Forage Germplasm Under Small-Plot Grazing: Evaluation Methodologies

International Tropical Pastures
Evaluation Network (RIEPT)

CIAT
Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture

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Contents

Preface

One limitation for developing productive and persistent pastures in the acid infertile soils of tropical America is the scarcity of forage germplasm alternatives—particularly legumes. CIAT's Tropical Pastures Program, through collections and interchange, has developed a germplasm bank with more than 9000[1] accessions of grasses and legumes. These are undoubtedly an important genetic base for developing new pastures capable of improving animal production in South America, especially in marginal regions.

A large number of grasses and legumes of wide genetic diversity are being evaluated at different sites within the International Tropical Pastures Evaluation Network (RIEPT). These evaluations are carried out by national programs, with support from CIAT's Tropical Pastures Program. Within the sequence established by the Network, the degree of adaptation and potential productivity of germplasm are first evaluated in agronomic trials (Regional Trials A and B), which are located in different ecosystems and subecosystems.

Since its formation, RIEPT has considered it important that germplasm selected in agronomic trials be evaluated in pastures—preferably as associations of grasses with legumes—and then subjected to different grazing management treatments to evaluate the effects of trampling and defoliation caused by the animal, to determine the appropriate grazing management system, and, finally, to ascertain the potential for animal production of the germplasm grown in pastures (Regional Trials C and D).

In order to define methodologies for evaluating forage germplasm under small-plot grazing (Regional Trials C), 53 specialists, representing 20 countries, participated in a workshop which was organized at CIAT and sponsored by the International Development

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[1] In 1992, the bank contained 20,000 accessions.

Research Centre (IDRC). This book is the third of a series on forage germplasm and pasture evaluation produced by RIEPT, and gathers the papers presented at the meeting, including the participants' methodological recommendations for Regional Trials C.

This book also seeks to unify the language as well as the concepts related to the interactions among soil, plants, and grazing animals. In addition, it intends to serve as a guide for setting up trials directed toward selecting persistent germplasm under different grazing management systems.

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Chapter 1

Pasture Development from New Germplasm: Research Problems

José M. Toledo*

Introduction

We are gathered here to participate in a workshop on methodologies for evaluating forage germplasm under small-plot grazing. This paper attempts to provide a framework for the discussions to be held during this workshop. First considered are the objectives and projections of the International Tropical Pastures Evaluation Network (RIEPT), one of whose functions is to carry out meetings such as this one. At the same time, problems that arise in the experimental process of developing pastures from new germplasm are presented and discussed.

In 1978, CIAT's Tropical Pastures Program, with the cooperation of national research institutions active in pastures research, took the initiative of forming the RIEPT for the acid-soil agricultural frontiers of tropical America. Its central objective was defined in 1979 (Toledo, 1982), that is,

> To contribute to the search for new pasture germplasm for the different production ecosystems prevalent in the poor, acid soils of the vast agricultural frontiers of the continent.

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Other, more specific, objectives were defined as (Toledo, 1982):

The use of genetic resources collected by international institutions such as CIAT, and by national institutions such as the Brazilian CENARGEN-EMBRAPA (Centro Nacional de Recursos Genéticos, Empresa Brasileira de Pesquisa Agropecuária).

Developing extrapolations based on knowledge of the range of ecosystems and subecosystems to which germplasm can adapt.

Developing and promoting scientific capabilities within the network in order to achieve efficiency in the experimentation process, which, in a dynamic and sequential manner, will incorporate promising germplasm in pastures and put these in appropriate production systems.

To fulfill these objectives, RIEPT relies on Regional Trials A (RTAs) that represent major ecosystems (well-drained isohyperthermic and isothermic savannas; poorly drained savannas; and rainy and semievergreen seasonal tropical forests), and carries out Regional Trials B (RTBs) at sites representative of the subecosystems found within these five major ecosystems. In the RTAs, an evaluation of the adaptation potential of germplasm under the conditions of a major ecosystem is first made, that is, the potential survival of the germplasm is assessed. The materials that survive and also show a high degree of productivity are exposed to subecosystem conditions in the RTBs, where evaluations are conducted under cutting to measure seasonal productivity (that is, under maximum and minimum rainfall), and so obtain a measurement that integrates adaptability and productivity potential. Until this stage, evaluations are made in monoculture, in small plots, with the only purpose of selecting germplasm adapted to the natural conditions (soil, climate, biotic pressures) of different ecosystems. By using uniform evaluation methodologies (Toledo and Schultze-Kraft, 1982), it has been possible to make multilocational analyses (Amézquita, 1982) that can extrapolate from known adaptation ranges of the selected germplasm.

It is evident, however, that agronomic experimentation (RTAs and RTBs) is not in any way sufficient to comply with the final objective of incorporating new germplasm options in pastures for animal production systems at the continent's agricultural frontiers. RIEPT therefore proposes to carry out regional trials under grazing in two phases. In the first, known as Regional Trials C (RTCs), the idea is to incorporate new germplasm in pastures to study its potential compatibility under grazing in small plots in terms of productivity (dry-matter yields and carrying capacity) and persistence (dynamics of botanical composition, changes in plant architecture, and seed reserves) under different grazing management systems.

In the second phase, Regional Trials D (RTDs), the best pastures in terms of **productivity, persistence**, and **ease of management** will be compared with the best pastures under traditional use. In these trials, pasture productivity as animal products (beef, milk, and calves) **within the context of the predominant production system in each region** will be measured.

At this meeting, the subject and problems of initial evaluations of germplasm under grazing in small plots (RTCs) will be discussed. This area offers many possibilities for debate, as well as complications in conceptualization, focus, and direction that will surely not be easy to condense and explain. Nevertheless, because of the high professional capacity and experience of the participants at this workshop, we are convinced that this meeting will contribute to the clarification of problems that will be raised during the deliberations on methodological alternatives relevant to this level of pasture selection and evaluation.

Ecosystem and Germplasm: Determinants of the Pasture Type to be Developed

With the goal of establishing a framework of reference for discussion, the relationship between germplasm and ecosystem should be first analyzed. The relationship between pasture use and production systems (from the most intensive to the most extensive) should also be examined.

The RIEPT has been working in the lowlands of tropical America, which encompass Central America, the Caribbean, and South

America. In this vast region, Cochrane (1982) has identified five major ecosystems:

Well-drained isohyperthermic savannas (Colombian and Venezuelan savanna plains, and the northern Brazilian savannas).

Well-drained isothermic savannas (predominantly the Brazilian Cerrados).

Poorly drained savannas (Casanare department in Colombia, Apure state in Venezuela, El Beni department in Bolivia, and the Boa Vista region and Pantanal de Corumbá in Brazil).

Tropical rain forest (northwestern Amazonian basin, that is, Colombia, Ecuador, and parts of Peru and Brazil).

Tropical semievergreen seasonal forest (the rest of the Amazonian basin, and the Tabuleiro zone in Bahia state of Brazil).

Each of these major ecosystems presents a wide diversity of soil fertility, soil drainage conditions, climates, and biotic factors which should all be recognized when discussing germplasm adaptation. This is exactly what Regional Trials A and B take into account when evaluating the potential adaptation of germplasm at various sites.

Germplasm is expected to adapt differently from site to site. It is, therefore, not correct to consider recommending, globally, a given germplasm for an entire ecosystem, relying only on data from one site. In the same way, it would be utopic to believe there exists a material capable of adapting itself to all the ecosystems and subecosystems of tropical America. Clearly, it should not be expected that, at all RIEPT sites, grazing trials will be done with the same germplasm. In addition, it should not be assumed that all germplasm will even be similar in terms of productivity potential and management requirements.

If, to the differences in adaptation of germplasm, we add their differences of aptitude to better fill alternative uses in diverse production systems, we will really be talking about a wide range of materials for evaluation, in the network, for the development of new pastures. Thus, alternative research techniques that permit the development of pastures relevant to different production systems are needed.

When we must decide on which germplasm to use in a given pasture system we often do not have sufficient information on the agronomic characterization (growth rates, potential compatibility, nutritional requirements, nutritive quality) of the germplasm chosen. We are therefore accustomed to deciding intuitively, thus increasing the risk of making mistakes that will become evident only in the more advanced stages of evaluation and so paying dearly in time, effort, and money. Such risks highlight the need for a good and relevant agronomic characterization as part of the research to facilitate decisions on further development of pastures, using new germplasm. It should not be expected that all grasses or legumes will survive and produce under the management system that we adopt according to a particular pasture stereotype.

The Germplasm, Pasture, and Production System Sequence

In researching the use of new germplasm in pastures and evaluating pasture productivity in terms of animal production, we should take into account the relation that exists between management techniques employed in evaluation and the eventual pasture use to be applied in the real animal production system.

In Figure 1, different sequential alternatives to mobilize germplasm for pasture development and then to production system are sketched. Starting from the "adapted" germplasm coming from Regional Trials A and B, two areas of research appear: that of pastures and that of pastures in production systems. Different levels of intensity in the use of pastures and the resources of the integral production system are considered. As examples, four arrows which point out alternative research paths for developing pastures from adapted germplasm cross these two research areas. In this way, the productivity of these pastures is evaluated under grazing and the improved selected pastures are finally accommodated into the animal production system.

The agronomic evaluations carried out in the RTAs and RTBs provide us with germplasm adapted to the natural conditions of the ecosystem (Figure 1); however, its adaptability to any of the various

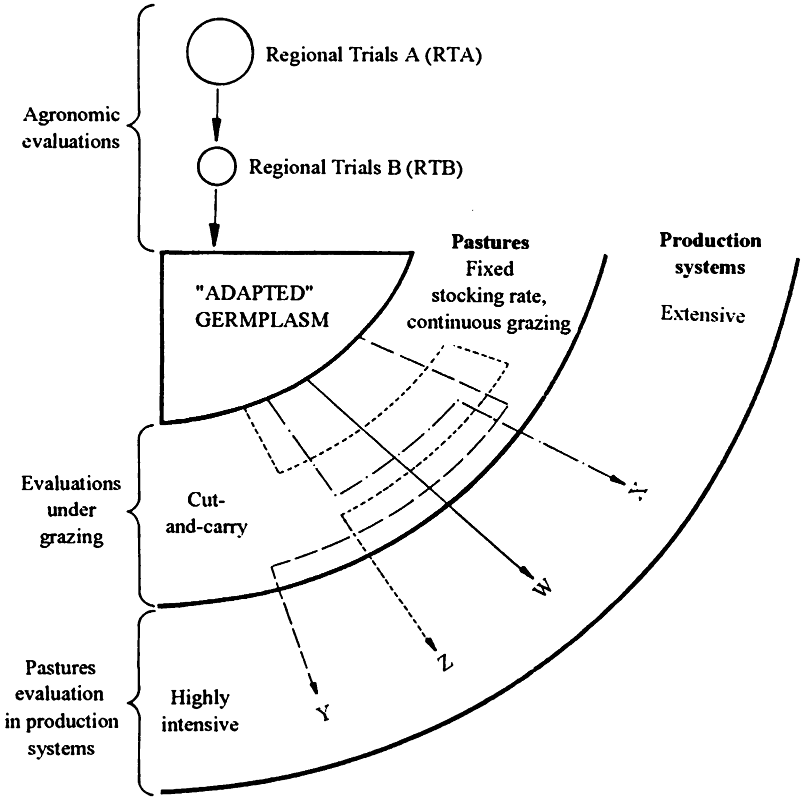

Figure 1. Sketch of the sequential activities and research alternatives employed to develop pastures, starting from "adapted" germplasm and arriving at animal production systems. Line W is the ideal research path. Line X shows an irregular, but acceptable, path that swings from intensive pasture management evaluation to fit an extensive animal production system. Line Y wrongly swings greatly from extensive pasture management evaluation to fit an intensive animal production system. Line Z describes a usual research path where research swings from intensive to extensive pasture management evaluation to fit a different intensity animal production system.

management systems is not yet known. It is necessary to evaluate these adapted materials under grazing before offering pastures best fit for a given animal production system.

There is a wide range of alternatives for pasture utilization (Figure 1), from the cut-and-carry system, through the continuous grazing system, to various grazing systems such as deferred, alternate, rotational in a few paddocks, highly intensive daily rotational, and others.

Finally, the animal production system also offers a broad spectrum of alternatives (Figure 1) that range from highly intensive systems (milking, fattening) to extremely extensive systems such as forage production for cow-calf operations in frontier areas.

The several possibilities of pasture management and use are affected by socioeconomic factors such as human population density, land prices, ratios between investment and profit, and government policies and subsidies. All these factors delimit the extent to which new technology is adopted and the intensity with which resources are managed. Ecosystem factors such as annual rainfall, length of growing season, degree of solar radiation, and soil fertility are also important because they determine the productivity potential of the new pasture technology. Finally, man himself who, through tradition and education, integrates his understanding of socioeconomics and of the natural resources available to him to define a specific pasture management system.

In Figure 1, line W, the ideal, starting from adapted germplasm, crosses the area of pasture research in a straight line and enters the area of animal production systems research in the most efficient way. Information on pasture management requirements and productivity in relation with the needs of the production system is therefore generated in a highly consistent manner. There is no doubt that this would be the most logical path for carrying out sequential research on germplasm evaluation and utilization in pastures, because it permits the direct application of results to animal production systems. Nevertheless, this is not the most usual route, mostly because researchers often do not have a clear vision of pasture management and use in the current or future production system. However, it should be recognized that it is necessary to adjust the evaluation techniques in order to logically and directly generate the most relevant information for building an accurate technological package from stage to stage in the evaluation process.

Research paths often diverge from the straight line W in pasture research. Figure 1 shows the examples of three other paths. Line X shows that pasture research is carried out by using an intensive pasture management (cutting and/or rotation) while the final use will be in continuous grazing in medium-to-low intensity animal production systems. This case, even though irregular, could conceptually be acceptable if impact is expected in terms of intensifying the production system.

Line Y represents a pasture evaluated within the concept of extensive (continuous grazing) management which final use would be in a medium- or high-intensity production system. In this case, the information generated at the pasture evaluation stage is of little use for the production systems researcher who will then have to make large intuitive adjustments and would probably make mistakes trying to fit the technology package to the actual animal production system. The consequence is likely to be that pastures and their recommended managements end up only marginally fitting the production system, having lost, in the research process, better and more suitable pasture management options.

Line Z describes a frequent situation in the pasture research process. Germplasm is, at first, selected and grasses and legumes are sown in mixtures to form pastures, which are managed intensively (e.g., cutting, or rapid and intense grazings as in mob grazing). This is followed by evaluation of pasture productivity under less intense grazing pressure (e.g., fixed stocking rate, or continuous grazing). That is, the researcher jumps from an intensive technique in the initial grazing evaluations of pasture development to a less intensive system for the evaluation of animal production, without producing information relevant to the final use of the pasture in the production system. This pasture is therefore passed on to production systems researchers accompanied by information that is, overall, confusing, contradictory, and barely applicable to the pasture utilization schemes used by farmers. Besides the serious inconsistency of the research focus, line Z also demonstrates that it suffers from the grave defect of leaving, in the research route, wide gaps of information that the researcher of the following stage has to fill in intuitively; thus, raising the probability of recommending pastures that are experimentally "good" but that, under farm conditions, will manifest low productivity and low persistence, resulting in what is frequent and worse: minimal or no adoption by farmers.

Number of Germplasm Entries and Type of Experimentation with Grazing in Small Plots

A third theme for discussing experimentation with grazing in small plots is the number of germplasm entries that are to be considered according to the objectives of the experiments.

Germplasm selection

If the objective is to evaluate and select environmentally adapted germplasm under a given grazing pressure, it will be necessary to include a high number of germplasm entries of different genera, species, and ecotypes, and graze them, following the normal tendency of researchers to use common grazing. The major problem of such trials is the interpretation when separating the following effects:

the animals' preferences (selectivity);

different dry-matter yields, resulting in different growth rates which, in turn, affect selectivity;

the animals' previous consumption habits; and

the effective grazing intensity, resulting in differences between entries (the most palatable are overgrazed, while the least palatable are undergrazed).

Usually, grazing with a high stocking rate over a short time is applied, with the intention of lessening those problems. Under this type of grazing, the effects animals have are similar to the effects of cutting and bear no important relationship with any utilization system. Very often, these experiments provide results difficult to interpret and leave doubts and frustration about the achievement of the proposed objective.

Developing adapted pastures

This objective considers the possibility of evaluating an intermediate number of germplasm entries. The RIEPT regards this objective as being at the Regional Trial C level where adapted materials, after having passed through the agronomic regional trials RTAs and RTBs, are evaluated for the first time under grazing. From four to ten legume entries, in association with a grass and under one or more grazing managements, are acceptable in this type of experiment. The aim is to determine, based on productivity and persistence, the compatibility of associations under grazing, as well learning about their management requirements.

Management possibilities

The research technique of using small plots under grazing can also be used to explore a larger number of management options in a reduced number of pastures. In these trials, one to three pastures could be exposed to more than one grazing management option. Management options may be grazing pressures, stocking rates, grazing systems (rotational, alternate, continuous), fertilization levels, and/or methods of planting. The best management technique to optimize pasture productivity and persistence would also be determined, thus generating vital information for the following grazing evaluations in larger scale experiments, whose goal is to evaluate animal production in a given system. The RIEPT considers this type of trial as one more type of Regional Trials C, especially if the selections resulting from the agronomic trials were few.

Figure 2 illustrates the number of accessions and their relationships with different objectives. The types of experiment can be clearly separated, permitting, according to objectives, a definition of alternatives for different numbers of entries. The broken line at about ten germplasm entries separates two different experimental problems: one corresponding to the selection of germplasm and the other to the development of pastures.

This separation raises the following questions:

1. When an experiment involves a high number of entries,

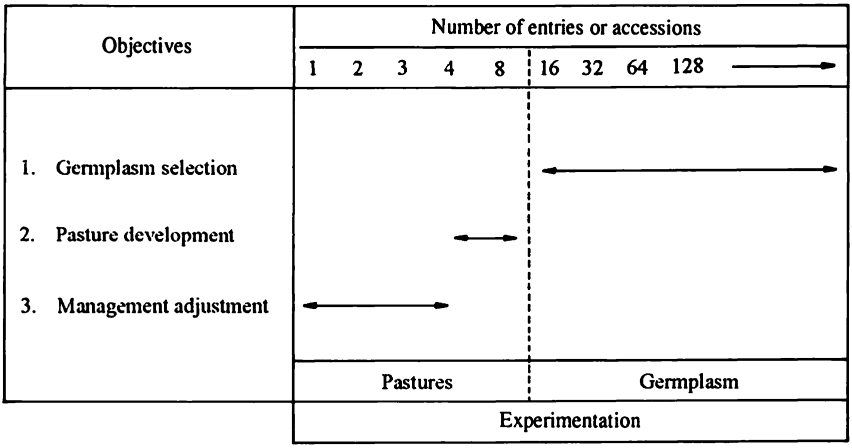

Figure 2. Experimentation in germplasm or pastures according to objectives and number of accessions.

Should common grazing be used?

Is this the only method available for conducting these trials?

How should germplasm entries be grouped?

What system or systems of grazing management should be used?

What measurements should be taken and how often?

What sized plot should be used?

What are the advantages of evaluating this material under grazing as opposed to evaluating under cutting?

What kind of information should be gathered before evaluating these materials under grazing?

2. In experiments involving a moderate number of entries or pastures, the questions would be:

Is individual pasture grazing the most efficient method?

How should entries be grouped?

What sized plot should be used?

What grazing management systems should be chosen when designing the experiment?

What measurements should be taken and how often?

3. When the number of selected germplasm entries is reduced, considerably more prior information is needed. The questions, in this case, would therefore be:

    What prior characterization of germplasm is needed to reach this level of evaluation?

    What parallel research is necessary to enable interpretation of the potentially confounding effects that are common in these first grazing trials (e.g., site specificity, or type of animal)?

Specificity by Site as Opposed to General Information

A fourth important theme for discussion at this meeting is the number of trials, their representativeness, and the possibility of extrapolating information obtained from Regional Trials C (RTCs).

The need for a uniform methodology of initial evaluation under grazing with a view to being able to compare results from different sites seems rejectable. Such rejection appears logical because it is difficult to apply uniform methodologies in pastures that contain different germplasm, adapted to different ecosystems, and with diverse end uses in production systems. At each site, for these grazing trials (RTCs and RTDs), different pastures and management systems are chosen according to the combination of germplasm, environmental conditions, and production systems. During this meeting, various experimental methodologies for developing pastures from new germplasm should therefore be discussed, rather than a search made for one specific methodology to be used in this type of trial.

A final important theme for discussion at this meeting is the convenience of carrying out trials on pastures formed with new germplasm (RTCs) at a large number of sites as against at only a few selected sites. As indicated earlier, this decision depends on the objective sketched out for these first grazing trials. If the objective is to select germplasm under grazing, this type of evaluation should be conducted at a large number of sites. However, if the objective is to incorporate promising germplasm in pastures under different management systems, it will be necessary to conduct the test at a smaller number of highly representative sites within an ecosystem and production system. Finally, by taking advantage of working within a research network, where information obtained by others is shared, a researcher can consider when RTCs can be omitted and when RTDs can be set up. These RTDs will test, within given regions, the best new pastures, comparing them in terms of animal production, using traditional pastures as control, and following the predominant animal production systems.

Conclusion

To open discussion at this meeting, attention has been given to important points that should be considered for the next three days. At the same time, the delegates—whose presence we appreciate—are invited to participate to the utmost in the discussions, taking into account that we want to change what, on this continent, was true until recently: evaluations under grazing have traditionally been regarded as an exclusive field of a few outstanding researchers. In order to advance pasture research, the number of scientists undertaking grazing work should be greatly increased. We propose to open discussions by analyzing the problems of germplasm evaluation under grazing in small plots, with the intention of defining the bases for developing and adjusting methodologies applicable to the whole continent. These important definitions will contribute to advancing adapted germplasm selections from RTAs, RTBs, and the many existing introduction nurseries to grazing, with the goal of developing, in a shorter time, better pastures that would have impact on the animal production systems of the vast agricultural frontiers of tropical America.

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Chapter 2

The Effect of Climate, Soil, and Grazing Management on the Production and Persistence of Tropical Pasture Germplasm

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Abstract

The production of tropical pasture species is determined by a complex of interacting factors which include the climatic variables of temperature, rainfall, and solar radiation; the soil's capacity to supply nutrients; the soil water available to the roots; and the effects of both current and previous defoliation regimes. Factors which can magnify the complexity include toxicities resulting from low pH, high soluble Al and Mn concentrations, and excess soluble salts in the soil; and the presence of other competing species such as sown grasses, legumes, or weeds.

Large variation exists in the response of pasture germplasm to the variables discussed. This variation is the key to identifying and subsequently promoting pasture cultivars better adapted to the varied tropical environments where high inputs of fertilizers and other technological improvements are not used for economic reasons.

There is a great need to understand the response of tropical pasture species when grown in different environments and on different soils, and when subjected to competition with other species and to different defoliation strategies. It will then be possible for tropical pasture management to be based on a more secure foundation.

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Introduction

The production of any given tropical pasture is primarily a function of the nutrient and water supplying power of the soil on which it grows, the climatic factors to which it has been and is being subjected in relation to those necessary for maximum growth, and the previous and current defoliation treatments. All these factors interact with each other and with the particular genotypes present in the pasture. The production of the pasture is therefore an integrated response to the influence of all these variables. In fact, the situation is even more complex if the effects of pests and disease organisms are also considered.

For convenience, I will first deal with the effects of climate, soils, and grazing management as separate components, and consider their interactions later in the paper in relation to selecting tropical forage germplasm.

Climatic Effects

Recent reviews have considered the effects of temperature (McWilliam, 1978), water (Turner and Begg, 1978), and light (Ludlow, 1978) on the growth of pasture species. Extremes of each of these climatic factors cause stress on plants and these physiological stresses as they affect tropical pasture plants have been reviewed by Ludlow (1980). My approach to the topic will be from the viewpoint of the agronomist rather than of the physiologist, although the line of demarcation is not so clear. In several areas, the two disciplines are becoming increasingly integrated, which is a most commendable development.

Temperature

Because most growth processes in plants are influenced by temperature, it is not hard to understand that it is the major factor controlling the distribution and diversity of pasture plant species

(McWilliam, 1978). In the tropics, the relatively high temperatures the year round offer the possibility of high dry-matter yields from pastures; in the subtropics, the temperature pattern throughout the year determines the pattern of yield distribution, particularly for tropical legumes (Jones, 1971). At high altitudes in the tropics, temperatures are lower and the diurnal range may increase, especially at higher latitudes.

Optimal temperatures for the growth of tropical grasses is usually 35 °C, with a maximum for growth at 40-45 °C and a minimum at 15 °C, below which little or no growth occurs (McWilliam, 1978). Most controlled-environment studies have been done at constant temperatures, which never occur in the field. Predicting the exact maximum and minimum temperatures for growth is difficult because of interactions between day and night temperatures (Ivory and Whiteman, 1978). Subtropical and high-altitude species may not be well adapted to the true tropics, for example, *Paspalum dilatatum* and *Pennisetum clandestinum* demonstrate a lowered tolerance of high temperatures (Ivory and Whiteman, 1978). The tropical legumes studied tend to have lower maxima for growth than do grasses.

From controlled-environment studies and field observation, the tropical legumes appear to fall into at least two groups, referred to by Sweeney and Hopkinson (1975) as the "warm tropical legumes" and the "cool tropical legumes." The former group appear to have a yield plateau above 27 °C and include *Macroptilium, Centrosema, Pueraria,* and *Stylosanthes* (Sweeney and Hopkinson, 1975; Whiteman, 1968). The "cool tropical legumes" are susceptible to high temperatures and show a yield plateau at temperatures below 28 °C. They include *Desmodium intortum, D. uncinatum, D. sandwicense, Neonotonia wightii, Macrotyloma axillare, Lotononis bainesii,* and *Trifolium semipilosum* (Herridge and Roughley, 1976; Sweeney and Hopkinson, 1975; 't Mannetje and Pritchard, 1974; Whiteman, 1968). It is not surprising to note that these species are either subtropical or occur at medium altitudes in the tropics.

Irrespective of individual species yield, there appears to be a linear decline in growth rate as temperatures drop from 28 °C to 14 °C, clearly indicating the marked effect of temperature on dry-matter yield in locations outside the hot tropics. In subtropical Queensland, no appreciable growth of *Centrosema pubescens* occurred until minimum temperatures exceeded 13 °C or maximum temperatures exceeded 25.5 °C (Bowen, 1959). Respective values for siratro were 14 °C and 21 °C (Jones, 1967 and 1971), but in *D. uncinatum* growth occurred when minimum temperatures exceeded 10 °C (Whiteman and Lulham, 1970).

In general, low-temperature stresses are more widespread than high-temperature stresses for tropical pasture plants. Of the tropical species studied, only *P. clandestinum, Chloris gayana,* and *Lotononis bainesii* show any ability to grow at low temperatures (Ludlow, 1980). Tropically adapted species such as *Brachiaria ruziziensis, Calopogonium mucunoides, Centrosema pubescens*, and *Pueraria phaseoloides* become chlorotic at 20 °C/20 °C day/night temperature (Ludlow and Wilson, 1970) and die when grown at 20 °C/6 °C ('t Mannetje and Pritchard, 1974).

The inability to harden when exposed to decreasing daylength and decreasing temperatures results in low resistance of most tropical species to frosting (Ludlow, 1980).

Of the tropical legumes, only *Lotononis bainesii* shows good leaf resistance to frosting. For other species, the leaves are killed, even with light frosts. There is, however, variation in the resistance of plants to frost kill; many avoid frost injury because of their growth habit and the position of their potential growing points aboveground (Ludlow, 1980). In *Centrosema virginianum*, ecotypes from high latitudes have highest survival rates under frosting in subtropical southeastern Queensland. This is associated with a decrease in the height of the lowest growing point that is correlative with an increase in latitude of origin (Clements and Ludlow, 1977).

There is little doubt that plant persistence can be reduced where temperatures are such as to cause stress and plants may be killed by moderate frosts (Jones, 1969). In southeastern Queensland, the persistence of siratro and other tropical legumes on heavily frosted low-lying areas is much poorer than on adjacent hill slopes. The repeated frosting which can occur, even after periods of warm weather in spring, is equivalent to a severe defoliation at a time when plants are actively growing. The poor performance of the cultivar Verano in the subtropics may again be because of the high temperature requirements of this species. In this respect, observations suggest that it is less tolerant of lower temperatures than are *S. humilis* and *S. scabra* cv. Fitzroy, although I know of no critical data comparing growth at different temperatures.

Regrowth after frosting is noticeably slower for twining or scrambling legumes such as *Macroptilium*, *Neonotonia*, and *Desmodium*, compared with growth on adjacent nonfrosted or lightly frosted areas—again this would result in poorer persistence if the associated species in the sward are able to grow vigorously after frosting.

As well as the effect of temperature on growth, flowering can be hastened at high temperatures and seed production increased as with, for example, siratro and other *M. atropurpureum* lines (Imrie, 1973); or suppressed as with, for example, *Lablab purpureus* where flowering does not occur if the minimum temperatures exceed 18 °C (Hill, 1967). Low temperatures, especially low night temperatures, can seriously reduce seed production in *S. humilis* (Schoonover and Humphreys, 1974; Skerman and Humphreys, 1973), which, being an annual, can result in low plant density and yields in subsequent years or even in the failure of the species to persist.

There are numerous instances where high or low temperatures have reduced seed in tropical grasses by adversely affecting the pollen or receptivity of the stigmas (Loch, 1980). In general, the truly tropical species are more adversely affected by low temperatures and the subtropical or high-altitude tropical species by very high temperatures. It is obvious that if such temperatures prevent seed set in species which depend on seed for regeneration then persistence will be adversely affected.

Temperature can greatly alter the morphology of some temperate pasture species, resulting in taller growth with larger leaves at high temperatures and more tillering at lower temperatures (McWilliam, 1978). Some tropical species may change from a determinate growth habit to an indeterminate habit with warm (24 °C), as compared with cool (19 °C), nights (Summerfield and Wien, 1980). Detailed studies on the effect of such fluctuations on the morphology of tropical pasture species have not been reported, but, in the case of cowpeas, the changes noted above could affect persistence in grazed pastures if the taller plants were then more heavily grazed.

Water

Most pastures encounter moisture stress at some time during the year and, as a consequence, their potential production is impaired. Water deficits occur not only when the loss of water by transpiration exceeds the supply from the roots; they are also a natural consequence of the flow of water along a pathway in which frictional resistances and gravitational potential have to be overcome (Turner and Begg, 1978). When plants are not stressed, the loss of water by evapotranspiration is governed by climatic factors; as the soil dries out, resistances within the plant result in a lower actual evapotranspiration and this is usually associated with a reduction in dry-matter yield.

The degree of water stress encountered is not only dependent on the total rainfall but also on its distribution throughout the year in relation to the evaporative demand, the soil characteristics, and the rooting pattern of the particular species. These factors determine the amount of water that may be transpired and this in turn is often related to yield. Thus, in Townsville stylo-based pastures, dry-matter yield was closely related to actual evapotranspiration estimated from a simple water balance model (McCown et al., 1974). In the unfertilized *S. humilis-Heteropogon contortus* pastures, P-fertilized *S. humilis-Cenchrus ciliaris* pastures, and N and P-fertilized *C. ciliaris* pastures, the calculated DM production per cm of evapotranspiration was approximately 50, 100, and 200 kg DM, respectively. These values compare well with the 74 kg legume DM obtained for a *M. atropurpureum-Paspalum plicatulum* pasture in southeastern Queensland (Jones et al., 1967). In this experiment, the calculated nitrogen fixation by the legume also correlated highly with annual effective rainfall, mainly because legume yield was also related to effective rainfall.

Water-use efficiency (WUE), or DM produced per unit of water used in evapotranspiration, has consistently been shown to be higher for tropical grasses with a C4 photosynthetic pathway compared with C3 grasses or tropical legumes (Turner and Begg, 1978). However, in these physiological experiments, the grasses were well supplied with nitrogen. In the absence of adequate nitrogen, C4 grasses may have lower WUE than legumes. For example, under irrigated conditions in Hawaii, plots of greenleaf desmodium and *Leucaena leucocephala* produced higher DM yields than several tropical grasses without applied nitrogen (Eriksen and Whitney, 1982). Although water use was not specifically measured, it is unlikely, under these conditions of full plant stand and adequate water, that the legumes would have used more water to achieve their higher yields.

In practice, it is often survival which is critical rather than differences in DM production. There is ample field evidence to show that species differ widely in their ability to tolerate drought. The mechanisms which plants use also differ (Ludlow, 1980). Some simply escape severe drought by being annual. For example, in Townsville stylo (Gillard and Fisher, 1978) and *Centrosema pascuorum* (Clements and Williams, 1980), flowering and seed set is so timed as to make maximum use of the length of the wet season for growth with seed set before drought completely desiccates the plants.

Others avoid water stress by several strategies. Siratro, for example, has a deep rooting system capable of extracting water from depth; a sensitive stomatal control, sensitive to both low atmospheric humidity and small changes in leaf water potential with stomata closure at the relatively high leaf water potential of -15 bar; leaves which, when water stressed, align themselves parallel to the sun's rays (paraheliotropism) to reduce radiation load, leaf temperature, and hence water loss; and a leaf area reduction mechanism whereby older leaves are shed and any new leaves produced are small, dark green, thick, and hairy during drought stress (Ludlow, 1980).

Yet other species tolerate water stress by their capacity to retain leaves on the plant at low water potential. Many tropical grasses are capable of reducing leaf water potential to -120 to -130 bar before leaf death occurs. This compares with -23 bar for siratro (Ludlow, 1980). However, many tropical legumes also tolerate stress, especially those adapted to the semiarid tropics. Species such as *S. hamata, S. scabra*, and *Centrosema pascuorum*, behave like grasses in many ways and can have water potentials as low as -100 bar (Ludlow, 1980). As a result, they can continue water loss and photosynthesis into the dry season.

Acclimation to water stress appears to be a common feature of tropical pasture species (Ludlow, 1980), although the mechanism and extent may vary between species. However, a species cannot be expected to develop water-stress tolerance simply by just being exposed to drought. The agronomist often knows the tolerance of the species he is using before the physiologist is able to give specific reasons. For example, siratro is known to be less tolerant of prolonged drought than is *S. scabra* or *S. hamata* in northern Australia. The persistence of species which cannot tolerate drought stress must be suspect in any environment where prolonged dry seasons are encountered. A series of dry years could result in their complete disappearance from the pasture. The reviews noted earlier (Ludlow, 1980; Turner and Begg, 1978) have highlighted the paucity of comparative studies between different species and cultivars of the effects of water stress on morphological and physiological processes. Such comparative studies would enable a better understanding of the ecological implications of the different strategies that plants use to avoid and tolerate moisture stress. It may then be possible, knowing details of the moisture regime in any area, to predict the best plant strategy for that environment and to select plants which possess it.

Light

There are two main aspects to be considered in understanding the effect of light on plants: first is the quantity of solar radiation received and, second is daylength. Although the total solar radiation is related to daylength, daylength per se has important effects on plants which are independent of the total daily solar radiation. This will be discussed later.

Swards which are well watered and well supplied with nutrients rarely have canopies which are light saturated (Ludlow, 1980). Under these situations, a response to increasing solar radiation would be expected. Such swards also show a decrease in the growth of tops and especially of roots when shaded (Eriksen and Whitney, 1981 and

1982). This is so for tropical grasses which possess the C4 pathway of CO_2 fixation, and for tropical legumes which possess the C3 pathway of CO_2 fixation, even though leaves of the C3 species are light saturated at 30%-50% of full sunlight illuminances, whereas leaves of the C4 species are not light saturated, even in full sunlight (Ludlow, 1978). The reason for the similar behavior of the swards of the two plant categories is because most leaves within the canopy receive low levels of radiation as a result of shading by leaves higher in the canopy. Under favorable conditions, therefore, the yields of pasture throughout the year should be related to the solar radiation falling on the crop. This was the case with irrigated pastures in southeastern Queensland (Jones et al., 1968) and with maize sown at different times throughout the year in Hawaii (Jong et al., 1982).

