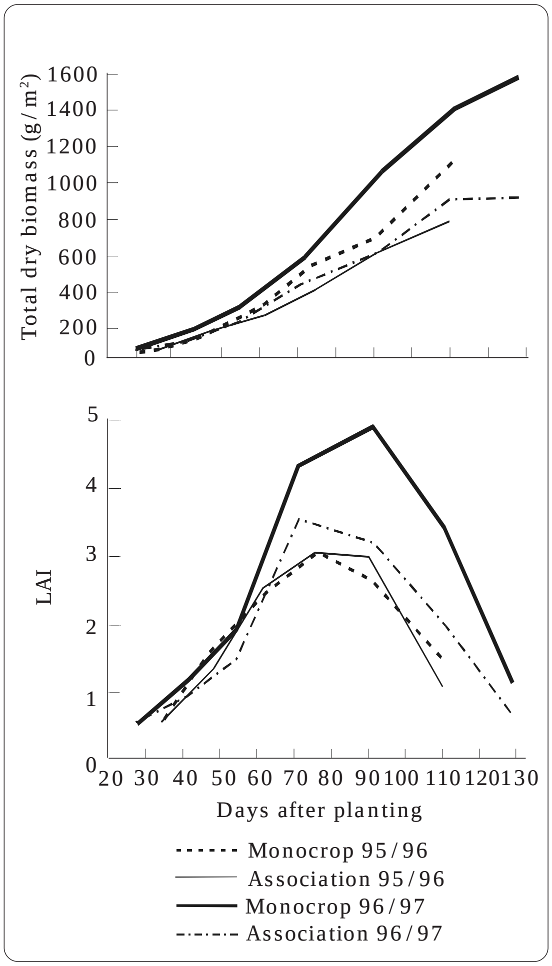

Figure 3. Evolution over 2 years of total dry biomass and leaf area index (LAI) of the rice cultivar Caipó grown as a monocrop or in association with the pasture *Brachiaria brizantha*.

In some of the six samplings, a significant interaction was observed between cropping system and genotype. The intermediate-cycle rice cultivar Caiapó, which had peaked growth in the fourth sampling at the same time as did the short-cycle materials, had higher biomass at the end of its growth than had other materials with a similar growth cycle, which peaked later. In addition, growth parameters in this cultivar were little reduced by *Brachiaria* interference, especially in Expt 1 (Figure 3).

When growth reduction of rice in the association (Figure 2) is compared with that of *Brachiaria* (Figure 1), the former showed greater effect on the latter than vice versa. This relatively greater efficiency of the rice plants can be attributed to their higher planting density, recommended for the *barreirão* system to give the crop an initial competitive advantage over the pasture.

Effect of competition on rice biological and grain yields

In Expt 1, BY of the rice monocrop was 776 g/m^2. In association with *B. brizantha*, it dropped to 557 g/m^2 (a 28.2% reduction). Grain yield was similarly affected by pasture competition, dropping from 359 to 242 g/m² (32%). The combined effect of competition on both parameters caused HI to drop from 46.5% to 43.6%. In Expt 2, planted under a more favorable environment, where nitrogen and water were more readily available, GY under monoculture was higher than in Expt 1, averaging 991 and 523 g/m², for BY and GY, respectively. The values obtained for these same parameters in association were 675 and 344 g/m² in 1996/97, also being higher than those obtained in 1995/96. The reduction caused by pasture interference was 34.5% for BY and 28.4% for GY, very similar to what was observed in 1995/96. Harvest indices, however, were higher in 1996/97: 52.8% under monocropping, and 50.7% in association.

Based on the reduced GY and BY under intercropping, compared with monocropping, the eight genotypes evaluated in the first year, were grouped into three classes:
(1) susceptible = reductions were higher than 40% (two materials);
(2) moderately tolerant = reductions were 20%-40% (five materials);
(3) tolerant = reduction was less than 20% (one material).

For Expt 2, the two most contrasting cultivars were selected: Caiapó (tolerant) and Rio Verde (susceptible), both traditional upland varieties that presented, respectively, the highest and lowest yields in association with pasture. Two more genotypes, classified as intermediately tolerant and possessing contrasting plant types were also included. These were cvs. Rio Paranaíba (traditional upland) and Progresso (modern upland). Figures 4 and 5 show these four genotypes' GY and BY in both experiments.

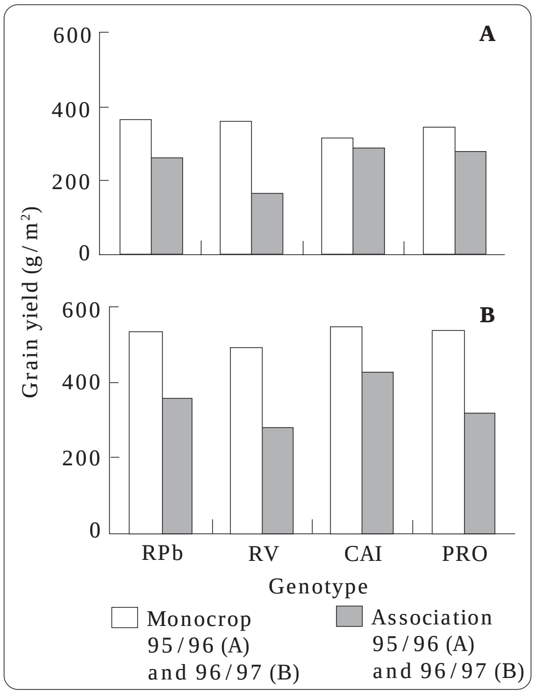

Figure 4. Grain yield over 2 years of four rice cultivars grown either as monocrops or in association with the pasture *Brachiaria brizantha*. Rice cultivars were RPb = Rio Paranaíba; RV = Rio Verde; CAI = Caiapó; PRO = Progresso.

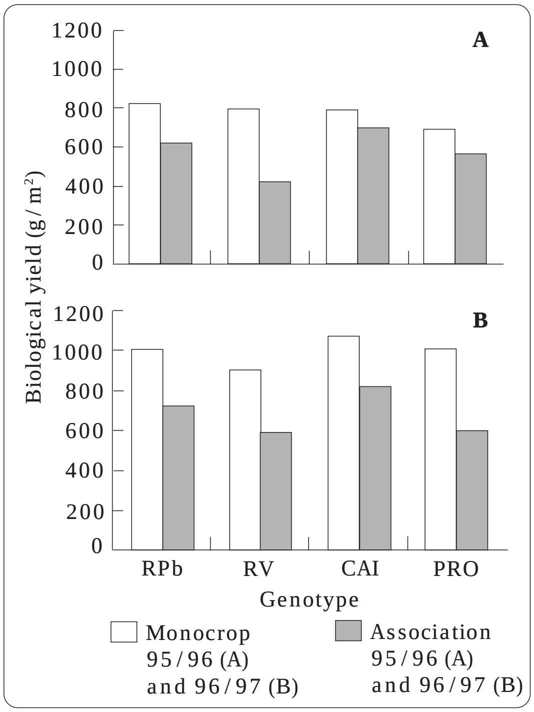

Figure 5. Biological yield over 2 years of four rice cultivars, grown either as monocrops or in association with the pasture *Brachiaria brizantha*. Rice cultivars were RPb = Rio Paranaíba; RV = Rio Verde; CAI = Caiapó; PRO = Progresso.

Although 'Caiapó' performed well in association in both experiments, it had greater reductions in GY and BY under monoculture in Exp. 2 than in Expt 1. The first parameter dropped by 9%-15.1%, and the other by 14%-21.9% in 1995/96 and 1996/97, respectively. In contrast, the relative susceptibility of 'Rio Verde' declined in Expt 2: GY dropped by 55%-43%, and BY by 43%-35%, respectively. 'Rio Paranaíba' maintained the same intermediate position, while 'Progresso' performed similarly to 'Rio Verde'.

Parameters related to yield of rice in association

Correlation studies, using data generated in the two experiments, indicated a variation in the parameters determining GY under association. In Expt 1 (eight cultivars), GY in association correlated only with the BY of the association (*r* = 0.874**) and with the total DM of the pasture (*r* = -0.771*). No significant correlation was detected between GY in association and any parameter measured in the monocropping. In contrast, in Expt 2, GY in association correlated highly with GY under monocropping.

To analyze these apparently contradicting results, Table 1 gives the correlation coefficients, calculated by using only the four materials common to both experiments. In the first year, as already pointed out, pasture and rice total biomass were the factors most related to GY under association. The intense effect of pasture growth on rice growth made yield under monocroppinge, and any traits related to it, perform a secondary role in determining yield under association. In contrast, in the second year, GY, and some growth parameters measured under monoculture, were highly correlated with GY under association.

Association creates competition for water, nutrients, light, and physical space, among other resources (Odum 1996). Accordingly, the differences between these 2 years can be attributed to differences in the level of

Table 1. Simple linear correlation coefficients between rice grain yield, measured in a rice/pasture association, and relevant parameters measured in either a rice monocrop or in a rice pasture association.

Parameter	1995/96		1996/97	
	Association	Monocrop	Association	Monocrop
Grain yield	—	-0.181 ns	—	0.715**
Biological yield	0.967**	0.046 ns	0.877**	0.829**
Rice straw at harvest	0.866**	-0.191 ns	0.421 ns	0.618*
Harvest index	0.619*	-0.259 ns	0.612*	0.172 ns
Biomass at flowering	0.403 ns	-0.107 ns	0.587*	0.867**
LAI at flowering	0.224 ns	-0.532*	0.521 ns	0.830**
Number of spikelets per panicle	-0.078 ns	-0.400 ns	0.746**	0.781**
Fertility of spikelets	0.336 ns	-0.464 ns	0.625*	0.709*
Plant height	0.418 ns	0.264 ns	0.656*	0.490 ns
Pasture dry biomass	-0.753**	—	-0.074 ns	—

a. LAI = leaf area index.
* = $P < 0.05$.
** = $P < 0.01$.

available resources. Thus, we can conclude that, under proper management and assuming good soil fertility and water availability, pasture interference with the rice crop and vice versa would be less intense, placing the genotypes' inherent competitive traits in a secondary role to their yield potential.

The apparent lack of correlation among plant traits and GY under association in Expt 1 leads to the assumption that the rice crop's capacity to compete in association with *Brachiaria* stems from several traits. The short-cycle ‘Guarani’ produced less biomass and leaf area than did the intermediate-cycle ‘Caiapó’, but their yields in association with pasture were similar. This result was not totally unexpected, as the competitive ability that determines success in association is regarded as a genetic trait difficult to define and to relate with specific biological traits (Harper 1963).

In Expt 2, with only intermediate-cycle cultivars, yield in association was favored by vigorous growth and a high number of spikelets, traits normally found in traditional upland rice cultivars. This finding suggested that traditional cultivars are more suitable for associated cropping systems than are modern upland plant types.

However, plant type, per se, does not guarantee good performance in association. Both cvs. Caiapó and Rio Verde have similar plant types, but their patterns of biomass accumulation in culms + leaf sheaths and in panicles were significantly different (Figure 6). ‘Caiapó’ had a substantial reduction in culm biomass, concomittant with increased panicle biomass, which suggests an intense translocation of carbohydrate reserves, both under monocropping and in association. For ‘Rio Verde’, culm biomass remained practically constant in both cases, which suggests low remobilization capacity, as already observed for this genotype by Raissac (1992).

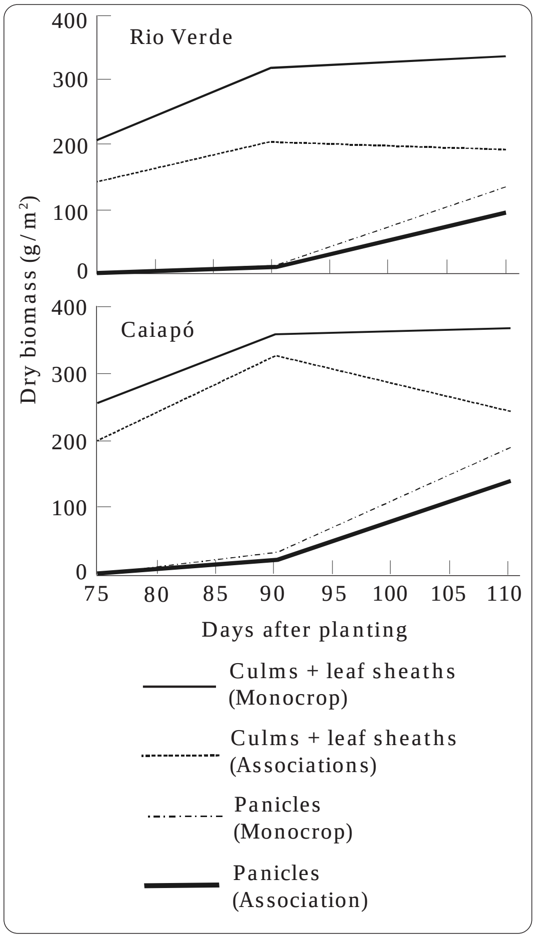

Figure 6. Evolution of biomass for culms + leaf sheaths and for panicles during the reproductive period of rice cultivars Rio Verde and Caiapó, grown either as monocrops or in association with the pasture *Brachiaria brizantha*, 1995/96.

Estimating carbohydrate remobilization is difficult, because it involves biochemical analyses or, ideally, the use of radioactive carbon markers. The apparent translocation rate (ATR) of photoassimilates—calculated on the basis of variation in weight of culms and panicles between flowering and maturity—has been used as a criterion to discriminate between genotypes for tolerance of environmental stresses, especially water stress (Reyniers et al. 1982). The application of this methodology, using data shown in Figure 6, suggests that 'Caiapó' has a higher ATR than does 'Rio Verde'. However, the high coefficients of variance obtained for this parameter, especially in Expt 2, indicates the need to improve the sampling method for use as a screening criterion. Part of this difficulty can be attributed to the spatial variability of *B. brizantha* population, which induces variation in the growth of the rice crop.

Data obtained in this study are still preliminary, meaning that we cannot ascertain with confidence those traits that should be used as selection criteria in breeding programs. Evidence suggests, however, that a short cycle, per se, enables the rice plant to escape severe competition with the pasture during the later stages of crop growth.

For genotypes with intermediate growth cycle, the ability to develop a large quantity of biomass in the vegetative period, when the pasture does not yet cause a shading effect, and accumulate reserves to be remobilized to grains during reproductive period, seems a desirable mechanism. This trait is found in genotypes of the traditional upland plant type, such as 'Caiapó'. The modern upland cultivars, recently released in Brazil, however, do not have this plant type. Nevertheless, they may have other traits that would guarantee a certain level of competitiveness with pasture. These, however, would need to be identified.

Effect of *Brachiaria brizantha* on Drought Response and Water Consumption of Upland Rice

Upland rice is highly susceptible to water deficit, particularly during the reproductive stage. Preliminary observations suggest that water stress can be minimized in the rice/pasture association system by preparing the soil with the moldboard plow, as recommended, thereby favoring root growth. The effect of *B. brizantha* on water consumption and drought tolerance in upland rice was studied in two experiments.

The first experiment was conducted under field conditions, with some modifications to recommendations for the *barreirão* system (Kluthcouski et al. 1991). These were late sowing, so that the reproductive period of the crop would coincide with the onset of the dry season, and increased pasture sowing density, that is, seeds sown at a rate of 10 kg/ha, instead of 5, to increase its competitiveness with rice.

The experimental design was a randomized complete block with split plots, consisting of two water treatments (irrigated control and water stress applied during reproductive growth stage), two cropping systems (rice as monocrop and in association with *B. brizantha* cv. Marandu), and two upland rice genotypes (Rio Paranaíba and CNA 7066). During the water stress period, we periodically determined leaf water potential, degree of leaf rolling, soil water content, LAI, and dry biomass. At maturity, GY and its components were determined.

The second experiment, to measure water consumption, was carried out in the dry season. Plants were grown in large cement water boxes measuring 1.08 × 1.28 m wide and 0.7 m deep. These had been filled with a 10-cm gravel layer, then with 1000 kg of a mixture of Dark-Red Latosol and sand. The experimental design was randomized complete block with three treatments: rice (cv. Guarani) in monoculture (T1); pasture in monocropping (T2); and rice/pasture association system (T3).

In T1 and T3, rice seeds were drilled in six rows, whereas in T2 and T3, *Brachiaria* seeds were sown in equidistant holes, again in rows. After establisment, plants were thinned to 125 rice plants in T1, 18 *Brachiaria* plants in T2, and 100 rice plants + 18 *Brachiaria* plants per box in T3.

Water was added to the boxes during the whole growth season and measured with a hydrometer. Daily consumption was estimated as the quantity of water needed for the soil to reach saturation, subtracting the amount of water drained from the boxes. LAI was estimated indirectly by measuring leaf width and length every 15 days, starting 23 days after planting (DAP) and continuing to day 83. Water uptake per unit leaf area was estimated only after the soil was entirely covered.

Effect of the association on drought tolerance in rice

In the field, the *Brachiaria*'s high sowing density favored its rapid growth, restricting growth of rice. At harvest, pasture dry biomass was 800 g/m^2, while that of rice was only 345 g/m^2. Water stress was imposed for 21 days, during the most critical stages of flowering and early grain filling. Consequently, the combined effect of pasture competition and water stress was severe, causing reductions of 60% in yield, compared with the respective controls. No interaction was observed between the water treatment and cropping system, again indicating that the rice plant's susceptibility to drought does not change when shifting from monocrop to association with pasture.

Despite the severe interference of pasture on crop yield, the association resulted in a significant physiological benefit to rice plants subjected to water stress. Their leaves showed less rolling (Figure 7), and the leaf water potential at the end of the stress period was 0.4 MPa higher than under rice monoculture.

This effect can be explained by the microclimate having been altered by shading from *Brachiaria* leaves, which gradually covered rice leaves during water stress. This benefit of association systems was previously described by Harper (1963). The

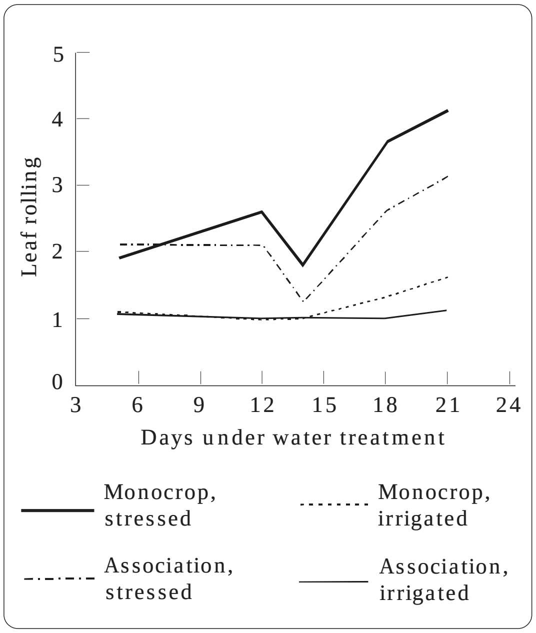

Figure 7. Evolution of leaf rolling scores (0 = no rolling; 5 = maximum rolling), in rice plants subjected to either water deficit or irrigation during the reproductive stage, and growing either as a monocrop or in association with the pasture *Brachiaria brizantha*.

reduced demand in evapotranspiration lowered rice transpiration, explaining the higher leaf water potential in the association at the end of the stress period, compared with rice monocrop. However, the benefit was not translated into yield maintenance, probably because of prolonged stress during the crop's most sensitive growth period.

Water consumption in association

Our findings indicated that *Brachiaria* consumed less water per box during the whole growth period than either rice under monocropping or rice in association with pasture, which had similar uptakes (Figure 8). This phenomenon can be attributed to the *Brachiaria*'s initial lower leaf area resulting from the smaller number of plants per box, compared with that of rice. However, the greater growth rate of the pasture under monocropping, resulted in a final LAI higher than that of rice under monocropping, although lower than that of the associated system.

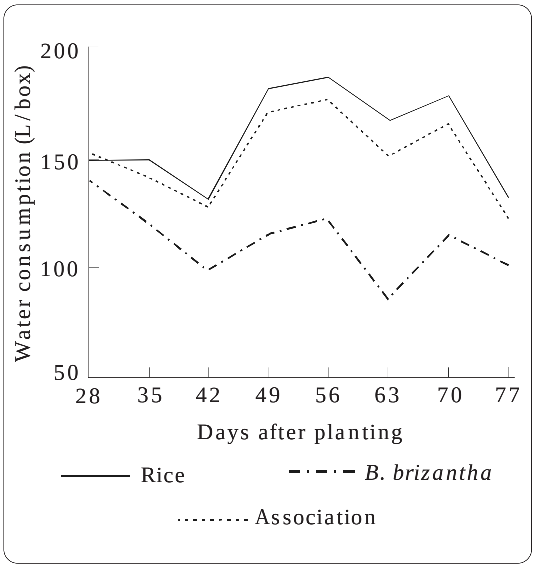

Figure 8. Evolution of water consumption by rice and the pasture *Brachiaria brizantha*, planted in large cement boxes and grown either as monocrops or in association.

The estimated water consumption per unit leaf area during the period between day 48 (full soil cover) and day 62 after planting was similar for all treatments. As *Brachiaria* leaf area increased between day 62 and day 83, water consumption per unit of leaf area declined significantly, in both the pasture monocrop and association. In contrast, the rice monocrop, although showing some reduction from the initial values, presented the highest water consumption values of all treatments (Figure 9).

Conclusions

The associated cropping system affected growth in both rice and pasture, and rice yield. The parameters determining rice yield under association varied in the two experiments, leading to the assumption that adequate soil fertility and water availability minimize the effect of one species on the other.

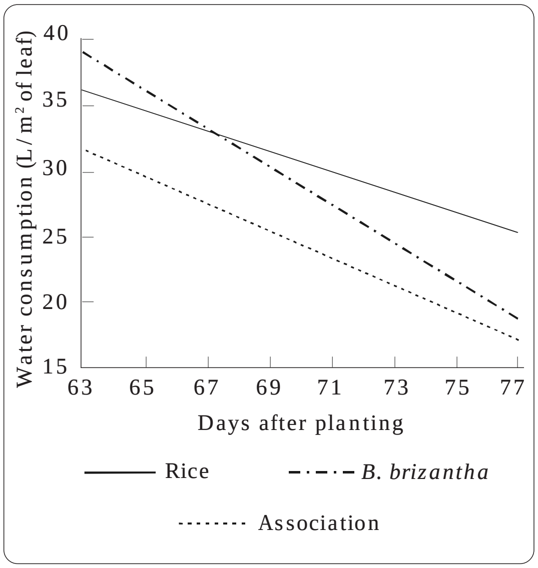

Figure 9. Water consumption per unit leaf area, after complete soil cover, by rice and the pasture *Brachiaria brizantha*, planted in large cement boxes, and grown either as monocrops or in association.

Short growth duration, per se, enables the rice crop to escape severe competition with *Brachiaria*, as this occurs late in the rice crop's cycle. Intermediate growth duration genotypes, independently of management practices, ideally, should have adaptive traits. The capacity to accumulate and remobilize storage carbohydrates could be used as a criterion to identify desirable genotypes, although the screening methodology needs improvement.

In association with pasture, the rice crop's responded to drought by showing reduced leaf rolling and maintenance of higher water potentials in relation to isolated crop. Moreover, the association's water consumption is not higher than that of rice under monocropping, hence, the cropping system does not increase the rice crop's susceptibility to water stress.

These studies should be continued to consolidate knowledge of rice plant traits that ensure adequate growth and yield in the presence of *B. brizantha* or other pastures.

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CHAPTER 14

Agropastoral Systems Based on Multiple-Purpose Legumes

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Contents

Abstract

Grain, meat, and milk farmers in the Brazilian *cerrados* are facing growing economic and environmental problems that may, over the long term, compromise natural resources and thus the sustainability of

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agriculture in the region. One option for intensifying agriculture and minimizing its negative impact on soil and water quality is to integrate crops and livestock across time and space as agropastoral systems. In 1992, a research project to develop agropastoral systems for the Brazilian *cerrados* was started by CIAT, the Empresa Brasileira de Pesquisa Agropecuária in the Cerrado (Embrapa Cerrados), and other institutions. The strategy was to develop systems based on integrating crops, pastures, and forage legumes (adapted to low and high inputs) and to quantify the impact made by these systems on production and soils. Most of the activities were carried out on farms around Uberlândia, State of Minas Gerais, Brazil. The legume *Stylosanthes guianensis* cv. Mineirão, introduced into a rice/pasture system with low inputs, increased animal production by more than 50%, compared with the control (no legume). This legume is only marginally adapted to the annual cropping system with high inputs. In contrast, *Arachis pintoi* BRA-031143 was more competitive with crops and forage grasses in high-input systems. This legume has high potential for use as a component in rotation with annual crops or as permanent cover in direct-sowing systems. Even so, chemical or mechanical methods are needed to temporarily control problems of competition. A case study confirmed the synergistic effects of this system on production and soil. Under crops, soil fertility increases, and under pastures, soil aggregation improves and organic matter increases as a result of better physical protection (especially important in sandy soils). Surveys of three watersheds near Uberlândia showed that the integrated crop and livestock system is beginning to gain the interest of grain producers.

Resumen

Los sistemas actuales de producción de granos, carne y leche en el Cerrado brasileño están presentando crecientes problemas económicos y ambientales. Esta situación podría comprometer la calidad de los recursos naturales y la sostenibilidad de la agricultura en esta región a largo plazo. Una de las opciones para intensificar la producción agrícola y minimizar su impacto negativo sobre la calidad del suelo y del agua consiste en la integración de sistemas agrícolas y pecuarios en el tiempo y el espacio (sistemas agropastoriles). A partir de 1992, el Centro Internacional de Agricultura Tropical (CIAT) y la Empresa Brasileira de Pesquisa Agropecuária en el Cerrado (Embrapa Cerrados) trabajaron conjuntamente con otras instituciones para desarrollar sistemas agropastoriles para el Cerrado brasileño. La estrategia de investigación consistió en desarrollar sistemas basados en leguminosas forrajeras adaptadas a bajo y alto uso de insumos y en cuantificar el impacto productivo y edáfico de la integración de sistemas de cultivos y pastos. La mayoría de las actividades se llevaron a cabo en fincas de la región de Uberlândia, Minas Gerais. La inclusión de la leguminosa *Stylosanthes guianensis* cv. Mineirão en un sistema de arroz-pasturas con bajo uso de insumos dio como resultado un incremento de más de 50% en la producción animal, en comparación con el control sin leguminosa. La adaptación de esta leguminosa a sistemas de cultivos anuales con alto uso de insumos fue marginal. *Arachis pintoi* BRA-031143 mostró una mejor adaptación a la competencia de los cultivos y de las gramíneas forrajeras en los sistemas de altos insumos. Esta leguminosa tiene un gran potencial de uso como componente de rotaciones con cultivos anuales o como cobertura permanente en sistemas de siembra directa. Sin embargo, es necesario usar métodos químicos o mecánicos para controlar temporalmente los problemas de competencia sobre los cultivos. Los resultados de un estudio de caso en un sistema agricultura-ganadería confirmaron la existencia de un efecto sinergístico de la integración sobre la producción y las condiciones del suelo. Durante el ciclo de cultivos se elevó la fertilidad en el suelo. Durante el ciclo de pasturas se mejoró la agregación del suelo y los niveles de materia orgánica. Estudios más detallados indicaron que bajo las pasturas ocurren mecanismos de protección física de la materia orgánica. Este proceso es de especial significado en suelos arenosos. Las encuestas en tres cuencas cercanas a Uberlândia mostraron que la integración de sistemas agrícolas y pecuarios está comenzando a ser usada por los productores de granos

Introduction

In less than 30 years, the Brazilian savannas or *cerrados* were converted into the most important frontier of agricultural expansion in the country. This rapid transformation was a result of technological advances in soil management, selection of cultivars adapted to the region's edaphoclimatic conditions, and massive investment by the state in infrastructure and development programs to promote occupation of this ecosystem.

The growth of agricultural activity in the region has had a positive impact on the generation of wealth and employment. However, it has also generated negative environmental impact such as increased soil erosion and compaction in annual cropping systems (Ayarza et al. 1993). In addition, pesticide use for controlling biotic stresses such as weeds, pests, and diseases has increased at accelerated rates. At the same time, more than 50% of pastures planted in the *cerrados* have degraded markedly, being characterized by severe loss of vigor, weed invasion, and pest attacks.

To reduce the negative impact of current management systems, alternative systems are being developed. Traditional systems of soil preparation are being replaced by minimum tillage systems where crops are planted into harvest residues or into cover crops controlled by herbicides. At the same time, soybean monoculture is being replaced by rotation systems with other crops, thus reducing weeds and pests. In livestock systems, grasses that are more resistant to spittlebug (*Deois flavopicta*) attack and crops for reclaiming pastures are being used (Kluthcouski et al. 1991; see Chapter 15 in this book).

A highly effective strategy for sustainably intensifying agricultural production and reversing degradation is that of establishing agropastoral systems, which integrate agricultural and livestock systems over time and space. This strategy is based on the synergistic effect on productivity and soil conditions that occurs when annual and perennial species are combined (Lal 1991; Spain 1990). This effect is reflected in a more efficient use of available nutrients, the soil's improved chemical, physical, and biological properties, and reduction of economic risks inherent in conducting these activities separately.

Over a 4-year period, CIAT's Tropical Lowlands Program and Embrapa's Centro de Pesquisa Agropecuária dos Cerrados (CPAC, also Embrapa Cerrados) worked with other institutions on a joint project to develop improved agropastoral systems for the Brazilian *cerrados*. The specific objectives of the project were to:

1. Develop agropastoral systems based on multipurpose legumes.
2. Evaluate, on-farm, the productivity of agropastoral systems.
3. Quantify the impact of integrating agricultural and livestock systems on production and soil conditions.
4. Characterize the potential of these systems in terms of the dynamics of current production systems.

This chapter describes the project's methodological approach for selecting components for the region, and presents the results of on-farm evaluations of legume-based prototypes.

Methodological Approach

Most activities were carried out on farms around Uberlândia, State of Minas Gerais, Brazil. The region is located at 19° S and 48° W, where the most important agroecological classes of the *cerrados* are found (Jones et al. 1992). In addition, the region has undergone rapid intensification of land use in recent years (Oliveira Schneider 1996). The region's soils are deep and well structured, with low natural fertility and high capacity for phosphorus fixation. According to the Brazilian classification system, these soils are Red-Yellow and Dark-Red Latosols (Anionic Acrustox and Typic Haplustox, respectively, according to the USDA classification system). Average annual rainfall is 1600 mm, concentrated between November and March. The dry season, from June to September, is very marked, with relative humidity dropping perhaps to less than 15%.

The study focused on developing agropastoral systems that are based on legumes that can adapt, as either components of rotations or permanent ground cover, to livestock and cropping systems with low or high use of inputs. Research carried out in other tropical regions indicates that legumes are key to increasing the sustainability of production systems (Boddey et al. 1996; McCown et al. 1993; Thomas et al. 1995). In our study, we evaluated the potential of *Stylosanthes guianensis* cv. Mineirão and *Arachis pintoi* BRA-031143 as components of these new systems. These legumes are adapted to the edaphoclimatic conditions of the *cerrados* and have great production potential (EMBRAPA-CPAC 1993).

Figure 1 summarizes the evaluation stages. Studies on the agronomic compatibility of *S. guianensis* cv. Mineirão and *A. pintoi* BRA-031143 were carried out in experiments on small plots for cutting. In one phase, their compatibility with several promising forage grasses was determined; in another, the combined effect of grasses and crops was studied on the establishment of legumes in a sandy soil with two levels of fertility.

The potential for both legumes as permanent ground cover in annual cropping systems had previously been evaluated in plots of legumes only.

On-farm assessment of the impact on production made by legumes as

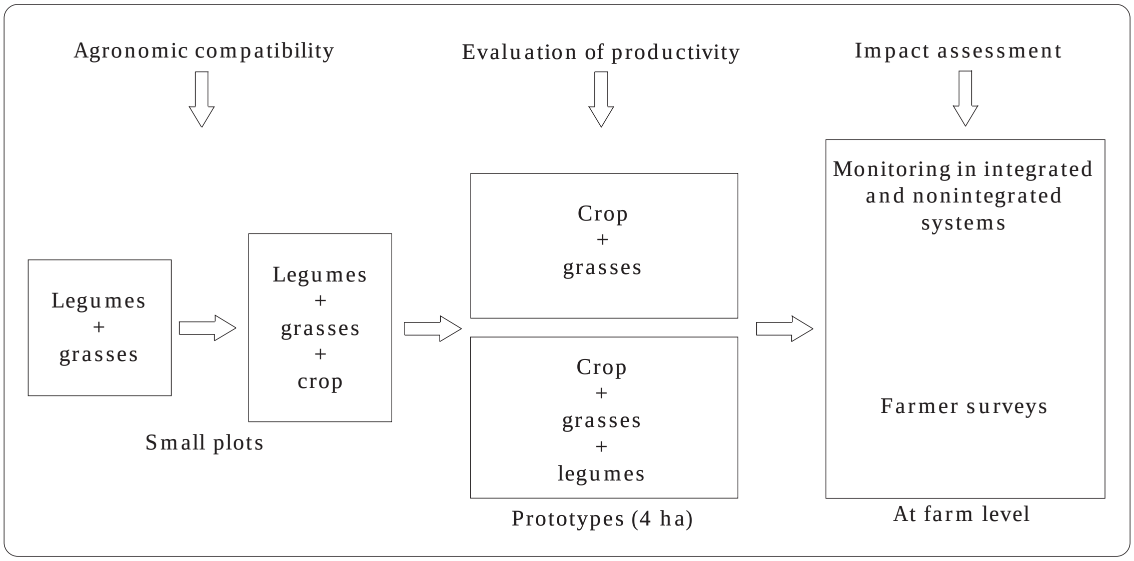

Figure 1. Sequence of activities followed to develop improved agropastoral systems, Minas Gerais, Brazil.

components of prototype agropastoral systems was carried out on 4-ha plots. The prototypes were planted as pastures and annual cropping systems with low and high use of inputs, respectively, in sandy and clayey soils. Table 1 gives the physicochemical properties of the soils in each selected system. The experimental design for the prototypes included a comparison between a system of crops + pastures versus a system of crops + pastures + legume mixture. The mixture comprised *S. guianensis* cv. Mineirão, *Neonotonia wightii* cv. Tinaroo, and *Calopogonium mucunoides* cv. Comercial. The last two legumes were included as controls to represent the commercial cultivars available on the market. *Arachis pintoi* BRA-031143 was not planted in the high-input systems for lack of sufficient seed.

The crop and forage grass components of the prototypes varied according to production system and level of fertility. In the low-input pasture system, rice was planted together with the grasses *Brachiaria decumbens* and *B. ruziziensis*. In the high-input systems, maize and the grass *Panicum maximum* cv. Vencedor were planted. In all the legume-based prototypes, the same mixture was

Table 1. Physicochemical characteristics of the 0-20-cm soil layer in the areas selected to establish prototype agropastoral systems, Uberlândia, Minas Gerais, Brazil (average of 20 composite samples per hectare).

Production system[a]	Clay (%)	OM (%)	pH (H_2O)	P (ppm)	Ca + Mg	K (meq/ 100 g)	Al	Aggregates > 2 mm (%)
Pastures (HI)	57	3.7	5.1	0.9	0.5	0.07	0.5	77
Pastures (LI)	17	0.7	5.3	1.1	0.4	0.13	0.6	73
Crops (HI)	57	3.4	6.2	34.0	4.9	0.12	0	50
Crops (LI)	13	0.7	6.3	26.0	2.4	0.25	0	46

a. HI = high inputs; LI = low inputs.

used. Fertilizer applications in the low-input prototypes consisted of lime at 1 t/ha, and P_2O_5, K_2O, and N at 70, 35, and 12 kg/ha, respectively, at sowing. After 60 days, N and K_2O were again applied at 20 and 60 kg/ha, respectively. In the high-input prototypes, only P_2O_5 was applied (at 20 kg/ha), being broadcast together with legume seeds. The farmer applied fertilizer to maize according to recommendations for the crop.

Parameters evaluated for the prototypes included grain production and animal productivity. Biomass production and botanical composition of pastures were measured three times a year. Changes in the stability of soil aggregates, percentage of organic matter (OM), and availability of N were measured at various depths in the soil profile. In the low-input prototype planted in sandy soil (17% clay), a control consisting of a degraded pasture was included.

Parallel with the research activities, seed multiplication of *S. guianensis* and *A. pintoi* was promoted in farm fields, and results disseminated through visits to fields carrying the prototype cropping systems.

The impact of agriculture-livestock integration on production and soil conditions was quantified in a case study carried out on the Santa Terezinha Farm near Uberlândia. This property is situated on a sandy soil, where cropping and pasture systems have been integrated for more than 10 years. All available data on land use and animal and crop productivity were collected. Changes in the physicochemical properties of the soil were analyzed in both crop and pasture cycles. This work was complemented with detailed studies on soil aggregation and OM composition.

The dynamics of grain production systems and of technological changes occurring in three watersheds over time were also characterized. The watersheds were located in the municipalities of Rio Uberabinha (Uberlândia), Ribeirão Santa Juliana (Santa Juliana), and Rio Bagagem (Iraí de Minas). Characterization was done through on-farm surveys with farmers. The results obtained were complemented with information from remote sensors.

In all stages of evaluation, farmers throughout the study area participated, collaborating in the selection of crop and grass components to be included in the small-plot trials and providing information for documenting the case study on the impact of agriculture-livestock integration. The level of participation was greatest during on-farm evaluation, analysis of impact, and characterization of the dynamics of production systems. Finally, several field days were held to analyze the different options and discuss their advantages and limitations.

Results

Agronomic compatibility of **Stylosanthes guianensis** *and* **Arachis pintoi** *with forage grasses and annual crops*

The aggressiveness of forage grasses and companion crops affected the establishment of the legumes in simultaneous-sowing systems. In an experiment that included 19 ecotypes of forage grasses associated with *S. guianensis* cv. Mineirão, this cultivar performed better with ecotypes of *Paspalum* and *B. brizantha* than with ecotypes of *Panicum maximum* and *B. decumbens* (Ramos et al. 1996). However, differences in compatibility were found between the legume and ecotypes of the same genus, for example, differences in compatibility with *B. brizantha* ecotypes were inversely related to the grasses' dry matter (DM) production. For ecotypes of *P. maximum* and *B. decumbens,* the negative effect on the legume was probably more related to other parameters of competition such as shade, root production, and nutrient absorption. As a genus, *Stylosanthes* is very sensitive to shade (Rodrigues et al. 1993) and to competition from grasses for N, Ca, and P (Rao et al. 1995).

In another experiment, the performance of several ecotypes of *A. pintoi*, *Centrosema macrocarpum*, *C. brasilianum*, and *Calopogonium mucunoides*, planted in association with *B. decumbens* CIAT 16488, was compared. Except for the *Arachis* ecotypes, most of the legumes disappeared as a result of problems with adaptation and diseases. The *Arachis* ecotypes evaluated associated well with the grass and retained their leaves for most of the dry season (Pizarro et al. 1996). In this study, significant differences in DM production between the commercial cultivar *A. pintoi* cv. Amarillo and the accession *A. pintoi* BRA-031143 were found (Figure 2).

Competition from the grasses not only affected the establishment of the legumes but also the growth of companion crops. In a system of simultaneous sowing, *P. maximum* cv. Vencedor significantly reduced rice production and the establishment of *S. guianensis* cv. Mineirão, compared with *Paspalum atratum* BRA-009610 (Table 2). However, this negative effect of the grasses was reduced significantly when they were planted 30 days after the crop and legumes were sown. With increase in soil fertility, the level of competition of the grass with the legume increased; thus, the *Stylosanthes* species practically disappeared when it was planted simultaneously with *P. maximum* cv. Vencedor and maize in a high-input system (Table 3). Compared with yields under monoculture, maize yields in this system were not much affected (<14% reduction in yield) by the companion grass. Sowing the grasses 30 days after the legume also reduced competition with the legume and crop (Table 3). The DM production of *A. pintoi* BRA-031143 was much lower in both production systems. However, its establishment improved after the maize was harvested.

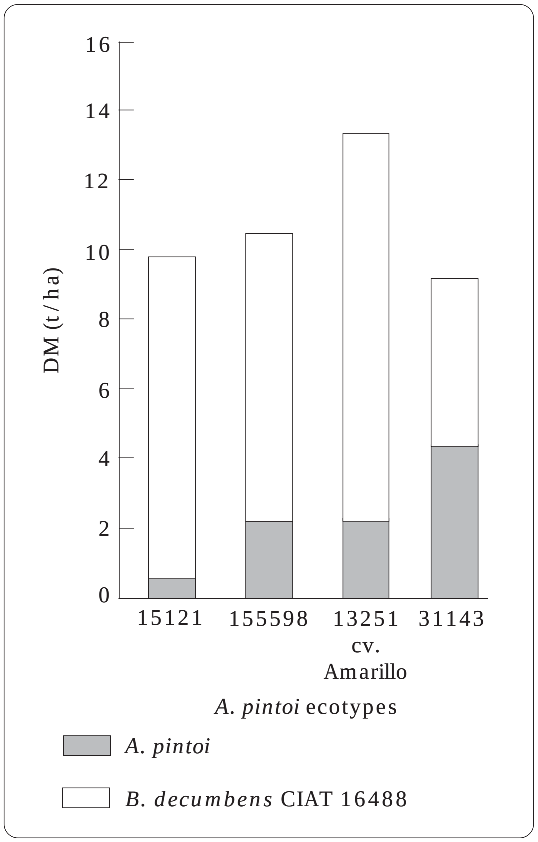

Figure 2. Effect of four ecotypes of the legume *Arachis pintoi* on the dry matter (DM) production of an association with the grass *Brachiaria decumbens,* Minas Gerais, Brazil.

Table 2. Effect of three forage grasses on rice yields and dry matter production of *Stylosanthes guianensis* cv. Mineirão and *Arachis pintoi* BRA-031143, planted on a sandy soil, Uberlândia, Minas Gerais, Brazil (average of three replicates).

Species[a]	Production (t/ha)[b]					
	Simultaneous sowing with:			Sowing 30 days after:		
	Grass	Rice	cv. Mineirão	Grass	Rice	cv. Mineirão
P. atratum	4.80	1.10 a*	1.37 a	0.62	2.18 a	1.82 a
B. brizantha	7.29	1.20 a	0.55 b	0.71	2.55 a	0.95 a
P. maximum	7.45	0.19 b	0.27 c	1.41	2.15 a	1.38 a
	Grass	Rice	*Arachis*	Grass	Rice	*Arachis*
P. atratum	5.67	1.01 a	0.16 a	1.98	2.44 a	0.02 a
B. brizantha	6.18	1.02 a	0.13 a	1.61	2.57 a	0.04 a
P. maximum	7.16	0.31 b	0.07 a	2.73	2.20 a	0.06 a
Monoculture	—	2.66	—	—	2.43	—

a. *Paspalum atratum* BRA-009610, *Brachiaria brizantha* cv. Marandú, *Panicum maximum* cv. Vencedor.
b. Values in the same column followed by the same letters do not differ significantly ($P < 0.05$), according to Tukey's test.

Table 3. Maize grain production (t/ha) and forage (dry matter, t/ha) in a maize/pasture system at two different times of sowing the grass in a sandy soil, Uberlândia, Minas Gerais, Brazil.

Planting system[a]	Grass	cv. Mineirão[b, d]	*Arachis*[c, d]	Maize[d]
Maize (monoculture)	—	—	—	6.36 a
Maize + legume (S)	—	1.81 a*	0.56 a	6.40 a
Maize + legume + *P. atratum* (S)	4.70	0.144 b	0.22 b	6.50 a
Maize + legume + *P. maximum* (S)	6.20	0.011 e	0.09 c	5.58 b
Maize + legume + *P. atratum* (30 days)	1.20	1.07 b	0.62 a	6.48 a
Maize + legume + *P. maximum* (30 days)	1.50	0.72 c	0.55 b	6.59 a

a. S = Simultaneous sowing; *P. atratum* = *Paspalum atratum* BRA-009610; *P. maximum* = *Panicum maximum* cv. Vencedor; 30 days = grasses planted 30 days after the crop and legume.
b. cv. Mineirão = *Stylosanthes guianensis* cv. Mineirão.
c. *Arachis* = *Arachis pintoi* BRA-031143.
d. Values in the same column followed by the same letters do not differ significantly ($P < 0.05$), according to Tukey's test.

Potential for Stylosanthes *and* Arachis *as permanent ground covers in annual cropping systems*

As ground cover, *S. guianensis* cv. Mineirão and *A. pintoi* BRA-031143 had opposite effects on maize growth and production. Preliminary observations in an experiment on a sandy soil showed that the growth of maize planted into a *Stylosanthes* ground cover was similar to that of maize under monoculture. In contrast, when planted into an *Arachis* ground cover, growth was severely affected. In this case, maize plants developed very little and showed severe symptoms of nutrient deficiencies, associated with the great quantity of *Arachis* roots in the 0-10 cm soil layer and the legume's capacity for vigorous regrowth at the onset of the rains. Later experiments showed that the competition of *A. pintoi* BRA-031143 could be temporarily reduced by applying 3.5 L/ha of glyphosate + 1% urea or by passing a subsoiler over the ground cover before planting maize (Figure 3). Other, more intensive, mechanical methods (e.g., passing a harrow and plow + harrow) also reduced the legume's competitiveness, but promoted incidence of weeds (Table 4).

Exploratory work with a broad range of herbicides showed that several alternatives exist for temporarily reducing *Arachis* ground cover. In all cases, this legume's ground cover was completely re-established over time. In contrast, the *Stylosanthes* ground cover disappeared after the maize harvest.

Productivity of the prototype agropastoral systems

Similarly to results from the small-plot experiments, *S. guianensis* cv. Mineirão

Figure 3. Maize production under a ground cover of *Arachis pintoi*, controlled with several mechanical and chemical methods in a sandy loam Latosol, Uberlândia, Minas Gerais, Brazil. Values followed by the same letter are not statistically different according to Tukey's test ($P < 0.05$).

Table 4. Effect of intensity of tillage and use of herbicides on the dry matter production (t/ha) of *Arachis pintoi* BRA-031143 and weeds.[a]

Intensity of tillage	No herbicide		With herbicide	
	Arachis	Weeds	*Arachis*	Weeds
No-tillage	10.89 a*	0.43 a	0.60 b	0.46 a
Subsoiler	4.05 b	0.75 a	0.08 a	2.17 b
Harrow	2.28 c	3.36 b	2.77 c	7.77 c
Plow + harrow	2.01 c	3.37 b	1.58 c	8.22 c

a. Values in the same column followed by the same letters do not differ statistically ($P < 0.05$), according to Tukey's test.

adapted well in the low-input systems, both in sandy and clayey soils. At rice harvest, 3 or 4 plants/m^2 of this legume were found. Although plants of the other legumes were also found, their populations were low. Rice yields in this system were very low because of the occurrence of short dry periods and competition from the grasses. In the high-input systems, all the legumes disappeared as a consequence of competition for light with *Panicum maximum* cv. Vencedor and the maize crop. Both maize production and grass establishment were optimal.

After 3 years of grazing, animal liveweight gain in the low-input, legume-based prototypes was 50% greater than in the crop/pasture prototypes (Table 5). This difference increased up to 80% after maintenance fertilizers (P_2O_5 and K_2O at 20 and 40 kg/ha, respectively) were applied. The greatest animal production in legume-based prototypes was associated with their higher carrying capacity, higher individual liveweight gains of the animals, and better quality diet. Differences were more marked during the dry season because of the greater capacity of *S. guianensis* cv. Mineirão to maintain a supply of green forage. The proportion of this cultivar in the pasture remained stable throughout evaluation—from 30% to 60% of the total biomass, depending on the time of year.

Animal liveweight gains in the crop/pasture prototype in the sandy soil were similar to those obtained with the degraded-pasture control treatment. Animal production in the high-input prototype on the clayey soil was twice as high as that on the sandy soil. Most of this difference was due to the greater availability of N for the grass in the clayey soil (1.29 mg/g versus 0.61 mg/g in the sandy soil). The effect of the low availability of N in the sandy soil was confirmed with the linear response of *P. maximum* cv. Centenário to the application of this nutrient (Figure 4). This limitation, due to low N contents in the soil, has been reflected over time in a growing proportion of perennial soybean (*N. wightii*) in the pasture and greater animal productivity in the legume-based prototype (Table 5). Recent evaluations of the botanical composition of the pasture showed that this legume constituted 40% of the biomass available in the pasture.

