Productivity of acid tropical soils in Latin America and the role of forage grasses and legumes

ichard yles iguel Angel José Ignacio
R.J. Thomas, M.J. Fisher, M.A. Ayarza and J.I. Sanz Scovino
Savanna Program, Centro Internacional de Agricultura Tropical
(CIAT), Cali, Colombia

I. Introduction

Sustainable agricultural productivity is now the key goal of both developed and developing countries (Edwards et al., 1990). In the latter, the option of increasing productivity solely by means of external inputs such as lime, fertilizer, and herbicides, remains beyond the reach of most farmers. Good stewardship of the soil then becomes of paramount concern as ideally, the nutrients needed for agricultural production should come predominantly from fluxes into and out of the soil organic matter rather than from fertilizer additions to the soil nutrient solution (Harwood, 1990). Any net loss of soil organic matter represents a loss of the farmer's capital, especially the poorer farmer as, in terms of a farmer's lifetime, the soil is an non-renewable resource.

In Latin America population growth rate is exceeding the rate of increase in agricultural output (Vera et al., 1993) and therefore productivity must increase with a concurrent maintenance or improvement of the soil. Various options to achieve such sustainable increases in productivity have been discussed by Sánchez and Salinas (1981), Toledo and Nores (1986), Sánchez (1987), and Goedert (1987) for both the humid tropics (mainly forest) and the acid soil savannas. Grass/legume pastures feature prominently in the proposed options discussed in the above articles. However in a summary of the research policies on soil management for sustainability, Bentley (1991) targeted research on the use of fodder grasses and legumes for sustainable agriculture and soil conservation as an "outrageously and consistently neglected" area. In this article we examine the role of forage grasses and legumes in production systems of the acid-soil savannas of Latin America. Evidence is presented from long term experiments with grass/legume pastures, which demonstrates both the soil improving qualities and the increases in productivity obtainable from the use of acid-tolerant forage germplasm with minimum external inputs.

II. Land use in Latin America

Two ecosystems dominate the land in tropical Latin America, the rain forests, and the savannas. Here we will address the main problems associated with agricultural production and soil management pertaining mainly to the savanna ecosystems in the region. Aspects of soil management in the rain forest regions are discussed elsewhere (e.g., Sánchez, 1987; Villachica et al., 1990; Smith et al., this meeting).

Generally, the lands of tropical Latin America are used for extensive cattle ranching with savannas covering about 45% of the land area or 243 million hectares (Huntley and Walker, 1982; Vera and Seré, 1985). The savannas represent the major under-utilized resource in the continent and are found on the Cerrados of Brazil (180 million hectares), the Llanos of Colombia (17 million), Venezuela (28 million) and Guyana (4 million) and the savanna of Bolivia (4 million) (Cole, 1986). In Brazil and Venezuela these lands are being rapidly exploited. Table 1 shows the trends in the areas under crop and pasture in Latin America.

The Latin American tropics carry some 250 m head of cattle, with an annual production of some 7 million metric tonnes or megatonnes (Mt) of beef and veal, and 31 Mt of milk representing 13.8 and 6.6 percent of the world total, respectively (Table 2).

The region however is not self sufficient in these commodities as production increases lag behind population growth and potential demand for beef (Vera et al., 1993).

There is, in addition, substantial crop production in tropical Latin America, with the major production areas occurring in Brazil (Table 3). Crop production includes 44 Mt of maize, of which Brazil (55 percent) and Mexico (27 percent) produce 82 percent of the total. In 1990, 17 Mt of rice was produced, of which 58 percent was produced in Brazil and 26 percent in the remaining tropical South American countries, and 23 Mt of soybean over 88 percent of which was produced in Brazil. Soybean production has expanded by over 12 percent on an annual rate in the 24 years 1966 to 1990 (Table 3). Although integrated crop-pasture systems exist in the region, over the last twelve years there have been substantial structural changes away from integrated crop-pasture systems particularly in the Brazilian Cerrados. In this region upland rice yields are low at around 1.5 t/ha, largely because the traditional varieties lodge easily when supplied with more than modest levels of fertilizer (Sanint et al., 1992). Moreover, grain quality is poor and prices are discounted by 20-30% when compared with the irrigated sector prices (Teixeira and Sanint 1988). With the restructuring of the economic support to crop production in Brazil, in many areas rice has given way to soybean monocropping. In the newly pioneered areas particularly, where beef still remains profitable, there have been large swings away from cropping to pastures (Sanint et al., 1992).

III. Constraints to production

The main soil chemical constraints in Latin America are low nutrient reserves, soil acidity and phosphorus fixation (Table 4). Around 75% of the soils in the savanna regions are either oxisols (43%) or ultisols (32%). Further details of the climatic and topographic parameters for the savannas have been summarized by Goedert (1987) and Vera et al. (1993). Eswaran et al. (1992) have estimated that oxisols can lose 50% of their sustainability under low input agriculture within 20 years, a rate which is much more rapid than alfisols, mollisols or vertisols. Thus even though these soils are endowed with relatively good physical conditions and great depth, they must be managed carefully for sustained production.

The pastures of the Cerrados of Brazil are mainly pure grass with about 40 million ha planted to a single genotype of *Brachiaria decumbens* which is usually established after a pioneer crop of upland rice (Zeigler et al., 1993). However without maintenance fertiliser these pastures are degrading mainly due to phosphorus and nitrogen deficiencies and attacks from spittlebugs (*Cercopids*), (Fenster and Leon, 1979; Spain, 1993; Salinas and Saif, 1990; Valerio J.R. and Nakano, 1988).

Similarly, on areas under monocropping of soybeans and other annual crops in Brazil, yields are not sustainable due to weed competition, depletion of low nutrient reserves and soil physical problems such as compaction and erosion (EMPA, 1987; Sánchez, 1976; Seguy et al., 1988; Spain, 1993; Stoner et al., 1991; Zeigler et al., 1993). In addition cropping in the Cerrados usually requires liming at rates of at least 2 t/ha to adjust the low soil pH (Goedert, 1983; 1987).

In unopened savanna regions such as the Llanos or plains of Colombia, cultivation of crops is limited by deficiencies in infrastructure, such as roads (Table 5) and a lack of a local source of lime to ameliorate soil acidity. These areas remain as extensive low-input low-output ranching systems utilising mainly native savannas grasses. The latter have a very low nutritional quality for grazing animals due predominantly to the low reserves of plant available nutrients (Lascano, 1992; Fisher et al., 1992).

IV. Approaches to alleviating the constraints

A. Selection of acid tolerant germplasm

X

1. Forage grasses and legumes

For areas of acid infertile soils of the lowland tropics, which have little prospect of utilizing even moderate levels of inputs of lime and fertilizer, the Tropical Forage Program of CIAT adopted the strategy of selecting acid-tolerant forage grass and legume species and developing low-input management techniques to establish the selected materials. Using a regional germplasm evaluation approach, a portfolio of acid-tolerant germplasm options for the major ecosystems of tropical America now exists (Toledo et al., 1989; Miles and Lapointe, 1992).

The results of this technology in terms of animal live weight gains (LWG) have been spectacular especially with a legume in the pasture. For example, in the Colombian Llanos grass/legume pastures have more than doubled animal LWG and shown a 10-fold increase in productivity per ha compared with a managed native savanna (Fig 1). The grass/legume pasture increased LWG per head by 50% and LWG/ha increased by 20-30% compared with the grass only pasture. Impressive improvements in reproductive performance and milk production have also been documented (Thomas et al., 1992).

2. Upland rice

CIAT's rice program has developed lines of upland rice that are adapted to savanna acid soils with aluminum saturation levels > 75% (Sarkarung and Zeigler, 1990). These lines are tolerant to moderate drought stress and prevalent diseases such as rice blast and the "hoja blanca" virus. The yield potentials are high, in the order of 3.5-5.0 t/ha and lodging problems are considerably reduced compared with other upland varieties for the savannas (Zeigler et al., 1993; Vera et al., 1993).

B. The role of legumes - long term effects

The fixation of nitrogen by forage legumes is a key component of the low-input technology for tropical pastures as grasses are usually N-deficient (Toledo and Nores, 1986). The input of N via biological fixation improves the nutritive value of the forage (protein and minerals) and hence animal production. In addition nutrient cycling is thought to be improved via increased litter quality and a faster transformation of nutrients into plant-available forms via animal ingestion and excretion (Floate, 1981). However for the Latin American tropics there is little evidence for this or indeed for the expected build up of organic matter under legumes (Gethin Jones, 1942) or pastures (Tate, 1987).