When all other limiting factors have been removed then pasture production will reflect the variation in solar radiation receipt, provided the plants in the pasture can meet the evaporative demand imposed by the radiation regime. Kikuyu grass in subtropical Australia, even when irrigated, is unable to do this in spring when high radiation levels occur, and production can be higher under cloudy conditions (Murtagh, 1978). Pangola grass in a far more stressful environment in northern Australia behaved differently, yielding twice as much as kikuyu under higher evaporative demand (Blunt and Jones, 1980).

In the tropics, the levels of radiation are usually high and are often the least variable climatic factor from year to year (Coaldrake, 1964). Although photosynthetic rate is closely related to radiation when other factors are nonlimiting (Ludlow, 1978), it is doubtful if radiation levels per se seriously limit the productivity of most tropical pastures except where cloud cover in the wet tropics is a constant feature of the environment. Pastures under tree crops are a specific case where shading is important to pasture production and persistence.

For these conditions, species which tolerate shade are needed and there is evidence to show that species do differ in their response to shade. In general, *Stylosanthes guianensis* has performed poorly under shade. Species which had reduced yields under shading in Hawaii include: *Desmodium intortum, Centrosema pubescens, Leucaena leucocephala, Desmodium canum*, and siratro for the legumes, and *Panicum maximum, Brachiaria miliiformis, B. brizantha*, and

Pennisetum clandestinum for the grasses (Eriksen and Whitney, 1981 and 1982). Siratro yields declined markedly under shade in southeastern Queensland compared with most other legumes; however, even under shade it still outyielded the other legumes tested in the same trial (IGC, 1974).

Seedling top growth of leucaena was little affected by shading, although root growth declined with increasing shade (Egara and Jones, 1977), whereas seedlings of *S. humilis* were killed by heavy shading (Sillar, 1967), illustrating the large differences in response to shading by different genera. It is of interest to note that grasses grew taller under shade whereas legume height was virtually unaffected by shading (Eriksen and Whitney, 1981 and 1982). This may have implications for tolerance of grazing under shaded conditions. Somewhat unexpectedly, yields of some grasses grown without nitrogen fertilizer increased under shade as did nitrogen uptake (Eriksen and Whitney, 1981; Wong and Wilson, 1980). Eriksen and Whitney suggested that yield at low N was reduced in full sunlight because the rate of chlorophyll destruction was faster than its replenishment.

In the mixed legume-grass sward, the ability to gain preferential access to radiation may be more important than the ability to tolerate shade (Ludlow, 1978). Thus, tall plants have an advantage over short plants and twining plants may be able to over-top their neighbors—an advantage which is cumulative because the over-topped plants then have a reduced growth rate. The theory that C3 legumes may have an advantage over C4 grasses under shaded conditions may need to be reviewed in the light of the finding that some grasses take up more nitrogen and give higher DM yields than when unshaded (Eriksen and Whitney, 1981; Wong and Wilson, 1980) and furthermore that the C4 grass outcompeted siratro under shade, especially when defoliated frequently (Wong and Wilson, 1980). Of course, in most experiments with artificial shade there is no competition for N and other nutrients as occurs in pastures under woodland or plantation crops and this could favor the legumes. Whatever better tolerance *D. intortum* had of shade was negated by root competition in mixtures with *Setaria* (Kitamura et al., 1981).

Daylength can influence yield by reducing the vegetative growth of species which become reproductive under specified daylengths, and also by a direct effect of daylength on yield. In controlled-environment studies, the yield of *M. atropurpureum* and *D. intortum* in particular was reduced under daylengths of 11 h compared with daylengths of 14 h, but other tropical legumes also had reduced yields ('t Mannetje and Pritchard, 1974). In the subtropics, when daylength and temperature decrease together during the autumn, a marked decline in productivity can occur. Dramatic reductions in yield can be measured when annual species are grown under daylengths which hasten flowering: *S. humilis* is a classic example ('t Mannetje and van Bennekom, 1974). Even in perennials, daylengths which cause the plant to become reproductive may cause low yields later in the season: an example is Tinaroo glycine which flowers only under short daylengths and so retains vegetative vigor long into autumn or early winter in the subtropics (Edye, 1967).

Before leaving this section, comment must be made on the importance of all climatic variables on pasture seed production. Unless the crop is attuned to the climatic conditions, seed production may fail. The significance of climate in relation to tropical pasture seed production has been considered in detail in other reviews (Hopkinson and Reid, 1979; Loch, 1980).

Soil and Nutrient Limitations

Soils differ widely in their physical and chemical properties, as well as in depth and their situation in the landscape. These differences can be reflected in the productivity and persistence of pasture species growing on them. Soils in the tropics and subtropics are often highly weathered and, in the wetter areas, often strongly leached (Isbell, 1978; Sánchez and Isbell, 1979). Emphasis has been given to soil fertility problems, since identification of deficiencies or toxicities offer possibilities for correction by use of fertilizers. Soils used for pastures are those which are, for one reason or another, unsuited to cropping and their soil fertility status is, on the whole, poor. These problems are not unique to tropical soils; what *is* unique is their magnitude in relation to the resources directed to their alleviation (Fox and Kang, 1977).

Major soil nutrient constraints to production from pasture species include deficiencies of N, P, S, and, to a lesser extent, of K, Mg, and trace elements; high soil acidity; salinity; and toxic levels of Al and Mn. These aspects in relation to the tropics have been well documented in several workshop proceedings (Andrew and Kamprath, 1978; Sánchez and Tergas, 1979; Vincent et al., 1977), and so will not be dealt with in detail here. Some deficiencies, such as N and P, are widespread in soils with potential for pasture improvement, while other problems may be more regional in distribution. Thus, high soil acidity and related problems are much more serious in soils in South America than in Australia (Sánchez and Isbell, 1979).

That soils differ widely in their ability to supply the nutrients necessary for good pasture growth is well known to agronomists. It is now becoming increasingly well established that there are also marked differences between pasture species in their ability to tolerate low levels of nutrients or to respond to increasing levels of any particular nutrient (Andrew and Johansen, 1978; Robson and Loneragan, 1978). However, as these reviewers point out, the underlying physiological mechanisms for the differences in response are poorly understood. Examples in the tropical genera include the superior ability of *Stylosanthes* species to tolerate low soil-P levels compared with genera such as *Desmodium, Macroptilium*, and *Centrosema* (Burt et al., 1980; Fenster and León, 1979); the intolerance of *Cenchrus ciliaris* to high soluble Mn levels compared with *Paspalum plicatulum* and *Setaria sphacelata* (Smith, 1979); the intolerance of *Neonotonia wightii* to low Ca and high Al compared with *M. lathyroides, D. uncinatum, L. bainesii*, and *S. humilis* (Andrew et al., 1973); and the high tolerance of some *Stylosanthes* species, such as *S. capitata*, to high Al which has been well documented at the Centro Internacional de Agricultura Tropical (CIAT).

The growth of legumes on acid soils is not only dependent on the plant per se but also on the legume-*Rhizobium* symbiosis. Plants dependent on symbiotically fixed nitrogen are usually more sensitive to high soil acidity and associated factors than are plants receiving fertilizer nitrogen, and an attempt has been made to group the various pasture legumes according to their tolerance or sensitivity to soil acidity (Munns, 1977). Not only do the plant species respond differently to acid-soil factors, but the *Rhizobium* symbionts also do. In the case of *L. leucocephala,* a species regarded as highly sensitive to soil acidity, the correct strain of *Rhizobium* (CB 81) is necessary for it to grow in acid soils (Norris, 1973).

The nutrient supply to plants can be greatly modified by the microorganisms present in soils. As well as *Rhizobium*, numerous other organisms inhabit the soil under pastures, particularly in the rhizosphere. They may affect plant growth in many complex ways but their ecology is not fully understood and man is unable to consistently modify them for increased pasture growth at this stage (Rovira, 1978). The endotrophic vesicular-arbuscular mycorrhizae greatly enhance the growth of many pasture species under conditions of low soil phosphorus and may be essential in these situations for the initiation of nodulation (Mosse, 1977). Numerous other beneficial effects in alleviating various stresses have been recorded (Jehne, 1980). Because soils differ in their mycorrhizal populations, it is conceivable that pasture productivity may be limited by the absence of efficient strains. However, the factors which govern mycorrhizal symbiosis in natural soils are not well understood (Jehne, 1980) and their contribution to differences in pasture productivity between soils is therefore relatively unknown.

In some soils, effective nitrogen fixation by organisms associated with roots of tropical grasses occurs (Döbereiner and Day, 1976). A number of organisms has been recorded in such associations but the species with the most widespread distribution is probably *Azospirillum brasilense*. It was recorded in the rhizosphere of 95% of the grasses collected in northern Australia (Weier, 1980). Soil factors known to influence the efficiency of the relationship include temperature, soil water status, pH, carbon-to-nitrogen ratio, and ease of decomposition of organic matter (Weier, 1980). The fact that grass species can influence the relationship is of importance to agronomists who may be able to identify species and soil combinations which promote N_2 fixation by tropical grasses. This could be of value in grass-legume pastures to confer extra competitiveness to grasses which may be difficult to maintain in grazed pastures with vigorous legumes. I do not think that such N_2-fixing associations are sufficiently well understood or efficient to replace the emphasis on legume technology for increased animal production in the tropics.

Factors, other than nutrient supply, influence the productivity and persistence of pasture species, for even when soils meet plants' nutrient requirements and are adequately watered, large differences in yield can be measured, even under controlled conditions. In general, tropical pasture legumes grow well on sands and loams; however, production and persistence on heavy clay soils are often poor. Exceptions are *Leucaena leucocephala* and *Clitoria ternatea* (Parberry, 1967). In addition, *Indigofera* species are well represented on soils in Africa as are *Acacia* species. The grass *Stylosanthes* is usually regarded as adapted to acid sandy soils, but some *S. hamata* are prevalent on alkaline clays (Burt and Miller, 1975; Burt et al., 1980). Reasons for these observed differences in adaptability are not fully known. Low productivity and persistence of the deep-rooted siratro on clay soil compared with an adjacent granitic soil were not because of moisture stress or nutrient supply: toxicity after the first year when roots penetrated was attributed to chloride uptake (Fisher, 1980).

Water-holding capacity—a function of soil depth and infiltration rate—can have large effects on both yield and persistence of pasture species. Soils with low surface infiltration rates or duplex soils may be able to store only small amounts of water in the profile, particularly if the rain occurs as intense falls separated by dry periods (McCown et al., 1976). Runoff or lateral drainage may result in low water storage in the profile and poor production in the following dry season. Because yield of legumes is strongly related to evapotranspiration, yield in the dry season depends on the quantity of water stored (McCown, 1973).

Some duplex soils may suffer the effects of waterlogging in the wet season and drought in the dry season—often a very bad combination for the production and persistence of legumes. However, a number of grasses (Anderson, 1974a and 1974b) and legumes (Humphreys, 1980; McIvor, 1976) are known to tolerate flooding. Even within species, large differences in tolerance of waterlogging have been recorded, which offers scope for selection and improvement of this character (Brolmann, 1978 and 1980).

In semiarid areas, sodic soils can pose problems with high levels of soluble salts and high exchangeable Na concentrations. The use of species tolerant of these conditions is the only viable approach to utilizing them effectively. Tolerance of salt by both grasses and legumes varies widely: with *Panicum coloratum* and *C. gayana* showing better tolerance than *Cenchrus ciliaris* and *P. maximum*; and *Medicago sativa, Macroptilium lathyroides*, and *M. atropurpureum* showing far better tolerance than *D. intortum, D. uncinatum*, and *S. humilis* (Russell, 1978). The low tolerance of *S. humilis* contrasts with the far better tolerance of *S. hamata* cv. Verano (K. Betteridge and R. J. Jones, unpublished data).

Thus soils factors which adversely affect the productivity and persistence of tropical pasture germplasm may be alleviated by soil amelioration, by the use of tolerant plants, or by a combination of both (Russell, 1978). In many cases, the use of high inputs to ameliorate soils for pastures would be uneconomical. With the use of more tolerant germplasm, it may be feasible to use smaller inputs. The variation in tolerance of species so far studied to different limiting conditions is encouraging and offers scope for further advances.

Grazing Management

The yield and persistence of all tropical pasture species can be greatly reduced by inappropriate grazing management (Harris, 1978). What is, or what is not, appropriate will differ among species and among various climatic areas. In general, legumes are more sensitive to grazing management than are grasses, but exceptions do occur. Emphasis is placed on the legume because if it fails, then the total pasture production will inevitably decline.

The two key variables in grazing management are the stocking rate imposed, which will influence the grazing pressure on the pasture or on particular components of the pasture, and the stocking method, that is, how the pastures are grazed. The second aspect involves decisions as to length of time the pasture is grazed or rested. Usually, the stocking rate chosen has the greater influence on pasture productivity and legume persistence, and any pasture can be reduced to almost zero production by overgrazing.

We still have much to learn about the grazing management of tropical pastures. After all, most legume species currently being developed have a very short history of domestication and we know relatively little about their ecology in grazed swards under different climatic regimes. The trailing and twining tropical legumes such as *Desmodium intortum, D. uncinatum*, siratro, and *Neonotonia wightii* are sensitive to frequent low cutting or heavy grazing (Humphreys and Jones, 1975; Jones, 1977). Their growing points are accessible to the grazing animal and regrowth from basal buds is slow. With increasing stocking rate, the percentage of siratro in *Setaria sphacelata*-siratro pasture grazed continuously declined with time as did DM yield. At 1.1 heifers per hectare, pasture production and percentage of legume remained fairly stable over time, whereas at 3.0 heifers per hectare, siratro was virtually eliminated (Jones and Jones, 1978). Under rotational grazing, the same pasture mixture gave lower yields and a lower percentage of siratro with increasing stocking rate from 0.8 to 2.8 steers per hectare, the decline in siratro yield was more rapid in a 3-week rotation than a 9-week rotation (Jones and Jones, 1978). In association with *Panicum maximum*, the percentage and yield of siratro were higher with continuous grazing than when grazed at either 3- or 6-weekly intervals (Stobbs, 1969). In association with *Cenchrus ciliaris*, siratro has also performed better with continuous grazing at a set stocking rate than with rotational grazing ('t Mannetje, 1980).

Siratro persistence is reduced by heavy grazing pressure: plants have a mean half-life of only 5 months at 3 heifers per hectare compared with 15 months at 1.7 heifers per hectare (Jones and Jones, 1978), indicating the need for recruiting new plants from seed to maintain populations and pasture production. At low stocking pressure, plants perennated well and developed strong stolons. Regeneration from seed was then less important than at higher stocking rates. Clearly, pasture stability with these twining tropical legumes is very sensitive to grazing management, the key component of which is the stocking rate. In practice, at the "correct" stocking rate, these pastures look undergrazed and have few weeds. Increasing the stocking rate results in weed ingress and lower production from the legume, which in turn reduces N input and results in even lower production and greater grazing pressure on the legume (Jones and Jones, 1978; Roberts, 1980).

Legumes more tolerant of frequent clipping do not behave as does siratro in grazed swards. *Lotononis bainesii* (Bryan, 1961), *Stylosanthes humilis* (Gillard and Fisher, 1978), *S. hamata* cv. Verano, *Desmodium heterophyllum* (Partridge, 1979), *Trifolium semipilosum* (Jones, 1973), and *Arachis glabrata* (Beltranena et al., 1981) do not show dramatic yield reduction with increased defoliation and tend to be more persistent and productive at high stocking rates. These species are also capable of setting seed under high grazing pressure such as *L. bainesii, T. semipilosum*, and *S. hamata* cv. Verano; or can spread by stolons or rhizomes such as *D. heterophyllum, A. glabrata*, and *T. semipilosum*. They could be adversely affected by low stocking rates that enable taller grasses to compete. Accordingly, they may need to be combined with more prostrate grass species for ease of management.

Grazing management to maintain a balance of grass and legume in the sward is made more difficult if large differences in relative palatability occur between the components of the pasture. More and more evidence is accumulating to show that, in general, grasses are preferred to legumes in the wet season, whereas the reverse is true in the dry season (Gardener, 1980; Stobbs, 1977). However, *Leucaena* appears to be well eaten in both seasons and siratro appears to be more readily eaten than either *S. hamata* cv. Verano or the relatively unpalatable *S. viscosa.*

Species uneaten in the wet season have a tremendous advantage over those that are eaten and this may cause problems of management to maintain a balance of species and prevent weed ingress. Knowing the characteristics of the species can help in designing managements to achieve the desired objective. This will be easier to achieve if complementary pastures are available for differential stocking. Thus, in the subtropics of southeastern Queensland, pastures based on siratro or *T. semipilosum* could be managed in a way that would benefit both. Lenient stocking in summer on siratro-based pastures would result in an increase in the legume component in autumn, whereas high stocking pressure on *T. semipilosum*-based pastures in summer would control grass growth, encourage clover spread and again result in higher legume content in autumn and winter (Jones and Jones, 1982). There seems to be insufficient data on most tropical pasture species to formulate reliable management techniques for different environments.

Palatable shrub species may require careful management to prevent overgrazing because they are usually sown in spaced rows readily accessible to the grazing animal. They may also be needed for specific purposes and so would need to be rested from grazing to produce quality feed in the dry season.

It is important to emphasize that legumes differ in their response to defoliation and that these differences may be reflected in their response to increasing stocking rate or grazing pressure. The nature of the associate grass, in terms of vigor or relative palatability, could modify the effects of grazing on the legumes which could be beneficial or harmful to the association. Some management strategy such as resting at the time of flowering of the legume or at the time of initial regrowth of the grass at the beginning of the wet season, may be necessary to restore the balance of the species which is overgrazed or otherwise disadvantaged.

Unfortunately, there are few detailed studies which report the effects of different grazing managements on the productivity and persistence of tropical germplasm. Furthermore, to be relevant, such studies should not only measure sward attributes but also animal production in a realistic grazing system. Where improved pastures form a small portion of the whole they can be grazed on a system which utilizes them to the full, that is, the put-and-take stocking system. Where improved pastures occupy a greater proportion of the farm, this option becomes more difficult or impossible to apply.

Two approaches to studying the effect of grazing management on tropical germplasm may be adopted. One is to set the system of management that may be employed in practice and then to select the germplasm under that system. The other is to select a species that shows exceptional promise and devise management systems that maximize productivity and persistence. Under our conditions in northern Australia, the former approach is more relevant to the extensive grazing system. In other situations, and with an outstanding genotype, the second approach may be the preferred strategy. For both strategies it would be important to measure animal production on the pastures managed in different ways to establish the claimed benefits of any given system for animal production. Results of the relatively few grazing management comparisons with tropical pastures indicate that productivity from continuously grazed pastures was as good as from the rotational grazing methods with which it was compared ('t Mannetje et al., 1976b). Most of the comparisons continued for only 3 years, so caution is needed in assessing the results. Furthermore, the rotational grazing strategies adopted appeared to be ad hoc rather than specifically designed to achieve a desired objective. Until such ecological objectives are clarified in relation to grazing management it is unlikely that forms of rotational grazing will be anything but a hit-or-miss approach. As pasture agronomists, we need to be able to predict responses to given management inputs for the species we promote if grazing management and pasture management in general is to become a science as well as an art.

Interactions

I have discussed as independent variables the effects of climate, soils, and grazing management on tropical germplasm in earlier sections. This is the approach usually adopted by physiologists, plant nutritionists, and soil scientists to study the variables influencing plant production. In pasture systems, it is difficult to change only one of these variables to the exclusion of the others. Often several variables will change together. For example, in autumn, daylength, solar radiation, and temperature are declining as is soil moisture. This, in turn, will reduce uptake of nutrients from the more fertile but now drier surface soil. In summer, the potential high growth rate of grasses may be limited by low soil moisture and low available nitrogen status. The complexities of interaction may be magnified by the presence of other competing species, the fertilizer regime, and the grazing animal, which selectively removes photosynthetic tissue from one component of the sward. The situation would be a "nightmare" to a scientist trying to study one variable in the field situation.

For the pasture agronomist, the species under test integrate these fluctuating inputs. He is interested in the different responses of some species compared with others without fully knowing the reasons for the different responses obtained. His interest often centers on the interaction between the genotypes under study and the many variables of climate, soils, and grazing management to which they have been exposed. The evidence to date suggests that, as a result of these planned and unplanned interactions, valuable new germplasm for tropical pastures has been identified and that interesting physiological differences between and within species have come to light. In addition, such studies have prompted other investigations which have led to new approaches to the selection of tropical pasture germplasm. This workshop should foster interaction at different levels among pasture scientists, which should lead to greater efficiency in identifying sources of variation in pasture plants. These, in turn, will lead ultimately to the development of pasture cultivars with high potential for increased production of animal protein from tropical pasture lands.

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Chapter 3

Relationship Between Pasture Structure and Utilization of Tropical Forage Plants

John Hodgson*

Abstract

Variations in sward canopy structure can exert an important influence on the ingestive behavior of grazing animals and hence on herbage intake and utilization. In tropical swards, the structural characteristics of major importance appear to be total herbage density or leaf bulk density and leaf-to-stem ratio. However, there is a need for a closer examination of the associations between sward variables and animal responses if selection for structural characteristics is to be put on a sound footing. Factors contributing to an increase in intake will normally improve the efficiency of utilization. However, in some circumstances they may inhibit selective grazing activity or contribute to increased herbage losses.

Identification of important structural variables requires detailed description of sward characteristics and animal responses. Once identified, initial screening for these variables should be accommodated within existing resources, but eventual selection for intake and utilization characteristics should be carried out under grazing conditions, particularly if mixed grass-legume swards are to be evaluated. The acceptable balances between grass and legume or between intake and feed reserves will be strongly influenced by the eventual application of the plant material under test.

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Introduction

Levels of performance in grazing animals in tropical regions are frequently low as a consequence of limited intakes of herbage of low nutritive value (Paladines, 1981; Stobbs, 1975b). Deficiencies in nutritive value are a consequence of wide seasonal fluctuations in plant growth, leading to extreme seasonal variations in herbage mass and botanical and morphological composition (e.g., Figure 1). Low nutritive value contributes directly to low herbage intake (Minson, 1982), but characteristics of the canopy structure of tropical swards have also been identified as contributory factors (Dirven, 1977; Stobbs, 1975b).

Restrictions in herbage intake have been associated with low levels of intake per grazing bite linked to limiting values of sward surface height, total herbage or leaf bulk density, and leaf-to-stem or live-to-dead ratio. The suggestion that efforts in plant selection and in sward management should be directed toward improving these parameters has been generally accepted (Stobbs, 1975b; Stobbs and Hutton, 1974).

These are important concepts which have had a substantial impact on thinking about desirable characteristics of plants for grazed swards. They form the basis for this paper. However, before considering the influence of sward canopy structure on herbage intake and utilization efficiency, it is important to clarify certain issues concerning the components of ingestive behavior and the responses of these components to variations in sward canopy structure.

Ingestive Behavior

Most of the experimental evidence on the relationships between sward structure and ingestive behavior demonstrates association, and causation is much more difficult to prove. This is not necessarily a major cause for concern but, where associations are complex, as they tend to be in this type of research (for example, Chacon et al., 1978), care is clearly needed in drawing conclusions which can be applied to

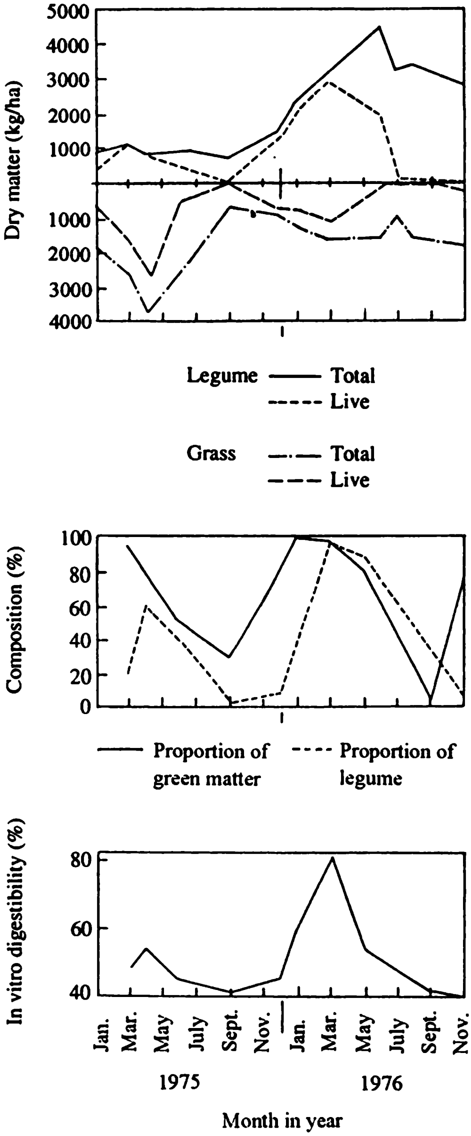

Figure 1. Seasonal variations in the diet selected by grazing cattle: (A) in herbage mass and botanical composition of *Stylosanthes hamata*-native grass pastures; (B) in the botanical composition; and (C) in digestibility. (Adapted from Gardener, 1980).

general selection programs. This is particularly true where different patterns of association can be identified in different circumstances (Chacon and Stobbs, 1976; Chacon et al., 1978). The implication is that, if the topic is important enough, it deserves further detailed examination in order to identify causation and critical ranges of influence for the parameters concerned.

Intake per bite (IB) is the dominant behavioral variable influencing daily herbage intake (Figure 2). The rate of biting (RB) and grazing time play a subsidiary role (Stobbs, 1975b), although this is not invariably the case (for example, Hodgson and Jamieson, 1981). Thus, concentration on IB alone may be dangerous in some circumstances, and measurement of the short-term rate of intake (IB x RB) may be a better measure of the impact of sward conditions

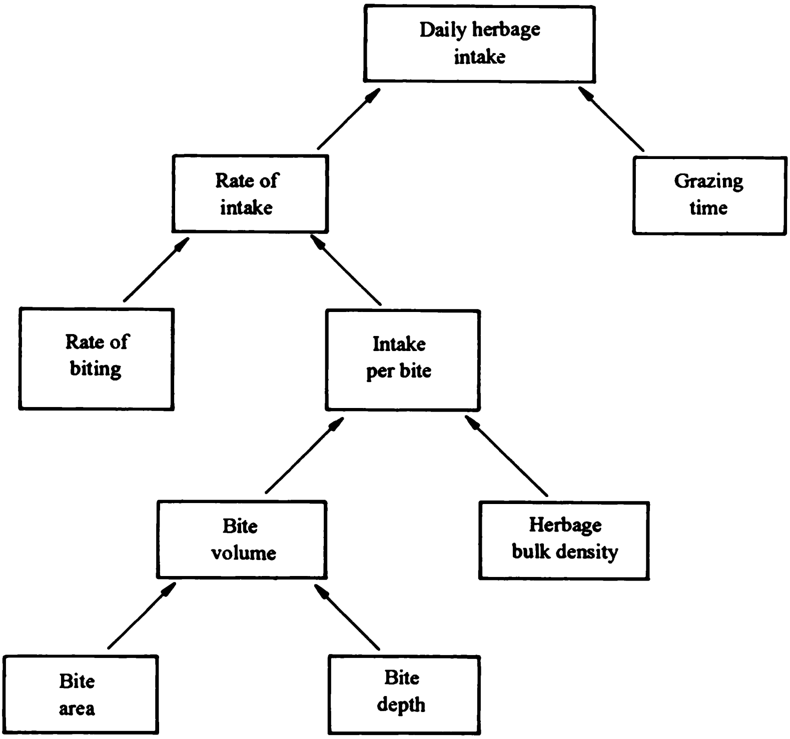

Figure 2. Components of ingestive behavior.

on the animal. Furthermore, although it is probably reasonable to consider change in grazing time as an attempt by the animal to compensate for the effect of sward conditions on IB, it is very likely that RB is usually affected directly by sward variables (Hodgson, 1982a). However, this interpretation requires a careful definition on the act of biting.

A "bite" may be defined as the act of tearing a mouthful of herbage from the sward. It does not include the manipulative jaw movements that gather herbage into the mouth and then chew it before it is swallowed (Hodgson, 1982b). In this case, the ratio of manipulative to biting jaw actions increases with increasing sward height (Chambers et al., 1981) in both cattle and sheep. However, if all manipulative and tearing jaw movements are defined as bites, then the effect of sward conditions on RB is likely to be less clear-cut. There is a need for more general agreement about the definition of this particular variable.

Despite the conceptual convenience of this view of ingestive behavior, caution is needed in making assumptions about some of the theoretical behavioral limits. For example, Stobbs' concept of a "critical bite size" (Stobbs, 1973a) may have been misinterpreted and, generally speaking, daily intake will tend to increase progressively with increasing IB to high levels (Hodgson, 1982a). Furthermore, although the effective upper limit of grazing time appears to be about 14 hours per day, the upper limit of grazing bites per day is not certainly known (Arnold, 1981; Stobbs, 1975b).

Sward Structure and Herbage Intake

Stobbs (1975b) identified low total herbage bulk density or leaf bulk density and low leaf-to-stem ratio as major limitations to IB and daily herbage intake in animals grazing tropical swards. If we pursue the mechanistic view of ingestive behavior, IB is the product of bite volume and the bulk density of the herbage occupying that volume (Figure 2). This provides a basis for rationalizing the effect of bulk density on IB, other things being equal. This is a reasonable concept to pursue in the case of relatively short, leafy swards where selection is limited, but it is less realistic in tall swards or where selection is important.

In the first case, bite volume can itself be viewed as the product of bite area and depth in the pasture (Figure 2). The work of Barthram (1981) shows that, in vegetative temperate swards at least, the depth of the grazed horizon (and therefore, presumably, bite depth) is directly related to the height of the sward canopy and is limited by the depth of the stratum containing, principally, leaf tissue (Hodgson, 1982a). In these circumstances, IB and rate of intake are closely related to sward surface height over the range of 4 to 40 cm and, apparently, largely independent of herbage density (Hodgson, 1982a).

This relationship holds both within and between temperate swards of perennial ryegrass (Hodgson, 1981b) and indigenous grasses (Forbes, 1982). However, the influence of sward height on IB is more tenuous in comparisons between tropical swards where components of total herbage density and leaf density assume great importance (Ludlow et al., 1982; Stobbs, 1973a). Variations in herbage bulk density would normally be expected to influence IB directly, and the absence of an effect in the studies on temperate swards may have been the result of the dominant effect of correlated changes in sward height. The influence of bulk density per se on IB may depend on the range of values examined (Figure 3), but there is little evidence from which to develop a general view of the relationship. The different patterns of response in IB to variations in sward height and density in tropical and temperate regions have been explained in terms of the usually greater height and lower density of tropical swards (Stobbs, 1975b; 't Mannetje and Ebersohn, 1980). However, the actual ranges of values of sward height and density observed in tropical and temperate swards in which behavioral responses have been measured do not appear to support this suggestion (Table 1), and it may be necessary to seek other explanations. One possibility is the usually greater robustness and larger unit size of leaves and stems in tropical than in temperate grasses (Dirven, 1977).

The sward characteristics affecting bite area have not been investigated at all. Bite area and bite volume are both likely to be directly related to mouth dimensions within animal species, and

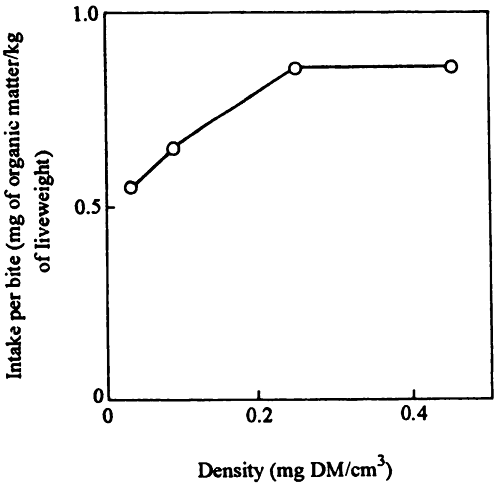

Figure 3. The relationship between total herbage bulk density and intake per bite. (Adapted from Stobbs, 1975a).

variations between species in the use of the lips and tongue to accumulate herbage for biting will influence both variables.

In the second case, animals tend to bite off individual leaves or groups of leaves and draw them into the mouth for chewing. Concepts of the ground area of a bite and of herbage bulk density probably have less meaning in these circumstances than the dimensions of individual leaves and the ease with which individual leaves or groups of leaves can be prehended for biting and manipulated for swallowing. The sward variables affecting these characteristics are complex, particularly when they are linked to the factors influencing selection between leaf and stem or live and dead material.

It is clear that canopy structure can influence intake directly, through its impact on the ease with which herbage can be ingested, even where selection between the various components of the sward is absent or negligible. Where selection is active, there is an additional effect in which the disposition of the preferred components within the sward canopy affects the ease of selection and hence both the composition of the diet and the rate of herbage intake.

Table 1. Mean values[a] and variation in the physical characteristics of tropical and temperate swards and in the herbage intake per bite of grazing cattle.

Physical characteristic	Tropical swards[b]	Temperate swards	
		Sown[c]	Indigenous[d]
	(n = 31)	(n = 32)	(n = 12)
Herbage mass (t DM/ha)			
Total	4.1(2.12)	4.0(1.92)	6.4(4.70)
Green leaf	2.0(1.15)	1.5(0.60)	1.2(0.49)
Proportion of green leaf	0.5(0.19)	0.5(0.19)	0.2(0.12)
Surface height (cm)	39(28)	34(21)	26(12)
Average bulk density (mg/cm^3)			
Total	1.2(0.79)	1.3(0.36)	3.0(2.20)
Green leaf	0.5(0.27)	0.6(0.30)	0.5(0.24)
Surface bulk density (mg/cm^3)			
Total	0.2(0.20)	0.3(0.19)	—
Green leaf	0.08(0.07)	0.15(0.07)	—
Intake per bite (g OM/kg LW)	1.0(0.73)	2.0(0.98)	0.7(0.22)

a. Mean values with standard deviation in parentheses.

b. Chacon and Stobbs, 1976; Hendricksen and Minson, 1980; Ludlow et al., 1982; Stobbs, 1973a, 1973b, and 1975a.

c. Combellas, 1977; Forbes, 1982; Hodgson and Jamieson, 1981; Jamieson and Hodgson, 1979.

d. Forbes, 1982.

The intensity of selection exhibited between the leaf and stem components of a mixed sward canopy will depend, on the one hand, on the preference contrasts between the alternative components of the sward and, on the other, on the distribution of the components and the degree to which they are intermingled within the canopy. The preferences exhibited between tropical legumes and grasses, and between the leaf and stem components of both, need no emphasis here (Gardener, 1980; Hendricksen and Minson, 1980; Stobbs, 1977). The contrast in selection between leaf and stem appears to be more extreme in tropical than in temperate grasses, although it is not always clear to what extent this reflects differences in stages of maturity rather than differences at similar stages of maturity. It may reflect, in part, the more rapid and complete lignification of the stem in tropical grasses (Minson, 1981) and, in part, the usually more robust nature of the stem which is associated with the potentially much lower tiller population densities and much greater tiller weights in tropical than in temperate species (Dirven, 1977). Whatever the reason, the magnitude of preference contrasts suggests that, where stem development is inevitable, then there may be some merit in a plant structure which allows selection to be exercised relatively easily.

The process of selection will normally result in enhanced concentration of nutrients in the herbage collected. It is also likely, other things being equal, to reduce both intake per bite and rate of biting, and the ultimate effect on nutrient intake will depend on the balance between these effects. There is no clear indication of the way in which sward conditions might influence this balance. There is evidence that the grazing strategies adopted by different animal species may favor the maintenance of either nutrient concentration or rate of intake (Forbes, 1982; Jarman and Sinclair, 1980).

It would be useful to know more about the variation in these characteristics within animal species.

So far, attention has been concentrated primarily on grazing in simple grass swards and on selection between the morphological components of single grass species. Discussion of the factors influencing selection within mixed grass or grass-legume communities introduces an additional set of considerations which are difficult to quantify because so little is known, except in general terms, about the factors influencing palatability in pasture plants. There is much scope for research into these factors and for manipulating them by genetic or biochemical means. However, although some notable successes have been achieved (Marten et al., 1973) progress is likely to be very slow because of the complexity of the topic (Arnold, 1981). The marked seasonal fluctuations in preference between legumes and grasses growing in mixed tropical swards are particularly intriguing (Gardener, 1980; Stobbs, 1977) and, although the importance of protective mechanisms for legumes growing in these mixed swards is acknowledged, there is surely scope for developing a better understanding of the factors involved.