The results obtained with the prototypes that included *S. guianensis* cv. Mineirão and *A. pintoi* created a growing interest among farmers in the study area to multiply seed of these legumes. In 2 years, 8 ha were planted

Table 5. Cumulative liveweight gain during 3 years of grazing in prototype agropastoral systems established as two production systems and in two soil types, Uberlândia, Minas Gerais, Brazil.

Production system	Input use	Soil type	Prototype	Annual animal production[a] (kg/ha)	Weight gain (%)
Pastures	Low	Sandy	Crop + grass	160	—
	Low	Sandy	Crop + grass + leg.	254	58
	Low	Clayey	Crop + grass	230	—
	Low	Clayey	Crop + grass + leg.	354	54
Cropping	High	Sandy	Crop + grass	236	—
	High	Sandy	Crop + grass + leg.	267	10
	High	Clayey	Grass alone	503	—

a. 3-year average.

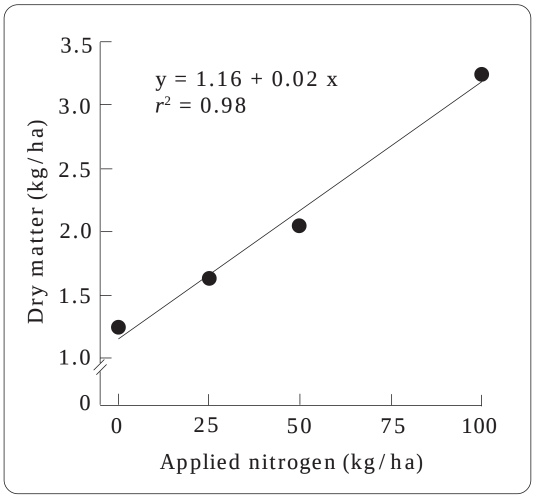

Figure 4. Regrowth of a 4-year-old pasture of *Panicum maximum* cv. Centenário, planted in a sandy Latosol, 45 days after applications of nitrogen, Uberlândia, Minas Gerais, Brazil.

to the former and 3.5 ha to the latter, yielding 122 and 235 kg of pure seed, respectively.

Impact of integrated agriculture-livestock systems on production and soil conditions

With the introduction of agricultural activity on the Santa Terezinha Farm in 1983, the original system of calf-fattening was transformed into an integrated system, in which cycles of crops and pastures were alternated over time and space. By 1992, all the original pastures of *B. decumbens* cv. Basilisk had been replaced by pastures of *P. maximum*, planted simultaneously with maize after a 3 to 4-year cycle of cropping (Table 6). From this time onward, the proportion of area under pastures remained at 40% of the total farm area. Despite this reduction in area, the animal-carrying capacity increased (Table 7), resulting in an increase in the per-hectare productivity of calves, compared with the traditional system.

The new production system also improved soil conditions (Table 8). During the crop cycle, soil fertility increased as a result of using fertilizers and amendments. During the pasture cycle, soil aggregation recovered, and OM increased by 30%, compared with areas that had been planted to crops for 4 years (Figure 5). Lilienfein (1996) found that C, N, and P contents were also enriched in the macroaggregates of these soils under pasture systems.

Table 6. Changes in the area under pastures over time at the Santa Terezinha Farm as a consequence of introducing crops in rotation with pastures, Minas Gerais, Brazil.

Year	Systems (in ha)		Total area (ha)	Animals (no.)	Carrying capacity (an./ha)
	Cerrados/pastures	Crops/pastures			
1983	1014	0	1014	1094	1.1
1984	970	0	970	1069	1.1
1985	858	61	919	1025	1.1
1986	647	80	727	804	1.1
1987	521	176	697	862	1.2
1988	293	296	589	821	1.9
1989	205	377	582	846	1.4
1990	115	493	608	892	1.4
1991	15	632	647	891	1.4
1992	0	412	412	1150	1.8

SOURCE: Ayarza et al. (1993).

Table 7. Economic efficiency of calf production in three systems with different degrees of management, Uberlândia, Minas Gerais, Brazil.

Parameter	Management system		
	Traditional	Improved	Crop/pasture
Pasture reclaimed/year (%)	1	10	25
Age of pasture (in years)	15-20	10	5
Hectares/cow	1.85	1.3	0.96
Calves/ha	2.8	5.7	6.6
Gross income/ha (US$)	43	95	110
Area in pastures	1728	2110	416
Total gross income (US$)	74,304	200,450	45,760

SOURCE: Fisher et al. (1995).

Table 8. Changes in the chemical properties of a sandy Latosol at the Santa Terezinha Farm after 4 years of continuous cropping, Uberlândia, Minas Gerais, Brazil (average of four composite samples).

Parameters	Depth (cm)	Native *cerrados*	Cropping system
pH	0-10	5.4	6.3
	10-20	5.2	5.9
	20-30	5.2	5.6
	30-40	5.2	5.0
Saturation of bases (%)	0-10	19.1	82.7
	10-20	22.6	84.6
	20-30	21.9	69.5
	30-40	17.7	52.0
P (ppm)	0-10	1.6	24.8
	10-20	0.6	2.0
	20-30	0.4	1.0
	30-40	0.3	0

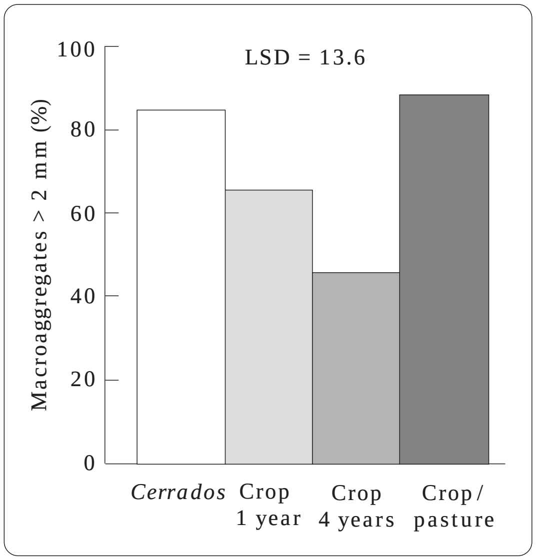

Figure 5. Effect of soil management on the proportion of macroaggregates in a sandy loam Latosol, Uberlândia, Minas Gerais, Brazil.

Additional measurements are currently being taken to evaluate the impact of the legume on soil properties. Preliminary results indicate that both mesofauna populations and litter of the associated pastures increased (Figure 6).

Potential for the adoption of agropastoral systems

The results of characterizing production systems in selected watersheds showed that annual crops occupy an average of 72% of the total farm area. The remainder is occupied by cultivated pastures and reserve areas located in unmechanizable areas (Smith et al. 1999). About half of the farmers interviewed also have dairy and beef cattle. During the rainy season, the animals remain in the cultivated pastures. During the dry season, the animals are confined and supplemented with silage and feed concentrates, usually produced from crops on the farm. This type of

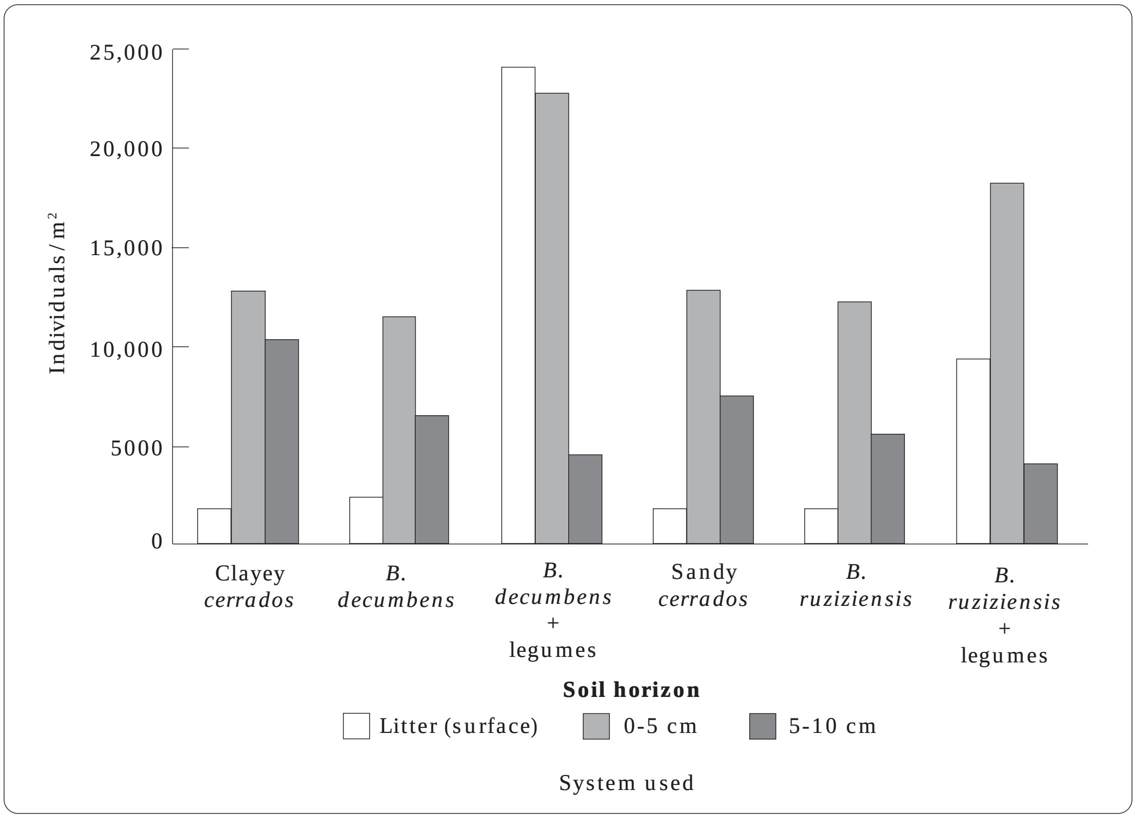

Figure 6. Mesofauna in soil horizons and litter of pastures in association, Uberlândia, Minas Gerais, Brazil.

integration has made it possible to take advantage of areas unsuitable for agriculture and increase the farmers' income through milk and meat production. Farmers perceive livestock as complementing rather than substituting their principal activity of grain production. Crop and pasture rotation is still a little-used practice among farmers. Only 6% have planted high-productivity pastures in agricultural areas for systems in confinement. Most have pastures in areas that are difficult to mechanize, and therefore difficult to sow crops.

Discussion

If a sustainable technology is to be rapidly adopted by farmers, it must generate benefits with respect to productivity and soil quality in both the short and long term, without causing structural changes to the production system (Spencer 1991). This could be achieved by introducing *S. guianensis* cv. Mineirão in livestock systems with low input use. This technology requires only small quantities of seed to establish (700-1500 g/ha), does not need additional soil preparation tasks, and requires very few inputs. Although the mechanisms by which this species adapts to the low availability of nutrients in the soil have not been studied in detail, legumes of this genus are known to be very efficient in associating with mychorrizae and, consequently, to have a high rate of phosphorus uptake by per unit of roots (Rao et al. 1997). These characteristics and the capacity to provide green forage during the dry season give this legume clear advantages over other species to improve the productivity of the system, even during critical times.

Despite the positive attributes of this legume, it is very sensitive to competition for light and nutrients. Thus, the type of companion grass and crop must be selected carefully. Grasses have a more profuse root system than do legumes, making it possible for them to explore a greater volume of soil for water and nutrients (Rao et al. 1996). Under conditions of higher soil fertility, the survival rate of *S. guianensis* cv. Mineirão is less as a result of the greater capacity of the companion species to respond to increased fertility.

The higher productivity of pastures with *S. guianensis* cv. Mineirão is related to the supply of N by the legume to the soil-plant-animal system. Cadish et al. (1993) determined that >80% of the N absorbed by several *Stylosanthes* species is derived from biological fixation. Part of this N is consumed as protein by the animals, and part is recycled to the soil through the animals' urine and feces and through processes of decomposing plant litter (Thomas 1992). These processes result in increased mineral N in the soil (Cadish et al. 1993; Freibauer 1996) and eventually in the greater availability of this element to the companion grass. Our study confirmed these ideas by finding higher N contents in tissues of the grasses that associated with *S. guianensis* cv. Mineirão than in tissues of the same grasses grown alone. The increase observed in the productivity of the associated pastures after fertilizer applications of P and K could also be related to the greater availability of N. However, the minor differences in animal production between pasture alone in the crop/ pasture system and the control (degraded pasture in sandy soil) indicate that the effect of pasture reclamation through use of crops is short term and that a source of N must be included to maintain increased productivity.

The behavior of *A. pintoi* BRA-031143 contrasts with that of *S. guianensis* cv. Mineirão. The *Arachis* species is a perennial legume with a prostrate growth habit, and has several mechanisms for persistence (Fisher and Cruz 1994). Although its initial growth is slow, it produces more roots than other legumes and is more efficient in absorbing nutrients (Rao et al. 1996). It also tolerates temporary shade. These characteristics, added to its excellent nutrient quality and its good capacity for ground cover, make it a plant that can adapt to intensive management systems with high input use. Once established in these systems, it can persist in association with grasses as aggressive as *P. maximum* cv. Vencedor and contribute to the maintenance of animal production in crop-rotation systems in sandy soils. Although this effect could not be documented, good persistence of this species was indeed observed in plots under grazing in the evaluated prototypes.

In Central America, *Arachis* has been used as permanent ground cover in plantations of coffee (Staver 1996), bananas (Granstedt and Rodríguez 1996; Pérez 1996), and oranges (Pérez-Jiménez et al. 1996). The advantages of these cropping systems included improved weed control, protection of soil against the impact of rain, and reduced nematode populations. However, the legume was slow and expensive to establish, and eventually competed with the crops.

The results obtained in these studies indicate that once the *Arachis* ground cover is established, weeds are reduced significantly, but the ground cover's competitiveness must be temporarily controlled to obtain good yields from crops such as maize. The objective of control is to minimize the ground cover's initial competition with the crop, yet permitting it to re-establish itself completely by the end of the crop's growth cycle. The ground cover's rate of recovery and incidence of weeds depend on the system used to control the ground cover. Methods that destroy the ground cover and disturb the soil also stimulate the germination of viable seeds of weeds. The use of the subsoiler gives better results. With this implement, which prepares the soil vertically, some mechanical damage to *Arachis* roots is caused but without totally destroying the ground cover. This reduces root competition and improves the physical conditions of the soil for the crop.

The results of monitoring agriculture-livestock systems confirmed the beneficial effect of integration on the system's productivity and on soil quality. Despite its great potential, only a few farmers have adopted this system. This is partly because changes are needed in infrastructure and management to handle both activities. In addition, a change in mentality is needed from both grain farmer and livestock owner, who are accustomed to working with just one activity (Spain et al. 1996). Apparently, this change is now beginning to take place among grain farmers, as the results of the surveys show, that is, they are beginning to perceive the economic benefit of crop/pasture integration, even when both activities are carried out in separate areas.

The adoption of crop and pasture rotation systems will take time but seems to be the most viable strategy for increasing the sustainability of agricultural systems on fragile soils. Including forage species as ground cover in direct-sowing systems for annual crops has great potential, given their ability to cover the soil, add value to the ground cover, and permit their eventual use as a component of crop-rotation systems. But other grass and legume species that adapt to *cerrado* soils and farmer management must still be identified.

Conclusions

The results obtained in these studies have demonstrated that agropastoral systems have the potential to increase productivity, reduce risks of degradation, and improve the soil's chemical, physical, and biological properties. The positive impact of these systems is still greater when forage legumes such as *S. guianensis* cv. Mineirão and *A. pintoi* BRA-031143 are included.

Stylosanthes guianensis cv. Mineirão is a legume that is adapted to low-fertility soils and can be easily established in rice/pasture systems to reclaim degraded pastures by applying low levels of inputs. In addition to improving the animals' diet, the availability of N in the soil-plant system increases and permits greater stability of pastures over a longer term.

In contrast, *A. pintoi* BRA-031143 is more adapted to production systems with intensive use of inputs. It is relatively tolerant of competition for light and nutrients, and once established, is a good ground cover. These attributes make it appropriate for systems with crop rotations and as a soil cover in direct-sowing systems.

The integration of agricultural and livestock activities on the one farm is relatively new to *cerrado* farmers. Those farmers who are already implementing this system perceive the economic and environmental advantages of this technology. The adoption of this system on a greater scale will largely depend on the capacity of livestock owners and grain farmers to adapt to the required structural changes. The research systems, in turn, will have to increase the supply of crop and pasture components and identify the appropriate management to maximize synergistic effects on production and soil quality.

The strategy of on-farm research made it possible to incorporate the farmer early on in the generation and assessment of the new technologies. In addition, it provided an opportunity of identifying problems earlier, and of conducting research under a broad range of conditions, as in our study, for which conditions ranged from extensive livestock systems on sandy soils with low input use to intensive annual cropping systems on clayey soils with high use of inputs.

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PART IV

Potential of Agropastoral Systems for the Sustainable Management of the Tropical Savannas of South America

CHAPTER 15

The *Barreirão* System: Recovering and Renewing Degraded Pastures with Annual Crops[1]

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Contents

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Abstract

The Brazilian savannas (or *cerrados*) have high potential for crop and livestock production. However, the use of either production system alone may lead to environmental degradation. The “*barreirão* system” provides a means of reclaiming or renovating pastures while exploiting the ecosystem commercially through planting annual crops and, yet, preventing environmental degradation. The system involves six stages: chemical analysis of soils, soil preparation, sowing, crop management, harvesting, and grazing. When developing the system, we determined, among other factors, levels of fertilizers required by different crops and of residual fertilizer available to pastures; amount of lime required and timing of application; type of equipment and adjustments needed for efficient use; the most adequate methods and timing for soil preparation; and socioeconomic conditions. In this chapter, we discuss results obtained from developing and transferring the *barreirão* system to resource-poor farmers and ranchers.

Resumen

El Cerrado brasileño es una bioma que presenta un potencial inmenso para la explotación agrícola y ganadera; sin embargo, ambas alternativas utilizadas aisladamente llevan a una degradación del ambiente. El Sistema Barreirão (SB) es una propuesta de recuperación/renovación de pasturas utilizando cultivos anuales asociados que busca solucionar el problema. El SB posee etapas fundamentales: el conocimiento del suelo, su preparación, la siembra, la conducción del cultivo, la cosecha de granos del cultivo y la introducción de ganado. Para el completo desarrollo del sistema fue necesario realizar varios experimentos para determinar factores, tales como los niveles de fertilizantes requeridos por los diferentes cultivos y el residuo para las pasturas, la cantidad de cal y el momento de

la aplicación, el tipo de maquinaria y los ajustes requeridos para su funcionamiento eficiente, el mejor método y época adecuada para preparación del suelo, y el análisis socioeconómico del sistema. En este capítulo se presentan y analizan los resultados obtenidos durante los años de desarrollo y de la transferencia del SB a los agricultores y ganaderos en Brasil.

Introduction

The Brazilian cerrados

The Brazilian savannas, or *cerrados*, not only represent the largest continuous land area in the world (around 200 million hectares) with a yet unexploited potential for food production, but they are also centrally located, and have abundant water resources and favorable climate and topography (Goedert et al. 1980). However, the soils form the principal constraints to both agricultural and animal production, because of their acidity, nutrient deficiencies, and low cation exchange capacity (CEC). To establish annual crops or pastures, soil acidity must first be corrected, organic matter (OM) content conserved, and its quality improved. The soil must also be protected against erosion, and plants provided with adequate quantities of balanced nutrients.

Unfortunately, the process of occupying and opening up the Brazilian *cerrados*, which began in the 1960s, did not take into account such requirements, thereby generating conditions for environmental degradation. On the one hand, the landowners, who, for the most part, have large extensions of land (Séguy et al. 1988), basically followed an extractive policy, applying technologies originally developed for other regions—especially those with temperate to subtropical climates—that were inadequate for the edaphoclimatic conditions of the tropical biome. On the other hand, the knowledge and technologies available for the adequate use of these natural resources were limited.

Some practices in use at that time for soil preparation, fertilizer applications, and control of erosion and overgrazing were either nonexistent or very harmful. Even so, the region continued to be dedicated mainly to pastures, because of farmers' attitudes, acidity and a naturally low fertility of soils; introduction of undemanding forage grasses such as *Brachiaria* spp., and the absence of more adequate and equitable policies and labor laws for the rural environment.

Degradation of cerrado *soils*

The inadequate use of *cerrado* soils resulted in significant environmental degradation. In conventional agriculture, or in the conventional establishment and recovery of pastures, the use of inadequate equipment, such as harrow plows, compacts subsurface layers and alters soil structure and surface, thus favoring weed invasion and soil erosion by water and wind (Kluthcouski et al. 1991a; Séguy et al. 1984). Application of fertilizers below minimum requirements and nutrient imbalances in the soil led to low yields. Finally, the practice of burning the land, erroneously supported by some farmers, contributes to impoverishing the soil by destroying OM, which represents 50%-80% of the CEC in soils. As a result, biological activity and the capacity for retaining water and nutrients are reduced, and the soils' susceptibility to erosion is increased. Moreover, some nutrients are released into the atmosphere as a result of burning. Of the 42 million hectares currently under sown pastures, about 34 million are degraded or are becoming so.

Likewise, 50% of the around 20 million hectares dedicated to grain production also presents similar problems of land degradation (Kluthcouski et al. 1993).

The principal losses registered in herds maintained on degraded pastures are related mainly to the production of lesser quality and lower value beef, reduced birth rate, increased mortality, and low milk production. In the *cerrados*, these losses are greater in the dry season (April-May to September-October), when these economic losses can surpass US$1 billion per year, based on an estimated 1% mortality of the herd and a liveweight loss of about 18 kg per animal (Yokoyama et al. 1995).

Beef production is of more concern. According to Correa (1986), cattle birth rate ranges from 50% to 60%, and calf mortality from 7% to 10% up to weaning and from 3% to 5% afterward. First parturition occurs in 4-year-old heifers, with the average age at slaughter being 4.5 years. Annual meat production is 20 kg/ha. With improved technology and on good-quality, recovered pastures, annual meat production can surpass 1000 kg/ha, while that of milk can reach 9000 kg/ha (Zimmer and Corrêa 1993).

Livestock owners have not adopted technology for recovering pastures, primarily because of the low cost of land, which encourages expansion of the area for exploitation. Machinery and equipment are scarce, and owners are reluctant to invest in the operational costs and inputs required for the direct recovery and renewal of pastures (Carvalho et al. 1990).

Meat production costs in Brazil are about 50% and 33%, respectively, of those in USA and Europe (Zimmer and Corrêa 1993). From an economic viewpoint, therefore, farmers' unwillingness to adopt technologies for recovering pastures in the *cerrados* is unjustified.

In recent years, research has generated several technologies to recover and renew pastures. These are:

- *Direct*, where soil amendments are used to correct acidity, together with fertilizers and soil management practices (Zimmer et al. 1994).

- *Rotation* with annual crops of intermediate (Séguy et al. 1994) or short cycles (Zimmer et al. 1994).

- *Association* of annual crops with forages, mainly those of the *Brachiaria* and *Andropogon* genera (Kluthcouski et al. 1991b; Sanz et al. 1993).

Each technology is applied to specific cases, according to the farmer's preferences, socioeconomic conditions, and technical knowledge. The direct, technical recovery of pastures requires knowledge and capital investment over the short term. Pasture recovery based on rotation with mechanized annual crops not only requires knowledge of both livestock and agriculture, but also machinery, tools, and farm infrastructure. Recovering pastures through associated crops requires substantial changes in soil and crop management practices, although it requires less investment than does the rotation method.

The quality of pastures recovered by any of these above-mentioned methods depends on the correct application of the technical recommendations and the type of animal management system being implemented.

The barreirão *system*

The *barreirão* system, named after the farm on which it was first developed, is a technology for pasture recovery and renewal in association with annual crops. The crops used are rice, maize, sorghum, and pearl millet (*Pennisetum typhoides*). Forages comprise species from the grassy genera *Brachiaria* and *Andropogon* and legumes, such as *Stylosanthes* sp., *Calopogonium mucunoides*, and *Arachis pintoi* (Kluthcouski et al. 1991b).

This system, which offers more than one alternative, was developed by taking into account the experiences of farmers who established most of the pastures in the *cerrados* in association with rice, although they did it empirically.

In the *barreirão* system, the selection of crops and forages to be associated depends on the farmer's interests and the farm's soil conditions.

Under current conditions, farmers running isolated livestock and agricultural operations in the *cerrados* find achieving a satisfactory cost-to-benefit ratio difficult. From a marketing viewpoint, the consumer demands cheaper prices for quality meat, as seen in many importing and competing countries. From an agronomic viewpoint, the technical, conventional forms of agriculture degrade the physical and biological properties of soils. In contrast, pastures that take advantage of residuals from fertilizer applications to crops recover these properties and exhaust only nutrients (Séguy et al. 1994). The rice crop, for example, when sown in areas with degraded pastures, can encounter the optimal environmental conditions for expressing its potential (Kluthcouski and Yokoyama 1994).

The *barreirão* system has been well accepted by farmers and, at present, millions of hectares have been recovered through its use. This confirms the effectiveness and quality of the effort to disseminate technology and of the collaboration among several strata of society (J. de C. Gomide, Chapter 8, this volume).

Economics of Technologies Available for Recovering and Renewing Degraded Pastures

Several factors influence a farmer's decision to adopt one type of technology over another for recovering and renewing their pastures. These factors include costs, which vary in relation to needs for services and inputs and the quality of pastures desired. Most livestock owners do not have access to machinery and implements.

The technological offer available to livestock farmers ranges from direct-recovery technologies to agriculture-livestock rotations. The direct-recovery methods can cost between US$86 and $494 (when R$ = US$0.85) per hectare, including all types of technology. These values are equivalent to 47.5 and 271.3 kg meat per hectare, respectively. Those direct-recovery technologies that recover pastures at A and B quality (Table 1) do not produce good pastures, resulting in low profitability.

Technologies involving associations cost from US$423 to $496/ha, which is equivalent to 232.5 and 272.5 kg meat

Table 1. Comparing cost-to-profit ratios per hectare of several technologies used for recovering and renewing pastures in the Brazilian *cerrados*.

Input and/or service	Unit[a]	Unit price (US$)[b]	Technology for recovering pastures													
			Pastures reclaimed through direct-recovery systems[c]								*Barreirão* system					
			A		B		C		D		Rice		Maize		Sorghum	
			Qt./ha	US$	Qt./ha	US$	Qt./ha	US$	Qt./ha	US$	Qt./ha	US$	Qt./ha	US$	Qt./ha	US$
Dolomitic lime	t	10.77			1.5	16.16	2.50	26.93	2.50	26.93	1.50	16.16	3.0	32.31	3.0	32.31
Natural phosphate	t	68.85			0.5	34.43										
Thermophosphate	t	185.89							0.80	148.71						
Acidulated phosphate	t	120.64					0.50	60.32								
Simple superphosphate	t	211.56					0.20	42.31		42.31						
Potassium chloride	t	246.15					0.05	12.31	0.20	19.69						
Formula 4-30-16	t	272.54							0.08		0.30	81.76	0.35	95.39	0.35	95.39
Ammonium sulfate	t	207.13					0.10	20.71		20.71	0.10	20.71	0.30	62.14	0.2	41.43
Zinc sulfate	t	330.48							0.10		0.02	6.61	0.02	6.61	0.02	6.61
FTE BR 12	t	418.84								12.57	0.03	12.57	0.03	12.57	0.03	12.57
Carbofuran/ thiodicarb	L	18.87							0.03		0.90	16.98	0.40	7.55	0.3	5.66
B. brizantha seed	kg	3.67					10.00	36.70		36.70	5.00	18.35	5.00	18.35	5.0	18.35
B. decumbens seed	kg	4.48	10.0	4.48	10.0	44.80			10.00							
Calopogonium sp. seed	kg	8.02								24.06						
Rice seed	kg	0.69							3.00		60.00	41.40				
Maize seed	kg	1.58											20	31.60		
Sorghum seed	kg	2.35													16	37.60
Distribution of phosphate + forage seed	H/M	23.00	0.5	11.50	0.5	11.50	0.50	11.50		11.50						
Transporting lime (at 100 km)	H/M	12.28				18.42		30.70	0.50	30.70		18.42		36.84		36.84
Distributing lime	H/M	23.00			0.5	11.50	0.50	11.50		11.50	0.50	11.50	0.5	11.50	0.5	11.50
Harrow plow (18 disks)	H/M	23.00	1.2	27.60	1.2	27.60	1.20	27.60	0.50	27.60	1.20	27.60	1.2	27.60	1.2	27.60
Harrow disk (3 disks)	H/M	23.00					2.00	46.00	1.20							
Moldboard plow (3 moldboards)	H/M	23.00								52.90	2.30	52.90	2.3	52.90	2.3	52.90

(Continued)

Table 1. (Continued.)

Input and/or service	Unit[a]	Unit price (US$)[b]	Technology for recovering pastures													
			Pastures reclaimed through direct-recovery systems[c]								*Barreirão* system					
			A		B		C		D		Rice		Maize		Sorghum	
			Qt./ha	US$	Qt./ha	US$	Qt./ha	US$	Qt./ha	US$	Qt./ha	US$	Qt./ha	US$	Qt./ha	US$
Leveling (36 disks)	H/M	23.00					0.60	13.80	2.30	13.80	0.6	13.80	0.6	13.80	0.6	13.80
Sowing	H/M	23.00							0.60		1.0	23.00	1.0	23.00	1.0	23.00
Nitrogen + potassium for ground cover	H/M	23.00									0.8	18.40	0.8	18.40	0.8	18.40
Ant control	Man-days	6.75									0.1	0.67	0.1	0.67	0.1	0.67
Seed treatment	Man-days	6.75									0.1	0.67	0.1	0.67	0.1	0.67
Harvest/transport/drying	H/M	23.00									1.0	23.00	1.0	23.00	1.0	23.00
Labor for harvesting	Man-days	6.75									1.0	6.75	1.0	6.75	1.0	6.75
Management (3% of costs)	U/D	—		2.52		4.93		10.21		14.39		12.34		14.45		13.95
Total costs	**US$**	**—**		**86.42**		**169.34**		**350.59**		**494.07**		**423.50**		**496.10**		**479.00**
Return from grain production	US$/ha	—										458.80[d]		447.10[e]		296.75[f]
Meat production needed to cover costs @ 11.5 kg per unit	Unit/ha	—		3.80		7.45		15.42		21.73				2.15		8.01
Rest period	Days	—	150		150		135		135		165		135		135	
Losses against column "D"[g]		—	15.92		15.92						31.84[h]					

a. H/M = hours per machine; U/D = unit cost per technical demonstration.

b. Prices in Goiânia in Nov/Dec 1994; R$1.18 = US$1.00; mean of the two lowest bids.

c. A = poor technology level; B = average technology level; C = good technology level; D = optimal technology level.

d. Productivity = 33.25 sacks (@ 60 kg)/ha. Market price = US$13.80/60 kg.

e. Productivity = 61.50 sacks (@ 60 kg)/ha. Market price = US$7.27/60 kg.

f. Productivity = 58.30 sacks (@ 60 kg)/ha. Market price = US$5.09/60 kg.

g. Calculation considering number of days when rest was exceeded, with daily liveweight gain of 0.7 kg, at the price of US$22.74/unit of 11.5 kg, averaged over 11 years (1984-1994).

h. Value covered by net gain obtained from grains.

SOURCE: EMBRAPA-CNPAF (1994).

per hectare, respectively. Return from the grain harvest covers 108%, 90%, or 62% of the costs, when the forage is associated with rice, maize, or sorghum, respectively. While farmers recover their total costs when associating pasture with rice, with maize or sorghum, they also need to raise 26.9 or 101.0 kg of meat per hectare, respectively, to cover total costs.

Pasture quality in the associated systems is at least equivalent to quality C pastures reclaimed through direct-recovery systems (Table 1). Success in using recovery technologies based on rotation, with respect to agricultural yield (profit-to-cost ratio in grain production), depends on both the technological level and farmers' knowledge. The transition from agriculture to livestock raising in the rotation method of the *barreirão* system can be done, using mainly maize or sorghum in association with forages. Logically, the cost of the transition is lower because the need for corrective dressings and fertilizers is reduced, since the areas have been previously improved for agricultural purposes.

The quality and quantity of inputs and services used in each technology make possible the ordering of technologies in terms of pasture quality on acid soils: maize grown in association with pastures > direct-recovery system D > the *barreirão* system with maize, sorghum, or rice > direct-recovery systems C, B, and A (Table 1).

Independent of the technology used, the period most suitable for recovering pastures is summer, which is the region's rainy season, when forage is most abundant and almost always in surplus. Practices that eliminate soil compaction, such as harrowing or deep plowing (disk and moldboard), can result in the forage performing better during the dry period (May-October), thereby reducing the need to supplement with feed, and even reducing differences in meat-production costs between the rainy and dry seasons, as reflected in changes in market prices.

Characteristics and Sequence of the Practices Constituting the *Barreirão* System

The *barreirão* system brings together practices for solving problems that are common in most soils under degraded pastures in the Brazilian *cerrados*. Any omission or alteration in the application of these practices can affect the production of the crop and/or forage. The six stages are soil analyses, soil preparation, sowing, crop management, harvesting, and grazing.

Soil analyses

Before the soil is disturbed, it should be chemically analyzed, preferably in July and September, using samples taken in the conventional way at two depths: 0-20 cm and 20-40 cm. Results should indicate whether additions of lime and P are needed.

Maize, sunflower, millet, the forage grass *Andropogon gayanus*, and forage legumes are susceptible to high soil acidity and require Ca + Mg at a rate of at least 3 meq/100 g soil. To calculate needs for lime, one of two methods can be used: determining base-saturation percentages (50%-55%), or calculating Ca + Mg + Al contents. For these more demanding crops, lime should be well mixed with the soil, that is, 60%-70% of the required lime is plowed into the topsoil with a harrow plow to no more than 35-40 cm deep. The rest of the lime (30%-40%) is applied on the soil surface just before leveling during the second stage.

Soil preparation

When preparing the soil, degraded pastures should be eradicated and incorporated into the topsoil, with one pass of a harrow plow at 10-15 cm deep. This operation should be done at least 30 days before the rainy season begins and before plowing. Deep plowing should be carried out preferable with a moldboard plow, making sure that the soil is moist throughout the area being worked. Leveling should be done 7 to 10 days after deep plowing and immediately before sowing.

Sowing

Good-quality seed of both annual crops and forages should be used. Crop seed should be treated with systemic insecticides (carbofuran, carbosulfan, and thiodicarb) to prevent attack by the spittlebug *Deois flavopicta* and larvae of soil pests. Sowing distances and densities for maize, sorghum, millet, and forages are as recommended traditionally (Table 2).

For rice the traditional sowing distance between rows should be reduced from 50 to between 30 and 45 cm. Early maturing varieties with short growth habits and erect leaves should be planted. Sowing densities range from 70 to 90 seeds/m for varieties with a short growing cycle, and from 60 to 70 seeds/m for those with an intermediate cycle. Seed of *Brachiaria* forages, with a crop value of 30%, should be planted at a density of 3-6 kg/ha. The quantity of *B. brizantha* and *B. decumbens* seeds that should be used per hectare can be obtained by dividing the constant 150 by the respective crop value. For *A. gayanus*, 10-20 kg/ha of good-quality seed, planted superficially, are needed. *Brachiaria* seed should be mixed with fertilizer before sowing in the same row as crops. When planting at distances of more than 70 cm between rows, an inter-row with the forage mixed with fertilizer should be planted.

Rates of fertilization for the rice crop are based on the soil analysis, taking into account that the residual effect should benefit the pastures. For rice cultivated in low-fertility Latosols of the *cerrados*, where P content may be less than 3 ppm and K content less than 45 ppm, good results have been obtained with minimum applications (kg/ha) of N (12 to 15), P_2O_5 (90), K_2O (30-45), FTE[2] (30), and zinc sulfate (20). Other annual crops such as maize and sorghum require at least 105 kg/ha of P_2O_5.

Fertilizer, alone or mixed with *B. decumbens* or *B. brizantha* seeds, should be incorporated to a depth of 8-10 cm in the soil; but the depth for sowing seeds of annual crops should be at the conventional 3-5 cm. In very sandy soils, deep planting of seeds should be avoided.

Associations should be sown, as should be other systems, with planters operating at a speed of 3-5 km/h. Only planters that have been tested beforehand should be used, with the seed feeder being a perforated disk that is either horizontal, inclined, or vertical, and set at 30-40 cm between the feeder mechanism and the furrow's bottom. For annual crops, planters should be able to place the fertilizer deeper than the seeds, and at a minimum variable distance of 30 cm between rows.

Crop management

Weed control is unnecessary, as the areas being used comprise degraded pastures. Crop management therefore

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[2] Fritted trace elements, a mixture of micronutrients used as a fertilizer.

Table 2. Principal recommendations for establishing associations of annual crops and pastures in the Brazilian *cerrados*.

Crop	Growing cycle	Sowing density (seeds/m)	Sowing depth (cm)	Spacing (cm)	Quantity of seeds (kg/ha)
Rice	Short	70-90	3-5	30-40	60-70
	Intermediate	60-70	3-5	35-45	45-55
Maize	—	4-6[a]	3-5	8-100	20-22
Sorghum	—	14-19 (grain) 11-15 (forage)	3-5	6-7	8-10
Millet		12-15	3-5	6-7	4-6
Forages					
A. gayanus	—	8-10[b]	0-1	Broadcast	10-20
B. decumbens		4-6[b]	8-10	CR[c]	5-6[d]
B. brizantha	—	4-6[b]	8-10	CR[c]	5-6[d]
B. humidicola	—	4-6[b]	4-6	CR[c]	3-4[d]

a. Plants per linear meter.
b. Plants/m^2.
c. In crop row (CR), with inter-rows in association with maize.
d. Crop value = 30%.

SOURCE: EMBRAPA-CNPAF (1994).

involves N application, which varies with the associated crop and with soil conditions, for example, 20 kg/ha should be applied for rice, or 40-60 kg/ha for maize. If soils are sandy, then, for rice, 50 kg/ha of K_2O should be applied before N. Any necessary plant protection should be carried out, according to general recommendations for the region.

Harvesting

Rice has an optimal time for harvesting, after that lodging develops and losses are incurred as the forage biomass rapidly increases after crop maturity. Harvesting practices and speed should follow those recommended for monocrops.

Grazing

This last stage of the *barreirão* system consists of introducing animals into the area after harvest and letting them graze for at least 30-60 days. This is necessary for good pasture development and production of forage seed, which is harvested with the crop. Even from the time grazing is initiated, pasture management and fertilizer application remain basic to the productivity and sustainability of a pasture-based production system.

Experimental Evaluation of the *Barreirão* System

Each stage has equal importance in technology development. The edaphoclimatic characteristics of the *cerrado* biome—particularly those constraints involving soil properties, rainfall variations during the rainy season, and the level of competition between forages and grain crops—constitute the basic assumption for conducting a series of studies to evaluate the *barreirão* system. New research on this system has given rise to attempts to improve the system, always considering the technological solution against economic results.

Applying lime

Correcting soil acidity and supplementing with Ca + Mg for crop growth are fundamental to producing grains and forages on the *cerrados*' acid soils. In the *barreirão* system, determining needs for liming depends on the same methodology and criteria used for monocultures. The rice crop, which is better adapted to the natural conditions of the *cerrados*, requires little lime and is thus considered as an ideal crop for opening up new areas.

Good rice production has been obtained from soils that have Ca + Mg at only 1 meq/100 g soil. However, if forage requirements are taken into account, then, for soils with Ca + Mg at less than 1.5 meq/100 g soil, lime should be applied at a rate of 4:1 of Ca:Mg (Table 3). Maize (Table 4), sorghum, and millet, in contrast, have high requirements for these nutrients and do not tolerate high soil acidity. For these crops, lime is indispensable when the soil contains Ca + Mg at less than 3 meq/100 g soil, and should also be applied, again, at a rate of 4:1.

Mixing lime with gypsum. Several studies show that the most economical process for correcting the acidity of the soil's subsurface layers is to apply gypsum (calcium sulfate) in a mixture with lime. Sulfates can capture base cations throughout the horizons, thus correcting the acidity and favoring root growth.

In the *barreirão* system, higher rates of any of the corrective dressings resulted in lower productivity of the maize hybrid BR 201 and *B. brizantha* (Table 5), but significant differences among the rates evaluated were not found. However, the best yields were obtained with lime-gypsum mixtures (in percentages) at 60:40 (maize) and 40:60 (forage). The distribution of Ca in the soil profile, to 60 cm deep, increased as the mixture contained greater quantities of gypsum.

Microliming. In the *barreirão* system, the reaction time for corrective dressings in the soil is not sufficient in that a minimum period of 90 days of moisture is needed between lime application and sowing of the crop or forage. Given that the principal factor determining the reaction time of an amendment is the size of its particles, finely ground lime can give better results more quickly than conventional limes. Although the maize crop did not

Table 3. Effect of increasing rates of lime on the production of the rice cultivar Guaraní and on green matter production of the forage grass *Brachiaria brizantha*, Brazilian *cerrados*.

Rate of liming (t/ha)[a]	Rice*		Forage*	
	Dry matter (t/ha)	Productivity (kg/ha)	Population (shoots/m)	Green matter (t/ha)[b]
0	3.1 b*	2.618 ab	47.75 a	29.38 b
3	4.7 ab	3.460 a	52.25 a	37.98 ab
6	6.8 a	2.390 a	54.63 a	42.40 a
CV (%)	20.8	14.9	6.73	19.7

a. Dark-Red Latosols (LVE); pH = 5.8; Ca + Mg = 1.8 meq/100 g soil; contents of P, K, Cu, Zn, Fe, and Mn = 0.9. 120, 2.1, 0.6, 154, and 47 ppm, respectively; OM = 1.9%; site = Hacienda "Barreirão", Piracanjuba, Goiás, Brazil.

b. Evaluation done at 60 days after the rice harvest.

* Averages in the same column followed by the same letters are not significantly different ($P < 0.05$), according to Tukey's test.

SOURCE: EMBRAPA-CNPAF (1994).

Table 4. Effect of methods of incorporating lime on the productivity of the maize hybrid BR 201 and on the green matter production of the forage grass *Brachiaria brizantha*, Brazilian *cerrados*.

Lime (t/ha)[a]	Maize*			Forage green matter (t/ha)*
	Plant weight (g)	Production (t/ha)	Population (plants/6 m)	
0	1767 b*	1.99 b	35.33 a	17.2 c
3 (harrow plow)	2700 a	3.46 a	36.67 a	25.7 ab
3 (plow)	2900 a	3.01 a	36.67 a	28.3 a
3 (harrow grader)	3073 a	3.36 a	35.67 a	22.0 bc
CV (%)	10.2	8.71	10.8	14.8
0	1767	2.74	35.33	17.20
3	2871	3.28	36.33	25.33
CV (%)	34.1	6.47	19.7	27.0

a. Quantity of applied lime and method of incorporation. Soil low-volatile amines (LVA); pH = 5.8; Ca + Mg = 2 meq/100 g soil; contents of P, K, Cu, Zn, Fe, and Mn = 0.8, 137, 2.1, 0.6, 154, and 50 ppm, respectively; OM = 2%; site = Hacienda “Barreirão”, Piracanjuba, Goiás, Brazil.

* Averages in the same column followed by the same letters are not significantly different ($P < 0.05$), according to Tukey’s test.

Table 5. Effect of a mixture of gypsum with lime on the number of plants, production of maize hybrid BR 201 and forage grass *Brachiaria brizantha*, and Ca content in *cerrado* soils, Brazil.

Lime-to-gypsum mixture[a]	Maize		Forage green matter (t/ha)	Ca (meq/100 g soil) at depth (cm):		
	Plants/m	Production (t/ha)*		30	60	90
100:[b]0	4	3.79 a*	16.82	2.0	1.5	1.3
80:20	5	3.55 a	12.80	2.7	1.7	1.2
60:40	4	4.30 a	15.23	2.3	1.2	1.4
40:60	4	4.21 a	15.40	2.2	1.7	1.4
20:80	5	4.09 a	13.93	1.8	2.3	1.3
0:100[c]	5	3.49 a	13.20	1.8	2.3	1.3
Check	5	1.49 b	14.33	1.9	1.5	1.3

a. Yellow-Red Latosols (LVA); pH = 5.7; Ca + Mg = 0.7 meq/100 g soil; contents of P, K, Cu, Zn, Fe, and Mn = 0.7, 103, 2.3, 0.5, 154, and 44 ppm, respectively; OM = 1.9%; site = Hacienda “Barreirão”, Piracanjuba, Goiás, Brazil.

b. Corresponding to 3 t/ha.

c. Corresponding to 5.76 t/ha.

* Averages in the same column followed by the same letters are not significantly different ($P < 0.05$), according to Tukey’s test.

SOURCE: EMBRAPA-CNPAF (1994).

show significant differences in statistical testing, grain production did increase by more than 1 t/ha when finely ground lime was used. For *B. brizantha*, green matter production increased significantly (Table 6).

The Ca and Mg present in lime, a low-cost input, are essential nutrients for plant production. These nutrients reduce acidity and aluminum toxicity, and so improve the soil. When a rice-pasture association is established in the *barreirão* system, lime should be

Table 6. Comparative effects of applying lime versus microliming on the number of plants and maize ears, maize production, and green matter production of the forage grass *Brachiaria brizantha*, Brazilian *cerrados*.

Type of lime (t/ha)[a]	Maize			Forage green matter (t/ha)*
	Plants/m	Ears (no./m)	Production (t/ha)	
Commercial				
3	5.1	4.9	2.28	0.344 b*
Microliming				
3 broadcast	5.2	5.3	3.34	0.446 ab
0.3 in the furrow	5.1	5.4	3.36	0.508 a
0.6 broadcast	5.1	5.4	3.08	0.386 ab
CV (%)	11.2	12.7	8.3	15.6

a. Yellow-Red Latosols (LVA); pH = 5.7; Ca + Mg = 2.6 meq/100 g soil; contents of P, K, Cu, Zn, Fe, and Mn = 1.1, 89, 2.6, 0.6, 363, and 33 ppm, respectively; OM = 1.5%; site = Hacienda "Barreirão", Piracanjuba, Goiás, Brazil.

* Averages in the same column followed by the same letters are not significantly different ($P < 0.05$), according to Tukey's test.

SOURCE: EMBRAPA-CNPAF (1994).

applied when the Ca + Mg content in the soil is less than 1.5 meq/100 g, but for maize, sorghum, or millet in association with pastures, the threshold is 3 meq/100 g soil.

Preparing the soil

Adequate soil preparation is fundamental to successful agricultural production. It helps reduce soil compaction, control annual and perennial weeds, and incorporate organic residues, amendments, or correctives.

In the *cerrados*, Oxisols (Latosols) and Entisols (quartziferous sands and Podzols) predominate, with problems of soil compaction and unequal fertility throughout the profile. These problems should be partially or totally eliminated by soil preparation. In areas with degraded pastures and heavy infestation of ant colonies, soil preparation is even more critical for handling the frequent problems of soil compaction, perennial weeds, and declining chemical fertility in subsurface soil profiles.

Surface incorporation of plant residues and corrective dressings. The surface incorporation, or preincorporation, of these materials is carried out with one or two passes with a harrow plow. The objective is to treat the top 10-15 cm of soil, eliminating the roots of existing vegetation, mixing in corrective dressings, initiating decomposition of OM, and destroying anthills; ensuring the quality of plowing, thus reducing the need for leveling; and ultimately improving production (Table 7).

Surface incorporation is carried out in the dry season (beginning of August to mid-October), 15-30 days before either the rainy season or sowing begins. If it is not carried out, performed too close to sowing, or done during the rainy season, crop productivity will drop, depending on OM content and other factors. Moreover, the crops and forages planted will be affected by increased competition from weeds and remaining pastures.

Table 7. Effect of preincorporation in areas of degraded pastures on the productivity of the rice cultivar Guaraní and the forage grass *Brachiaria brizantha*, Brazilian *cerrados*.