A grazing experiment on an oxisol in Colombia with grass and grass-legume pastures has been used to examine the beneficial long term effects of a forage legume in terms of soil improvement and increased animal productivity.

The pastures were sown in 1978 at Carimagua 4°30'N, 71°19'W, 150 masl. This area receives around 2200 mm rainfall annually, mainly during May-November with a distinct dry season between December and March. Soils are oxisols (tropeptic haplustox isohyperthermic) with pH(H_2O) 4.7-4.9, aluminum saturation > 84%, 3 cmol(+)/kg Al, and low amounts of available nutrients in the order of 0.1 cmol/kg Ca and Mg; 0.1 cmol/kg K and P (Bray II).

The grass *Brachiaria decumbens cv. Basilisk* (CIAT 606) was sown in 1978 alone or with 6 m strips of *Pueraria phaseoloides* CIAT 9900 (kudzu) in duplicated 2 ha paddocks (Tergas et al, 1984). The legume strips initially covered about 30% of the total area but gradually the legume became distributed throughout the pasture. Rates of fertilisation at establishment were (kg/ha), 33 P on the grass and 44 P, 40 K, 14 Mg and 22 S on the strips of legume. In 1979 the strips received 18 K, 10 Mg and 22 S as a maintenance fertiliser and thereafter all pasture treatments received 10 P, 9 K, 92.5 Ca, 8 Mg and 11 S every two years up until 1987. After this date fertilization of the pastures was discontinued.

Continuous grazing started in December 1978 and details of the stocking rates used are given by Lascano and Estrada (1989). Basically the stocking rates varied between 1 and 2 animals/ha depending on the season. Liveweight gains were measured every 56 days and forage availability and botanical composition 4 times per year using quadrat cuts.

1. Animal production

These pastures have now persisted for 14 years and increases in animal production due to the legume *P. phaseoloides* were first observed in the rainy season after 3 years compared with the *B. decumbens* grass only pasture (Fig 2). Differences in animal LWG during the dry seasons however, were noted during the first year

(Fig 3). The legume content in this pasture has fluctuated around a mean of 37% (Lascano and Estrada, 1989).

2. Soil chemical parameters

After 10 years the soil organic matter levels were higher in the 0-2 cm profiles of the grass and grass-legume pasture compared with the native savanna but there were little or no differences in soil organic nitrogen levels between the pastures (Table 6). In these soils the contribution of the legume carbon to soil organic matter was estimated by $\delta^{13}C$ isotope measurements using the difference in natural levels of $\delta^{13}C$ between the C_4 grasses and C_3 legumes (e.g. Cerri et al., 1991). The results (Fig 4) show that the legume contributed 29% of the total soil carbon in the top 2 cm of soil and this contribution decreased gradually down the soil profile (Rao et al., 1992).

3. Soil physical parameters

There were little or no significant differences between the treatments in terms of soil bulk density, resistance to penetration, water infiltration rates or total porosity (Ayarza unpublished). However there was a better distribution of soil aggregates under the grass and especially the grass/legume pasture compared with the undisturbed savanna (Fig 5). Over 33% of the aggregates from the grass/legume pasture were larger than 0.5mm. For the grass only pasture this value was 25% while only 10% of the savanna soil aggregates were greater than 0.5mm.

4. Soil fertility

N mineralisation

The qualitative differences in soil organic matter and differences in soil aggregate distribution noted above were accompanied by differences in potential rates of N mineralisation between soil from the grass only and grass-legume pastures as measured by two incubation methods (Table 7). Potential rates of mineralisation were consistently higher with soil from grass/legume pastures compared with grass only pastures irrespective of the method used.

Yields of a subsequent upland rice crop.

In 1989 one half of the experiment described above was sown to one of the new acid-tolerant upland rice varieties (CIAT line 6196-33-11-1-3) with differing levels of fertilisation (Sanz et al., 1993). The experiment was repeated with a second rice crop in 1990. The benefit of the legume to the rice crop can be seen in the data from the treatment receiving 25 kg/ha P but no N (Table 8). For the first rice crop an extra 1.7 t rice/ha was obtained after the grass-legume pasture compared with the grass only pasture representing about 28 kg N/ha or approximately the equivalent of 86 kg N fertilizer/ha (assuming a nitrogen harvest index of 0.65 and a fertilizer recovery rate of 50%). For the second rice crop the yield advantage from the grass-legume pasture was 0.8 t/ha.

5. Period to attain 80% of the benefits

It is relevant to ask how long is it necessary to maintain a grass/legume pasture on an oxisol in order to obtain the yield benefits noted above. One approach is to use a model of the expected levels of N mineralisation from the grass/legume residues using data weighted for both grass and legume annual dry matter production and their respective rates of litter decomposition during the wet season (Thomas and Asakawa, 1993). During the dry season decomposition is about 2-3 times slower than during the wet season and is ignored here. Annual pasture DM production was estimated to be about 15 t DM/ha/yr (212 day wet season) with animals consuming 40% of the pasture. This leaves a total of 9.0 t DM/ha/yr as above ground material which turns over each year (assuming production is at steady state on an annual basis). Then using a 37% legume content and concentrations of N in grass litter of 0.6% N and 1.91% N in legume litter (Lascano and Estrada, 1989; Thomas and Asakawa, 1993), we estimate a return to the soil of 63.6 kg legume N (3.33 t x 1.91% N) and 34.0 kg grass N (5.67 t x 0.6% N). For the contribution from roots we assume a shoot:root ratio of 1.4 (Rao unpublished) and a N concentration of 0.6% N giving 36 kg root N (6 t x 0.6% N).

Thus the total amount of N available for recycling via decomposition is about 133.6 kg N/ha (63.6+34+36). Decomposition of tropical forage grass and legume litter can be described by a single exponential decay model (Thomas and Asakawa, 1993). From this study the weighted mean daily decomposition rate constant for grass and legume N was around 0.0015. Using this rate constant we can estimate the cumulative amounts of N available from mineralised plant residues for each year of a 10 year period. These data are presented in Fig 6. We estimate that after 2 years we would obtain around 80% of the benefits of a 10 year old pasture in terms of N mineralised per year, and 90% after 3 years. The actual amounts of N available may vary depending on the validity of some of the assumptions made above, but the pattern of N availability over time is unlikely to differ greatly. Thus we might expect significant benefits in terms of N supply to a subsequent crop from a moderately grazed grass-legume pasture, with a legume content of 37%, after 3-4 years if year 1 is considered only for establishment. Changes in soil physical conditions however, are likely to require longer periods. The expected input of N into the soil pools with varying legume contents and degrees of pasture utilization have been discussed elsewhere (Thomas, 1992).

C. The use of inputs

1. Forage grasses and legumes

The establishment of acid-tolerant grasses and legumes requires moderate levels of fertilization (Sánchez and Salinas, 1981). Ranges in kg/ha for the major nutrients are; 10-20 P; 10-20 K; 50-400 Ca; 10 Mg. The legume component is expected to supply the N input although there is some evidence that small doses of starter N may aid the establishment of certain legumes, e.g. *Arachis pintoi* (Thomas, 1993). These levels can be further reduced if the fertiliser is applied in bands, e.g. 5 kg P/ha can be used instead of 20 kg (Ayarza and Spain, 1991). Where micronutrient deficiencies occur with Zn, Cu and B, applications of between 1-3 kg element/ha are recommended (Ayarza, 1991).

2. Upland rice

The new CIAT upland rice varieties planted in the plains of Colombia are currently receiving in kg/ha, 300 dolomitic lime, 50 P, 100 K, 80 N and 5 Zn. Of major importance is the fact that some of these lines, e.g. CIAT line 23 (Oryzica sabana 6), do not require liming at rates sufficient to raise the soil pH and they are much less nutrient demanding than either the other upland varieties currently in use in the region or an irrigated rice variety (Table 9).

The low input technology described by Toledo and Nores (1986) was aimed at production from very marginal lands but as these soils are improved under grass/legume pastures and crops are grown, possibilities will arise for intensification of this integrated crop-pasture system. However from a nutrient balance standpoint, it is obvious that as more nutrients are removed in crop products and as the nutrient cycles become more "leaky" as a result of this intensification, there will be a need to replace the losses from the system. Fertilizers supplemented with other on-farm resources such as crop residues, animal and green manures will then become increasingly important.