Stobbs (1975b) emphasized the need to concentrate attention on conditions in the surface horizons of the sward which are most accessible to the grazing animal, rather than on average conditions in the sward as a whole. He demonstrated the marked changes in bulk density and morphological composition from top to bottom of the sward canopy, and stressed the importance of the associated changes in the nutritive value of herbage in the different horizons (Figure 4). This is a very reasonable view, particularly because bulk densities in the surface strata of a sward can be very low indeed (Stobbs, 1975b). However, such a view is only tenable when animals are known to concentrate their grazing activity close to the sward surface and this is unlikely to be strictly true, except in the case of swards with a dense leaf horizon. In order to understand animal responses properly, there is a need to describe the structure of the whole sward profile in some detail, not only of the vertical distribution of the herbage and its morphological components, but also of the dimensions, alignment, and association of individual leaves and stems. It is doubtful whether techniques exist to make this possible in most circumstances, and there is much room for developing improved techniques of sward description.

In the foregoing discussion, sward canopy structure has been considered in the vertical plane, but in most circumstances it is virtually certain that animal responses will also be heavily conditioned by variations in canopy structure and composition in the horizontal plane. This will clearly be the case in relation to the grazing of, for instance, brunch grass swards or open shrub communities. Experimental investigation of these circumstances is difficult because

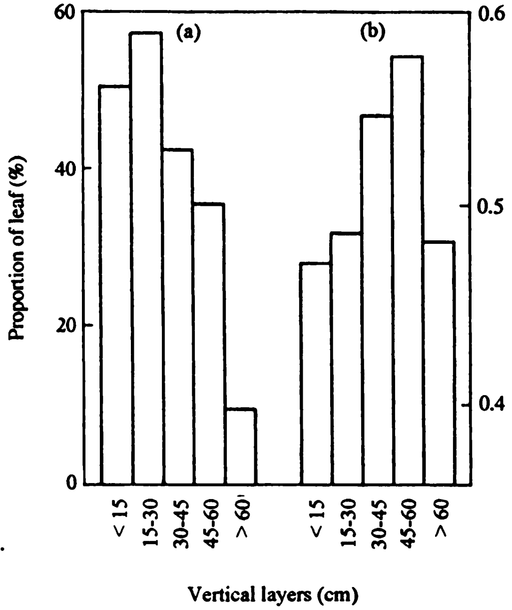

Figure 4. Variation in (a) leaf proportion and (b) in vitro digestibility with height within the canopy of an 8-week regrowth of a *Chloris gayana* sward. (Adapted from Stobbs, 1973b).

of the problems in describing canopy structure and the distribution of individual components in three dimensions (for example, Dale, 1978), and the virtual impossibility of measuring animal activity in relation to specific sites within a plot.

Before becoming too involved in selection programs that incorporate sward structure as an important component, it is necessary to be certain which components of that structure are of primary importance. Variations in sward surface height, total herbage bulk density and leaf bulk density, and leaf-to-stem and live-to-dead ratios have all been associated with variations in herbage intake or the components of intake (Hodgson, 1982a; Stobbs, 1975b). However, the inevitable correlations between the sward variables in most studies make objective evaluation of cause and effect extremely difficult ('t Mannetje and Ebersohn, 1980). There is a need for a much more rigorous definition of the responses to individual variables, and the important patterns of interaction between them, in order to put selection for structural characteristics on a sound footing.

Sward Structure and Herbage Utilization

The sward characteristics which influence herbage intake are also likely to have a substantial impact on the efficiency of herbage utilization. By definition, at any given stocking rate, plants with high intake characteristics will have higher utilization efficiency, that is,

$$\frac{\text{consumption per unit area}}{\text{growth per unit area}}$$

than plants with low intake characteristics. The primary factors contributing to high utilization efficiency, as well as to high intake, are likely to be leafiness and high leaf density, and fine leaves and stems with limited structural tissue.

On a sward basis, efficient utilization is normally desirable in its own right, although the importance attached to it is presumably conditioned by the feed reserves normally carried in conventional systems and the risks of abnormal periods of limited or no herbage production. In these circumstances, feed reserves are clearly of strategic importance, but they can also interfere with new plant growth and dilute the nutritive value of the diet by interfering with the selection of new leaf in the subsequent growing season (Hodgson and Grant, 1980). The use of fire to clear unutilized residues at the end of the dry season helps to resolve this conflict, although not always without cost to the species balance of the sward. The characteristics contributing to high utilization efficiency in favorable climatic conditions can also contribute to excessive losses, through senescence and decomposition in wet conditions, for example, and through wind shatter after drying off. Thus, assessment of desirable sward characteristics depends, to some extent, on the range of climatic conditions to which the plants are likely to be exposed.

In mixed swards, preferred species will be utilized more efficiently than other species, sometimes to the detriment of their future growth and persistence (Watkin and Clements, 1978), particularly in tropical swards where the preference contrasts are often substantial and where environmental stresses can be severe. In general terms, preference is likely to be linked to leafiness (Arnold, 1981) and, particularly during the dry season, to the retention of live leaf. The practical value of improvements in these characteristics may only be apparent, therefore, in circumstances where it is possible to maintain a balance in intake characteristics across the constituent species or varieties in a sward, or where there are technical advantages in grazing very simple swards with one or a few constituent varieties. Any attempts to select for improved palatability must clearly be carried out against the background of a clear concept of the plant associations and the management framework within which the improved material is likely to be placed. This is likely to be particularly important in the case of the tropical legumes, some of which are also sensitive to grazing because of their trailing growth habit ('t Mannetje and Ebersohn, 1980).

Selection of preferred plant species or morphological components will be more difficult in a closed canopy with herbage of high bulk density made up of relatively small plant units than in an open canopy with relatively large units. Thus, selection for high leaf density will probably result in a reduction in the balance of selection between constituents of the sward, even with no change in preference rating, unless genotypic increases in leaf density are accompanied by greater stratification of plant species.

Protection of the growing point and young leaves from grazing animals by the surrounding mature tissue can have an important impact on production, particularly in tall tropical species (Dirven, 1977). Selection for leafiness and finer leaves and stems will reduce this protective element, but will presumably tend to reduce sensitivity to defoliation because of the larger number of smaller tillers which result (Dirven, 1977). Protection of growing points may be particularly important in shrub and tree species, where variations in branch and twig structure and in leaf arrangement would be expected to have marked effects on the ease with which animals can penetrate the foliage. All of these factors could be considered to be negative intake characteristics but, if they prevent excessive grazing of individual plants at critical phases of growth, they may make a positive contribution to herbage production and consumption per unit area.

Selection for Sward Structure

There is now little question that herbage intake can be substantially affected by a range of characteristics which have to do with the structure of the sward canopy and the distribution of the plant components within it. These characteristics can only be identified in grazing experiments but, once identified, the aspects of plant morphology which contribute to sward structure should be easy to measure and classify at a very early stage in any selection program.

There is less certainty about the exact nature of the characteristics in question and their relative importance in specific circumstances. There is an urgent need for a clearer understanding of the factors involved because, until this is achieved, any selection program involving structural characteristics is bound to have a degree of uncertainty attached to it. If progress is to be made, there is a need for more refinement and standardization of concepts and techniques than has so far been achieved, and for rigorous testing of concepts in critical research studies.

In considering the factors likely to contribute to increased herbage intake and utilization, it is important not to lose sight of the fact that the same factors may increase herbage losses in adverse climatic conditions and, in mixed swards, may increase the susceptibility of "improved" species to excessive defoliation. The balance between advantage and disadvantage will often be a fine one and needs to be considered carefully. Wastage per se may not be of great consequence in areas of adequate rainfall where the quantity of feed produced is seldom a limiting factor, but its consequences may be serious in areas of seasonal feed shortage or in conditions where dead herbage interferes with access to new green feed.

The topic of grass-legume balance in the sward and in the diet of grazing animal is now, rightly, a major issue. Current evaluation programs are yielding benefits, although it is perhaps questionable whether there is more than a superficial understanding of the factors determining animal reactions. This is clearly an area requiring substantial research effort and, given the comprehensive nature of its own legume and grass collections, CIAT is in a unique position to promote such work.

The initial screening of accessions for physical and morphological characteristics should make few additional demands on existing resources, although it may be argued that selection should at least be based on observations under sward conditions and under grazing management. Evaluation of animal responses in terms of diet selection or ingestive behavior should be possible on plots of limited area (Hodgson, 1981a), depending on the measurements involved and the degree to which common grazing of several plots is acceptable. Even measurements of herbage intake can be contemplated for cattle on plots of 0.5-1.0 ha. These observations are short-term in nature and require standardized conditions, but they are essential to identifying parameters important to evaluation programs. Observation of plant responses to grazing are feasible on plots of similar size, although this may place unacceptable constraints on feasible grazing managements.

Ultimately, there is always some uncertainty about the degree to which the assessment of a particular pasture is likely to be influenced by the patterns of change with time in herbage mass, botanical composition, plant morphology, and sward structure which occur as a consequence of a specified set of management rules. This is likely to be a much more serious consideration for tropical swards than it would normally be for temperate swards. Although there is clearly merit in carrying out evaluation procedures within the context of managements which are normal in the area of potential release, there are grounds for concern about the implications of this approach to the progressive nature of a research and evaluation program. In particular, there must be doubts the merits of fixed stocking-rate managements which take no account of the potential for cushioning supply and demand imbalances by the use of limited areas for special-purpose crops. Management decision rules based on specified patterns of variation in sward conditions provide a much firmer basis for the interpretation of observed sward and animal responses. Although it is recognized that this approach requires preliminary evidence of a general nature on plant responses to sward management, it is important to the accumulation of a body of information and understanding which is vital to the development of a flexible and progressive plant selection and evaluation program.

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Chapter 4

Edaphic and Climatic Factors that Affect Intake and Selectivity of Forage Plants Under Grazing

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Abstract

The effect that fertilization and season have on intake and acceptability of forage species is reviewed. From this review one concludes that a positive effect can be achieved on the intake and acceptability of some grasses and legumes by fertilizing with superphosphate or with calcium and sulfur. Some of the papers reviewed associate this effect with the correction of mineral deficiencies, with changes in plant growth and morphology, and with the reduction of certain chemical components such as tannins. The season markedly influences the selection animals make in legume-grass associations, the selection being more toward legume in the dry season when the grass loses its quality, as compared with the wet season when grass is preferred.

Preference tests should be included in the legume evaluation sequence, so to detect, early on, those species or accessions with palatability problems. Such tests would also help determine the possible influence of fertilization on acceptability. Finally, the effect of season on animal selectivity on grass-legume associations should also be evaluated under small-plot grazing. This would help define more clearly the type of management that an association should have in a given ecosystem.

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Introduction

Arnold (1981), in a recent review on this subject, outlined very well the factors that interact in the selection of diet by a grazing animal. In summary, characteristics of the animal's reflexes and senses (e.g., sight, smell, touch, and taste) and pasture characteristics (e.g., species present, their relative availability, and their physical and chemical attributes) affect selection of diet by a grazing animal. However, factors associated with the environment where the pasture grows (e.g., soil type and fertility), and factors related to the animal (e.g., species, individuality, physiological condition, grazing habit, and previous experience), can modify the diet that an animal selects.

Because this paper does not discuss the factors that may influence selectivity under grazing, the reader is referred to literature dealing with these factors (Arnold, 1981; Heady, 1964; Hodgson, 1981). This paper reviews evidence on the effects that fertilization and season have on intake and selectivity of forage species with emphasis on legumes. Also discussed are some implications of the change in degree of acceptability of certain forage species—because of climate and soil fertility—on developing methodologies to evaluate forage species under grazing.

Effect of Fertilization on Intake and Selection of Forage Species

The beneficial effect of fertilizer application, such as superphosphate, on grass-legume associations has been measured in terms of increases in the proportion of legume in the pasture (Shaw, 1978), changes in the chemical and botanical composition of the pasture (Ritson et al., 1971), and increases in animal production (Edye et al., 1971). In general, increases in animal production as a result of superphosphate application have been related to increases in the proportion of available legumes (Evans and Bryan, 1973) and to correction of mineral deficiencies, particularly phosphorus (Edye et al., 1971).

However, there is evidence that fertilization with superphosphate produces a direct effect on the intake of some forage species.

The effect of fertilization with superphosphate, sulfur, and calcium on intake and selectivity of grasses and legumes is reviewed: Playne (1972) studied the effect of fertilization with superphosphate on the intake of *Heteropogon contortus* and *Stylosanthes humilis* by sheep in cages (Table 1). For the grass, the application of 125 kg/ha per year of superphosphate resulted in a significant increase in intake of dry matter that was associated with an increase in S (0.07% to 0.14%) and P (0.054% to 0.084%) in the vegetative tissue. For *S. humilis*, the same level of superphosphate did not significantly increase consumption, although there was an increase in S (0.14% to 0.18%) and P (0.097% to 0.164%) in the vegetative tissue. It is possible that, in the unfertilized legume, the level of S (0.14%) did not limit intake, because, according to Dawnes et al. ([1975], cited by Rees and Minson [1978]), the critical level of S for the animal is 0.1%.

Table 1. Effect of fertilization with superphosphate on the contents of calcium, phosphorus, and sulfur of *Heteropogon contortus* and *Stylosanthes humilis*, and on their intake by sheep.

Variable in the forage[a]	Level of fertilization[b]	Forage[c]	
		H. contortus	*S. humilis*
Calcium (%)	N 0	0.30	1.17
	N 1	0.31	1.15
	N 2	0.33	0.93
Phosphorus (%)	N 0	0.054	0.097
	N 1	0.084	0.164
	N 2	0.105	0.198
Sulfur (%)	N 0	0.07	0.14
	N 1	0.14	0.18
	N 2	0.15	0.20
Daily intake (g DM/kg$^{0.75}$)	N 0	38.8a	75.2d
	N 1	47.0b	76.3d
	N 2	43.5c	83.6d

a. Dry matter.

b. N 0 = None; N 1 = 125 kg; N 2 = 750 kg, respectively, of superphosphate/ha per year.

c. a, b, c = means are significantly different at $P < .05$; d = means are not significantly different at $P > .05$

SOURCE: Playne, 1972.

The effect of fertilization with superphosphate on legume intake has also been studied by Hunter et al. (1978) who, in addition, evaluated the effect of supplementing the animal with S. The intake and digestibility of *S. guianensis* by sheep in a cage were greater than those by the control, where the animals were offered fertilized legume (250 kg/ha of superphosphate), with S supplement being intermediate (Table 2). In this study, the correction of a S deficiency was, without doubt, the main effect produced in *S. guianensis* by fertilization with superphosphate, a result that coincides with those obtained by Rees and Minson (1978) with *Digitaria decumbens*. Nevertheless, other factors associated with fertilization, such as increase in nitrogen, probably also contributed to increasing intake of the fertilized legume. With regard to forage intake, Rees and Minson (1978) indicate that fertilization with S has as its primary effect the alleviation of a deficiency when it exists—which is also achieved, as their work with *D. decumbens* shows, by supplementing the animal with S (Table 3) However, secondary factors associated with S fertilization exist, which can influence intake through changes in growth rate, in the leaf-stem relationship, and in the chemical structure of the plants (Table 4).

Table 2. Effect of sulfur supplement and fertilization with superphosphate on the digestibility of *Stylosanthes guianensis* and its intake by sheep.

Variable	Control[a]	Fertilization with superphosphate[b]	Sulfur supplement[c]
Digestibility (%) of dry matter	20.3a ± 0.3	35.2b ± 0.7	29.6c ± 2.0
Intake of dry matter (g/animal per day)	142a ± 11	628b ± 12	202c ± 8.0

a. Fertilization at establishment, using 120 kg/ha of superphosphate; a, b, c = means differ significantly at $P < .1$.

b. Fertilization with 250 kg/ha of superphosphate and 120 kg/ha at establishment.

c. Supplement was 0.5 g of sulfur as sulfate.

SOURCE: Hunter et al., 1978.

Table 3. Effect of sulfur supplement and fertilization on the digestibility of several fractions of *Digitaria decumbens* and its intake by sheep.

Forage variable	Sulfur supplement (g/day)	Treatment[a]		Year
		Control	Fertilization	
DM digestibility (%)	0	53.3b	54.1	1971
	0.06	56.9c	54.1	1972
Hemicellulose digestibility (%)	0	57.8b	61.6	1971
	0.06	62.9c	62.8	1972
Digestibility of cellular contents (%)	0	61.2d	56.8e	1971
	0.6	62.2	56.2	1972
Daily DM intake ($g/kg^{0.75}$)	0	44.0b	48.6	1971
	0.6	53.6c	50.1	1972

a. For the control, 0 and 66 kg of S/ha in 1971 and 1972, respectively; for fertilization, 0 and 116 kg of S/ha in 1971 and 1972, respectively. b, c = Values differ because of S supplement. d, e = Values differ because of S fertilization.

SOURCE: Rees and Minson, 1978.

Table 4. Effect of sulfur fertilization on forage production and chemical composition of *Digitaria decumbens*.

Variable in the forage	Treatment		
	Control	Fertilization	Significance
Production (kg/ha)	4040	5280	**
Proportion of leaves (%)	15.00	21.60	**
Sulfur (%)	0.10	0.16	***
Phosphorus (%)	0.23	0.21	NS
Calcium (%)	0.46	0.49	NS
Neutral detergent fiber (%)	65.60	67.80	NS
Acid detergent fiber (%)	36.10	38.50	**
Hemicellulose (%)	29.40	29.20	NS
Cellulose (%)	30.30	31.10	NS
Lignin (%)	5.90	7.40	**

** = Significant $P < .01$.
*** = Significant $P < .001$.
NS = Not significant $P > .05$.

SOURCE: Rees and Minson, 1978.

Literature on the effects of calcium fertilizer on forage quality is scarce. Studies with legumes from temperate zones indicate that adding Ca to the soil causes an increase in protein content in *Lespedeza* hay, resulting in greater weight gains by sheep (Smith and Hester, 1948). More recently, Rees and Minson (1976) found that when fertilizing *D. decumbens* with Ca, the intake and digestibility of dry matter and hemicellulose of the forage increased as did the concentration of Ca in the vegetative tissue (Table 5). Contrary to the findings with S, supplementing the animal with Ca did not produce increases in intake or digestibility, which suggests that the effect of Ca on intake was caused by changes in the chemical structure of the plant and/or by an increase of Ca in the diet. However, in another study with *Panicum maximum* in an acid and infertile soil, increases in digestibility resulting from applying Ca could not be related to the internal chemical changes in the plant such as in structural carbohydrates, but, rather, was related to changes in plant morphology, for example, in a greater production of leaves (Rolando, 1981).

Table 5. Effect of animal calcium (Ca) supplement and pasture fertilization with Ca on the digestibility of several fractions of *Digitaria decumbens* and its intake by sheep.

Variable in the forage	Animal Ca supplement (g/day)	Pasture treatment		
		Control (no Ca)	Fertilization (760 Ca kg/ha)	Difference
DM digestibility (%)	0	45.8	48.0	**
	1.4	45.2	47.2	**
Hemicellulose	0	52.1	56.1	**
digestibility (%)	1.4	50.8	55.1	**
Intake ($g/kg^{0.75}$	0	39.4	43.2	**
per day)	1.4	38.2	43.2	**

** Significant differences between the control and fertilization ($P < .01$).

SOURCE: Rees and Minson, 1976.

The effect of superphosphate application on the selection of forage species under grazing has been studied by McLean et al. (1981) in legume-native grass associations, using legumes such as *S. humilis, S. hamata, S. scabra,* and *S. viscosa.* As a result of fertilization, the proportion of legumes in the available forage doubled, but the quantity present in the diet quintupled (Table 6). This increase in legume selectivity was not related to the greater legume availability because of fertilization. This is shown by the lack of correlation ($r = .13$, $P > .05$) between the index of relative selection (percentage of legume in the diet/percentage of available legume) and the percentage of legume in the pasture. Superphosphate fertilization did not produce an increase in the concentration of nitrogen or phosphorus in the tissue of the forage available in the pastures. According to McLean et al. (1981), this indicates that the greater selection of fertilized legume may have been associated with the Ca and S of the superphosphate applied.

Other studies exist in which attempts have been made to relate soil fertility with intake of legumes, particularly of those which contain tannins as, for example, *Lespedeza cuneata* (southern United States). This legume is characterized by its adaptation to low-fertility soils and by its ability to produce regrowth under drought conditions. However,

Table 6. Effect of superphosphate fertilization on the availability of legume forage and on the proportion of legumes selected by esophageal-fistulated cattle grazing associations of native grasses with *Stylosanthes*.

Treatment[a]	Legume available as forage (%)	Proportion of legume selected (%)	Legume selection index[b]
Without fertilization	24 ± 2.6	12 ± 3.4	0.5 ± 34
With fertilization	45 ± 2.5	58 ± 5.9	1.3 ± 31
Difference	**	**	**

a. Fertilization with 100 kg/ha of superphosphate at establishment and 25 kg/ha per year as maintenance.

b. Selection index = (selected legume)/(available legume).

** Significant differences at $P < .01$.

SOURCE: McLean et al., 1981.

it is not well accepted by animals, probably because of its high tannin contents, as indicated by studies with progenies of *L. cuneata* having different tannin contents (Donnelly, 1954; Wilkins et al., 1953). Wilkins found that voluntary intake of *L. cuneata* genotypes with 4.8% of tannins was 72% higher than the intake of genotypes with 12% of tannins.

The tannin content of *L. cuneata* has been associated with soil fertility. Casual observations have suggested that animals consume *L. cuneata* more avidly when it is fertilized, apparently because tannin contents are reduced (Wilson, 1955). Other research has shown that most variations in tannin contents in *L. cuneata* result from differences in soil characteristics (Stitt et al., 1946), with tannin contents being greater in low-fertility soils. Increments in polyphenols have been associated with nitrogen and phosphorus deficiencies in the soil (Davies et al., 1964) and with potassium deficiencies (Wilson, 1955).

The importance of the *L. cuneata* studies lies in the fact that some legume tribes such as Hedysareae, have a large number of species which contain tannins (Marshall et al., 1979). Tannins have also been detected in different concentrations in different *Desmodium* species (Hutton and Coote, 1966; Rotar, 1965). For example, *Desmodium tortuosum* has low levels of tannins, whereas *D. intortum* cv. Greenleaf (Ford, 1978) and *D. ovalifolium* CIAT 350 (CIAT, 1980) have higher levels of tannins. *Desmodium ovalifolium* CIAT 350 is a promising legume for the acid low-fertility soils of Latin America, because of its great productivity and its ability to associate with aggressive grasses (Grof, 1982). Nevertheless, as occurs with *L. cuneata*, its acceptance by cattle is low, which may possibly be associated with its high tannin contents.

Given the favorable characteristics of *D. ovalifolium* CIAT 350, high priority was given to investigating factors associated with its low acceptability to the grazing animal. At the Centro Nacional de Investigaciones Agropecuarias (CNIA) at Carimagua, in the Colombian Eastern Plains (Llanos Orientales), the possible interaction of soil fertility with tannins and selectivity of *D. ovalifolium* were studied. The results of this study (Figure 1) indicated that maintenance fertilization with P and Ca or with P,

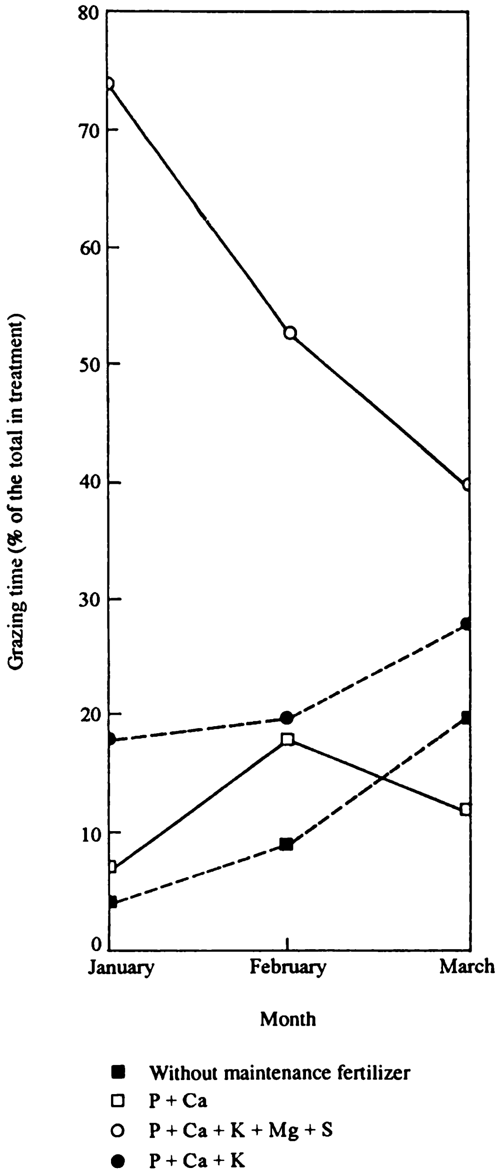

Figure 1. Distribution of the animals' grazing time (%) on *Desmodium ovalifolium* CIAT 350 (CIAT, 1981).

Ca, and K did not increase preference for the legume in relation to the control. However, by adding P, Ca, K, Mg, and S, preference increased. The increased acceptance of *D. ovalifolium* CIAT 350 under more complete fertilization was associated with a greater production of biomass, a reduction of tannins (equivalent catechins), and an increase in N, S, and K in the foliar tissue (Table 7). Later data from a follow-up study indicated that S may be the critical element that affected preference for *D. ovalifolium* CIAT 350 under conditions found in the Colombian Llanos.

Effect of Season on Selection of Forage Species

Since techniques for fistulating animals in the esophagus were introduced, considerable information on selection of pasture by grazing animals has been obtained. Studies where the selectivity of

Table 7. Effect of fertilization on the production and chemical composition of *Desmodium ovalifolium* CIAT 350.

Variable in foliar tissue[a]	Fertilization treatment			
	Control[b]	P + Ca[c]	P + Ca + K[c]	P + Ca + K + Mg + S[c]
Available forage (kg/ha)	3432a	3844a	3424a	5680b
Tannins (equivalent catechins)	37.5a	37.0a	34.1ab	28.7b
Nitrogen (%)	1.99a	2.01a	2.09a	2.59b
Mineral contents				
P (%)	0.118a	0.133ab	0.130ab	0.140b
Ca (%)	1.05	1.13	1.08	1.03
K (%)	0.617a	0.643b	0.707c	0.740d
Mg (%)	0.245	0.239	0.232	0.246
S (%)	0.094a	0.102a	0.121b	0.145c

a. Dry matter.

b. Fertilization at establishment was 46 kg of P; 259 kg of Ca; 43 kg of K; 11 kg of Mg; and 22 kg of S per ha, May, 1978. a, b, c, d = means are significantly different at $P < .05$.

c. Maintenance fertilization was 26 kg of P; 117 kg of Ca; 37 kg of K; 22 kg of Mg; and 44 kg of S per ha, August, 1980.

SOURCE: CIAT, 1982.

legumes in grass-legume associations has been measured are reviewed here in terms of season. Hunter et al. (1976) studied selectivity by steers grazing a native grass-*S. humilis* association in a region of Australia characterized by a dry, tropical climate and an annual rainfall of 865 mm, 80% of which falls between December and March while the rest falls as occasional rain during the dry period (April to September). The results (Figure 2) indicated that the legume contributed considerably to the diet (30%) during the months of March, April, and May, which coincide with the end of the rainy season and the beginning of the dry season, when the quality of the associated grasses is reduced. In the following months—and even when the legume constituted 34%, on the average, of the forage offer—the presence of the legume in the diet was minimal.

In the same region of Australia, Gardener (1980) studied selectivity by the animal grazing an association of native grasses with *S. hamata*. The legume made an important contribution to the diet of the animals for almost five months, during March to July (Figure 3), once again a period that coincides with the dry months of the year.

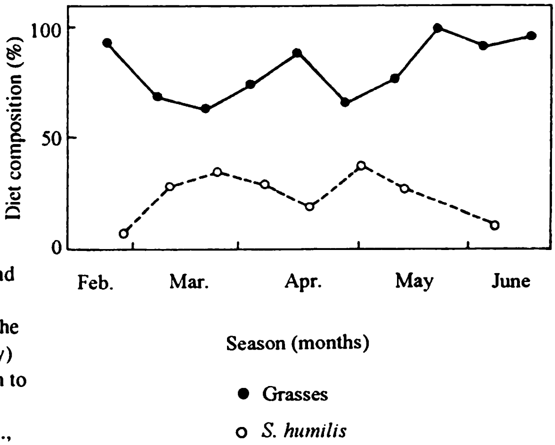

Figure 2. Selection of grasses and *Stylosanthes humilis* under grazing during the rainy season (February) and dry season (March to June) in Landsdown, Australia (Hunter et al., 1976).

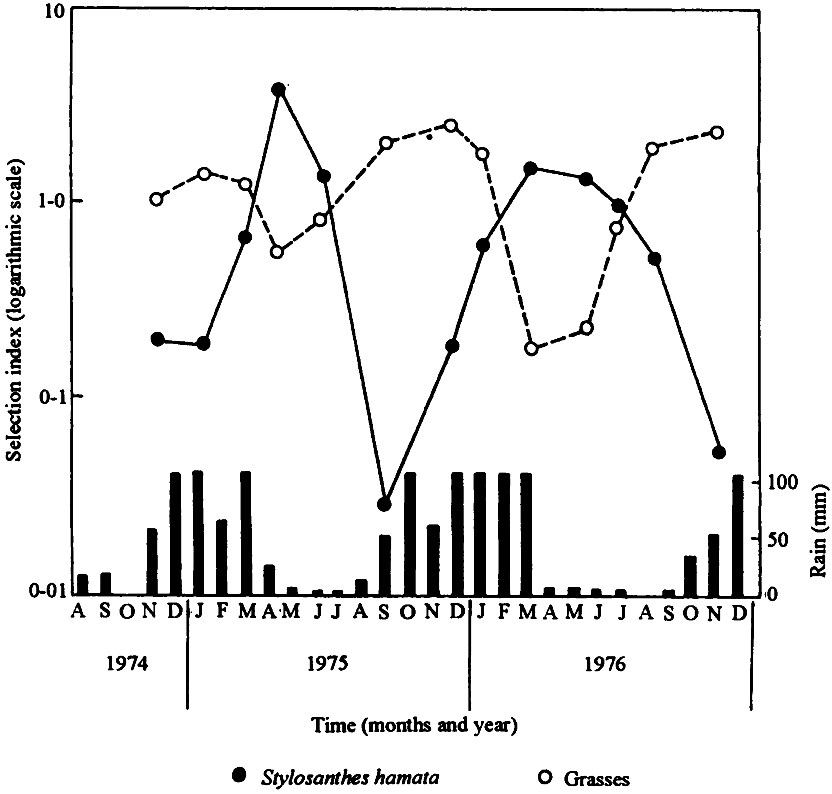

Figure 3. Selection index (forage in diet (%)/available forage (%)) during a period of 25 months, in a native grass-*Stylosanthes hamata* association, Landsdown, Australia (Gardener, 1980).

In those zones of Australia with a monsoon climate (Katherine, Northern Territory)—and where 80% of the annual rainfall also occurs between December and March—the selection of legumes in associations of a grass with several *Stylosanthes* species was greater in the dry season (McLean et al., 1981). Work conducted by Stobbs (1977) in a subtropical region of Australia (Samford, southeastern Queensland) indicated a greater selection of *Macroptilium atropurpureum* cv. Siratro in association with *Setaria anceps* cv.

Nandi in autumn, the beginning of the dry season, than in spring, the rainy season (Table 8). The quantity of legume selected by the animal was related to its relative palatability in different seasons of the year and to its availability in the pasture.

The effects of season on legume selection have also been studied in grass-legume associations at Carimagua, Colombian Llanos (CIAT, 1981). Measurements taken with esophageal-fistulated animals during the rainy months (April to October) and dry months (November to February) in associations of *Andropogon gayanus* cv. Carimagua 1 with ecotypes of *S. capitata* and with *Pueraria phaseoloides* indicated that the legume was selected in a greater proportion in the dry season (Figure 4). In addition, it was observed that the presence of legume in the selected diet was influenced by the proportion of legume in the available forage. Complementary studies on selectivity in grass-legume associations on small plots of the CIAT-Quilichao substation have indicated an increase of legume in the diet as the number of days of occupation increased in a rotational grazing system. This contributed toward maintaining an adequate level of protein in the diet (Figure 5). In these studies, the greater proportion of legume in the diet was associated with a reduction of protein contents in the

Table 8. Effect of season on the proportion of *Macroptilium atropurpureum* cv. Siratro in the pasture and in the diet of esophageal-fistulated cattle at two stocking rates.

Season	Stocking rate (animals/ha)	Proportion of legume (%)	
		Available forage (green portion)	Selected forage (dry matter)
Spring[a]	1.11	2	2
	2.96	6	3
Summer	1.11	18	9
	2.96	22	10
Autumn[b]	1.11	41	62
	2.96	51	73

a. Rainy season in Samford, southeastern Queensland, Australia.
b. Dry season.

SOURCE: Stobbs, 1977.

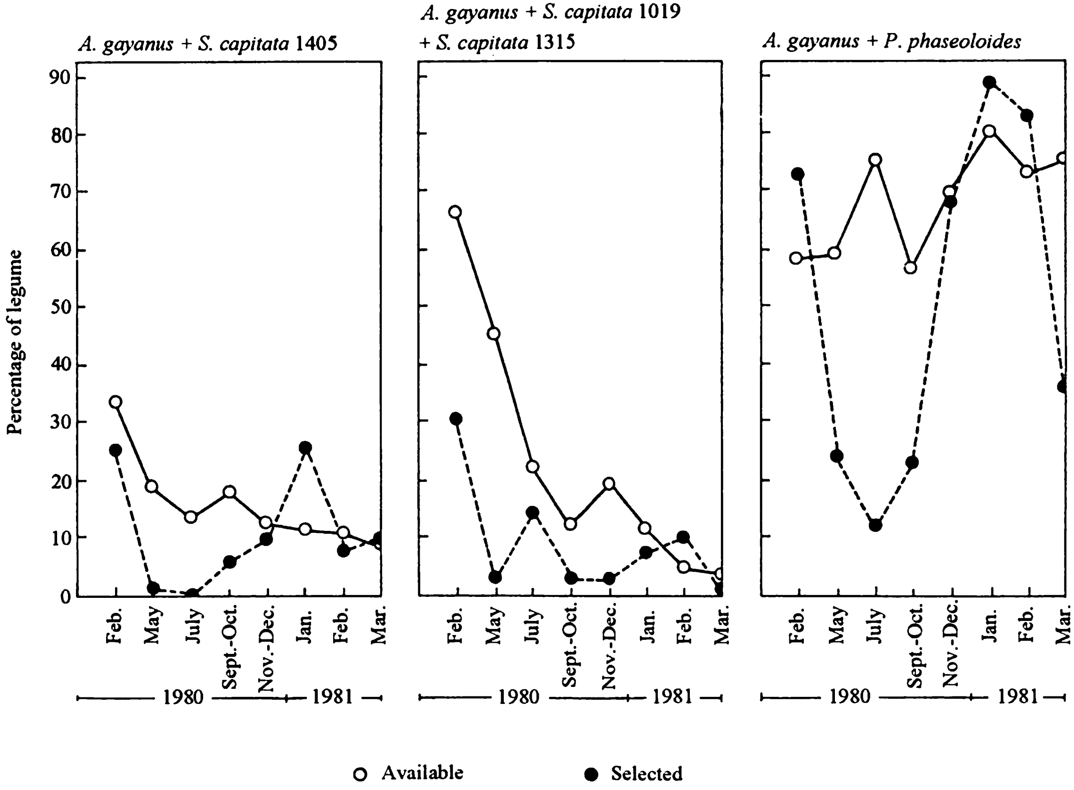

Figure 4. Proportion of legume available and selected by esophageal-fistulated steers in mixtures of *Andropogon gayanus* with ecotypes of *Stylosanthes capitata* + *Pueraria phaseoloides*, Colombian Eastern Plains (CIAT, 1981).