Soil preparation method	Rice production (t/ha)[a, *]		Forage green matter (t/ha) in 1991/92[b]
	1990-91	1991-92	
Direct plowing	2.26 a*	1.63 b	20.23
Preincorporation + plowing	2.63 a	2.28 a	23.23
CV (%)	15.6	16.7	—

a. Fertilizers used as recommended for the *barreirão* system, Hacienda "Barreirão", Piracanjuba, Goiás, Brazil.

b. Leaves and stalks; evaluation carried out 60 days after the rice harvest.

* Averages in the same column followed by the same letters are not significantly different ($P < 0.05$), according to Tukey's test.

SOURCE: EMBRAPA-CNPAF (1994).

Plowing depth. Deep soil preparation with the moldboard plow helps reduce compaction of the topsoil (0-40 cm); incorporate organic residues and corrective dressings to a greater depth; partially or totally eliminate roots of perennial weeds; and incorporate anthills into the subsoil.

Once the soil has sufficient moisture—preferably at field capacity—plowing should be carried out to a depth of 35-40 cm. This is fundamental for better root development and for favoring infiltration and storage of water, thus resulting in more stable production over time (Table 8). Although disk plows present good results with rice crops and forages, and yields are higher than those obtained with a harrow plow, moldboard plows should be preferred as their structure, especially designed for this task, permits better soil penetration. Soils under degraded pastures resist plow penetration more because of compaction and the presence of old roots and perennial weeds. In these cases, moldboard plows provide a homogeneous preparation.

Table 8. Effect of type of plowing tool used (after preincorporation in areas of degraded pastures) on the productivity of the rice cultivar Guaraní and the forage grass *Brachiaria brizantha*, Brazilian *cerrados*.

Tool	Rice production (t/ha)[a, *]			Forage green matter (t/ha) in 1991/92[b]
	1990-91	1991-92	1992-93	
Harrow plow	1.70 b*	1.94 b	0.67 b	17.30
Disk plow	2.79[c] a	2.43[d] a		—
Moldboard plow	2.96 a	2.63 a	2.28 a	23.23
CV (%)	19.5	15.3	26.5	—

a. Fertilizers used as recommended for the *barreirão* system, Hacienda "Barreirão", Piracanjuba, Goiás, Brazil.

b. Evaluation carried out 60 days after the rice harvest.

c. 26" disk plow.

d. 32" disk plow.

* Averages in the same column followed by the same letters are not significantly different ($P < 0.05$), according to Tukey's test.

SOURCE: EMBRAPA-CNPAF (1994).

After plowing, further mechanization tends not only to compact the soil again, but also to alter the soil's surface structure. If plowing is well done, with well-calibrated implements, the next step, leveling, can sometimes be eliminated. If leveling is necessary, only one pass should be carried out, 2 days before sowing.

Soil preparation helps minimize the effects of water deficit. A short period of water deficit can cause, in the rice crop, a 13.7% and 14% reduction in grain production and dry matter (DM) content, respectively (data not shown). Deep soil preparation with a moldboard plow minimizes the effect of a water deficit, increasing grain production by 29.6% and DM production by 23.2% (Table 9). This practical result indicates that, under moderate water deficit (10-15 days drought), good soil preparation can substitute supplementary irrigation. In this study, however, the response of the rice cultivar Guaraní in terms of grain production to the interaction between soil preparation and soil water regime was not confirmed. Under water-deficit conditions, or under supplementary irrigation by sprinkling, and following the recommended soil preparation, higher production was basically a result of better development of the rice plant's aerial parts and roots.

Density and depth of root system. Under monoculture, deep plowing markedly affects the depth and better distribution of roots in the soil profile. It also helps control weeds, and improves fertility, water infiltration, and the soil's physical properties (Kluthcouski et al. 1988).

Eliminating soil compaction, improving fertility, and incorporating fertilizers to a 40-cm depth positively affects root distribution and depth in the soil (Guimarães and Castro 1982; Kluthcouski et al. 1988). Root systems grown under the *barreirão* system developed well for both rice cv. Douradão (evaluated at the end of the reproductive phase) and *B. brizantha* grown in association (evaluated during flowering). In contrast, the root systems of degraded pastures alone, left as control over the same periods, were poorly developed. Crop rotation—degraded pastures of *B. decumbens* with rice cv. Douradão—and adequate soil preparation provided better environmental conditions for developing roots, which grew to as deep as 1.4 m (EMBRAPA-CNPAF 1994). The root system was densely developed in the top layer (0-20 cm) and,

Table 9. Averages of grain yield and dry matter (DM) weight of rice and pastures in association, according to watering regime (treatments) and the method of preparing the subtreatment.

Treatments	Rice production (t/ha)[a]	DM production (t/ha)	
		Rice	Pastures[b]
Water deficit	2.60	5.09	0.82
Supplementary irrigation	3.10	5.95	0.85
Conventional preparation	2.41	4.77	0.97
Recommended preparation	3.37	6.27	0.69
CV (%)	17.9	14.4	60.4

a. Fertilizers used as recommended for the *barreirão* system, Hacienda "Barreirão", Piracanjuba, Goiás, Brazil. The statistical analyses showed significant differences among the treatments at 5% for productivity and DM weight for rice and at 1% for subtreatments.

b. Evaluation carried out at rice harvest.

SOURCE: EMBRAPA-CNPAF (1994).

although density declined slightly with depth, it remained acceptable to 1.4 m deep.

Except in the first top centimeters of the soil, the root systems of degraded pastures alone were characterized by less developed roots. At deeper layers, root density diminished drastically, disappearing completely after 1 m—an indication of degradation of the soil's physicochemical properties. The deepening of the root system and the increase in its density—made possible by adequate soil preparation, fertilizers, and association with other plants—enabled the crop or forage to better absorb the nutrients and water still stored in the soil, particularly during the dry season.

Applying fertilizers

In the *barreirão* system, nutrients must be available in residual form to guarantee adequate development of forage species. Data available so far are insufficient for establishing the quantity and quality of nutrients needed to support productive pastures. Nevertheless, working within the economic limits of the average farm and the crops' potential response, minimum fertilizer levels can be established for less demanding crops such as rice and for more demanding ones such as maize and sorghum. These levels would be applicable to the poor *cerrado* soils, where concentrations of P range from 0 to 3 ppm, and of K from 0 to 45 ppm.

Fertilizer recommendations should be based on the results of soil analyses. Decisions on options for improving P levels in the soil—through the application of natural and partially acidulated phosphates or thermophosphates—and on base fertilizer applications at sowing are the joint responsibility of technician and farmer. These practices are necessary for good pasture establishment.

Base fertilizer applications. Traditional rice varieties adapt well, requiring relatively small rates of fertilizers, to the natural conditions of those areas of the *cerrados* that have not yet been degraded. Under these conditions, high rates of fertilizer are not necessarily reflected in production increases (Table 10), and may even cause excessive plant growth and thus lodging of the crop (Table 11). Forages grown in association have also been observed to react likewise. Rates of 50 kg/ha of P_2O_5 do not induce significant increases in yield of the rice crop, but higher rates tend to result in excessive lodging of the plants before grain filling, thereby reducing production through loss of harvest. Under experimental conditions, the maximum levels of P were ascertained to be 90 kg/ha P_2O_5 and 45 kg/ha K_2O.

Maize and rice crops do not differ much in their extraction and nutrient transfer to the grains. In the *barreirão* system, rice mobilizes 24% of the P_2O_5 and 22% of the K_2O applied, compared with 42% and 33%, respectively, for maize (see references and data in Table 12). If no losses occur through erosion or leaching, this means that most of the applied nutrients are retained in the soil or in the OM, that is, in residual form, and available to pastures.

Nitrogen application is fundamental, not only to improve the C-to-N ratio and so reduce the detrimental effects of decomposition, but also to provide plants with greater initial vigor. Zinc is the most limiting micronutrient in *cerrado* soils (Lopes 1983) and, ideally, should be added at a rate of about 5 kg/ha. For maize and soybeans, the application of 30 kg/ha

Table 10. Effect of fertilizer levels and of forage species on the rice crop's productivity.

Level of fertilizer[a]	Species in association	Rice productivity (t/ha)[b]	Relative production (%)
A1	*B. brizantha*	2.20	
	B. decumbens	2.32	
	A. gayanus	1.85	100
Average		2.04	
A2	*B. brizantha*	1.93	
	B. decumbens	2.31	
	A. gayanus	2.48	109
Average		2.24	
A3	*B. brizantha*	1.94	
	B. decumbens	2.45	
	A. gayanus	2.37	110
Average		2.24	

a. Dark-Red Latosols (LVE); pH = 5.9; Ca + Mg = 1.8 meq/100 g soil; contents of P, K, Cu, Zn, Fe, and Mn = 0.4, 125, 2.2, 0.4, 63, and 18 ppm, respectively; OM = 1.2%; site = Hacienda "Barreirão", Piracanjuba, Goiás, Brazil. The formula 4-30-10 was used, plus 20 kg/ha of $ZnSO_4$ and 30 kg/ha of FTE BR 10, applied as mixtures: A1 = 165 kg/ha; A2 = 355 kg/ha; A3 = 525 kg/ha.

b. Average of the rice cultivars Guaraní and Rio Paranaíba and distances of 40 and 50 cm between rows.

SOURCE: EMBRAPA-CNPAF (1994).

Table 11. Effect of fertilizer levels for rice cultivar Guaraní grown in association with the forage grass *Brachiaria brizantha* on the production of rice and forage green matter.

Fertilizer level[a]	Rice production (t/ha)*	Lodging in rice[b]	Forage green matter (t/ha)[c]
A1	1.25 b*	1	4.67
A2	2.05 a	4	11.82
A3	2.15 a	5	18.23
A4	1.85 a	5	21.80
CV (%)	11.3	—	22.90

a. Dark-Red Latosols (LVE); pH = 5.6; Ca + Mg = 1.5 meq/100 g soil; contents of P, K, Cu, Zn, Fe, and Mn = 0.7, 154, 2.4, 0.5, 187, and 42 ppm, respectively; OM = 1.7%; site = Hacienda "Barreirão", Piracanjuba, Goiás, Brazil; A1 = check (0); A2 = 150 kg/ha of 4-30-10 + 10 kg/ha of $ZnSO_4$ + 15 kg/ha of FTE BR 10; A3 = 2 × A2; A4 = 4 × A2.

b. On a scale where 1 = no lodging; 5 = 100% lodging.

c. Leaves and stalks; average of six 1-m^2 replicates; evaluation carried out 60 days after the rice harvest.

* Averages in the same column followed by the same letters are not significantly different ($P < 0.05$), according to Tukey's test.

SOURCE: EMBRAPA-CNPAF (1994).

Table 12. Quantities of N, P_2O_5, and K_2O extracted by rice and maize crops through stubble (dry leaves + stalks) and grains.

Crop	Production (t/ha)	Stubble production (t/ha)	Extraction (kg/ha) in:					
			Stubble			Grains		
			N	P_2O_5	K_2O	N	P_2O_5	K_2O
Rice[a]	4.52[b]	4.38[b]	33.4	3.8	123.2	49.9	22.0	18.7
Maize[c]	3.75	5.00	38.0	12.0	55.0	57.0	23.0	15.0

a. Average of five varieties planted in October.

b. SOURCE: Ohno and Marur (1977).

c. SOURCE: Malavolta (1967).

FTE BR 12 (a fertilizer mix of micronutrients) is also recommended. With the application of 105 kg/ha P_2O_5 and nutrients in quantities similar to those applied for the rice crop, yields of more than 3.5 t/ha in maize, and 3 t/ha in sorghum have been reached.

Mixing thermophosphates with water-soluble sources of phosphorus. Phosphorus, when applied to *cerrado* soils under natural conditions, loses its solubility. However, the immediate availability of this nutrient is desirable, on the one hand, for annual crops, and on the other, for controlling its availability to perennial crops such as forages. Soluble P can be obtained by applying water-soluble sources, which, however, are highly variable. Together with their degree of solubility in water, such variability strongly affects their prices.

By combining phosphates of intermediate solubility such as thermophosphates with soluble sources, formulas, or superphosphates, the costs of phosphate applications can be reduced while still meeting the requirements of the associated crops. An advantage of the thermophosphates is that, in addition to phosphorus, they provide various micro- and macronutrients. Some studies have demonstrated that, on a basis 100 kg of P_2O_5, a mixture of thermophosphate and superphosphate in any proportion results in rice yields that are higher than the check (Table 13). Even though higher rice grain yield was obtained with sources of soluble P, no significant differences were found among the proportions of thermophosphate-to-water-soluble source (20:80 and 60:40) in the presence of other nutrients, as

Table 13. Effect of applying proportional rates of thermophosphate and commercial formulas on (1) production and lodging of the rice cultivar Guaraní, (2) development of the forage grass *Brachiaria brizantha*, and (3) P content in this forage and soil.

Yoorin (thermophosphate) 4-30-16[a]	Rice production (t/ha)*	Lodging in rice[b,*]	Forage development[c,*]	P content in:	
				Forage (%)	Soil (ppm)
0:100	3.19 a*	3 a	4.5 a	0.10	1.1
20:80	3.11 ab	4 a	4.0 a	0.10	1.2
40:60	2.79 b	3 a	4.0 a	0.09	1.7
60:40	2.99 ab	4 a	4.0 a	0.08	2.5
80:20	2.76 b	3 a	4.0 a	0.08	2.7
100:0	2.74 b	3 a	4.0 a	0.07	2.8
0:100[d]	3.03 a	3 a	4.0 a	0.10	1.1
Check	0.96 c	2 b	4.0 a	0.06	1.0
CV (%)	8.85	35.4	12.0	—	—

a. Dark-Red Latosols (LVE); pH = 5.7; Ca + Mg = 0.7 meq/100 g soil; contents of P, K, Cu, Zn, Fe, and Mn = 0.4, 86, 2.4, 0.4, 209, and 38 ppm, respectively; OM = 1.9%; site = Hacienda “Barreirão”, Piracanjuba, Goiás, Brazil.

b. On a scale where 1 = no lodging; 5 = 100% lodging.

c. On a scale where 1 = poor, 2 = regular, 3 = good, 4 = very good, 5 = excellent.

d. No micronutrients.

* Averages in the same column followed by the same letters are not significantly different ($P < 0.05$), according to Tukey’s test.

SOURCE: EMBRAPA-CNPAF (1994).

recommended for the *barreirão* system. Mixtures of this type are not available on the market, making their preparation on the farm necessary.

FTE and zinc. In the *cerrados*, some micronutrients, especially zinc, are deficient for crop and forage production. Studies on the rice-*B. brizantha* associations indicate that the best rice yields are obtained with applications of 30 kg/ha of FTE BR 12 and 20 kg/ha of zinc sulfate (Table 14). Treatments that most negatively affected rice yield were the check with no Zn but with FTE and the application of Zn combined with the highest rates of FTE. Forage production was highest in the grass when both micronutrient sources were present. Lime applications increased the need for Zn and that the best results of liming were obtained when combined with the lowest levels of P fertilizer (Table 15).

Nitrogen and potassium applications for crop development. Applying N fertilizer to the developing maize crop is an indispensable practice in the *barreirão* system, whereas K applications depend on the soil's texture and K content. In very sandy soils, maize crops almost always need K fertilizers.

In contrast, applying N fertilizers to developing rice crops is debatable, taking into account the indirect effects that this practice can have on the plants. This nutrient tends to favor excessive growth and lodging in plants. In susceptible varieties, it favors more intense attack by the rice blast fungus (*Pyricularia grisea*), especially in drought years. The best results for development have been obtained with applications of both N and K. In this case, a small but significant effect was found for the interaction between the

Table 14. Effects of applying micronutrients on lodging and production of rice, development of the forage grass *Brachiaria brizantha*, and zinc uptake.

Treatment (kg/ha)[a]		Traits of the rice crop			Forage development[c,*]
FTE	Zn	Lodging[b,*]	Productivity (t/ha)*	Zn content in leaf (ppm)	
0	0	4.25 a*	2.31 b	12	3.95 a
30	0	3.75 a	2.33 bc	13	4.29 a
60	0	4.00 a	2.87 b	14	4.41 a
120	0	3.75 a	2.90 b	16	4.30 a
0	20	4.50 a	2.96 b	12	4.39 a
30	20	4.75 a	3.30 a	14	4.11 a
60	20	5.00 a	2.65 bc	15	4.25 a
120	20	4.25 a	2.79 b	17	4.68 a
CV (%)		26.4	12.1	5.3	—
No FTE		4.38	2.63	12	4.17
With FTE		4.29	2.81	14	4.34
No Zn		3.94	2.60	14	4.24
With Zn		4.63	2.93	15	4.36

a. Yellow-Red Latosols (LVA); pH = 5.5; Ca + Mg = 3.6 meq/100 g soil; contents of P, K, Cu, Zn, Fe, and Mn = 0.7, 86, 2.2, 0.5, 121, and 40 ppm, respectively; OM = 1.6%; site = Hacienda "Barreirão", Piracanjuba, Goiás, Brazil.

b. On a scale where 1 = no lodging; 5 = 100% lodging.

c. On a scale where 1 = poor, 2 = regular, 3 = good, 4 = very good, 5 = excellent.

* Averages in the same column followed by the same letters are not significantly different ($P < 0.05$), according to Tukey's test.

SOURCE: EMBRAPA-CNPAF (1994).

Table 15. Effect of increasing rates of P, Ca, and Zn on the rice-*Brachiaria brizantha* (Bb) system.

Treatment[a]			Rice production (t/ha)*	Bb (plants/m)	Nutrient contents in the:					
					Leaf			Soil		
P[b]	Ca[b]	Zn[b]			P (ppm)	Ca (%)	Zn (ppm)	P (ppm)	Ca (meq/100 g soil)	Zn (ppm)
60	0	0	2.67 ab*	1.33	—	—	—	—	—	—
60	0	10	2.49 b	2.00	—	—	—	—	—	—
60	0	20	2.72 ab	2.50	—	—	—	—	—	—
60	0	40	3.12 a	2.33	—	—	—	—	—	—
60	0	80	2.87 ab	1.17	—	—	—	—	—	—
120	0	0	2.91 ab	2.17	—	—	—	—	—	—
120	3	40	2.74 ab	2.83	—	—	—	—	—	—
120	3	40	2.56 ab	1.67	—	—	—	—	—	—
120	6	40	2.90 ab	1.33	—	—	—	—	—	—
Check			1.39 c	2.50	—	—	—	—	—	—
Average			2.64	1.99						
C.V. (%)			11.1	60.7						
—	—	0	2.672	1.33	—	—	12	—	—	0.66
—	—	10	2.494	2.00	—	—	13	—	—	0.73
—	—	20	2.722	2.50	—	—	13	—	—	0.77
—	—	40	3.129	2.33	—	—	13	—	—	0.90
—	—	80	2.879	1.17	—	—	14	—	—	1.20
C.V. (%)			8.6	31.8						
60	—	—	2.80	2.83	0.10	—	—	0.60	—	—
120	—	—	2.74	1.67	0.12	—	—	1.65	—	—
C.V. (%)			4.8	36.6						
—	0	—	3.12	2.33	—	0.43	—	—	1.80	—
—	3	—	2.74	2.83	—	0.50	—	—	2.60	—
—	6	—	2.90	1.33	—	0.68	—	—	2.85	—
C.V. (%)			6.7	31.8						

a. Soil LVA; pH = 5.5; Ca + Mg = 3.6 meq/100 g soil; contents of P, K, Cu, Zn, Fe, and Mn = 0.7, 86, 2.2, 0.5, 121, and 40 ppm, respectively.

b. P as P_2O_5 (kg/ha); Ca as lime (t/ha); Zn as zinc sulfate (kg/ha). Other nutrients applied as recommended for the *barreirão* system, Hacienda "Barreirão", Piracanjuba, Goiás, Brazil.

* Averages in the same column followed by the same letters are not significantly different ($P < 0.05$), according to Tukey's test.

SOURCE: EMBRAPA-CNPAF (1994).

fertilizer application and rice blast index (RBI; Table 16).

Where soils are of very low fertility and the water deficit is as long as 23 days, as occurs in Goiânia, State of Goiás, Brazil, a high incidence of pyricularia can be observed in rice panicles when fertilizer was applied during development. The best yields were obtained by applying K during this stage in Goiânia, and by applying a combined N and K fertilizer in Piracanjuba, Goiás (Table 16).

Table 16. Applying fertilizers during crop development and its effects on rice production and the rice blast index (RBI)[a] on *cerrado* farms, Brazil.

Fertilizer	Hacienda "Capivara", Goiânia, GO[b,*]		Hacienda "Barreirão", Piracanjuba, GO[c,*]	
	Production (t/ha	RBI (%)	Production (t/ha)	RBI (%)
Check	1.07 b	8.33 b	2.07 b	2.67 ab
+ N	1.17 ab	20.68 a	2.21 b	4.89 a
+ K	1.39 a	6.69 b	2.18 b	2.40 b
+ N + K	0.99 b	20.27 a	2.80 a	3.82 a
CV (%)	17.5	46.1	12.7	41.0

a. Expressed as the percentage of panicles attacked, averaged across three cultivars.

b. Yellow-Red Latosols (LVA); pH = 5.1; Ca + Mg = 0.9 meq/100 g soil; contents of P, K, Cu, Zn, Fe, and Mn = 0.9, 47, 2.0, 1.1, 99, and 120 ppm, respectively.

c. Dark-Red Latosols (LVE); pH = 5.8; Ca + Mg = 8.6 meq/100 g soil; contents of P, K, Cu, Zn, Fe, and Mn = 2.3, 137, 1.6, 2.3, 77, and 110 ppm, respectively; OM = 2.8%.

* Averages in the same column followed by the same letters are not significantly different ($P < 0.05$), according to Tukey's test.

SOURCE: EMBRAPA-CNPAF (1994).

Seed treatment

Although areas with degraded pastures can offer advantages in terms of reducing pest and disease incidence, they also present appropriate natural conditions for the reproduction and survival of the spittlebug, an insect pest that attacks grassy species, stunting their development. Preventive treatment of seeds of annual crops such as rice, maize, sorghum, and millet is thus essential. Systemic insecticides, based on carbofuran, carbosulfan, and thiodicarb, are the most suitable against the spittlebug.

Termites are other soil pests that can affect the yield of the rice crop, especially in years when rains are irregular. This insect can be best controlled with products based on carbofuran (Table 17). The

Table 17. Influence of seed treatment and soil preparation[a] on the infestation and damage by rhizophilous termites on the rice cultivar Guaraní grown in association with the forage grass *Brachiaria brizantha* in the *barreirão* system, Hacienda "Santo Antônio", Santo Antônio de Goiás, Brazil.

Treatment	Stalks attacked (%)*	Ratio of root-to-stalk weights*	Termites/L soil (no.)*
No treatment	3.1 a*	0.218 a	6.9 a
Carbosulfan	3.2 a	0.234 a	3.4 a
Carbofuran	0.3 b	0.223 a	2.1 a
Carbofuran + carboxin	0.3 b	0.235 a	3.3 a
Carbofuran + pyroquilon	0.4 b	0.247 a	3.9 a
Soil preparation			
With plowing	1.3 a	0.243 a	1.5 b
With harrowing	1.6 a	0.220 a	

a. Soil is similar to that listed in footnote a, Table 16, for Goiânia, Goiás; fertilizer applications as recommended for the *barreirão* system.

* Averages in the same column followed by the same letters are not significantly different ($P < 0.05$), according to Tukey's test.

SOURCE: EMBRAPA-CNPAF (1994).

hymenopterous *Elasmopalpus lignosellus*, or lesser cornstalk borer, is an erratic pest that can severely damage associated annual crops. Seeds should be treated with the above-mentioned insecticides.

The disease of greatest economic importance in rice farming is rice blast although in areas of degraded pastures the *P. grisea* inoculum may not exist. Nevertheless, in operations using the *barreirão* system, some severe attacks of the disease were observed, even with tolerant or resistant rice varieties. The chemical product that best controls blast is based on pyroquilon (Filippi and Prabhu 1990; Prabhu 1990), permitting the green matter of rice stalks to be maintained over longer periods after the grains have physiologically matured, thus reducing lodging. Treating seeds of the most susceptible varieties, such as cv. Rio Verde, had a significant effect on disease control. In contrast, cultivar Douradão (susceptible) showed no positive response to the application. Instead, pyroquilon intensified the cultivars' propensity to lodge, probably because of their greater height and heavier panicles (Table 18).

Sowing

In monoculture and in the *barreirão* system, poor establishment affects grain yield. Placing the fertilizer below the seed of the annual crop improves yield. The homogeneous distribution and correct sowing density of seeds throughout the furrows are essential for improved plant production, particularly in C4 types such as sorghum, millet, and *Brachiaria* spp. Placing forage seeds, especially of *B. decumbens* and *B. brizantha*, at greater depths and mixed with fertilizer, can increase their competition with annual crops, particularly rice. The density, sowing time, and planting distance between seeds are also important aspects to be considered.

Varieties. Varieties adapted to the region should be preferred. For sorghum (Table 19) or millet, varieties tolerant of soil acidity are recommended. For maize (Table 20), the varieties should be tolerant of acidity and aluminum, and ears should be well inserted into the stalk to prevent losses during harvest. Short-cycle rice cultivars (100-110 days), which permit a greater period of growth

Table 18. Effects of seed treatment, with or without pyroquilon, on the production of three upland rice varieties grown in association with the forage grass *Brachiaria brizantha*.

Variety[a]	Treatment	Production (t/ha)*	Lodging in plants[b]
Guaraní	Yes	2.06 c*	5
	No	2.58 b	4
Douradão	Yes	3.35 a	2
	No	3.34 a	1
Rio Verde	Yes	1.51 d	1
	No	0.52 e	1
CV (%)	—	5	—

a. Diminishing order of tolerance of pyricularia: Guaraní > Douradão > Rio Verde. Fertilizer applications as recommended for the *barreirão* system, Hacienda "Barreirão", Piracanjuba, Goiás, Brazil.

b. On a scale where 1 = no lodging; 5 = 100% lodging.

* Averages in the same column followed by the same letters are not significantly different ($P < 0.05$), according to Tukey's test.

SOURCE: EMBRAPA-CNPAF (1994).

Table 19. Production of sorghum hybrids grown in association with the forage grass *Brachiaria brizantha* cv. Marandú at Ituiutaba, Minas Gerais, Brazil.[a]

Hybrid	Production (t/ha) according to sowing date[b]			
	8 Dec 1993	18 Jan 1994	9 Feb 1994	Average
AG 122 (maize control)	1.99 (0.56)[b]	2.44 (0.68)	1.60 (0.45)	2.014 (0.56)
AG 1017	2.19 (0.49)	2.70 (0.60)	2.22 (0.50)	2.375 (0.53)
AG 2005-E	2.97 (0.66)	4.08 (0.91)	3.34 (0.75)	3.469 (0.77)
BR 303	2.89 (0.64)	3.66 (0.82)	3.44 (0.77)	3.336 (0.74)
BR 304	2.82 (0.63)	3.34 (0.74)	2.28 (0.50)	2.815 (0.62)
Average	2.57 (0.60)	3.24 (0.75)	2.58 (0.59)	2.802 (0.64)

a. Fertilizer applications: 500 kg/ha of 4-20-20 + FTE, 2 t/ha of lime, 50 kg/ha of N during development of crops sown on 18 Jan and 9 Feb; and 92 kg/ha in split applications for crops sown on the first sowing date (8 Dec).

b. Values in parentheses indicate rates of return; production costs = US$359.86/ha.

Table 20. Production of maize varieties grown in association with the forage grass *Brachiaria brizantha* cv. Marandú at six sites, Brazil.[a]

Variety	Maize production (t/ha) by site						
	Piracanjuba-GO	Guapó, GO 1992/93[b]	Rondonópolis-MT 1992/93[b]	Santo Antônio de Goiás-GO 1992/93[c]	Goiânia, GO 1993/94[d]	Gabriel Moneiro-SP 1993/94[e]	Average[f]
AG-106	3.93	3.90	1.94	—	—	—	3.91
AG-510	3.69	5.12	2.59	3.11	4.53	4.22	4.13
AG-612	—	—	—	3.22	—	—	—
Agromen-1022	1.72	3.48	—	2.08	—	3.77	2.76
Agromen-1030	1.73	3.73	—	—	—	—	2.73
Agromen-2007	—	—	—	2.24	1.95	3.22	2.47
Agromen-2010	—	—	—	3.82	2.00	—	2.91
BR-106	3.60	2.52	—	3.85	2.13	—	3.02
C-125	—	—	2.54	2.38	—	6.11	4.24
C-126	5.38	1.91	—	—	—	—	3.64
C-425	2.92	4.22	1.89	2.27	—	4.11	3.38
C-133	3.52	3.44	1.94	3.69	3.34	6.11	4.02
C-233	4.29	2.69	—	—	—	—	3.49
C-322	4.92	3.29	—	2.81	3.86	5.38	4.05
Dina-100	2.750	2.89	1.66	3.33	3.66	—	3.16
EMGOPA-501	4.92	2.54	0.92	—	—	—	3.73
CMS-36	—	—	—	1.95	—	—	—
Pioneer-3210	5.89	3.15	—	2.78	—	3.33	3.79
XL-605	4.59	3.71	—	—	—	—	4.15
XL-678	2.12	2.32	0.92	—	—	—	2.22
XL-678-C	2.67	2.84	1.94	—	—	—	2.75

a. Fertilizer applications as recommended for the *barreirão* system; application of lime, if necessary, before sowing.

b. Average of 4 samples.

c. Average of 2 samples.

d. Average of 10 samples.

e. Result of one sample.

f. Does not include data from Rondonópolis, MT, Brazil.

within the rainy season, are preferred as they permit the better development of associated forages, although this does not impede the use of more productive intermediate-cycle cultivars (130-140 days). Some tall varieties such as Caiapó, with an intermediate cycle and droopy leaves, can give shade faster, producing more in association than in monoculture.

Plant phenotype is highly important in rice-pasture associations. Overall, short varieties are less competitive than tall ones.

Sowing distance and density for annual crops. In the *barreirão* system, the distance between furrows needs to be reduced for rice sowing and seed density per row needs to be increased (Table 21) because this crop is less competitive than is maize, sorghum, or millet. Rapid shading of the soil thus becomes possible, reducing plant growth in the forage. A distance of 30-45 cm between furrows is recommended, this spacing being smaller as the cycle is shorter and the variety has fewer shoots.

Significant modifications in plant height have not been observed in rice grown in association with forages or planted in monoculture. However, grain production is reduced by about 8% when rice is grown in association with *A. gayanus* and by 21% when grown in association with *B. brizantha* (Table 22). The increased sowing density of the rice crop produced greater grain yield, on the average, of the 12 varieties and lines evaluated.

Sowing distance and density for forages. The adjustment of the distance between furrows for sowing forage species not only determines the best ground cover, but also the capacity for obtaining better forage production. Sowing density, in turn, not only helps improve pasture quality, but also affects the yield of the annual crop, especially of rice. In *Brachiaria*, no differences have been observed among sowing the seeds by broadcasting, in the same furrows where the annual crop is sown, or between them (Table 23), provided that the edaphoclimatic conditions and sowing time are those indicated for the rice crop's optimal development. Similarly, the simultaneous planting of crop and forage did not affect rice yield. Accordingly, the most economical method is to plant *Brachiaria*

Table 21. Effect of sowing distance and density on the production of the upland rice cultivar Guaraní grown in association with the forage grass *Brachiaria brizantha*.[a]

Distance (cm)	Production of rice grain (t/ha) over period*			
	100 seeds/m		50 seeds/m	
	1990/91[b]	1990/91[c]	1991/92[b]	1991/92[c]
50	3.28 b*	2.07 a	2.23 b	1.79 a
40	3.85 a	2.28 a	2.91 ab	2.13 a
30	—	—	3.90 a	2.64 a
CV (%)	15.5	—	14.3	24.6

a. Fertilizer applications as recommended for the *barreirão* system.
b. Piracanjuba, Goiás (GO).
c. Santo Antônio de Goiás, GO, Brazil.
* Averages in the same column followed by the same letters are not significantly different ($P < 0.05$), according to Tukey's test.
SOURCE: EMBRAPA-CNPAF (1994).

Table 22. Effect of competition of the forage grasses *Andropogon gayanus* and *Brachiaria brizantha* on plant height and production of rice at several sites in the Brazilian *cerrados*.[a]

Treatment	Plant height (cm)			Production (t/ha)				
	Guapó, GO	Piracan-juba-GO	Nova Mutum-MT	Guapó-GO	Piracan-juba-GO	Nova Mutum-GO	Average[b]	Relative (%)
Rice alone	114	117	90	4.33	2.69	1.77	2.932	100
Rice + *A. gayanus*	115	117	91	4.26	2.76	1.06	2.697	92
Rice + *B. brizantha*[c]	113	119	89	3.48	2.25	1.18	2.307	79
Rice + *B. brizantha*[d]	110	118	89	3.56	2.57	1.23	2.459	84

a. Fertilizer applications as recommended for the *barreirão* system.
b. Average of 12 rice varieties and/or lines.
c. Rice planted at a density of 60 seeds/m.
d. Rice planted at a density of 100 seeds/m.

SOURCE: EMBRAPA-CNPAF (1994).

Table 23. Effect of sowing time and spatial arrangement of the forage grass *Brachiaria brizantha* (Bb) on the production of the rice cultivar Guaraní.[a]

Arrangement of Bb with respect to rice	Sowing time			
	With rice (t/ha)		30 days after rice (t/ha)	
In same row	2.43	—	2.47	100
Between rows	2.59	2.51	2.60	105
Broadcast	2.58	2.62	2.58	105
Average	2.53	2.56	—	—
Relative production (%)	100	101	—	—

a. Fertilizer applications as recommended for the *barreirão* system, Hacienda "Barreirão", Piracanjuba, Goiás, Brazil.

simultaneously in the furrow with the annual crop and broadcast *A. gayanus*, thereby reducing the number of operations.

Sowing density for forages can interfere not only with rice yields (Table 24), but also with the yields of other annual crops. Densities greater than 4-6 plants/m^2 of the forages *A. gayanus*, *B. brizantha*, and *B. decumbens* will reduce rice yields noticeably. Field studies showed that *A. gayanus*, because of its slow initial development, may compete less with a crop. In summary, the higher sowing densities for forages can reduce crop productivity, although they do not always generate better pastures, whereas lower densities for forages favor the annual crop. Similarly, the earlier the sowing is after the onset of the rainy season, the better the forage's development will be after the grains have been harvested.

Mixing forage seeds with fertilizers. Because *Brachiaria* seed must be sown and machinery suitable for the *barreirão* system is lacking, this seed is mixed with fertilizer, then incorporated into the soil. To sow other forages such as those of the *Panicum* and *Andropogon* genera, conventional practices are followed, because if their seed is mixed with fertilizers, the salts in the fertilizers may damage the seed. For the

Table 24. Effect of sowing density of three forage species grown in association with the rice cultivar Guaraní on rice production and green matter (GM) production of the forages.[a]

Forage	Sowing density (kg/ha)	Plants/m² (no.)	Rice production (t/ha)[b]	GM production (t/ha)
A. gayanus	0	1.75	3.54 (100)[c]	8.33
	10	2.00	3.07 (87)	16.27
	20	4.27	2.87 (81)	21.57
Average			3.16	15.39
B. decumbens[c]	0	1.00	3.90 (100)	11.30
	5	13.3	1.85 (48)	20.30
	10	29.2	0.89 (23)	27.30
Average			2.21	19.63
B. brizantha[d]	0	1.75	3.64 (100)	10.40
	5	7.93	2.28 (63)	23.87
	10	18.25	1.63 (45)	23.43
Average			2.51	19.23

a. Fertilizer applications as recommended for the *barreirão* system, Hacienda "Barreirão", Piracanjuba, Goiás, Brazil.
b. Values in parentheses are percentages.
c. Crop value = 40%.
d. Crop value = 60%.

SOURCE: EMBRAPA-CNPAF (1994).

barreirão system, seed-fertilizer mixtures should be prepared, then incorporated into the soil within 24 h. Prolonged storage can reduce the germinability of *B. brizantha* seed by more than 80% (Table 25).

Depths for applying fertilizers and sowing forage seeds. Forage species of the genera *Panicum* and *Andropogon* should be planted close to the surface. Those of the genus *Brachiaria*, mainly *B. brizantha* and *B. decumbens*, should be incorporated into the soil at a depth of 8-10 cm. This practice delays seedling emergence in these forages, thereby reducing competition for the rice crop. Studies on fertilizer use and sowing depths have shown that this practice produces the best results for crops likely to be limited in growth because of low soil fertility, variable climatic conditions, and different sowing times. On comparing sowings at 3, 6, 9, and 12 cm below the surface in soils of average texture, minor variations were observed in the forage population, but with a significant increase in grain yield of the rice crop as the

Table 25. Germination of the forage grass *Brachiaria brizantha*[a] and green matter (GM) production of aerial parts, 60 days later, according to storage time after mixing the seeds with fertilizers.

Storage (days)	Germinated plants (no./plot)*	GM (t/ha)*
0[b]	108 a*	5.79 a
0[c]	99 b	5.33 ab
0[d]	93 b	5.32 ab
4	84 c	5.15 ab
8	40 d	4.79 ab
14	23 e	4.21 b
22	16 f	0.84 c
CV (%)	6.52	13.1

a. *B. brizantha* seeds, crop value = 40.3% (51.7% for purity and 78% for germination), equivalent to 547 seeds per plot, mixed with 300 kg/ha of 4-30-16, 30 kg/ha of FTE, and 20 kg/ha of $ZnSO_4$. The emergence of plants in the nonfertilized plot took 17 days. Except for the first treatment, all the other *B. brizantha* seeds, with or without fertilizer, were incorporated at a depth of 8 cm.
b. Forage seed planted at 3 cm deep and fertilizer incorporated at 8 cm deep.
c. Forage seed and fertilizers mixed on the day of sowing, both placed at 8 cm deep.
d. Forage seed incorporated at 8 cm deep, no fertilizer.
* Averages in the same column followed by the same letters are not significantly different ($P < 0.05$), according to Tukey's test.

SOURCE: EMBRAPA-CNPAF (1994).

seed-fertilizer mixture was incorporated at greater depths (Table 26). Either very clayey or very sandy soils can hinder seedling emergence, especially if a dry period occurs soon after sowing. Where possible, local evaluations should be conducted to determine the best depth for fertilizer applications and for sowing forage seeds.

Machinery for sowing. The adjustment of the planter and speed of operation greatly influence the success of sowing. Some planters on the market do not have the necessary mechanisms for practicing the *barreirão* system, and are thus unsuitable. During sowing, the machine should operate at 3-5 km/h. Adjustments made for sowing should ensure:

1. Correct dosages of seed and fertilizer
2. Adequate depth of furrows for fertilizer application and sowing
3. Appropriate horizontal distance between rows for fertilizer application and sowing
4. That seed-feeder mechanisms do not damage seed

To make planters more adjustable, they should have:

1. A minimum distance of 30-40 cm between the seed-feeder mechanism and the bottom of the furrow receiving seed
2. A spring system that makes possible the differentiation between depth of fertilizer application versus placement of seeds of annual crops
3. A variable distance between rows, the minimum being 30-35 cm
4. A seed-feeder system in the form of a horizontal, inclined, or vertical perforated disk
5. Fertilizer-feeder mechanisms that prevent the formation of vacuums inside the planters' dispenser boxes
6. Mechanisms for controlling sowing depth

Analyzing the growth of annual crops and forages

The development of associated species, especially of their leaves, is modified by interspecific competition. Initially, annual crops, ideally, should develop

Table 26. Effect of depth of fertilizer incorporation and of sowing seed of two forage grasses on the associated crop's (rice) productivity.

Forage	Sowing depth (cm)	Number of forage plants/m*	Evaluation of forage[a]	Rice production (t/ha)[b, *]
B. decumbens	3	6.5 a*	3.92	1.58 bc
	6	6.3 a	4.17	2.13 ab
	9	7.8 a	4.03	2.23 a
	12	7.0 a	4.65	1.73 abc
B. brizantha	3	6.3 a	4.40	1.20 c
	6	4.5 a	4.37	1.60 bc
	9	7.5 a	4.10	1.64 bc
	12	5.2 a	4.22	2.08 ab

a. On a scale where 1 = poor, 2 = regular, 3 = good, 4 = very good, 5 = excellent.

b. Fertilizer applications as recommended for the *barreirão* system, Hacienda "Barreirão", Piracanjuba, GO, Brazil.

* Averages in the same column followed by the same letters are not significantly different ($P < 0.05$), according to Duncan's test.

SOURCE: EMBRAPA-CNPAF (1994).

with minimum competition from forages until harvest. From then on, forage species should develop at a rate that would permit grazing as soon as possible.

Figures 1 and 2 show the results of trials for evaluating the growth rate of associated crops. From seedling emergence onward, maize, sorghum, millet, and rice crops affect the growth

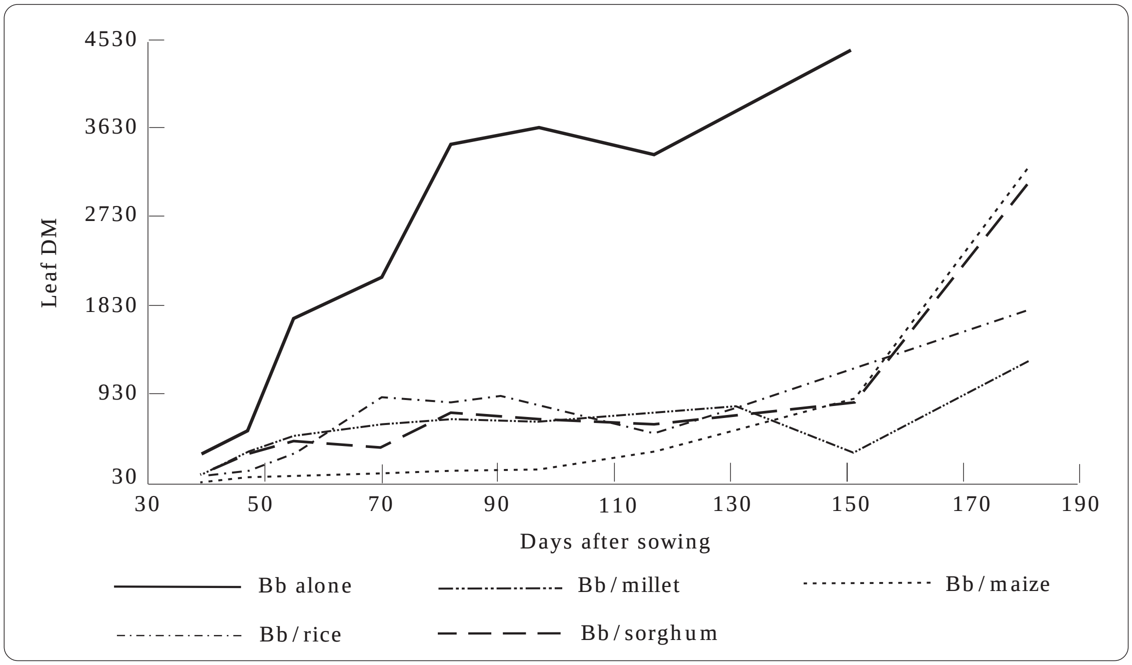

Figure 1. Leaf dry matter (DM) production (kg/ha) of the forage grass *Brachiaria brizantha* cv. Marandú (Bb) grown in monoculture and in association with millet, maize, rice, and sorghum.

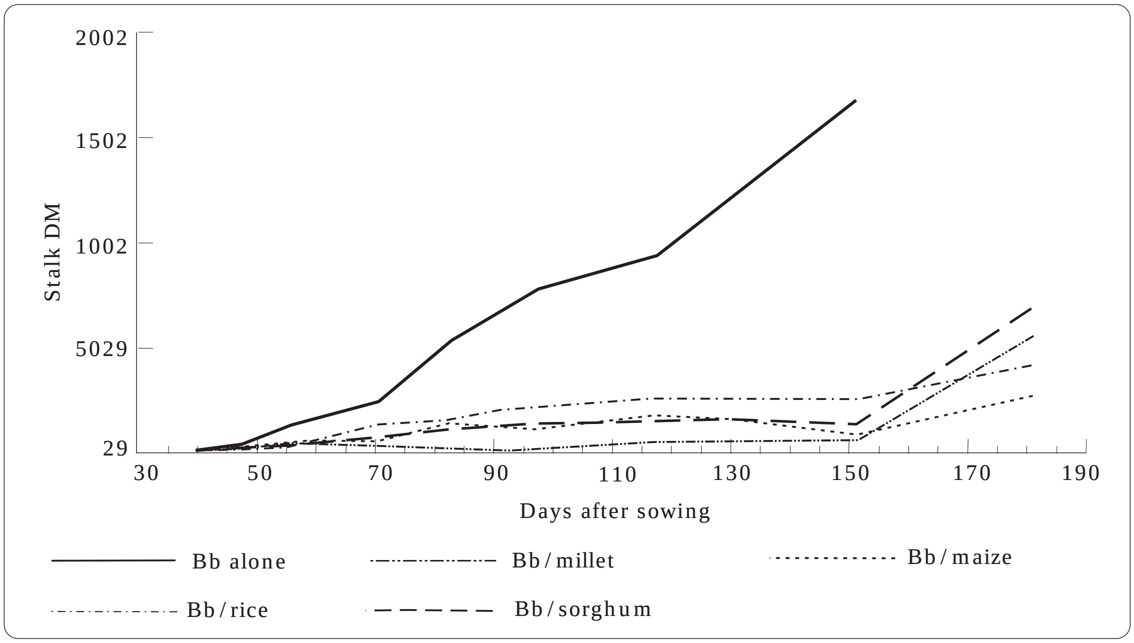

Figure 2. Stalk dry matter (DM) production (kg/ha) of the forage grass *Brachiaria brizantha* cv. Marandú (Bb) grown in monoculture and in association with maize, sorghum, rice, and millet.

of leaves and stalks in the associated grass, resulting in lower values than for *B. brizantha* cv. Marandú under monoculture.

Sorghum, millet, and rice crops were harvested 110 days after seedling emergence, whereas maize was harvested at 131 days. Forage under monoculture began senescence and lodging at 150 days after emergence. In contrast, the forage grown in association with any of the four crops mentioned above during the same period had higher leaf production than stalk production, probably because the pastures were cut when the crops were harvested. The increased production of new shoots and leaves also favored soil cover (Figure 3). Production of the maize, sorghum, millet, and rice crops was, respectively, 3.58, 2.24, 1.26, and 2.56 t/ha. Daily maximum growth rate (Figure 4) of the forage under monoculture was 392 kg/ha, whereas, when in association with maize, sorghum, rice, and millet, production was 32, 75, 91, and 26 kg/ha, respectively.

All the crops evaluated competed with *B. brizantha* cv. Marandú, interfering with its leaf and stalk growth. At 180 days after emergence, recovery in the forage was better when grown in association with millet, followed by sorghum, rice, and maize (data not shown).

Sites for Evaluating the *Barreirão* System

During 1987/88 and 1990-1994, 81 demonstration units of the *barreirão* system were established and monitored in seven states of Brazil. During these periods, yields varied from 0.60 to 3.41 t/ha for rice and from 2.10 to 7.43 t/ha for maize (Table 27). The average yields per hectare were 33.5 sacks (60 kg each) for rice and 61.5 sacks (60 kg each) for maize. In the *barreirão* systems monitored by the technical group from EMPRAPA Arroz e Feijão (CNPAF), total loss did not occur because of the effect of rainfall distribution. In some cases, yield reductions were observed, which could have been attributed to intense attack by the rice blast fungus. Soils of the sites where the *barreirão* systems were implemented were predominantly of low fertility, with high-to-intermediate acidity and a clayey-to-sandy texture.

Pasture Performance on Farms

A survey of 20 livestock owners who used the *barreirão* system showed that their farms varied in carrying capacity between the dry and rainy seasons of 1993 and 1994:

> In the 1993 dry season, the average stocking rate was 0.6 AU/ha on degraded pastures, while on recovered pastures under the *barreirão* system, it was 1.2 AU/ha—a 100% increase. In the rainy season, the increase was 117%, that is, the average rose from 1.2 to 2.6 AU/ha.
>
> In the 1994 dry season, the carrying capacity rose from 0.7 to 1.5 AU/ha, which represents an increase of 114%. In the rainy season of that same year, the increase was 100%, rising from 1.2 to 2.4 AU/ha.

As can be observed, there was a significant increase in the carrying capacity of the pastures renewed with the *barreirão* system.