It is also evident that although the technologies developed for the region are called "low-input", as pointed out by Sánchez and Salinas (1981), this does not imply the elimination of fertilizer. The aim is to maximise the output per unit of fertilizer added and minimise nutrient losses from the soil-plant system by improving nutrient cycling. Phosphorus is probably the nutrient requiring most attention as the acid-tolerant pasture and rice germplasm cannot be established without additions of purchased phosphorus and there are insufficient amounts available in the unamended soils to improve recycling. Improvements in the efficiency of fertilizer use are possible as it has been demonstrated, for example, in long term experiments on the Brazilian Cerrados, that the recovery of phosphorus fertilizer is high even with high phosphorus fixing soils and this, combined with the residual value of the fertilizer, makes phosphorus fertilization economically worthwhile (Goedert, 1983). Further Le Mare et al. (1987) have shown with Cerrado soil, that phosphorus fertilizer could be used more efficiently when combined with green manures or crop residues. More studies of this sort are needed to improve fertilizer efficiency.

Another important aspect of the use of inputs relates to the persistence of the legume component, which can be a problem in grazed pastures. As discussed by Sprent and Raven (1985), if the major soil nutrients other than N are limiting then, from an evolutionary viewpoint, it is better that legumes invest energy and photosynthate into producing a greater volume of root tissue than nodule tissue so that they can scavenge the soil for nutrients including N. Legumes are often quoted as requiring greater amounts of nutrients, such as phosphorus, than grasses but this remains controversial and unproven. In addition some tropical forage legumes require less phosphorus than certain grasses (Sánchez and Salinas, 1981). Nevertheless if we can extend Sprent and Raven's evolutionary perspective to legume persistence, then the legume-based systems will have greater chances of success if all nutrient deficiencies other than N are alleviated. This will also increase the competitiveness of the legumes in grass/legume pastures. In acid soils, external inputs and the rapid recycling of the limiting nutrients will play a major role in this scenario.

The use of acid-tolerant germplasm, which are less nutrient demanding than unadapted varieties, with improved nutrient use efficiency and the strategic use of external inputs are key factors in the successful management of the savanna acid soils for increased production. Much needs to be done to improve our knowledge of this area, especially the integration of fertilizer inputs with other on-farm resources including crop residues, animal and green manures.

V. Integrated rice-pasture systems

Since 1989 the technologies associated with the use of acid-tolerant forage and upland rice germplasm have been combined and tested in rice-pasture systems (Vera et al., 1993; Sanz et al. 1993; Zeigler et al., 1993). This has usually taken the form of the simultaneous sowing of forage grasses and legumes with rice to establish an improved grass/legume pasture with a pioneer crop of rice in either previously unopened areas of native savanna or already opened savannas with degraded pastures. In Brazil the technology has been used successfully since 1987 to recuperate degraded pastures on limed soils or soils with pH(H_2O) 5.0-5.9 in a system known locally as the "Sistema Barreirão". In this system upland rice is sown with *Brachiaria* spp. but without forage legumes (Kluthcouski et al., 1991). A third possible use is the rotation of cereals and pastures in a classic legume-based ley. In all of these systems the rice crop is harvested after 105-120 days, the pastures establish much faster than the traditional low-input technology by utilizing the residual fertilizer not removed by the rice crop. The improved grass/legume pastures are then ready for grazing after the rice harvest whereas traditionally the pasture requires one year to establish. The system is more efficient in land preparation and fertilization and reduces erosion and nutrient leaching by establishing a ground cover faster and more completely than the separate establishment of rice or pasture. In addition the overall nutrient status of the acid soils are improved as a result of the application of fertilizers (Vera et al., 1993) in a manner similar to that reported for the humid tropics (Sánchez, 1987).

Further, as we reported above (Table 8), when rice is grown after a grass/legume pasture increased yields can be expected compared with cropping after a grass only or native savanna pasture. Thus there is the potential for intensifying the system in repeated pasture/crop sequences.

The rice/pasture systems are proving to be successful in the Llanos of Colombia where the break-even yield for the cost of the rice-pasture system is around 1.6 t/ha of rice. Yields in excess of 2 t/ha have been obtained in on-farm trials over 3 consecutive years (Vera et al., 1993). In 1992 between 5-6,000 ha were sown to either rice or rice-pastures. Prior to 1990 these areas were used exclusively for extensive ranching. In Brazil it has been estimated that about 50,000 ha of degraded pastures have been renovated by sowing rice/pastures using the "Sistema Barreirão" (Kluthcouski pers. comm.). Thus the systems are both agronomically feasible and economically attractive (Rivas et al., 1991; Sanint et al., 1990).

In financial terms the rice crop dramatically improves the cash flow of pasture improvement by providing substantial revenues within the year of establishment (Sanint et al., 1990). This improvement in cash flow can allow further cropping and reduce the number of years a pasture is used. Thus the problem of pasture management and particularly legume persistence, becomes less critical as the pasture can be converted to crops with or without undersowing with improved grass and legume species. The system will however require crop production expertise either from the grazier or via contract arrangements. The latter is already occurring in the Colombian Llanos.

Potential of rice-pastures

In Brazil where upland rice has been a traditional pioneer crop it has been usual to use large amounts of lime (at least 2 t/ha) and the traditional rice lines have been prone to lodging where N supply is also high (Teixeira et al., 1989). The new acid-tolerant lines require less lime (currently 300 kg/ha are used) and are less prone to lodging. The root systems are more able to withstand stresses from aluminum and water compared with the traditional lines. Yields of 3-4 t/ha are possible compared with average yields of 1.2 t/ha in the Cerrado. In addition they attract prices equal to those of the irrigated sector.

It has been estimated that by the year 2025 there is likely to be 50 million ha of improved pasture in the Cerrado (currently there are 30 m ha). If half of the area is renovated every 6 years with rice/pasture an additional 4.2 m ha of rice would be established yielding 7.6 million tons of rice (at 1.8 t/ha). This would meet half of the additional rice needs for Brazil by 2025 (Ernstberger, 1989).

During the 1980's Brazil's economic difficulties resulted in a drastic reduction in subsidies to agriculture in the Cerrados (Sanint et al., 1992). As mentioned earlier there is a trend away from cropping to pasture in some of this area, which will require a more input efficient system to reverse. The rice-pasture system is an example of such an improved system, but it is recognised that policies will undoubtedly play a key role in the adoption of such systems. In particular the concept of ley farming in the tropics, i.e. rotating rice and other grain crops with pastures, is relatively new and will need more information on opportunity costs and policy requirements as well as further evidence for its advantages over alternative land uses (Saleem and Fisher, 1993).

Although yields of monocropped rice using the new CIAT lines have been maintained for 3 successive years in Colombia, it is not known how long monocropping can be sustained on the oxisols of the Llanos with the present technology. It is possible that the problems of soil compaction and erosion encountered in the Brazilian Cerrados will also occur in the Llanos.

VI. Future need for long term research

Although the successful use of grass/legume pastures has been demonstrated for enhanced animal and subsequent crop production on an oxisol, there remains the need to repeat these findings with other environments and soil types and with different crop-pasture sequences. Lack of legume persistence remains an unsolved problem in many environments but this aspect assumes lesser importance if pastures can be renovated economically with the rice-pasture system described above. An alternative currently under study is the sowing of a cocktail of legumes combining rapid establishment of one legume (e.g. *Stylosanthes* spp. or *Centrosema* spp.) with the longer term persistence of a legume such as *Arachis pintoi*.

Studies of factors affecting legume persistence and pasture degradation are ongoing in a 5 year experiment at the ICA-CIAT experimental station in Colombia (Fisher et al., 1993). The testing of crop-pasture rotations with combinations of rice, maize, soybeans, sorghum, green manures and grass/legume pastures is currently underway both in Colombia (ICA-CIAT) and in Brazil at EMBRAPA-CPAC, Planaltina. Both of these efforts involve long term rotation experiments using 5 year cycles. The main hypothesis being tested is that integrated crop-pasture systems are more efficient in the use of inputs and that they are more productive and sustainable than either continuous cropping or pasture alone. The role of tillage and other crop management practices currently ongoing in Brazil (e.g. Seguy et al., 1993), which mainly involve crops and green manures, are complementary to the activities described above.

By comparing native savanna with improved grass and grass/legume pastures with known differences in soil quality, soil chemical and physical factors are being identified which may serve as indices of sustainability for the soil resource base. These will need to be tested in other agroecosystems.

The on-station experiments are planned for a minimum of two rotation cycles and are being complemented with on-farm monitoring of similar systems together with on-farm participatory research. This approach will expose the hypothesis and technologies mentioned above to the rigors of actual farm conditions as well as providing an historical perspective of land use in existing integrated crop-pasture systems.

VII. Conclusions

1 - Data from a long term grazing experiment confirm the value of forage grasses and especially legumes, for the improvement of soil quality while at the same time increasing animal productivity with only minimum inputs of maintenance fertilisation.