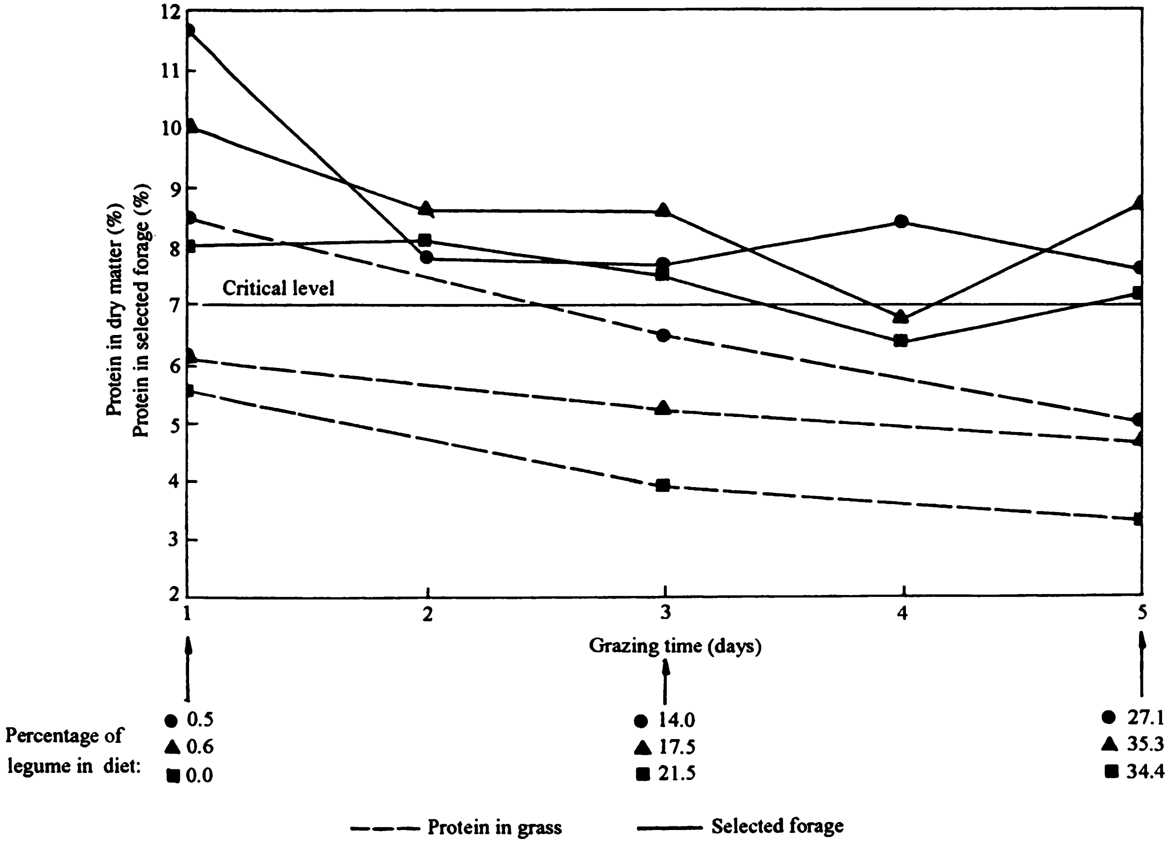

Figure 5. Protein contents in available grass and selected forage in an association of *Desmodium ovalifolium* with *Andropogon gayanus* + *Brachiaria decumbens* + *Panicum maximum* in common grazing every four (●), six (▲), or eight (■) weeks (CIAT, 1981).

available grass, suggesting that animals consumed legumes when the quality of the available grass diminished, as happens during dry periods of the year.

Germplasm Evaluation

Fertilization and acceptability of legumes

The increase in degree of acceptability to cattle of some forage species—and especially of certain legumes—through fertilization opens a new line of research in forage evaluation programs. This research would be justified with tropical legumes adapted to a determined ecosystem, but whose usefulness as forage plants might be limited because of problems of acceptability to cattle.

Some examples of tropical legumes that have problems of acceptability in different regions are *Indigofera hirsuta* and *Zornia brasiliensis* in the Colombian Llanos (O. Paladines and B. Grof, personal communication); *Calopogonium mucunoides* in the Cerrados of Brazil (CIAT, 1980); *C. caeruleum* in Puerto Rico (Warmke et al., 1952); *D. gyroides* and *S. scabra* cv. Seca in Quilichao, Colombia (CIAT, 1981); and *S. viscosa* in Australia (L. Reid, personal communication). Some of these legumes, and others with acceptability problems that are introduced into germplasm evaluation programs, should be evaluated under different fertilizer levels, particularly in ecosystems with low-fertility soils.

Palatability studies should be part of a germplasm-screening sequence, in order to detect, as early as possible, those species, particularly legumes, with serious problems of acceptability. However, such evaluation would be justified only for those legumes that have shown good adaptation to a given ecosystem.

To determine the degree of legume acceptability to the grazing animal, "cafeteria" type experiments could be implemented in several stages. The first stage would aim to determine the relative palatability of legumes of different genera, species, or ecotypes within species under the level of fertilization recommended for establishment of each material being tested. Legumes presenting palatability problems in these studies—even though exhibiting good attributes as forage plants—would pass to the second stage where animal preference for those legumes would be evaluated again under different levels of fertilization, ideally in association with grass. This second stage is to identify cause-effect relationships through the analysis, over several seasons, of volatile and nonvolatile chemical components.

It is conceivable that experiments to evaluate the palatability of forage species in the first stage will be limited by scarcity of seed. In such a case, preference studies could be carried out in plots where agronomic evaluations of germplasm have previously been made. It would therefore be important that the agronomic experiments be conducted in plots that allow grazing in several replications.

Season and legume acceptability

Based on the information reviewed, it is clear that season influences an animal's selection of legume. During the dry months of the year, when the grass sets seed and loses quality, the animals select more legume, with the corresponding favorable result in the diet's quality. However, during the rainy season, the low acceptability of certain legumes may mean legume dominance. It is possible, however, that competition between grass and legume is largely determined by the duration of the dry period, growth rate, availability of forage, grazing system, and stocking rate or grazing pressure. In ecosystems with little drought stress, management of grasses associated with well-adapted, aggressive, but relatively unacceptable legumes will probably require some form of rotational grazing to maintain the grass-legume balance over time.

In order to better visualize management strategies of grass-legume mixtures, it is important to use methodologies that allow the researcher to determine the effect of season on animal selectivity. This, of course, implies measuring the botanical composition of the forage on offer and, if possible, determining the selection over the year by esophageal-fistulated steers. To implement such measurements, it would be necessary, in small-plot grazing experiments, to graze mixtures individually, allowing animals to select. Grazing should not be suspended during the dry season and residual forage after grazing is left rather than removed. These conditions should be taken into account when designing methodologies for evaluating grass-legume associations, particularly in production systems that use the same pasture the year round.

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Chapter 5

Effect of Grazing Management on Tropical Pasture Utilization

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Abstract

The factors of grazing management that influence tropical pasture utilization are discussed in this review. The principal objective is to consider stocking rate and grazing system effects—and their interaction—as related to the evaluation of germplasm under grazing.

It is inferred that the study of interactions between stocking rate and grazing system is important for determining, not only animal production, but also management of forage species (principally legumes associated with grasses) and so ensure their persistence. It is therefore suggested that, when evaluating new germplasm in small plots, management factors be included in order to better understand the alternatives for use of the germplasm within a determined ecosystem or, in simpler grazing tests, the potential that the new germplasm will have for animal production.

Introduction

Tropical forage species, especially grasses, have a large capacity for using radiant energy, carbon dioxide from air and water, and soil nutrients to produce large quantities of dry matter that can be used for

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beef or milk production. Nevertheless, Whyte (1962) pointed out that, in terms of animal production, the potential of tropical forages was largely a myth, and that for a long time the greatest contribution of livestock products was coming from temperate zones.

In spite of progress in tropical pastures research, especially in the use of legumes for increasing forage potential even more (Hutton, 1970), and despite experimental results demonstrating animal productivity in the tropics (Table 1), beef production in the tropics continues to be low. Yet, proportionately, it has the greatest cattle population in the world (Jasiorowski, 1973).

The main reason for this phenomenon is that, even when environmental factors such as humidity and temperature, are not limiting, soil fertility is adequate, and large quantities of dry matter of good nutritive value are produced, animal utilization of forage plants does not reach even 50%. It is variable both in grasses (Table 2) and in grass-legume associations (Okorie et al., 1965; Olubajo and Oyenuga, 1971).

The purpose of this review is to discuss some concepts related to tropical pasture utilization from the viewpoint of grazing management.

Table 1. Potential beef production, estimated on natural and cultivated tropical pastures.

Pastures	Environment	
	Humid, with 5-6 months of drought (kg/ha per year)	Humid, no drought (kg/ha per year)
Natural		
Good management	10-80	60-100
With legumes	120-170	250-450
Cultivated		
Grasses-legumes	200-300	300-600
Fertilized with N	300-500	800-1500

SOURCE: Stobbs, 1974.

Table 2. Utilization of three tropical grasses, with fertilization and intensive management. Averages of humid and irrigated regions in Puerto Rico.

Grass	Annual dry matter offered (kg/ha)	Utilization efficiency (%)	Weight gain		Conversion efficiency[a] (kg DM/kg LW)
			per animal (kg)	per ha (kg)	
Napier	42,224	35.4	203	1233	34.2
Guinea	35,124	45.7	200	1308	26.8
Pangola	31,761	43.5	198	1139	27.9
Average	36,369	41.5	200	1226	29.6

a. Conversion efficiency is expressed as kg of DM used to obtain a weight gain of 1 kg; LW = liveweight.

SOURCE: Vicente-Chandler et al., 1967.

The emphasis is on grass-legume associations, considering the importance that legumes have for improving animal productivity in tropical America.

Utilization

Pasture utilization can be conceived as the efficiency with which the dry matter produced is converted into animal product (Noy-Meir, 1980). This definition recognizes the necessity of establishing the true value of a pasture—once that value is transformed into animal product—as an indirect measurement of forage utilization.

The intake, or utilization of forage, and animal production are related to the quantity of forage species present in the pasture. If all other factors associated with intake of forages in grazing (Figure 1) remain more or less constant, animal production per unit area would be directly related to the availability of pasture.

This relationship can be described by means of an asymptotic curve (Figure 2) in which the intake of dry matter would increase (in terms of pasture availability) to a point of inflection or change beyond which

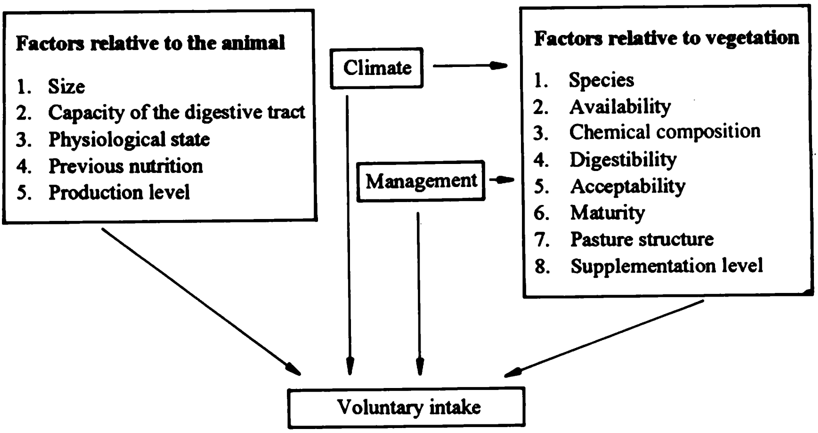
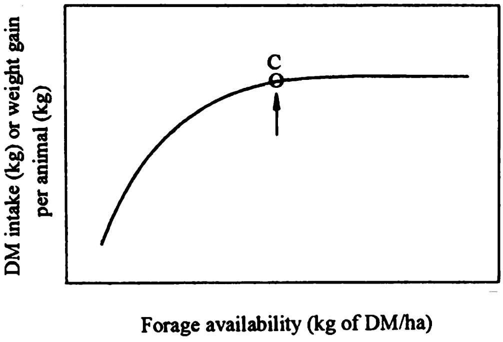


Figure 1. Factors related to consumption of forages in grazing (Johnson, 1970).

Figure 2. General relationship between forage availability and animal production. C = point of change beyond which a greater availability of forage does not produce increase in productivity (Paladines, 1972).



a greater availability does not produce increase in productivity. However, this relationship is not so simple (Stobbs, 1975) because a strong interaction between the pasture and grazing animal exists. In addition, factors of pasture management have a large influence on animal pasture usage ('t Mannetje, 1972).

Factors of Pasture Management

The main objective of pasture management is to ensure long-term animal productivity, by maintaining pasture stability, especially that of legumes, which are the most valuable and unstable component of the system. Among the factors of pasture management that most affect its utilization are stocking rate, grazing system, and duration of rest and occupation periods in the rotation.

Stocking rate

The stocking rate is the most important factor that influences forage utilization, by establishing a strong interaction between forage availability as a result of plant growth, and defoliation and intake of forage by animals. The persistence of species in the pasture, especially of legumes, is altered by the stocking rate and also varies according to morphological and physiological characteristics of the plants.

Several researchers have established relationships between stocking rate and production of pastures represented by distinct types of models that seem to differ according to type of pasture and the ecosystem for which those pastures have been chosen.

Mott (1960) proposed a relationship where gain per animal is maximum when the stocking rate is low and maintains itself thus as the stocking rate gradually increases until the point where it begins to diminish rapidly with successive increases in stocking rate (Figure 3). Mott suggested that the relationship would be better described as grazing pressure, that is, the quantity of dry matter of the forage present per grazing animal, instead of the conventional stocking rate understood as the number of animals per unit of surface area at a

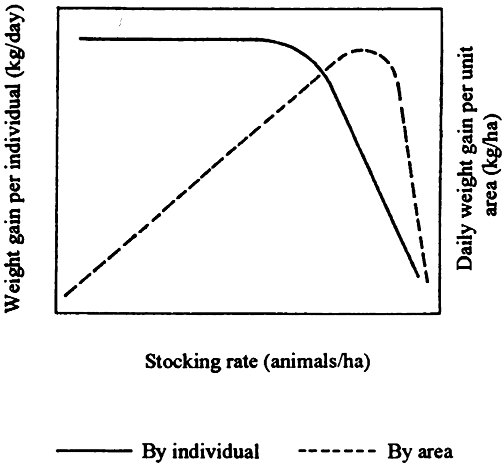


Figure 3. General relationships between stocking rate and weight gain per individual and per unit of area (Mott, 1960).

moment. Paladines (1972) interprets this relation in terms of quantity of forage available and intake per animal, which would be equivalent to weight gain, provided that the factors determining forage quality were not influenced by the stocking rate or the grazing pressure (Figure 2).

Other researchers such as Riewe (1961) and Cowlishaw (1969), established a linear type relationship between gains per animal and stocking rate over a wide range of stocking rates and pasture types. Jones and Sandland (1974) proposed a model (Figure 4) in which this relationship remains linear over a range of stocking rates established in grazing experiments. This relationship is achieved especially when it is applied to pastures of grass-legume associations where legumes have the most influence on animal productivity and are more severely affected by an increase in stocking rate. The author of this review found, in a review of data generated in different tropical regions, that the linear relationship proposed by Jones and Sandland (1974) is achieved in almost all studies on pastures of grass-legume associations (Table 3).

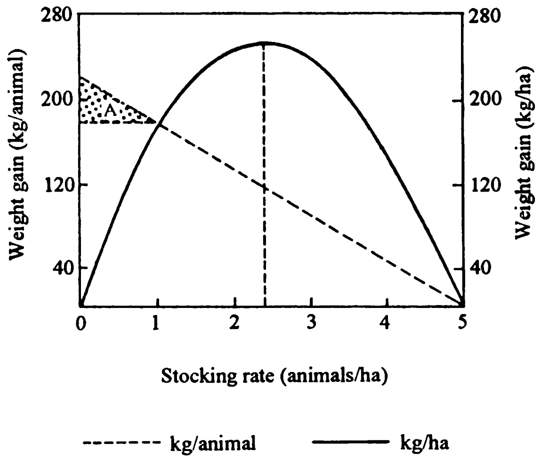


Figure 4. Relationship between stocking rate and weight gains per animal and per hectare. (A = effect—not very important—of constant weight gain before the stocking rate of 1 animal/ha) (Jones and Sandland, 1974).

Table 3. Linear regressions calculated for the relationship between stocking rate (X, animals/ha) and weight gain (Y, kg/animal) in tropical grass-legume associations under different rainfall regimes.

Rain (mm)	Regression	Regression coefficient	Sources
720	Y = 198.5 - 52.9 X	-0.98	't Mannetje and Nicholls, 1974
905	Y = 141.7 - 35.6 X	-0.79	Shaw, 1978
1070	Y = 241.1 - 56.7 X	-0.99	Jones, 1974
1090	Y = 208.8 - 18.2 X	-0.95	Vilela et al., 1978
1700	Y = 201.6 - 24.7 X	-0.96	Toledo and Morales, 1979
2650	Y = 220.0 - 31.8 X	-0.99	Partridge, 1979

SOURCE: Tergas, 1982.

Although there are discrepancies in the model that describes the relationship between stocking rate and animal production, there is, nonetheless, a consensus among researchers that, as the stocking rate reduces, gain per animal increases to a level related to the animal's metabolism and maturity of the forage. Stobbs (1969) pointed out that in pastures of *Hyparrhenia rufa,* in Uganda, production per animal diminished with low stocking rates because of the scarce nutritive value of the forage associated with its excessive growth and maturity.

However, Edye et al. (1978) found that the stocking rate did not have a significant effect on annual animal production because of the antagonistic effect of the rainy and dry seasons (Figure 5). During the rainy season, animal production increased with the increase in stocking rate—an increase that was, in addition, related to an increase in the availability of total green and dry matter. However, during the dry season the opposite was observed. Edye et al. believe that it is possible that, in the humid tropics, excessive pasture growth reduces the quality of forage and therefore its use by the animal, resulting in poor animal productivity when low stocking rates are used.

At Carimagua, Colombia, with the grasses *Brachiaria decumbens, B. humidicola*, and *Andropogon gayanus*, an excessive accumulation of pasture was observed when stocking rates were low, especially at the beginning of the rainy season, resulting in less utilization efficiency of pasture in terms of animal production.

At the same time, the quantity of dead material in the pasture increases as the rainy season advances and may represent more than 50% of pasture offered, negatively influencing animal production, especially if the stocking rates are low during this critical time of year (Figures 6, 7, and 8).

In New Zealand, Campbell (1966b) found an increase in dead forage when stocking rates were decreasing. Stuth et al. (1981) point out that little information is available on the effect of defoliation on rates of maturity of temperate zone pastures, and point out the necessity of investigating the relationship that exists between pasture availability and seasonal rates of senescence. Because tropical pasture species mature more rapidly and the dry season usually lasts longer in

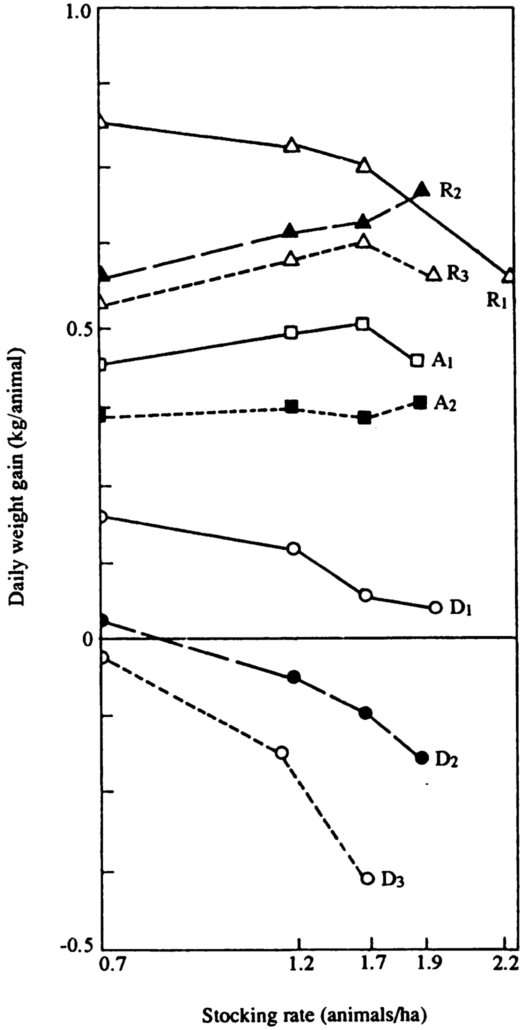


Figure 5. Relationship between stocking rate and changes in weight per animal for three rainy seasons (R), three dry seasons (D), and two annual periods (A) (Edye et al., 1978).

tropical regions, rates of senescence could influence pasture utilization considerably, according to pasture management and especially to stocking rate.

Stocking rate has a very marked effect on legume persistence when in association with tropical grasses (Figures 9 and 10). This effect

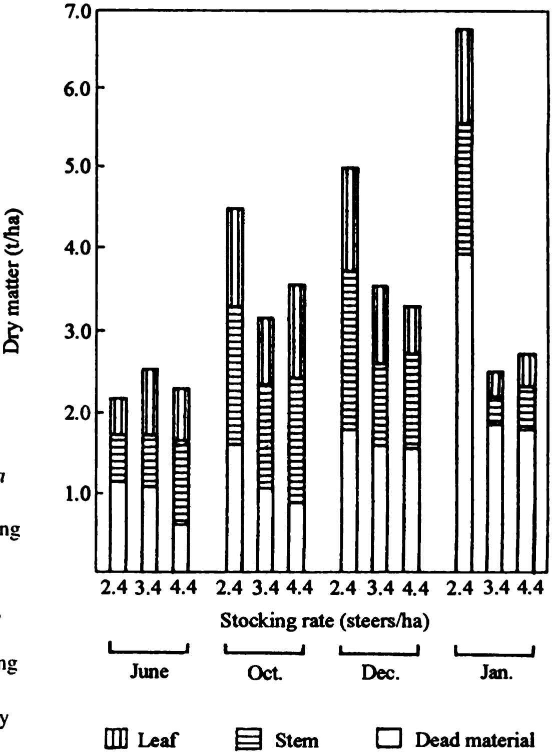


Figure 6. Forage availability in terms of plant parts of *Brachiaria humidicola* in continuous grazing with three fixed stocking rates in the rainy and dry seasons at Carimagua, Colombia, in the first year of grazing, 1981. Sampling dates: June, October, December, and January (Tergas et al., 1982).

varies according to the characteristics of the forage species (Roberts, 1979) so that the prostrate legumes are more tolerant of high stocking rates than the twining and bushy legumes. Bisset and Marlowe (1974) found a relationship among stocking rate, gains per animal, and number of plant crowns of siratro per ha (Figure 11). When, at one of the experimental sites, the number of siratro plant crowns was maintained at around 100,000/ha, animal production did not vary significantly with an increase in stocking rate. At another site, however, when the stocking rate was increased, the number of crowns dropped from 39,000 to 12,000/ha and animal production diminished significantly. The difference was attributed to the legume's better adaptation and establishment at one of the sites, resulting in a more vigorous development of stolons and secondary crowns.

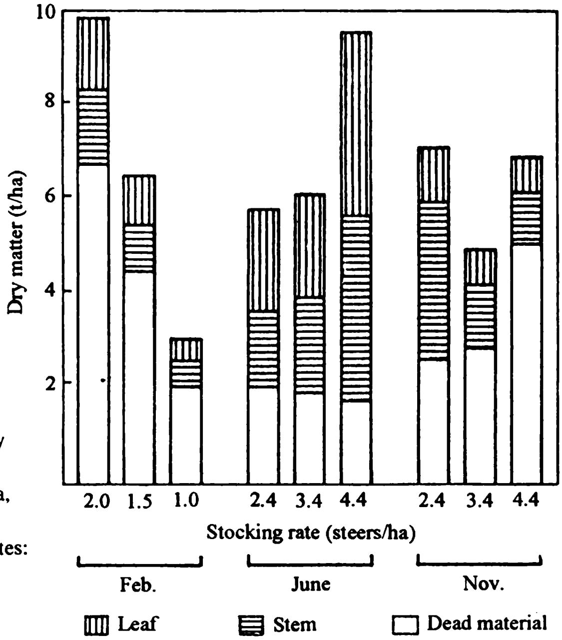


Figure 7. Forage availability in terms of plant parts of *Andropogon gayanus* under continuous grazing with three different stocking rates in rainy and dry seasons at Carimagua, Colombia, in the third year of grazing. Sampling dates: February, June, and November (ICA-CIAT, 1982).

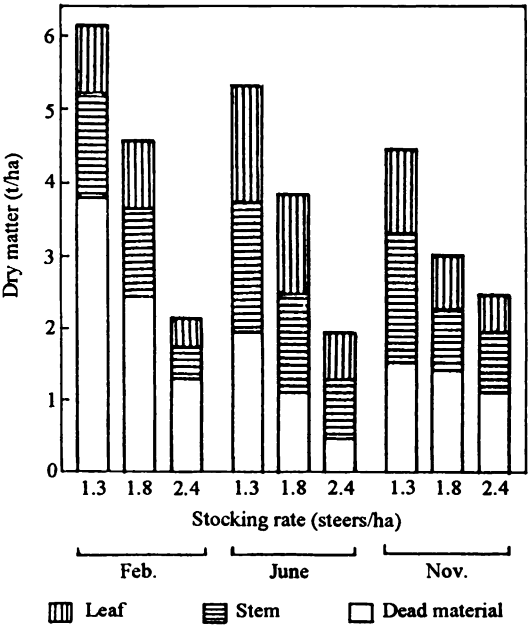


Figure 8. Forage availability in terms of plant parts of *Brachiaria decumbens* under continuous grazing with three different and fixed stocking rates during the year at Carimagua, Colombia, in the sixth year of grazing. Sampling dates: February, June, and November (ICA-CIAT, 1982).

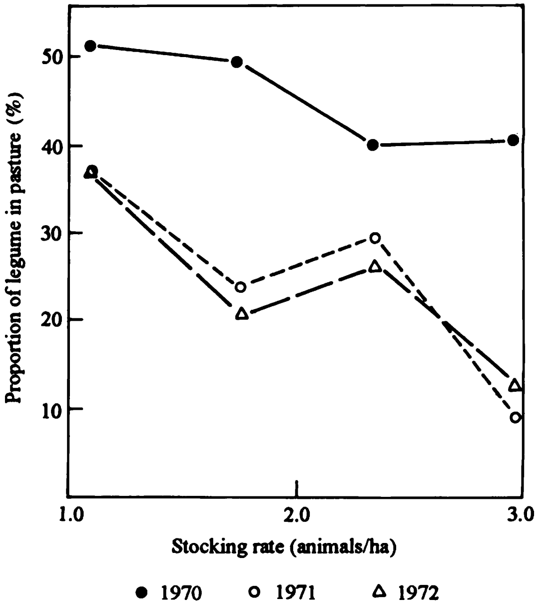


Figure 9. Effect of stocking rate on the proportion of legumes in the *Setaria*/siratro association (Jones, 1974).

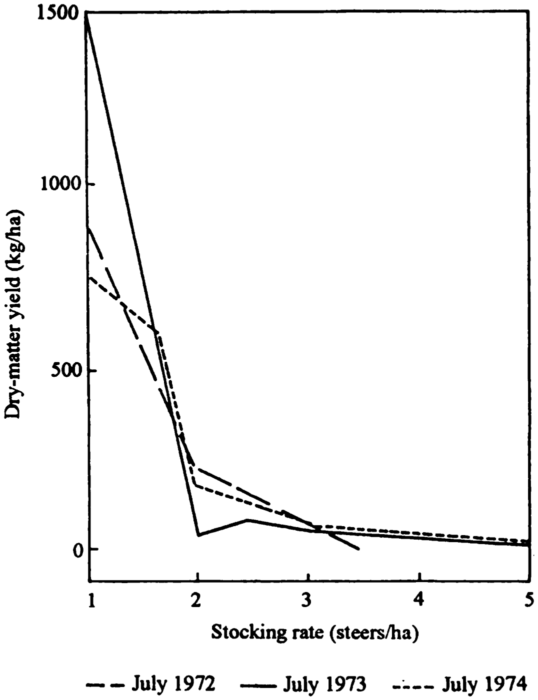


Figure 10. Effect of stocking rate capacity on legume yield in pastures of siratro/*Setaria anceps* cv. Kazungula during July in 1972, 1973, and 1974 in Koumala, central Queensland, Australia (Walker, 1975).

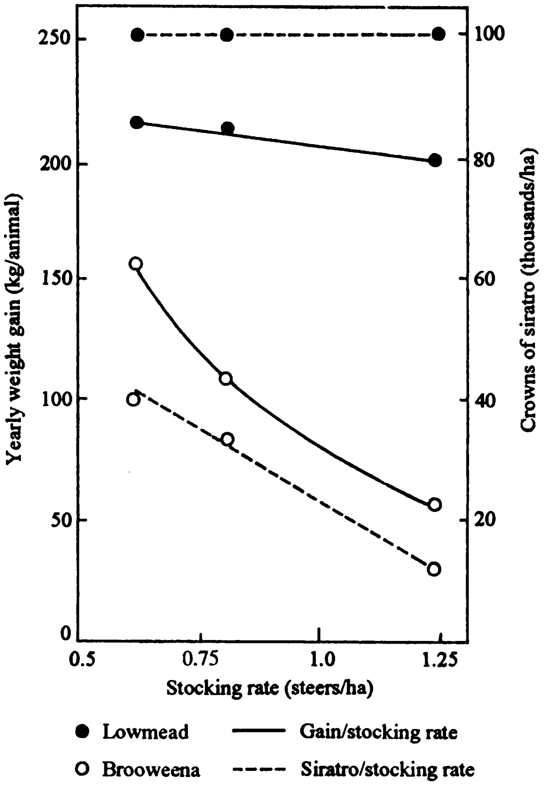


Figure 11. Relationship among stocking rate, weight gain per animal, and number of siratro crowns at two sites in Queensland, Australia, during the fifth year of grazing, 1970. (Bisset and Marlowe, 1974).

Grazing systems

The majority of research studies on utilization of tropical pastures of grass-legume associations have been conducted under conditions of continuous grazing. It was believed that the advantages of rotational grazing appear only with high stocking rates. In the Australian humid tropics, Grof and Harding (1970) found greater animal production in a system of alternate grazing with two fields of *Panicum maximum* in association with *Centrosema pubescens*, and employing high stocking rates. However, in Uganda, in a region characterized by a sharply defined dry period, Stobbs (1969) did not find significant differences between continuous grazing and rotational grazing with three and six paddocks, respectively, in an association of *P. maximum* and siratro with high stocking rates. Riewe (1976) pointed out that in studies which compare continuous and rotational grazing systems (temperate zone grass-legume associations, applying different stocking rates), an interaction is invariably presented; and in such a way that the low stocking rates favor continuous grazing while the high stocking rates favor rotational grazing (Figure 12).

It is certain that no study has demonstrated advantages for animal production in employing the rotational grazing system rather than the continuous grazing system, when using grass-legume associations. Yet, it is considered possible that, in the long term, some system of intermittent grazing will be needed when relatively high stocking rates are used, in order to favor the persistence of the legumes (Stobbs, 1969). This statement has been supported by Jones (1979) who found that reduction in siratro yields, as a result of increasing the stocking rate, was less marked when the grazing frequency was 9 weeks than when it was 3 weeks. At the same time, weed invasion was smaller when applying the 9-week frequency. It is evident that other similar long-term research studies should be carried out, above all in humid tropical ecosystems and employing aggressive legumes that, because of the lack of well-defined dry periods, are not as well preferred throughout the year by the grazing animal as are the accompanying grasses.

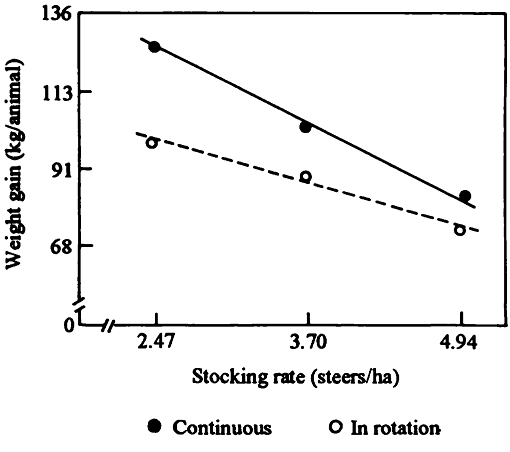


Figure 12. Effect of stocking rate on the annual weight gain per steer in a pasture of White Dallis Clover with continuous and rotational grazing of 5 and 25 days (Riewe, 1976).

Evans (1982) considers that the benefit derived from rotational grazing is more related to the balance of species that make up the pasture than to the increase in nutritive value of forage or to animal production. Nevertheless, in environments where there is great seasonal variation in the intake of aggressive and relatively unpalatable legumes in relation to the intake of accompanying grasses, animal production could become limited by the predominance of legumes in the association. This happens at Carimagua, Colombia, in an association of *Desmodium ovalifolium* with grasses of good relative palatability such as *B. decumbens* and *A. gayanus*. In these pastures, animal production diminished significantly when the legume became dominant (CIAT, 1980).

Rest periods

The duration of the rest period is directly related to the rotational grazing system. An interaction exists between defoliation of pasture by animals, leaf area present after grazing, and the rest period of the pasture between grazings, determining the pasture's production (Campbell, 1966a). According to this relation, the speed of the pasture's regrowth depends on the leaf area index of the residue remaining after grazing, that is, the surface of the active leaves of that residue present per unit of soil surface. Paladines (1972) explains that, according to this concept, the best pasture utilization is achieved if defoliation is carried out when the leaf area index has barely surpassed its optimal point and does not exceed its minimal point—which would affect the carbohydrate synthesis of the residual pasture. That optimal point, however, is not easy to determine in practice.

The optimal leaf area index would be related to characteristics of the forage species, that is, to the accumulation of carbohydrate reserves in the roots, the presence of active growing points, the balance between photosynthetic capacity and transpiration, and other functions on which the type of management appropriate for better pasture persistence depends heavily. Applying this concept to pasture management would require short grazing periods and long rest periods. Under tropical conditions, such rotation would have to be modified according to the characteristics of the forage species, and the regime and distribution of rainfall, because, normally, long rest periods lead to reduced forage quality that would affect animal production.

Germplasm Selection

Germplasm that is to be selected for use as a pasture component, besides being characterized by its adaptation to the ecosystem and to production-limiting factors, should be evaluated for its capacity to tolerate frequent defoliation under different grazing intensities. However, Blaser et al. (1974) point out that grazing method and intensity should instead be based on the morphological and physiological characteristics of the forage species. For example, the method and intensity of grazing are less important when dealing with annual species than with perennial species; and perennials of erect growth habit—which are easily defoliated—will require some type of intermittent grazing to ensure their persistence and animal productivity.

Riewe (1976) suggests that the differential behavior of forage plants with regard to grazing intensity and method could be explained in terms of growth habit and physiological response to defoliation. In palatable, easily defoliated species of erect growth habit, regrowth increases at the expense of the roots' reserve carbohydrates, while in prostrate and stoloniferous species, which are not completely defoliated by grazing, regrowth does not depend as much on the carbohydrate reserves in the stolons and roots. Both cases, however, refer to temperate zone species and may not necessarily be interpreted in the same way for tropical species which are typified by higher and more continuous growth rates throughout the year. However, they should be studied in germplasm evaluations as characteristics that may be related to persistence of forage species. The ability to improve legume persistence by adequate grazing management will depend largely on the knowledge acquired of how management affects such important aspects of forage persistence as plant survival, seed production in grazing, and the regeneration and survival of new seedlings (Jones and Mott, 1980).