Liveweight losses in animals on degraded pastures were, for the dry seasons of 1991 to 1994, 0.36, 0.29, 0.34, and 0.27 kg/day, respectively.

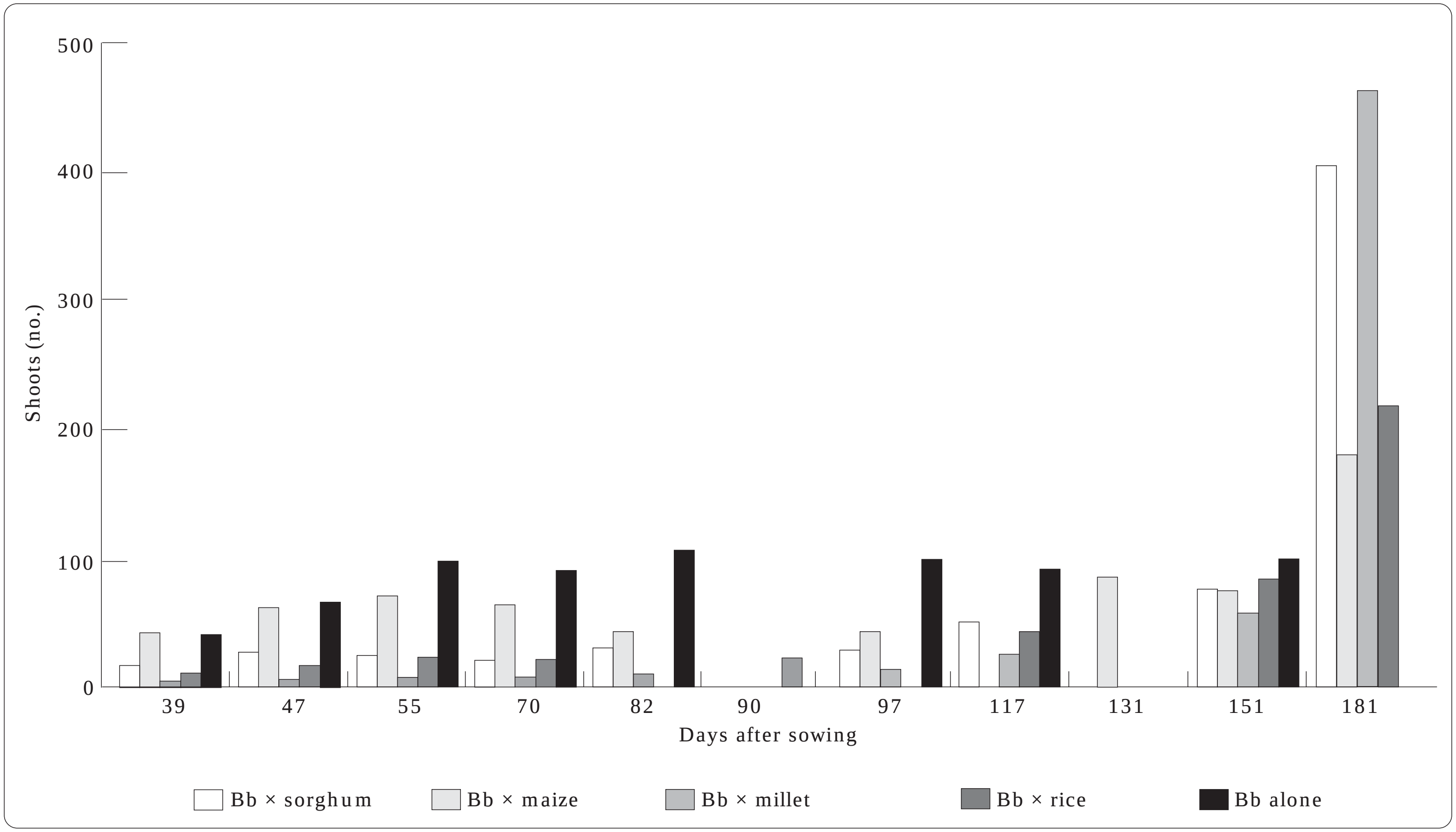

Figure 3. Evolution of the number of shoots of the forage grass *Brachiaria brizantha* cv. Marandú (Bb) grown in monoculture and in association with sorghum, maize, millet, and rice.

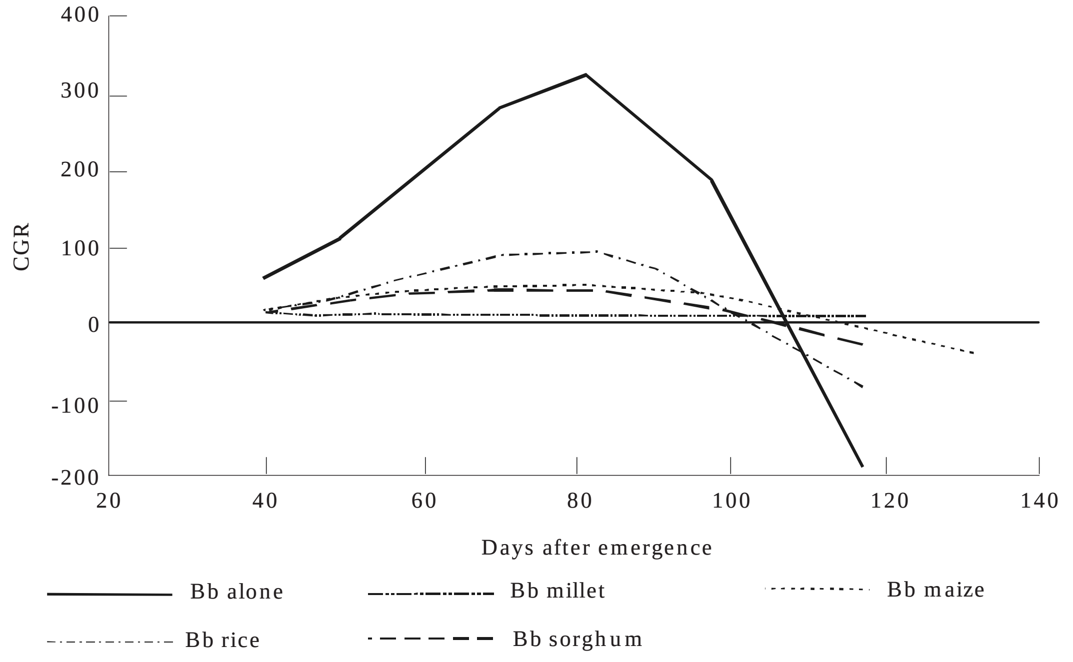

Figure 4. Daily crop growth rate (CGR) (kg/ha) of the forage grass *Brachiaria brizantha* cv. Marandú (Bb) grown in monoculture and in association with millet, maize, rice, and sorghum.

Table 27. Production of rice and maize in demonstration units of the *barreirão* system over four growing seasons and across seven states of Brazil.

Growing season	Crop	Sites (no. of tests)[a]	Production (t/ha)		
			Average	Maximum	Minimum
1987/88	Rice	GO, MT (5)	2.06	2.65	1.41
1990/91	Rice	GO (11)	2.04	2.58	0.99
1991/92	Rice	GO, MT, MG, TO, MS (15)	2.28	3.20	1.10
1992/93	Rice	GO, MT, MG (8)	1.86	2.16	1.44
1992/93	Maize	GO (3)	4.02	5.52	3.18
1993/94	Rice	GO, SP, MS, MG, BA, TO (23)	1.80	3.41	0.60
1993/94	Maize	SP, MS, GO, MT, MG (16)	3.36	7.43	2.10

a. Sites in the Brazilian states of GO = Goiás; MT = Mato Grosso; MS = Mato Grosso do Sul; TO = Tocantins; MG = Minas Gerais; SP = São Paulo; BA = Bahia.

According to these preliminary results, the average daily liveweight gain per animal in 1994 was 0.3 kg in the dry season and 0.5 kg in the rainy season.

Farmers point out reasons for not adopting the *barreirão* system: lack of adequate machinery (90%) > lack of specific credit (70%) > costs of machinery and implements (60%) > farmer’s lack of experience and interest (60%) > lack of specific technical assistance (35%).

Socioeconomic Analysis of the *Barreirão* System

The *barreirão* systems in which rice was planted in association with forages, was analyzed economically in terms of its crops and demonstration units. The analysis showed that production costs remained stable over a 4-year period, even though the value of the harvest underwent considerable variation (Table 28). However, the profits-to-costs ratio varied from 0.83 to 1.27, meaning that, as well as recovering pastures, farmers obtained additional profits. The variations in production for the 1992/93 and 1993/94 seasons, compared with the 1991/92 season, were due to short periods of drought; in some cases, to replacing the rice cultivar Guarani with cv. Douradão, which is more susceptible to rice blast; and to harvest losses caused by a lack of machinery at the appropriate time.

In evaluating 19 *barreirão* systems, the profits-to-costs ratio for maize ranged from 0.80 to 1.06 (Table 29). In 1993/94, a 13% increase was observed in production costs, together with a 16% reduction in productivity, compared with the preceding period. However, the profits-to-costs ratio considers only grain production of rice and maize. Residues that remain in the pastures (through soil preparation, fertilizer application, and seeds) represent nearly 63% of production costs (Yokoyama et al. 1992). Thus, farmers benefit not only through grain production but by using the recovered pastures for meat or milk production. Fertilizer applications and soil management are the most costly tasks in the *barreirão* system.

Table 29. Economic results of demonstration units using the *barreirão* systems that used maize-forage associations.

Detail	Periods	
	1992/93[a]	1993/94[b]
Production (no. of 60-kg sacks)	67	56
Total income (US$/ha)	402.00	341.60
Production costs (US$/ha)	376.32	424.86
Rate of return	1.06	0.80

a. Three demonstration units in GO (see footnote a, Table 27, for explanation of this and other Brazilian state acronyms).
b. Sixteen demonstration units in GO, MG, MS, MT, and SP.

SOURCE: Yokoyama et al. (1995).

Other Benefits of the *Barreirão* System

The socioeconomic analysis presented in the previous section includes the direct relationships between profits

Table 28. Comparative production costs, prices, production, and rate of return of the *barreirão* systems that used rice-forage associations.

Growing season	Production costs (US$/ha)	Relative costs (%)	Rice prices (US$/60 kg)	Relative prices (%)	Production (60-kg sacks/ha)	Relative production (%)	Rate of return
1990/91[a]	356.21	100	13.35	100	34	100	1.27
1991/92[b]	277.95	78	7.97	60	38	112	1.09
1992/93[c]	321.80	90	10.00	75	31	91	0.96
1993/94[d]	334.69	94	9.30	70	30	88	0.83

a. Eleven demonstration units in GO (see footnote a, Table 27, for explanation of this and other Brazilian state acronyms).
b. Fifteen demonstration units in MT, MS, TO, GO, and MG.
c. Eight demonstration units in MT, GO, and MG.
d. Twenty-three demonstration units in GO, MT, MS, SP, BA, and MG.

SOURCE: Yokoyama et al. (1995).

and costs, considering only grain production and excluding returns from (1) meat and milk production; (2) probable increase in the herd's birth rate and reduction in animal mortality; (3) reduction or elimination of costs for controlling anthills and perennial weeds; (4) reduction or elimination of liveweight losses and of herd mortality in the dry season; (5) better quality carcass production; and (6) probable reduction of the need for mineral supplements for animals.

With respect to soils, other benefits include (1) the profile's improvement by reducing compaction, correcting acidity, and increasing nutrients and OM; (2) reduced water erosion; and (3) the favoring of deep rooting by forage species, thus facilitating work with agricultural machinery.

Ecological benefits resulting from the *barreirão* system include (1) better ground cover and reduced soil degradation, thus favoring availability of food for herbivores; (2) reduction in the rate of opening up new areas, particularly in the Amazon Basin; (3) reduction in (a) erosion of river watersheds due to greater infiltration of water through the soil, and (b) pollution of water sources for urban centers; (4) increased volume and quality of groundwater; and (5) reduction in use of chemical products to control weeds and pests.

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To save space, the following abbreviations are used:

CNPAF	Centro Nacional de Pesquisa de Arroz e Feijão
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária

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CHAPTER 16

Improved Rice/Pasture Systems for Native Savannas and Degraded Pastures in Acid Soils of Latin America

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Abstract

Long-term, continuous cultivation of annual crops in the South American savannas is questionable, and, although improved grass/legume pastures protect the soil, their establishment costs are far beyond the reach of the average farmer. Within this region, characterized by low-fertility acid soils, more than 15 million hectares are under highly degraded *Brachiaria* pastures. Reclaiming these pastures as pure-grass systems is impractical because of the length of time farmers must wait to recover the investment made in inputs. More profitable is to plant adapted rice (*Oryza sativa*) lines in association with grass/legume mixtures (selected specifically for this environment) in areas under degraded pastures. Rice yields can be more than 3 t/ha, and, at the same time, either a new pasture is established or the old degraded pasture is reclaimed and the residual fertilizer from the crop improves soil fertility. After the rice harvest, the reclaimed pasture is ready for grazing. Forage legumes alone can also be planted simultaneously with rice on degraded pastures. Once these legumes are well established, pasture quality and, ultimately, soil quality improves. Factors contributing to pasture degradation will probably affect rice production. Soil nutrient imbalances and deficiencies can be corrected with inputs bought with the income from the rice harvest, without farmers having to assume large risks.

Resumen

El sistema de cultivos anuales en forma continuada en el ecosistema Sabana de América del Sur ha sido cuestionado a largo plazo. Por otra parte, las pasturas mejoradas gramíneas-leguminosas, aunque protegen el suelo, tienen costos de establecimiento que van más allá de las posibilidades del promedio de los productores. En esta región, caracterizada por suelos ácidos de baja fertilidad, existen más de 15 millones de hectáreas en pasturas de *Brachiaria* sp. en estado avanzado de degradación. La recuperación de estas pasturas como un sistema de sólo gramínea no es atractivo, debido al largo tiempo que debe transcurrir antes de que el productor reciba algún retorno económico por la inversión necesaria en insumos. La siembra de líneas adaptadas de arroz (*Oryza sativa*) en asociación con mezclas de gramíneas-leguminosas seleccionadas para este ambiente, en zonas con pasturas degradadas y como parte de un sistema de cultivo, permite obtener altas producciones de arroz (más de 3 t/ha), a la vez que se logra el establecimiento de una nueva pastura o la recuperación de una ya degradada y el aprovechamiento del fertilizante residual como un mejorador químico de la fertilidad del suelo. Después de la cosecha de arroz, la pastura recuperada quedó lista para pastoreo con animales. Las leguminosas forrajeras también se pueden sembrar al mismo tiempo con el arroz sobre las pasturas degradadas, y cuando se establecen bien mejoran la calidad de las pasturas y finalmente la calidad del suelo. Los factores que contribuyen a la degradación de las pasturas probablemente afectarán la producción de arroz. El retorno económico de la cosecha de arroz permite corregir los desbalances y deficiencias en el suelo sin asumir grandes riesgos.

Introduction

The savanna ecosystem of South America covers about 250 million hectares of acid soils (mainly Oxisols), of which 16 million are found in Colombia (Cochrane et al. 1985). Most of these are adequate for annual cropping or establishing improved pastures. As a result of economic and population pressures, agricultural production now needs to be intensified by transforming native savannas into lands for annual crops or improved pastures. For the last 15 years, the Centro Internacional de Agricultura Tropical (CIAT), together with national research and extension institutions, has been developing improved agricultural systems for this environment (Zeigler and Toledo 1993).

However, these systems can be unsustainable, for example, after 3 years of continuous cropping, upland rice production is reduced to nonviable economic levels by weed competition and declining soil nutrients (Seguy et al. 1988). Likewise, continuous cropping of other annual crops such as maize and soybean can result in serious problems of soil erosion. Moreover, pure-grass pastures tend to degrade after several years of grazing, unless they are adequately fertilized (Buschbaker 1986; Uhl and Buschbaker 1985; Vera and Seré 1985).

Some associated grass/legume pastures perform well under commercial conditions typical of the region. However, once they have become degraded, economic factors constrain their establishment or reclamation. These pastures require a minimum capital investment—e.g., in soil preparation, fertilizers, and seeds—for adequate establishment and reclamation and, usually, farmers are not willing to invest in these practices (Vera and Seré 1985).

When pastures include a nitrogen-fixing forage legume that is well managed, a following rice crop can be expected to benefit from an increased supply of nitrogen to the soil. In the case of degraded pastures, fertilizers applied to the rice crop are expected to stimulate the growth of the seed bank in the soil, thereby promoting the presence of the legume in the ecosystem.

The study described in this chapter was divided into two components: (1) the use of an upland rice crop to establish an improved grass/legume pasture in native savanna, and (2) the use of an upland rice crop and a forage legume to reclaim degraded pastures.

The first component consisted of determining whether a permanent improved grass/legume pasture could be successfully established in an Oxisol when grown in association with upland rice. The second component was to identify the best method for establishing the grass/legume/upland rice mix in native savanna or degraded pastures. The procedure consisted of establishing both rice monocrops and rice with grass/legume associations in plots larger than 2500 m^2, and of comparing rice yields and pasture dry matter production 1 year after planting.

Methodology

Sites and soils

For the study's first component, two trials (Trials 1 and 2) were conducted at the Matazul Farm, located 40 km east of the Municipality of Puerto López in the Department of Meta, Colombia. The Farm is located at 4°19' north and 72°39' west, with an altitude of 160 m above sea level. The annual averages for temperature and rainfall are 27 °C and 2200 mm, respectively. The dry period extends from December to March, followed by a bimodal rainy season. In July and August, short dry periods of 1-2 weeks occur. Soils are Oxisols (isohyperthermic Tropeptic Haplustox) with a pH of 4.5 and low availability nutrients Ca (at 0.2 meq/100 g), Mg (0.08 meq/100 g), K (Bray 2, 0.1 meq/100 g), and P (Bray 2, 2 mg/kg). Aluminum saturation is greater than 80%. In both trials, native savanna was burned, and the soil immediately prepared for planting rice/pasture associations.

For the second component, Trials 3, 4, and 5 were conducted. Trial 3 was performed at the CIAT-Carimagua Experiment Station, located in the Colombian Eastern Plains at 4°36’ north and 71°19’ west of Carimagua, with an altitude of 175 m above sea level. The soil is an Oxisol (isohyperthermic Tropeptic Haplustox). Trials 4 and 5 were performed at the Santa Cruz and El Tigrillo Farms, respectively, located at about 195 and 200 km west, with similar environmental conditions. The results of soil chemical analyses for the three sites were as follows: pH between 4.2 and 4.5; available P between 1.5 and 2.0 mg/kg; and K, Ca, and Mg (meq/100 g) between 0.06-0.10, 0.15-0.20, and 0.06-0.08, respectively. Aluminum saturation was between 80% and 90%.

Planting

For all trials, for monocropped rice, furrows were spaced at 17 cm, whereas for rice/pasture associations, furrows were 34 cm apart to prevent the pastures competing with the rice. To plant the grasses and legumes (Trials 1 and 2), seeds were broadcast immediately before planting the rice. For Trials 3, 4, and 5, no grass seed was used; instead, we relied on the seed bank and stolons present in the soil.

Trials 1 and 3 were planted with 60 kg/ha of the rice line CT6196-33-11-1-3 (Line 3, the most advanced in 1989 for disease resistance). Trial 2 was planted with 80 kg/ha of CT6947-7-1-1-1-7-M (Line 6 of 1990, with similar characteristics as Line 3). Trials 4 and 5 were planted with 80 kg/ha of CT7244-9-2-1-52-1 (Line 23 for 1991, equally resistant to diseases).

In Trials 2 and 4 (as one treatment), and in Trial 5, early soil preparation was achieved by burning the vegetation, followed by two passes with the chisel plow at 40 cm deep. These practices were performed at the beginning of the dry season (early December), followed by later soil preparation. In the same Trials 2 and 4 (as one treatment), and in Trials 1 and 3, soil preparation consisted of burning the vegetation-if this has not been previously done-followed by two passes with a disc plow to destroy large soil aggregates and incorporate broadcast fertilizers. Plowing was done 2 weeks before planting at the start of the rainy season in May. The rice was harvested toward the end of August.

Fertilizer applications

When nutrients were not applied as treatments, a base fertilization (kg/ha) was done as follows (Table 1): application of N (80 kg urea), P (50 kg; i.e., either 25 kg Huila rock phosphate and 25 kg triple superphosphate, or triple superphosphate only); K (100 kg KCl), Zn (5 kg $ZnSO_4$) (except in Trials 1 and 3); and 300 kg/ha of dolomitic lime, broadcast and incorporated with the last harrowing 2 weeks before planting. In Trials 1 and 3, P was broadcast and incorporated before planting. In Trials 4 and 5, P and Zn were applied to seed at planting. Huila rock phosphate is an apatite, having a P content of 8% and medium solubility in ammonium

Table 1. Basic fertilization rates, when nitrogen and phosphorus were not applied as treatments. 1989.

Parameter	3, 5, or 8 weeks after planting (kg/ha)		At planting (kg/ha)		Dolomite lime (kg/ha) 2 weeks before planting
	N	K	P	Zn	
Rice	30, 20, 30	30, 50, 20	25, 25	5	300
Pasture		20	20		200
Source	Urea	KCl	HRP, TSP[a]	$ZnSO_4$	Dolomitic lime
Nutrient (%)	46	50	8, 20	15	Ca = 30; Mg = 5

a. HRP = Huila rock phosphate; TSP = triple superphosphate.

citrate at pH = 7.0 (Chien and Hammond 1988).

Experimental design and treatments

Trials 1 and 3, at each selected site, and Trial 5 had a random complete block design with three replicates. Trials 2 and 4 had a split-plot design with three replicates.

Trial 1, which compared monocropped rice with rice/pasture associations after native savanna (1989), included three treatments, each of which was carried out in nine plots of 100 × 100 m. Rice Line 3 was planted in all plots either alone or in association with one of two mixes of grasses and legumes: *Andropogon gayanus* cv. Carimagua 1 with *Stylosanthes capitata* cv. Capica, or *Brachiaria dictyoneura* cv. Llanero with *Centrosema acutifolium* cv. Vichada. Planting rates for *A. gayanus*, *B. dictyoneura*, *S. capitata*, and *C. acutifolium* were 10, 3, 3, and 4 kg/ha, respectively.

Trial 2 examined the effect of (1) timing of soil preparation, and (2) the method of applying fertilizer on rice establishment and production under monoculture and in association with pastures after native savanna (1990). The main plots were either early or late soil preparation; the subplots were rice as a monocrop (Line 6); rice + (*B. dictyoneura* + *C. acutifolium);* and rice + *A. gayanus* + *S. capitata*). Sub-subplots consisted of fertilizers applied either by broadcasting or incorporating with seed. The main plots measured 150 × 150 m; subplots 50 × 100 m; and sub-subplots 25 × 100 m. The last were planted along the field's length to facilitate mechanical cultivation. The total area was 9 ha, and the planting rates for the pastures were the same as used in Trial 1.

Trial 3 compared rice in grass/legume associations with rice in pure-grass pastures (1989). Three adjacent sites were selected that had previously been planted with different pasture types:

1. *B. decumbens* + *Pueraria phaseoloides*, 10 years of establishment
2. *B. decumbens* alone, 10 years of establishment
3. Native savanna

In each pasture, two levels of P, and three levels of N (P × N) were applied as treatments in 400 m^2 plots. The P levels were 25 and 50 kg/ha (50% TSP + 50% HRP). The N levels (urea) were 0 and 40 kg/ha, applied in dosages of 15, 10, and 15 kg/ha at 25, 40, and 60 days after planting, respectively; and 80 kg/ha of N distributed in dosages of 30, 20, and

30 kg/ha, with the same frequency as the previous applications.

Trial 4 examined the reclamation of degraded *B. decumbens* pastures by rice cropping and legume-based pastures (1990). The *B. decumbens* pastures were 10 years old and had been managed under minimum harrowing to turn the soil and no fertilizer applications. The main plots were those of early and late soil preparation, and the subplots were with and without sowing *S. capitata* (3 kg/ha) + *C. acutifolioum* (4 kg/ha). The main plots measured 100 × 100 m and the subplots 100 × 50 m, with a total area of 6 ha.

Trial 5 compared the reclamation of degraded pastures of *B. dictyoneura* by rice cropping with or without legumes (1991). *Brachiaria dictyoneura* because of its hardiness and aggressiveness, is seldom found in a degraded state. However, for this experiment, we found a slightly degraded *B. dictyoneura* pasture with a high percentage of weeds, caused by overgrazing and lack of an adequate fallow period. The treatments consisted of planting or not planting *Arachis pintoi* (4.5 kg/ha) + *Desmodium ovalifolium* (1.3 kg/ha). The plots measured 150 × 50 m, totaling 4.5 ha in area. Table 2 summarizes the trials.

Table 2. Summary of the treatments used in all trials by sites, Eastern Plains of Colombia, 1989-1990.

Trial	Site	Rice-seeding rates	Pasture seeding	Preliminary soil prep.	Treatments		
					Main plots	Subplots	Sub-subplots
A. Establishing grass/legume pastures with a rice crop							
Trial 1	Matazul Farm	60 kg/ha CT6196-33-11-1-3 (Line 3)	Broadcast before rice planting	None	• Rice • Rice + *B. dict.*/ *C. acut.* • Rice + *A. gay.*/ *S. cap.*		
Trial 2	Matazul Farm	80 kg/ha CT6947-7-1-1-1-7-M (Line 6)	Broadcast before rice planting	Early, Burning + chisel plow	• Early prep. • Late prep.	• Rice • Rice + *B. dict.*/ *C. acut.* • Rice + *A. gay.*/ *S. cap.*	• Fertilizers, broadcast • Fertilizers, with seeds
B. Reclaiming degraded pastures							
Trial 3	Carimagua Experiment Station	60 kg/ha CT6196-33-11-1-3 (Line 3)	Natural re-seeding	None	• Native savanna • *B. dec.* • *B. dec.*/*P. phaseoloides*	2 levels of P, 3 levels of N	
Trial 4	Santa Cruz Farm	80 kg/ha CT7244-9-2-1-52-1 (Line 23)	Natural re-seeding	Early, Burning + chisel plow	• Early prep. • Late prep.	+ or - *S. cap.*/ *C. acut.*	
Trial 5	El Tigrillo Farm	80 kg/ha CT7244-9-2-1-52-1 (Line 23)	Natural re-seeding	Early, Burning + chisel plow	• Rice • Rice + *A. pintoi*/ *D. ovalifolium*		

For all trials, plant emergence was measured 20 days after planting, together with rice dry matter production (grain and chaff) and biomass in aerial parts of associated pastures (grass + legume + weeds). The measurements were made at eight different sites of 1 × 1 m, randomly chosen in each plot. Grain production of commercial rice in the total experimental area was determined by using a combine harvester. Soil pH, P, K, Mg, Al, Zn, Cu, S, B, and organic matter (OM) contents were determined for each treatment before fertilizer application and after rice harvest by mixing several subsamples from each replicate. In a similar fashion, the nutrient contents were determined, including crude protein, P, B, K, Ca, Mg, S, and Zn in plant samples from each treatment.

Results

Trial 1

The new upland rice Line 3 produced good yields of more than 2 t/ha with moderate fertilizer applications, and did not show significant yield decrease when planted with improved tropical pastures on low-fertility acid Oxisols (Table 3). Weeds, an important problem in pasture systems, were observed in all treatments, probably resulting from either the increased fertility under this new system or being introduced as contaminants in rice and pasture seeds.

Analyses of nutrients in aerial biomass per unit area showed that the rice crop accumulated more nutrients than did the pastures and weeds, but they also suggest that pastures competed with rice, especially for P, K, and Mg (Figure 1), although not affecting grain production. In general, the *A. gayanus* + *S. capitata* pasture absorbed more P, K, Ca, and Mg than did the *B. decumbens* + *C. acutifolium* pasture.

Soil analyses showed that the P, K, Ca, and Mg contents were greater after harvest than before rice cropping (Table 4), except for Zn, which declined significantly. Apart from Zn, the soils after the first harvest were chemically better than those of the original native savanna. Pastures developed well with the residual fertility from the rice crop and, initially, were ready for light grazing and, later, for permanent grazing.

Trial 2

Early soil preparation resulted in an increase of about 1 t/ha in rice production in all treatments, compared with late preparation (Table 5). Yields

Table 3. Rice grain yield (14% moisture content) of Line 3, and pasture biomass in monocropped rice and rice in association with pastures, Matazul Farm, Eastern Plains of Colombia, 1989.

Treatment[a]	Rice (t/ha)*	Dry matter (t/ha)*		
		Grass	Legume	Weeds
Monocropped rice	2.23 a	—	—	0.65 a
Rice + Bd/Ca	2.09 a	1.22 a	0.21 b	0.67 a
Rice + Ag/Sc	1.95 a	1.77 a	0.44 a	0.43 a
$LSD_{0.05}$	0.52	0.59	0.14	0.22

a. Rice line = CT6196-33-11-1-3 (Line 3); Bd = *Brachiaria dictyoneura;* Ca = *Centrosema acutifolium;* Ag = *Andropogon gayanus;* Sc = *Stylosanthes capitata.*

* Averages in the same column followed by same letter are not significantly different ($P < 0.05$) according to Duncan's test.

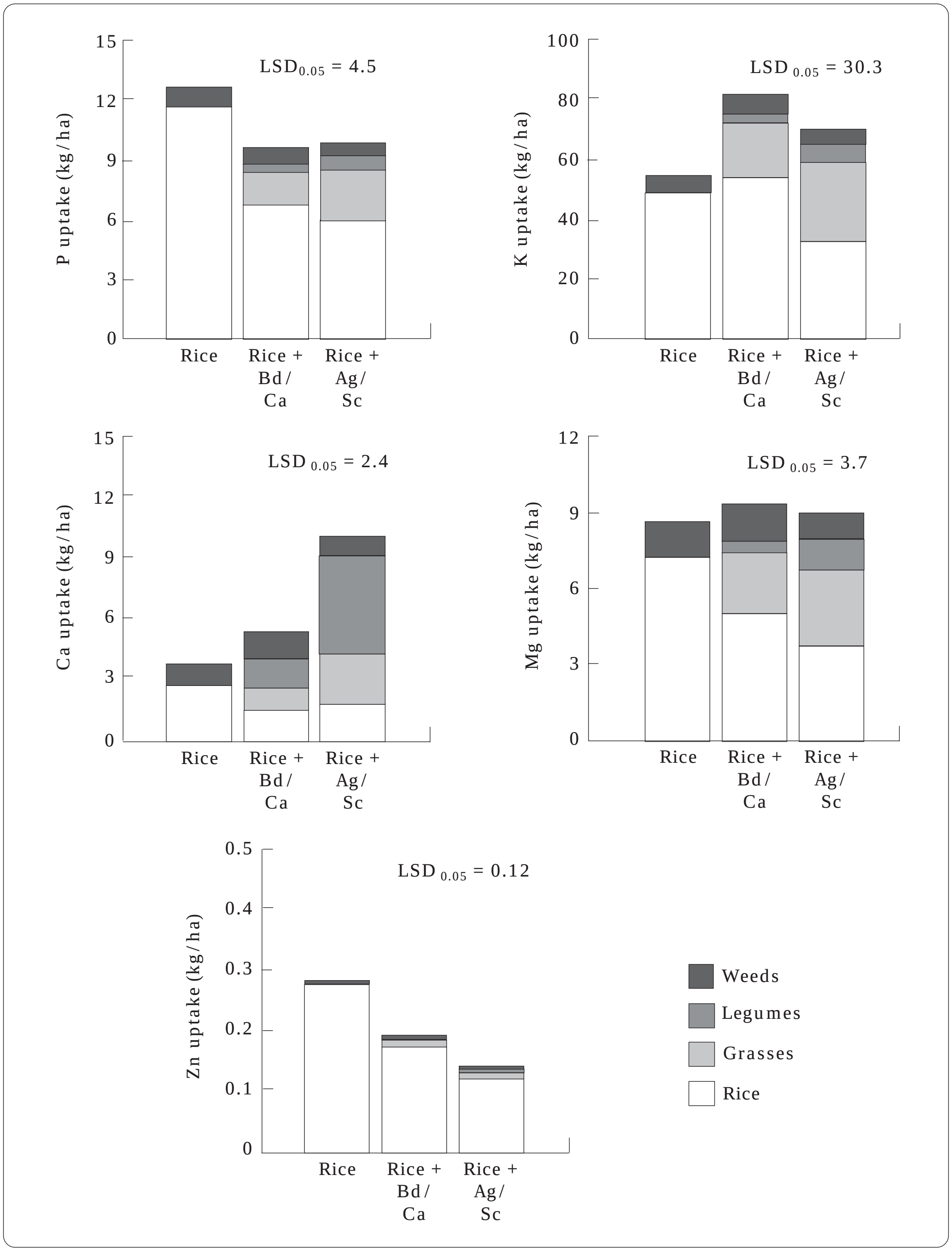

Figure 1. Amounts of nutrients per unit area in the aerial biomass of rice, legumes, grasses, and weeds, Matazul Farm, Eastern Plains of Colombia, 1990. (Bd = *Brachiaria decumbens*; Ca = *Centrosema acutifolium*; Ag = *Andropogon gayanus*; Sc = *Stylosanthes capitata*).

of monocropped rice were greater when fertilizers were broadcast under early soil preparation conditions than when fertilizers were applied with seed. No differences were observed when fertilizers were applied under late soil preparation. When rice was associated with pastures, fertilizer application with the seed resulted in significantly higher rice yields than with broadcast

Table 4. Availability of nutrients in the soil (kg/ha) before and after a rice crop in the crop/pasture associations used for pasture establishment, Matazul Farm, Eastern Plains of Colombia, 1989.

Soil nutrients	P	K	Ca	Mg	Zn
Before rice cropping	3.2	54.6	68.0	14.4	0.74
After rice cropping	9.1	67.1	112.0	31.2	0.46
After rice cropping + Bd/Ca[a]	11.8	89.2	124.0	28.8	0.42
After rice cropping + Ag/Sc[b]	19.6	70.2	116.0	28.8	0.42

a. Bd = *Brachiaria dictyoneura;* Ca = *Centrosema acutifolium.*

b. Ag = *Andropogon gayanus*; Sc = *Stylosanthes capitata.*

Table 5. Effect of timing of soil preparation (early or late), and of the method of fertilizer application (broadcast (B) versus with seed (S)) on the establishment and production of rice/pasture systems, Matazul Farm, Eastern Plains of Colombia, 1990.

Treatment[a]	Dry matter production (t/ha) under preparation*							
	Early				Late			
	Rice[b]	Grass	Legumes	Weeds	Rice	Grass	Legumes	Weeds
Monocropped rice								
S	2.87 b	—	—	0.02 b	2.05 a	—	—	0.25 c
B	3.07 a	—	—	0.03 ab	1.92 a	—	—	0.48 a
Rice + Bd/Ca								
S	2.51 c	0.41 c	0.08 a	0.04 ab	1.89 a	0.81 a	0.13 c	0.18 d
B	2.22 d	0.54 c	0.08 a	0.10 a	1.44 b	1.19 a	0.14 bc	0.38 b
Rice + Ag/Sc								
S	2.31 d	1.24 b	0.06 a	0.01 b	1.58 b	1.01 a	0.19 b	0.17 d
B	1.88 e	2.53 a	0.08 a	0.03 b	0.99 c	1.51 a	0.31 a	0.339 b
$LSD_{0.05}$	0.18	0.67	0.05	0.07	0.18	0.71	0.05	0.075

a. Rice line CT6947-7-1-1-1-7-M (Line 6); S = fertilizer applied with seed; B = fertilizer applied by broadcasting; Bd = *Brachiaria dictyoneura*; Ca = *Centrosema acutifolium;* Ag = *Andropogon gayanus;* Sc = *Stylosanthes capitata.*

b. Paddy rice, with a corrected moisture content of 14%.

* Averages in the same columns followed by the same letter do not differ significantly ($P > 0.05$) according to Duncan's test.

fertilization (Table 5). Dry matter production of weeds was less when fertilizers were applied with seed than when broadcast after late soil preparation (Table 5).

Trial 3

Production of rice planted after *B. decumbens* + *P. phaseoloides* yielded more than 3 t/ha (Figure 2) in all treatments, including those in which no N was applied, or in those receiving only 25 kg P/ha. However, applying 50 kg P/ha had no effect on yields. When N applications were increased from 0 to 80 kg/ha, rice production increased by about 0.5% t/ha. Poor paddy rice yields (1.3 t/ha) were observed when rice was planted in pastures of *B. decumbens* alone with no N application + 25 kg/ha or 50 kg/ha of P. However, the application of 40 kg/ha of N increased production to 3 t/ha, and the application of 80 kg N/ha resulted in an additional increase of 0.5 t/ha. No differences in

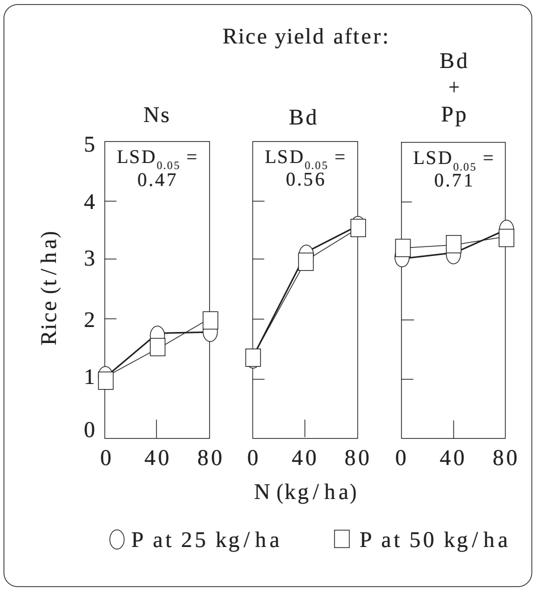

Figure 2. Rice establisment and production when planted in a 10-year-old *Brachiaria decumbens* pasture, CIAT-Carimagua, Eastern Plains of Colombia, 1989. ($LSD_{0.05}$ across sites = 0.47; NS = native savanna; Bd = *Brachiaria decumbens;* Pp = *Pueraria phaseoloides*).

rice production were observed by applying different rates of P. Production of rice planted after native savanna was low (less than 2 t/ha) and less than that obtained by planting rice after improved pastures. The initial soil analysis at the three sites indicated that the status of K, Ca, and Mg was better under improved pastures than under native savanna (results not included).

Trial 4

The results of this trial (Table 6) indicate again a high yield for rice Line 23 (more than 3.4 t/ha) and adequate reclamation of the degraded pastures. No differences were found between early and late soil preparation treatments.

During early preparation, grass burning was difficult because of the lack of plant material in the degraded pasture. At rice harvest, the *B. decumbens* pasture had recovered and was ready for grazing. The legumes were in the same condition as the grasses, and the grass/legume association was in excellent condition, with a ratio of grass to legume DM of 1.5:1 and 1.8:1.

Soil analyses before the trial and after the rice harvest (Table 7), showed that nutrient levels were not affected by fertilizer application to the crop, in contrast with the 10-year-old well-fertilized pasture (see Trial 3, previous page).

Trial 5

Initially, the rice grew poorly with foliar symptoms of severe Mg deficiency but *B. dictyoneura* developed well. Soil analyses (0.11 and 0.06 meq/100 g soil of Ca and Mg, respectively) and tissue analyses (0.21% of Ca and 0.04% Mg) confirmed Mg deficiency and low levels of Ca in the rice crop. When applying 135 kg/ha of Ca and 160 kg/ha of Mg as chlorides as an additional treatment on a different plot, the rice crop recovered well. With this additional treatment, rice yields doubled (Figure 3), despite the aggressive growth of *B. dictyoneura*. Both this grass and the legumes established well, and evaluation was continued under grazing.

Discussion

High yields (2-3 t/ha) can be obtained when rice is planted in association with pastures and with moderate input applications. Yields of pasture established simultaneously with rice were between 0.41 and 2.54 t/ha of DM for the grasses, and 0.07 and 0.44 t/ha DM for the legumes, with no effect on rice yields. Established rice/pasture associations had low weed populations and completely covered the soil throughout the year. Previous

Table 6. Rice yield and dry matter production (t/ha) of pastures and weeds in the reclamation of a degraded pasture of *Brachiaria decumbens*, Santa Cruz Farm, Eastern Plains of Colombia, 1990.*

Treatment	Rice crop[a]	Grass (*B. dec.*)	Legume		Weeds
			Centrosema acutifolium	*Stylosanthes capitata*	
Early soil preparation					
+ legume	3.56 a	0.44 a	0.11 a	0.17 a	0.093 a
- legume	3.64 a	0.68 a	—	—	0.14 a
Late soil preparation					
+ legume	3.48 a	0.53 a	0.11 a	0.17 a	0.25 a
- legume	3.40 a	0.74 a	—	—	0.19 a
$LSD_{0.05}$	0.57	0.29	0.06	—	0.22

a. Rice line CT7244-9-2-1-52-1 (Line 23).

* Numbers in the same column followed by same letters are not significantly different ($P < 0.05$) according to Duncan's test.

Table 7. Availability of nutrients in the soil (kg/ha) before and after a rice crop used to reclaim a degraded *Brachiaria decumbens* pasture, Santa Cruz Farm, Eastern Plains of Colombia, 1990.

Soil nutrients	P	K	Ca	Mg	S	Zn
Before the crop	6.6	31.2	152.0	12.0	22.7	0.42
After the crop	4.6	46.8	120.0	16.8	21.8	1.12
After rice crop + legumes[a]	6.6	54.6	176.0	19.2	33.4	0.74

a. Legumes = *Stylosanthes capitata* and *Centrosema acutifolium*.

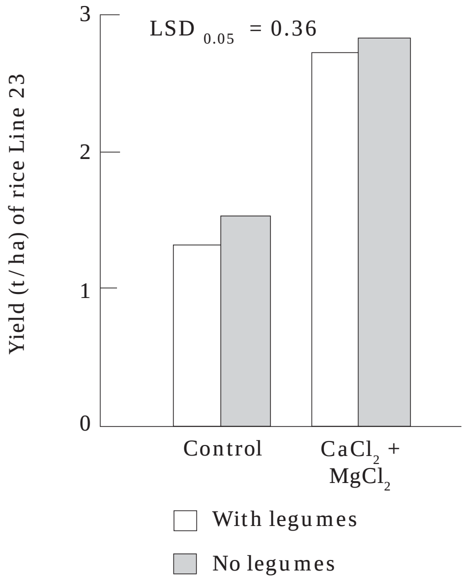

Figure 3. Rice production with and without forage legumes planted on a degraded *Brachiaria dictyoneura* pasture, El Tigrillo Farm, Eastern Plains of Colombia, 1991.

research at CIAT (1989) indicated that, with early soil preparation, twice the rice production could be obtained than with late soil preparation. In Trial 2, the effect of early soil preparation, in addition to suppressing weeds, could have resulted from the release of K^+ and NH_4^+ from Al-chlorite/Al-vermiculite after postharvest drying and wetting (Sanz and Rowell 1988; Sylvester-Bradley et al. 1988).

In this work, the effect of early soil preparation could have been confounded by the effect of burning and chisel plowing. Research is currently being conducted to separate the effects of these practices and to evaluate possible alternatives to burning. A dense plant population in the pastures might produce a negative impact on rice development and production, especially if the plant population is dense during the initial stages of crop development. In Trial 1, with treatments of rice + *B. decumbens/ C. acutifolium* and rice + *A. gayanus/ S. capitata*, the average germination of the pasture components was 0.6 and 0.9 plant/m^2, 20 days after planting, respectively. In Trial 2, with late soil preparation treatments, plant density for pastures was 13.9 and 18.2 plants/ m^2, and rice production was lower than in Trial 1, although pasture production was not affected by the initial planting density (Tables 3 and 5).

Improved pastures may be plowed, and will spontaneously reestablish when planted with rice. Rice yield (3.5 t/ha) after improved pastures can be greater than after native savanna. Acceptable yields of rice may be achieved even without the application of N fertilizer, if the crop is planted after a grass/legume pasture. In all cases, reestablishment of associated pastures was successful.

Nutrient absorption by rice was reduced when planted in association with pastures on native savanna, although competition for P, Mg, and Zn might limit production under these circumstances. However, in both years, after planting rice and rice/pastures, the Ca and Mg levels in the soil remained higher than the initial figures. P and K were high after the first year of harvest, remaining at the same level during the second year. This indicates that, after rice harvest, the residual fertility in the soil is sufficiently significant for pastures to take advantage of it. Nevertheless, low P, K, and S reserves in the soil suggest that pastures can degrade easily unless the initial competition is reduced. Zn is very low in these soils, and was so highly absorbed by rice that it had to be applied in the second year.

In this work, the contribution of N by the legume refers to a 10-year association of grass/legumes. Thomas et al. (1992), conducting research at CIAT-Carimagua and using pasture productivity and legume content in *B. decumbens* alone and in association with *P. phaseoloides*, estimated that 80% to 90% of the potential benefit of this legume in N fixation is obtained between years 3 and 5, meaning that a 10-year wait is unnecessary.

Grass/legume pastures combine the large financial benefit of an annual crop in the short term with long-term productivity and improved soil properties. The rice/pasture system improves the soil nutrient status through the direct application of the most important elements as fertilizers, nitrogen fixation by legumes, and increased soil OM resulting from the abundant biomass of the associated pasture. The production alternative of annual crops and permanent pastures may therefore be mutually beneficial in cattle-raising areas where no cropping was previously possible. The new upland rice lines developed for adaptation to acid low-fertility soils represent new production options.

The large plots used in this work, combined with commercially viable production levels, indicate that the agropastoral system of rice and grass/ legume pastures is feasible. This large-scale experiment facilitates long-term studies under realistic commercial system conditions to establish, document, and assess those factors that determine sustainability.

The gallery forests of native savannas, with their wealth of species (Burman 1991) and natural beauty, comprise a precious natural resource. Sustainable management alternatives may help stabilize production in areas already opened up and thus reduce pressure on gallery forests through clearing. The development of adequate agricultural systems and management policies is needed to ensure the conservation of existing reserves of the native savanna and for the expansion of the agricultural frontier without deleterious effects on the environment.

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CHAPTER 17

Integrated Agropastoral Production Systems

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Contents

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Abstract

To establish integrated agropastoral production systems, the biological and socioeconomic aspects involved in agricultural production must be understood. These systems must be ecologically and socially acceptable. Pasture degradation is visible in the Brazilian savannas (or *cerrados*), where about 50% of pastures are degraded. Likewise, croplands present severe problems, particularly soil compaction and erosion and outbreaks of pests and diseases. These problems can be tackled through various alternatives of integrating crops and livestock production. One alternative is to change from growing annual crops to rotating forages with annual crops such as oats and maize and using crop residues as animal feed. Income from grain production also helps buy dietary supplements for animals being fattened, but confined to pasture. Several of these practices are economically feasible, but further research is needed to perfect them, especially those related to control and management, to encourage ranchers to use and develop integrated crop-and-livestock production systems.

Resumen

Para el establecimiento de sistemas integrados de producción agropastoril es necesario conocer los factores biológicos y socioeconómicos involucrados en los procesos de producción agropecuaria. Estos deben ser ecológica y socialmente aceptables. La degradación de las pasturas en áreas de Cerrado de Brasil es marcada y cerca del 50% de ellas ya están en proceso de degradación; igualmente con cultivos anuales presentan graves problemas de compactación, erosión y ocurrencia de plagas y enfermedades. Para enfrentar este problema existen varias alternativas en proceso en la región que integran sistemas agrícolas y ganaderos. La introducción de la agricultura en fincas ganaderas ha permitido la transformación de áreas con cultivos anuales en sistemas de rotación con forrajeras como avena y maíz. Los sistemas de suplementación de los animales con pastos en confinamiento al final de la época de ceba, han sido posibles por la producción de granos en las propiedades rurales. Varias de esas prácticas han mostrado viabilidad económica, pero aún es necesario desarrollar investigaciones para perfeccionar estos sistemas, especialmente en relación con las técnicas de control y manejo gerencial que faciliten a los ganaderos el uso y desarrollo de los sistemas integrados agricultura-ganadería.