2 - On acid soils, the improved soil conditions can result in increased yields of a subsequent acid-tolerant rice crop. The combining of rice and pastures in pasture-crop rotations has been demonstrated to be agronomically and economically viable on acid soils that are representative of large areas of Latin American savannas. This technology is an example of enhanced productivity while contributing to the maintenance or improvement of soil

quality. The technology has the potential for a large impact with a minimum financial and ecological cost (Sanint et al., 1990). The two key factors in the success of this technology are 1) acid-tolerant germplasm and 2) high fertilizer use efficiency of both pasture and rice plants.

3 - To avoid problems associated with monocropping on savanna soils, e.g. soil compaction, erosion and weed infestation, an option would be the establishment of pasture-crop rotations with a pasture phase of 3-4 years rather like a classical ley farming system. The likelihood of the adoption of ley farming systems will depend on technological factors such as the existence of a viable forage seed industry, the availability of fertilizers and improved extension activities and infrastructure. In addition various policy requirements such as access to credit and subsidy incentives should be in place in order to stimulate interest from farmers (e.g. see Saleem and Fisher, 1993).

4 - There is now an urgent need to explore additional alternatives to rice-pasture, which should include a wider set of acid-tolerant germplasm (e.g., maize, sorghum, soybeans) in order to achieve sustainable crop-crop and crop-pasture systems.

5 - Although the research reported here has been exclusively concerned with acid soil savannas the principle of the integrated use of grass/legume pastures with crops for soil

improvement and production increases at relatively low costs should be applicable to other agroecosystems in the region, including the forest margins and hillsides, where pastures are ubiquitous (CIAT, 1991). The technology can increase production from existing agricultural lands thereby relieving pressure on areas such as the tropical rain forests and it can also be used to recuperate degraded lands. A key factor is the ability to establish at low or economical cost, productive grass/legume pastures as a means of overcoming the problems of decreasing fallow periods in cropping systems and the beginning of soil degradation.

Acknowledgements

The data reported in this review are the result of multidisciplinary research activities conducted by the rice, forage, and savanna programs of CIAT together with counterparts in the national research programs of Colombia (ICA) and Brazil (EMBRAPA). We acknowledge these contributions and thank our colleagues for their permission to use unpublished data.

References.

Ayarza, M.A. 1991. Efecto de las propiedades químicas de los suelos ácidos en el establecimiento de las especies forrajeras. p. 161-185. In: C.E. Lascano and J.M. Spain (eds.), *Establecimiento y renovación de pasturas*. CIAT, Cali, Colombia.

Ayarza, M.A. and J.M. Spain. 1991. Manejo del ambiente físico y químico en el establecimiento de pasturas mejoradas. p. 189-208. In: C.E. Lascano and J.M. Spain (eds.), *Establecimiento y renovación de pasturas*. CIAT, Cali, Colombia.

Bentley, C.F. 1991. Soil management research in the search for sustainable agriculture. p. 167-173. In: R. Lal, and F.J. Pierce (eds.), *Soil management for sustainability.* Soil and Water Conservation Society, Ankeny, Iowa.

Cerri, C.C., B.P. Eduardo and M.C. Piccolo. 1991. Use of stable isotopes in soil organic matter studies. p. 247-259. In: *Stable isotopes in plant nutrition, soil fertility and environmental studies.* IAEA, Vienna.

CIAT. 1990. *CIAT Tropical Pastures Annual report* 1989. Working Document No. 70. CIAT, Cali, Colombia.

CIAT, 1991. *CIAT in the 1990s and beyond: A strategic plan, Part 2 (supplement)*, CIAT, Cali, Colombia, 125 pp.

CIAT. 1992. *Trends in CIAT commodities 1992.* Working document No. 111. CIAT, Cali, Colombia.

Cole, M.M. 1986. *The savannas biography and geobotany.* Academic Press, London, 438 pp.

Edwards, C.A., R. Lal, P. Madden, R.H. Miller, and G. House (eds.). 1990. *Sustainable agricultural systems.* Soil and Water Conservation Society, Ankeny, Iowa, 696 pp.

EMPA, 1987. *Diagnostico e prioridades para a agropecuaria do Estado de Mato Groso.* Empresa de Pesquisa Agropecuaria do Estado de Mato Groso, Cuiaba, MT, Brazil, 147 pp.

Ernstberger, J. 1989. Study on the social benefits of rice research in Brazil. GTZ report, Weikenstephan Project No. 857860.101.100, 229 pp.

Eswaran, H., J. Kimble, T. Cook and F.H. Beinroth. 1992. Soil diversity in the tropics: implications for agricultural development. p. 1-16. In: R. Lal and P.A. Sanchez (eds.), *Myths and Science of soils of the tropics.* SSSA Special Publ. No. 29. SSSA, Madison, Wisconsin.

Fenster, W. and L. Leon. 1979. Management of phosphorus fertilization in establishing and maintaining improved pastures on acid, infertile soils of tropical America. p. 109-123. In: P.A. Sanchez and L.E. Tergas (eds.), *Pasture production in acid soils of the tropics*. CIAT, Cali, Colombia.

Fisher, M.J., C.E. Lascano, R.R. Vera and G. Rippstein. 1992. Integrating the native savanna resource with improved pastures. p. 75-99. In: *Pastures for the tropical lowlands: CIAT's contribution*. CIAT, Cali, Colombia.

Fisher, M.J., C.E. Lascano, R.J. Thomas, M.A. Ayarza, I.M. Rao, G. Rippstein and J.H.M. Thornley. 1993. An integrated approach to soil-plant-animal interactions on grazed legume-based pastures on tropical acid soils. In: *Proc. XVII Intl. Grass. Cong. New Zealand/Australia Feb 8-21*, 1993. in press.

Floate, M.J.S. 1981. Effects of grazing by large herbivores on nitrogen cycling in agricultural ecosystems. p. 585-601. In: F.E. Clark and T. Rosswall (eds.), *Terrestrial nitrogen cycles*. Ecol. Bulln. No. 33. Swedish Natural Science Research Council, Sweden.

Gethin Jones, G.H. 1942. The effect of a leguminous cover crop in building up soil fertility. *E. Afric. Agric. J.* 8:48-52.

Goedert, W.J. 1983. Management of the Cerrado soils of Brazil: a review. *J. Soil Sci* 34:405-428.

Goedert, W.J. 1987. Management of acid tropical soils in the savannas of South America. p. 109-127. In: P.A. Sanchez, E.R. Stoner and E. Pushparajah (eds.), *Management of acid tropical soils for sustainable agriculture: proceedings of an IBSRAM inaugural workshop.* Bangkok, Thailand. IBSRAM.

Harwood, R.R. 1990. A history of sustainable agriculture. p. 3-19. In: C.A. Edwards, R. Lal, P. Madden, R.H. Miller and G. House (eds.), *Sustainable agricultural systems.* Soil and Water Conservation Society, Ankeny, Iowa.

Huntley, B.J. and B.H. Walker. 1982. Introduction. p. 1-2, In: B.J. Huntley and B.H. Walker (eds.), *Ecology of Tropical Savannas*, Ecological Studies Series, Vol. 42. Springer-Verlag, Berlin.

Kluthcouski, J., A.R. Pacheco, S.M. Teixeira and E.T. de Oliveira. 1991. *Renovacion de pastagens de cerrado com arroz: I. Sistema Barreirão.* Documento 33, EMBRAPA-CNPAF, Goiania, Go. Brasil. 20 pp.

Lascano, C.E. 1992. Managing the grazing resource for animal production in savannas of tropical America. *Trop. Grass.* 25:66-72.

Lascano, C.E. and Estrada, J. 1989. Long-term productivity of legume-based and pure grass pastures in the eastern plains of Colombia. p. 1179-1180. *Proc XVI International Grassland Congress*, Nice, France.

Le Mare, P.H., J. Pereira and W.J. Goedert. 1987. Effects of green manure on isotopically exchangeable phosphate in a dark-red latosol in Brazil. *J. Soil Sci.* 38:199-209.

Miles, J.W. and S.L. Lapointe. 1992. Regional germplasm evaluation: A portfolio of germplasm options for the major ecosystems of tropical America. p. 9-28. In: *Pastures for the tropical lowlands: CIAT's contribution*. CIAT, Cali, Colombia.

Rao, I., M.A. Ayarza, R.J. Thomas, M.J. Fisher, J.I. Sanz, J.M. Spain and C.E. Lascano. 1992. Soil-plant factors and processes affecting productivity in ley farming. p. 145-175. In: *Pastures for the tropical lowlands: CIAT's contribution*. CIAT, Cali, Colombia.