The socioeconomic conditions surrounding cattle production systems in the American tropics require pasture species that are tolerant of stress under continuous grazing, and that can respond to simple or nominal management. As a result, selection of forage germplasm should be based on such characteristics. Nevertheless, those species of great forage value, but requiring more intensive management, should be evaluated and selected for specific production systems.

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Chapter 6

Dynamics of Pasture Discharge and Its Architecture

Juan Gastó*

Abstract

An analysis is presented of the relationships between the form of grazing land or pasture—a form that is expressed by its architecture in the ecosystem—and the dynamics of discharge in the pasture used by cattle. The objective of searching and demonstrating relationships of this nature is to establish a conceptual framework that will help the phytogeneticist make decisions on the improvement of species destined for pasture.

The first part of this study analyzes pasture architecture with regard to the form of phytocoenosis and the design of improved forms. Also presented is a general function of architecture that allows a description of plant form.

The second part of the study describes and compares diverse discharge models. These models are applicable to specific processes of a biotic and abiotic nature. From this background, one deduces a general function of pasture discharge that is analyzed in its turn as a forage flow from phytocoenosis to zoocoenosis. Some parameters related to discharge such as grazing intensity and use intensity, as well as ecological cost of the harvest, are included in the study.

Finally, the discharge of an annual Mediterranean meadow is described as an example of the process.

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Introduction[1]

A pasture, considered as an ecological system, behaves in the same manner as an accumulator of matter, energy, and information, whose goal is to later free the accumulated charge as a flow of forage toward the consuming organism. The kinds and the capacity of accumulation and freeing of the charge are related to components of the pasture system and to its connections. The forage or feed that the pasture produces is barely a fraction of one of many components of the ecosystem, the forage plant, of which only some organs and tissues are used.

The objective pursued in breeding forage species should be that of modifying already existing genotypes that, when introduced to pasture ecosystems, will produce phenotypes that allow an improvement in pasture quality. In other words, it is a question of generating germplasm that will be employed in pasture improvement and not a question of directly improving the pasture.

One of the attributes that is looked for when improving forage plants is their capacity to accumulate a charge in the form of digestible dry matter. Given the characteristics of the system, the architecture which the plant should have, as well as the location and magnitude of its storage organs, regulate the charging capacity of the plant. Phytocoenosis should, therefore, be considered as the storage structure of digestible nutrients of the ecosystem.

The characteristics of pasture discharge of phytocoenosis—when being submitted to harvesting, in this case by the herbivore—should be in harmony with the system and with the requirements of the harvester. This purpose is achieved by designing plants and pastures with structures that, besides adapting themselves to the system where they will be developed, will possess characteristics that generate a discharge process of closer approximation to the optimum.

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[1] *See* Glossary at the end of this chapter.

It is not sufficient to have available species, cultivars, or both of forage plants that will be of high bromatological quality and whose forage production will be large. It is necessary that those components—species or cultivars—be adjusted to the rest of the components of the ecological system. The breeder often ignores this restriction; yet, without it, it is not possible to develop pasture systems that will exhibit, in a sufficient magnitude, attributes, such as homeostasis, resilience, stability, longevity, harmony, or periodicity, that are considered essential for the normal functioning of the system. Those components should also present an architecture that will generate discharge functions compatible with the necessities of the harvester.

Although it is possible to describe the architecture of a pasture by means of a function, and also to characterize the discharge of a given architecture, when improving pasture, one should look for genotypes that will be expressed as phenotypes that are compatible with the discharge requirements appropriate for the desired optimum in the livestock system considered as a whole. This study, therefore, first makes a general analysis of plant architecture with regard to its form and design. Diverse models have been employed to describe discharge of physical, chemical, mechanical, or biological systems. The comparative analysis of these models provides a general model capable of describing discharge of the ecosystem, which is here analyzed as a flow model.

This study thus analyzes the proposal developed over more than a decade as a subject of interest for pasture and cattle specialists, and breeders. The available empirical information shows the general theoretical proposals as highly congruent with field results. Because of their simplicity, the proposal and the resolution model approximate a natural solution of the problem of pasture discharge and, at the same time, provide simple quantifying tools.

Discharge

Nature contains diverse models of physical and biological systems that, upon being discharged, demonstrate similar behavior (Krebs, 1977). In those systems, the degradation of humus in a forest, the profile of luminous intensity, a first order chemical reaction, the reduction of hosts of Atlantic salmon, the disappearance of digestive products from the rumen, the discharge of a condenser with a resistance, and the harvest of phytoplankton by zooplankton are considered as examples of discharge processes. These processes of such diverse systems represent a simple phenomenon, governed by the same principle (González B., 1979) and described by an exponential equation whose exponent has a negative value. Inductively, therefore, one can suppose that pasture harvest is adjusted to the same general equation (González B. et al., 1981).

Some of these systems processes are detailed below:

a. Degradation—through the action of microorganisms—of forest humus generated by the falling of leaves, branches, and other plant remains is a phenomenon that can be adjusted to the following equation (Clark and Paul, 1970; Olson, 1963):

$$\frac{x}{x_o} = e^{-kt} \qquad (1)$$

where x_o = the initial quantity of humus;
x = the residual quantity of humus at time t; and
k = the decomposition coefficient.

b. Reduction of hosts of Atlantic salmon (*Salmo salar*), can be adjusted to the following equation:

$$N_t = N_o e^{-zt} \qquad (2)$$

where N_t = the number of examples present at time t;
N_o = the number of examples present, beginning at time t_c; and
z = the exponential coefficient of disappearance, or net rate of loss (Gee et al., 1978).

c. The discharge of a condenser with a resistance is adjusted to the following equation (Kalashnikov, 1959):

$$U = Ee^{t/rc} \tag{3}$$

where U = the instantaneous value of a condenser's tension;
c = the capacity of the condenser;
r = resistance; and
E = the tension of the condenser upon beginning discharge.

d. The grazing pressure of zooplankton on phytoplankton can be expressed by the following equation:

$$p = p_o e^{-[\propto(n)-w]\,t} \tag{4}$$

where p = the quantity of phytoplankton at time t;
p_o = the initial quantity of phytoplankton at time t_o;
n = the quantity of nutrients that determine growth of the phytoplankton;
w = the rate of elimination; and
$\propto$ = a constant.

When $\propto (n) \rightarrow 0$,
then $p = p_o e^{-wt}$ (5)

This same function was studied by Colinvaux (1973) and Phillips (1978) in a population of Copepoda of the genus *Galanus* that was depredating a population of phytoplankton (*Clamidomonas* algae) and obtained the following equation:

$$C_t = C_o e^{-kt} \tag{6}$$

where C_t = the concentration *of Clamidomon*as at time t;
C_o = initial concentration of *Clamidomonas,* beginning at time t_o; and
k = the coefficient of disappearance.[1]

It is possible to assume that the net change produced in the system will correspond to the charge minus the discharge (Noy-Meir, 1975; Olson, 1963). Stating the problem in this manner and according to the law of energy conservation, one has:

$$\frac{\nu Q}{\nu t} = \frac{\nu G}{\nu t} - \frac{\nu Q}{\nu v} \qquad (7)$$

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[1] Other processes, already mentioned, are described as follows:

i. Extinction of light in a plant community. Monsi and Saeki (1953) and Saeki (1963) observed that the luminous intensity that a plant cover receives is reduced as the ray of light penetrates the foliage canopy. The reduction can be described by the following equation which describes Bouger's Law (Reifsnyder and Lull, 1965):

$$\frac{I}{I_o} \qquad e^{-kF} \qquad (a)$$

where k = the coefficient of light extinction, which is constant in each case;
I_o = luminous intensity at a height x;
F = the leaf area index accumulated from the highest part of the foliage canopy until height x.

ii. Kinetics of a first order reaction (Pauling, 1967):

$$[A] = [A_o]e^{-kt} \qquad (b)$$

where [A] = the concentration of A at any time;
$[A_o]$ = the concentration of A at time t_o;
k = the reaction coefficient.

iii. Disappearance of digestive products from the rumen. This mammalian process conforms to the following equation:

$$x = e^{-kt} \qquad (c)$$

where x = the fraction of the product at time t; and
k = the coefficient of disappearance of the product.

The product can be a plant part or some nutritive element (Berger and Yokohama, 1977; Laredo and Minson, 1975). Equation (c) is a special case of equation (1), where $x_o = 1$; the unit represents the whole; and the value of x is always a fraction of 1.

This equation points out that the changes in the charge (v/vt) are a result of changes produced by growth over time (v_G/v_t) minus the changes produced by the harvest upon increasing grazing intensity (v_Q/v_v).

If a system's rate of charge is close to zero, then the net change produced in the system results from discharge. In addition, discharge is a dependent variable of the charge present. The system considered presents the following parameters:

Q = total charge present at the moment of initiating
the discharge process;
C = nonharvestable charge present; and
k = intrinsic rate of discharge.

These parameters can be considered as constants for a given system and time. The dependent variable Q corresponds to the charge present at a given instant and is expressed in kg/ha of dry matter. The independent variable v represents units of grazing intensity—(zoomass · time)/surface unit—usually being expressed in tons · hour/ha.

Variations in the charge are considered as resulting from harvesting—the latter being proportional to the quantity of charge present, Q, minus the charge not available, C. In addition, the variations are proportional to the intrinsic rate of discharge, k. The following equation, therefore, develops:

$$\frac{dQ}{dv} = -k(Q - C) \qquad (8)$$

By solving the differential equation, the following solution is obtained:

$$Q = (Q_o - C)e^{-kv} + C \qquad (9)$$

Some authors have adjusted pasture discharge curves to the equation, causing grazing in dryland pastures with high animal densities (Olivares E. and Gastó C., 1979; González B., 1979; Gastó C. and Olivares E., 1979).

Discharge as a flow

Pasture discharge by cattle can be considered as analogous to flow, in such a way that:

$$J'_p = \frac{Q}{A \cdot v} \qquad (10)$$

where J'_p = forage flow from the pasture to the animal;
Q = the quantity of forage harvested by the cattle for their ingestion;
A = the area undergoing grazing; and
v = grazing intensity.

In accordance with the previous expression, forage flow receives the following units:

$$J'_p = \frac{\text{mass of forage}}{\text{surface} \cdot [(\text{zoomass} \cdot \text{time})/\text{surface}]}$$

Forage flow J'_p is determined by the difference of potential existing between the status of the pasture system at a given instant and its final status, called true potential Q and minimum consumable potential C, respectively.

"Potential" corresponds to a property emerging from the pasture architecture, which is a function of topological arrangement and of the size and number of pasture components. It is possible in practice to utilize, as an index of the magnitude of pasture potential, dry-matter content per unit of area. In this manner, true potential corresponds to the value, as mass, of forage dry matter present per unit of pasture area, while the minimum potential corresponds to the mass of dry matter per unit of area, not available to cattle. The statuses of pasture undergoing a process of discharge are found at a topological distance (L), determined by the architecture ($\curlywedge$) of these same statuses.

Forage flow can be expressed, in a manner analogous to flow exchange, by the following expression:

$$J'_p = K'\frac{Q - C}{L\curlywedge} \qquad (11)$$

To quantify conductivity K' and topological distance L is a complex task; thus, the relationship between both is set up as a resistance to discharge, whose final expression is:

$$J'_p = \frac{Q - C}{R_p} \qquad (12)$$

where R_p = resistance to forage flow, represented by the relationship $L\wedge / K'$

In practice, forage flow from the pasture toward the animal can be calculated by deriving the general discharge equation (9), that relates the charge present, Q, to grazing intensity, v:

$$\frac{dQ}{dv} = -k(Q_o - C)e^{-kv} \qquad (13)$$

Grazing intensity

To provide a general solution for the problem of harvest, a unit of grazing intensity (v) has been proposed, one that includes time of permanence of a certain zoomass of the harvester in a determined area (Olivares E. and Gastó C., 1979). In this manner, the concept of [(harvesting zoomass) · (time of harvest)] per surface unit has been introduced and can be expressed in tons · hour/ha.

One (ton · hour/ha) is equivalent to the permanence of one ton of zoomass of harvesting organisms, during one hour, on a one-hectare surface:

$$\frac{\text{ton} \cdot \text{hour}}{\text{ha}} = w_i \cdot t \cdot A^{-1} \qquad (14)$$

where t = time, in hours;
w_i = sum of the individual liveweight of the harvesting organisms, expressed in tons; and
A = surface undergoing grazing, expressed in ha.

The unit (ton · hour/ha) expresses the intensity of grazing activity. According to the terminology proposed by the Range Team Glossary Committee (1974), the relationship zoomass/surface corresponds to instantaneous animal density. If this relationship is considered with permanence in grazing, t, an expression of intensity is finally obtained, responding to the above-mentioned unit.

A stricter relationship would imply the metabolic weight of the animal and of the product harvested (Córdova et al., 1978; González B. et al., 1981; Spedding, 1971), a relationship that should be further studied. In this case, the unit would be the (metabolic ton · hour/ha), defined as the permanence, during one hour, of a quantity of organisms whose metabolic weight, $w_i^{0.75}$, adds up to one ton, on a one-hectare surface:

$$\frac{\text{metabolic ton} \cdot \text{hour}}{\text{ha}} = w_i^{0.75} \cdot t \cdot A^{-1} \qquad (15)$$

Utilization intensity

The utilization intensity (ψ) can be defined as the relationship that exists between the discharge of a pasture (Q_o - Q_i) and the initial charge (Q_o) before discharge, in accordance with the following equation:

$$\psi = \frac{Q_o - Q_i}{Q_o} \qquad (16)$$

Utilization intensity is related to grazing intensity (v), to the architecture of the harvested system ($\curlywedge f$), and to that of the harvester ($\curlywedge z$), so that:

$$\psi = f(v, \curlywedge f, \curlywedge z) \qquad (17)$$

This function can be solved, thanks to the general discharge equation, where the value of Q_i is determined in relation to grazing intensity, v. The rest of the components of the general function, $\curlywedge f$ and $\curlywedge z$, are contained in the intrinsic discharge rate, k, in the residue of unavailable charge, C, and in the initial charge, Q_o. The base of the natural logarithm represents the general type of discharge of any system, which is based upon principles of general validity. In this manner, one has:

$$\psi = \frac{Q_o - [(Q_o - C)e^{-kv} + C]}{Q_o} \qquad (18)$$

Palatability has been defined in different ways (Cook, 1954; Heady, 1975; Stoddart and Smith, 1955). In the present study, it has been used to mean the maximum utilization intensity of an acceptable forage species ($\psi_{i\ max.}$). The maximum acceptability is based on conservation reasons relative to plant physiology, pasture ecology, the origin of the soil, and other aspects that determine the inconvenience of submitting the harvested element to greater discharge intensities, even when the harvester could discharge the pasture to a greater degree.

This same concept is valid for maximum utilization of all species contained in the pasture, a practice that has been termed "adequate pasture use" ($\psi_{f\ max.}$). The utilization intensity of the pasture should not surpass this value, which is determined in each case according to the architecture of phytocoenosis and zoocoenosis, and by means of tables applicable to each site and animal species (Cook, 1954; Stoddart and Smith, 1955).

The utilization intensity of each species in a pasture (ψ_i) when the pasture reaches the proper intensity of adequate use, does not necessarily agree with its palatability ($\psi_{i\ max.}$), and in any case, it should be equal to or less than its palatability.

The value of $\psi_{max.}$ of pasture is determined according to palatability of the species that make up the pasture and according to the appropriate characteristics of the pasture considered as an ecosystemic group. In order to do that, experimental results that will allow the factor of adequate pasture use to be adjusted empirically to environmental conditions are needed. That value of $\psi_{max.}$ is, therefore, an ecological optimum.

The calculated value of intensity, ψ_c, however, is an anatomical and morphological limitant for phytocoenosis, as well as for zoocoenosis, that intrinsically restricts a greater discharge of the system. As a result, this value is not modifiable by man (Figure 1).

Maximum utilization intensity of a pasture can be set according to the physiological characteristics of the harvester related to the magnitude of forage flow from the pasture toward the animal. This value, even when it can be superior to the ecological maximum intensity, should not—because of pasture conservation and its

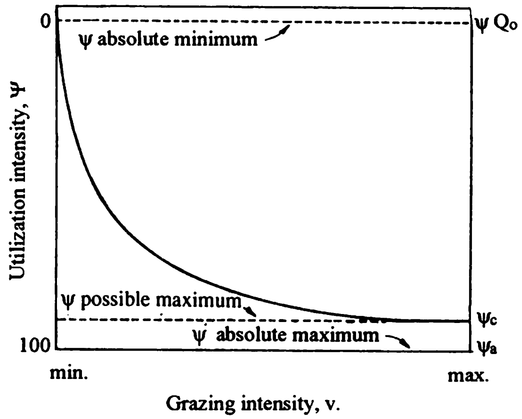


Figure 1. Relationship between grazing intensity and utilization intensity where the possible or acceptable maxima are indicated according to a criterion of optimization. ΨQ_o = initial intensity, before discharge; Ψ_c = calculated intensity; Ψ_a = absolute intensity; min. = minimum; max. = maximum.

long-term productivity—surpass the maximum acceptable intensity from an ecological point of view ($\psi_{\text{ecol. max.}}$).

Physiological optimal intensity can be changed if the harvester is modified, which is achieved by modifying the animal species, the race, its fattened status, or the season of forage utilization. Economic maximum intensity ($\psi_{\text{econ. max.}}$) should be equal to or superior to the previously indicated intensities, so that it will allow an achievement of positive economic results within a plan of ecological feasibility, and of conservation of pasture and animal health.

Experimental derivation of the discharge function

The discharge studies of a Mediterranean annual pasture of central Chile were conducted in five different phenological states. The first harvest season corresponded to the vegetative state and the second to the preflowering state. The following discharge was produced in the flowering state of the pasture; the following season corresponded to the fruit-bearing state; and the last to the state of pasture maturity (González B. et al., 1981).

The results of the discharge process were adjusted to the general function proposed, by adopting different coefficients for each state of phenological development (Table 1)—for each one of which a discharge curve was constructed (Figure 2).

The results indicate that when forage is abundant, the rate of discharge is elevated. As the potential difference between availability of forage or energy at a given instant (Q_i) and the magnitude of nonharvestable dry matter (C) becomes less (Q_i - C), the intensity of the flow diminishes until it becomes insignificant, that is, when Q_i approaches C.

Significant differences were not observed in energetic equivalents within each period of discharge, perhaps as an effect of the high animal density employed. In fact, one of the effects of using a pasture with a high animal density is to reduce selectivity (Fontenot and Blaser, 1965). When the density of the elements (forage components) that constitute a captive population (pasture) is low, animals tend to adopt a nonselective behavior, maintaining the proportions of the elements that make up the initial captive population (Werner and Hall, 1974; Krebs, 1977). Because of the low variability of energetic equivalents of the samples within each period of discharge, the intrinsic rates of discharge (for dry matter as well as crude energy) have a similar value for each phenological state considered.

Table 1. Parameters calculated for discharge curves of dry matter at distinct periods of harvest.

Phenological state	Initial availability, Q_o (kg DM/ha)	Intrinsic rate of discharge, k	Minimum harvestable potential, C (kg DM/ha)	Coefficient of determination, R^2
Vegetative	672	1.16×10^{-3}	118	0.92
Preflowering	1057	4.42×10^{-4}	416	0.75
Flowering	983	3.84×10^{-4}	305	0.91
Fruiting	307	9.71×10^{-4}	200	0.93
Maturity	2287	1.49×10^{-3}	200	0.96

SOURCE: González B., 1979.

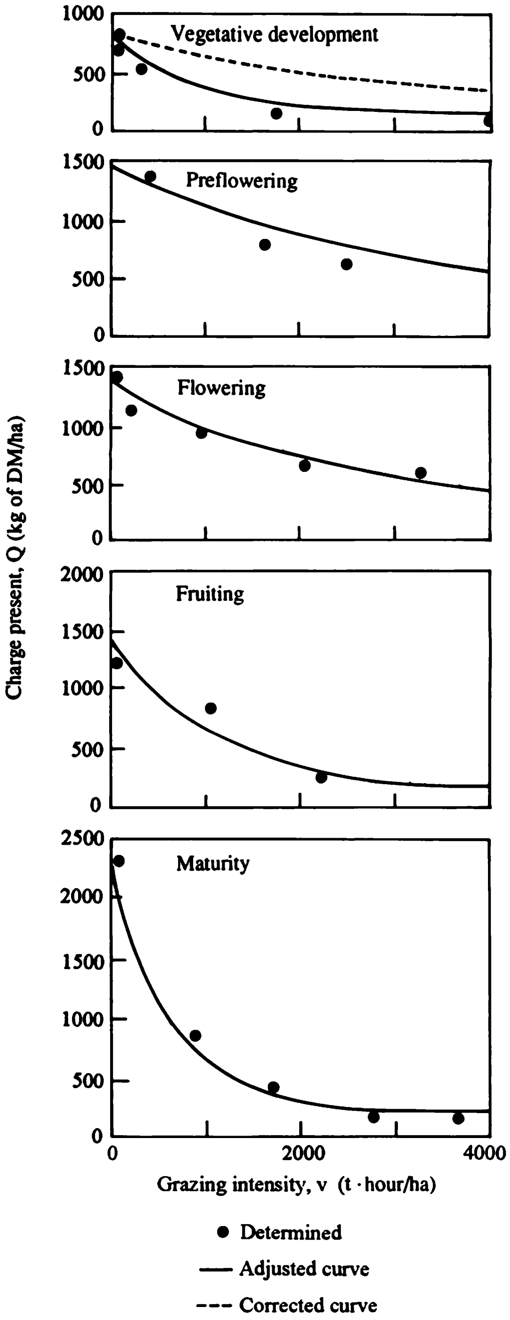


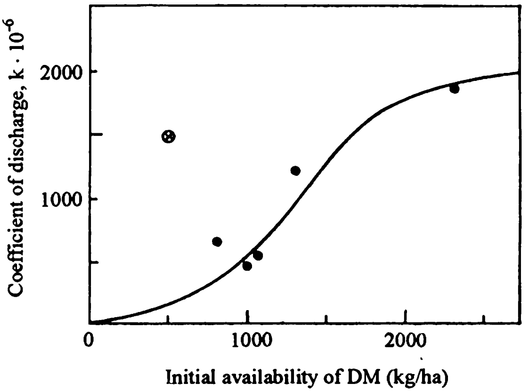
Figure 2. Discharge curves of dry matter in a Mediterranean annual pasture at different phenological states (González B. et al., 1981).

Considering the curves calculated, not only for the discharge of dry matter but also for the discharge curves of crude energy, and studying the results obtained by Olivares E. and Gastó C. (1979) for discharge curves of dry matter and for the discharge curve of digestible energy, one can affirm that the discharge of any pasture element conforms to equation (9) described earlier.

The relationship between initial availability in each period of discharge—according to the experimental results of the study—and intrinsic rate of discharge, k, of each harvest period but adjusted to equation (9), indicates that the values are adjusted to a sigmoid function (Figure 3). The coefficient of determination, r^2, has a value of 0.94, pointing out that, in this case, forage availability acts as a limitant of discharge (González B., et al., 1981).

The absolute value of forage flow progressively diminishes (Figure 4) when pasture utilization intensity, v, increases. The relation between forage flow and grazing intensity can be of practical use. When the animals' requirements to maintain a certain level of secondary production is known, a straight line is traced, parallel to the abscissa, opposite to the forage flow that satisfies those requirements. The straight line crosses the curve that describes the relationship flow-utilization intensity, with a value v_e in the abscissa corresponding to this point. This grazing intensity (v_e) is the maximum intensity of harvest to which the pasture should be submitted to obtain at least the level of secondary production desired. With the zoomass in grazing known and the surface undergoing grazing, one can determine the time of permanence necessary to reach grazing intensity v_e.

If a determined quantity of forage is considered, the production of the herbivore is related to intake (Willoughby, 1959); therefore, it is possible to plan pasture utilization so that animals that are potentially more productive will graze before those animal species that have fewer requirements (Fontenot and Blaser, 1965). Forage use is thus put in order because yields of the potentially more productive animals are greater, and forage flow is also greater when pasture utilization intensities are low.



$$y = B/(1 + b\,e^{-ax})$$

$B = 1600$ $a = 0.00283$ $b = 42.7$ $r^2 = 0.94$

Figure 3. Variations in intrinsic rate of discharge as a function of initial availability. (The value ⊗ was not considered because it was estimated to be in error.) From González B. et al., 1981).

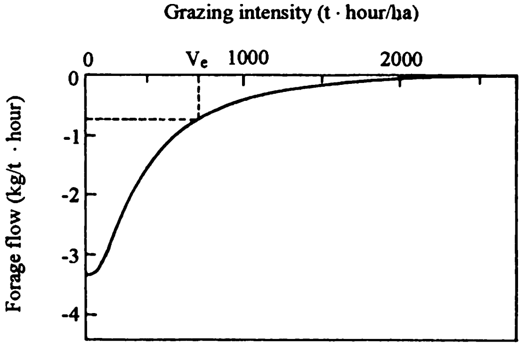


Figure 4. Variations in forage flow upon varying pasture utilization intensity in the phenological state of maturity of the forage species (González B. et al., 1981).

It is possible to establish a tridimensional relationship among initial forage availability, forage flow, and grazing intensity, a relationship that generates a response surface as indicated in Figure 5.

As initial availability of forage increases, forage flow, at low grazing intensities, also increases. As grazing intensity increases, forage flow decreases. When a high initial availability exists, forage flow diminishes sharply upon increasing the grazing intensity. However, when initial availability is low, reduction in flow is less than with a high initial availability. This causes the slope's of the discharge curves, for the initial phenological states, to be less than the slopes of the more advanced phenological states. It is possible to affirm, in a general way, that forage flow is of little magnitude when initial availability is low, or when grazing intensity is high.

Pasture Architecture

Architecture (∧) can be defined as the topological arrangement of the ecosystem's components (Nava et al., 1976). Components of an ecosystem are understood as topological categories that order matter and energy at a certain level of information or entropy. Architecture also represents the different forms that a group of structures or elements can acquire. Integration of the diverse structures that the pasture contains as an ecological system—laid out spatially by ordering and defined magnitudes—constitutes the architecture of the pasture ecosystem.

Architecture and structure are, therefore, closely related but different concepts so that, for a given group of structures, a group of possible architectures exists. The same group of constitutive elements of a given pasture can be ordered in different ways that generate different styles, forms, or architectures (Riveros et al., 1976).

The ecosystem's architecture can be the result of the natural evolutionary process that is expressed through genetic evolution of organisms, morphological changes of their plasticity, and ecological series. Instead of the resulting form being the adaptation process of

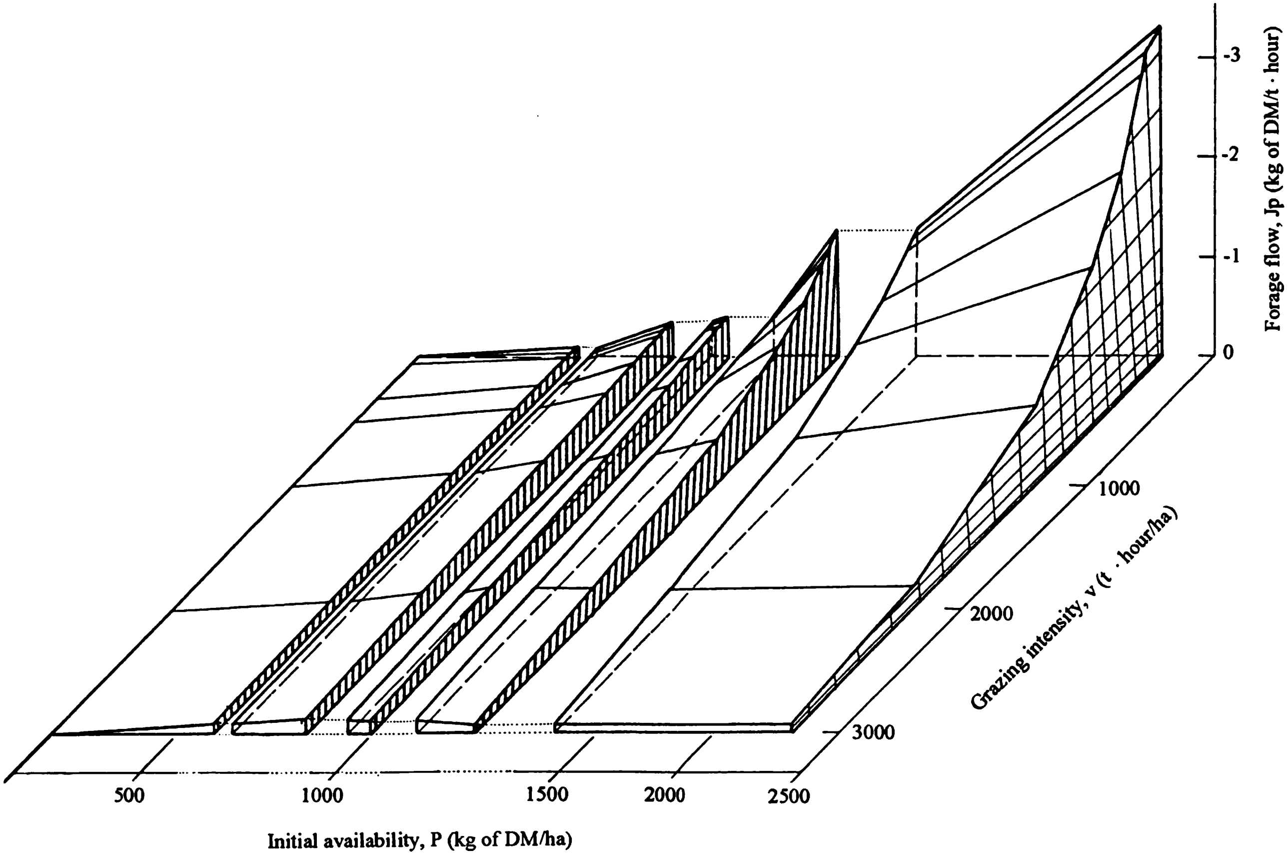


Figure 5. Response surface that describes pasture utilization. (The graphic has been split and blown up toward the right.) From González B. et al., 1981.

phytocoenosis to the environment, it is feasible to design the system's architecture anthropically.

The diverse biological structures that constitute the system's architecture can be designed so that they will be perpetuated through genetic mechanisms. Architecture, however, contains a nongenetic component derived from the interaction between organisms and the environment, or between these and operators of the process of anthropic artificialization.

Form

The characterization of a pasture by its standing phytomass—present at a given instant—or by its bromatological value, is not sufficient for its description nor does it allow the establishment of faithful relations between this description and an image of the same that will represent the effect and types of pasture utilization by the animal. Any representation that is made of the pasture, with a goal of analyzing its elements, processes, and possibilities for improvement should include its form or architecture (Harre, 1960).

The Platonic—and transcendent—meaning of form as the essential nature of an object (Lotspeich, 1963) is not enough to solve problems of an ecosystemic type: for that, it is necessary to define form operationally according to conventional heuristic norms. Therefore, the form of a pasture ecosystem should be described by means of its architecture (Maelzer, 1965a and 1965b; Udvardy, 1959).

It thus turns out to be convenient to formally define the concept of pasture to differentiate it from the concept of forage. A pasture has been defined as that ecosystem whose principal synusia produces plant tissue useable directly by herbivores reared for human consumption. Forage, however, is only that plant tissue that is directly usable by the herbivore reared for human consumption. The essential difference between the concepts is that, in the first case, it is a question of an ecosystem *in situ,* and in the second, of one of the ecosystem's components, namely, phytocoenosis, which does not contain any connotation of spatial arrangement in the original system but which is integrated into it with the abiotic components and with the rest of the elements of biocoenosis, generating a defined architecture or style.

The ordering or arrangement of the ecosystem's variables is represented by levels of integration and by topological organization (Caswell et al., 1972). Symbolically, it is represented by

$$\sigma\,(\eta)$$

where σ represents topological arrangement, denoting qualitative as well as quantitative aspects, and
η is the size of the variables of state that integrate the system, that is, the topological vector.

By definition, architecture ($\wedge$) is

$$\wedge = f\,(\sigma, \eta) \qquad (19)$$

The categorizing of defined topological arrangements implies the size of each category. Size is represented symbolically by the vector whose components, η_1 and η_2, correspond to number and mass or volume of topological elements, respectively. The topological components that constitute the architecture of the ecological system are represented by $\sigma\,(\eta)$. The way to modify a given topological arrangement is by altering the components of the topological vector, namely, its number (η_1), its mass or volume (η_2), and its spatial-temporal dimension (σ). The integration of all the components (a, b, ..., z) that constitute the ecosystem's pasture architecture is represented as:

$$\wedge = f\,[\sigma_a(\eta_a),\ \sigma_b(\eta_b), \ldots, \sigma_z\,(\eta_z)] \qquad (20)$$

The integrated group of ecosystem components behaves in a different way from its simple sum, since emerging holistic attributes belonging to the general topology of the system appear. These emerging properties are a result of the change in conditions of restriction of connections among topological components, an event that modifies ecological functions of the ecosystem's components regarding rules of allocation of the former to the latter. In other words, the change in topological arrangement among components is achieved through one of the following:

a. change of number (η_1) and size (η_2) of some component; or

b. change in spatial ordering of the components (σ); or

c. alteration in the interchange relations of matter, energy, or information of the components.

Forage and pasture

The essential differences between forages and pastures are therefore centered around the facts that for a pasture,

a. There is a greater number and diversity of elements than in forage.

b. Not all its components are usable by the herbivore.

c. The topological arrangement (σ) of its usable components is a result of other attributes of the system, and it has been defined as such.

An essential difference therefore exists between forage and pasture, that rests in the topological arrangement of plant structures usable by the cattle. This difference—that can be of considerable magnitude, especially in pastures characterized by a high proportion of foliage support elements—is not formally considered in the laboratory analyses that are practiced for determining pasture quality. In these analyses, the topological arrangement of the usable plant components is systematically ignored, so that only forage quality and not pasture quality can be quantified with these components. Descoings' study (1975) identified morphological types of graminoid species that could occasionally have similar bromatological values but different architectures, thus generating pastures of different qualities.

Disregarding for the moment the bromatological value of plant tissues and organs, the problem can be centered only on form or topological arrangement of the pasture's plant components. Form, that in each case corresponds to a determined style of topological arrangement, necessarily has an origin. The corresponding process is termed morphogenesis (Thom, 1975) and occurs within the framework of action of two other different processes. One of them is genetic evolution of organisms and populations, where iterative action of the production mechanisms of variability and selection of the best adapted organisms lead toward the formation of genotypes—and phenotypes—structured ad hoc for the system. The other process is of systemgenesis, which, through ecological succession, leads toward metastates that can end in a climax, or rather, as usually happens, in a disclimax.

The final result of this process is the development of an ecosystem adapted to the general environment, where the integrating elements of the system are found in harmony among themselves and with the environment. This situation may not be ideal for man and, in that case, it will be necessary to design an ad hoc architecture that will permit optimization of the system. For this work, breeders, ecologists, pasture growers, zootechnicians, and other scientists should be integrated to achieve an optimal design, not only of the forage plant but also of the pasture.

Design

Design can be defined as the creation of models for the purpose of optimizing a phenomenon (Wymore, 1976). According to this definition, design generates pasture models that satisfy a group of criteria, normally implicit, related to the improvement of a reality—the pasture—that is manifested by known phenomena.

The design is carried out in three stages. The first is begun with an idea from which, in the end, some concepts are derived, within a process that implies the creation of something that had not existed before. Therefore, this stage, rich in unexpected situations and inventions, constitutes the limit between imagination and reality. The second stage is the one in which structure is developed according to a given form. The third stage is the final definition of the structure in its last details. In this stage, the design is carried to reality (Blumrich, 1970). Dealing with a pasture, it is necessary to design the vital form of the plant—which is achieved through genetic mechanisms—as well as its topological organization, which occurs through ecological mechanisms and through system management and utilization.

Function of Architecture

Image

The architecture of the plant—or of phytocoenosis—should be described with the help of some model or image that will represent it (Flórez and García, 1972; Gary, 1976). Although it is not possible to elaborate images that will represent a phenomenon faithfully, exactly, and exhaustively, it is necessary to decide upon some model that will correspond, in a certain way, to reality and that will contain its relevant elements according to the purpose pursued in its elaboration. Therefore, the model should be specific.