Introduction

To successfully establish integrated agropastoral production systems, the factors affecting them—soil, climate, crops being grown, production systems, animal species, and type of operation (beef or dairy cattle, goats, sheep or swine)—must be understood. Also important to understand are the socioeconomic aspects related to marketing, transport, storage, financial resources, and, above all, the type of farmer or livestock owner involved in the process. The farmer—whether cultivating crops or owning livestock—is the one who will be making the final decision as to the system to use in terms of resources available, management capacity, and preference for a given type of operation based on the possibility of improving income.

The need to solve environmental protection problems while improving production systems has renewed interest in integrated soil conservation systems at the microwatershed level, rotation of grain crops, and use of agropastoral systems.

The concept of sustainable agriculture has been widely disseminated, together with the idea that its impact should benefit all sectors of society. According to U.S. agricultural laws (Affin 1994), the sustainability of cropping and livestock activities depends on an integrated system that uses crops and animals adapted to the specific conditions of each locality or region. To be sustainable, such a system should meet several simultaneous and long-term requirements, including meeting the population's food and fiber requirements; enhancing both environmental quality and natural resources; and efficiently using nonrenewable resources and those inherent or belonging to the community, integrating, where possible, natural biological controls and cycles. Moreover, such a system should not only be economically viable but also enhance the quality of life for farmers and for society as a whole. In other words, sustainable cropping and livestock operations should maintain or improve production, and result in economic profits for farmers, without adversely affecting the environment while benefiting society in general.

However, to achieve such goals, more complete studies are needed on cropping and livestock production flows and systems. In Brazil, such studies are scarce, having only recently been initiated by EMBRAPA. These concepts are also being taught at some universities.

Most production systems in Brazil were developed by the farmers themselves, who applied their creativity to solve their production constraints, bringing together various cropping and livestock production technologies and activities. Many of these systems are being carried out with very little control over production and economic flows and with generally low managerial capacity. Only a few companies and rural landholders in the Brazilian savannas (or *cerrados*) have developed integrated production systems, characterized by good managerial skills and control over their production data.

In this chapter, some production conditions of the *cerrados* are described, highlighting problems and research.

Characteristics of the Brazilian *Cerrados*

Production

The *cerrado* biome is mostly located in central-eastern Brazil, encompassing the states of Mato Grosso, Mato Grosso do Sul, Goiás, Tocantins, and the Federal District. It covers an area of about 204 million hectares, of which about 94 million are under cultivated pastures (50 million), native pastures (30 million) (Ondei 2003), annual crops (12 million), and perennial crops (2 million).

According EMBRAPA Cerrados (unpublished data), the *cerrados* could be exploited as follows (in numbers rounded to millions of hectares): 60 for cultivated pastures, a similar area for upland crops, 10 for irrigated crops, 66 for environmental preservation, and 6 for permanent crops.

The area under cultivated pastures unexpectedly began growing in the 1970s, from 11 to 29 million hectares by 1980 and to about 50 million hectares by 2000. This increase can be attributed to the introduction, by special development programs, of *Brachiaria* grasses since 1980 and, more recently, of *Panicum maximum* cultivars. The current growth rate is lower, being about 600-800 thousand hectares per year. These increases have occurred by replacing native pastures and adding annual or perennial crops, depending on the economic situation of each microregion. Since 1995, the use of crop/pasture rotation has increased significantly, especially the sowing of pastures after annual summer crops and even crop/pasture associations.

The above-mentioned pasture areas today carry cattle numbering 72.3 million heads, representing 41% of the Brazilian herd, itself numbering 176.3 million heads. Meat production in the *cerrados* represents about half of the nation's production of 7.15 million tons. In recent years, milk production has also grown significantly in the region. In other areas of the *cerrados*, 12 million hectares of annual crops are grown, providing 35% of the 120 million tons of the nation's grains, and 2 million hectares of perennial crops.

The evolution of expansion of cultivated pastures in the region suggests that they are approaching the limit of their potential area as estimated by EMBRAPA Cerrados. Native pastures are becoming increasingly restricted to habitats of natural preservation, such as the Pantanal, areas of insertion in the Amazon, and semiarid regions.

Although precise data are not available on the relative importance of each forage species in the composition of cultivated pastures in the *cerrados*, Table 1 shows that *Brachiaria* species constitute 85% of these pastures (Zimmer and Correa 1993). This situation remains current

Table 1. Approximate relative distribution of the forage grasses most planted in the Brazilian *cerrados*, 1995.

Species	Distribution (10^3 ha)	Relative distribution (%)
Brachiaria decumbens	26,400	55
B. humidicola	9,600	20
B. brizantha	4,320	9
B. ruziziensis, B. dictyoneura	480	1
Subtotal	40,800	85
Panicum maximum cv. Colonião	3,840	8
P. maximum cvs. Tanzania, Tobiatã, Vencedor	960	2
Subtotal	4,800	10
Other genera		
Andropogon, Hyparrhenia, Melinis, Cynodon	2,400	5
Total	48,000	100

SOURCE: Adapted from Zimmer and Correa (1993).

today, even as new cultivars are being released. Lately, more *B. brizantha* has been planted.

The use of forage legumes is difficult to estimate: they probably cover 1%-2% of the total area, with the most widespread species being *Calopogonium mucunoides*. Recently, EMBRAPA Gado de Corte and EMBRAPA Cerrados released *Stylosanthes guianensis* cv. Mineirão, a cultivar of *S. capitata*, and *S. macrocephala* cv. Campo Grande, which are being well accepted by cattle farmers. Recently, CEPLAC released *Arachis pintoi* cv. Belmonte, which is now being disseminated among farmers.

Studies of beef cattle in the *cerrados* (Corrêa 1995) indicate that, from 1970 to 1985, native and cultivated pastures, taken as a whole, expanded from 59.7 to 85.2 million hectares, while the herds increased from 26.3 to 53.2 million heads of cattle (IBGE 1995), demonstrating the increase in area under cultivated pastures.

The expansion of area under cultivated pastures during 1970-1980 ranged from 57% to 65%, but diminished during 1980-1985 by 26% to 37.9% (Corrêa 1995).

Despite the difficulties in determining the size of the herd effectively grazing native pastures versus that grazing cultivated pastures, on the average, animal carrying capacity is <1 an./ha for both types of pastures. Although, in the 1970s, pasture productivity increased significantly, levels could not reach 1 animal unit per hectare (AU/ha).

The beef cattle herd in the *cerrados* is composed mostly of mixtures of zebu races (*Bos indicus*), with the Nelore race predominating. More recently, fiscal incentives for producing early maturing steers encouraged an expansion of crosses of Nelore with European races of different origins. The crossbred population is >50 million animals, that is, more than one third of the national herd.

According to Corrêa (1995), the predominant production systems in the *cerrados* are based on pasture systems with extensive livestock raising. If these systems are compared with those of other countries that have smaller herds and where the agroclimatic conditions are more adverse than in those of the *cerrados*, then the zootechnical indexes for this region are most modest. However, various practices—for example, classifying the herd by categories, periods of seasonal mating, early weaning, adequate mineral supplements, and managing the herd's health—have been introduced and adopted, thereby contributing to a gradual evolution of these indexes. Special incentives such as credit would, perhaps, have promoted faster evolution of the zootechnical indexes. In any case, the lack of such credit and defects in the existing systems have led to the livestock sector providing its own capital and being less dependent on credit institutions than are other parts of the agricultural sector. But since the mid-1990s, pasture reclamation has been increasing, as has the use of fertilizers, pasture irrigation, and crop/pasture systems, with consequent increases in productivity.

The most limiting production factor continues to be the scarcity of forage during the dry season, which prolongs the productive cycle. This factor raises the age, not only for slaughter in steers but also for puberty in heifers. Males are slaughtered at 3½-4 years old when they reach a liveweight (LW) of

450-480 kg, with a carcass yield of 52% (about 225 kg). Heifers reach the age for service at about 3 years old and their first calving occurs when they are 4 years old. The lack of adequate diet during the dry season causes LW losses in lactating cows, and provokes anestrus, which results in a high number of nonpregnant cows. Under such circumstances, herds have an average birth rate of 54%, a calf mortality of 6.5%, and a weaning rate of 51% (Corrêa 1995). But recently, the productivity of the Brazilian herd has improved, showing a growth rate of 8.1% during 1993-2002. Meat production (carcass equivalence) over the same period grew by 18.7% (FNP/ BOVIPLN 2002). The *cerrados* showed similar trends, and also significant growth in milk production.

Despite the recent increases in production and productivity, many cattle growers still have problems in achieving efficiency and production stability, mainly because of a lack of resources for soil conservation and pasture reclamation. Because properties are mostly small to medium sized, with corresponding management levels, these farmers usually do not follow recommended management and pasture reclamation practices.

About 35% of the 120 million tons of the Brazilian grain crop is produced in the *cerrados*. The most important crops are rice, maize, and soybean. Table 2 shows that yields in the region are similar to or higher than the national averages.

Technologies for grain production vary in sophistication, ranging from average to advanced, as most production is found on average to large farms.

The main constraint to grain production is the lack of an efficient system for transporting inputs and products. Heavy taxes further reduce the competitiveness of grain production in the region. For example, taxes and costs of transporting soybean from Rondonópolis (Mato Grosso) to the port of Santos (São Paulo), plus shipping costs, represent about 40% of the product's value, thus reducing competitiveness of production in the *cerrados*, even if productivity indices are good.

Table 2. Total production of the three principal grain crops (rice, maize, and soybean) in the 1994/95 and 2002/03 harvests in Brazil overall and the Brazilian *cerrados* specifically.

Crop	Region					
	Brazil			*Cerrados*		
	Area (10^3 ha)	Production (10^3 t)	Productivity (t/ha)	Area (10^3 ha)	Production (10^3 t)	Productivity (t/ha)
Harvest 1994/95						
All grains	39,000	81,600	2.10	10,000	23,000	2.30
Rice	4,770	11,430	2.39	1,200	2,262	1.88
Maize	13,520	36,660	2.71	2,220	7,123	3.23
Soybean	11,750	26,350	2.24	5,200	12,100	2.32
Harvest 2002/03						
All grains	42,500	114,915	2.70	13,415	38,917	2.97
Rice	3,172	10,726	3.38	955	2,244	2.35
Maize	9,528	33,697	3.53	2,310	9,663	4.18
Soybean	18,088	50,330	2.78	9,350	25,680	2.74

SOURCE: CONAB (1995).

Soils and climate

The information presented above suggests that insufficient feed, especially during the dry season, is the principal constraint to successful beef cattle operations in the *cerrados*.

If meat production is considered as a function of the interaction of the animal with its environment, represented by the soil-plant-climate complex, then the *cerrados* present some highly typical and limiting aspects, compared with other production regions around the world.

For grain production, the principal climatic limitations are the dry seasons and occurrence of short dry spells (*veranicos*) during the rainy season, particularly in January. They usually last 10 days, and sometimes occur twice in a month. Rainfall distribution is therefore the most important climatic component related to cropping and livestock production. Castro et al. (1994) classified the *Cerrados* as a region with an annual rainfall of 1200-1800 mm in 60% of the area and of 800-1200 mm in 28% of the area. Depending on rainfall distribution and soil type, risks are average to high for rainfed agriculture.

These characteristics partly explain why pastures occupy most of the areas opened up for agriculture. However, although pastures have an advantage over upland cropping, dry seasons and periodic dry spells also affect them.

The interaction of climate with the physicochemical properties of *cerrado* soils is significant for the productivity and sustainable production of integrated crop-and-livestock production systems.

Table 3 lists the principal soil classes of the *cerrados* (Adamoli et al. 1986): Latosols (49%), Podzols (15%), and quartzose sands (15%), accounting for about 80% of the region's soils.

Table 3. Principal soil classes, Brazilian *cerrados*.

Class	Synonym (USDA)[a]	Area (km^2)	Percentage of region
Latosols	Oxisols	935,870	46.0
	Ultisols	57,460	2.8
Podzols	Alfisols	307,677	15.1
Red soils	Alfisols	34,231	1.7
Cambisols	Entisols		
	Inceptisols	61,943	3.0
Lithosols	Entisols	148,134	7.3
Quartzose sands	Entisols	309,715	15.2
Hydromorphic laterites	Alfisols		
	Inceptisols	122,664	6.0
Gley	Inceptisols	40,752	2.0
Others		19,154	0.9
Total		2,037,600	100.0

a. From the U.S. Department of Agriculture (USDA) soil taxonomy.

SOURCE : Adamoli et al. (1986).

The clay contents of these soils range from 8% to 80%, with the quartzose sands being at one extreme and the very clayey Latosols at the other. Average clay contents are 10%-20%. Water available in the soil is removed at pressures ranging from 0.1 to 1.0 bar, regardless of soil texture or color (Wolf 1975).

Chemically, about 95% of the soils are dystrophic, that is, they are characterized by a saturation of bases of <50%, which can be explained by the low CEC, which ranges from 3.9 to 13.9 meq/100 cm^3 of soil. Most of the soils are allitic, with an Al saturation of >50%. Because many plants, including some forage grasses, are sensitive to Al saturation at >30%, their performance is jeopardized under such soil conditions. For annual crops, soil conditions are normally corrected by applying lime and average-to-high quantities of fertilizers. Table 4 gives the most important chemical characteristics of *cerrado* soils.

Problems with Monoculture

Degraded pastures

Pastures must sustain levels of production and quality required by grazing animals, and be able to overcome the harmful effects caused by pests, diseases, and weeds. The degradation of pastures is an evolutionary process, involving the loss of vigor, productivity, and capacity for natural recovery, and is basically caused by inadequate management (Macedo 1993).

Brachiaria grasses predominate in the tropical pastures of central Brazil. Independently of the cultivar used, a pasture—when subjected to inappropriate management practices (e.g., lack of fertilizer applications or rest periods)—has a naturally declining production cycle. That is, during the first years, the pasture produces substantially high amounts of dry matter (DM), which production declines

Table 4. Chemical characteristics of the arable layer of the principal soil classes, Brazilian *cerrados*.

Chemical characteristics	Soil class		
	Latosols	Dystrophic Podzols	Dystrophic quartzose sands
pH (H_2O)	4.5-5.2	5.0	5.2
C (%)	0.5-2.4	0.9	0.5
$Ca^{2+} + Mg^{2+}$ (meq/100 g)	0.2-5.7	0.7	0.4
K^+ (meq/100 g)	0.02-0.4	0.1	0.1
Al^{+++} (meq/100 g)	0.7-1.4	1.1	0.7
P (ppm)	0.5-3.4	1.0	1.6
CEC (meq/100 cm^3)	3.9-13.9	5.8	3.7
Saturation of bases (%)	5.9-43.9	13.8	13.5
Al^{+++} saturation (%)	16.4-85.9	57.0	57.4

SOURCE: Adapted from Adamoli et al. (1986).

over time at a rate in accordance with the type of management being used. Pasture performance is also influenced by the cyclical occurrence of rainy and dry periods. Studies carried out by Euclides (1994) and Euclides et al. (1993a, 1993b) demonstrated that the production of three cultivars of *Panicum maximum* (Colonião, Tobiatã, and Tanzania), *B. decumbens* cv. Basilisk, and *B. brizantha* cv. Marandú, when submitted to controlled grazing pressure, had a diminishing production cycle. By the fourth year, LW gains were significantly less than those observed during the first years of pasture use (Table 5).

This study was carried out on a Dark-Red, clayey Latosol, with a low natural fertility (1-2 ppm of P, 0.10 mg of K, 7%-10% saturation of bases, and 60%-70% of Al saturation). The pastures received at planting 1 t/ha of dolomitic lime, 350 kg of simple superphosphate, 100 kg of potassium chloride, and 40 kg of fritted trace elements (FTE). Fertilizers were not applied during development or production, and animal management was uniform. Pastures of *Panicum* cultivars daily offered 8 kg of DM per 100 kg of LW, whereas *Brachiaria* pastures offered 15 kg of DM per 100 kg of LW.

The most drastic decline occurred with *P. maximum* cv. Colonião, which also suffered bare soil problems (45%) and weed invasion (5%). In addition, nutrient contents of the forages declined drastically during the first and third year. In all *P. maximum* cultivars, concentrations (g nutrient per kg DM) of N decreased from 21 to 15; of P, from 1.8 to 0.9; and of K, from 17 to 13, whereas for the *Brachiaria* species, concentrations of N dropped from 19 to 15; of P, from 1.4 to 1.0; and of K, from 21 to 11 (Macedo et al. 1993).

In an experiment with *B. brizantha* cv. Marandú, with no fertilizers and using weaned animals, slaughter weight could be reached at 30 months with a stocking rate of 1.4 AU/ha. Under such soil conditions, however, this cultivar began having problems regrowing and developing after 2 years of use. In the second and third cycle, LW gain per hectare declined by 27%. But, at 1.8 AU/ha the gain per hectare declined 34% in the second cycle and 51% in the third cycle, compared with the first cycle (Zimmer et al. 1994). Given the concept of degradation, some intervention in the system is needed—at least with an application of phosphate fertilizers—to reduce or reverse degradation. This means that heavy stocking rates comprise a major

Table 5. Liveweight gain of calves grazing pastures of *Brachiaria* species and *Panicum* cultivars, and percentage of weeds and bare soil after 3 and 4 years, respectively, of continuous grazing, Brazilian *cerrados*.

Cultivar	Stocking rate (calves/ha)	Weight gain (kg/ha per year)		Bare soil (%)	Weeds (%)
		Avg. of 3 years	Year 4		
Colonião	2.1	324	240	45	5
Tobiatã	2.5	324	240	25	1
Tanzania	2.3	414	330	25	1
Marandú	2.3	446	365	1	0
B. decumbens	2.4	342	310	1	0

SOURCE: Euclides (1994); Euclides et al. (1993a, 1993b).

factor in pasture degeneration in the *cerrados*.

Following up the concept, degradation is characterized by a set of factors that interact with each other, making it dynamic. Thus, degradation can be reduced or aggravated by the management practices used, such as stocking rate, pasture management system, and fertilizer use.

So far, we have analyzed those aspects related to the reduction of pasture productivity. We also need to address those aspects related to the incidence of pests, diseases, and weeds.

Although the relationship between a pasture's nutritional status and spittlebug attack has not yet been sufficiently clarified, the pest shows preference for some pasture species. According to Valério (1988), *B. decumbens*, widely cultivated in central Brazil, is highly susceptible to attack by this pest. Some grass species such as *B. brizantha* and *Andropogon gayanus* appear resistant. Without doubt, successive spittlebug attacks, associated with inadequate animal management, accelerate degradation of *B. decumbens* pastures. Recently, damage in *B. brizantha* cv. Marandú has been detected as being caused by *Mahanarva fimbriolata*.

The presence of anthills in large numbers also indicates degrading pastures. In addition to the direct damage that ants cause, the hills make using agricultural machinery more difficult. Since the mid-1990s, the brown stink bug (*Scaptocoris castanea*), a soil pest, has been causing damage in several forages. Its presence is increasing, especially in light-textured soils.

The occurrence of bushy *cerrado* weeds in degraded pastures is mostly a result of the method used to clear native vegetation. Where crops (rice, soybean, or maize) were initially planted in the cleared areas, using intensive land preparation systems (plows and harrows), weed regrowth was less intense. In contrast, areas opened up by slashing and burning the vegetation and applying a single pass of a harrow-plow were more susceptible to weed invasion. Pastures established under these conditions do not persist and are invaded by weeds adapted to the ecosystem.

Farmers' efforts to clear such weedy areas have not been successful. Mechanical weeders usually cut down only aerial plant parts, thereby stimulating both lateral and vigorous regrowth in the weeds. Studies carried out by EMBRAPA Gado de Corte showed that one pass of the harrow, even with heavy equipment (harrow-plow), was not sufficient to prevent regrowth of native vegetation in reclaimed pastures, with or without surface fertilizer application (Table 6).

Agriculture as an agent of degradation

Monoculture, together with bad management practices, has affected the productivity, and stimulated the degradation, of natural resources. After the *cerrados* were opened up, the introduction of livestock and development of new management techniques—such as correction of the soil's acidity and low fertility, and use of new species and better adapted cultivars—led to a great expansion of the area planted to soybean. In the southern *cerrados*, crop associations (soybean/wheat) or soybean monocrops comprised a constant in agricultural operations. In the last 10 years, the cultivation of maize in

Table 6. Dry matter (DM) weight of bushy weeds in degraded pastures of *Brachiaria decumbens* after treatment, with or without harrow and fertilizer application (1985), and one pass of a mechanical weeder every year from 1986 to 1988, Bandeirantes, Mato Grosso do Sul, Brazil.

Treatment	DM of weeds (t/ha per year)		
	1986	1987	1988
Reclamation, no harrow			
B. decumbens (control)	0.59	0.39	0.23
B. decumbens (fertilizer + legume)	0.51	0.27	0.21
B. decumbens (fertilizer)	0.50	0.24	0.16
Reclamation with harrow			
B. decumbens (control)	0.37	0.19	0.18
B. decumbens (fertilizer + legume)	0.37	0.27	0.16
B. decumbens (fertilizer)	0.29	0.25	0.15
Probability (*F*): Treatments	ns	ns	ns
Harrow	0.01	0.05	0.01

SOURCE: Macedo and Zimmer (1993).

succession to soybean (within the same rainy season) has become common practice, presenting good results, even under major climatic risks. In areas with drier falls, using the same system involves the sequence soybean/sorghum.

In recent years, diseases and pests such as stem rot, soybean brown stink bug, soybean gall nematode (*Meloidogyne javanica*), and, more recently, soybean cyst nematode (*Heterodera glycine*) have caused serious losses of soybean crops (Mendes 1993; Sosa-Gomez et al. 1993; Yorinori et al. 1993). These researchers emphasize that the practice of monocropping has contributed most to the persistence of these pests and diseases, stimulating their development. The soybean cyst nematode, for example, was identified in soybean-growing areas characterized by 10-12 years of monoculture (Mendes 1993).

Farmers—for both economic and operational reasons—manage land almost exclusively with the use of harrows. The incorrect use of these implements has caused a series of problems related to the pulverization of surface soil layers, thereby destroying the structure of soil aggregates and compacting the arable layer. Denardin (1984) has demonstrated deterioration of soil physical properties over extensive areas of croplands in the Grande Dourados, Mato Grosso do Sul (Table 7).

Also associated with poor management of soils under monoculture is the concentration of fertility in the upper layers of the soil profile (Table 8). Land under monoculture is characterized by extremely high levels of P, Ca, and Mg contents in the first 6-10 cm of the soil. Root distribution is therefore concentrated near the soil surface, making the crop more vulnerable to lack of water during dry spells.

Since the mid-1990s, soil management has been improving with increasing use of zero tilling. In the *cerrados*, zero tilling is used on about 8.9 million hectares (Bernardi et al. 2003), that is, on more than 50% of the 14 million hectares of annual

Table 7. Physical characteristics of a Red Latosol after 3.5 and 7 years of preparation with heavy harrow + harrow-grader, Ponta Porã, Mato Grosso do Sul, Brazil.

Depth (cm)	Density (g/cm^3)		Aggregate stability (%)	
	3 years	7 years	3 years	7 years
0-6	—[a]	—[a]	—[a]	—[a]
6-14	1.20	1.43	78	48
14-23	1.19	1.40	79	58
23-30	1.18	1.25	78	56

a. No soil structure.

SOURCE: Denardin (1984).

Table 8. Distribution of fertility in the profile of a Red Latosol after 7 years of cropping and preparation with a harrow, Ponta Porã, Mato Grosso do Sul, Brazil.

Depth (cm)	pH (1:1)	Al (meq/100 mL)	Ca + Mg (meq/100 mL)	P (ppm)	K (ppm)	OM (%)
0-2	6.0	0	8.10	13	>200	5.4
2-4	5.8	0.05	9.05	82	>200	5.3
4-6	5.8	0	8.60	12	171	5.3
6-10	5.4	0.30	6.00	5	142	5.1
10-15	5.0	1.25	3.90	5	98	5.1
15-20	4.9	1.90	1.95	1	60	4.5
20-25	4.8	2.15	1.30	1	40	3.7
25-30	4.7	2.05	1.15	1	28	3.4

SOURCE: Denardin (1984).

crops. As well as zero tilling, direct sowing is becoming common practice for the region's pastures.

Alternatives for Integrating Crop-and-Livestock Production Systems

Pastures in association with annual crops

The pasture/crop association, whereby a forage is planted with annual crops or after them, has been used in the *cerrados* since the 1930s and 1940s. Grasses such as molasses grass (*Melinis minutiflora*), *Panicum maximum* cv. Colonião, and jaragua grass (*Hyparrhenia rufa*) were established in fertile soils by sowing or planting stolons in interrows with maize, rice, or bean, either simultaneously or after the planting of these crops (Rocha 1988). In the 1970s, when *Brachiaria* species were introduced, planting *B. decumbens* at the same time or after the rice crop became routine.

Pastures are usually planted together with seeds of the rice crop or are broadcast. Sometimes they are planted at the first weeding after rice emergence. Results have been variable, depending on factors such as soil fertility, planting rate for the pasture, and rainfall. Because the most commonly used forage species had been *B. decumbens* cv. Basilisk, pastures have, on the whole, developed satisfactorily. This cultivar, because of its growth habit, aggressiveness, and capacity for adaptation, covers the soil rapidly and has a higher animal carrying capacity than does native pasture.

Kornelius et al. (1979) found that rice could be sown simultaneously with forage crops to establish pastures in the *cerrados*. Table 9 presents the results obtained with different systems of sowing and rates of P applications for associated plantings of rice with forages. The study points out that, without fertilizer applications, forages competed less with the crop—that is, to the extent soil fertility improved, forages were more competitive.

When fertilizers were applied, forage species performed according to their degree of adaptation and response to different fertilizers. The best adapted species with the least capacity to respond to fertilizer applications affected rice production least. *Melinis minutiflora* and *B. decumbens* most affected rice production when fertilizers were applied (Table 9).

In another study, after the *cerrados* were opened up, Kornelius et al. (1979) analyzed the possibility of establishing pastures with rice in different crop sequences. Even then, distinct advantages were already evident: the associated planting of pastures + crops helped cover the costs of applying lime and fertilizers, which were very high with respect to the value of the land. Results showed that planting crops for 1 or 2 years would be sufficient to pay the costs of pasture establishment, including lime and fertilizers.

Macedo and Zimmer (1990) showed the possibilities of simultaneously planting maize and *B. brizantha* cv. Marandú after cultivating soybean for 2 years in a quartzose sand in Bandeirantes, Mato Grosso do Sul. In this study, maize was planted in January (late season) and in October (normal season, i.e., conventional planting time), with sowing densities for the forage grass ranging between 0 and 6.0 kg/ha of viable pure seed. The forage seed was broadcast and incorporated with a harrow-grader. Maize was then planted at 1 m between rows and without fertilizer applications.

Table 9. Effect of simultaneous planting on rice grain production and on the number of *Brachiaria decumbens* and *Melinis minutiflora* plants, using two levels of fertilizer application, Brazilian *cerrados*.

Species	Planting system	P_2O_5 (kg/ha) for:			
		Rice (t/ha)		Forage (plants/m^2)	
		0	230	0	230
B. decumbens	Broadcasting	2.2	2.8	0.95	1.66
	Rice rows	4.8	3.6	0.95	1.63
	Interrows	6.4	8.8	1.08	1.24
M. minutiflora	Broadcasting	23.9	57.7	1.09	1.27
	Rice rows	36.4	70.8	0.98	0.97
	Interrows	40.1	86.6	1.04	1.19
Rice monocrop				0.97	1.86

SOURCE: Adapted from Kornelius et al. (1979).

The resulting maize grain production is given in Table 10. Planting in the late season significantly affected maize production, and forage planting density had a linearly negative effect on maize grain production. In addition, DM production of the forage grass at first harvest, although high under monoculture, was negatively and significantly affected by competition from the maize crop. However, later results (480 days after using the pasture, and at the standardization grazing at 410 days) showed that soil cover and the forage's total DM production were unaffected by simultaneous planting with maize.

Reclaiming degraded pastures

Degraded pastures can be reclaimed through the use of annual crops in two ways:

1. *The rapid method*. Rice and maize crops are established after soil preparation at the end of the dry season and sowing at the beginning of the rainy season, in which the forage regrowth is spontaneous via natural resowing. In this case, the pasture would be used after the annual crop is harvested. The greatest difficulty with this system lies in the control of the initially high quantity of forage seed present in the soil, which results in excessive competition with the crop (maize or rice). For maize, lime should be applied at least 90 days in advance.

2. *The long-term method*. Annual crops of rice, maize, or soybean, or rotations of these crops, are established. Two or more years later, the pasture is established. This system implies total control over old plants and of those that emerge spontaneously from naturally sown *Brachiaria* seeds. The land must therefore be prepared in the dry season to eliminate old plants and apply herbicides to control spontaneous seedlings. In this case, dicotyledonous crops such as soybean, sunflower, and cotton are preferable because they facilitate control of *Brachiaria* with herbicides.

Research projects that seek to reclaim pastures with annual crops normally evaluate other practices so that results can be compared. In Planaltina, DF, Carvalho et al. (1990) evaluated several systems for reclaiming degraded pastures of *B. decumbens*, among them with crops of maize, sorghum, and rice (Table 11). Of these, only maize had a satisfactory production. The authors

Table 10. Effect of sowing density of viable pure seeds of *Brachiaria brizantha* cv. Marandú on the productivity of associated crops and on the forage's dry matter production in quartzose sandy soil, after 2 years of soybean, Bandeirantes, Mato Grosso do Sul, Brazil.

Planting density (kg/ha)	First cycle (Jan-May 1987)[a]			Second cycle (Oct 1987/Feb 1988)[b]		
	Maize	Forage (t/ha)		Maize	Forage (t/ha)	
	(t/ha)	With maize	No maize	(t/ha)	With maize	No maize
0	2.02	—	—	—	—	—
0.75	1.79	4.28	4.87	3.73	3.18	10.40
1.50	1.36	3.96	5.99	3.66	3.92	10.35
3	1.08	5.60	6.76	2.99	4.18	13.51
6	0.99	5.77	7.82	3.00	4.51	14.76

a. Late planting.
b. Conventional planting time.

SOURCE: Adapted from Macedo and Zimmer (1990).

Table 11. Effect of different treatments for reclaiming degraded pastures on the forage production of *Brachiaria decumbens* and forage legumes[a], and yields of three crops[b], EMBRAPA Cerrados, Planaltina, DF, Brazil.

Treatment[c]	*B. decumbens*[d] (t/ha for period)		Legumes[d] (t/ha for period)		Grain yield (t/ha)
	115 days[e]	164 days[e]	115 days[e]	164 days[e]	
T1	2.46 bc*	2.69 bc	—	—	—
T2	1.32 def	2.29 bc	—	—	—
T3	3.46 a	3.97 ab	—	—	—
T4	1.65 cde	2.94 abc	—	—	—
T5	1.09 rf	3.65 abd	0.05 b	0.44 b	—
T6	0.43 f	1.85 c	0.08 b	0.40 b	3.664 (maize)
T7	2.30 a	4.98 a	0.48 a	1.31 a	0.961 (sorghum)
T8	3.15	3.63 abc	0.48 a	1.66 a	0.322 (rice)

a. *Calopogonium mucunoides*, *Stylosanthes capitata*, and *S. macrocephala*.
b. Maize, sorghum, and rice.
c. T1 = control
T2 = harrow
T3 = T2 + fertilizer application (corrective dressing) + liming
T4 = T3 + plow
T5 = T4 + legumes
T6 = T5 + fertilizer application at sowing + maize
T7 = T5 + fertilizer application at sowing + sorghum
T8 = T5 + fertilizer application at sowing + rice
d. Averages in the same column followed by the same letter do not differ significantly ($P < 0.05$), according to Duncan's test.
e. After the first pass of the harrow (20 Dec).

SOURCE: Adapted from Carvalho et al. (1990).

attributed this result to a lighter attack of pests on this crop and its better capacity to compete, which means that the forage grass initially grew more slowly than when it was associated with sorghum or rice. Zimmer et al. (1994) also observed a high degree of competition from *B. brizantha* when in association with rice and maize crops in Campo Grande, Mato Grosso do Sul.

Although the different reclamation methods gave satisfactory results, *Brachiaria*'s strong competition with the associated crops was a result of the high number of grass plants germinating naturally.

In our study, under conventional planting (plots prepared in October with one lime application, one pass each of the plow and harrow, and, 30 days later, one application of simple superphosphate incorporated with the harrow), the quantity of viable pure seeds in the soil was 25 kg/ha, and the number of *Brachiaria* plants in the plots with only rice and maize and no weeding was 65 plants/m^2. In contrast, plots prepared by the inversion method (one lime application, one pass of a heavy harrow, type Roman, and a later pass of each of the plow and harrow for leveling and incorporating superphosphate) had 72 plants/m^2.

The fertilizer applications significantly favored the reclamation of a degraded pasture after 8 years of grazing (Table 12). However, the applications of corrective dressing and fertilizer were done with high rates of inputs. The fertilizer applications for

Table 12. Effect of different methods of preparing the soil, fertilizer application, and production of annual crops on the reclamation of degraded pastures of *Brachiaria brizantha* cv. Marandú in a clayey Dark-Red Latosol.

Preparation method	Cropping system	Grain (t/ha)	Pasture dry matter (t/ha)		
			After harvest[a]	Second period[b]	Fourth period[c]
No preparation	No fertilizer (degraded)	—	2.02	1.01	2.54
	Rice with fertilizer	—	5.04	1.24	3.20
	Maize with fertilizer	—	7.04	1.42	3.25
Harrow (type Roman)	No fertilizer	—	1.61	0.87	2.67
	Rice with fertilizer	—	4.50	1.26	4.17
	Maize with fertilizer	—	4.86	1.40	3.85
Conventional	Rice only	1.78	—	—	—
	Rice + forage	0.68	4.96	1.53	3.36
	Forage + rice with fertilizer	—	7.10	1.49	3.31
	Maize only	2.46	—	—	—
	Maize + forage	1.12	5.91	1.57	3.49
	Forage + maize with fertilizer	—	8.89	1.40	3.62
	Soybean only	1.76	—	—	—
	Forage + soybean with fertilizer	—	7.37	1.39	3.42
Inversion	Rice only	1.86	—	—	
	Rice + forage	0.53	4.51	1.09	2.36
	Forage + rice with fertilizer	—	8.38	1.45	3.64
	Maize only	2.85	—	—	
	Maize + forage	1.19	6.47	1.52	3.43
	Forage + maize with fertilizer	—	10.26	1.33	4.12
	Soybean only	1.94	—	—	—
	Forage + soybean with fertilizer	—	8.75	1.37	3.78

a. Degraded pasture evaluated at crop's harvest after 170 days of growth between January and March, except for methods "No preparation" and "Harrow (type Roman)", when it was evaluated after 125 days of growth.
b. Second growing period of 100 days (10 Aug to 20 Nov 1991).
c. Fourth growing period of 120 days (10 Nov 1993 to 2 Mar 1994).

SOURCE: Zimmer et al. (1994).

rice in the developmental stage consisted of 1.65 t/ha of dolomitic lime, 350 kg/ha of the formula 0-20-20 plus zinc, and 200 kg/ha of ammonium sulfate. For maize, also applied in the developmental stage, applications were 3.7 t/ha of lime, 500 kg/ha of simple superphosphate, 450 kg/ha of formula 0-20-20, 40 kg/ha of FTE BR-16, and 400 kg/ha of ammonium sulfate. For soybean, the same fertilizers as those applied for maize were used, except for ammonium sulfate.

Crop plantings and fertilizer applications were done in rows but, when rain failed, replanting was necessary, requiring another pass with the harrow. That operation damaged the crops as the fertilizers had moved from the crops' roots, thereby benefiting pasture development.

Rice and soybean production under monoculture was satisfactory, but maize production was reduced, even in weeded plots, as a consequence of the late application of corrective dressings to the soil. The presence of *Brachiaria* with rice and maize reduced the production of these crops by more than 50%. The application of trifluralin (1.7 L/ha) was sufficient to control *Brachiaria* in the soybean crop. Soybean cv. Doko, with or without lime application 30 days before sowing, had good grain production. In contrast, maize cv. BR-201 was negatively affected when lime was applied too close to planting time. Crop production tended to be higher when the soil was prepared with the inversion method.

Response of pasture to fertilizer applications was significant, regardless of the mode of application. The rice and maize crops competed with the forage, and their production was lower during the first growing cycle when the pasture was associated with them. Planting *B. brizantha* with soybeans, before their leaf fall, did not produce positive results in that agricultural year.

Data related to regrowth during the second growing period, between August and November (the experimental area was used for grazing between April and August), showed little difference among treatments. Although rainfall was scarce during that period, growth was more reduced than during the first year. In the fourth growing cycle, similar trends were observed—in this case, with growth between November and March, grazing between February and November, and good rainfall. However, differences among treatments were not notable. These effects have been observed in other experiments, where the impact of renewal was more marked during the first year.

Controlling competition from forages

Because the principal difficulty in establishing rice and maize crops in association with *Brachiaria* is the excessive quantity of the pasture's seeds and consequently of its plants, some trials were carried out to reduce competition from this grass. Barcellos et al. (1995) evaluated the effect of five methods of soil preparation with three plows (harrow-plow, disk, and moldboard) on the plant population and production of *Brachiaria* in association with maize in Planaltina, DF. Table 13 shows that a pass with the harrow during the dry season favored maize production slightly, but that the various methods of preparing the soil had little effect on the population and production of *Brachiaria*.

One possibility with rice or maize crops is to use herbicides to control the population and growth of *Brachiaria*, although weeding in the interrows is also a good alternative. Tables 14 and 15 show the results of different practices for controlling *B. brizantha* in rice and maize crops, respectively. However, results are preliminary only and the treatments should be repeated under other conditions and with other herbicides at other rates and methods of application.

The strong competition of *B. decumbens* with rice and maize crops was also observed in other experiments of pasture reclamation by Kichel et al. (1996) and Miranda et al.

Table 13. Effect of the soil preparation method on the reclamation of degraded pastures of *Brachiaria brizantha* in terms of number of plants and dry matter (DM) production. The forage was cultivated simultaneously with maize, EMBRAPA Cerrados, Planaltina, DF, Brazil.

Treatment/season		*B. brizantha*		Maize[c] (t/ha)
Dry	Rainy	Plants[a] (no./m²)	DM[b] (t/ha)	
Harrow	Harrow	39	5.31	1.36 ab*
Harrow	Disk plow	26	5.84	1.63 ab
Harrow	Moldboard plow	24	4.16	1.71 b
	Harrow + disk plow	23	5.96	1.15 b
	Harrow + moldboard plow	29	4.68	1.19 b
Control			3.57	

a. New and old plants at 42 days after planting maize.
b. DM accumulated in 240 days.
c. Average grain production over 2 cropping years (1990/91 and 1991/92); averages in the same column followed by the same letters do not differ significantly ($P < 0.05$), according to Duncan's test.

SOURCE: Barcellos et al. (1995).

Table 14. Effect of different methods of pasture reclamation on the control of *Brachiaria brizantha* in terms of number of plants and dry matter (DM) production and on rice production, Brazilian *cerrados*.

Treatment[a]	*B. brizantha*		Rice (t/ha)
	Plants (no./m²)	DM (t/ha)	
1. Control: degraded grass	—	3.19	—
2. *B. brizantha* with preparation, no fertilizer	85	2.42	—
3. *B. brizantha* with preparation, with fertilizer	95	9.24	—
4. Rice + *B. brizantha* with preparation and with fertilizer	88	4.29	0.97
5. *B. brizantha* + cv. Mineirão[b]	75	5.39	1.18
6. Weeding at 20 days	83	3.36	1.26
7. Weeding at 20 and 40 days	96	3.00	1.80
8. Total weeding	—	—	1.93
9. Fenoxaprop-p herbicide (1.5 L/ha)	94	3.47	1.50
10. Pendimethalin herbicide (2.5 L/ha)	67	4.47	1.84

a. Treatments 4 to 10 received the same management practices.
b. The legume *Stylosanthes guianensis*.

SOURCE: Zimmer et al. (1994).

(l996) at EMBRAPA Gado de Corte (Tables 16 and 17). In these experiments, where the soil was an allitic, dystrophic Dark-Red Latosol, Cerradão phase (pH = 5.4; OM = 3.08%; P = 1.7 ppm), with Ca, Mg, K, Al, saturation of bases, and CEC at 0.63, 0.31, 0.07, 0.46, 1.01, and 7.26 mg/100 mL, respectively; and 14% and 31% of saturation of bases and aluminum. The data in both tables indicate that the rice crop was more competitive with *B. decumbens* than was maize, with the forage drastically reducing production in this crop. With both crops, however,

Table 15. Effect of different methods of pasture reclamation on the control of *Brachiaria brizantha* in terms of number of plants and dry matter (DM) production and on maize production, Brazilian *cerrados*.

Treatment[a]	*B. brizantha* Plants (no./m^2)	*B. brizantha* DM (t/ha)	Maize (sacks/ha)
1. Control: degraded grass	—	2.89	—
2. *B. brizantha* with preparation, no fertilizer	104	12.74	—
3. *B. brizantha* with preparation, with fertilizer	108	4.97	—
4. Rice + *B. brizantha* with preparation and with fertilizer	77	4.86	3060
5. *B. brizantha* + cv. Mineirão[b]	87	5.25	3120
6. Weeding at 20 days	105	1.83	4080
7. Weeding at 20 and 40 days	80	—	5640
8. Total weeding	—	—	5760
9. Fenoxaprop-p herbicide (1.5 L/ha)	20	1.70	4860
10. Pendimethalin herbicide (2.5 L/ha)	35	2.70	2280

a. Treatments 4 to 10 received the same management practices.
b. The legume *Stylosanthes guianensis*.

SOURCE: Zimmer et al. (1994).

Table 16. Number of plants/m^2, production of dry green matter (DGM), and total DM (TDM) of *Brachiaria decumbens* and legumes, and grain production of the rice crop, Brazilian *cerrados* (average of four replicates).[a]

Treatment[b]	*B. decumbens* Plants (no./m^2)	*B. decumbens* DGM (t/ha)	*B. decumbens* TDM (t/ha)	Rice (t/ha)
1. Control[c]	—	2.54 b*	6.52 b[b]	—
2. Direct reclamation	16	6.93 a	10.00 a	—
3. Direct reclamation + legume[d]	29	6.64 a	9.44 a[c]	—
4. Rice (conventional method)	55	1.31 c	1.98 c	0.99 c
5. Rice (inversion method) + fertilizer	23	1.56 c	2.03 c	2.22 b
6. T5 + lime + fertilizer	25	1.05 c	1.39 c	2.59 b
7. T6 + weeding	25	0.76 c	1.07 c	2.78 a

a. Averages in the same column followed by the same letters are not significantly different ($P < 0.05$), according to Duncan's test.
b. Treatments (T):
    1. Degraded *B. decumbens* pasture.
    2. Direct reclamation with surface application of 2 t of lime, and fertilizers P_2O_5 as simple superphosphate, N, P_2O_5, K_2O, and FTE BR-16, all incorporated with a heavy harrow, at 90, 16, 80, 80, and 50 kg/ha, respectively.
    3. T2 + introduction of *Calopogonium mucunoides* and *Stylosanthes guianensis*.
    4. Conventionally planted rice: one pass each of plow and harrow, and fertilizer applications of 6, 30, and 30 kg of N, P_2O_5, and K_2O, respectively.
    5. Rice, using the inversion method of soil preparation (one pass each of heavy harrow, moldboard plow, and harrow-grader), and fertilizer applications of 12, 90, and 48 kg of N, P_2O_5, and K_2O, respectively, plus 30, 20, and 20 kg/ha of FTE-BR 12, zinc sulfate, and N, respectively, 45 days after planting. When sowing the rice, 3 kg/ha of seeds of *B. brizantha* were added.
    6. T5 + 2 t lime, 40 kg P_2O_5 as simple superphosphate, and 20 kg N at 15 days; and 20 kg N at 35 days after sowing.
    7. T6 + one weeding to control *B. decumbens* at 20 days after sowing.
c. 300 days of growth; the other treatments had 135 days.
d. Values are for both pasture grasses and legumes.

SOURCE: Adapted from Kichel et al. (1996).

Table 17. Number of plants/m², production of dry green matter (DGM), and total dry matter (TDM) of *Brachiaria decumbens* and legumes, and grain production of the maize crop, Brazilian *cerrados* (average of four replicates).[a]

Treatment[b]	*B. decumbens*			Maize (t/ha)
	Plants (no./m²)	DGM (t/ha)	TDM (t/ha)	
Control	—	2.21	6.89 c	—
Direct reclamation	26	4.85	12.24 ab	—
Direct reclamation + legume[c]	40	5.69	10.91 b	—
Maize (conventional method)	75	3.58	5.76 cd	0.39 d
Maize (inversion method) + fertilizer	35	2.85	7.68 b	1.55 c
T5 + lime + fertilizer	35	4.89	7.73 b	2.98 b
T6 + weeding	35	3.33	3.64 d	4.56 a

a. Averages in the same column followed by the same letters do not differ significantly ($P < 0.05$), according to Duncan's test.

b. Treatments (T):
  1. Degraded *B. decumbens* pasture.
  2. Direct reclamation with surface application of 3.6 t of lime, and fertilizers P_2O_5 as simple superphosphate, N, P_2O_5, K_2O, and FTE BR-16, all incorporated with a heavy harrow, at 40, 16, 20, 20, and 40 kg/ha, respectively.
  3. T2 + introduction of *Calopogonium muconoides* and *Stylosanthes guianensis*.
  4. Reclamation with maize, using conventional planting: one pass each of the plow and harrow, and fertilizer applications of 2.0 t lime, 50 kg each of P_2O_5 and K_2O, and 22 kg N incorporated into the cover at 35 days.
  5. Reclamation with maize, using the inversion method of soil preparation (one pass each of the heavy harrow and moldboard plow) and fertilizer applications of 2 t lime, 45 kg P_2O_5 as simple superphosphate, and 16, 40, and 40 of N, P_2O_5, and K_2O, respectively, plus 40 kg FTE-BR 16 and 45 kg/ha N incorporated into the cover 45 days after planting.
  6. T5 + 3.6 t lime, 90 kg P_2O_5 as simple superphosphate, and 40 kg N at 15 days and 40 kg N at 35 days after planting.
  7. T6 + weeding to control *B. decumbens*, 20 days after planting.

c. Includes 20% legumes.

SOURCE: Adapted from Miranda et al. (1996).

competition from the forage must be reduced in the initial phase to obtain good grain production.

A new technique is now being evaluated for reducing forage competition with annual crops in systems where they are planted in association. This technique, called "Santa Fé" (Kluthcouski et al. 2000), is described as sowing pasture together with annual crops, such as rice, maize, sorghum, millet, or soybean, and applying herbicide to control the pasture's growth. In this case, lower doses of herbicides are applied, for example, 6 to 18 g of the active ingredient nicosulfuron are applied per hectare for maize, and 25% of the recommended dosage of haloxyfop-methyl for soybean. Other weeds are controlled with currently used herbicides for the specific crops.

Soybean production was reduced in the associated planting but was more than 2400 kg/ha; under monocropping, production reached 2900 kg/ha. Maize productivity was identical in both systems (>6300 kg/ha). Silage production in both systems was >48 t/ha for maize and 32 t/ha for sorghum. These systems allow the use of pasture during the dry season, producing good soil coverage for direct sowing in the next season.

The barreirão *system*

The *barreirão* system is another alternative for reclaiming *Brachiaria* pastures (see Chapter 15, this volume). This system was improved by Kluthcouski et al. (1991), based on the inversion method for preparing the soil, and adapted by Seguy et al. (1984) at EMBRAPA Arroz e Feijão. This system consists in reclaiming *Brachiaria* pastures by planting rice or maize.

In Bandeirantes, Mato Grosso do Sul, growing soybean for 1 or 2 years helped reclaim degraded *B. decumbens* pastures on sandy soils after 10 years of use (Tables 18 and 19). However, the treatments of no or surface preparation did not eliminate the regrowth of shrubby *cerrado* plants. An application of 1.7 L/ha of trifluralin effectively controlled *B. decumbens* in the soybean crop, and permitted the establishment of *B. brizantha* and *A. gayanus* in association with *Calopogonium* after 1 or 2 years of soybean.

The reduced growth of the forage species in the second year was caused by high leaching of K in the sandy soils. Table 20 shows P and K contents in the soil profiles under degraded *B. decumbens* pastures and under croplands with 1 or 2 years of soybean. In the latter case, given the low content of this nutrient in the soil, K had to be applied, being incorporated as deeply as possible, to the established crops.