Rivas, L., Toledo, J.M. and Sanint, L.R. 1991. Potential impact of the use of pastures associated with crops in the tropical savannas of Latin America. p. 78-91. In: *Trends in CIAT Commodities 1991*, G. Henry, (ed.) CIAT Working Document No. 93. CIAT, Cali, Colombia.

Saleem, M.M.A. and M.J. Fisher. 1993. Role of ley farming in crop rotations in the tropics. *Proc XVII Inter. Grass. Cong. New Zealand/Australia*, Feb 8-21, 1993 in press.

Salinas, J.G. and S.R. Saif. 1990. Nutritional requirements of *Andropogon gayanus*. p. 99-156. In: J.M. Toledo, R. Vera and J.M. Lenné (eds.), *Andropogon gayanus Kunth: A grass for tropical acid soils*. CIAT, Cali, Colombia.

Sánchez, P.A. 1976. *Properties and management of soils in the tropics*. J. Wiley & Sons, NY. 618 pp.

Sánchez, P.A. 1987. Management of acid soils in the humid tropics of Latin America. p. 63-107. In: P.A. Sanchez, E.R. Stoner and E. Pushparajah (eds.), *Management of acid tropical soils for sustainable agriculture: proceedings of an IBSRAM inaugural workshop*. Bangkok, Thailand. IBSRAM.

Sánchez, P.A. and J.G. Salinas. 1981. Low-input technology for managing Oxisols and Ultisols in tropical America. *Adv. Soil Sci.* 34: 279-406.

Sánchez, P.A. and T.J. Logan. 1992. Myths and science about the chemistry and fertility of soils in the tropics. p. 35-46. In: R. Lal and P.A. Sanchez (eds.), *Myths and science of soils of the tropics*. SSSA Special Publication No. 29, SSSA, Madison, Wisconsin.

Sanint, L.R., L. Rivas and C.O. Seré. 1990. Improved technologies for Latin America's new economic reality: Rice-pasture systems for the acid savannas. p.117-131. In: *Trends in CIAT commodities 1990*. Working Document No. 74, CIAT, Cali, Colombia.

Sanint, L.R., C.O. Seré, L. Rivas and A. Ramirez. 1992. The savannas of South America: Towards a research agenda for CIAT. p. 149-177. In: *Trends in CIAT commodities 1992*. Working Document No. 111, CIAT, Cali, Colombia.

Sanz, J.I., R.S. Zeigler, S. Sarkarung, D.L. Molina, M. Rivera. 1993. Rice-pasture systems for acid soil savannas in S. America (in press).

Sarkarung, S. and R. Zeigler. 1990. Developing rice varieties for sustainable cropping systems for high rainfall acid upland soils of tropical America. Paper presented at the International Symposium on Rice Production on Acid Soils of the Tropics, Kandi, Sri Lanka, 1990 in press.

Teixeira, S.M. and L.R. Sanint. 1988. Arroz de sequeiro. In: *Agroanalysis* 12:11-16.

Teixeira, S.M., L. Yokoyama and L. Seguy. 1989. Technical change in agriculture: the impact of alternative agricultural systems for the central west Brazil. In: *10th Seminaire d'economie et sociologie*, CIRAD, Montpellier, France.

Tergas, L.E., Paladines, O., Kleinheisterkamp, I. and J. Velásquez. 1984. Productividad de *Brachiaria decumbens* sola y con pastoreo complementario en *Pueraria phaseoloides* en los llanos orientales de Colombia. *Producción Animal Tropical* 9: 1-11.

Thomas, R.J. 1992. The role of the legume in the nitrogen cycle of productive and sustainable pastures. *Grass For. Sci.* 47:133-142.

Thomas, R.J., C.E. Lascano, J.I. Sanz, M.A. Ara, J.M. Spain, R.R. Vera and M.J. Fisher. 1992. The role of pastures in production systems. p. 121-144. In: *Pastures for the tropical lowlands: CIAT's contribution*. CIAT, Cali, Colombia.

Thomas, R.J. 1993. Rhizobium requirements, nitrogen fixation and nutrient cycling. In: *The Biology and Agronomy of forage Arachis*, May 25-28, 1993, CIAT, Colombia, in press.

Seguy, L., S. Bouzinac, A. Pacheco, V. Carpenedo and V. da Silva. 1988. *Perspectiva de fixacao da agricultura na regiao centro-norte do Mato Groso.* EMPA-MT, EMBRAPA-CNPAF, CIRAD-IRAT. 52 pp.

Seguy, L., S. Bouzinac and C. Pieri. 1993. Tillage and crop management practices. In: *Evaluation for sustainable land management in the developing world*. Proc. Intl. Workshop, Sept 15-20, 1992, Chiang Rai, Thailand, in press.

Spain, J.M. 1993. Neotropical savannas: prospects for economically and ecologically sustainable crop-livestock production systems. In: *Manejo de los Recursos Naturales en Ecosistemas Tropicales para una Agricultura Sostenible.* Instituto Colombiano Agropecuaria, Bogota, Colombia, in press.

Sprent, J.I. and J.A. Raven. 1985. Evolution of nitrogen-fixing symbioses. *Proc. Roy. Soc. Edin.* 85B:215-237.

Stoner, E.R., E. de Freitas Jr., J. Macedo, A. Mendes, I.M. Cardoso, R.F. Amabile, R.B. Bryant and D.J. Lathwell. 1991. Physical constraints to root growth in savanna oxisols. *TropSoils Bulln*. No. 91-01. North Carolina State Univ. Raleigh, NC. 28 pp.

Tate III, R.L. 1987. *Soil organic matter, biological and ecological effects*. J. Wiley & Sons, NY. 291 pp.

Thomas, R.J. and N.M. Asakawa. 1993. Decomposition of leaf litter from tropical forage grasses and legumes. *Soil Biol. Biochem.* in press.

Toledo, J.M. and G.A. Nores. 1986. Tropical pasture technology for marginal lands of Tropical America. *Outlook Agri.* 15:2-9.

Toledo, J.M., J.M. Lenné and R. Schultze-Kraft. 1989. Effective utilization of tropical pasture germplasm. p. 27-57. In: *Utilization of genetic resources: suitable approaches, agronomic evaluation and use.* FAO Plant production and protection paper No. 94, FAO, Rome, Italy.

Valerio, J.R. and O. Nakano. 1988. Danos causadas pelo adulto da Cigarrhina *Zulia entreriana* na producao e qualidade de *Brachiaria decumbens*. *Pesq. agropec. bras., Brasilia* 23: 447-453.

Vera, R.R. and C.O. Seré (eds.) 1985. Sistemas de producción pecuaria extensiva; Brasil, Colombia, Venezuela. *Informe final del Proyecto ETES*, 1978-1982. CIAT, Cali. 538 pp.

Vera, R.R., R.J. Thomas, R., L.R. Sanint and J.I. Sanz. 1993. Development of sustainable ley-farming systems for the acid-soil savannas of tropical America. *Symposium on the ecology and sustainable Agriculture in tropical biomes*, Rio de Janeiro, Brazil 2-9 February, 1992, in press.

Villachica, H., Silva, J.E., Peres, J.R. and Magno C. da Rocha, C. 1990. Sustainable agricultural systems in the humid tropics of South America. p. 391-437. In: *Sustainable agricultural systems* C.A. Edwards, R. Lal, P. Madden, R.H. Miller and G. House (eds.) Soil and Water Conservation Society, Ankeny, Iowa, U.S.A.

Zeigler, R.S., Toledo, J.M. and J.I. Sanz. 1993. Developing sustainable agricultural production systems for the acid soil savannas of Latin America. In: *International symposium on agroecology and conservation in temperate and tropical regions.* Sept. 26-29, 1991, Padova, Italy, in press.

LEGENDS TO FIGURES

Figure 1. Productivity of savanna and improved pastures on an oxisol. Data from CIAT (1990).

Figure 2. Relative animal live weight gains from B.decumbens/ P. phaseoloides pastures compared with B. decumbens alone during the rainy season on an oxisol in the Colombian llanos. Data from Lascano & Estrada (1989). o - measured values **o** - fitted regression line, $y = 105.33e^{0.144x}$, $r^2 = 0.68$.

Figure 3. Animal live weight gains during the dry season with B. decumbens alone or in association with P. phaseoloides. Data from Lascano & Estrada (1989). Mean production values (1979-87) were significantly different between treatments at $P<0.048$.

Figure 4. Total C and $\delta^{13}C$ values for soils under different long-term pastures. B. decumbens with or without P. phaseoloides are 10 year old pastures. P. phaseoloides alone pasture is 8 years old. Numbers in brackets are the

percentages of soil C derived from the legume. Data from Rao et al. (1992).