The image that will be elaborated will allow us to understand and state the phenomenon as it is presented in nature. Once that objective is achieved, it is necessary to find the solution, which implies returning to the phenomenon. The image, as a result, should be able to contrast itself with the phenomenon. In the study of pasture utilization, the image should permit the quantitative description of its discharge in a topological dimension, because of dealing with a system whose attributes are related to the topological organization of forage in the ecosystem.

The elaboration of isomorphic images of the pasture's architecture can be achieved through the procedure of stratified cutting in the vegetation, proposed by Monsi and Saeki (1953), which has been modified by Gastó C. and Olivares E. (1979) for specific situations such as the description of shrubs that grow in an isolated manner or in low densities. This procedure allows us to describe vertical profiles of pasture vegetation.

Instead of describing vegetation through cuttings of the horizontal strata—thus constructing a vertical profile of the vegetation—Gastó C. and Olivares E. (1979) generate a concentric image of the components. A shrub (*Atriplex repanda*) was studied, one whose form, when grown in isolation, approximates a hemisphere. As a result, it was described with an image adjusted to that geometric form (Figure 6) in which the active, passive, and changing-state components were indicated. In the same manner, distribution curves

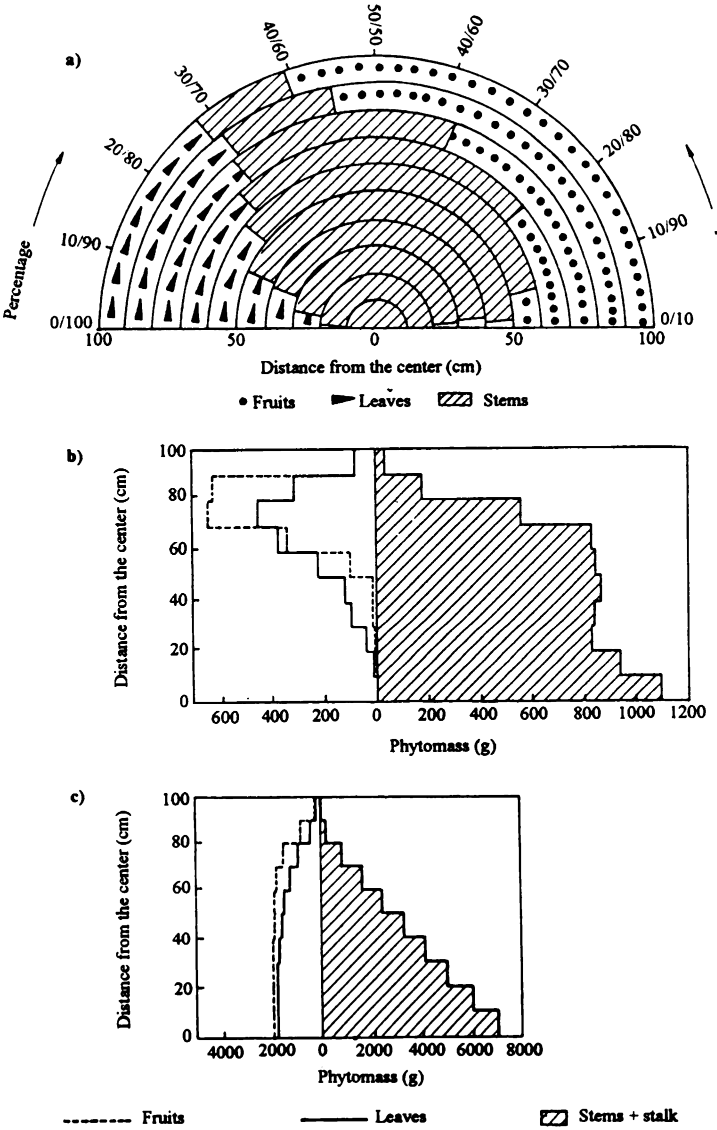


Figure 6. Isomorphic images of an *Atriplex repanda* Phil. plant in an 8-year-old pasture used by sheep with a 12-month frequency. (a) Outline of stratification of cuttings on the plant in a hemispherical manner. (b) Noncumulative stratification, by layer, of the active, passive, and changing-state components. (c) Cumulative stratification. From Gastó C. and Olivares E., 1979.

of the phytomass components were presented, representing the isomorphic functions of the plant (Figures 7 and 8).

Homomorphic model

The proposals of Shinozaki et al. (1964), relating to the tubular theory—where the existence of a relation between active and passive tissue is proved—make it possible to establish general relations that allow homomorphic description of any plant architecture. Starting from some of the authors' postulates, and employing experimental results obtained in the characterization of the pasture's architecture, a homomorphic model that allows us to characterize the plant's form with only two variables was proposed (Gastó C. and Olivares E., 1979).

The plant's form should be adjusted to the characteristics of the constituting material—especially of the sustaining tissue, that is, stems—as well as to the mass and location of the elements that are supported—in this case, leaves, fruit, and stems located in upper layers. Therefore, there exists a close relation between the supported mass and the sustaining mass, which should be related to the resistance belonging to the material.

Shinozaki et al. (1964) determined a straight-line relationship between both masses that partially characterizes the plant. They concluded that the straight-line function between foliage and sustaining tissue is discontinued when the plant's structure increases beyond a certain value until, finally, the increase in support is not accompanied by a corresponding increase in foliage.

The results of the study indicate that the relation between sustaining tissue and foliage is adjusted to an exponential function of the following type:

$$y = A(1 - e^{-bx}) \qquad (21)$$

where b = the slope of the curve; and
A = the value of the asymptote in y, when the foliar phytomass reaches a maximum.

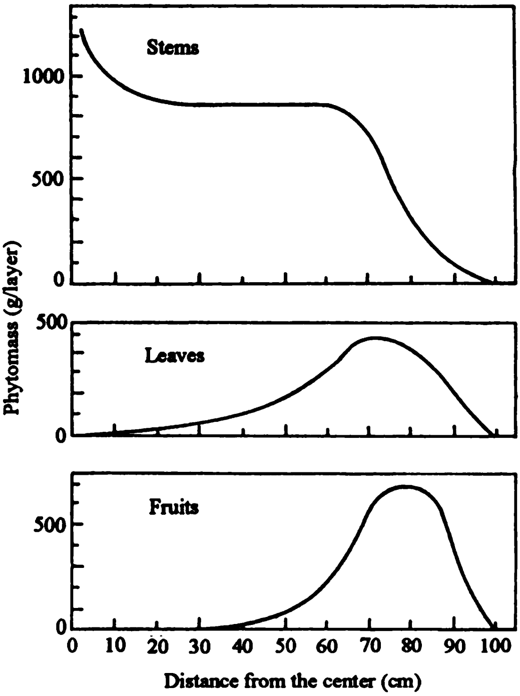


Figure 7. Isomorphic image of the elements of the architecture of *Atriplex repanda* plants, before their utilization, indicating the phytomass of each component in the respective layers (Gastó C. and Olivares E., 1979).

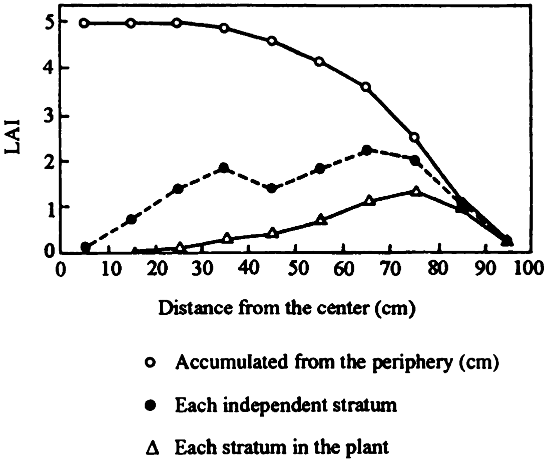


Figure 8. Isomorphic image of leaf area index (LAI) of *Atriplex repanda* plants, before their utilization (Gastó C. and Olivares E., 1979).

The importance of this relation lies in the fact that with only knowing the value of the asymptote and that of the slope, it is possible to describe the plant's architecture (Figure 9). The characterization of the pasture through the elaboration of its homomorphic image—as has been indicated—is a requirement for the establishment of general relations between the pasture's architecture and its discharge function.

Discussion

The problems of pasture management and utilization can be put in a context that will consider the architecture of phytocoenosis, the latter conceived as a unit of loading of matter, energy, and information. They should also be proposed within the context of the general discharge process, described in the framework of the general equation of discharge analyzed above.

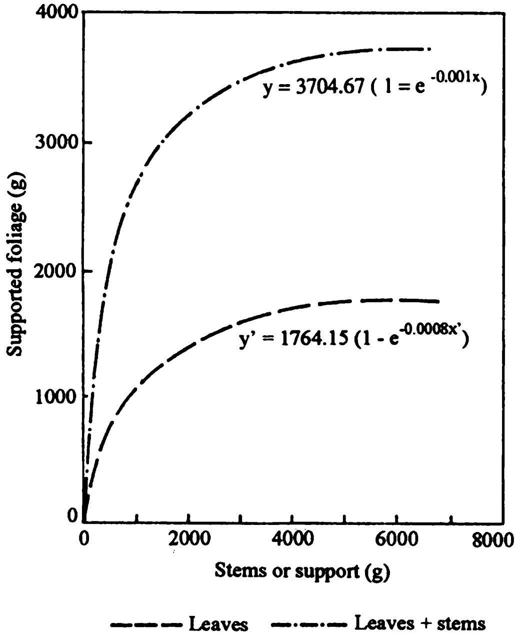


Figure 9. Homomorphic model of the architecture of *Atriplex repanda* that represents the relation between phytomass of foliage (or that of foliage and fruits) and that of stems (Gastó C. and Olivares E., 1979).

Form has been analyzed from diverse angles: metaphysical, physical, geometric, of design, and, above all, biological. From this last dimension, form acquires multiple expressions, centering its analysis in diverse anatomical and morphological interpretations that, in general, are distinguished by their degree of faithfulness, precision, and detail.

From the time of Linnaeus, the floral and fruit organs represented specificity of the individual and, as a result, morphology was concentrated on those structures, taking away consideration of vegetative structures. Later, with the development of cytology, genetics, and the laws of heredity, cellular, and chromosomal structure acquired greater importance. Nevertheless, the form of the whole plant, or of phytocoenosis in the ecosystem, has not received the attention that it merits.

In the design of pasture ecosystems, the abstract characterization of form is required in a first stage, where form is considered as a group of structures, processes, and events that generate the essential attributes of the ecological system such as stability, homeostasis, resilience, productivity, and longevity. These attributes should be considered in the genetic design of plants and in pasture improvement in general. Without a general abstract model (that will be simple in an extreme and that will represent the phenomenon faithfully), it is difficult to design pastures. When this model is available, it is necessary—in searching for better species and phytocoenosic morphologies—to employ empirical procedures that, through successive approximations of trial and error, will finally lead to the proximity of the solution. This process is apparently very complicated.

A pasture should be considered as a natural accumulator whose purpose is to transform and accumulate matter, energy, and information in conditions such that it can be discharged according to certain modalities and with a defined flow toward the consuming herbivore. The pasture's attributes as an accumulator can be developed and optimized within the context of general principles and laws applicable to accumulators, and subject to a modification in structures that make up their architecture.

The minimum persistent phytomass—that remains in the pasture—is a result of the plant's architecture. Passive components, especially sustaining and defense organs, may not be harvestable because of their morphological structure, and therefore they remain in the plant after the pasture has been used by the animal. The conformation (architecture) and habits of the harvester also affect the residue of unharvestable phytomass of the phytocoenosis. The interaction of the architecture of phytocoenosis and zoocoenosis with types of management and utilization of the ecosystem determine the magnitude and qualities of residual phytomass after pasture utilization.

Characterizing the architecture of the pasture's phytocoenosis, as a function of its parameters of architecture and discharge, is important for discussion of pasture improvement. The model of architecture and discharge, presented in this work, is a search for abstract images that will allow us to find a general solution to the problem. In this relation between the plant's architecture and its discharge attributes, the problems that the pasture sets up, as well as the breeding of the species that make up the pasture, are integrated better.

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Glossary to Chapter 6

The following glossary defines the technical terms used in this chapter. The author is a specialist in the mathematical interpretation of pasture ecology.

Accession = *see* Entry.

Anthropic = relative to the influence that man exercises on his environment through opposition to the natural influxes that the environment receives. Example: a fertilized soil.

Artificialization = transformation of a natural state of the ecosystem into an artificial one.

Biocoenosis = collectivity of living beings in a unit of environment. Biotic community formed by animals and plants that are mutually conditioned; it is maintained across time within a defined territory and in a state of dynamic equilibrium through the reproduction of its own organisms that integrate it, depending only on the inanimate exterior environment and not—or only in a nonessential way--on organisms outside the biocoenosis. It is usually divided into zoocoenosis (animal collectivity) and phytocoenosis (plant collectivity).

Biotype = (biological form, biological type, biotype) = category in which plants are included—from any systematic position—that fundamentally agree in their morphological-biological structure and, in a special way, in characters related to adaptation to the ecological environment. Example: a tree, shrub, or grass are, more or less, defined biological forms.

Captive population = one that is attacked or destroyed (consumed) by another or other organisms as depredators.

Climax = (climax formation, from the North American geobotanists) = final stage of the equilibrium in the geobotanical succession (or regional stage of stable biological maximum). Example: a natural forest is a climax; destroyed by man, it is substituted by another type of vegetation (shrubs, pastures) or by rotated fields. If the region were abandoned to itself, it would finally reproduce the native climax.

Density (caloric) = mean dispersion of each component, in the quantitative analysis of a synusia. It is considered on Norlinn's 10-degree scale, that takes in species or densities that are *scarce* (grades 1 and 2), *spread out, abundant*, or *closed* (grades 8, 9, and 10).

Disclimax = distinct from the climax, it is a community that is established when the climax is destroyed by, for example, grazing, or cropping.

Ecological system = coordination of plant organisms according to characteristics of the environment that they inhabit.

Ecology ("plant" is implied) = study of the relations between plant life and the seasonal environment. Study of the organism in relation to the *environment* in which it develops, figuring out the influences of this environment—organic as well as organized—on that organism (mesological influence). If physiology studies the *causes* of vital phenomena, ecology focuses on the effects (of the environment on plant organisms).

Ecosystem = system integrated by a community of animals, plants, and microorganisms, with the physical and chemical environment (abiotic environment) interrelated with them.

Ecotype = variety or lineage within a species, adapted to a particular environment (*see* Entry).

Entry = plant species or ecotype of homogeneous and constant morphological characteristics and of common and stable genetic characters (homozygous genome). It is principally a taxonomic concept.

Germplasm = reproductive cell; by extension, any cell or group of cells (germinal or somatic) capable of transmitting biological heredity.

Harmony = proportion and correspondence of the parts of a whole.

Holistic = that possesses, as an organic or integral totality, a reality independent from the simple sum of its parts, and is larger than those parts.

Homeostasis = in superior animals, the capacity to conserve a constant internal status and a certain independence from the environment.

Homomorphic (homomorph) = of a similar form although possibly of a different structure. Organisms of very distinct systematic entities that offer a similar aspect. Of a constant form within the species (= uniform).

Host = a grouping of relatively undefined limits. Example: a school of fish that follows a defined route in the ocean. Group of families related among themselves.

Isomorphic (isomorph) = of the same form although, at times,of a distinct structure; said of similar organs of diverse plants.

Grassland (in phytogeography) = region in which the simorph "graminetum" dominates, whether it is mesophytic, hygrophytic, or xerophytic (the last of steppeland character).

Open population = one in which plants are more or less spread out, and in which an invasion of other organisms can easily occur.

Pasture (pasture land) = grassland = land where there is abundant grass; fertile meadow that can be cut; site where cattle graze.

Periodicity = regular succession, at determined times, of diverse vital phenomena. If it depends on external factors, it is called etiogenic periodicity; if it depends on internal factors, it is called autonomous periodicity.

Phytocoenosis = more general unit of the collectivity that encompasses the idea, not only of cohabitation in the environment but also of a certain objective relation of plants among themselves.

Phytomass = sum of all the plant structures of a medium such as roots, stems, leaves, etc.

Resilience = quantity of a body that, after being stretched out, folded, or, especially, compressed, can recover its initial form or position.

Secondary production = plant growth (or succession that occurs after partial or total destruction of vegetation of an area, caused directly or indirectly by man.

Structure (biocoenotic) = characteristic combination of subordinated communities in a biocoenosis.

Synesia = a more general unit of the plant community. Specialized botanical cohabitation, that is, habitation of a sum of individuals in the same exterior environment. Synesia simply expresses an evident reality. Phytocoenosis (*see above*) includes the concept of community.

Synusia = ("existence in common" = society) community made up of species belonging to a biotype determined from uniform ecological requirements. Example: the arboreal stratum of a pine grove. Ordinarily, a certain number of synusiae intervene in the structure of an association. (The term "symorphic" has practically the same meaning.)

Systemgenesis = origin or creation of a system, that is, of a group of interrelated factors, definable in terms of structure and function.

Zoocoenosis = community of animals in a unit of environment, where they not only cohabit but they also maintain a certain objective relation among themselves (*see* Phytocoenosis).

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Chapter 7

Germplasm Evaluation by Cutting and Grazing in Small Plots: Comparison of Results

Andrew L. Gardner*

Abstract

The evaluation of pasture plants is complicated by the fact that no absolute yield exists with which experimental results can be compared. Evaluation techniques should therefore simulate as far as possible the conditions to be encountered on commercial farms, thus suggesting that modifications to evaluation methods will be necessary on a regional basis. Such considerations can be introduced at an early stage of germplasm evaluation. When cutting techniques are used to simulate grazing, care is required to ensure that no interaction between germplasm and defoliation method exists. In pure grass swards, defoliation by cutting would be acceptable, but for mixtures the selective effect of the grazing animal is preferable. While some transfer of fertility may exist when a series of plots are grazed together, this effect could be greatly exceeded if uneven grazing occurs over the area. Grazing by many animals for a short period of time is not representative of normal management and offers little advantage over a cutting technique. Only by measuring yield at critical times of the year can realistic grazing periods and grazing pressures be used.

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Introduction

The evaluation of pasture plants is fraught with problems not encountered in the purely agronomic evaluation of crop plants. In the first place, the grazing animal is an additional complicating factor and, under most circumstances, the herbage produced must be converted to an animal product before it can acquire an economic value. Secondly, because the techniques used to measure pasture production and utilization affect the productivity of the pasture, there can be no absolute pasture yield with which to compare the results of one evaluation technique or another. This is because we are dealing with plants that are repeatedly harvested, either by cutting or grazing, and what is done to a plant one week will affect its production the next week, month, or even year.

The situation is therefore very complex: the experimental techniques used provide variable results which are to be extrapolated to commercial production systems that themselves are variable. The best that can be hoped for is to provide guidelines and alternative solutions which can be modified to the requirements of the individual producer.

In 1947, Lynch suggested that better techniques of pasture evaluation were necessary. Thirty-four years later, Hodgson (1981) was repeating this plea. Oram (1972) believed that poor evaluation techniques were probably responsible for the lack of release of new, and better, pasture grasses, citing the example of Australia where, after extensive testing of annual grasses, only one cultivar was released in the past 70 years. This cultivar had been developed by selecting individual plants from grazed pastures in the region where the new cultivar was required.

What this example suggests, and what has become increasingly accepted in recent years, is the need to consider where and how pasture plants are to be used and to adapt the evaluation technique accordingly. As Morley (1978) stated, "It might be almost irrelevant, for example, to discover that one cultivar withstands defoliation to ground level better than another if such treatment is not likely to be imposed on a significant fraction of grasslands in real animal production systems."

The following discussion of cutting and grazing techniques emphasizes this need to keep in focus the real, or conceptual, production systems where the plants will be used when designing and interpreting pasture evaluation experiments.

Objectives and Techniques of Pasture Plant Evaluation

It may seem unnecessary to raise the point that a pasture evaluation program must have a definitive stated objective, but how often is it said that the objective is to find an improved species or cultivar? The next question must be: improved for what: greater total yield, better seasonal distribution, better persistence, or something else? There seems little point in producing "improved" plants and then looking for a place to use them. The objective must surely be to find a plant that will correct some defined deficiency in native or naturalized species or in currently available selected plants.

If, for example, the commonly used grass were capable of producing 20,000 kg dry matter/ha with an average digestibility of 65% and good quality retention for dry-season grazing, then we should perhaps be content with this and devote our resources to some more rewarding exercise. In most regions of tropical America this situation probably does not arise and, especially with tropical legumes, there is an urgent need for persistent and productive plants. It is, however, worth keeping in mind that plant selection and evaluation may not be the best use of scarce resources.

Put in another way, what is required is market research. This is an essential step for any successful enterprise, to make sure that there is likely to be a need and demand for the product that has to be sold; in this case, improved pasture plants. This means that the clients (farmers) must be identified and described, as must the problems and constraints of their systems of production.

Such considerations would only be necessary toward the end of an evaluation program but, if they are considered from the beginning, more objective and relevant evaluation techniques can be devised. Porzecanski et al. (1979) conducted a preliminary evaluation of grasses and legumes in Mato Grosso do Sul, Brazil, with two main production systems in mind. The first system was an extensive beef cow-calf system on poor land where it was unlikely that fertilizer would be used. The second system was a semi-intensive beef rearing and fattening on cultivated pastures established after two or three years' cropping, mainly of rice, where some residual fertilizer from the cropping phase was available to the pasture. The preliminary evaluation was therefore done at two fertility levels, natural fertility (no fertilizer), and improved fertility where all known deficiencies were at least partially corrected. Needless to say, considerable interaction was found between fertility level and plant productivity and, after only two years of work, the program was on its way to providing plants for the two defined and distinct commercial production systems.

Considering the large differences that exist among regions of tropical grasslands in the Americas, it is difficult to understand how or why evaluation techniques should be standardized. Even within a country such as Brazil, the ecology and requirements of pasture plants in the Amazonas, the dry northeast, and the Cerrados of the central plateau are so vastly different as to require separate introduction breeding and evaluation programs. It is true that some basic concepts can be agreed upon which will influence the choice of evaluation techniques such as the desirability of cutting or grazing. But decisions on fertility levels, the need to evaluate grasses alone or with legumes, or the frequency and intensity of defoliation must be regional, or systems oriented, the decisions depending on how the local agronomist sees the problem to be solved.

Having clearly defined how, where, and for what situation a plant is to be introduced, the decision on which evaluation technique is to be used should be easier. The effects that some of these decisions have on the results of the evaluation studies, as well as the precautions needed in interpreting and extrapolating these results, will now be considered below.

Defoliation by Cutting or Grazing

Because of the large number of introductions or shortage of seed, initial evaluation is usually done in the absence of a grazing animal and performed by cutting and removing the herbage produced. This discussion, however, will be concerned with the next phase of evaluation where plant numbers have been reduced to manageable levels and seed supply allows the establishment of small replicated plots where the effects of the grazing animal can be evaluated.

Before discussing the relative merits of the cut-and-remove or cut-and-graze techniques, the decision regarding frequency of defoliation should be considered. The criterion adopted for defoliation is often the time at which plants reach "grazing height" and, in many cases, this involves monthly defoliation during the main growing season. As plant growth becomes restricted by water stress or temperature, or both, the defoliation interval becomes longer, to an extent that a plant is never defoliated because it did not reach the predetermined height. This is contrary to many commercial situations where, during stress periods, because of more or less constant stock numbers under yearlong grazing, the defoliation interval decreases and plants are put under considerable stress. The intensity of such stress is mainly a function of the length of the restriction period and the stocking rate. Unless this real life aspect is taken into consideration there is a danger of selecting plants totally unsuited to the system in which they are expected to be used.

It could be argued that there is no need to be realistic in second-phase evaluation where no animal data are yet available and that unadapted plants will be rejected at a later stage. While this is so, plants are released without evaluation in terms of animal product, signifying a waste of resources in testing plants that should have been eliminated earlier. Even if all selections passed through the animal phase before release, early elimination is less wasteful.

The difference between cutting and grazing, with respect to the amount of plant material removed, stems from the fact that a cutting blade is unselective, while animals, even at high stocking densities, are selective and do not remove all herbage at one moment nor at a uniform height. This results in different rates of regrowth from cut and grazed plants. However, the fact that yields under cutting may differ from yields under grazing is not a reason to reject cutting as an evaluation technique.

By restricting this review to germplasm evaluation techniques, some errors caused by extrapolation from cutting to grazing can be ignored. For example, Woodman and Norman (1932) concluded that, since a 5-week cutting interval produced most starch equivalent, rotational grazing with a 5-week cycle would also maximize animal production. That this was not necessarily so is now history and, although important from a management point of view, such considerations need not enter this discussion.

What is of interest and importance is the possibility that a treatment by evaluation technique interaction may exist whereby one plant could be superior to a control or standard plant under cutting but inferior under grazing. Since these evaluation trials attempt to predict what will happen when the plants are eventually grazed in commercial systems, this type of interaction is obviously undesirable. If the utilization system envisaged is cut-and-carry, then such considerations do not arise but the cutting regime used must simulate the real world system.

The type of treatment-technique interaction that could arise is seen in Caro-Costas and Vicente-Chandler's (1961) example where height of cutting interacts with pasture species (Table 1).

Two solutions exist that can mitigate this problem. One is to use cutting heights appropriate to each species, or, if these were unknown or not desired, then a height is used that is closest to the contemplated commercial management. Neither solution is perfect, but the agronomist must be aware that results could be biased by selecting a specific cutting height when deciding on experimental methods and interpreting results.

It is therefore not really surprising that results from cut plots sometimes give only poor or erroneous estimates of performance under grazing. For example, Watson and Whiteman (1981) conducted a grazing experiment at four stocking rates with *Brachiaria mutica, B. decumbens*, and *Panicum maximum* because cutting experiments had

Table 1. Yields (lb of dry matter/acre)[a] of five tropical grasses under two cutting heights.

Cutting height (inches)[b]	Molasses	Pangola	Pará	Napier	Guinea
7-10	12,056	19,937	19,720	23,201	25,223
0-3	3,945	29,296	24,728	27,880	24,651
	**	**	**	**	NS

a. 1 lb = 0.4536 kg; 1 acre = 0.4047 ha.
b. 1 inch = 2.54 cm.
** Difference of yields is significant at 1% level.
NS Difference of yields is significant at 5% level.

SOURCE: Caro-Costas and Vicente-Chandler, 1961.

suggested that the commonly used grass, *B. mutica,* was inferior to the others. The grazing trial, however, showed *B. mutica* to be superior to *B. decumbens*, with *P. maximum* the poorest. In fact, the animals had to be withdrawn from the *P. maximum* paddock at the highest stocking rate.

When mixtures of tropical grasses and legumes have to be evaluated, the cutting technique becomes more problematical because of palatability differences. Unless grazing is extensive and rotational, the animal will selectively graze the grasses during the main growing season—hardly the same situation as a uniform unselective cut.

This effect can be appreciated from the results in Table 2, which come from a second-phase evaluation of 25 tropical legumes where common grazing was interspersed with sampling periods to estimate growth in different seasons. In this experiment, being conducted at the Centro Nacional de Pesquisa de Gado de Leite (CNPGL), Minas Gerais, Brazil, the total area available for grazing was 6500 m^2, of which the actual plots occupied 3000 m^2 or 46%. The area had been grazed since 8 January by a variable number of animals and, for 3 weeks, by four dairy heifers of 200 kg average liveweight. Visual estimates were made on 22 April at the end of the wet season.

Only the results of a representative selection of legumes are given in Table 2 which shows that, despite a fairly high stocking density, several legumes were ungrazed. The accompanying molasses grass was grazed to within 10 cm of soil level. If these plots had been cut rather than grazed the end result would have been a reduction in legume persistence and a biased estimate of the quality of the mixtures for the dry season. Jones et al. (1980) did find, however, that the best performing *Macroptilium atropurpureum* line gave, under separate grazing, the same results as those of the legume under a cutting regime.

Another differential defoliation effect of grazing compared with cutting is caused by uneven grazing over the experimental area. Such a case was reported by Gardner and Centeno (1966) in an experiment

Table 2. Visual estimates of animal preference for legumes (0 = not grazed, 1 = all grazed) by crossbred dairy heifers under common grazing of tropical legumes growing with *Melinis minutiflora*. Means of three replicates.

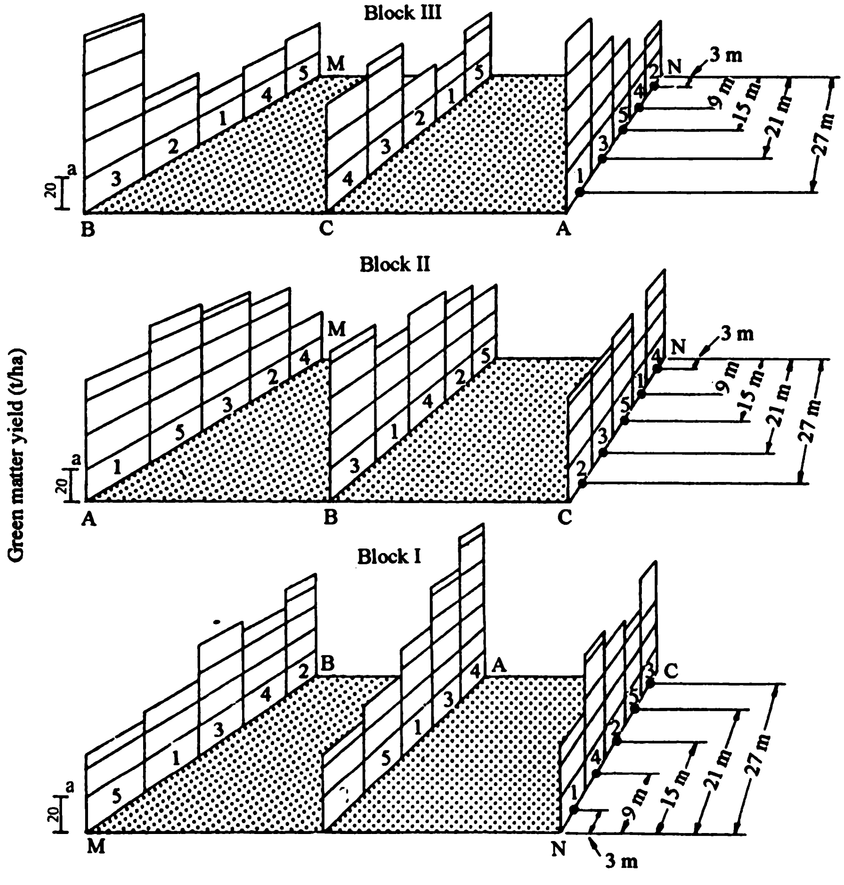
Legume	Proportion of legume grazed
Dolichos axilaris[a]	0
Indigofera subulata (Minas Gerais)	1
Macroptilium atropurpureum cv. Siratro	1
Stylosanthes guianensis cv. IRI 1022	1
Stylosanthes guianensis cv. CIAT 63	0
Stylosanthes capitata (Viçosa)	0
Stylosanthes scabra (Bahia) CGL 841	0
Galactia striata (commercial)	1/3
Teramnus uncinatus CGL 721	0
Centrosema pubescens (commercial)	0
Macroptilium bracteolatus[b] (Minas Gerais)	0
Neonotonia wightii cv. Tinaroo	1/3
Pueraria javanica (commercial)[c]	0
Rhynchosia minima CGL 074	0

a. Now known as *Macrotyloma axillare*.

b. Now known as *M. bracteatum*.

c. Now known as *P. phaseoloides*.

comparing five cultivars of *Trifolium repens* under three grazing frequencies. The yields of forage obtained in the second year of the trial are given in Figure 1. There were increasing production gradients in Blocks I and III from the lines M and N. A similar situation, although less marked, was evident in Block II. It was also evident that the gradient was greater under grazing frequencies A and B, while under frequency C, especially in Block II, it was hardly detectable.



a. ⊢—⊣ = 20 t/ha.

Figure 1. Green forage yields of five varieties of white clover for the period December 1963-December 1964. Varieties are numbered 1-5; frequencies of grazing are denoted as A, B, or C; and distances from base lines M and N to plot centers are 3, 9, 15, 21, or 27 m.

The important, and unfortunate, fact brought out by this diagram was that the yields appeared to be related to the positions of the subplots (cultivars) within the main plots (grazing frequencies) and not to the growth potentials of the cultivars. The fact that the observed effect was more marked in grazing frequencies A and B was no doubt a result of the number of grazings (maximum of two days each) which were 26, 17, and 14 for frequencies A, B, and C, respectively.

It was possible to adjust the observed yields by covariance, using as the independent variable the distance of the center of each subplot from base lines M and N as shown in Figure 1. What has to be discussed here, however, is why and how these production gradients occurred.

No quantitative data were taken by which the grazing behavior of the sheep could be characterized, but it was observed that subplots nearest to the lines M and N (Figure 1) were preferentially grazed and that resting periods were spent at the other extremes of the main plots. Although uneaten herbage was removed by postgrazing trimmings cuts, the effect was cumulative and it became increasingly difficult toward the end of the trial to leave an even stubble.

It is probable that the rectangular shape of the main plots (30 x 10 m) induced the animals to congregate at one end, as was also noted by Sears (1944). Moreover, the long axis of the main plots was at right angles to a public road on one side and an internal road on the other side. Movement on these roadways may have caused the animals to rest at the points farthest from these sources of disturbance. This resulted in a poorer utilization of the soiled and trampled herbage while the more heavily grazed subplots had slower regrowth with a consequent weakening of the plants as the experiment progressed.

The effect of accumulative fertility as a result of excreta on the areas where the sheep tended to camp cannot be ruled out. However, because pure pastures of white clover were involved, it is probable that, to a large extent, urine nitrogen substituted for nitrogen fixed by nodule bacteria, thus producing a compensating effect.

The importance of the effect of uneven grazing, as measured in this experiment, can be judged by the fact that some observed yields were adjusted by as much as 25% (up or down) as a result of the covariance analysis. If relative yields can be masked to this extent then important differences could be overlooked or spurious results obtained.

One obvious solution to this problem is to individually fence and graze each plot but the cost of this may rule it out for experiments with many treatments. Where common grazing of plots is dictated by the nature of the experiment then square, rather than rectangular, paddocks should be used with a large discard area around the actual experimental area. A safe margin would probably be achieved with only half of the paddock covered by experimental plots. The experimental areas should also be situated away from outside influences such as roadways.

Transference of Fertility

Common grazing of a series of plots can introduce a further complicating factor, in addition to possible effects of uneven grazing, because of the return of nutrients in the feces and urine of animals. If an even return of animal excrement is assumed then this must result in a reduction in differences among treatments since higher yielding plots will receive fewer nutrients then they should, while lower yielding plots receive more than they should. The importance of this effect has been measured by Lynch (1947) who carried out two experiments comparing the response to phosphate plus calcium under separate or common grazing and found response increases of 7.9% and 4.2% when plots were grazed separately instead of together with several other fertilizer treatments. Sears (1949), comparing his proportional return of dung-and-urine technique with normal return, found that, although the ranking of treatments did not alter, the differences between treatments were greater under proportional return. Relative differences between treatments within systems varied as much as 19% according to the system used.

Before concluding that these results prove that common grazing should be avoided if real differences among pasture plants are not to be masked, it should be remembered that they were obtained under "mob grazing" by sheep on well-formed perennial ryegrass swards. If we move to sparse semiarid zone pastures grazed by cattle, the picture becomes very different. Vallis (1972) showed that considerable losses of nitrogen take place by volatilization of ammonia under dry conditions and sparse ground cover.

It, therefore, appears that transference of fertility can have an effect on relative yields, depending on the efficiency of nitrogen return. When cattle rather than sheep are grazed at stocking densities closer to commercial conditions, then the effect should be reduced if not eliminated. The errors introduced by not grazing (nonselective defoliation) would have to be set against a possible masking of difference by transfer of fertility.

Where only species or cultivars are being compared and not fertilizer treatments, the technique devised by McNeur (1963) of returning a mixture of organic and inorganic fertilizers could be useful. He estimated that his technique gave similar results to the proportional return of Sears' (1949) dung-and-urine technique. The possibility of separately fencing each plot has not been considered as a practical alternative, although if nitrogen levels are to be compared this would become necessary.