During the first year, incorporation was done with two passes of the harrow-plow; in the second, with one pass of the plow before soybean was sown. This resulted in a better

Table 18. Availability of dry matter (DM) of grasses and legumes and percentage of legumes after 1 year of soybean planted in a 10-year-old *Brachiaria decumbens* pasture, which had degraded and was then reclaimed through fertilizer application and/or surface preparation, quartzose sand, Bandeirantes, Mato Grosso do Sul, Brazil, 1986.

Treatment	Grass[a]	Legume[a]	Leg.	Grass[b]	Legume[b]	Leg.
	(t/ha)[b]		(%)	(t/ha)[c]		(%)
After soybean[c]						
B. brizantha + *Calopogonium* sp.	3.94	0.72	15	5.07	0.38	7
B. decumbens + *Calopogonium* sp.	4.11	0.35	8	3.95	0.24	6
Andropogon gayanus + *Calopogonium* sp.	1.79	1.36	43	1.19	1.30	52
Surface preparation[d]						
B. decumbens + fertilizer + *Calopogonium* sp.	3.28	Scarce	Scarce	1.89	Scarce	Scarce
B. decumbens + fertilizer	2.83	—	—	2.28	—	—
B. decumbens	2.34	—	—	1.72	—	—
No preparation[e]						
B. decumbens + fertilizer + *Calopogonium* sp.	2.96	—	11	1.73	—	1
B. decumbens + fertilizer	3.29	—	—	—	—	—
B. decumbens	2.53	—	—	0.14	—	—

a. Amendments and fertilizers were first applied at 300, 250, 50, and 40 kg/ha for dolomitic lime, simple superphosphate, K_2O, and FTE BR-16, respectively. Soybean was then grown for 1 year, followed by conventional planting of grass/legume pastures.

b. Harvest at 90 days (t/ha).

c. Harvest at 120 days (t/ha).

d. Fertilizer application and surface planting + harrow (type Roman).

e. Fertilizer application and surface planting.

SOURCE: Zimmer et al. (1994).

Table 19. Availability of dry matter (DM) of grasses and legumes after 2 years of soybean/oats on a 10-year-old degraded *Brachiaria decumbens* pasture, quartzose sand, Bandeirantes, Mato Grosso do Sul, Brazil, 1987.

Treatment	DM (t/ha)	
	Grass	Legume
No oats after soybean		
B. brizantha + *Calopogonium* sp.	1.42	0.52
B. decumbens + *Calopogonium* sp.	1.43	0.44
A. gayanus + *Calopogonium* sp.	1.37	0.66
Average	1.41	0.54
Oats after soybean		
B. brizantha + *Calopogonium* sp.	2.37	0.63
B. decumbens + *Calopogonium* sp.	2.10	0.38
A. gayanus + *Calopogonium* sp.	1.71	0.61
Average	2.06	0.65

SOURCE: Zimmer et al. (1994).

Table 20. Phosphorus and potassium contents of a quartzose sandy soil after 1 and 2 years of soybean crop in the reclamation of a *Brachiaria decumbens* pasture, Brazilian *cerrados*.

Depth (cm)	P contents (ppm) of soil after:		P and K contents of soil after:			
	Soybean (1 year)	*Brachiaria* (10 years)	Soybean (2 years)		*Brachiaria* (11 years)	
			P (ppm)	K (meq/100 g)	P (ppm)	K (meq/100 g)
0-5	60	4	25	10	5	20
5-10	55	3	34	13	4	14
10-15	15	3	27	15	3	15
15-20	4	2	12	11	2	13
20-30	3	2	18	10	4	13
30-40	—	—	9	8	2	10
40-50	—	—	8	9	1	8

SOURCE: Zimmer et al. (1994).

distribution of nutrients in the soil profile.

In these sandy soils, at least two thirds of the K needed by the soybean crop should be applied in the developmental stage. In addition, the area under annual crops should be used for a maximum of 3 years before returning to pasture. In these cases, the soybean crop should be planted for 1 or 2 years, followed, in the last year, by planting the forage with maize or rice.

Interest in pasture renewal has arisen recently with grain sorghum, forage sorghum, and pearl millet crops, with special emphasis on the last two, which can be used directly by animals. This constitutes a system based on cropping and pasture reclamation, with no investments in machinery and installations needed for grain production.

In Goiânia, Goiás, Carvalho (1995) obtained faster and better reclamation of *B. brizantha* pastures, using the *barreirão* system with maize only, rather than with sorghum, rice, or pearl millet. After 180 days, there were 462, 405, 202, and 183 tillers/m^2, respectively. Forage DM production was lower in the associations than under monoculture. Grain production was 3.58, 2.24, 1.16, and 2.56 t/ha for maize (*barreirão* system), maize, sorghum, and rice, respectively.

Pasture renewal with maize facilitates the use of total biomass 45-50 days after planting the maize. In Rio Brilhante, Mato Grosso do Sul, *B. decumbens*, renewed with pearl millet in the cropping season of 1993/94, permitted an occupation period of 114 days with 3 AU/ha (4.8 an./ha) and an animal LW gain of 850 g/day (470 kg/ha). In this evaluation, income with respect to animal LW gain was US$325/ha, and the cost of renewal was US$210, resulting in a profit of US$115/ha (Kichel et al. 1999).

Other practices of pasture reclamation

Other practices of pasture reclamation, which are really maintenance activities, are being used by farmers and evaluated by researchers. An example of such a practice is the highly promising case of direct sowing for *Brachiaria* species. It consists of directly sowing soybean into areas of degraded pastures that had been established on soils previously used for annual cropping. The objective is to maintain soil fertility and pasture productivity. The technique consists of the following tasks:

1. Withdrawing the animals at the end of the dry period.

2. After the first rains, in September or October, and after pasture regrowth, glyphosate is applied at a rate of 2.5-3.0 L/ha, 21 days before planting. If necessary, 1.5 or 2.0 L/ha of glyphosate is also applied at planting. The pasture must then be properly developed.

3. In Mato Grosso do Sul, soybean is directly sown, normally between 15 October and 30 November. Fertilizers are applied according to soil conditions.

4. Postemergence herbicides are applied to eliminate weeds that germinate.

5. Soybean is harvested between March and April, followed by planting oats, pearl millet, or maize for grazing. In September, pearl millet is planted directly with *Brachiaria*, and the pasture regrows.

This planting system is used on an area of 700 ha, under the management of the Fundação Mato Grosso do Sul, which achieved an average production of 2.16 and 2.76 t/ha for *B. decumbens* and *B. brizantha*, respectively.

When evaluating soil characteristics, biomass production under the direct sowing system was 3.5 t/ha, while under conventional sowing, it was 3.7 t/ha. Positive aspects of the direct sowing system include a high root population, improved soil structure, and a high quantity of DM in decomposition (JC Salton 1998, personal communication). On another farm, direct sowing into *B. brizantha* produced 3.6 t/ha of DM, compared with 3.53 t/ha of DM for conventional sowing. Costs were US$34 lower for direct sowing.

Farmers sometimes carry out direct sowing over 2 years. A farmer in Maracajú, Mato Grosso do Sul, had

700 ha, 350 of which was established with *B. brizantha*. Half of this planting was 1 year old and the other half, 2 years old. The other 350 ha was directly sown with soybean, with a distribution in area and time similar to that for the pasture. The farmer applied a rotation system entailing the use of the pasture for 2 years, followed by planting soybean, oats, and maize over an equal period. In the area with *B. brizantha* (350 ha), the farmer maintained about 1000 animals in the rainy season; and in winter he added the 350 ha where the oats and maize were planted after soybean. The system with oats is possible only in the southern part of the *cerrados*, where drought is less severe.

Direct sowing over pasture is a practice that has been diffusing fast in recent years because of its great advantages, farmers' interest, and governmental programs of pasture reclamation and grain production.

This cropping system takes into account the sustainability of pasture productivity; but, in areas of pastures and soils that have been reclaimed by using annual crops, problems still exist, given that the great impact of renewal is manifested only during the first year. Consequently, the pasture should be permitted to degrade again to renew it with crops, applying maintenance fertilizers or sowing directly into it. After reclaiming both soil and pasture, the main constraint is nitrogen. Several questions arise: Is nitrogen fertilizer application viable? What does it cost? How can legumes be developed to fix sufficient nitrogen?

Application of maintenance fertilizer is basic for the persistence of pasture, especially with legumes, and for animal production. In Minas Gerais, Vilela et al. (1982) obtained good forage production in grass/legume pastures. Consequently, animal LW gains increased with annual applications of 20 and 40 kg/ha of P_2O_5 and K_2O, respectively, over 7 years (Table 21).

Through fertilizer application for maintenance or pasture reclamation, the system's sustainability can be improved. Macedo (1995) found physical conditions (permeability, porosity, and retention of moisture) to improve in a Dark-Red, dystrophic, clayey Latosol when maintenance fertilizer was applied to *B. decumbens* and *P. maximum* cvs. Tanzania and Tobiatã in Campo Grande, Mato Grosso do Sul.

However, no clear advantages of maintenance fertilizers could be seen

Table 21. Effect of levels of maintenance fertilizer applications, using P_2O_5 and K_2O in the pasture association *Panicum maximum*/*Stylosanthes guianensis* cv. Gracilis/*Macroptilium atropurpureum* cv. Siratro/*Neonotonia wightii* and comparing year 1 with year 7, Alto São Francisco, Minas Gerais, Brazil.

Characteristic	Levels of fertilizer application[a]					
	0		20		40	
	1	7	1	7	1	7
Grass cover (%)	53	15	58	58	59	74
Legume cover (%)	11	2	15	10	15	25
Occupation (AU/ha)	1	0.3	1.2	1.2	1.4	2
Annual LW gain/ha	229	70	360	360	376	500

a. 0, 20, and 40 kg/ha per year of each of P_2O_5 and K_2O.

SOURCE: Vilela et al. (1982).

for meat production, even after several years of using the pastures, or for the soil's physicochemical conditions for annual crops, especially in associated pastures. More long-term research projects are therefore necessary.

Annual Forages in Croplands

In the *cerrados*, the areas for producing annual crops such as soybean, maize, and rice are usually left to rest after harvest during the dry season (May to October). However, many farmers in the southern region plant oats after harvesting the summer crop; and in warmer regions (central and northern *cerrados*), they plant pearl millet or sorghum.

These systems aim to protect the soils and to provide litter DM for direct sowing. Recently, with the appearance of new, longer cycle, pearl millet and sorghum cultivars, this practice has tended to spread. These systems also permit the use of species for direct grazing of animals during the dry and rainy seasons, as is being done with maize, or for making hay and silage.

Pearl millet can be established in rotation with annual crops or for pasture renewal, as described previously. Pasture can be grazed in the fall after the soybean harvest or in spring or summer. These pastures can also be cultivated under supplementary irrigation, and many farmers use them to graze their beef or dairy cattle. In Ponta Porã, Mato Grosso do Sul, Thiago et al. (1995) obtained better performance from calves being fattened when these grazed oats in the dry season and pearl millet in summer. The treatments evaluated were (1) 100% pasture with *B. brizantha* (traditional system); (2) 50% of area under *B. brizantha* pasture and 50% under oats in winter and pearl millet in summer; (3) Treatment 2 + supplements with concentrates at a rate of 0.8% of LW. The stocking rate was 1 AU/ha and was adjusted only in the control. Nelore, Nelore × Charole, and Nelore × Chianina calves were used, separated into groups of weaned and yearlings at the beginning of the experiment. The animals remained for two cycles on oats and one cycle on pearl millet. Only the pure Nelore remained for more than two cycles on pearl millet before reaching slaughter weight.

Grazing oats and pearl millet favored animal performance but, in the second cycle of oats, performance was not satisfactory as only the supplements provided a better weight gain (Tables 22 to 24). Only the crossbred animals receiving supplements of annual pasture or annual pasture + concentrates reached slaughter weight by November 1994. The Nelore animals reached this weight only after the following rains (February 1995). In winter (dry season), *B. brizantha* had a crude protein (CP) content of 5.8% and an in vitro organic matter digestibility (IVOMD) of 47%, whereas oats reached a CP of 21.7% and an IVOMD of 70%. In summer, *B. brizantha* had a CP of 11.5% and an IVOMD of 67%, whereas maize had a CP of 21% and an IVOMD of 74%.

In Rio Brilhante, Mato Grosso do Sul, steers with an initial LW of 220 kg also performed better when grazing oats, followed by *P. maximum* cv. Tanzania and pearl millet (Table 25). Differences were also found among the genetic groups used.

The system that involves the use of annual forages (oats, pearl millet, or sorghum) in grazing is actually more important in those operations where livestock and grains are jointly produced. In these systems, the

Table 22. Effect of oat supplements on daily liveweight gain (g/animal) in crossbred and pure Nelore animals.[a]

Treatment[b]	Grazing cycle	Crossbred		Nelore		Average of treatments
		W[c]	So[d]	W[c]	So[d]	
T1		253	175	148	189	191 a
T2	July/Oct	590	569	363	460	499 b
T3	1993	655	760	438	576	607 c
Genetic group		503 a		362 b		
T1		48	-175	-117	-213	-38 a
T2	July/Sept	8	-145	-119	-147	-105 b
T3	1994	366	-187	331	224	327 c
Genetic group		62 a		7 b		

a. Averages in the same column or row followed by the same letters are not significantly different ($P < 0.05$), according to Duncan's test.

b. The treatments evaluated were T1 = pasture with 100% *Brachiaria brizantha* (traditional system); T2 = pasture was 50% of area with *B. brizantha* and 50% with oats in winter and pearl millet in summer; T3 = T2 + concentrate supplements at a rate of 0.8% of LW.

c. W = weaned calves, 7-8 months old.

d. So = yearlings, 12-13 months old.

SOURCE: Thiago et al. (1995).

Table 23. Effect of maize on daily liveweight gain (g/animal) in crossbred and pure Nelore animals, Brazilian *cerrados*.[a]

Treatment[b]	Grazing cycle	Crossbred		Nelore		Average of treatments
		W[c]	So[d]	W[c]	So[d]	
T1		690	651	592	631	641 a
T2	Nov/Feb	959	993	764	805	880 b
T3	1993/94	810	775	703	882	817 b
Genetic group		830 a		730 b		
T1		824	726	743	726	726 a
T2	Nov/Feb	998	895	739	721	811 a
T3	1994/95	611	639	611	603	616 b
Genetic group		765 a		695 b		

a. Averages in the same column or row followed by the same letters are not significantly different ($P < 0.05$), according to Duncan's test.

b. The treatments evaluated were T1 = pasture with 100% *Brachiaria brizantha* (traditional system); T2 = pasture was 50% of area with *B. brizantha* and 50% with oats in winter and pearl millet in summer; T3 = T2 + concentrate supplements at a rate of 0.8% of LW.

c. W = weaned calves, 7-8 months old.

d. So = yearlings, 12-13 months old.

SOURCE: Thiago et al. (1995).

genetic potential for the animal is also important. For example, crossbred animals perform better, not only in terms of LW gains but also in the finishing phase during the dry season when the market price is 20% to 30% higher.

Using Crop Residues

In sustainable crop-and-livestock production systems, the use of crop residues is not promising because soil cover would be affected, the costs of collecting residues are high, and their

Table 24. Liveweight (kg/animal) within genetic groups for every treatment, Brazilian *cerrados*, Nov 1994/Feb 1995.[a]

Treatment[b]	Grazing cycle	Crossbred W[c]	Crossbred So[d]	Nelore W[c]	Nelore So[d]	Average of treatments
T1		342	370	282	328	331 a
T2	Nov 1994	370	427	323	380	331 a
T3		428	478	362	421	422 c
Genetic group		407 a		350 b		
T1		425	443	358	405	408 a
T2	Feb 1995	487	518	398	453	464 b
T3		490	542	423	482	484 b
Average		467 a	501 b	393 c	447 d	
Genetic group		484 a		420 b		

a. Averages in the same column or row followed by the same letters are not significantly different ($P < 0.05$), according to Duncan's test.

b. The treatments evaluated were T1 = pasture with 100% *Brachiaria brizantha* (traditional system); T2 = pasture was 50% of area with *B. brizantha* and 50% with oats in winter and pearl millet in summer; T3 = T2 + concentrate supplements at a rate of 0.8% of LW.

c. W = weaned calves, 7-8 months old.

d. So = yearlings, 12-13 months old.

SOURCE: Thiago et al. (1995).

Table 25. Patterns of crossbred and pure Nelore animals in pastures of oats, *Panicum maximum* cv. Tanzania, and pearl millet, Remanso Hacienda, Rio Brilhante, Mato Grosso do Sul, Brazil, 1994/95.

Genetic group	Average daily liveweight gain (g) Oats (July-Aug, 56 days)	cv. Tanzania (Sept-Oct, 65 days)	Maize (Nov-Dec, 69 days)	Total gains[a] for 190 days DLWG (g)	TLWG (kg)
½ Hereford × ½ Nelore	939	139	700	579	110
½ Brown Swiss × ½ Nelore	795	75	728	524	100
½ Simmental × ½ Nelore	921	35	738	552	105
¾ Nelore × ¼ Brown Swiss	789	63	690	505	97
¾ Nelore × ¼ Simmental	716	37	671	467	88
7/8 Nelore × 1/8 Simmental	513	120	652	429	81
Three-cross (½ Chianina × Nelore/Brown Swiss)	1020	86	738	599	114
Three-cross (½ Devon × Nelore/Brown Swiss)	977	-12	651	520	98
Dairy cattle	902	128	642	540	103
Average gains/period	840	60	710	520	100

a. DLWG = average daily liveweight gain; TLWG = total liveweight gain for the period.

SOURCE: Joao Candido Abella Porto, EMBRAPA Gado de Corte (1995, unpublished data).

nutrient value is very low. However, some uses can be important, such as giving animals free access to the cropped areas, allowing them to select better quality components. However, this system can favor weed invasion.

Under certain circumstances, excess residues must be removed to establish the following crop. This can facilitate harvesting as in the case of irrigated rice when a second sowing of the crop is desired. Animal manure should always be incorporated into those areas where residues are removed.

In the *cerrados*, the availability of crop residues is high, but their collection is not feasible. Moreover, the soils are poor in OM, and removing these residues prejudices soil characteristics such as OM content and the associated CEC.

Residues of rice, common beans, maize, and wheat, and even of sugarcane should be used in sites less than 25 km away from the harvested areas to keep transport costs down. The application of urea or ammonium sulfate to harvest residues increases CP contents and reduces fiber, improving the residues' use by grazing animals (Reis and Rodrigues 1993). Although this treatment is more effective for poor quality hays, its cost usually does not provide added advantages. When offered as an exclusive source of nutrients to the animals, residues lead only to small LW gains.

Residues of sugarcane, whether as green matter or bagasse, have the same limitations as harvest residues. Self-hydrolyzed bagasse is of better quality and is being used in cattle confinement operations located near cane alcohol and sugar industries. The principal prospect for using this residue lies primarily in energy production for industry.

Silva et al. (1992) discuss the use of agricultural and industrial residues for animal feed, including harvesting, treatment, and use.

Supplements for Grazing Animals

Dietary supplements for grazing operations have attracted the attention of many livestock owners, especially those handling integrated crop-and-livestock production systems. Supplementation is normally carried out in one or more of the following stages: calving, suckling, weaning, and fattening.

The advanced age at slaughter for *cerrado* cattle is the result of their poor performance, due to stress during dry seasons in different stages of their raising, especially fattening. Dietary supplements during dry seasons will therefore favor the animals' continuous development.

In the region, 80% of pasture growth occurs in the rainy season and 20% in the dry season. Thus, one management strategy would be to reserve part of the surplus forage from the wet season for the dry. However, because of storage, such forage is of poor quality, and the animals' diet must be improved by protein and energy supplements. These dietary supplements will help reduce the age for either slaughter (producing an earlier maturing calf with greater commercial value) or first calving.

Normally, dietary supplements include grains such as maize, sorghum, and soybean, or flours, meals, hays, and industrial products such as urea. Supplements are more logical when farmers produce the inputs on their farms. Another alternative is to grow forage legumes in protein banks, to which animals have access during dry periods.

Dietary supplements during the initial stages of calf-raising will improve their weight at weaning. Normally, ground maize + 20% soybean flour is used. With these rations, additional LW increases of 20-30 kg can be obtained by weaning time.

Table 26. Effect of dietary supplements during grazing on the age and period for slaughter for pure Nelore calves, Brazilian *cerrados*.

Supplement treatment	Slaughter age (in months)	Period of profitability	Ranking
A. Supplements only during the first dry season	31	June	4
B. Supplements only in the second dry season	28	February	2
C. Supplements during both the first and second dry seasons	26	December	3
D. Supplements in the first dry season, confinement in the second	23	September	1
E. No supplements (control)	38	December	5

Euclides et al. (1995) evaluated four alternative supplements for use with pastures of *B. decumbens* in Campo Grande, Mato Grosso do Sul. The animals were weaned, pure Nelore calves. Treatments were (1) dietary supplements during the first dry season after weaning; (2) supplements during the second dry season only; (3) supplements in both dry seasons; (4) supplements during the first dry season and confinement during the second. All the animals were treated until their slaughter at a LW of 440 kg.

Supplements consisted of a ration composed of 80% ground maize and 20% soybean meal. To guarantee an average daily consumption of rations equivalent to 0.8% of the LW, 1700 g per animal were provided daily during the first dry season of 75 days, and 3500 g per animal daily during the second season of 85 days. Table 26 gives the economic results of this study, with the following points to be kept in mind:

1. Slaughter age for treatments C and B was 26 and 28 months, respectively, because slaughter took place in the rainy season to free the pastures for use in the following dry season.

2. The pastures were left to rest, starting in January and February, which is ideal for *B. decumbens* in central Brazil.

3. Animals, 26 or 28 months old at slaughter, were classified as early maturing calves.

4. The greater or lesser profitability of alternative systems of beef cattle production is still a function of the average prices for fattened steers in effect during dry periods. For example, if price differences during these periods were not considered, treatments A and E would have continued in the last places, while treatment B would have been the best, followed by treatments C and D.

The same pattern of response occurred with Angus × Nelore animals; indeed, they reached slaughter weight even earlier (Table 27) (Euclides et al. 1995).

When evaluating the opportunity to supplement grazing during the dry season, the following points should also be considered, together with those mentioned above:

Table 27. The effect of dietary supplements during grazing on the age and period for slaughter for Angus × Nelore calves, Brazilian *cerrados*.

Supplement treatment[a]	Slaughter age (in months)	Period of profitability
A	26	March
B	25	February
C	24	January
D	21	October
E	29	July

a. For an explanation of the treatments, see Table 26.

SOURCE: Euclides et al. (1995).

1. If dietary supplements are to be successful, the pasture must be in a condition to provide sufficient biomass (2.5-3.0 t of DM) at the beginning of the dry season. For example, *B. decumbens* pasture should be 25-30 cm high.

2. Before starting dietary supplementation, farmers should measure animal LW gain from May onward so that they may administer supplements only during the strictly necessary period, that is, when the animals are close to losing weight.

The preliminary results of a second experiment with Angus × Nelore animals indicate that the daily LW gain during the first dry season was 620 g per animal in animals receiving supplements, compared with only 73 g in control animals, which received no supplements.

Urea can also be used as a supplement, but its management is difficult. Valadares Filho (1995) mentions that the addition of 3%-5% urea reduces the consumption of concentrate by grazing animals.

Confinement

Confinement is carried out by those farmers who produce crops for silage and grains and by others who manage animals jointly with other livestock owners. The former group of farmers place their animals in confinement with grains and silage, using appropriate equipment and technology. Such farmers normally acquire harvesters and the equipment necessary for transporting forage to the feeding troughs in the open field.

Confinement, which lasts 80-120 days over the dry season, constitutes the finishing stage of the animals for sale during August to November. The objective is to produce a younger and better quality animal (zebu × European race), raised by grazing, with or without supplements of oats, pearl millet, or maize. The animals are normally confined when they have a LW of 350-380 kg, and are sold when they reach a slaughter weight of 450-470 kg and when market prices are 20% to 30% higher.

Another advantage of confinement is reduced occupation of pastures during the dry season. For grain or cattle farmers, this system improves the financial flow of their operations by allowing them to sell their animals before making investments for the summer crops.

The techniques for confining animals are widely known. The principal difficulty is to produce sufficient volumes of concentrate necessary to feed the animals. Feeding represents 70%-80% of the costs of operating the system. According to Thiago and Costa (1994), the economically viable animal LW gain ranges from 700 to 1100 g/day, depending on animal type, age, and initial weight.

The diets normally contain, at 50%-70% by volume, hay, silage, or sugarcane; and, at 30%-50%, concentrate of maize, sorghum, soybean, cotton, meal, flour, and residues from grain cleaning.

The need to produce low-cost feed gave rise to new agricultural alternatives. Silages, hays, or grains for confinement are produced during normal planting times or as rotation crops. This latter system has been disseminated in recent years, with maize, sorghum, pearl millet, or oats being sown after the summer crops. Today, they are used as crops following forages such as *Brachiaria* and *Panicum* species for silage. Crop rotation has several advantages, including the maintenance of soil cover, possibility of rotating short-term crops, intensive land use, weed control, and more rational use of machinery and labor.

The following are some crop rotation systems, in which the principal crop is planted during the normal period (October-November) and the rotation crop from February until the end of April.

- Soybean, followed by pearl millet, sorghum, or oats.
- Maize followed by pearl millet or oats.
- Maize for silage followed by sorghum, pearl millet, oats, or legumes for green manure or cutting. The legumes can be associated with sorghum or pearl millet.
- Beans followed by maize, sorghum, or pearl millet.
- Rice followed by sorghum or pearl millet.

The rotation crops can be used for producing grains, silage, hay, or cut fodder for immediate supply to the animals. These crops usually yield less than the crops grown in the normal period, their productivity being highly dependent on rainfall and favorable temperatures during the growth cycle.

Maize as a rotation crop normally produces 2-3.5 t/ha of grain and 10-15 t/ha of silage. Sorghum, which is resistant to drought, has higher productivity, although its potential is variable, depending on the variety best adapted for sowing in rotation. In trials carried out by EMBRAPA Agropecuária Oeste (Dourados, Mato Grosso do Sul), the performance of three sorghum cultivars differed according to planting time (Table 28). For eight grain-sorghum cultivars grown in rotation at different locations, Ribas and Zago (1986) found that, in Capinópolis (MG), production ranged

Table 28. Analyses of grain production of sorghum cultivars by individual season and by the seasons combined, Dourados, Mato Grosso do Sul, Brazil, 1982.[a]

Cultivar	Grain production (kg/ha) at planting time:			Production (kg/ha) summer + winter
	Nov 21 (summer)	March 30 (winter)	April 23 (winter)	
BR-300	2556	1796 a*	1577 a	1796 a
Contiouro	2401	233 c	368 b	1000 c
AG-1002	1919	1204 b	1499 a	1541 b
F	2.27 ns	49.99**	14.59**	38.75**
CV (%)	19	21	31	10

a. Averages in the same column or row followed by the same letters are either not significantly (ns) or significantly different (**) at $P < 0.05$, according to Duncan's test.

from 3.5 to 4.8 t/ha; in Patos de Minas (MG), from 5.6 to 6.7 t/ha; in Santa Helena (GO), from 5 to 6.6 t/ha; and in Inhumas (GO), from 1.4 to 7.9 t/ha. The authors also reported production between 26 and 38 t/ha of DM for five forage sorghum cultivars in identical areas. For 28 sorghum lines for cutting and grazing, when grown in rotation in Capinópolis, production ranged from 36 to 50 t/ha, with sowing in February and cuts between April and May. In Mato Grosso do Sul, production of grain sorghum ranging from 1.5 to 4 t/ha has been found in rotation plantings.

To confine 100 animals over 100 days with daily LW gains of 0.7-1.0 kg per animal, and considering a production of 30 t/ha of maize or sorghum silage, 2 t/ha of sorghum grain as a rotation crop, and 2.1 t/ha of soybean; and an average daily consumption per animal at 20 kg of silage, 2 kg of sorghum, and 0.5 kg of soybean plus 130 g of urea and 50 g of mineral mixture, then 19.5 ha would be used as follows:

Maize silage: 20 kg/animal per day = 2000 kg × 100 = 200,000 kg (± 7 ha)

Grain sorghum: 20 kg/animal per day = 200 kg × 100 = 20,000 kg (± 10 ha)

Grain soybean: 0.5 kg/animal per day = 50 kg × 100 = 5,000 kg (± 2.5 ha)

In this system, maize is planted in October before soybean (the most popular crop in the region) is planted in November. Sorghum is planted in rotation with maize for silage, and harvested at the end of January. Harvesting maize for silage somewhat complicates pest control for the soybean crop, which is carried out at the end of January. Sorghum is harvested at the end of May, after the soybean harvest. Confinement is implemented between May and June until August or October, when farm workers are relatively unoccupied.

Other forms of forage production for animal confinement exist, depending on equipment, facilities, and availability of residues and byproducts from agroindustries.

Socioeconomic Aspects

For integrated agropastoral production systems to be highly efficient economically and in terms of preserving natural resources, farmers have to have good managerial capacity and reasonable control over field operations, and receive sufficient financial support.

The farmer's interest in a given type of operation depends on personal preferences, and on the possibilities of obtaining reasonable economic profit. Under certain circumstances, a livestock owner may not be interested in grain production *per se*, but is able to contract services, or lease in partnership agricultural lands for cropping. In the *cerrados*, about 40% of grains are produced on leased lands. However, considering the high costs of certain annual crops, an attractive option may be not to charge for leasing land where pasture reclamation is considered, and even offer to collaborate with the purchase of inputs to obtain, in return, improved pastures within a short period. Under these conditions, farmers can take advantage of an additional area with oats, pearl millet, sorghum, or pastures like *Brachiaria* or *Panicum* species by grazing animals that would gain 90 to 180 kg of LW per hectare, compared with 30 or 90 kg/ha on degraded pastures.

The opportunity costs for the direct reclamation of pastures or through annual crops should be well analyzed, especially in terms of the investments required, because the farmer will have increased expenditures and will need a guarantee of a return on these investments. Special attention should be given to costs of inputs and to future marketing possibilities to guarantee the long-term economics of the business.

Special attention should also be paid to the system's productivity: if investments in pasture reclamation are to be made, then the herd must have the genetic potential and receive the proper management to guarantee efficient use of the pasture. For a herd with a 60% birth rate and 8% mortality, the internal rate of return on pasture reclamation is 6.9% when rice is cultivated for 1 year; 8.43% in direct reclamation, and 10.1% when soybean is cultivated for 2 years. When the birth rate increases to 80% and mortality is reduced to 4%, then the rates of return for the three systems are, respectively, 12.7%, 12.8%, and 18.3%.

When oats and pearl millet are used for grazing or as dietary supplements in confinement, the objective and animal type should be well defined, taking into account slaughter age at the time of the best market prices and carcass quality. Some states of Brazil are applying lower taxes for calves of a slaughter age that is less than 30 months.

For the herds' adequate physical and economic development, various forms of pasture use and supplements should be considered. In a simulation study on the use of agropastoral systems, Cezar (1995) found that lowering slaughter age from 42 to 26 months reduces the pasture area needed by 28% and, to sell the same number of animals, the herd is smaller by 19%. These figures represent an increase of 40% in meat production per hectare.

Table 29. Effect of reduced slaughter age on certain system characteristics and physical and economic indicators.

Parameter	42 months		37 months		26 months	
	Quantity	Index	Quantity	Index	Quantity	Index
System characteristic						
Area (ha)	4047	100	3443	85	2901	72
Supplements first dry season	No	—	No	—	Yes	—
Confinement	No	—	Yes	—	Yes	—
Age at first calving (years)	3	—	3	—	3	—
Weight at weaning (kg)	150	—	150	—	150	—
Time of sale of fattened steers	Harvest	—	Between harvests	—	Between harvests	—
Physical and/or economic indicator						
Total animals per year	7138	100	6466	90	5787	81
Total animals sold per year	1325	100	1326	100	1329	100
Days of confinement	0	—	65	—	96	—
Annual profits (%)	18.55	100	20.50	110	23	124
Liveweight sale per hectare per year (kg)	114.01	100	134.14	118	159.76	140
Carcasses sold per hectare per year (kg)	38.51	100	57.09	118	68.04	140
Weaned calf per cow per year (kg)	108	100	108	100	108	100

SOURCE: Cezar (1995).

Table 29 shows relationships between slaughter age and physical indicators. When fiscal incentive is added in the case of early maturing calves, the gross margin is increased by 42% (Table 30), even though their performance was no higher than that of 37-month-old steers that had been confined for 65 days. This result was due to a longer period of confinement (96 days) for the calves, which increased costs per animal. Tables 31 and 32 present aspects related to the effect of liveweight at weaning on the production and profitability of meat production.

Table 30. Effect of reduced slaughter age on economic indicators, without considering capital interest.

Indicator[a]	42 months		37 months		26 months			
					No incentive		With incentive	
	Value	Index	Value	Index	Value	Index	Value	Index
Gross margin/ha per year	48.80	100	63.94	131	64.38	132	69.62	142
Gross margin/animal sold	148.05	100	166.02	111	140.55	94	151.94	102
Gross margin/liveweight sold	0.42	100	0.47	111	0.40	95	0.43	102
Gross margin/kg carcass sold	1.00	100	1.12	112	0.95	95	1.02	102

a. In R$; exchange rate: R$1.00 = US$1.00.

SOURCE: Cezar (1995).

Table 31. Effect of weight at weaning on the economics of producing early maturing calves, Brazilian *cerrados*.

Parameter	Weight at weaning:		
	150 kg	180 kg	220 kg
System characteristic			
Area (ha)	2901	2901	2901
Dietary supplements first dry season	Yes	Yes	Yes
Confinement	Yes	Yes	Yes
Restricted feeding	No	No	No
Age at first calving (years)	3	3	3
Days of confinement	96	66	26
Slaughter age (months)	26	25	23
Physical indicator			
Animal use	23	23	23
Carcass (kg/ha)	68.04	68.06	68.04
Economic indicator (and index)[a]			
Gross margin/ha	56.98 (100)	63.61 (111)	71.01 (127)
Gross margin/kg of meat	0.83 (100)	0.93 (112)	1.04 (125)

a. In R$; exchange rate: R$1.00 = US$1.00.

SOURCE: Cezar (1995).

Table 32. Estimate of the effect of restricted feeding on the profitability of producing early maturing calves with reference to a weaning weight of 150 kg, Brazilian *cerrados*.

Parameter[a]	Weaning weight (and relative profitability)		
	150 kg	180 kg	220 kg
Gross margin per hectare per year	56.98 (100)	59.12 (104)	67.00 (118)
Gross margin on carcass sold per year	0.83 (100)	0.86 (104)	0.98 (118)

a. In R$; exchange rate: R$1.00 = US$1.00.

SOURCE: Cezar (1995).

Research Needs

Before establishing sustainable agropastoral production systems, researchers need to focus their work on the following themes:

1. Improved characterization of degraded agricultural soils and pastures.
2. Crop systems in rotation, including cultivars of crops and forages, both annual and perennial.
3. Cultivars of crops and legume pastures useful for reclaiming degraded pastures, especially in sandy soils.
4. Fertilizer applications for reclaiming and maintaining degraded pastures.
5. Management of forages for establishing with annual crops.
6. Methodologies for effective research on sustainable production systems.
7. Developing maize, rice, and soybean cultivars adapted for planting in association with forages.

Research on systems does not attract much attention from either scientists or institutions because experiments are costly and long term, requiring years to obtain concrete results. In the *cerrados*, the experience of EMBRAPA Gado de Corte and EMBRAPA Cerrados has shown that, from the outset, information is relevant and useful for interested farmers. This fact should be used to guarantee continuity of research to consolidate that information. This line of research should be institutional, not belonging to one researcher or group of researchers.

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To economize space, the following acronyms are used:

CNPAF	Centro Nacional de Pesquisa de Arroz e Feijão (*of* EMBRAPA)
CNPGC	Centro Nacional de Pesquisa de Gado de Corte (*of* EMBRAPA)
CPAC	Centro de Pesquisa Agropecuária dos Cerrados (*of* EMBRAPA)
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária
SBZ	Sociedade Brasileira de Zootecnia

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CHAPTER 18

Evaluation of Agropastoral Systems in the Colombian Eastern Plains

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Contents

Abstract

To convert the Colombian Eastern Plains into an agricultural food production area, crop and pasture varieties must be developed that can tolerate the region's acid soils. To achieve this goal, the Instituto Colombiano Agropecuario and the Corporación Colombiana de Investigación Agropecuaria worked in collaboration with CIAT to evaluate agropastoral systems on Oxisols that were characterized by 86% aluminum saturation, P content at 2 ppm, and organic matter (OM) content at 2.5%. Three tillage systems (conventional, vertical, and minimum) were applied in a strip design to two rotational systems (rice/soybean and rice/cowpea), followed by either *Brachiaria dictyoneura* pasture or native savanna pasture at two rates of fertilizer application.

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Cowpea yields were not measured, the crop being incorporated into the soil. In the first cycle (1995), rice and soybean yields differed significantly for fertilizer application levels, but did not differ for tillage systems. In the second cycle (1996), yields of rice in rotation after soybean increased significantly but, again, with no differences across tillage systems. The highest increases in yield were obtained with rice/cowpea/rice. Soil properties also changed: bacterial populations increased significantly, particularly under conventional tillage, whereas fungi and actinomycetes were more stable. Availability of P, Ca, and Mg increased, compared with undisturbed savanna soil but OM content decreased significantly as bacterial populations increased. The lowest values for soil resistance to root penetration were observed for the rice/cowpea rotation with minimum tillage. These preliminary results demonstrated the potential benefits of crop rotation and green manure incorporation for establishing high-quality, low-cost pastures in acid soils.

Resumen

Para convertir los Llanos Orientales de Colombia en una región agrícola de producción de alimentos, deben desarrollarse variedades de cultivos y pasturas que puedan tolerar los suelos ácidos de la región. Para lograr esta meta, el Instituto Colombiano Agropecuario (ICA) y la Corporación Colombiana de Investigación Agropecuaria (Corpoica) han trabajado en colaboración con el CIAT para evaluar sistemas agropastoriles en Oxisoles que están caracterizados por un 86% de saturación de aluminio, un contenido de P de 2 ppm y un contenido de materia orgánica (MO) de 2.5%. Se establecieron tres sistemas de labranza (convencional, vertical y mínima) en un diseño de franjas en dos sistemas de rotación (arroz/soya y arroz/caupí) seguido de una pastura de *Brachiaria dictyoneura* o de una pastura de sabana nativa. Se aplicaron dos tasas de fertilizante. No se midieron los rendimientos de caupí, siendo el cultivo incorporado al suelo. En el primer ciclo (1995), los rendimientos de arroz y soya difirieron significativamente respecto a los niveles de aplicación de fertilizante, pero no difirieron respecto a los sistemas de labranza. En el segundo ciclo (1996), los rendimientos del arroz en rotación después de la soya aumentaron significativamente, pero nuevamente sin diferencias entre los sistemas de labranza. Los mayores aumentos en el rendimiento se obtuvieron con arroz/caupí/arroz. Las propiedades del suelo también cambiaron: las poblaciones de bacteria aumentaron significativamente, especialmente en los sistemas de labranza convencional, mientras que los hongos y los actinomicetos fueron más estables. La disponibilidad de P, Ca y Mg aumentó, en comparación con el suelo de sabana sin perturbar, pero el contenido de MO disminuyó significativamente en la medida que aumentaban las poblaciones de bacteria. Los menores valores de resistencia a la penetración de raíces fueron observados en el sistema de rotación arroz-caupí con labranza mínima. Estos resultados preliminares demuestran los beneficios potenciales de la rotación de cultivos y la incorporación de abonos verdes para el establecimiento de pasturas de alta calidad y bajo costo en suelos ácidos.

Introduction

The Colombian Orinoquia, better known as the Eastern Plains, is an extensive area of flat high plains lying northeast of the Eastern Cordillera of the Colombian Andes. Characterized by savanna vegetation, these plains cover about 17 million hectares—15% of the national territory—and are currently underused, the main activity being extensive livestock production on low-quality native savanna pastures. The region, however, has high potential for both agricultural and animal production (about 4.6 million hectares) as the soils have favorable physical, chemical, and biological properties and can be productive if appropriately managed. To achieve this potential, new production technologies, such as integrated crop management, that operate on the principles of equity and conservation are needed to contribute not only to the growth of agricultural and livestock production but also to the conservation of natural resources (soils, water, and the environment).

The establishment of integrated, sustainable, production systems is, over the medium-to-long term, the greatest challenge for researchers, particularly when it involves incorporating new areas into a country's agricultural and livestock sectors. Research on crops for food production in the Eastern Plains has been led by the Colombian Institute for Agriculture and Livestock (ICA, its Spanish acronym), together with the Colombian Corporation for Agricultural Research (ICA, its Spanish acronym). The focus has been on generating improved varieties tolerant of acid soils (see Chapter 9, this volume). To improve animal production, the institutions, with CIAT's collaboration, have introduced pastures and forage legumes with high genetic potential (Valencia and Leal, 1996).

These developments in germplasm improvement have been an important component for sustainable production under the conditions of the Colombian Eastern Plains. However, technologies are still needed to efficiently and rationally use soil as a resource in integrated production systems, whereby improved pastures can be established at low cost. These technologies should be oriented toward recovering the physical, chemical, and biological properties of degraded soils, as well as efficiently managing biotic factors with integrated pest control programs so that agricultural and livestock production becomes highly stable and competitive.

Under current production systems, one area of incipient research is related to soil microbial populations. Native soil microorganisms help improve the soils' physical and chemical properties (and thus crop nutrition) through atmospheric nitrogen fixation and degradation of resistant substrates that, nevertheless, make more efficient both the solubilization of fertilizers and absorption and translocation of nutrients (García 1984). In sustainable agricultural systems, soil microorganisms perform an important role in the dynamics of organic matter (OM) and in nutrient recycling through immobilization and mineralization (Castro and Amézquita 1991).

Soil microflora are characterized by their diversity, as represented by five principal groups—fungi, bacteria, actinomycetes, algae, and protozoa—of innumerable genera and species. The most numerous soil bacteria comprise the genera *Pseudomonas* and *Arthrobacter* (75%-90%). Soil actinomycetes are heterotrophic, degrading a broad range of nitrogen and carbonated compounds such as celluloses, hemicelluloses, proteins, and, possibly, lignins. Similar to fungi, they are more common in dry soils with temperatures around 28 °C. In plate counting, levels of hundreds of thousands (10^5) to hundreds of millions (10^8) of colonies per gram of soil can be found (Pelczar et al. 1982).

The endotrophic vesicular-arbuscular mycorrhizae (VAM) are fungi of the Endogonae family, members of which are found in symbiotic associations with the roots of almost all species of higher order plants. No host-specificity for this symbiosis has been found for VAM fungal species. Although VAM are found naturally in all climates and soils, they are more common in the tropics. The VAM symbiotic association is essential for the nutrition of most plant species and comprises an important microbiological resource with a high potential for benefiting both ecology and economy (Sieverding et al. 1989).

Through the VAM fungi's external mycelia, the mycorrhizae-infected roots can explore a larger volume of soil, thus facilitating the absorption of nutrients, especially of the less mobile elements such as P, Zn, S, Ca, Mo, and B. The fungi transport nutrients, mainly P as organophosphates, through the mycelia toward the roots and exchange them in the root epidermal cells for carbohydrates, which the fungi require for their development.

Other benefits that plants derive from associating with VAM fungi include the synthesis of plant hormones, the improvement of the plant's resistance to or tolerance of root diseases, and an increase in the efficiency of other symbionts such as *Rhizobium* bacteria. Indirectly, this association contributes to the plant's tolerance of adverse environmental conditions, including water stress, soil temperature extremes, pH and nutrient imbalances, and the presence of toxic substances or elements in the soil (Sieverding et al. 1989).

One alternative for determining changes that occur in an ecosystem is to evaluate the dynamics of microorganisms as indicator of the agroecological impact that the introduction of different tillage systems and crop rotations used in agropastoral systems can cause. Thus, by evaluating the physical, chemical, and microbiological properties of acid soils, more sustainable management practices can be defined for agropastoral systems. These practices would improve nutrient recycling and balance in the ecosystem, thereby reducing erosion and increasing biological activity.

Methodology

Six agropastoral systems that include two pasture systems were evaluated at "La Maloca" Farm in the Colombian Eastern Plains, 31 km from Puerto López toward Puerto Gaitán in the Department of Meta. Undisturbed native savanna soil was used as check. Soils are Oxisols with Al saturation at 86%, P content at 2 ppm, and OM content at 2.5%. The average altitude of the area is 360 m above sea level; average annual rainfall is 2200 mm; temperatures are around 27 °C; and relative humidity is about 78%.

We evaluated three tillage systems, six production systems, and two levels of soil fertility within a total area of 4 ha. Experimental units of 320 m^2 were distributed in a split-plot design with three replicates. Tillage operations were done exclusively during the first semester of each year. All experimental units first received a pass with a disc harrow for incorporating dolomitic lime, before receiving the treatments, which were as follows:

1. Conventional tillage with two passes of the deep harrow and one pass of the surface harrow;

2. Vertical tillage, consisting of one pass of a vibrating chisel plow and one pass of the surface harrow; and

3. Minimum tillage, with one pass of the surface harrow.

For each treatment and its replicates, the production systems used were:

- Rice/soybean (3 years, 3 cycles), followed by an introduced improved forage grass pasture (i.e., *Brachiaria dictyoneura* cv. Llanero) planted with rice for the fourth year

- Rice/soybean (3 years, 3 cycles), followed by an introduced improved forage grass pasture (i.e., *Brachiaria dictyoneura* cv. Llanero) planted with maize for the fourth year

- Rice/cowpea (3 years, 3 cycles), followed by an introduced improved forage grass pasture (i.e., *Brachiaria dictyoneura* cv. Llanero) planted with rice for the fourth year

- Rice/cowpea (3 years, 3 cycles), followed by an introduced improved forage grass pasture (i.e., *Brachiaria dictyoneura* cv. Llanero) planted with maize for the fourth year

- Introduced improved forage grass pasture (i.e., *Brachiaria dictyoneura* cv. Llanero) for 4 years

- Undisturbed native savanna pasture as a check

Crop materials used were those developed for acid soils:

1. 'Oryzica Sabana 10', a rice variety that tolerates Al saturation up to 85%-90%, and has high yielding potential and good grain quality

2. 'Soyica Altillanura 2', a soybean variety that tolerates Al saturation up to 70%

3. 'ICA Menegua', a cowpea variety that was used as a green manure

4. 'Sikuani V 110', a maize variety that tolerates Al saturation up to 70%

5. *Brachiaria dictyoneura* cv. Llanero, an improved forage grass that is well adapted to the conditions of the Eastern Plains, having outstanding characteristics in terms of soil coverage, forage production, tolerance of the spittlebug infestation, good seed production, and palatability to grazing animals

The recommended fertilizers for each crop under savanna conditions were N, P_2O_5, K_2O, and Zn, which were respectively applied (kg/ha) at 120, 120, 120, and 3 for rice and 0, 80, 60, and 0 for soybean. Fertilizer rates were (1) the complete dosage just described, and (2) 66% of this rate.

Over an 18-month period, information was obtained on plant height, dry matter (DM) production, reaction to diseases, and yield components in rice, soybean and cowpea. Standard soil analyses were done, including for trace elements, together with physical (e.g., penetrometry, water infiltration, density, and porosity) and biological (i.e., determining numbers of colony-forming units of bacteria, fungi, actinomycetes, and mycorrhizae) analyses (García 1984; ICA 1993).

For the physical and chemical analyses, samples were taken from the top 30 cm of soil in each experimental treatment after the first cycle of the rice/soybean rotation. The physical analyses of bulk density were done with undisturbed soil samples obtained with metal rings—three samples per treatment at depths of 0-10, 10-20, and 20-30 cm—using the gravimetric method and a pycnometer, respectively. Measurements of soil resistance were done with an electronic penetrometer, taking four readings per treatment after the crop was harvested. Once a year, during the dry season, infiltration measurements were performed for each treatment, using infiltrometer rings. Structural stability was determined for the topsoil, using Yoder's method, with three samples per treatment (IGAC 1990).

The evaluation of agropastoral systems was initiated in the first semester of 1995, with the sowing of rice. Sowing was carried out under conventional, vertical, and minimum tillage systems, using a split-plot design.