Figure 5. Aggregate size distribution of soil particles in the 0-10 cm layer from a clay loam oxisol under a long term B.decumbens pasture with and without P. phaseoloides compared with the native savanna. (Ayarza, unpublished)

Figure 6. Estimated kg N mineralised/ha/yr for a 10 year old B.decumbens/P. phaseoloides pasture on an oxisol.

Table 1. Trends in the land areas in crop and pasture in Latin America. Source: CIAT, 1992).

Regional group	Permanent pastures		Annual and permanent crops	
	1973/80	1989	1973/80	1989
	millions of ha			
Brazil and Mexico	213.47	244.50	87.98	103.36
Tropical South America	126.87	137.62	19.23	21.33
Central America	11.86	13.77	6.33	6.86
Caribbean	6.59	7.00	6.16	6.60
Tropical Latin America	376.79	402.89	119.70	138.09

Table 2. Livestock commodity data for tropical Latin America, including the Caribbean (Source: CIAT, 1992).

Commodity	Annual Production				Stock	
	1974/81	1990	Proportion of world total	per capita	1974/81	1990
	millions metric tons		%	kg	'000 head	
Beef and veal	4.61	7.05	13.8	18	201.5	250.0
Cow milk	25.15	31.12	6.6	81	26.9	32.5
Pig meat	2.46	2.54	3.7	7	67.8	71.8
Poultry meat	2.00	4.30	11.6	11	747.0	1211.0

Table 3. Data for the principal crop commodities in tropical Latin America, including the Caribbean (Source: CIAT, 1992).

Commodity	Annual Production			Annual growth rate 1966/90	
	1974/81	1990	per capita	area sown	yield per ha
	millions metric tons		kg	%	%
Wheat	3.05	9.62	25	3.00	2.10
Maize	25.96	44.38	115	0.60	2.04
Potatoes	5.58	9.06	23	0.17	2.00
Cassava	31.32	30.94	80	0.18	-0.61
Rice, paddy	9.50	17.34	45	1.09	1.69
Dry beans	3.81	3.97	10	1.33	-1.07
Soybeans	0.92	23.32	67	12.23	1.61
Sorghum	2.31	7.89	20	4.15	1.49

Table 4. Main constraints in terms of soil chemistry in Latin America

	Area x 10^6 ha	% of total area
Low nutrient status	941	43
Aluminum toxicity	821	38
High P fixation by iron oxides	615	28
Acidity without Al toxicity	313	14
Low CEC	118	5
High P fixation by allophane	44	2
Others (e.g. salinity, alkalinity)	246	10
Total area	2172	

Data adapted from Sanchez and Logan (1992)

Table 5. Road length density in savanna regions

Region	Paved roads km/1000 km^2
Venezuelan llanos	50.9
Brazilian cerrados	5.7
Colombian llanos	0.1

Data from Vera and Seré, 1985

Table 6. Soil OM and total N in 10 yr old pastures compared with a native savanna.

Pasture	Depth cm	% OM	% N
Native savanna	0 - 2	4.07 ± 0.13	0.160 ± 0.007
	2 - 10	3.50 ± 0.17	0.096 ± 0.007
B. decumbens	0 - 2	4.82 ± 0.27	0.189 ± 0.016
	2 - 10	3.56 ± 0.13	0.110 ± 0.008
B. decumbens/ P. phaseoloides	0 - 2	4.90 ± 0.22	0.164 ± 0.009
	2 - 10	3.62 ± 0.10	0.101 ± 0.006

Data from Thomas unpublished, means of 10 samples ± S.E.

Table 7. Potential N mineralization rates of soil under *B. decumbens* or *B. decumbens* + kudzu pasture measured by two methods.

	µg N g soil^{-1} day^{-1}	
	B. decumbens	*B. decumbens* + kudzu
Incubation in pots in glasshouse for 4 weeks	0.519 ± 0.085	0.913 ± 0.116
Anaerobic incubation at 40°C for 7 days	3.86 ± 1.33	6.84 ± 1.69

Data from Thomas unpublished, Means of 15 samples ± S.E.
Soil depth 0-20 cm.

Table 8. Yields of a rice crop sown after a 10 yr old grass or grass/legume pasture.

Year	tonnes rice/ha	
	B. decumbens	*B. decumbens* + kudzu
1989	1.36 ± 0.17	3.07 ± 0.26
1990	1.40 ± 0.21	2.22 ± 0.21

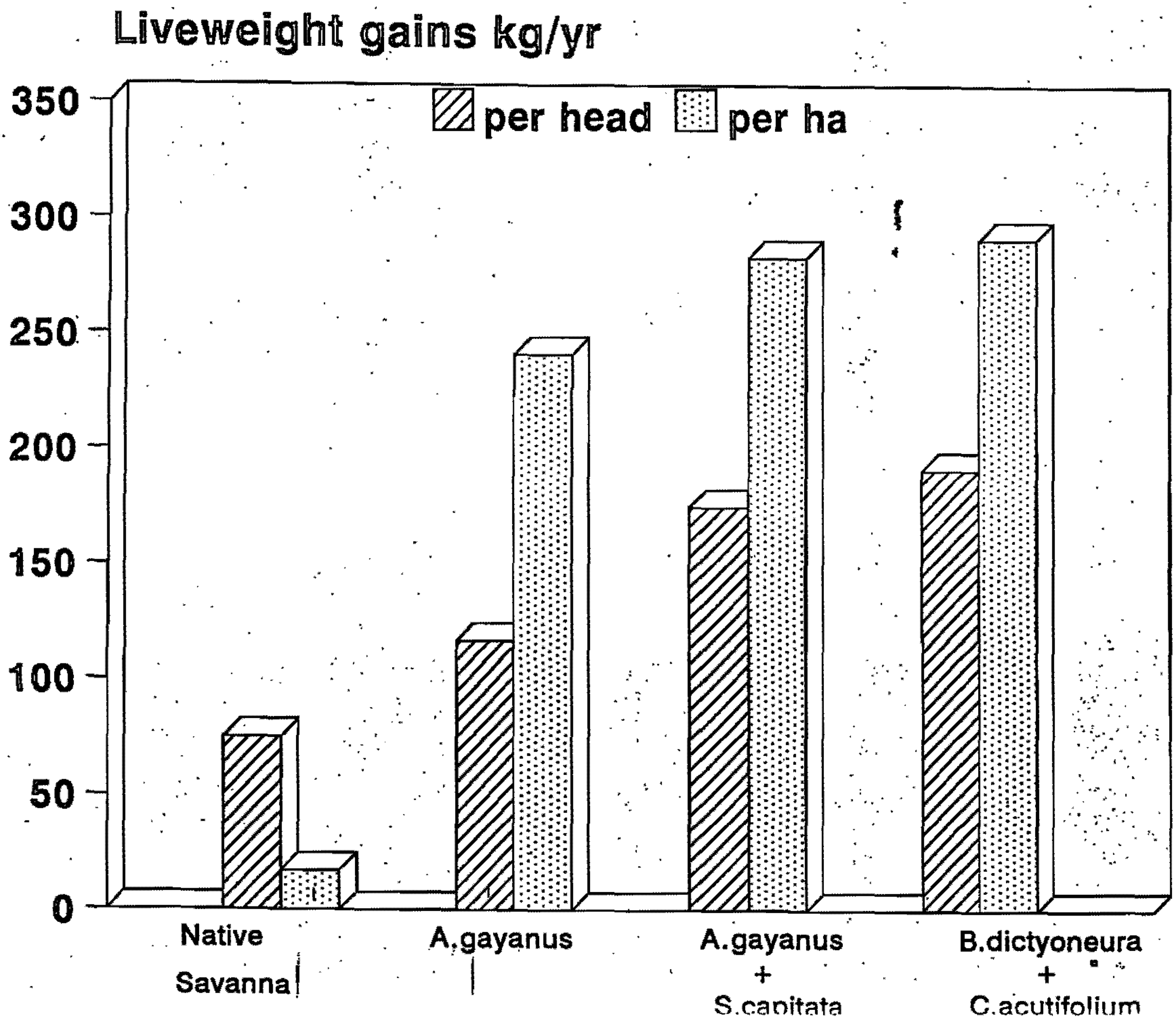
The rice crop received 0 N and 25 kg P/ha
± S.E. (Sanz et al., 1993, Fisher unpublished)

Table 9. Range of nutrient contents per tonne of upland rice.