Effects of Nutrient Levels under Grazing or Cutting

Apart from fertility transference, some thought must be given to plant nutrient requirements under cutting or grazing.

In the case of potassium, Blue and Gammon (1963) and Wolton (1963) showed that, by cutting and removing the herbage, a deficiency can be created even where potassium fertilizer is applied. It would therefore be wise to monitor soil potassium availability to ensure that no artificial deficiency was being created. When grazing animals are present the problem should not occur.

The situation with regard to phosphorus is rather confused. McLachlan and Norman (1966) reported that grazed pastures would require less phosphorus than cut ones, while Ozanne and Howes (1971) found exactly the opposite. What is important, from the germplasm evaluation point of view, is that the tests be carried out at a soil phosphate level similar to where the plants are to be used.

Whether the plots are cut or grazed should not, over a few years, cause important divergence from real life conditions because inorganic phosphorus becomes only slowly available, while organic phosphorus is even slower unless feces are incorporated into the soil (Bromfield, 1961).

As has been mentioned with respect to transference of fertility, the effect of urine nitrogen on herbage growth will depend to a large extent on local conditions. However, if grasses are being evaluated with a common legume then no nitrogen fertilizer is likely to be applied but grazing animals would be necessary to maintain a realistic grass-legume balance (Frame, 1966; Sears, 1949). Although common grazing may introduce transference of fertility effects, the penalty for not grazing on grass-legume pasture may be botanically atypical swards. Tropical legumes, like their temperate counterparts, tend to disappear when nitrogen is applied to grass-legume pastures (Jones, 1970).

With respect to pure grass pastures, there will be a need to apply nitrogen to maintain productivity and the amount used will depend on the researcher's decision as to where the results are to be applied. If an intensive system of high nitrogen input is contemplated, then the moisture regime has to be adequate to ensure good utilization of the nitrogen applied. This means that nitrogen returned in urine would probably be effective in influencing yield. Does this then mean that grazing would be essential under these conditions? Not necessarily so, since the major interest would be in comparative yield of selected germplasm and not absolute yield.

If response to nitrogen of various grasses was a selection criterion then there may be a need to graze the experiment when a very high level (> 400 kg N/ha) was contemplated, because here the return through the animal would be important. If, however, lower levels of nitrogen were used, all grasses would probably still be on the linear part of the response curve even when fertilizer plus urine nitrogen were considered.

To Graze or Cut

Most researchers would agree that the early introduction of the animal in a germplasm evaluation program is desirable but, unless the animal management is realistic, the hoped-for results may not be achieved. Since relative defoliation, nutrient return, and treading effects are partly functions of the number and type of animals grazing a pasture, it follows that an artificial technique such as "mob grazing" may not truely reflect what is likely to happen in practice. The use of many animals for a short period would eliminate selective defoliation which could be a critical aspect of grazing. Also, nutrient return and treading effects would only stimulate this one specific form of intensive management. It can therefore be legitimately asked, is there any benefit to be derived from this technique compared with cutting?

Insofar as selective grazing is concerned, nothing would be gained and the treading effect, while present, would be completely atypical if, for example, a grazing period coincided with a heavy rainfall. Nutrient return would be achieved, and could be important in maintaining a realistic botanical balance in grass-legume mixtures, but would also result in a reduction of treatment differences by transference of fertility. The importance of these fertility effects would depend on local soil, plant, and climatic conditions.

It therefore appears doubtful if worthwhile progress, in terms of realism, can be made by using a "mob grazing" technique rather than a simple cut-and-remove method, provided some simple precautions are taken.

Where more realistic grazing management is introduced, the problem of selective grazing may exist when many species are evaluated under common grazing. Where grasses are sown pure and grazing periods are interspersed with yield estimations, the occasional trimming cut can reduce or eliminate any tendencies of over- or undergrazing. In a current experiment evaluating 25 grasses of divergent growth habits at the CNPGL no problems in this respect have been encountered.

When the evaluation is to be of pure species sown in small plots not individually fenced, then a choice exists as to whether a cutting or cutting-and-grazing technique will be used. Mixtures, either of grasses or grasses and legumes, would be better grazed in a realistic manner since animal preference can so profoundly affect botanical composition. In these trials a continuous record of dry-matter production is probably not required, thereby allowing long realistic grazing periods. A few production recording periods would be sufficient to provide data on plant performance at points of major interest during the year. In the case of tropical legumes, considering current use and problems, it would be enough to know that a given introduction had persisted well under a certain grazing management rather than its dry-matter production under an unreal cutting sequence. A careful record would have to be kept of grazing habits so that results could be interpreted correctly and, should gross over- or undergrazing occur, the technique may have to be changed or a separate investigation carried out to detect the causes.

A technique does exist for the introduction of the important influences of stocking rate, grazing, and resting periods at the small-plot stage of evaluation (Gardner, 1967; Shaw et al., 1976). It may be considered worthwhile to use this method under certain circumstances in a second-phase evaluation trial.

Since the perfect method of germplasm evaluation has yet to be invented, the research worker has to decide, for his own particular circumstances, what would be the best course to follow. It is hoped that this review will assist in making this decision easier.

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Chapter 8

Selection of Pasture Cultivars from Many Germplasm Entries Under Grazing

Bert Grof*

Abstract

Grassland improvement work, particularly in the early stages of developing a program for tropical regions, involves a comparison of new accessions selected from wild populations whose potential as cultivated forages is often unknown.

Pasture species evaluation strategies employed at CIAT's main savanna research station in the Colombian Eastern Plains (Llanos Orientales) and appropriate techniques for testing large numbers of accessions under grazing are discussed.

During the 1977-1982 period, 41 accessions of 14 leguminous species and seven grass species have been screened with the techniques described. Results of preliminary grazing tests of *Centrosema* spp., *Desmodium ovalifolium*, and *Stylosanthes capitata* are reported.

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Introduction

Cultivated forage species must play an increasing role in livestock production in tropical regions of the world. They would help reduce the effects of deficiencies in native pastures, build soil fertility, and permit better livestock nutrition on a relatively economical scale. CIAT's (Centro Internacional de Agricultura Tropical) Tropical Pastures Program is concerned with improving grazing-land resources in the tropical lowlands ("llanos" and "campos cerrados") of South America. One major limiting factor to livestock production in these interior savanna regions is the low nutritive value of native grasslands which comprise inferior, fire, subclimax vegetation.

The introduction of improved forage grasses and the addition of a legume or legumes to supply the much-needed nitrogen (protein) is the most economical means of producing more beef and milk per unit area at lower cost. To achieve wider use of cultivated pastures, a first essential is to improve the system of forage plant introduction and to reduce the length of time which must be spent on small-plot screening tests.

Pasture research in CIAT during the past decade has been directed toward discovering the species and cultivars of legumes which are most suitable for and most persistent under grazing conditions, and how they can be established and maintained in association with competing grasses in a sown mixture.

The research that has been conducted is diffused in the sense that many species and genera are involved, especially in the early stages of germplasm evaluation. In our case, most of the species which eventually reach the advanced stage of evaluation in grazing productivity experiments are recently introduced and domesticated species whose performance as sown forages is largely unknown.

The forage species evaluation strategies reported in this paper are employed at Carimagua, CIAT's main savanna research station. The station is located at latitude 4°36' N, longitude 71°19' W, and 175 m above sea level. The "llanos" are predominantly isohyperthermic well-drained savannas where the wet season's mean temperature exceeds 23.5 °C. Annual rainfall, over 9 years, averages 2083 mm and is distributed from April through November. The soil is an acid Oxisol (pH 4.1) of low base status, deficient in N, P, K, Ca, Mg, S, and some microelements. In addition, the soil shows a marked Al toxicity: Al saturation is 86.5%.

Preliminary Evaluation of Forage Species

Pasture cultivars are usually selected by conventional screening methods: the first to be carried out are preliminary observations of agromorphological characters in row plots, for example, presence or absence of stolons, rhizomes, capacity of the species to produce viable seed; followed by cutting experiments carried out in small sward plots and in pure stand.

To be successful in forage species introduction and evaluation, a large collection of forage species with a broad genetic base must be available to the pasture researcher. If this prime requisite is met, the researcher is faced with a colossal dilemma: how to reduce this large volume of material to a manageable few species which are well adapted to the environment and which fit certain specific criteria.

At this stage of species evaluation, the principle of "inverted pyramid" should be employed. This involves rapid selection from a broad-based gene bank, using well-chosen parameters with the ultimate objective of identifying a few superior forage species for evaluation under grazing. Time-consuming measurements of plant height, spread, and yield should be avoided at this stage.

Additional Evaluation

After characterization and initial screening for resistance to pests and diseases, there are two or three additional steps in the evaluation technique that should be made before testing the species in grazing productivity experiments.

Small-plot clipping experiments are valuable for comparing new accessions with established cultivars. Clipping frequency tests can be used to simulate the effects of frequent or continuous grazing. In the case of grass-legume associations, the relative growth rates of component species will give an early indication of their compatibility under different frequencies of defoliation. For example, to find a legume companion for the aggressive, stoloniferous grass *Brachiaria humidicola* is difficult, but is of considerable economic importance. For example, *Arachis pintoi* (Krap *et* Greg.) is a wild peanut species from the State of Bahia, Brazil, that was introduced through the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia. Under evaluation, it showed promise to combine well with this grass under various frequencies of cutting (CIAT, 1982). Appreciable amounts of the legume were maintained in association with *B. humidicola*, apparently because of the legume's high initial growth rate after defoliation (Table 1). An observation such as this, however, has yet to be confirmed under realistic grazing conditions.

Measurement of Response to Grazing

Assessment of herbage cultivars or mixtures is a particularly complex problem. Most of the comparative production data is in terms of

Table 1. Dry-matter yield (kg/ha) of *Brachiaria humidicola* in association with *Arachis pintoi* under four frequencies of cutting.

Cutting frequency (weeks)	Grass (kg/ha)	Legume[a] (kg/ha)	Total grass + legume (kg/ha)
2	1702.8	316.4 (15.59)	2029.2
4	2366.8	678.0 (22.27)	3044.8
6	2697.2	602.0 (18.25)	3299.2
8	3248.8	707.2 (17.88)	3956.0

a. Figures in parentheses are percentages of dry matter.

dry-matter yield. For *Macroptilium* lines Jones et al. (1980) found a good correlation between dry-matter yield under cutting and dry-matter yield under grazing. However, they concluded from their experiments on animal production versus dry-matter yield that data collected from plots cut to simulate grazing must be extrapolated with extreme caution to actual grazing conditions. Results from several other experiments support these latter conclusions. Much has been written about the presence of the grazing animal as a factor in forage species and cultivar evaluation. There is a widespread belief that some species perform better when grazed than when cut but there are few experiments in which this hypothesis has been tested. There are experiences to the contrary as well, for example, in our trials, the tufted *Andropogon gayanus* cut at 6-weekly intervals yielded as well or better than stoloniferous species of *Brachiaria* (Grof, 1982). However, presentation yields of grazed *B. humidicola* and *B. decumbens* were significantly better than those of *A. gayanus* (Grof, 1982).

Evaluation of Several Species or Ecotypes Under Common Grazing

The use of animal production experiments is an elaborate and expensive way of measuring the relative productivity of species and selected cultivars.

In the initial stages of pasture species evaluation, it is often desirable to test a wide array of species or a range of ecotypes of the same species. It is impractical to consider testing all of them in terms of animal production. Because of the limitations of dry-matter yield data obtained under a cutting system of management, it is highly desirable that only some carefully chosen species be compared, using animal performance as a measure of productivity.

The grazed nursery

The effect of the animal on pasture plants can be determined by a technique where a large number of cattle are turned into a pasture comprised of a number of replicated plots of different species. The object is to graze intensively for a short period so all plots are defoliated and palatability effects will be reduced.

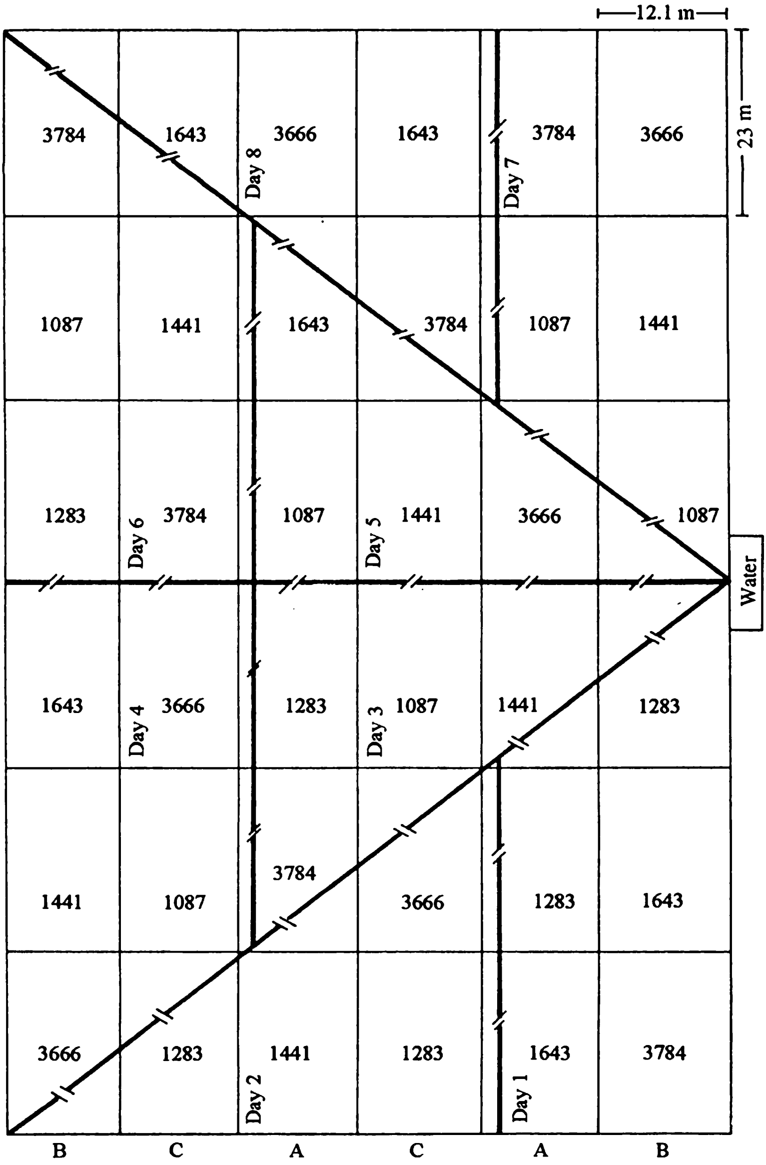
This technique was used in the evaluation of the first set of anthracnose-resistant ecotypes of *Stylosanthes capitata, S. macrocephala*, and *Desmodium ovalifolium*. Each of these legumes, from a total of 32 accessions, were established in replicated plots and were oversown with *Brachiaria decumbens* and *Andropogon gayanus* in a checkerboard design with subdivisions of 1 ha. During the dry season, 30 head of cattle grazed the total trial area of 12 ha and stock numbers were increased to 60 during the rainy season. Intervals between grazing averaged 4 weeks during the wet season and 6 weeks in the dry season. Stock numbers and grazing interval were adjusted so that most of the available forage was consumed in 2 days. Presentation yields, or dry matter "on offer," were recorded at the beginning of each grazing period.

"Close-folding"

A type of "close-folding" technique is being used in a current grazing test comprised of three grass species with six legumes. The inevitable preferential grazing is minimized by using electric fence lines. The 18 treatment combinations were established in duplicate plots and the total area of 1 ha was quartered with movable fence lines; within subdivisions, the movement of animals was controlled daily. Stocking rate was 2 animal units per ha and the trial was grazed for 8 days and spelled for 32 days during the 8 months of wet season and for 40 days in the dry season. A sketch plan of experimental layout is shown in Figure 1.

Testing advanced lines under grazing

Several species of *Centrosema* and ecotypes of *Stylosanthes capitata* and *Desmodium ovalifolium* have been selected and were available for preliminary evaluation under grazing at the Carimagua Research Station by the end of the seventies. A standard design consisting of 200-300 m^2 plots per treatment was employed and 10 or



Grasses

A = Native pasture
B = *Melinis minutiflora*
C = *Andropogon gayanus*

Legumes

1643 *S. macrocephala*
1087 *S. leiocarpa*
1441 *S. capitata*
1283 *S. guianensis*
3666 *D. ovalifolium*
3784 *D. ovalifolium*

Figure 1. Sketch plan of a grazing test plot of three grasses with six legumes, planted 4 July 1981. The area (1 ha) is subdivided by electric fence lines (—/⁄—).

more accessions were arranged in four randomized blocks. This area of 1.25 hectares was rotationally grazed as part of a set of three plots of the same size and similar design. The rotational cycle was 1 week of grazing and 2 weeks of spelling. A stocking rate of 2-2.5 animal units (AU = 420 kg) per ha was superimposed during the 8 months of wet season with one seasonal change to 1.6 AU/ha during the dry season.

Centrosema spp.

The forerunner of a grazing test was a clipping experiment in which 30 accessions of eight species of *Centrosema* were compared under a seasonal cutting regime. Grouped means of species indicated that for the llanos ecosystem, *C. macrocarpum*, *C. brasilianum*, *C. acutifolium*, and *C. pubescens* contain accessions of potential value as forage cultivars (Table 2). The annual *C. pascuorum* produced appreciable amounts of dry matter early in the wet season, but this legume completed its life cycle before the end of the rains. *Centrosema virginianum* is evidently not adapted to the very acid, highly Al-saturated soil of the savannas and the *C. schiedeanum* accession that was tested was badly affected by leaf diseases. These unsuitable species were discarded from further evaluation.

Table 2. Mean yields of dry matter of 30 accessions of eight species of *Centrosema* under a seasonal cutting regime during the period December 1979-March 1982, Carimagua, Llanos Orientales, Colombia.

Species	Number of accessions	Means[a] of all accessions DM (kg/ha) ($\bar{X}$ nine harvests)
C. macrocarpum	5	3814.78a
C. brasilianum	4	2773.47b
C. acutifolium	2	2757.38bc
C. pubescens	8	2391.62c
C. pascuorum	5	1089.81d
C. virginianum	2	
C. schiedeanum	1	1084.68d
Centrosema sp.	3	

[a] Values followed by a different letter are significantly different at $P < .05$ according to Duncan's Multiple Range Test.

In the follow-up grazing test, 16 accessions of promising *Centrosema* spp. were compared in mixture with *Andropogon gayanus*. All species in this trial were readily accepted by grazing animals and no preferential grazing was evident at any stage. The parameters used in the evaluation process were presentation yields or dry matter "on offer" and sown pasture composition. Stocking rate was 2.5 animals/ha during the 8 months of wet season and dry-season stocking rate was reduced to 1.6 animals/ha.

Presentation yields determined on 15 harvest or/grazing dates between October 1980 and March 1982 were in agreement with the results of the clipping experiment, that is, *C. acutifolium*, *C. brasilianum*, and *C. macrocarpum* produced high dry-forage yields under grazing as well. However, *C. acutifolium* yielded consistently more dry forage than the other two species which were outstanding mainly during the dry season. Further observations showed a better survival of *C. brasilianum* on account of its free-seeding habit while plant density declined in *C. macrocarpum* (Figure 2).

Stylosanthes capitata

Ten ecotypes of *S. capitata* representing early and mid-season forms were evaluated in association with *Andropogon gayanus*. Pasture characteristics studied included presentation yields and botanical composition of the pasture. All details were the same as in the *Centrosema* experiment.

In this experiment, dynamic changes were recorded in grass-legume content. Plant population of mid-season ecotypes showed a rapid decline in the second year, following establishment. Data on yield and pasture composition indicated that four early flowering, free-seeding ecotypes persisted and yielded better under grazing than two mid-season lines of *S. capitata* (Table 3).

Desmodium ovalifolium

This forage legume exhibited its ability to compete with aggressive stoloniferous grasses such as *Brachiaria humidicola*. Nine accessions

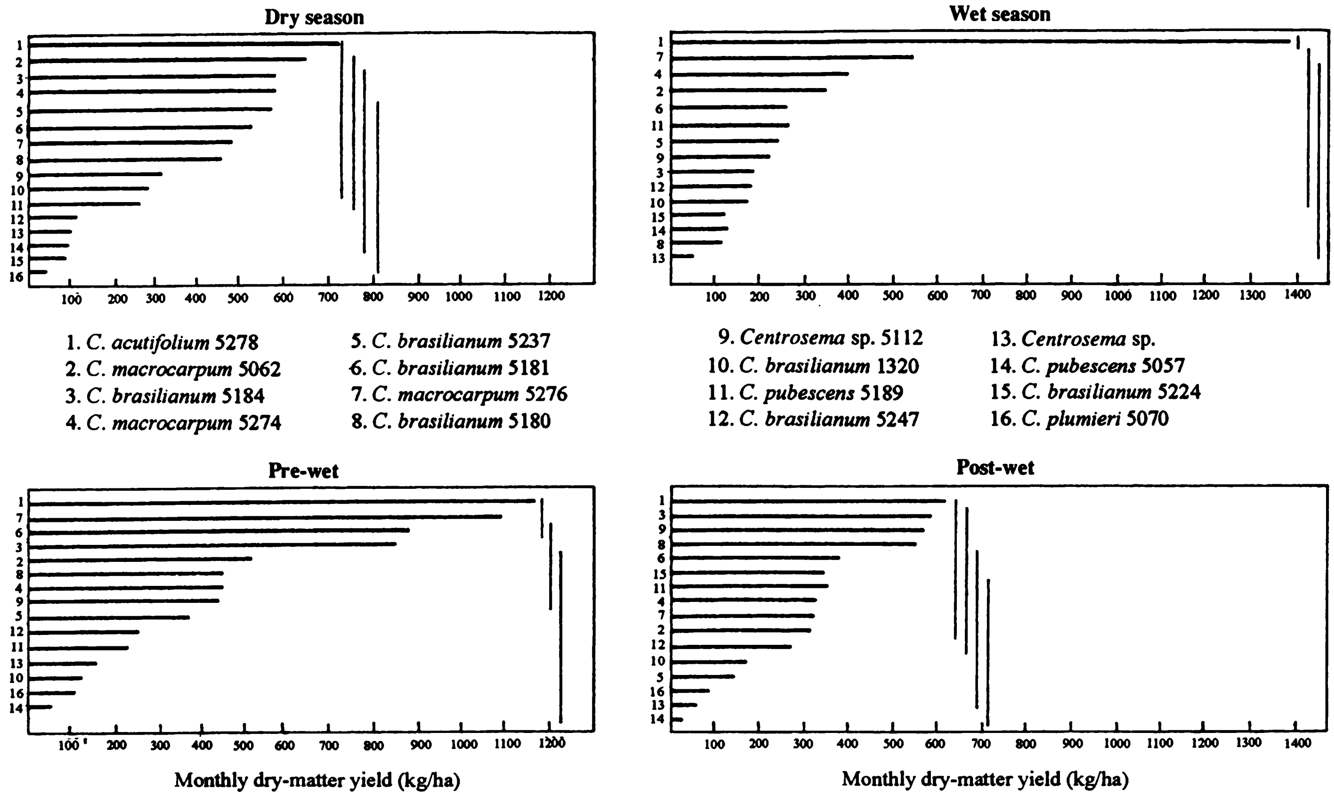


Figure 2. Monthly presentation yields (kg/ha) of 16 accessions of *Centrosema* spp. grown in association with *Andropogon gayanus*, Carimagua, Llanos Orientales, Colombia. Mean values connected by the same line are not significantly different at $P < .05$ according to Duncan's Multiple Range Test.

Table 3. Mean number[a] of plants of six *Stylosanthes capitata* accessions grown in association with *Andropogon gayanus* in a 3-year-old grazed pasture, Carimagua, Llanos Orientales, Colombia.

CIAT accession no.	No. of plants/m^2
1728 (early flowering)	26.00a
1693 (early)	22.85a
1019 (early)	21.58a
1943 (early)	15.20b
1318 (mid-season)	2.88c
1315 (mid-season)	2.50c

a. Values followed by a different letter are significantly different at $P < .05$ according to Duncan's Multiple Range Test.

of *Desmodium ovalifolium* were included in the standard grazing test with the treatments arranged in four randomized blocks. Presentation yields recorded for 15 harvest dates indicated significant yield differences. Additional data were recorded for the seed production capacity of the nine accessions (Figure 3). Again, significant ecotypical variability was obtained in seed production and seedling regeneration under the 1-week grazing and 2-weeks spelling system.

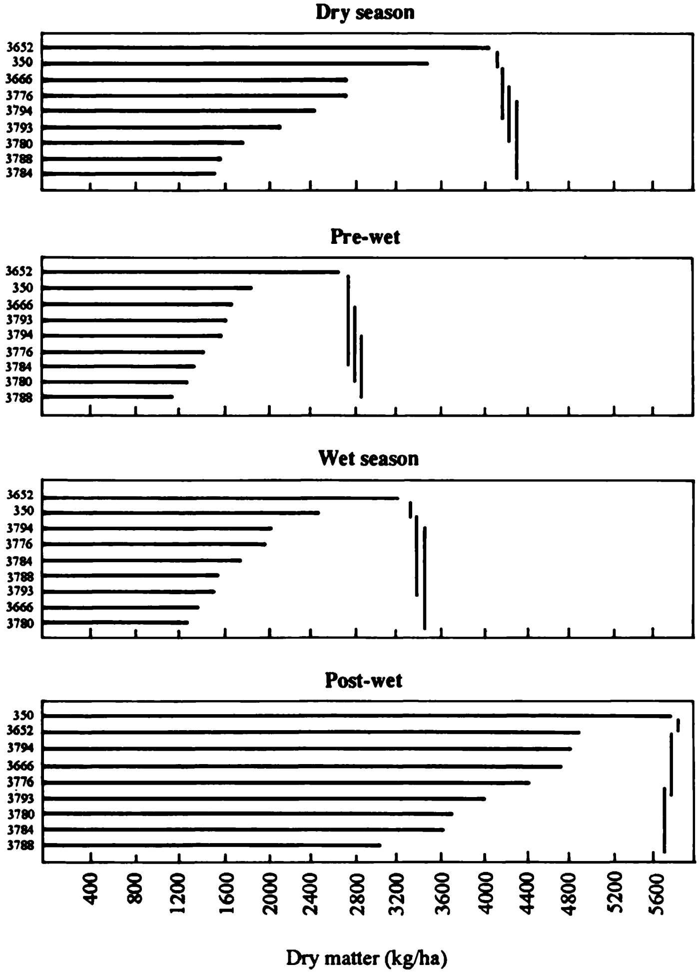


Figure 3. Presentation yields of nine ecotypes of *Desmodium ovalifolium* in association with *Brachiaria humidicola*, Carimagua, Llanos Orientales, Colombia. Mean values connected by the same line are not significantly different at $P > .05$, according to Duncan's Multiple Range Test.

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Chapter 9

Evaluation Under Grazing of Pasture Germplasm in Advanced Stages of Selection

Raymond J. Jones*

Abstract

Evaluation under grazing is an important stage in the evaluation of pasture germplasm for the selection of potential new cultivars. Entry to this stage of evaluation presupposes an already existing adaptation to the climatic and edaphic conditions of the relevant area or areas, high yield, resistance to pests and diseases, and a clear-cut objective for the eventual use of the germplasm under evaluation.

Common grazing of all accessions under evaluation is usual at this stage but care needs to be taken to avoid bias. Suggestions for avoiding bias include grouping accessions of similar plant form and including them in separate experiments, the separation of fertilizer treatment variables, the use of two or more grazing regimes, and the use of individually grazed plots.

Practical problems concerning number of sites, strategies to use, duration of experiments, and pasture measurements are discussed.

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It is suggested that the theoretical procedures for the effective evaluation of tropical pasture germplasm under grazing are already known, but that there is a need that they be effectively used. Two techniques in use at the CSIRO's Division of Tropical Crops and Pastures are described. They may be relevant to studies elsewhere. If the basic principles for evaluation under grazing are followed we can confidently expect that the superior pasture accessions will select themselves.

Introduction

Evaluation of tropical pasture plants under grazing is an important phase in the overall pasture evaluation program to identify, release, and promote new pasture cultivars. Such a program usually commences with the assembly of a wide range of grasses and legumes which are subjected to a sequence of evaluation stages, each of which approaches closer to the real-world situation and ends when superior grasses and legumes have been released to the grazing industry as new cultivars (see review by Jones and Walker, 1983, for references). The sequence of events (there are five main stages) which may comprise the pasture evaluation program is shown in Figure 1.

The objective of the third stage in evaluation (evaluation of elite genotypes in sward experiments at representative ecosystem sites under grazing) is to promote those species or accessions which are worthy of further testing in animal production experiments. It is vital that the methods of evaluation at this stage identify those accessions which are inferior to the current control cultivars for one reason or another so that they can be eliminated from further and more costly evaluation at subsequent stages.

Requirements for Stage III Selection

The requirements for entry to Stage III evaluation will follow from the overall objectives of the evaluation program. These should be clearly stated so that all personnel in the program are aware of and are in

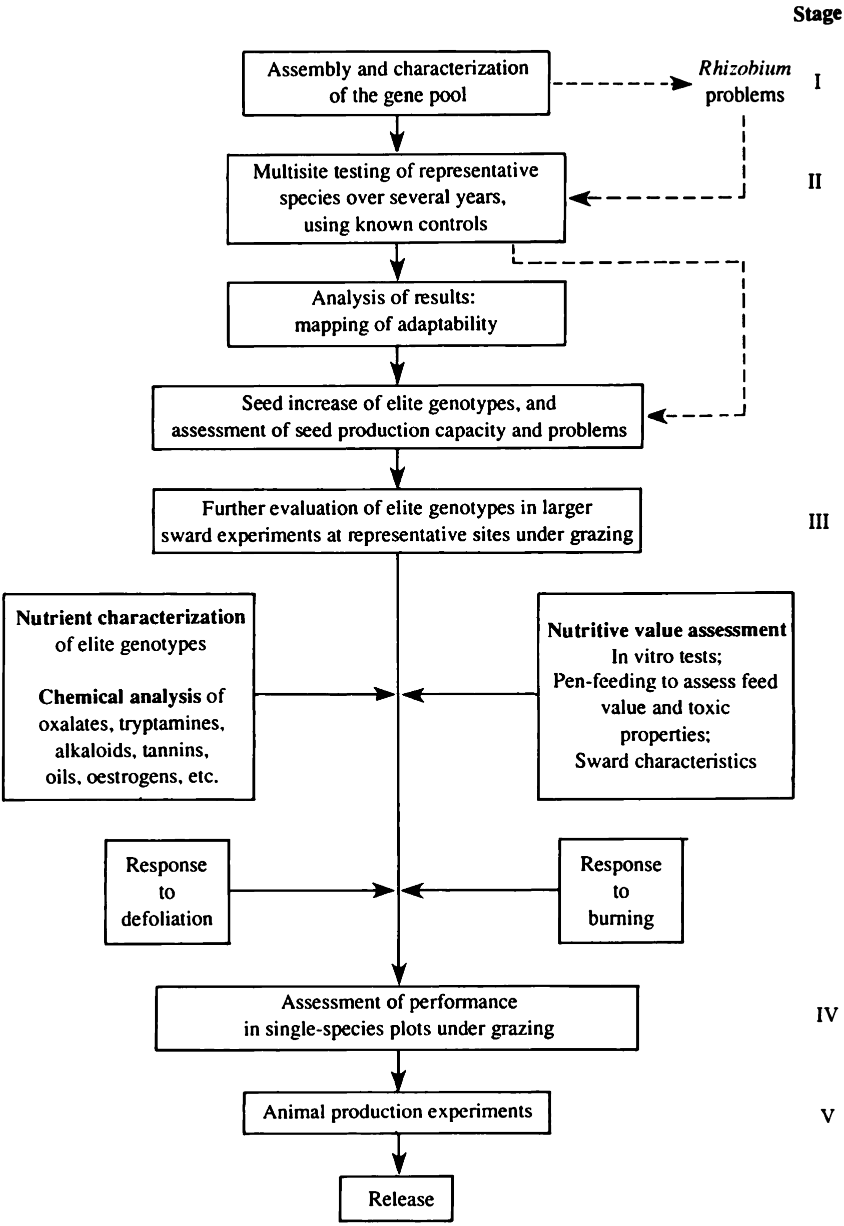

Figure 1. Sequence of events that comprise an evaluation program for forages. (From Jones and Walker, 1983.)

agreement with the defined objectives. Unless objectives are clearly defined, inappropriate species may be selected or inappropriate records taken.

Defined objectives could, for example, be specified as one of the following:

a grass for intensive grazing with nitrogen fertilizer under irrigation;

a grass compatible with existing, proven legumes under a minimal-input fertilizer regime under semiarid conditions;

a legume for cracking clay soils of high base saturation and high pH;

a legume with wide adaptability for the humid tropics for both low-input and high-input systems;

legume-grass combinations or low-input systems in the Cerrados;

a legume for oversowing in open woodland on infertile red earth soils in northern Australia; or

a legume for leys in a no-till cropping-livestock system.

If the objective can be clearly stated, even if the objective is more complex and of wider scope than the examples given above, then the evaluation program can be more logically devised and interpreted. In general, evaluation programs are often very broadly based when pasture research commences in any area. This is as it should be. However, as work progresses, limitations of existing plant material become better documented and the objectives become more clearly focused. It is expected, therefore, that the evaluation strategies will change with time and with the accumulation of new information. For the purpose of this paper, I will assume that little previous evaluation under grazing has been done, but that a large collection of both legumes and grasses have been grown in nursery plots and in small-scale sward-cutting experiments over a range of representative soils and ecological zones for a sufficient period of time to assess their adaptation to the climatic areas in which they have been grown.

Criteria of merit (Bryan et al., 1964; Shaw et al., 1976a) for selection based on the data collected will then include:

high yields (of the species sown, not just total plot yields);

good yield distribution over the season;

good feeding value—chemical composition, digestibility, leafiness, acceptability;

persistence—plant density in the final year in relation to that in the first year;

disease resistance;

tolerance of insect pests;

compatibility with associated legumes or grasses;

absence of high levels of deleterious components such as oxalates;

ability to seed well or to be readily propagated vegetatively;

ability of legumes to nodulate effectively, using indigenous or applied *Rhizobium*;

absence of thorns, spines, or hooked seed pods or burrs, especially if destined for sheep grazing;

plant morphology—taller species may be required in weedy situations, short species for growing under coconuts so that fallen nuts can be seen! and

ability to grow and persist with no or little fertilizer inputs, and yet able to respond to applied nutrients.

If control cultivars were included in the early assessments then all these attributes can be directly related to those of the controls, either by quantitative assessment or by subjective scoring techniques. Clearly there would be no point in continuing the evaluation further if no accessions were superior to the controls.

From the earlier Stage II results (Figure 1), therefore, plants known to be adapted to the climatic and edaphic conditions will be selected. Their suitability to the environment will be reflected in their high and relatively well distributed yield and in their resistance to pests and diseases. In many situations, high total yield in mixtures will be associated with good legume growth since, in the absence of an outside nitrogen source, yields on low-fertility soils will be low. Observations on general plant form, pattern of growth and regrowth, pattern of flowering, and seed set recorded in the early phases of evaluation should be used by the experimenter in addition to data on yield and persistence. Care can therefore be taken when choosing high-yielding accessions which are excessively stemmy, or which may have other undesirable features such as thorns, or which are excessively late-flowering and so do not set seed.

The rigor in excluding accessions which are superior to the control cultivars will depend very largely on the numbers involved. If only a few are judged to be superior to the control, then all these superior selections could proceed to evaluation under grazing. Where a large number of accessions are eligible on the basis of superiority to the control, then a reduction in numbers may be warranted. If the data for these accessions are subjected to multivariate analysis (Williams, 1976), it may be possible to select representatives from the various groupings. An alternative is to subjectively select those with differing habit, origin, and flowering behavior; choosing only a few representatives from groups which are similar in many of the characters measured. Those not chosen initially may well be tested under grazing later if the particular group from which they came prove to be outstanding in their performance.