Results

Agronomic performance of crops according to tillage, fertilizer application level, and production system

No significant statistical differences in yield were found among the tillage systems, whereas the response to fertilizer application was evident and significant. With applications of N, P_2O_5, K_2O, and Zn at 120, 120, 120, and 3 kg/ha, respectively, average yield was 2.19 t/ha of paddy. At 66% of these fertilizer rates, average yield was 1.76 t/ha. In the second cycle (1996A), after rotation with soybean, yields increased significantly (on the average, by 1.20 t/ha), but differences were still not observed among tillage systems, whether in the rice/soybean or rice/cowpea system. The greatest increases in yield were obtained with the rice/cowpea system (Table 1).

The benefits obtained through the rice/soybean rotation or through the incorporation of cowpeas are partly due to the symbiotic fixation of nitrogen by bacteria—*Bradyrizobium japonicum* in soybean and *Rhizobium* sp. in cowpea—which contributed nitrogen for

Table 1. Yield (t/ha) of the rice cultivar Oryzica Sabana 10 in different agropastoral production systems, and of soybean after rice, Colombian Eastern Plains, 1996A.

Tillage system	Rice after			Soybean after rice 1995B
	Native savanna 1995A	Cowpea 1996A	Soybean 1996A	
Conventional	2.13	3.39	3.28	1.28
Vertical (chisel plow)	2.03	3.50	3.21	1.26
Minimum	1.73	3.25	2.87	1.56
Average	1.98	3.38	3.12	1.36
CV (%)	15.6	8.6	8.4	21.4
LSD	0.53	0.32	0.62	0.39

subsequent crops. The greatest benefits, however, were obtained when plant material was incorporated into the soil.

However, the soybean variety Soyica Altillanura 2, tolerant of Al saturation at 70%, is a highly viable alternative for sustainable production in the acid soils of the Colombian Eastern Plains. In the first cycle after rice, the average yield of this variety was 1.36 t/ha, with no statistical differences among tillage systems and levels of fertility, although yield tended to increase with minimum tillage (1.56 t/ha) (Table 1). It should be noted, however, that for the second-semester sowings (soybean and cowpea), land preparation was uniform for all experimental units: after one pass of the weed-cutter to cut rice stubble, dolomitic lime was applied at a rate of 300 kg/ha, with one pass of the harrow to incorporate it. The aim behind this procedure was to ensure that tillage treatments were applied only in the first semester, thereby reducing excessive mechanization of soils during the second semester.

Cowpea is regarded as a crop that lets plots rest, because it is not harvested but incorporated into the soil. It helps maintain and improve soil properties and productivity and reduce incidence of weeds, insect pests, and diseases. In addition, it is a multipurpose, Al-tolerant, species with a short growth cycle. The best response in rice production was achieved under the rice/cowpea system, with an average yield of 3.38 t/ha. However, one disadvantage is that, once incorporated, cowpea plant materials decompose very quickly, leading to a potential, rapid loss of nitrogen.

The production of green matter (GM) and DM in soybean and cowpea was evaluated at 45 days after seedling emergence. Statistical analyses showed differences between crops for both variables. Cowpea produced, on the average, 2.50 t/ha of DM, whereas soybean produced 1.87 t/ha of DM (Table 2).

No differences across tillage treatments were observed. Although the DM-to-GM ratio was greater for soybean (33.7%), cowpea produced more DM (i.e., 0.63 t/ha more than did soybean). These results suggest that the high water content accumulated by the cowpea plant favors plant decomposition via bacterial action.

With the minimum tillage method, the yield of paddy tended to be less than that of the other treatments, whereas, in soybean, the opposite occurred (Table 1). One reason for the

Table 2. Production of green (GM) and dry (DM) matter of soybean ('Soyica Altillanura 2') and cowpea ('ICA Menegua') under three tillage systems, Colombian Eastern Plains, 1995B.

Tillage system	Cowpea (t/ha)		Soybean (t/ha)	
	GM	DM	GM	DM
Conventional	11.39	2.52	5.33	1.89
Vertical	12.05	2.47	5.05	1.77
Minimum	11.73	2.50	6.27	1.95
Average	11.69	2.50	5.55	1.87
DM-to-GM ratio	21.4%		33.7%	

difference is that the various passes of the surface harrow and impact of rain lead to the formation of surface crusts in the soil. Small seeds such as those of rice and forage grasses, planted at 3 cm deep, have greater difficulty in emerging and growing through the soil, unlike the larger soybean seeds, whose imbibition capacity and cotyledonous strength help break this thin encrusted layer more easily.

Similar effects occurred in the establishment of *B. dictyoneura*. At 45 days after sowing, the population of seedlings/m^2 of this grass was reduced, being less than 1 plant/m^2 in the minimum tillage treatment. This low number contrasts with the more acceptable number of seedlings (5/m^2) under the conventional tillage and chisel plow treatments. Given the stoloniferous growth habit of this grass, this higher number ensured better establishment and faster coverage of the soil. Coverage was more than 75%, with no weeds, contrasting with the minimum tillage treatment, in which coverage was only 10%-15% and invasion of broad- and narrow-leaved weeds was more than 60%.

Dry matter production of *B. dictyoneura* cv. Llanero was 4.82 t/ha under the conventional system, 4.70 under vertical tillage, and 0.42 under minimum tillage. Under these treatments, production of broad-leaved weeds was, respectively, 0.07, 0, and 1.04 t/ha; and of narrow-leaved weeds, 0.04, 0, and 2.55 t/ha.

The conventional and chisel-plow tillage systems are adequate for planting pastures under the specific conditions of this soil because they provide good forage production after 5 months, with more than 4 t/ha of DM and low weed incidence.

During the evaluation of these systems, disease and pest incidence was not sufficiently high to justify application of chemical products. Where weed control was not exercised, weed invasion was highest under the minimum tillage system as a result of less competition from the rice crop or pastures.

Changes in soil properties

Microbiological. The evaluation of population dynamics of microorganisms under different agropastoral systems was carried out in 1995 and 1996 by measuring colony-forming units per gram (cfu/g) of the soil rhizosphere. Table 3 shows the effect of tillage and production systems on the microbial population in the soil rhizosphere (1995A).

Table 3. Effect of tillage system, rice crop (1 day after harvest), and pasture on microbial populations (cfu/g)[a] in the soil rhizosphere, Colombian Eastern Plains, 1995A.

Tillage system	Rice			*Brachiaria dictyoneura*		
	Bacteria × 10^2	Fungi × 10^3	Actinomycetes × 10^4	Bacteria × 10^2	Fungi × 10^2	Actinomycetes × 10^4
Conventional	580.0	3.5	4.4	1100.0	3.0	29.0
Vertical	130.0	3.0	23.0	230.0	51.0	8.7
Minimum	21.0	1.5	3.7	500.0	1.5	11.0
	Bacteria		Fungi		Actinomycetes	
Native soil (undisturbed)	5.4	8.0	4.9	5.4	8.0	4.9

a. cfu = colony-forming units per gram of soil; average of two replicates.

The population of soil bacteria under the cropping and pasture systems evaluated increased significantly, compared with undisturbed native savanna soil, from hundreds (10^2) to tens of thousands (10^4) of cfu/g of soil, particularly under the conventional tillage system. In contrast, fungi and actinomycetes were more stable across the different production systems, maintaining average populations of 10^4 cfu/g of soil (Table 3).

Undisturbed native savanna soils have very low initial bacterial populations (e.g., 5.4×10^2 cfu/g), which can multiply very rapidly under favorable conditions, such as when the rice and *B. dictyoneura* systems were introduced, especially under the conventional tillage treatment. Bacterial populations even temporarily exhaust nutrient supplies. Little is known about the performance of bacteria under the soil conditions of the Colombian Eastern Plains, or of their importance in terms of soil fertility and structure.

However, bacteria found in both undisturbed native soil rhizosphere and disturbed soil are known to be heterotrophic, that is, they depend on organic substances for their energy supply. Morphologically, two types of colonies exist and, under the microscope, short, rod-shaped, mobile bacilli were observed, characterizing them as Gram-negative (Sánchez 1986). The specific physiological tests for classifying and identifying the bacteria have yet to be performed.

Results of the 1996A sampling after the first cycle of rotation and incorporation of cowpea indicate that bacterial populations increased most under the rice/cowpea system, growing from 10^2 to thousands (10^3) cfu/g. In contrast, under the rice/soybean, *B. dictyoneura*, and native savanna pasture systems, they averaged 10^2 cfu/g (Tables 4 and 5). The actinomycete populations were highly stable across all production and tillage systems.

The fungi found in the rhizospheres of undisturbed native savanna soil and under all production systems were heterotrophic. The colonies were isolated in pure culture, characterized according to their specialized reproductive structures (hyphae, sexual spores or conidia, and conidiophores), then classified as belonging to the genera *Aspergillus*, *Penicillum*, *Fusarium*, and *Mucor*. The fungal population in the soil was more stable than that of the bacteria, growing more slowly. These fungi are

Table 4. Effect of tillage and rotational production systems on microbial populations (cfu/g)[a] in the soil rhizosphere, Colombian Eastern Plains, 1996A.

Tillage system	Production system					
	Rice/soybean			Rice/cowpea		
	Bacteria × 10^2	Fungi × 10^2	Actinomycetes × 10^4	Bacteria × 10^2	Fungi × 10^2	Actinomycetes × 10^4
Conventional	92.0	16.0	3.0	260.0	16.0	4.3
Vertical	48.0	4.0	3.9	88.0	2.8	4.3
Minimum	68.0	2.8	2.6	64.0	40.0	3.6
	Bacteria			Fungi		Actinomycetes
Native soil (undisturbed)	5.6	12.0	1.7	5.6	12.0	1.7

a. cfu = colony-forming units per gram of soil; average of two replicates.

Table 5. Effect of tillage and pasture systems on microbial populations (cfu/g)[a] in the soil rhizosphere, Colombian Eastern Plains, 1996A.

Tillage system	Production system					
	Brachiaria dictyoneura			Native savanna		
	Bacteria × 10^2	Fungi × 10^2	Actinomycetes × 10^4	Bacteria × 10^2	Fungi × 10^2	Actinomycetes × 10^4
Conventional	18.0	24.0	3.9	52.0	12.0	3.0
Vertical	60.0	2.0	4.1	72.0	0.8	2.2
Minimum	81.0	7.6	3.2	44.0	2.5	5.7
	Bacteria		Fungi		Actinomycetes	
Native soil (undisturbed)	5.6	12.0	1.7	5.6	12.0	1.7

a. cfu = colony-forming units per gram of soil; average of two replicates.

responsible for degrading cellulose and hemicellulose.

Mycorrhizae were found within the microbial flora in the rhizospheres of both undisturbed and disturbed native savanna soil, with a low percentage of infection and reduced number of spores. In the initial microorganism population, more actinomycetes (10^4 cfu/g) were found in the undisturbed native savanna soil than were bacteria and fungi. Actinomycete populations remained stable across the different production systems. In culture media, different types of colonies were observed, all Gram-positive.

Actinomycetes, common in dry soils, are heterotrophic organisms with highly variable morphology, making them difficult to classify. They probably play an important role in humus formation, given their ability to degrade resistant substances of high molecular weight in plant tissues (e.g., cellulose, polysaccharides, hemicellulose, keratin, and oxalic acid). These substances are then converted into highly polymerized humic acids (Burbano 1989).

Chemical. Changes in the nutrient contents of soil occurred as a result of tillage, rotation, and incorporation of green manures, compared with undisturbed native savanna soil. Under the different production systems, increases in availability of P, Ca, and Mg were observed as expected, but the OM content was reduced as a consequence of increased bacterial populations. Under the rice/soybean system, OM and exchangeable Al were the lowest, and available P, and exchangeable Ca and Na were the highest of the production systems (Table 6). Among the tillage systems, a similar trend for reduced OM contents was also observed (Tables 7 and 8), especially under the rice/soybean and rice/cowpea systems.

When compared with undisturbed native savanna soil, trace elements varied differently, that is, Fe, Cu, and Mn contents declined under the different production systems, whereas B and Zn contents increased. In general, the greatest changes occurred in the rice/cowpea system with increases from 0.15 ppm of B for undisturbed native savanna soil to 0.76 ppm of B under rice/cowpea, and from 1.0 to 2.37 ppm for Zn (Table 9). These results agree with those obtained in other studies (Angel and Prager 1990; Restrepo and Navas 1982; Sánchez and López 1983).

When compared with undisturbed native savanna soil, trace element

Table 6. Chemical analysis of macronutrients in soils under four production systems, Colombian Eastern Plains, 1996A.

Production system	pH	OM (%)	P (ppm)	Al	Ca	Mg	K	Na	Al sat. (%)
				(meq/100 g soil)					
Rice/soybean	4.6	1.6	4.4	1.2	0.28	0.10	0.05	0.12	71
Rice/cowpea	4.6	1.9	3.2	1.6	0.24	0.10	0.06	0.07	77
B. dictyoneura	4.6	1.9	2.6	1.4	0.25	0.10	0.03	0.06	76
Native savanna	4.6	2.2	2.8	1.6	0.25	0.10	0.03	0.07	78
Native soil (undisturbed)	4.8	2.3	2.0	1.4	0.14	0.04	0.04	0.12	80

Table 7. Effect of tillage on the chemical properties of soil under a rice/soybean system, Colombian Eastern Plains, 1996A.

Production system	pH	OM (%)	P (ppm)	Al	Ca	Mg	K	Na	Al sat. (%)
				(meq/100 g soil)					
Conventional	4.5	1.5	2.2	1.3	0.27	0.09	0.05	0.07	73
Vertical	4.6	1.7	6.7	1.2	0.27	0.10	0.04	0.07	71
Minimum	4.6	1.5	4.2	1.2	0.29	0.10	0.04	0.07	71
Native soil (undisturbed)	4.8	2.3	2.0	1.4	0.14	0.04	0.04	0.12	80

Table 8. Effect of tillage on chemical properties of soil under a rice/cowpea system, Colombian Eastern Plains, 1996A.

Production system	pH	OM (%)	P (ppm)	Al	Ca	Mg	K	Na	Al sat. (%)
				(meq/100 g soil)					
Conventional	4.6	2.0	2.5	1.6	0.23	0.09	0.04	0.05	80
Vertical	4.6	1.9	3.5	1.5	0.24	0.09	0.05	0.07	77
Minimum	4.7	1.8	2.5	1.5	0.24	0.09	0.09	0.07	75
Native soil (undisturbed)	4.8	2.3	2.0	1.4	0.14	0.04	0.04	0.12	80

Table 9. Analysis of trace elements in soil under four production systems, Colombian Eastern Plains, 1996A.

Production system	Trace element (ppm)				
	Fe	B	Cu	Mn	Zn
Rice/soybean	26	0.32	0.32	1.20	1.23
Rice/cowpea	20	0.76	0.31	1.39	2.37
Brachiaria dictyoneura	21	0.26	0.28	1.22	1.12
Native savanna	19	0.31	0.32	1.21	1.77
Native soil (undisturbed)	43	0.15	0.40	1.40	1.00

contents under different tillage systems showed a trend that was similar to that under production systems. The largest (but not significant) differences were observed for the minimum tillage system (Tables 10 and 11).

Under the production systems with *B. dictyoneura* and native savanna pastures, available P and exchangeable Ca and Mg increased, but OM and exchangeable K declined, with the highest nutrient content occurring under native savanna pasture. In these systems, trace elements showed results similar to those of the rice system, that is, decreased Fe, Cu and Mn contents. These results were similar to those of studies carried out by Restrepo and Navas (1982), and Sánchez and López (1983).

Physical. Under all production systems, resistance of soil to root development was minor (0.5-1.5 MPa) in the first 6 cm. Under the rice/cowpea system, values were lower than under the other production systems, especially when minimum tillage was used. Under the rice/soybean system, values were higher, with no differences observed across tillage systems, whereas under native savanna and *B. dictyoneura* pastures, values were similar to those of the rice/soybean system.

Other physical characteristics such as bulk density and total porosity of soil confirmed the results in the rice/cowpea system with minimum tillage as the soil had a normal apparent density (1.30 g/cm^3) and good total porosity (47%). Other researchers found similar responses when evaluating different tillage systems (Castro and Amézquita 1991; Herrera 1989), whereas under the rice/soybean system, the opposite occurred: density increased under minimum tillage and porosity declined (Tables 12 to 15). This differential effect of bulk density

Table 10. Effect of tillage on trace elements in soil under a rice/soybean system, Colombian Eastern Plains, 1996A.

Production system	Trace element (ppm)				
	Fe	B	Cu	Mn	Zn
Conventional	23.0	0.30	0.22	1.2	1.4
Vertical	23.5	0.24	0.35	1.2	1.4
Minimum	31.2	0.41	0.37	1.2	0.8
Native soil (undisturbed)	43.0	0.15	0.40	1.4	1.0

Table 11. Effect of tillage on trace elements in soil under a rice/cowpea system, Colombian Eastern Plains, 1996A.

Production system	Trace element (ppm)				
	Fe	B	Cu	Mn	Zn
Conventional	19.5	0.37	0.32	1.3	1.3
Vertical	18.5	0.87	0.30	1.3	3.1
Minimum	22.7	1.24	0.30	1.5	2.6
Native soil (undisturbed)	43.0	0.15	0.40	1.4	1.0

Table 12. Effect of three tillage and two production systems on the porosity and bulk density of soil, Colombian Eastern Plains, 1996A.

Tillage system	Production system				
	Rice/soybean			Rice/cowpea	
	Depth (cm)	Density (g/cm^3)	Porosity (%)	Density (g/cm^3)	Porosity (%)
Minimum	0-10	1.38	44.8	1.30	47.8
	10-20	1.43	42.8	1.31	47.4
	20-30	1.50	40.0	1.35	45.8
Conventional	0-10	1.28	48.6	1.26	49.4
	10-20	1.40	44.0	1.37	45.2
	20-30	1.46	41.6	1.51	39.6
Vertical	0-10	1.32	47.0	1.36	45.4
	10-20	1.34	46.4	1.42	43.0
	20-30	1.48	40.6	1.48	40.6

Table 13. Effect of three tillage and two pasture systems on the porosity and apparent density of soil, Colombian Eastern Plains, 1996A.

Tillage system	Pasture system				
	Brachiaria dictyoneura			Native savanna	
	Depth (cm)	Density (g/cm^3)	Porosity (%)	Density (g/cm^3)	Porosity (%)
Minimum	0-10	1.35	46.0	1.29	48.2
	10-20	1.36	45.4	1.35	45.8
	20-30	1.48	40.8	1.50	39.8
Conventional	0-10	1.32	47.0	1.24	50.4
	10-20	1.38	44.8	1.35	45.8
	20-30	1.48	40.8	1.44	51.8
Vertical	0-10	1.27	49.2	1.17	53.0
	10-20	1.42	43.0	1.30	48.0
	20-30	1.47	41.0	1.38	44.8

Table 14. Effect of tillage system on the porosity and bulk density of soil under two production systems, Colombian Eastern Plains (Puerto López), 1996A.

Tillage system	Production system			
	Rice/soybean		Rice/cowpea	
	Porosity (%)	Density (g/cm^3)	Porosity (%)	Density (g/cm^3)
Conventional	44.7	1.38	44.6	1.38
Vertical	44.5	1.39	42.9	1.42
Minimum	42.4	1.43	47.0	1.31

among production systems can be attributed to the incorporation of plant material, which helps improve the soil's physical properties.

In general, porosity of the first 10 cm of soil ranged from 44.8% to 53% and tended to decline as depth increased, ranging from 39.6% to

Table 15. Effect of tillage on the porosity and bulk density of soil under two pasture systems, Colombian Eastern Plains (Puerto López), 1996A.

Tillage system	Pasture system			
	Brachiaria dictyoneura		Native savanna	
	Porosity (%)	Density (g/cm^3)	Porosity (%)	Density (g/cm^3)
Conventional	44.2	1.39	46.0	1.34
Vertical	44.3	1.39	47.9	1.30
Minimum	43.9	1.40	44.6	1.38

51.8% at the 30-cm level (Tables 12 and 13). Changes in soil bulk density and porosity were relatively small when the production and tillage systems were compared. These inversely proportionate characteristics presented statistically significant changes in terms of soil depth (Table 16).

It is important to point out that, given the fragility of these soils, any tillage system that is used increases the basic rate of water infiltration from moderate (2.0-6.3 cm/h) to moderately fast (6.3-12.7 cm/h) or fast (>12.7 cm/h) (Table 17). If the infiltration rate is faster, it will lead to increased consumption and loss of water by percolation, and thus to increased leaching of exchangeable bases.

Table 16. Porosity and bulk density of soil according to depth, and averaged across three tillage and four production systems, Colombian Eastern Plains, 1996A.*

Depth (cm)	Porosity (%)	Bulk density (g/cm^3)
0-10	48.0 a*	1.30 c
10-20	44.9 b	1.38 b
20-30	41.4 c	1.47 a

* $P < 0.05$.

Conclusions

Our results led us to conclude the following:

1. Better results were obtained with the rice/cowpea rotation system than with the rice/soybean system.
2. In contrast to soybean, rice yields increased significantly with increased fertilizer application.
3. The *B. dictyoneura* pasture established better under both

Table 17. Effect of three tillage and four production systems on the basic infiltration rate (cm/h) of soil, Colombian Eastern Plains, 1996A.

Tillage system	Production system				Rate of infiltration
	Rice/soybean	Rice/cowpea	*Brachiaria dictyoneura*	Native savanna	
Conventional	5.25	11.35	14.01	8.24	Moderately fast
Vertical	10.28	10.13	8.46	14.2	Moderately fast to fast
Minimum	9.30	8.92	11.18	7.09	Moderately fast
Native soil (undisturbed)	3.05	3.05	3.05	3.05	Moderate

conventional and vertical tillage systems.

4. Bacterial populations under production systems increased significantly, particularly under the conventional tillage system. The fungal and actinomycete populations were more stable across different production systems.

5. Crop rotation and incorporation of green manures increased available P and exchangeable Ca and Mg, compared with undisturbed native savanna soil. However, OM contents were reduced significantly.

6. In the rice/cowpea and rice/soybean production systems, soil resistance to root development was <0.5 MPa in the top 6 cm, increasing progressively with depth. The lowest resistance values were found for the rice/cowpea system with minimum tillage.

7. It is possible to achieve sustainable crop-livestock production on Oxisols of the Eastern Plains of Colombia by combining the strategic use of acid soil adapted crop and forage germplasm together with implementation of conservation tillage and addition of organic matter through green manures.

Our findings correspond to 2 years of research on agropastoral production systems in the acid soils of the Colombian Eastern Plains. The work is to span another 3 years to evaluate animal performance under different production systems. Nevertheless, the information generated so far shows the potential of crop rotation systems and crop/pasture associations for the savannas of the Colombian Eastern Plains.

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PART V

Acquired Experiences and the Road to the Future

CHAPTER 19

Overcoming Soil Constraints in Latin American Savannas: New Approaches and Potential Trade-offs

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Abstract

The Latin American savannas represent one of the last frontiers for agriculture expansion in the world. However, in some areas where agriculture is established but cropping is becoming more intensified, or even as new areas come under crop production, they are mismanaged to a degree that the soil and water resource base is deteriorating. The main effects are soil compaction, loss of organic matter, and increased weed invasion. Currently, as much as 50 million hectares in the Brazilian savannas or *cerrados* that were sown to grass-only pastures are estimated to be degrading. The soils in these savannas are mainly Oxisols characterized by low levels of soil nutrients, low exchangeable ion capacity, and high levels of soil acidity and aluminum saturation. When these soils are subjected to mechanized agriculture, they rapidly lose their initial good physical structure. Brazil successfully upgraded its *cerrado* soils by heavily investing in inputs and amendments. The initial problems of soil compaction and shallow penetration of amendments were solved by subsoil plowing and the use of more mobile liming sources such as gypsum. Building on this investment, such soils are now increasingly being used with conservation-tillage practices. Other Latin American countries with savannas are also attempting to introduce these practices as they are believed to be more efficient and less degrading than the traditional practices associated with pastures, maize, soybean, and upland rice monocropping. Recent work conducted by CIAT and partners that form part of the CGIAR's Systemwide Program on Soil, Water and Nutrient Management (SWNM) has revealed some additional problems of using Oxisols. The success of adoption of these more sustainable practices often requires the development of a fertile "arable layer" to improve the rooting environment of the soil for plant growth. In the Brazilian *cerrados*, studies have shown that the movement of water and nutrients down the soil profile can be greater under conservation tillage than under conventional practices, thus suggesting higher risks of nutrient leaching and contamination of water supplies. In the savannas of the Colombian Eastern Plains, crop rotations that include fertilization and green manures were shown to be relatively inefficient in nitrogen use, with a marked accumulation of more than 100 kg/ha below the main rooting depth at 40-80 cm and a poor transfer of N from litter sources. Thus, there are trade-offs between the substantial benefits that a pasture phase in agropastoral systems bring in terms of improved soil structure and increased nutrient-use efficiency, and the increased potential for nitrate leaching and groundwater contamination during crop phase. Various approaches are required to address these problems and all require further study.

Resumen

Las Sabanas Latinoamericanas (SL) son una de las últimas fronteras mundiales para la expansión agrícola. Sin embargo, cuando se intensifica el uso de las tierras agrícolas, o incluso cuando nuevas áreas entran en producción, un deficiente manejo resulta en degradación de las tierras, evidenciado por invasión de malezas, compactación de suelos y pérdida de la materia orgánica del suelo. Sólo en Brasil se estima que hay unos

50 millones de hectáreas de pasturas en los Cerrados (Sabanas) en proceso de degradación. Los suelos de las SL son mayormente Oxisoles muy ácidos, con bajos niveles de nutrientes, baja capacidad de intercambio catiónico y alta saturación de aluminio. Cuando se someten a mecanización, pierden rápidamente su buena estructura física original. Brasil invirtió exitosamente en aplicación de enmiendas y agroquímicos a sus Cerrados y resolvió los problemas iniciales de compactación del suelo y escasa penetración de las enmiendas, mediante arado subsuperficial y uso de enmiendas más móviles, como yeso. Gracias a estos esfuerzos, los suelos del Cerrado se usan cada vez más con prácticas de labranza de conservación, que se estiman ser más eficientes y sostenibles que los sistemas convencionales de labranza para monocultivos con arroz, maiz, soya o pastos. Trabajos recientes del CIAT y sus socios, como parte del programa intercentros del CGIAR para el Manejo de Suelos, Aguas y Nutrientes (SWNM) han revelado algunos problemas en el uso de los suelos de sabanas. La adaptación exitosa de esas prácticas más sostenibles frecuentemente necesita el desarrollo previo de una “capa arable” para mejorar la zona radicular para los cultivos. En los Cerrados, estudios mostraron que el movimiento de agua y nutrientes en el perfil del suelo puede ser mayor bajo labranza de conservación que en labranza tradicional, sugiriendo mayores riesgos de lixiviación de nutrientes y contaminación de las fuentes de agua. En las sabanas de Colombia se mostró que rotaciones de cultivos, incluyendo fertilización y uso de abonos verdes, son ineficientes para usar el nitrógeno con acumulaciones mayores de 100 kg/ha por debajo de la zona radicular, y una pobre transferencia de N desde la hojarasca. En consecuencia, se necesita lograr un balance entre el mejoramiento en la estructura del suelo y la mayor eficiencia en el uso de fertilizantes a través de sistemas agropastoriles, y de otra parte el mayor potencial para lixiviación de nitratos y contaminación de aguas. Para enfrentar estos problemas se requiere de investigaciones adicionales.

Introduction

The Latin American savannas occupy about 270 million hectares, or around 50% of the world’s savanna areas. They represent some of the last land available for expanding agricultural production (Borlaug and Dowswell, 1997). The soils of these lands are dominated by Oxisols and Ultisols that characteristically have low inherent fertility, high acidity and aluminum saturation, and low and variable cation-exchange capacity. Rainfall and temperatures generally favor crop production, although some areas suffer from short-term dry periods during the rainy season that can decrease crop growth.

The Brazilian *cerrados* are the largest and most developed savannas in Latin America. Before the 1960s, the *cerrados* were used mostly for extensive cattle ranching using native pastures of low carrying capacity. From the 1970s onward, the *cerrados* developed according to the pathway shown in Figure 1. Pastures were improved by introducing new exotic grasses such as *Brachiaria* spp. and *Panicum maximum*, which were often sown with a pioneer crop such as upland rice (Thomas et al. 2000). Grain crops (e.g., soybean [*Glycine max* (L.) Merr.], maize [*Zea mays* L.]), coffee, fruit crops, and tree crops (e.g., *Eucalyptus* and *Pinus* spp.) were also introduced into monocropping or

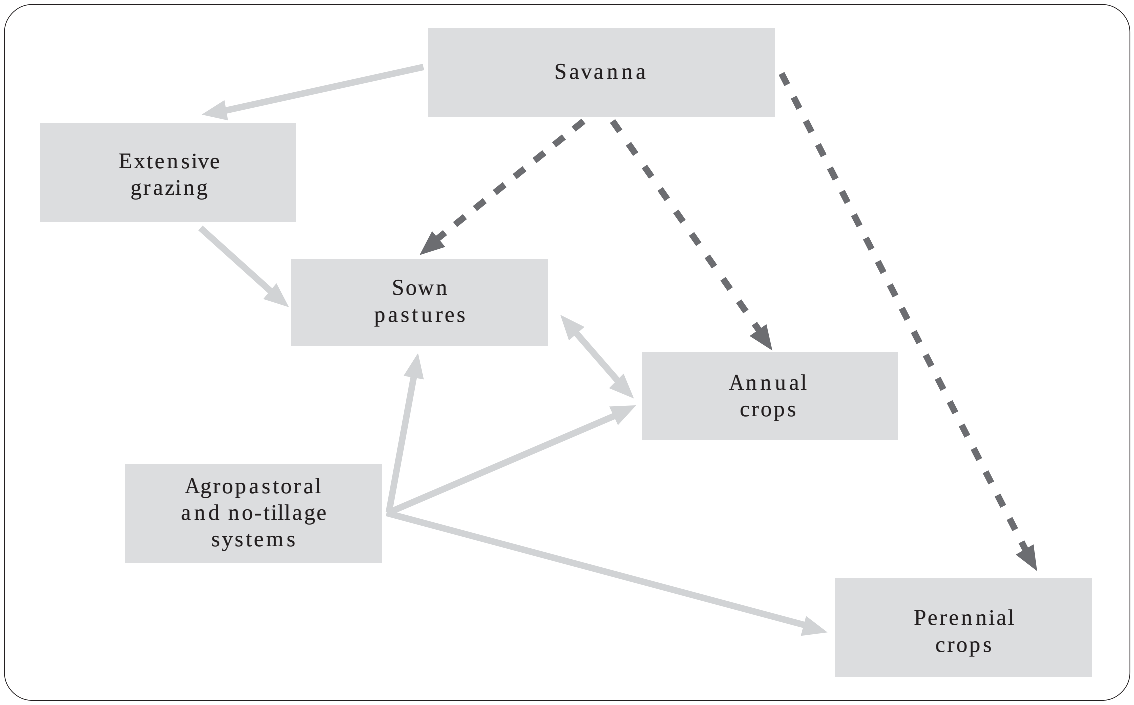

Figure 1. Agricultural development path of the savanna ecosystem (*cerrados*) in Brazil and being adopted in Bolivia, Colombia. Adapted from Friesen et al. 1999. Research follows the development path. (Solid arrows indicate major research emphasis; dotted arrows indicate minor research emphasis.)

rotational systems (Spehar and Souza, 1995).

The main production systems of the *cerrados* remain pastures and monocropping. However, it is becoming increasingly recognized that these systems are experiencing forms of land degradation that include loss of organic matter (OM), declining soil fertility, increased incidence of pests and diseases, and loss of soil structure and compaction due to inappropriate tillage practices (Chapter 2, this volume). About 50 million hectares of pastures in Brazil alone are estimated to be undergoing some form of degradation (Chapter 17, this volume). Recent research efforts in the savannas have thus focused on improving production systems in terms of increased efficiency and long-term sustainability.

Farmers have responded to the realization that pastures and monocropping are not sustainable, and alternative systems such as agropastoralism, silvopastoralism, and perennial cropping are emerging in the Brazilian *cerrados*. In addition, a variety of conservation-tillage techniques (minimum and no-tillage systems) are being rapidly adopted (Thomas et al., 2000). Other South American countries with savannas (mainly Bolivia, Colombia, and Venezuela) have shown considerable interest in these new technologies. However, the adoption of conservation-tillage systems requires that the low-fertility of savanna soils be improved in terms of soil nutrients and OM. Experience from Colombia (Amézquita 1998; Amézquita et al. 2000) indicates that, without a buildup of soil fertility in the rooting zone, conservation-tillage technologies are unlikely to be successful. Brazil's successful conversion of its savannas into productive agriculture was driven by strong government support in the form of input subsidies, infrastructure and policy (Friesen et al. 1999). This provided the basis for the adoption of the more sustainable production systems involving rotations and conservation tillage. Unfortunately, such policies and government support are no longer possible in the current global macro-economic environment. Thus, the development of the savannas in other Latin American countries requires somewhat different approaches to those taken in the Brazilian *cerrados* to overcome the constraints to more intensive agricultural production.

The main soil constraints for acid-soil savannas have been periodically described (Lopes and Cox 1977; Goedert 1987; Thomas et al., 2000) and include high soil acidity, rapid loss of OM under cultivation, low levels of macro- and micronutrients, very low effective cation-exchange capacity, low water holding capacity, low infiltration, periodic water stress, high bulk density, soil compaction, surface sealing, and soil erosion. Technologies for alleviating soil constraints have been summarized recently by Spehar and Souza (1995), Sánchez (1997), and (Thomas et al. 2000). They include more precise liming; use of more soluble forms of calcium such as gypsum to alleviate subsoil acidity; improved guidelines for improving soil fertility and managing soil nutrients such as phosphorus, potassium, and micronutrients; and overcoming of soil physical constraints through the development of specialized machinery for subsoil plowing. These technologies have been accompanied by the development of crop and pasture varieties tolerant of the low pH and high aluminum saturation of acid soils, and of pests and diseases (Borlaug and Dowswell 1997). As these new varieties and technologies developed, production systems on the Brazilian *cerrados* have gradually moved away from monocropping or pastures to more complex mixed systems including:

- Agropastoral systems with a grass or grass/legume pasture phase lasting 3-5 years;
- Sequential crop rotations with cereals and legumes; and
- Conservation tillage.

By reducing the need for massive inputs, these technologies and varieties have also enabled farmers to establish more intensive and sustainable systems in the savannas outside of Brazil where extensive grazing has been the dominant land-use system.

We discuss each of these systems below and put forward the suggestion that the sustainability of any of them depends on the construction and maintenance of an “arable layer”. We then discuss some of the potential risks of these systems especially with respect to nitrogen dynamics.

Sustainable Production Systems

Agropastoral systems

Pastures have been successfully established with a pioneer crop such as upland rice in the savannas of both Brazil (i.e., sistema *barreirão*) and Colombia. The benefits of this system in terms of productivity and soil improvement were described by Vera et al. (1992). Further benefits can be obtained by including a forage legume, as in Brazil where introduced grass species are being planted after soybean in mixed-farming systems (Spehar and Souza, 1995). Improvements occur in nutrient cycling, carbon accumulation, soil structure, and biological activity. These are summarized in Table 1 (Vera 1998).

Table 1. Beneficial effects of grass/legume pastures in agropastoral systems.

Parameter	Benefit[a]
Animal production	
Animal liveweight gain	++
Reduction in age at first calving	+
Reduction of calving interval	+
Milk yields	+
Crop yield	
Upland rice after pasture	++
Soil improvement	
Total soil carbon	+
Soil carbon in sand-size organic-matter fractions	++
Potential N mineralization rates	+
Wet aggregate stability	+
Water infiltration rates	+
Microbial P	+
Nutrient cycling via litter	+
Earthworm populations	++

a. + = an increase of <100%, compared with a grass-only or native savanna pasture; ++ = an increase of >100%, compared with a grass-only or native savanna pasture.

Despite these promising results, including on-farm experiences, the adoption of crop/pasture systems in the *cerrados* and elsewhere has been slow (Smith et al. 1999; Spain et al. 1996). Farmers tend to perceive these systems as requiring more infrastructure and capital and more complex farm administration. Savanna farmers have traditionally been either ranchers or crop farmers, but rarely mixed farmers. Spain et al. (1996) also pointed out that few crop and forage options are available.

Sequential crop rotations

Crop rotations, mainly maize/soybean, have been practiced in the Brazilian *cerrados* since the 1980s (Spehar and Souza 1995). The practice was adopted as a result of problems of declining sustainability of soybean monocropping and the need to diversify crop production (Spain et al. 1996). Araújo et al. (1989) demonstrated that a maize/soybean rotation was more productive in terms of crop yields than was monocropping. The inclusion of a legume green manure, either alone or as an intercrop with maize, was also shown to increase the amounts of nutrients being recycled with an additional benefit of improved nematode control with the maize/legume intercrop (Spehar and Souza 1995). Grain crops yielded better after a green manure than under monocropping (Pereira et al. 1992). Information on the efficiency of these systems is, however, lacking.

The "arable layer" concept and conservation tillage

The rapid spread of conservation-tillage technologies (minimum and no tillage) in Brazil is receiving widespread attention and has achieved popularity among farmers and research institutes, probably because conservation tillage helps address problems found in already cultivated *cerrado* soils, such as low OM, low moisture-holding capacity, soil compaction, pests and diseases, and weeds. Farmers report that conservation tillage improves the efficiency of their operations by reducing the number of machine operations and costs. With a more or less permanent ground cover, erosion is controlled and compaction problems are probably reduced, although not eliminated.

Even so, no tillage can result in surface compaction, but not the deeper compaction associated with conventional tillage. Under no tillage, nitrogen fixation by legumes is higher than under conventional tillage, according to reports from Australia (Hughes and Herridge 1989; Wheatley et al. 1995) and southern Brazil (Ferreira et al. 2000). Soil nitrates are also reduced, *Rhizobium* strains survive more, and water and temperature conditions are better than under conventional tillage.

Details of the different types of conservation-tillage practices used in the *cerrados* were described by Thomas et al. (2000). In the most favorable areas of the *cerrados*, double or triple cropping is possible under no tillage (Spehar 1996). Interestingly, the rapid adoption of no tillage by soybean farmers, in particular, in the *cerrados* is not often associated with immediate economic benefit. Indeed, a survey undertaken in the state of Minas Gerais showed that farmers did not clearly agree on no tillage reducing the variable costs of production (Smith et al. 1999). These farmers did, however, recognize the benefits of no tillage in terms of moisture conservation, easier management, and increased economic viability over time. The lack of other competitive technologies was also cited as a reason for the widespread adoption of no tillage.

Not all tropical savanna soils are immediately suitable for successful application of no tillage systems. Some of them present diverse physical and/ or chemical constraints that impede proper root development, limiting the productive capacity of the plants. In these cases, before no tillage systems can be implemented, the prevailing constraints must be removed in the soil volume to be explored by roots. To achieve this, it is necessary to build up an “arable layer” with none or minimum limitations for root and plant development (Amezquita et al. 1998). The exact nature of the “arable layer” concept (illustrated in Figure 2) will depend on the prevailing constraints, for example, high bulk density, soil compaction, erosion and loss of soil structure versus a depletion of soil nutrients and the type of crops to be cultivated.

The “arable layer” concept includes tillage practices to overcome physical constraints, an efficient use of amendments and fertilizers to correct chemical constraints and imbalances, and the use of deep rooted forage grasses, green manures and other OM inputs such as crop residues, to

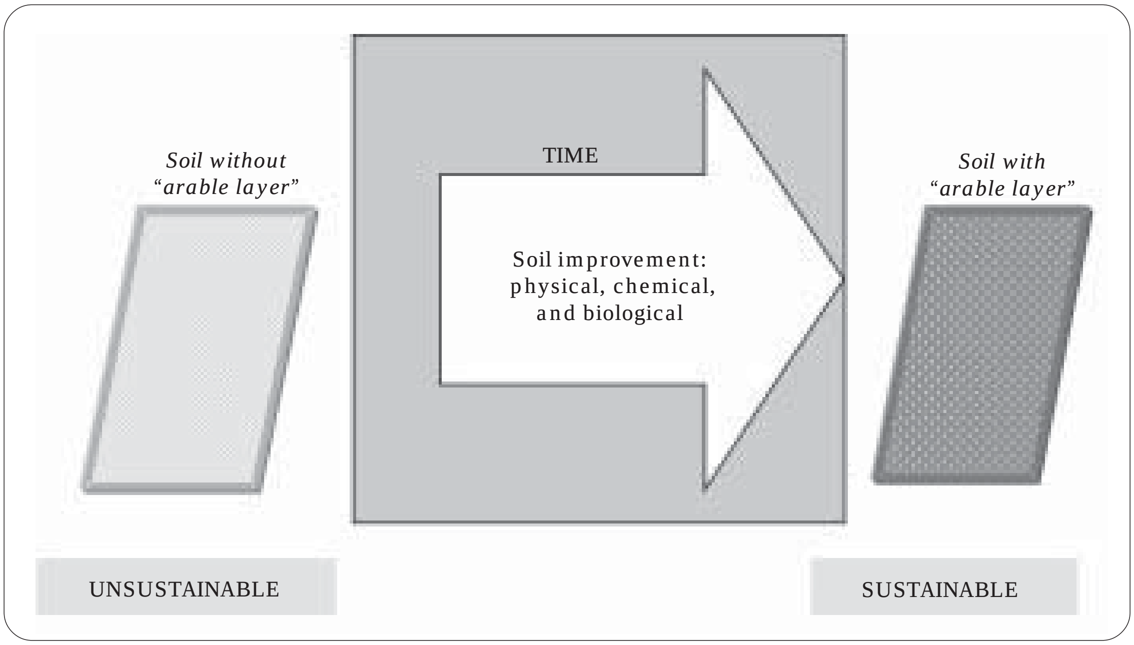

Figure 2. The “arable layer” concept. *(See text for explanation.)*

improve the soil's "bio-structure" and biological activity (Amezquita 1999; Phiri et al. 2003). The use of deep-rooting plants in rotational systems to improve soil conditions and recover water and nutrients is also envisaged in this scheme. This concept builds on earlier suggestions for the better management of tropical soils (e.g., Nye and Greenland 1960). To be functional, however, more attention needs to be given to the driving forces behind farmer decision making and the existing policies for intensifying agriculture on savanna lands.

Nitrogen Dynamics in Crop and Agropastoral Rotations

Nitrogen cycling and accumulation of nitrates in savanna Oxisols under crop and agropastoral rotations were studied in a long-term cropping systems experiment established in 1993 on a well-drained, silty, clay Oxisol (tropeptic haplustox, isohyperthermic) at Carimagua in the Colombian Eastern Plains (mean annual rainfall = 2240 mm and temperature = 27 ºC). The experiment compared the effects of alternative systems (in large 0.36-ha plots) based on upland rice or maize on various soil properties and processes, including nutrient cycling (Friesen et al. 1998). In addition to monocultures, rice and maize were rotated within years with cowpeas or soybeans, respectively, grown as either grain legume crops and as green manures (GMs) incorporated at flowering. A further rotation involved rice or maize under-sown with an "improved" grass/legume pasture which was grazed with cattle for 4-5 subsequent years. Native savanna plots were maintained as control or baseline treatments. Experimental details have been described elsewhere (Friesen et al. 1998). In addition to legume residues, N was supplied to systems as urea fertilizer applied to rice (three splits: 20, 30, and 30 kg/ha), maize (two splits: 40 and 80 kg/ha) and legumes (starter application: 20 kg/ha). N release from residues, residue and fertilizer N recovery by crops, N leaching and balances were determined in various systems.

N release from crop/GM residues

The rates of N release from decomposing crop and GM residues were determined during two or three seasons using litter bag techniques (Table 2). As indicated by their standard deviations, there was considerable variation between seasons in the rate of N release from residues (expressed as half-lives), especially

Table 2. Effect of composition and management on the rate of release of nitrogen (N) from crop residues and green manures (GM) in an Oxisol.

Material applied	N (%)	C/N ratio	Lignin/N ratio	Half-life of N released (days)	
				Surface applied	Buried (5 cm)
Rice residues[a]	0.93 (0.20)	47 (12)	7.8 (0.7)	79 (70)	39 (16)
Maize residues[b]	0.89 (0.14)	51 (6)	11.9 (3.1)	43 (17)	35 (8)
Cowpea-GM	2.90 (0.09)	16 (3)	4.8 (0.8)	32 (15)	12 (2)
Soybean-GM	2.39 (0.26)	17 (1)	3.7 (1.1)	36 (11)	18 (1)

a. Values are means (standard deviations in parentheses) from three rice seasons.
b. Values are means (standard deviations in parentheses) from two maize seasons.

from those applied to the soil surface. Variation in residue composition (Table 2) was insufficient to explain the variability in N release. In gross terms, release rates were higher from GMs than from cereal residues, as expected from their compositions. However, neither the C/N ratio nor lignin/N ratio explained the comparatively minor variations in N release rates observed between rice and maize residues or between cowpea and soybean GMs.

The release of N from residues and GMs was exceedingly fast (Table 2). Based on the simple exponential decay model, incorporated GMs released 90% of their N content within 40-60 days of application. For crop residues, 90% of N was released within 4 months of incorporation.

N recovery from residues and fertilizer

The rapid release of N from crop and, especially, GM residues carries with it the risk of substantial N loss before following crops are sufficiently well established to recover the mineralized N from the soil. Experiments using isotope methodologies (IAEA 1990) in which ^{15}N-labeled residues were applied in microplots indicated N recovery by crops between 9% and 14%, with apparent losses ranging from 15% to 50%. The remaining N was incorporated into the soil organic N pool. Recovery of N was least from legumes, which decomposed most rapidly.

Recovery of N from fertilizers was greater than that from crop and GM residues (Table 3). From 25% to 40% of applied urea was recovered in total biomass (including roots and weeds); between 34% and 46% was found in the soil to a depth of 60 cm. Fertilizer N recovery in biomass in rice systems (where the application was split into three) was greater than was recovery in maize systems (where the application was split into two). Part of the difference was also due to the greater weed growth in rice systems. Poor recovery of N derived from the GM (incorporated in late 1994) by the 1995 rice and maize crop is reflected in the absence of any significant dilution of fertilizer N in the crop in the GM systems, compared with the monoculture systems (Table 3).

Table 3. Total recovery of fertilizer urea-N from grain and harvest residues, and from the soil profile at harvest under monocultures (M) and green manure rotations (GMR) on an Oxisol at Carimagua, Eastern Plains of Colombia.

N pool	Fertilizer applied (%) to:			
	Rice systems		Maize systems	
	M	GMR	M	GMR
Rice grain	7	9	14	19
Straw + roots + weeds	31	30	11	12
Soil (0-60 cm)	45	46	44	34
Total recovery	84	85	70	65

N balances and losses in monocultures and GM rotations

Combining results on recovery of N derived from fertilizer and GMs in rice grain and soil pools, and considering the amounts of N recycled from rice residues, N balances were calculated for soils under rice monoculture and rice/GM rotation systems (Table 4). These estimates indicate that, even with fertilizer and GM inputs, there is a net drain on soil N reserves under these systems, although the rotational system is almost balanced. Negative balances were due principally to volatilization and, more importantly, as shown below, leaching of N derived from fertilizer and GMs. Total losses of N under rice monoculture and rice/GM were about 80 and 150 kg/ha, respectively.

Table 4. Estimated soil nitrogen balances under rice systems on an Oxisol in the Colombian Eastern Plains.

Inputs and exports from soil N pool	Rice monoculture (kg/ha)	Rice/green manure crop rotation (kg/ha)
Residues	+11	+12
Fertilizer	+20	+19
Green manure	0	+23
Plant uptake	-79	-59
Change in N pool	-48	-5

A progressive buildup of mineral-N concentration in the surface layers was revealed when we took sequential measurements of soil-profile mineral-N concentrations under monoculture and rotational systems throughout the dry season after incorporation of GM residues. This N began to move downward through the soil profile with the first rains of the wet season (Figure 3). Most of the mineral N was in the NO_3 form, with the total NO_3 content to 1 m depth being about 5 to 6 times greater than that in native savanna soil. Quantities of N in the profile were qualitatively related to the N content of the residues applied. Moreover, total soil profile (0-100 cm) contents of mineral N under rice and rice/GM systems over and above that found under native savanna before rice was sown in 1994 (40 and 130 kg/ha, respectively) were of similar magnitude to the losses estimated above (Table 4).