Nutrient	Kg nutrient/t rice			
	Rice line			
	CIAT 3	CIAT 23	IAC 47	IR8
P	2-5	2	10-15	5
K	10-26	13-22	58-66	36
Ca	0.2-3	2-3	16-19	3
Mg	1.5-6	1.5-3	10-13	4
S	0.9-3	1-2	6-20	2
Zn	0.004-0.110	0.004-0.10	0.1-0.15	0.04

CIAT lines are acid-tolerant upland rice varieties
IAC47 is a Brazilian upland variety
IR8 is an irrigated rice variety

Data from J.I. Sanz (unpublished)


Liveweight gains kg/yr
per head
per ha
350
300
250
200
150
100
50
0
Native Savanna
A.gayanus
A.gayanus + S.capitata
B.dictyoneura + C.acutifolium

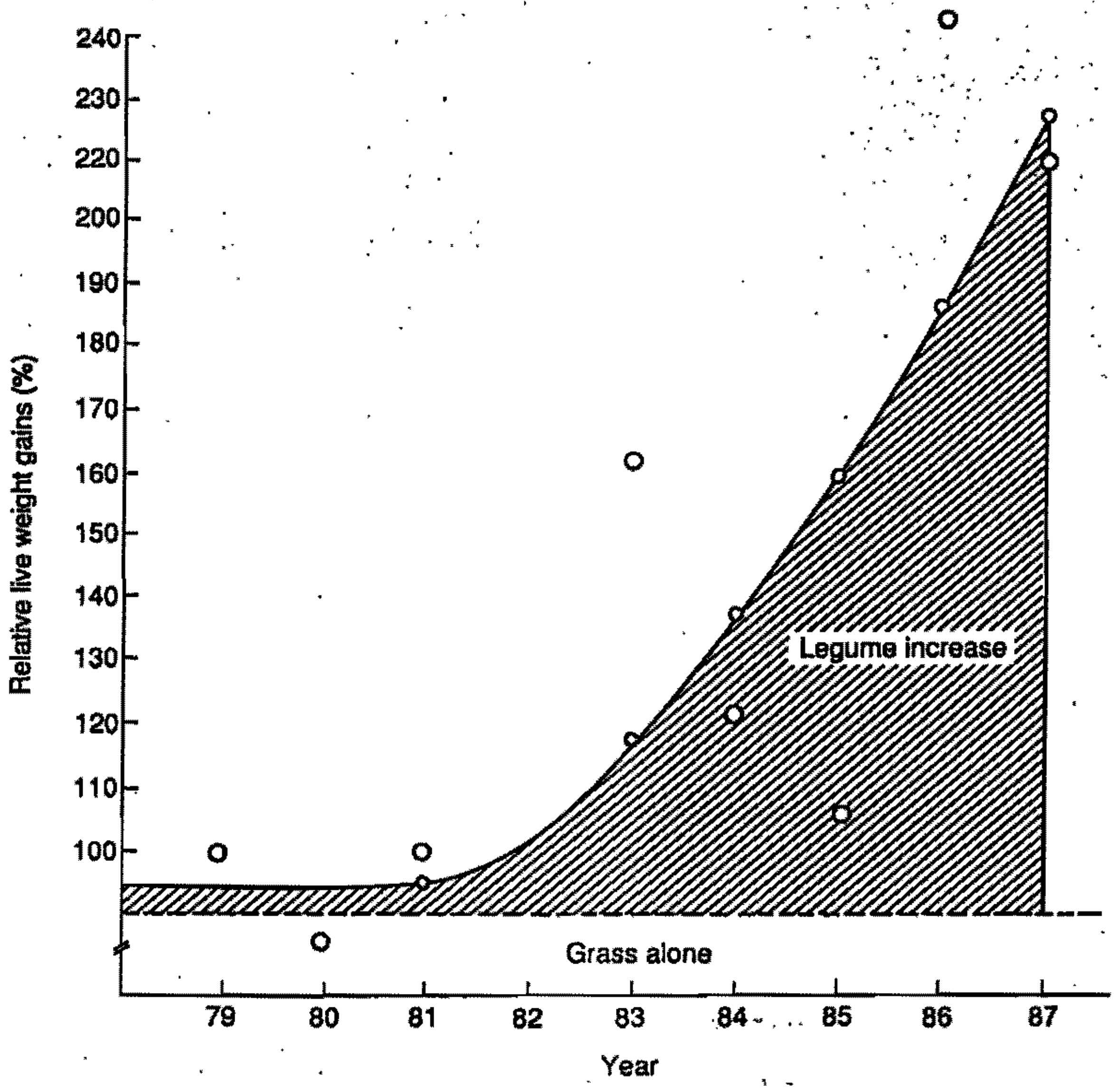

Relative live weight gains (%)
240
230
220
200
190
180
170
160
150
140
130
120
110
100
Legume increase
Grass alone
79
80
81
82
83
84
85
86
87
Year

Fig3 (04403) C43

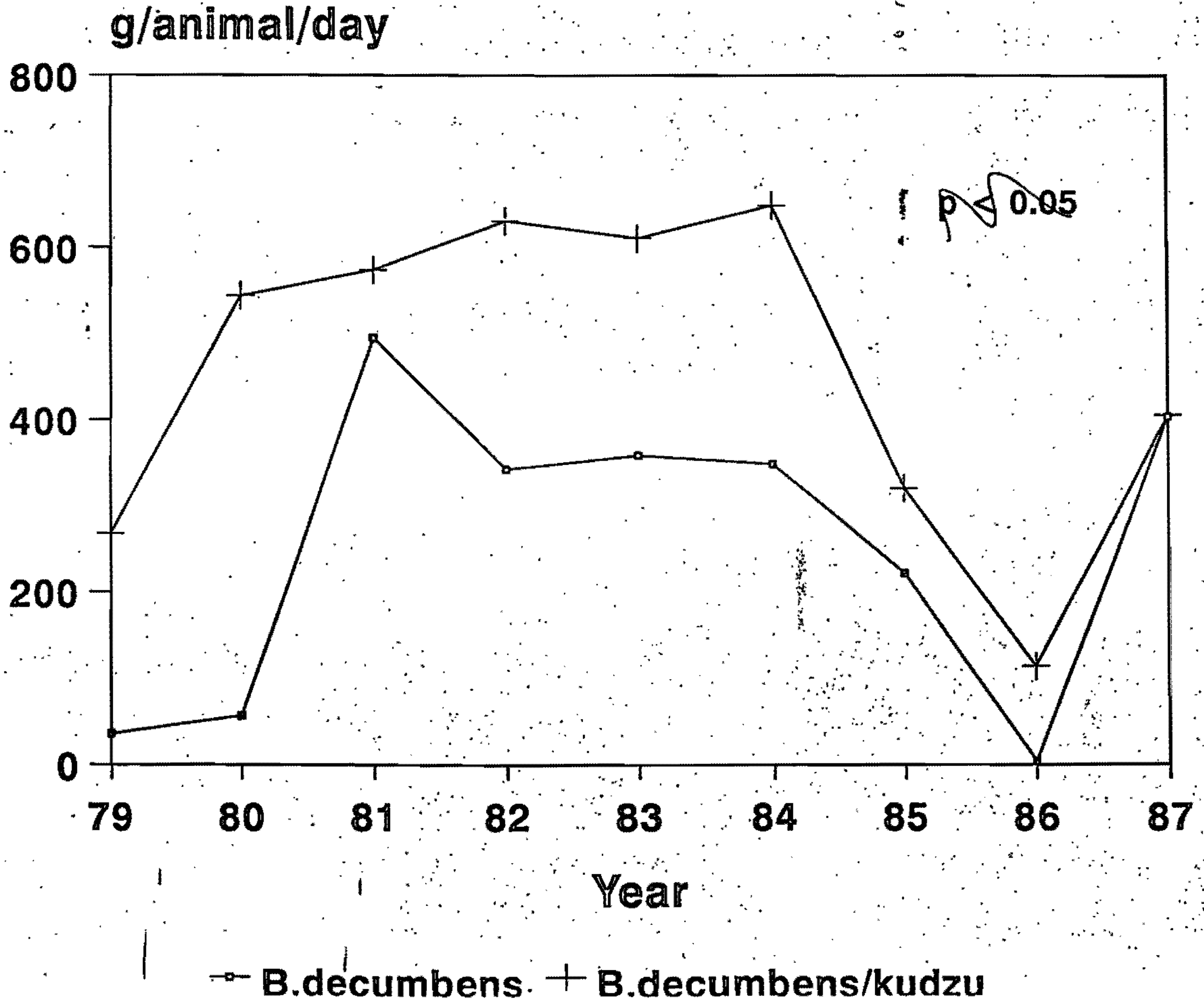


Fig 4

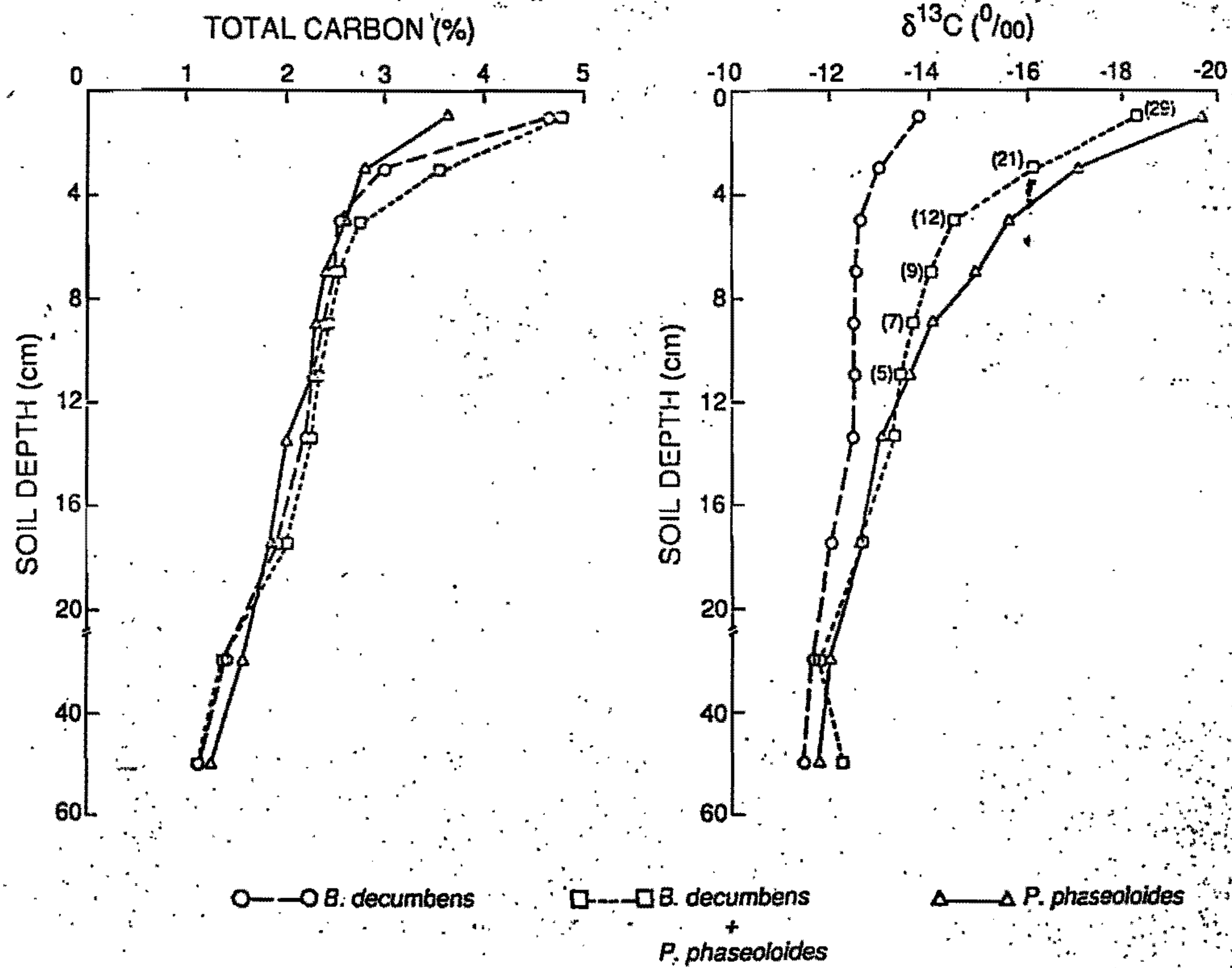

TOTAL CARBON (%)
0
1
2
3
4
5
SOIL DEPTH (cm)
4
8
12
16
20
40
60
$\delta^{13}C$ ($^0/_{00}$)
-10
-12
-14
-16
-18
-20
0
4
8
12
16
20
40
60
SOIL DEPTH (cm)
(29)
(21)
(12)
(9)
(7)
(5)
B. decumbens
B. decumbens + P. phaseoloides
P. phaseoloides

Fig. 5 [illegible]

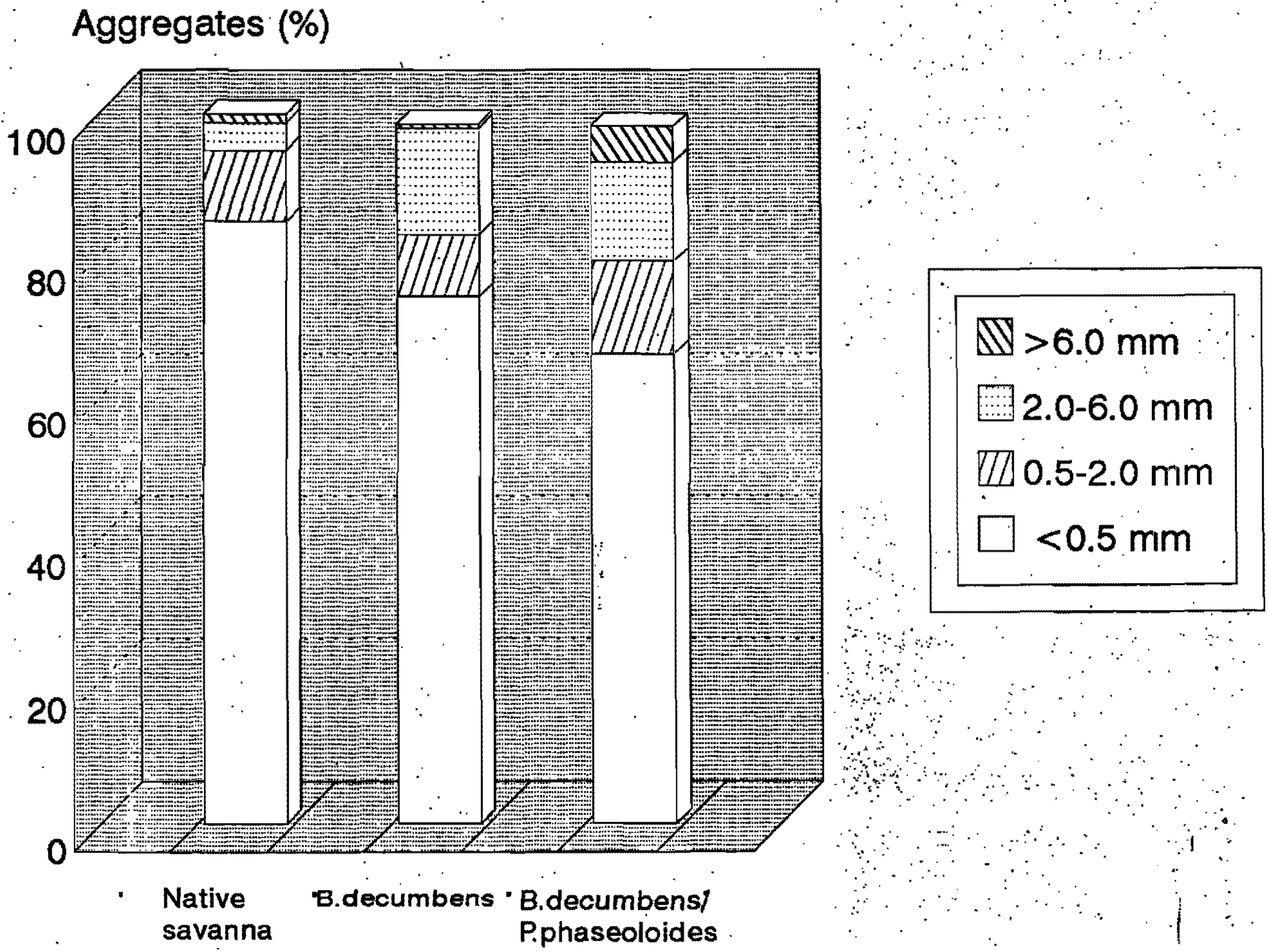

Aggregates (%)
100
80
60
40
20
0
Native savanna
B.decumbens
B.decumbens/ P.phaseoloides
▧ >6.0 mm
▒ 2.0-6.0 mm
▨ 0.5-2.0 mm
☐ <0.5 mm

Fig 6 . OHIOL.FH3 , May 31