Similar measurements, taken at intervals of about 2 weeks throughout the rainy season, indicated a substantial movement of NO_3 (derived from both residues and fertilizer applications) through the soil profile under both rotations and monocultures (results not shown). This movement essentially rendered the N recycled from residues and GMs inaccessible to the subsequent crop. By rice harvest in September, most mineral N had leached to below 60 cm (Figure 3).

The CERES rice model was used to evaluate the availability and fate of N derived from GM residues in the rice/GM system, starting from the date of incorporation of residues. There was reasonable agreement between observed and predicted rates of N release from cowpea GMs (results not shown). However, concentrations of mineral N in the soil profile were underestimated,

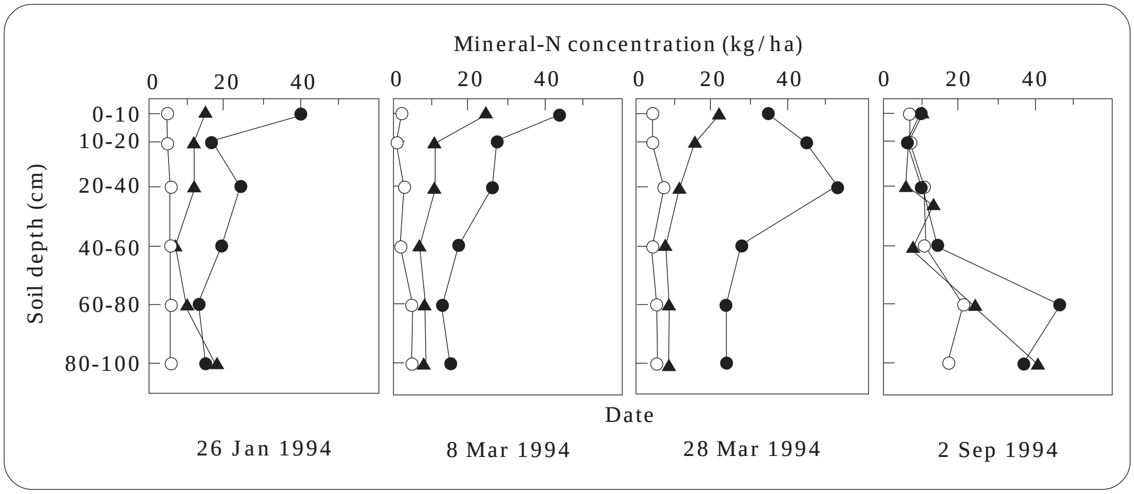

Figure 3. Evolution of mineral-nitrogen (N) concentrations in an Oxisol profile under savanna (○), rice monoculture (▲), and rice/green manure (●) systems through the dry season (January to March) and after the rice harvest (September), Colombian Eastern Plains.

and fluxes throughout the profile were overestimated for the intervening dry season between GM incorporation and rice sowing (Figure 4). Differences were probably a result of underestimating the soil-N mineralization rates or of failing to account for the effects of positive surface charge on oxidic clay minerals in Oxisols, which may significantly affect NO_3 retention and transport in these soils with near natural pH (4.3) (Bowen et al. 1993). When adsorption coefficients were included in the simulation, predicted NO_3 leaching agreed much more closely with observed values.

Nutrient Leaching under No-Tillage Systems

The effects of conventional tillage (CT) and no tillage (NT) on the chemical soil solid phase and soil solution were compared in a Brazilian savanna Oxisol to test the hypothesis that differences in mineralization and leaching rates between CT and NT systems can result in different soil solution compositions. Details of this study have been published elsewhere (Lilienfein et al. 2000).

Three spatially disconnected experimental plots each for CT and NT cropping systems were selected in existing on-farm land-use systems in southeastern Uberlândia (State of Minas Gerais, about 400 km south of Brasília). Although not an entirely randomized selection, replicate plots of each land-use system were separated from each other by a distance of at least 1.3 km, all had slopes of <1°, and all had soils developed from fine limnic sediments of the lower Tertiary weathered homogeneously to a depth of several meters.

The CT soils were disk harrowed two or three times per year and used for maize/soybean rotations for 12 years prior to the experiment. The NT systems were established 1-3 years before the experiment and had been under CT as described above for the preceding 9-11 years. In 1997, maize was planted on the CT plots (11 November) and soybeans on the NT plots (28 November). Both CT and NT plots

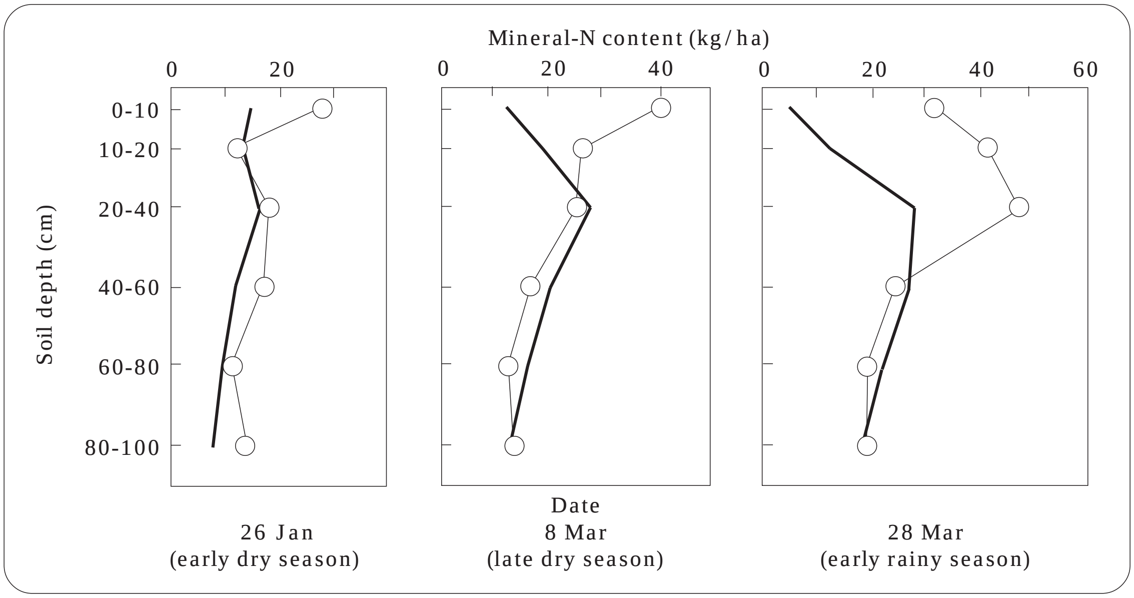

Figure 4. Observed (○) and predicted (——) mineral-nitrogen (N) profiles in a silty clay Oxisol under rice/green manure rotation throughout the dry season and after green manure incorporation on the previous 19 November.

were fertilized with N, P, and K at an annual average of about 70, 100, and 160 kg/ha, respectively. The experiment was carried out during the 1998/1999 rainy season. CT and NT plots were fertilized on 29 October with P and K at 42 and 63 kg/ha, applied as $Ca(H_2PO_4)_2$ and KCl, respectively, and sown to soybeans on 9 and 10 November. Observations were taken from 10 m × 10 m areas equipped with tensiometers and suction cups to collect soil solutions at different depths for chemical analyses within each of the six plots. Tensiometers and rain collectors were placed within and between the crop rows. The single pulse of chloride (Cl^- from KCl fertilizer) acted as a tracer of the water regime in all treatments at the beginning of the rainy season (Lilienfein et al. 2000).

Concentrations of Cl^- in soil solution at 0.15 and 0.3 m depth increased at

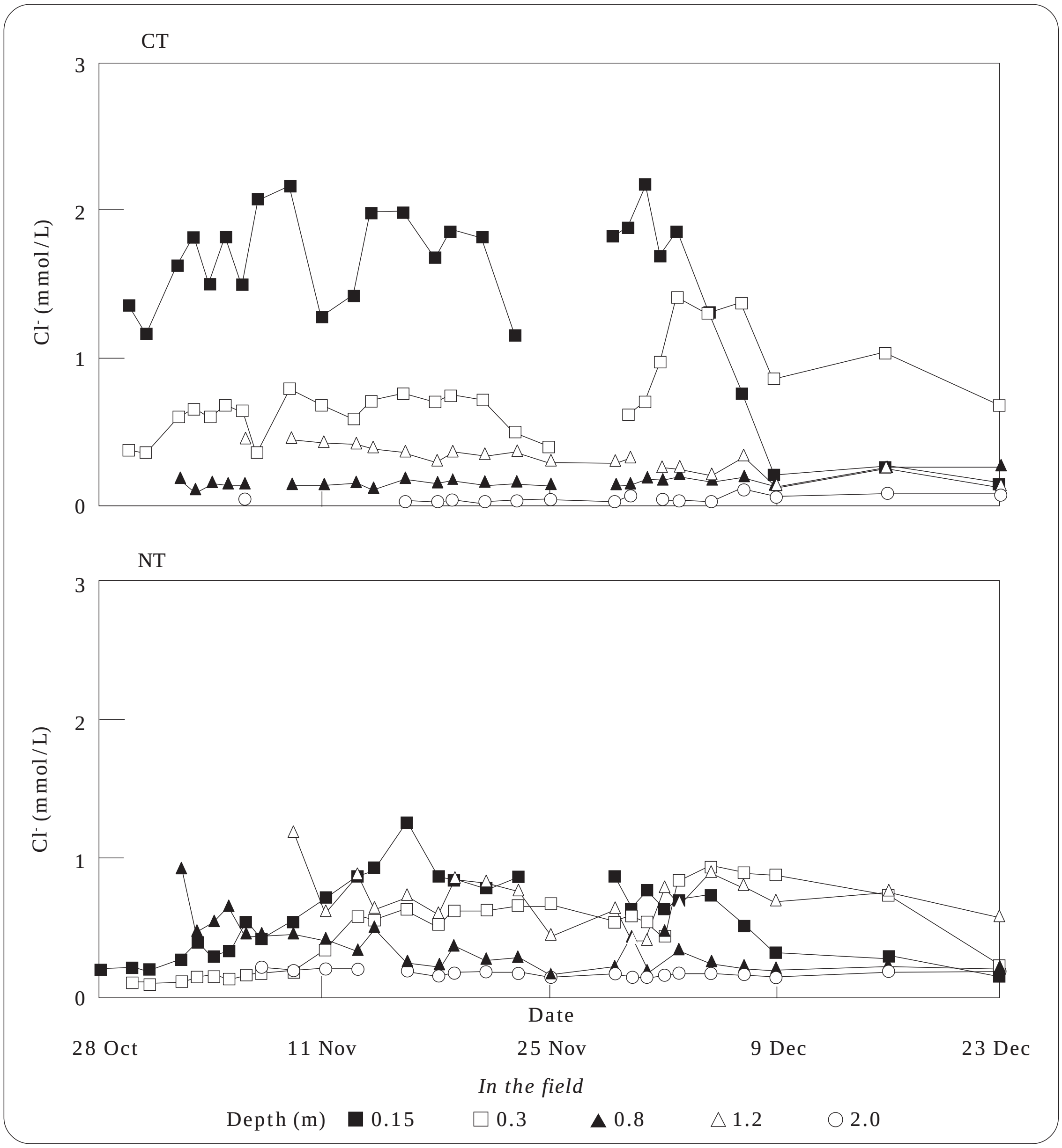

Figure 5. Course (m) of soil solution Cl^- concentrations in conventionally tilled (CT) and untilled (NT) Oxisols at the beginning of the rainy season (28 October to 23 December), Brazil, 1998. Adapted from Lilienfien et al. (2000).

the beginning of the monitored period (Figure 5), reaching a maximum at the 0.15-m depth on 8 and 16 November in the CT and NT soils, respectively, and at 0.3 m depth on 3 and 5 December in CT and NT soils, respectively. At greater depths, Cl^- concentrations in NT soil decreased at the beginning of the monitored period, probably because Cl^- remaining from the preceding rainy season was leached. The highest Cl^- concentrations at the 0.3 to 1.2-m depths in NT soil occurred nearly simultaneously between 2 and 5 December. During the monitored period, the Cl^- pulse did not reach the 0.8 to 2.0-m depths in CT soil nor the 2.0-m depth in NT soil.

The results indicate that Cl^- in NT soil was rapidly transported down to 1.2 m depth, probably because of preferential flow through soil macropores, which was not observed in CT soil. The reason for the differences may be greater pore continuity and, therefore, higher hydraulic conductivity in NT soil than in CT soil. In CT systems, plowing destroys the pores (Chan and Mead 1989). These differences in leaching rates may also explain the higher average Cl^- concentrations in soil solution at 0-0.3 m deep and lower ones at 0.8-2 m deep in CT than in NT soil between 28 October and 23 December (Lilienfein et al. 2000).

Conclusions: Trade-offs and Approaches to Improved Sustainability

The intensification and sustainability of agricultural production on the infertile and fragile Oxisols and Ultisols of the South American savannas depends upon the adoption of technologies and production systems that build soil fertility, conserve or increase soil OM, and maintain or improve soil physical characteristics (structure, aggregate stability, etc.), and enhance soil biological activity. Our research suggests the need for both (1) build-up of a fertile "arable layer" that will support increased root growth and soil exploration by crops and forages, and (2) ultimately use of minimum or no tillage to maintain soil cover, reduce OM loss and enhance soil biological activity. The use of adapted acid soil tolerant crop germplasm combined with legumes and forages in rotations provide a means for intensification without the massive investments in lime and other inputs that were previously required to open this agricultural frontier. However, our research also shows that these systems are not adopted without risk, particularly with respect to N management.

Legume green manures can supply substantial quantities of biologically fixed N to cropping systems, provided that a large proportion of their N requirements is derived from fixation. Under humid tropical conditions such as those of the Colombian savannas, this N is released rapidly to the soil and, because it is less easily managed, crop recovery is less efficient than with N fertilizer whose supply could be more easily synchronized with crop demand. In a high leaching environment, poor N supply-demand synchrony can result in substantial leaching of NO_3 to below the crop rooting zone, as seen in our studies on the Colombian savannas (Friesen et al. 1998) as well as in Brazilian soils (Cahn et al. 1992) and western Kenya (Hartemink et al. 1996). This leaching could lead to eventual contamination of groundwater.

Prediction of NO_3 production and flux in soil under crop production systems involving legume rotations would aid in system management to minimize N losses to the environment and increase the efficiency of N use by crops. The CERES-rice simulation model was able to predict N fluxes in the rice/GM system when anion retention on oxidic mineral surfaces was considered. However, much broader testing is required, using GMs with more diverse decomposition characteristics and soils with different abilities to retain nitrates.

When no-tillage is combined with legume green manures and cover crops, there is considerable potential and risk of leaching of substantial amounts of NO_3 beyond the rooting zone and potentially to ground water. The faster appearance of an initial Cl^- pulse to the soil surface at greater soil depth under a no tillage system in Brazil, compared with conventional tillage, indicated faster solute transport along preferential pathways due to higher pore continuity. This was confirmed by the lower average nutrient concentrations in the surface soil solution and higher ones in the subsoil solution under no tillage than under conventional tillage (Lilienfein et al. 2000). The consequence may be higher nutrient losses from the rooting zone by leaching under no tillage than under conventional tillage systems. Similar results have been reported for no-tillage systems under temperate conditions (Fawcett et al. 1994).

The accumulation of nitrates in soils below the crop's rooting zone in acid savanna soils suggests the need for a multi-pronged approach to minimize a potential environmental hazard and to increase the efficiency of a lost resource. Firstly, systems management (including selection of appropriate legume species) needs to be modified to reduce excessive N inputs to the soil and to improve the synchrony of supply and crop demand. Secondly, crop demand for N should be increased through better management to more closely approach theoretical yield potentials. For example, in our studies on the Colombian savannas, maize yields usually fell in the range of 3-4.5 t/ha, far below their yield potential of 10-12 t/ha. Such a yield gap may well be related to an inadequately developed "arable layer" as well as insufficient adaptation to acid subsoil conditions. A third approach may be to incorporate deeper rooting crops such as sorghum or millet, or deep rooting forages such as Brachiarias into the systems to recover this valuable nutrient source. Short-term fallow shrubs and tree species may also be appropriate for small-holder farming systems. All of these approaches require further study in order to minimize the trade-offs between improved sustainability with reduced tillage and rotations, and increased leaching of environmentally hazardous nutrients.

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CHAPTER 20

Research on Agropastoral Systems: What We Have Learned and What We Should Do

*E. P. Guimarães**, *J. I. Sanz***, *I. M. Rao***, and *E. Amézquita***

Contents

Abstract

The savannas of Brazil, Colombia, Venezuela, and Bolivia have high potential for the sustainable production of grains, meat, milk, fruit, and forest products. To successfully exploit these regions, suitable systems must be developed to adequately manage the soils, which are typically of low fertility, acid, physically fragile, and biologically poor. The savannas are already used for extensive livestock production, an inefficient system of exploitation based on native pastures. Currently, the entire savanna ecosystem is changing as native pastures are being replaced by introduced pastures, crops, and crop/pasture rotations. Research on sustainable systems, particularly in the Brazilian *cerrados*, has led to the development of acid-soil adapted cultivars of crops such as soybean, rice, and maize. By combining adapted cultivars of both crops and forages in agropastoral systems, farmers are transforming the

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savannas, with crop/livestock production systems becoming significant components in strategies for exploiting the savannas. In Colombia and Venezuela, adapted rice cultivars play significant roles in the intensified exploitation of their plains. In Bolivia, more emphasis is given to agrosilvopastoral systems, in which trees play an important role. The social insecurity of certain regions and lack of infrastructure have discouraged investment, thus limiting the adoption of agropastoral technology. While the overall research objective for the Latin American savannas is to improve the economic and ecological sustainability of crop/livestock systems, the major challenge is to encourage national leaders and the international community to continue supporting research efforts for the sustainable development of these savannas.

Resumen

El ecosistema de sabanas en Brasil, Colombia, Venezuela y Bolivia presenta alto potencial para la producción sostenible de granos, carne, leche, frutas y maderas. Sin embargo, para alcanzar este objetivo es necesario desarrollar sistemas apropiados para el manejo de los suelos. Los suelos en este ecosistema son ácidos y de baja fertilidad, de estructura frágil y biológicamente pobres; por tanto, requieren sistemas de manejo que mitiguen y corrijan estas condiciones. En esta región predomina la ganadería extensiva de baja eficiencia basada en pasturas nativas; no obstante, en los últimos años ha sufrido una transformación importante, mediante el remplazo de la sabana nativa por pasturas y cultivos mejorados. En Brasil, especialmente en los campos Cerrados, se ha venido haciendo un gran esfuerzo en investigación sobre sistemas sostenibles para solucionar los problemas de producción agrícola. Como resultado de estos esfuerzos se han desarrollado materiales genéticos de soya, arroz, maíz y otros cultivos, con potencial para crecer en suelos con limitaciones edáficas. En la búsqueda de soluciones productivas, la combinación de pasturas con cultivos adaptados cambió el escenario de las sabanas brasileñas y los sistemas agropastoriles comenzaron a hacer parte de la estrategia de utilización del ecosistema. En Colombia, como resultado de la obtención de germoplasma adaptado de arroz, se intensificó el uso del ecosistema sabanas de los Llanos Orientales. En Venezuela, la situación ha sido similar a la de Colombia, pero en Bolivia ha sido un poco diferente, ya que allí se decidió concentrar los esfuerzos de investigación en sistemas agrosilvopastoriles. En todos los casos, los problemas de sostenibilidad siempre han sido el objetivo principal de las investigaciones. Por otra parte, la inseguridad social en algunas regiones, como es el caso de los Llanos Orientales de Colombia, la falta generalizada de maquinaria agrícola apropiada para el desarrollo de nuevos sistemas de producción y de infraestructura han desestimulado las inversiones de los productores —agricultores y ganaderos— en estas regiones. La tarea en el futuro consistirá en la motivación de los dirigentes y la comunidad internacional para dar seguimiento a los trabajos de utilización sostenible de los recursos en este ecosistema.

Introduction

Brazil, Colombia, Venezuela, and Bolivia account for about 50% of savanna ecosystems worldwide, and are among the few frontiers still available for agricultural expansion (Borlaug and Dowswell 1994). Savanna soils are characterized by high acidity and low natural fertility and biological activity. Although their physical characteristics are good, these soils are highly vulnerable to erosion and structural loss when tilled. Although extensive farming systems predominate, few are efficient and most are based on native pastures.

The savanna ecosystem has undergone major transformation in recent years with the native savanna gradually being replaced by improved pastures and adapted crops (Vera, Chapter 1, this volume). Brazil ranks first in developing the economic and sustainable use of savannas because of its policy of providing fiscal incentives for farmers, which was implemented in the 1970s. Work initially involved technologies and germplasm introduced from southern Brazil and, as a result, production and economic gains were not encouraging, especially those related to crops. Likewise, livestock production first developed slowly, but accelerated with the introduction of improved tropical forages that were adapted to the region's soil and climatic conditions. A major research effort was needed to overcome soil limitations and develop cultivars—mainly of soybean, rice, and maize—capable of producing high yields under these conditions. The combination of adapted pastures and crops changed the scenario for the Brazilian savannas as initially low-technology agropastoral systems formed part of the strategy to use the ecosystem more rationally (Lopes et al., Chapter 2, this volume).

To identify options that would intensify the use of savannas in the Colombian Eastern Plains, CIAT carried out research in collaboration with the Colombian Institute for Agriculture and Livestock (ICA, now the Colombian Corporation for Agricultural Research [CORPOICA, its Spanish acronym]). In the early 1990s, the first rice germplasm to produce efficiently under the region's limiting conditions was developed. Several germplasm alternatives for both pastures and crops (e.g., soybean) had already been developed but were little used by farmers. The effort of developing agropastoral systems for the Colombian savannas therefore forms part of the overall effort to increase the sustainability of farms and agriculture in these regions.

The situation for Venezuela is similar to that of Colombia. Pasture alternatives were developed before germplasm of annual crops were adapted to the savannas' limiting conditions. Research by the Fondo Nacional de Investigaciones Agropecuarias (FONAIAP) emphasized use of the Venezuelan Eastern Plains, searching for materials that would tolerate water stress and soil fertility. These strategies have advanced slowly, and the integration of that research into agropastoral systems is still a goal sought by agricultural researchers, farmers, and large-scale livestock producers.

The history of savanna development in Bolivia differs somewhat. The Centro de Investigación Agrícola Tropical (CIAT-Santa Cruz), decided to concentrate research on those systems in which trees play an important role. Pastures were combined with tree fences and arboreal live barriers in agrosilvopastoral systems. Crops for this system are still being studied, and tested in adaptation trials in regions of interest to the Government.

In the aforementioned countries, the problems of developing sustainable production systems have constituted a fundamental goal of research. Continuous planting of crops such as soybean in Brazil (Cardoso 1993) and rice in Colombia (Preciado 1997) has led to gradually declining soil quality and, thus, to reductions in yield. Moreover, the problems of pasture degradation caused by overgrazing or poor management practices have further decreased yields, stimulating soil erosion, water stress, loss of soil structure, and increased compaction and resulting in a general loss of the soil's productive capacity, as observed in Colombia and Venezuela.

Several factors have discouraged farmers from investing in these regions, including social insecurity in some savanna regions (e.g., in the Colombian Eastern Plains), overall lack of adequate agricultural machinery for soil and crop management, and deficient road and storage infrastructure. Nevertheless, research has generated a large volume of information that has also stimulated investment in savanna areas.

The evolution of the development of agropastoral systems, the problems met, and future expectations are described below.

Acquired Experiences

Independently, in each country, the use of savannas was initially based on the isolated development of agricultural and livestock components. Efforts were aimed at identifying the best pasture or crop germplasm and the best agricultural management techniques (Friesen et al. 1997; Kluthcouski et al. 1991; Macedo 1995; Rao et al. 1993; Spain et al. 1996; Thomas et al. 1995; Thomas et al. 1999; Vera et al. 1992; Zeigler and Toledo 1993; Zeigler et al. 1995). The potential of these technologies in integrated pasture/crop systems, however, was not considered.

In Brazil, after several *Brachiaria* species were identified as alternatives for increasing savanna productivity, crop germplasm, for example, of rice, was developed for adaptation in association with *Brachiaria* spp. (Kluthcouski et al. 1991). Soybean was another tropical crop that was selected and which rapidly occupied most of the savannas (Roessing and Guedes 1993; Spehar et al. 1993), promoting development. Maize varieties adapted to poor, acid soils were also developed (Bahia-Filho et al. 1997).

The isolated use of pasture or crop components rapidly showed the unsustainability of these systems. Seguy et al. (1988) showed how rice yields in Mato Grosso, Brazil, drastically declined, probably because of competition with weeds and decline in nutrient reserves in the soil. Euclides (1994) presented similar data for pastures. In Colombia, Valencia and Leal (Chapter 9, this volume) presented alternatives developed for the Colombian Orinoquia and identified useful genetic material for pasture renewal such as the forages *B. dictyoneura* and *Andropogon gayanus* and rice variety Oryzica Sabana 6, adapted to the region's conditions. However, before rice appeared, the soybean variety Soyica Altillanura 2 (Valencia 1994) was available. Preciado (1997) gave important data on soil management and reported on the important role weeds play in the stability of agropastoral systems in the Colombian Eastern Plains.

In Venezuela (Rodríguez et al., Chapter 11, this volume), grass and legume germplasm, showing potential as pastures for the Venezuelan Eastern Plains, were identified in collaborative work carried out within the International Tropical Pastures Evaluation Network (RIEPT, its Spanish acronym). Promising rice and maize lines were also identified and are now under final testing and seed multiplication.

Bolivia's case is no different; cattle raisers' need for improved pastures has encouraged research to be directed toward searching for alternatives based on pasture and crop components (Martínez, Chapter 12, this volume).

As can be noted, all national research programs in the region aimed to develop, in an isolated manner, different system components, particularly grass varieties, that would meet the demands of cattle raisers, the savanna's first colonizers. Soybean, maize, and rice farming emerged more recently, in response to market demand for grains. Subsequently, the idea of integrated crop/livestock systems arose in an attempt to solve sustainability problems arising from the use of pure pastures and monocropped grains or legumes.

Farmers using agropastoral systems are not only interested in crop yields and profitability, but also, and even more so, in herd productivity. Studies conducted on improved pastures in the Colombian Eastern Plains showed daily animal liveweight gains during the dry season of up to 600 g per animal (Lascano and Euclides 1996).

For the sustainable exploitation of agropastoral systems, research must take into account the animal component, particularly its genetic potential, to achieve greater productivity per animal and per unit area. In the Brazilian *cerrados*, the poor genetic quality of cattle results in the average slaughter age being 48 months. Magnabosco (2000) found that selected Nelore cattle had daily liveweight gains of about 300 g per animal during the dry season, and about 700 g during the rainy season. Slaughter age for an animal weighing 450 kg had dropped to 24 months.

In addition to advances in generating adapted forage germplasm, important information was generated in other areas of research, such as that of soils, which comprise the most important factor for sustainable production. New concepts have been generated to guarantee integrated improvement (physical, chemical, and biological), stability in intensifying use, and increased sustainability. Amézquita et al. (Chapter 4, this volume) discuss how the way soil is used affects its properties and interferes with ecosystem sustainability. Their findings were corroborated by results obtained in Brazil and Colombia (Amézquita 1998a, 1998b).

Specific studies on agricultural machinery for soil preparation and its effect on the sustainability of the savanna ecosystem have indicated that continuous use of heavy harrows destroys soil structure, produces surface sealing, and causes compaction, thus preventing normal root development in pastures and crops. This, in turn, accelerates land degradation and increases stress from lack of water and nutrients. Trials on sandy and clayey soils, which are typical of the savannas, have shown that early soil preparation—that is, before the rains—leads to increased grain production and can double rice production (CIAT 1989).

The use of equipment such as subsoilers, disk plows, and moldboard plows is recommended for adequate soil preparation in the Brazilian *cerrados*. However, their use cannot be generalized for all conditions: in Colombia, for example, soils prepared with moldboard plows did not produce the expected results because all organic matter and nutrients were incorporated into the subsoil, interfering with rice development. In the Colombian Eastern Plains, vertical preparation with rigid chisels should be used, complemented with a minimal number of passes with the harrow (Amézquita 1998b).

Research on tillage, currently conducted by CIAT in the Eastern Plains (Amézquita 1998a; Thomas et al., Chapter 19, this volume), introduces the concept of creating an “arable layer”. This is a surface layer, 0 to 30 cm deep (depending on the crop), that does not present physical, chemical, or biological constraints to the crops being planted. The use of agropastoral and agrosilvopastoral systems is fundamental for this strategy because, with these systems, roots are capable of maintaining the favorable physical conditions created by the appropriate tillage, thus resulting in physical, chemical, and biological sustainability of the soil. Once the arable layer is built, soils should be submitted to the more resource-conserving “zero” or “reduced” tillage systems.

Studies on soil fertility have demonstrated that crops should be planted before pasture because crop residues and residual fertilizers help supply the pasture’s requirements, whether established alone or in association. Fertilizer recommendations for crops are well known, but, in the case of pastures, cattle raisers are still reluctant to recognize the need for maintenance fertilizers. Zimmer et al. (Chapter 17, this volume) presented the results of maintenance fertilizer applications in improved pastures and their effect on production sustainability. Kluthcouski et al. (Chapter 15, this volume) presented a series of trials showing the advantageous effects on subsequent pastures of applying lime, phosphorus, and potassium to rice and maize crops.

Advances have also been made on understanding competition between crops and pastures. Pinheiro et al. (Chapter 13, this volume) presented preliminary data that indicated the main physiological characteristics that favor rice development when competing with pastures. This information can be useful in plant breeding when selecting for rice genotypes that are better adapted to agropastoral systems. These studies revealed differences among cultivars for tolerance of competition. Early maturing genotypes presented higher yields because they reached the productive phase before the pasture started to negatively affect their yield.

From the methodological viewpoint, systems research has posed many questions, from aspects on how and when to conduct evaluations to ways of analyzing results. For example, in rice/pasture associations, rice farmers expect to obtain a maximum increase in crop production. In contrast, cattle raisers lose interest in maximizing rice yields once this crop begins competing with the pasture to the detriment of the latter. These insights should be considered when analyzing the viability of agropastoral systems because strong competition between pasture and crop will adversely affect the initial increases expected and, thus, the farm’s cash flow.

Most systems research should be conducted on farm, as recommended by Muzilli (Chapter 3, this volume).

Under these conditions, the use of traditional statistical designs is not always viable. Researchers must therefore be creative if they are to achieve desired comparisons and responses. Statistical analyses must be conducted differently, and methodologies should be adjusted to that reality. Amézquita et al. (Chapter 6, this volume) present some alternative procedures.

Technology Transfer

As previously mentioned, Latin Americans have developed their own technologies for agropastoral systems. Pasture and crop varieties have been adapted to the soil and agroclimatic conditions of the savannas. Studies with animals have searched for the most productive breeds adapted to these conditions. Soil and crop management practices in agropastoral systems have been developed in terms of system interactions. To do all this, experimental methodologies had to be adapted to determine the significance of the results.

One strategy used to disseminate the information generated by agropastoral systems studies was the traditional preparation of technical publications. Many results and experiences were also shared and transferred during technical visits, particularly those supported by the Programa Cooperativo de Investigación y Transferencia de Tecnología para los Trópicos Suramericanos (PROCITROPICOS). This program has contracted consultants to develop, together with national institutions, projects to sustainably utilize savanna resources. The Food and Agriculture Organization (FAO) also participated in these technology transfer projects. Unfortunately, these initiatives did not produce the expected results, mainly because of limited financial support from the international community.

Countries with savannas have different levels of development and participate with different intensity in the accumulation of experiences for rational savanna exploitation. Therefore, the principal strategy used to transfer technology was that of CIAT's, which, with support from the Inter-American Development Bank (IDB) and including the participation of national programs, was to conduct workshops on agropastoral systems in different countries. The technological achievements and experiences obtained in these workshops are presented in this volume.

The principal purpose of these events was to disseminate research results and exchange ideas and experiences among participating countries. Five workshops were held: two in Colombia (1992 and 1996), and one in each of Brazil (1993), Venezuela (1994), and Bolivia (1995). The workshops consisted of 1 or 2 days of theoretical presentations with discussions of results, followed by 2 days of field visits, and a fifth day reserved for planning joint and individual activities for the following year.

This strategy led to the informal creation of an Agropastoral Network, mentioned by Vera (Chapter 1, this volume). The distribution of responsibilities (Table 1 of that chapter) illustrates the level of interaction existing among the groups conducting research on agropastoral systems in the region. Obviously, the financial resources and fund-raising capacity of each country and institution will determine the speed at which this strategy can be implemented.

Problems in Expanding the Use of Agropastoral Systems

Of the four countries where the savanna ecosystem is important, Brazil is the only one that continues to emphasize studies in that area. Although Bolivia, Colombia, and Venezuela continue to conduct research on the topic, they face different types of problems in prioritizing savanna research.

Bolivia's socioeconomic situation does not allow the country to invest heavily in agropastoral systems research, even though the efforts of CIAT-Santa Cruz are yielding good results with agrosilvopastoral systems. The country's priority research is directed toward small farmers on hillsides. Investments in the savannas are made by farmers of neighboring countries, such as Brazil, who migrate, with their *cerrado* experience, to the Bolivian savannas and grow crops, using Brazilian technologies. Currently, the sustainable development of the region therefore depends more on Brazilian advances in savanna research than on Bolivian strategy. Limited governmental intervention in the development of infrastructure, such as roads and storage facilities, also discourages local farmers from exploiting the savannas.

Although the presence of CIAT-Palmira has increased interest in the sustainable use of the Colombian Eastern Plains, local institutions and the Government have restricted their activities and investments, mainly because of social insecurity. Even though the infrastructure is insufficient, there is tangible political effort to use the region. The agropastoral systems technology, using rice and maize in association with pastures, is available. Experiences with tree crops, such as cashew and mango, have shown potential.

Until recently, Venezuela was considered essentially as a petroleum-producing country that did not give priority to agriculture. However, with the fall of international petroleum prices in recent years, Venezuela's interest in its agricultural potential has awakened. Because the country's financial conditions in past decades were extremely good, Venezuela can count on an excellent road infrastructure. However, concern for agricultural research was, and is, limited. Currently, despite having access to the technologies of neighboring countries, Venezuela has made little progress.

Prospects

Although populations in Latin America are not growing as fast as in other regions of the world, the demand for food is increasing and the resources to meet this demand are increasingly limited. Agricultural production in ecosystems such as the savannas should therefore be intensified but in a sustainable manner, that is, without degrading the environment. To do so, farmers will have to increase their use of available technologies and researchers should continue generating new alternatives of use and management.

The potential usefulness of the savannas is, accordingly, immense. However, scientists must, in the future:

- Develop technologies that lead to the sustainable productivity of soils to make possible an equally sustainable agriculture;

- Develop high-yielding crop and pasture germplasm that is adapted to the agricultural, soil, and climatic conditions of the savannas;
- Continue studying the effects of different systems on the chemical, physical, and biological properties of the soil;
- Continue work on the recycling of chemical elements, such as nitrogen, phosphorus, and potassium, to determine the most efficient systems of biological nitrogen fixation and of nutrient and water absorption and use;
- Continue adapting and developing agricultural machinery to the region's soil conditions;
- Increase the monitoring of pests and diseases to analyze their evolution under reduced pressure, compared with monoculture;
- Broaden knowledge of weed management in association systems;
- Conduct in-depth studies on new systems for the savannas, for example, minimum tillage; and
- Emphasize long-term studies on the aforementioned issues to determine their effects on the sustainability of systems.

Parallel to the above, and based on the results obtained, governments should be encouraged to:

- Formulate policies on the sustainable exploitation of the savannas to prevent the incorporation of other ecosystems, such as the Amazon Basin, into agriculture;
- Create special incentives for the use of soil amendments and fertilizers, mainly lime and phosphorus sources;
- Provide incentives for the agricultural machinery industry to design equipment more adapted to the needs of savanna farming;
- Promote research in those fields presenting potential for that ecosystem; and
- Provide training and technology transfer programs that emphasize the savannas.

International institutions can also play an important role in the use of savannas by:

- Catalyzing national initiatives and obtaining international resources;
- Creating awareness of the importance of the Latin American savanna ecosystem for world food production;
- Promoting the sustainable use of the ecosystem as a way of preserving other ecosystems, such as the Amazon Basin, that are significant from the global viewpoint; and
- Promoting and facilitating interaction among countries, either by creating special mechanisms such as the Agropastoral Network, or by holding specific events such as workshops and seminars.

The bases for continuing work that has impact on the savanna ecosystem of tropical Latin America have been informally established by the Agropastoral Network for Savannas. From now on, each country is to motivate its leaders and the international community to monitor the sustainable exploitation of the savanna ecosystem. There is still a long road to hoe, because the attainment of sustainable livestock and agricultural production is a target that can be met only by long-term studies that warrant strong political and social support.

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APPENDIX

Acronyms and Abbreviations Used in the Text

Organizations

ADB	Asian Development Bank, Philippines
AFES	French Soil Science Association, France
ANDA	Associação Nacional para Difusão de Adubos, Brazil
APA	Associação dos Produtores de Arroz, Brazil
ASA	American Society of Agronomy, USA
BSC Ltda.	Bio-Statistics Consulting, Ltd., Colombia
CA	Département des Cultures Annuelles (*of* CIRAD), France
CAF	Corporación Andina de Fomento, Venezuela
CATI	Coordenadoria de Assistência Técnica Integral, Brazil
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza, Costa Rica
CEPLAC	Comissão Executiva do Plano da Lavoura Cacaueira, Brazil
CGIAR	Consultative Group on International Agricultural Research
CIAE	Centro de Investigaciones Agropecuarias del Estado, Venezuela
CIAT	Centro de Investigación Agrícola Tropical, Bolivia
CIAT	Centro Internacional de Agricultura Tropical/*International Center for Tropical Agriculture*, Colombia
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo/*International Maize and Wheat Improvement Center*, Mexico
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement, France
CNPAF	Centro Nacional de Pesquisa de Arroz e Feijão (*now* Embrapa Arroz e Feijão), Brazil
CNPGC	Centro Nacional de Pesquisa de Gado de Corte (*now* Embrapa Gado de Corte), Brazil
CNPMF	Centro Nacional de Pesquisa de Mandioca e Fruticultura Tropical (*now* Embrapa Mandioca e Fruticultura), Brazil

CNPMS	Centro Nacional de Pesquisa de Milho e Sorgo (*now* Embrapa Milho e Sorgo), Brazil
CNPq	Conselho Nacional de Desenvolvimento Científico e Tecnológico, Brazil
COMALFI	Sociedad Colombiana de Control de Malezas y Fisiología Vegetal, Colombia
CONAB	Companhia Nacional de Abastecimento, Brazil
CORDECRUZ	Corporación de Desarrollo de Santa Cruz, Bolivia
CORPOICA	Corporación Colombiana de Investigación Agropecuaria/ *Colombian Corporation for Agricultural Research*
COTRIJUI	Cooperativa Regional Tritícola Serrana Ltda., Brazil
CPAC	Centro de Pesquisa Agropecuária dos Cerrados (*now* Embrapa Cerrados)
CPAO	Centro de Pesquisa Agropecuária do Oeste (*now* Embrapa Agropecuária Oeste), Brazil
CPATSA	Centro de Pesquisa Agropecuária do Trópico Semi-Árido (*now* Embrapa Semi-Árido), Brazil
DFID	Department for International Development, UK
DID	Departamento de Informação e Documentação (*of* EMBRAPA)
EMATER	Empresa de Assistência Técnica e Extensão Rural, Brazil
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária
EMPA	Empresa Mato-grossense de Pesquisa Agropecuária, Brazil
EPAMIG	Empresa de Pesquisa Agropecuária de Minas Gerais, Brazil
ETES	Estudio Técnico y Económico de Sistemas de Producción Pecuaria (*of* CIAT, Brazil, Colombia, and Venezuela)
EU	European Union
FAO	Food and Agriculture Organization of the United Nations, Italy
FEALQ	Fundação de Estudos Agrários “Luiz de Queiroz” (of the Universidade de São Paulo), Brazil
FEDEARROZ	Federación Nacional de Arroceros, Colombia
FONAIAP	Fondo Nacional de Investigaciones Agropecuarias, Venezuela
FUNEP	Fundação de Estudos e Pesquisas em Agronomia, Medicina Veterinária e Zootecnia, Brazil
IAEA	International Atomic Energy Agency, Austria
IAPAR	Instituto Agronômico do Paraná, Brazil
IBEC	Institute of Biodiversity and Environmental Conservation
IBGE	Instituto Brasileiro de Geografía e Estatística, Brazil

IBRAFOS	Instituto Brasileiro do Fosfato
IBSRAM	International Board for Soil Research and Management, Thailand
ICA	Instituto Colombiano Agropecuario/ *Colombian Institute for Agriculture and Livestock*
ICARDA	International Center for Agricultural Research in the Dry Areas, Syria
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics, India
IDB	Inter-American Development Bank/ *Banco Interamericano de Desarrollo (BID)*
IDRC	International Development Research Centre/ *Centro Internacional de Investigaciones para el Desarrollo (CIID)*, Canada
IFAD	International Fund for Agricultural Development, Italy
IFDC	International Fertilizer Development Center
IFPRI	International Food Policy Research Institute, USA
IGAC	Instituto Geográfico “Agustín Codazzi”, Colombia
IICA	Instituto Interamericano de Cooperación para la Agricultura
IIMI	International Irrigation Management Institute (*now* IWMI), Sri Lanka
IITA	International Institute of Tropical Agriculture, Nigeria
ILRI	International Livestock Research Institute, Kenya
INTA	Instituto Nacional de Tecnología Agropecuaria, Argentina
INTSORMIL	International Sorghum and Millet (a Collaborative Research Support Program)
IPEACO	Instituto de Pesquisa Agrícola do Centro-Oeste, Brazil
IPGRI	International Plant Genetic Resources Institute, Italy
IPRA	Investigación Participativa en Agricultura/ *Participatory Research in Agriculture* (*of* CIAT)
IRAT	Institut de recherches agronomiques tropicales et des cultures vivrières (*of* CIRAD), France
IRI	Instituto de Pesquisas, Brazil
IRRI	International Rice Research Institute, Philippines
ISTRO	International Soil Tillage Research Organization, Netherlands
IWMI	International Water Management Institute, Sri Lanka
JIRCAS	Japan International Research Center for Agricultural Sciences
MAC	Ministerio de Agricultura y Cría, Venezuela
MAS	Consortium for Managing Acid Soils (*of* SWNM)

MBAT	Misión Británica en Agricultura Tropical, Bolivia
ODA	Overseas Development Administration (*now* DFID)
PDVSA	Petróleos de Venezuela, S.A.
PLUS	Plan de Uso del Suelo (project to protect the natural resources of the Department of Santa Cruz), Bolivia
POTAFOS	Associação Brasileira para Pesquisa da Potassa e do Fosfato (Brazilian office of PPI/PPIC)
PPI/PPIC	Potash & Phosphate Institute/Potash & Phosphate Institute of Canada
PROCIANDINO	Programa Cooperativo de Investigación y Transferencia de Tecnología Agropecuaria para la Subregión Andina, Ecuador
PROCITROPICOS	Programa Cooperativo de Investigación y Transferencia de Tecnología para los Trópicos Suramericanos
RIEPT	Red Internacional de Evaluación de Pastos Tropicales/ *International Tropical Pastures Evaluation Network*
SBZ	Sociedade Brasileira de Zootecnia
SMSS	Soil Management Support Services (*of* USDA)
SWNM	CGIAR Systemwide Program on Soil, Water and Nutrient Management
TPP	Tropical Pastures Program (*now* Tropical Forages Project *of* CIAT)
TROPILECHE	Consorcio de Investigación sobre Sistemas de Producción Animal de Doble Propósito (*of* CIAT and ILRI)
UEPAE	Unidade de Execução de Pesquisa de Âmbito Estadual, Brazil
UNEP	United Nations Environment Programme
UNESP	Universidade Estadual Paulista “Julio de Mesquite Filho”, Brazil
USDA	United States Department of Agriculture
WRI	World Resources Institute

Other acronyms and abbreviations

A-D	scale of levels of technology, where A = poor and D = optimal
AEI	agronomic efficiency index
AEZ	agroecological zone
Ag	*Andropogon gayanus* (forage grass)
Al	aluminum
ANOVA	analysis of variance
ATR	apparent translocation rate (*of* photoassimilates in plants)
AU	animal unit

B	boron
BA	Bahia, Brazilian state
Bb	*Brachiaria brizantha* cv. Marandú (forage grass)
Bd	*Brachiaria dictyoneura* (forage grass)
BIB	balanced incomplete blocks (experimental design)
BY	biological yield (in rice)
C	carbon
C	profitability of capital
Ca	calcium
Ca	*Centrosema acutifolium* (forage legume)
CAI	'Caiapó' (rice cultivar)
CD-ROM	compact disk-read only memory
CEC	cation exchange capacity
CEf	comparative efficiency index (*for* agroecosystems)
cfu	colony-forming unit (for counting microbes)
CGR	crop growth rate
Cl	chlorine
CP	crude protein
CR	crop row
CT	conventional tillage
Cu	copper
CV	coefficient of variation
cv.	cultivar
DAH	days after harvesting
DAP	days after planting
DF	Distrito Federal, Brazil
DGM	dry green matter
DLWG	average daily liveweight gain
DM	dry matter
DORs	domains of recommendation
DSSAT	Decision Support System for Agrotechnology Transfer (family of models for crop production)
Fe	iron
FTE	fritted trace elements (mixture of micronutrients used as fertilizer)
G	forage grass
GM	green manure
GM	green matter
GM	gross margin
GO	Goiás, Brazilian state
GY	grain yield (in rice)
H/M	hours per machine
HI	harvest index
HI	high input
HRP	Huila rock phosphate (fertilizer)
INM	integrated nutrient management
IPM	integrated pest management
IPT	individual plant treatment (in reference to fertilizers, herbicides, etc.)
IVOMD	in vitro organic matter digestibility
K	potassium
L	forage legume
L	profitability of land
LAI	leaf area index
LI	low input
LSO	land surface occupation index
LUI	land use index
LVA	Latossolo Vermelho-Amarelo/*Yellow-Red Latosol*
LVA	low-volatile amines (as found in soils)
LVE	Latossolo Vermelho-Escuro/*Dark-Red Latosol*
LW	liveweight
Mg	magnesium
MG	Minas Gerais, Brazilian state

Mn	manganese
Mo	molybdenum
MS	Mato Grosso do Sul, Brazilian state
MT	Mato Grosso, Brazilian state
N	nitrogen
NCC	North Carolina phosphate rock-commercial (fertilizer)
NCG	very finely ground NCC
Ns	native savanna
ns	not significant
NT	no tillage
OM	organic matter
P	phosphorus
P	probability
PC	principal components (statistics)
PCA	principal component analysis
PE	Pernambuco, Brazilian state
PFS	predominant farming system
pH	pouvoir hydrogène/ *hydrogen power* (the degree of acidity or alkalinity of a solution)
PN	plant number
Pp	*Pueraria phaseoloides* (forage legume)
PR	Paraná, Brazilian state
PRO	'Progresso' (rice cultivar)
R	erosivity factor of the Universal Soil Loss Equation
RBI	rice blast index
RCB	randomized complete block design (for experiments)
RIBD	family of resolvable incomplete block designs (for experiments)
RPA	research priority area
RPb	'Rio Paranaíba' (rice cultivar)
RPTN	relative power of total neutralization
RV	'Rio Verde' (rice cultivar)
S	sulfur
S1-S5	cropping systems with pastures
Sc	*Stylosanthes capitata*
SE	standard error of mean
SP	São Paulo, Brazilian state
spp.	species (plural)
T	experimental treatment
TDM	total dry matter
TDW	total dry weight
TLW	total leaf dry weight
TLWG	total liveweight gain
TO	Tocantins, Brazilian state
TSP	triple superphosphate (fertilizer)
U/D	unit cost per technical demonstration
VAM	vesicular-arbuscular mycorrhizae
VC	variable costs
W	profitability of labor
Zn	zinc

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