From Stage I and II testing programs (Figure 1), therefore, the superior germplasm will be selected on the relevant criteria discussed above.

There may be both grasses and legumes which will have to be considered and their evaluation under grazing may be done together or separately. With more than, say, five entries of each (that is, 25 treatments to be compared), separate experiments to compare legumes and grasses may be warranted to reduce the size of the experiment to manageable proportions.

Grazing Management of Experimental Plots

There are many different ways in which plots can be grazed. With large numbers of entries—more than 10—communal grazing of all species under test is the only practical way for most situations. The frequency and severity of grazing can be varied greatly and it would be expected that the ranking order of a set of species could be changed accordingly.

For intensive pasture situations, where controlled rotational grazing would be practiced by the farmers, it may be possible to impose this same grazing management to the pasture accessions under test. The plots may then be grazed heavily every 4 to 6 weeks throughout the year.

However, where the species under test will be used in more extensive ranching situations under a more or less continuous grazing system, then this form of grazing will be impossible to duplicate in small-sward experiments. Nevertheless, the reaction of plants to grazing and trampling and the effects of such reaction on competition between species in the sward and with invading weed species can be measured.

Whichever system of grazing is planned, it is important to reduce bias as much as possible. This can arise particularly when very palatable species form only a small proportion of the number being evaluated. This could result in severe overgrazing which will prevent the expression of their yield potential and enable weed ingress. Using a larger herd of animals for 2 to 3 days of grazing is usually a better strategy than the use of fewer animals over a prolonged period. In this way there will be little opportunity for the animals to regraze plants preferentially defoliated when grazing started. This bias can also be reduced by allowing sufficient time between grazings to enable plants to recover from heavy grazing. In this context, intervals of 6 to 8 weeks would be preferable to intervals of 3 to 4 weeks.

Bias can also result from uneaten residues contributing to the next yield estimate. Clearly, this will be more serious when plots are grazed and sampled frequently. Such bias can be reduced by mowing all plots to a constant height immediately after each grazing but, as

Shaw et al. (1976a) demonstrate, there is little point in grazing to 20 cm and then mowing at 10 cm, because most of the defoliated effect could be from the mowing. It is also important not to introduce additional bias by this procedure which can occur if tufted species and prostrate species under test are mown to a low height. This procedure could severely retard the regrowth of the tufted species and so bias the results in favor of prostrate species. If mowing is done with a rotary slasher, then some twining legumes such as siratro, could be severely damaged as the suction effect of the mowing, combined with the rotary action of the blades, may sever stolons below the planned cutting height to the detriment of subsequent regrowth.

Uneaten residues can result from high contamination with feces, and may be particularly marked near drinking troughs. To prevent such fouling, water troughs should be sited on a discard area away from the experimental plots and be of sufficient size to prevent animals lining up to drink. Evaluation plots of the type under consideration usually have no provision for shade and so the water intake can be very high. If water pressure is low, then a large trough rather than an individual drinking-bowl arrangement should be supplied.

It is important to use the species of animals for which the pasture is intended, so that pastures for beef production should be grazed by cattle rather than by sheep or goats. These species graze differently, although I know of no experimental evidence to show that the ranking of species under test would be changed if different animals were used to graze the same set of species. Steers are usually used for grazing pasture-evaluation plots but there is no reason why other classes of stock should not also be used.

Methods for Reducing Bias

As noted in the previous section, bias can arise for many different reasons. In these small-plot grazing experiments a major cause of bias is variation in plant form and reaction to grazing pressure. In addition, relative palatability can introduce further bias. Some control can be effected by grouping plants for evaluation under grazing by separating fertilizer rates, by using two or more grazing methods to measure interactions and by grazing species separately. These will be discussed in turn.

Grouping of accessions

If there is a wide disparity in plant form among accessions to be evaluated then it may be illogical to compare them together under communal grazing. For example, to include a range of *Stylosanthes scabra, Leucaena, Macroptilium,* and *Arachis glabrata* introductions in the one communally grazed experiment could lead to all kinds of problems in obtaining a uniform grazing and in obtaining meaningful yield estimates. The plants differ so much in form and relative palatability that it would be hard to imagine any worthwhile data being obtained from the experiment. It would be as difficult to get meaningful results from a comparison of grasses which included *Pennisetum purpureum* introductions, with, say, *Axonopus* or *Paspalum notatum*. Shrub legumes would also compared separately since, in addition to having a vastly different plant form, they may be managed for specific purposes such as provision of dry-season forage. For this purpose, grazing would be withheld for the latter half of the wet season to enable accumulation of material for later feeding.

Separation of fertilizer treatments

To avoid excessive grazing of some fertilizer treatments, it is imperative that these be separately fenced from unfertilized or lightly fertilized treatments. There is increasing evidence to show that not only do animals preferentially graze fertilized plots in mineral-deficient areas, which has been known for many years, but that they may selectively graze components of those fertilized or unfertilized plots. Thus, in northern Australia, animals selected far more legume on superphosphate-fertilized paddocks than on unfertilized paddocks of grass plus *Stylosanthes* spp. on a phosphorus-deficient soil (McLean et al., 1981). It is likely that deficiencies of other nutrients could also influence relative palatability.

Use of different grazing regimes

Assessment of the reaction of a species or a mixture of species to grazing will be very restricted and open to bias when only one system of grazing is employed. The use of two or more methods of grazing will enable the assessment of interactions and the relative stability of the accessions to variations in the grazing imposed. Of necessity, this will require internal fencing and the provision of gates and laneways to enable the various grazing treatments to be imposed.

Variation in grazing frequency rather than in grazing intensity is probably more applicable to small plots which are communally grazed, because varying grazing intensity could lead to bias by excessive grazing of very palatable species as discussed earlier. Any interactions of lines by grazing treatment will be of great interest. In general, the species or mixtures which do well under all the grazing treatments imposed will have greater flexibility in commercial use and should be selected. Unexpected results may be obtained. In one experiment, the large tillered, succulent, and palatable *Setaria splendida* CPI 15899 did well under both a lenient and a frequent grazing regime compared with a range of *S. sphacelata* var. *sericea* ecotypes. It was anticipated that this introduction would do poorly under frequent grazing. However, the plants produced many more but smaller tillers under the frequent grazing regime and remained persistent (Jones, 1965).

Use of individually grazed plots

This method has obvious advantages in removing bias resulting from selective grazing. The method is not applicable when large numbers of accessions have to be compared, and so is more relevant where only a few legumes or grasses have been shown to be superior to the control from earlier cutting experiments. Alternatively, this method could be used when some doubt exists as to the value of a species which may have been excessively grazed when tested with other species. As such, it would be a valuable intermediary between the communally grazed experiment and a full-scale grazing experiment to measure animal production. The method has been described in more detail elsewhere (Jones et al., 1980) and will be discussed more fully later.

Practical Problems to be Considered

The final proposals for small-scale testing of species under grazing are usually a compromise between theoretical requirements and practicably achieveable goals. This is so for almost all aspects of the overall program. These various aspects will be considered below.

Number of sites

Availability of resources, including manpower and seed availability, often limit the number of sites that can be considered. Cooperative efforts can extend the scope of the evaluation program, leading to a more complete understanding of the germplasm under consideration. Such cooperative efforts, if well coordinated, should be encouraged. The number of sites will, of necessity, be fewer than was possible in the Stage II testing, but the information obtained at those sites could well be used to identify sites which are different in some clearly defined way. We have stressed the need for testing sites to be representative and fully documented in terms of vegetation, climate, and soil characteristics (Jones and Walker, 1983). Using a range of sites will expose the germplasm to a wider range of climatic conditions than will prolonged testing at any one site and will also lead to greater confidence in recommendations which will result from the testing program. Furthermore, such a strategy will identify those accessions with a broad range of adaptability which should be given priority in any subsequent evaluation and promotion.

Evaluation strategies

Having identified the superior material from Stage II testing (Figure 1), the next step is to find the best strategy for the grazing evaluation. In most programs, legumes should have priority over grasses because it is nitrogen that limits the productivity of most pasture ecosystems. Usually, legumes are evaluated in the presence of a grass or grasses, and grasses are evaluated with a reliable legume or mixture of legumes. This latter strategy is a safeguard against the loss of any one legume through site peculiarities, diseases, or pests. It is the method of choice if grasses are being evaluated over a number of sites because the chances of retaining a legume at each site will be greater. If different stocking pressures are also imposed there may be a better chance of retaining a legume at each stocking pressure with a mixture of legumes.

Where legumes are being evaluated, a proven pasture grass should be used as the associate species, preferably two separate grass species are used—one tufted and one prostrate—to measure the compatibility of the legumes with each of these plant forms. The grasses may be vegetatively established to ensure a constant plant density in all plots (Jones et al., 1967) or more commonly sown as seed over all legume treatments. The testing of all combinations of grasses and legumes which have shown promise in cutting experiments could result in a very large experiment at each site. It may then be necessary to graze replicates separately to obtain a more uniform grazing. In addition, some form of blocking strategy may be required to give increased precision over the normal randomized block designs usually used.

For example, when evaluating 49 different pasture mixtures under grazing, a 7 by 7 lattice design was used in an endeavor to increase precision (Jones et al., 1969). Where vegetatively propagated grasses are to be compared, the spacing employed needs to be given much consideration if bias is to be avoided. In comparing a number of *Panicum* accessions in Cuba, Monzote et al. (1979) used a standard spacing of 70 cm by 70 cm and noted higher weed invasion and lower yields from the shorter, less densely tillering types. It is probably better to use a closer spacing for all entries because there will be less bias if taller cultivars thin out than if shorter cultivars are prevented from expressing their potential by too wide a spacing.

Plot size will depend on the type of design chosen and the nature of the species under evaluation. Tall species will require larger plots to overcome border effects. Plots grazed individually will need to be much larger than those included under a common grazing system. In general, researchers have used plot sizes which range from a minimum of 10 m^2 to 50 m^2 for experiments with common grazing, to 200 m^2 and above for individually grazed plots. Where relatively low numbers of accessions are compared with only one grazing management system, then four to six replicates have commonly been employed. With a large number of accessions or where several stocking pressures have been imposed, two to four replicates are more common. However, for each experiment, the help of an experienced statistician should be sought as his/her knowledge of the local scene could lead to suggestions for improved layout and design to increase precision of the comparisons being made.

Duration

A minimum of 3 years, or preferably 5 years, especially if seasons are atypical, is needed for reliable results. Often the nitrogen release after land preparation is sufficient to give good grass growth and heavy competition to the legume for a 2-year period. Vigorous grasses not particularly compatible with legumes could then give highest yields. Results from later years should be given more weight than those of early years when soil moisture and nitrogen release associated with land preparation may have favored some species. The longer the evaluation period, the better the chances of identifying disease or pest problems. It is far better to encounter them at this stage than in later, more costly, experiments or in farmers' fields after release to the industry. Persistence can only be measured in time, there is no shortcut in estimating this character!

Pasture measurements

The types of pasture measurements made in evaluation experiments have been described elsewhere in some detail (Shaw et al., 1976b; 't Mannetje, 1978). I do not intend repeating these here. It is important to choose relevant measurements to enable selection of the accessions best suited to meet the requirements set out during the planning of the evaluation program. Key measures are yield and persistence combined with some measure of feeding value and animal acceptance in comparison with a control treatment. In most experiments, some assessment of mineral composition and in vitro digestibility are about the only estimates of feeding value that can be undertaken routinely. Estimates of intake are impossible with common grazing but could be taken on individually grazed plots by pre- and postgrazing sampling, bearing in mind the errors that are often associated with the methods currently available (Campbell, 1969; Corbett and Greenhalgh, 1960).

Frequency of sampling for yield

Yield estimates by various techniques are often made immediately before each grazing, and botanical composition is estimated from the same samples. Such frequency of sampling may not always be essential, especially after the first year when trends can be noted. In individually grazed plots, relative yield differences between treatments can be measured at a single annual sampling applied throughout the year (Jones, 1979). It is probable that similar conclusions can be drawn from other experiments. If this is so, then more effort can be directed to other measurements and observations which may explain the yield differences or botanical changes in the experiment. If plots are small, then cutting quadrats prior to every grazing could convert the experiment to a cutting trial.

Animal preference

It is important to record obvious differences between accessions in acceptance by grazing animals so that the yield data can be viewed with greater confidence as reflecting true differences in productivity. This is especially relevant with previously untried species. After each grazing the residue can be scored for each plot, bearing in mind that seasonal differences could occur as a result of variation in production of inflorescences. In addition, the plots can be observed when animals are first introduced and their preference noted. An observation tower can facilitate such measurement but is not essential. Even where a common grass is used in legume evaluation experiments preference for the grass associated with particular legume treatments has been noted (Jones et al., 1967). In this instance, preference was a reflection of the nitrogen concentration in the associate grass.

Pasture persistence

For a perennial pasture, even an evaluation for 5 years is a fairly short span of time. Measures that will add confidence to the conclusions regarding the persistence of the pasture include the measurement of soil seed reserves (Jones and Bunch, 1977), survival of germinating seedlings in the field, and the longevity of tagged plants. The ingress of weed species is also indicative of reduced plant vigor or failure of replenishment of the sown species. Species or species combinations which show an increase in weed content with time should be viewed with caution even if the mean yields over time are good.

Disease and pest incidence

Measurements of disease and pest incidence will have been recorded in Stage II testing; however, we have examples where disease and pest susceptibility have shown up, even after release of tested plants. There is a constant need, therefore, to observe the plants in the grazed situation for any sign of damage, to identify the disease or pest involved, and obtain advice on its likely importance.

General observations

Sampling plots is often a very busy time and it is easy to miss observations on the plants while collecting yield data. Walking over the plots at intervals between periodical sampling and making notes—these days a pocket tape recorder makes it easy—can be very rewarding and will give the experimenter a "feel" for the various species in the experiment. After particular stresses such as drought, frost, waterlogging, or insect attack, valuable information may be obtained for other situations or which may modify data already obtained.

Alternative Methodologies for Evaluation

The extremely complex interactions which occur in grazed pastures are impossible to simulate outside the field situation. There seems to be no shortcut, therefore, to exposing plants to the whole complex of variations in soil and climatic factors, the tearing, trampling, and fouling by grazing animals, and to the array of pests and disease organisms which may attack them (Jones and Walker, 1983). However, there is ample scope to become more efficient in the whole process and to coordinate the performance of species across sites and even across countries. Although we are dealing specifically with small-plot evaluation under grazing in this workshop, the results obtained depend very much on the efficiency of the Stages I and II testing (Figure 1) and the final outcome will depend on further stages of testing that involve animal production measurements.

It could be argued that after Stage II testing the promising plant material should be released to the grazing industry or pasture seed industry and that government agencies should then withdraw and allow the best species to find their niche in the market place. Personally, I see this as an unsatisfactory alternative strategy, particularly in developing countries where the promotion of sown pastures is only just beginning. Under these conditions, failure of any given untried package could not only result in hardship for the individual, but would also result in great resistance to further promotion of improved pasture.

Furthermore, the involvement of the pasture agronomist at all stages in the development of new cultivars is vital if there is to be feedback in the selection or breeding of even better germplasm.

Two approaches to the evaluation of pasture germplasm which have proved to be useful in the CSIRO's Division of Tropical Crops and Pastures may be of value elsewhere. They are described below.

Strip planting

This strategy proposed by Gladstones (1975) for handling large number of lines but where seed is often limiting. The method has been developed at the CSIRO's Davies Laboratory by R. L. Burt and J. G. McIvor for evaluating both legumes and grasses under grazing where seed or planting material is in short supply and where ability of accessions to spread is an important characteristic. The method involves sowing seed or planting rooted tillers in rototilled strips in the existing woodland or grassland situation. These strips may or may not be fertilized and are spaced 2 to 4 m apart. Establishment in the prepared seedbed can be studied and later the ability to spread by seed or vegetatively into the undisturbed adjacent areas. Productivity and spread are usually measured together with persistence of the original sowing and the acceptability by animals. The method has considerable merit in selecting accessions for use in large-scale sowings by air into undisturbed ecosystems and could be very useful on steep country where total cultivation could result in serious soil erosion and contamination of some plots by washed seed from others. The method has proved useful in legume studies on phosphate deficient soil (R. L. Burt, personal communication), in grass studies over a range of soils (McIvor et al., 1982), and in widescale evaluation studies in central Queensland (B. Walker, personal communication).

Individually fenced plots

In this method each germplasm entry is separately fenced and grazed intermittently by one or more animals on a regular basis (see Jones et al., 1980, for details). Each plot can be viewed as one unit in a fixed grazing rotation. It is regularly grazed by one or more animals at any given grazing interval, but the animals spend the remainder of their time on similar pasture elsewhere. Unlike the system where plots are grazed to a low stubble height by a large number of animals over a few days, this system more closely resembles the set-stocked system of grazing which is common to many tropical areas. Under this system feed surplus is accumulated through the growing season for use in the dry season. Different stocking rates can be imposed simply by varying the plot size, and different grazing intervals can be designed in the same way. In the example of Jones et al. (1980), eight pastures were compared at stocking rates that were equivalent to two and three steers/ha and with two replications. If each plot was considered to be one paddock in a six-paddock rotation where paddocks were grazed for one week and rested for five, then plots of 0.083 and 0.056 ha are required on a total area of only 2.2 ha.

For an experiment of this kind to be effective, it is important that a uniform establishment on all plots is achieved. This may necessitate careful management in the establishment year. Once the grazing sequence commences it may be difficult for a poorly established pasture ever to recover, especially if the species is a shy seeder under grazing. For this reason it may be better to graze the pasture leniently in the first year to promote seed set of the sown species.

The method has been used for the evaluation of breeders' lines of *Macroptilium atropurpureum* at three different sites in Queensland and for the evaluation of a number of lines of *Urochloa* in conjunction with a common suite of legumes (McIvor, 1982). A similar approach, but using the two replicates alternately, that is, 2 weeks on and 2 weeks off, is being used by Gardener (1975) at our laboratory for the comparison of a number of *Stylosanthes* accessions at different fertility levels. Since the yearling steers remain on the experiment yearlong, plots are larger: 0.5 ha. All are stocked with only one yearling steer and in this instance some preliminary animal gains are also available. Over a number of years valuable animal-gain data have also been obtained.

In Conclusion

As far as I am aware, no one has compared different methods for the evaluation of a large set of tropical pasture accessions under small-plot grazing and then compared the lines selected by the different methods in animal production experiments. Even if such a comparison had been undertaken it is doubtful if the results would have been accepted by agronomists for all situations. In the absence of such definitive information it is therefore difficult to say that any one method for evaluation in small plots is better than another.

In this paper I have attempted to set out some principles which may be used in such evaluation studies to avoid bias.

Small-plot evaluation under grazing is not just one stage which will pass and be replaced by others. There will inevitably be a need for such testing as long as improvement in productivity is considered possible. No one experiment is going to provide all the information even at one site. New material from plant-collecting missions, and subsequently from plant-breeding programs, will need to be evaluated under grazing. Although the task of evaluating promising pasture species is a formidable one, the principles are fairly well established. Provided the accessions are subjected to relevant management by way of fertilizer strategies and grazing pressures on representative areas, then reliable results can be anticipated. Given these basic requirements the superior plants have a habit of selecting themselves!!

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Chapter 10

Evaluation of Pasture Germplasm Under Different Grazing Management Systems

Gerald O. Mott*

Abstract

Three steps in forage germplasm evaluation, leading to the identification of superior cultivars, are discussed. Emphasis is given to the use of the grazing animal to defoliate the collection of accessions, beginning in the introduction nursery to provide preliminary information on acceptability and persistence of genotypes. As the evaluation continues, the number and complexity of experimental variables increase to include components of grazing management. A range of factors encompasses both the spectrum of environmental circumstances and the defoliation management systems likely to be encountered under farm conditions.

Response surface methodology provides designs for estimating optimal operating conditions when multiple factors are studied in combination. Central composite designs and their modifications are suggested as alternatives for providing information around the optima when several experimental and response variables are of interest. Some examples of response surface designs are given for forage germplasm evaluation.

In evaluating forage germplasm, past emphasis was primarily to select for the highest yielding lines. However, these selections are not necessarily the most persistent under grazing. The farmer is interested

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in persistence which suggests that the plant breeder and agronomist should reevaluate the methods used to screen superior lines. This paper illustrates experimental designs which will provide information on the interactions between forage plants and the grazing animal. The interface between the animal and the plant, especially the effect that the stress imposed by the grazing animal has on plant survival and production, is also discussed.

Steps in Evaluation

At the beginning of the selection program, a large number of accessions may be available for screening. If the lines selected are to be used primarily for grazing then the animal should be brought into the evaluation scheme as early as possible. Some investigators have made their initial plantings of introductions and breeders' lines as single plants or seeded rows in a physical configuration to allow the experimental area to be fenced for grazing. During the first year after planting, agronomic characteristics are recorded. In the second year, the lines are subjected to grazing to identify differences in acceptability and responses to defoliation. For convenience in discussing appropriate designs, the second screening step assumes that the initial selection has reduced the number of accessions within a species to ten or fewer. These accessions are planted within single enclosures for further evaluation by grazing animals. The third step of the evaluation is made on one to three selected superior lines to determine their response to the components of grazing management and other experimental variables appropriate for pastures within the region. In all cases, the experimental variables are imposed and the responses measured on only the plants. No animal measurements are recorded.

Step 1. Initial evaluation of introductions and breeders' lines

The investigator may have available for evaluation only as few as 20 introductions or breeders' lines or he may have several hundred accessions, depending on their availability from germplasm banks. In any case, his ultimate objective must be the release of a superior cultivar which will be defoliated by the grazing animal and which must continually furnish feed and be persistent under the stress of grazing. Persistence may result from the longevity of the original plants or the regeneration of plants from seed, tillers, or other vegetative means of reproduction. Since only a very limited amount of propagation material is available during the initial screening process, it may not be possible to provide for replications of individual accessions when evaluating under a grazing regime. It should be emphasized that at this stage, the objective is to eliminate a major portion of the inferior accessions so as to reduce the number of lines to a manageable level for further testing.

Currently, it is perceived that at least two different objectives may have merit if grazing animals are introduced into the initial screening process. In the first case, a low grazing pressure or a short grazing period is imposed on the initial evaluation nursery to permit a high level of selectivity and allow grazing animals to indicate their preference. Occupancy rates and defoliation scores have been recorded as response variables and have been used to identify accessions which have superior nutritive attributes (Barnes et al., 1970; Burns et al., 1978; and Simons and Marten, 1971). This type of defoliation may be continuous or intermittent during the grazing season to determine whether there exists an interaction in animal preference between time of defoliation and accession. A seasonal profile of accession preference may have merit in formulating mixed pastures or a succession of pasture plants for grazing systems which will maintain a high level of digestible energy consumption. This step in the evaluation scheme should serve to identify the accessions with the highest quality.

An alternative to lax grazing is a very intense system of grazing which deliberately abuses the accessions under study. The purpose is to identify those accessions which will withstand overgrazing and persist under such treatment. The effects of trampling, defoliation, and excreta are extreme. The argument for this type of animal-plant study is that most farmers at some time during the grazing season will abuse their pasture and that persistence under farm conditions may be more important than yield and quality of feed.

Each of the two procedures appears to have merit for the purpose for which they were designed. In between these two extremes are all levels of defoliation and it may be argued that an intermediate level would be most appropriate. If resources are available, it is suggested that the two procedures be conducted in sequence: first, identifying the accessions which are most acceptable to the grazing animal in the first year; then, intensive grazing in the second year to determine those accessions which can withstand severe grazing stress. Such a sequential procedure should serve to identify those accessions of highest quality and those which will persist in the farmers' pastures.

It is assumed that only a limited amount of plant material will be available for this initial phase which probably will preclude the application of more than one grazing treatment in a single replication. The size of the enclosure may vary to accommodate the number of accessions available. The range of variability between accessions within a single enclosure may be reduced by limiting the accessions to a single species or to more than one closely related species.

A convenient experimental unit (single enclosure) is illustrated in Figure 1, Step 1, which may be planted with single plants or with rows with each row (or two or three rows) representing a single accession. The dimensions "W" and "L" may be 20 m by 50 m or some larger dimension if additional accessions are to be accommodated. A row spacing of one meter is usually adequate. All borders and lanes are planted with a nonspreading grass species which can be maintained by power mower. All the accessions within a single enclosure are grazed in common.

The measurements recorded in the initial screening include morphological characteristics, location of reproductive meristems, adaptation to soil and climatic conditions, disease and insect resistance, vigor, seed production, and rate of regrowth after defoliation. In addition, samples of forage may be collected for chemical analysis and in vitro dry-matter disappearance.

Step 2. Response to frequency and intensity of defoliation

After the number of accessions has been reduced to 10 or fewer, the investigator may be in a position to consider determining the response

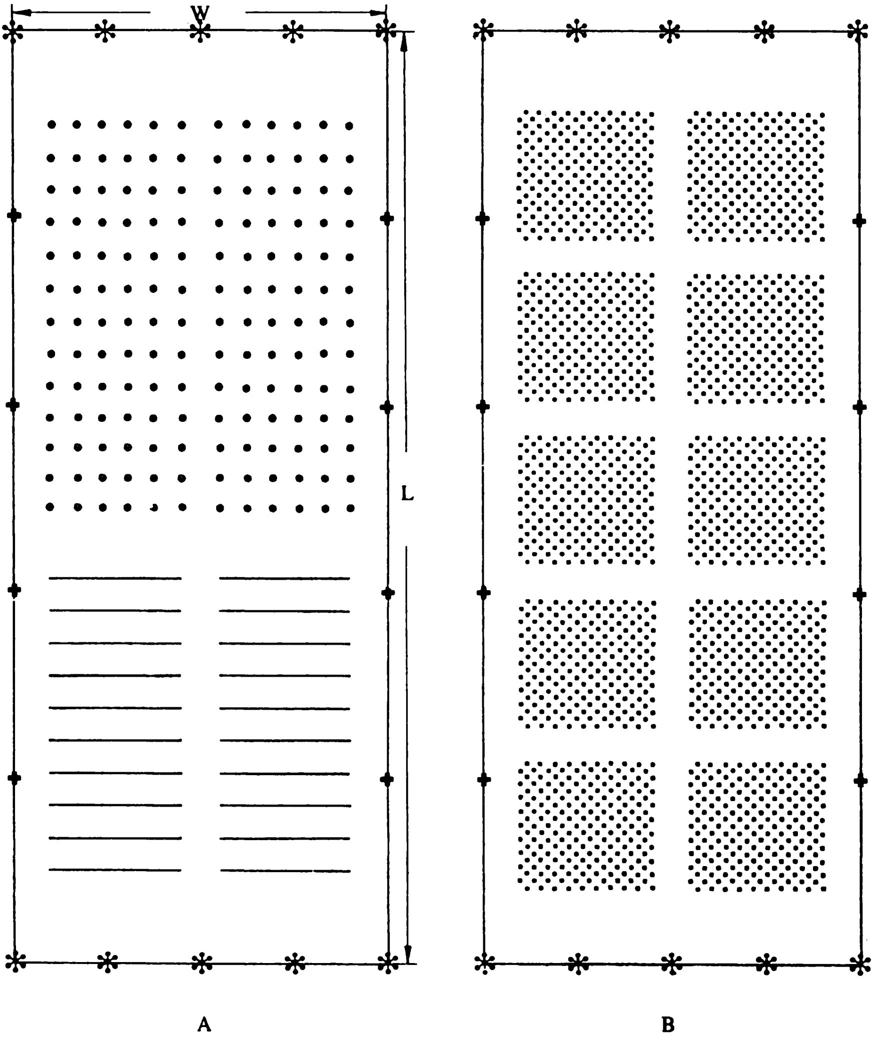

Figure 1. Configuration of an experimental unit for Step 1 (A) and Step 2 (B) in the evaluation scheme. The size of the experimental unit may be variable. A convenient size is 20 m (W) by 50 m (L). * Permanent fence; + temporary electric fence.

of the selected lines to different systems of defoliation. It has been traditional for the plant breeder to test his introductions and breeders' lines in an experiment using height and frequency of cutting. Some comparisons between cutting and grazing suggest that many pasture species may respond differently to these methods of defoliation and that interactions occur between accessions and defoliation management. Because of rising costs and lack of adequate resources, many investigators are now considering alternative methods to clipping in evaluating their accessions. The experimental variables, frequency and intensity of defoliation by the grazing animal, have been imposed on a number of species and mixtures of species in the forage evaluation scheme. The frequency of defoliation has varied from continuous grazing to grazing periods of 1 to 4 days and rest periods of 14 to 56 or more days. The intensity of defoliation has also been used as an experimental variable to generate different degrees of defoliation as measured by the residual dry matter remaining on the pasture at the end of the grazing period.

This procedure replaces the height of cutting in clipping trials and provides information more relevant to the farmer's situation. The time of year at which defoliation occurs and the length of the grazing period also may be of interest as experimental variables.

The field design for this type of study may consist of less than 10 accessions within a single enclosure (see Figure 1, Step 2). The size of the experimental unit, adjustment of stocking rate, length of grazing time, and frequent monitoring of the forage residue allow satisfactory control over the degree of defoliation. Each accession subplot is planted in such a manner as to create a continuous sward. It may be desirable to plant the accessions under study in association with one or more other species to create a mixture appropriate to farm practice. Accessions of a grass species in association with one or more legumes or several accessions of a legume with one or more grasses are important considerations.

A buffer strip of a sod-forming nonspreading species of grass completely surrounds each accession subplot and extends to the fence boundaries. The grass border impedes the spread of any aggressive accessions and reduces the border effect around the experiment units.

The grass strip may be easily maintained by clipping and does not interfere with the grazing process on the experimental lines being evaluated.

A completely random or randomized complete block design of the grazing management treatments (a single enclosure is the experimental unit) form the main plots of such trials. Two or more replications of each treatment should be provided. In unusual circumstances, more complicated designs may be used but otherwise are seldom justified. Individual accessions within the management treatments constitute a split-plot feature of the design.

The response variables of interest are similar to those in Step 1 and include leaf area, reserves, location, and vulnerability of apical meristems, tillering, and forage quality measurements (Harris, 1978). Because this step aims to provide a wide spectrum of defoliation management, persistence, yield, leaf-to-stem ratios, regrowth rates, number of vegetative and reproductive tillers, and tiller dynamics are responses of interest.

Step 3. Grazing management studies: pasture response

Grazing management and defoliation practices are powerful determinants of growth, persistence, and composition of pastures (Harris, 1978). The grassland scientist should be highly sensitive to the stresses which the farmer will impose on any new species or cultivar. There are many defoliation management systems available to the farmer. A combination of grazing and hay or silage harvesting, continuous grazing, rotational grazing, including a multitude of variations of grazing periods, rest periods, and grazing pressures, are alternatives from which the farmer may select. If the new cultivar is to be used by the farmer as a harvested forage, then there is no doubt that the evaluation must be a study of height, frequency, and season of defoliation. If, however, the new cultivar is to be defoliated under farm conditions by the grazing animal, experimental results from a wide spectrum of grazing management options should yield information which will allow the farmer to select the system which will provide the best combination of yield, quality, and persistence.

Most forage agronomists would prefer to have new cultivars evaluated for their animal production potential; first, in a carefully controlled grazing trial, then in an on-farm evaluation as part of the total feeding system. However, very few investigators have the resources or can afford the luxury of such evaluation procedures. They are placed in a position of having to release new cultivars with something less than a full complement of information. If new cultivars are to be released, based on their superior persistence, yield, and quality under a wide range of environmental circumstances, defoliation systems, and management practices, then each investigator must allocate his resources wisely. Access to grazing animals for defoliating plants must be a major resource in forage evaluation schemes. This leads to a discussion of experimental designs which will be most efficient in yielding the desired information.

Response Surface Methodology

There are four types of designs which provide information useful for response surface analysis (Balaam, 1975). These are complete factorials, fractional factorials, central composite design, and rotatable design. Each of these designs shall be considered here as belonging to a family of designs within the framework of response surface methodology. Most agriculturists are familiar with complete and fractional factorial experiments designed to generate a set of independent comparisons from a choice of treatments (Steel and Torrie, 1960). It has been traditional to present the analysis of factorial experiments as main effects and interactions and some method of multiple comparisons procedures. The notion that factorial experiments can be analyzed, using least-squares response-surface methodology has not been widely recognized. As researchers have become more familiar with the methods available to them and the availability of the high-speed computers for fitting appropriate models, plant and animal scientists have become more adventurous in exploring designs which give estimates of optimal levels of two or more factors.

Inclusive and Sequential Experimentation

Since the introduction of central composite designs by Box and Wilson (1951), nonfactorial response surface designs have been used very successfully in engineering, industry, and chemistry. In these areas of experimentation the length of each study (run) is relatively short, extraneous variables are well under control, which reduces the experimental errors to a minimum, and the experimental material is adaptable to sequential study. In biological studies, and especially in forage-livestock experimentation, a study may span several years; the experimental errors are relatively high because many variables are not controllable and the experimental material is not well adapted to sequential treatment.

Nevertheless, reasonable ranges of most experimental variables in forage-livestock experiments are already known. The scale of measurement of both the experimental and response variables is well understood and the need for transformations is minimal. The characteristics of forage evaluation experimentation suggests that the entire range of each experimental variable of interest be investigated rather than only a small segment of the response surface. Since long-term effects of treatments are usually of greatest interest, the treatment combinations should be selected with great care at the outset. The addition of another treatment combination (design point) means the commitment of additional resources which, in the case of forage-animal studies, increases the costs considerably.

Selecting the Set of Experimental Variables (Treatment Combinations)

For statistical reasons and ease of computational procedures, it has been more convenient to select experimental variables where successive levels are in equal increments. Simple coding may be used to accomplish the analysis with a minimum of effort (see Steel and Torrie, Chapter 11, 1960). In the use of regression analysis to fit a response function to a set of data, it is argued that equal increments of the experimental variables are not necessary. This author is more comfortable with a systematic experimental design which circumscribes the limits and provides good coverage of the experimental region. A warning has been expressed by Box et al. (1978) on the use of a haphazard set of design points for deciding what form of response function to use.

With respect to grazing management alternatives, there are three primary components. These are length of grazing period, length of rest period, and grazing pressure. Maraschin (1975) and Serrão (1976) studied a mixture of "Coastcross-1" Bermudagrass (*Cynodon dactylon* (L.). Pers.) and greenleaf desmodium (*Desmodium intortum* (Mill.) Urb.), using a modified central composite design for the three experimental variables, days grazing, days rest, and grazing pressure (see Table 1 and Figure 2). The response variables studied in this trial were:

Pasture production and yield—

- Total dry matter available per cycle, tons of DM/ha
- Growth rate, kg of DM/ha daily
- Net dry-matter yield, tons of DM/ha
- Stocking rate, tons of liveweight/ha daily and animals/ha daily
- Dry matter consumed, kg DM/100 kg per body weight daily

Botanical composition—

- Percentage of grass in mixture
- Percentage of greenleaf desmodium in mixture
- Percentage of weeds
- Percentage of litter

Forage quality—

- In vitro organic-matter digestibility (IVOMD) of grass component
- Crude protein of grass component

Table 1. The treatment combinations of length of grazing period, length of rest period, and grazing presure of the central composite design, plus the extra treatments.

Treatment combination	Treat no.	Grazing period (days)	Rest period (days)	Grazing pressure[a] (MT/ha)
Factorial points	1	3.5	14	1.0
	2	10.5	14	1.0
	3	3.5	42	1.0
	4	10.5	42	1.0
	5	3.5	14	2.0
	6	10.5	14	2.0
	7	3.5	42	2.0
	8.	10.5	42	2.0
Axial points	9	14.0	28	1.5
	10	1.0	28	1.5
	11	7.0	56	1.5
	12	7.0	0	1.5
	13	7.0	28	2.5
	14	7.0	28	0.5
Center points	15	7.0	28	1.5
	16	7.0	28	1.5
	17	7.0	28	1.5
	18	7.0	28	1.5
	19	7.0	28	1.5
Extra treatments	20	7.0	42	1.5
	21	7.0	14	1.5
	22	7.0	28	1.0
	23	7.0	28	2.0
	24	3.5	28	1.5

a. Grazing pressure = metric tons/ha of residual DM left after grazing.

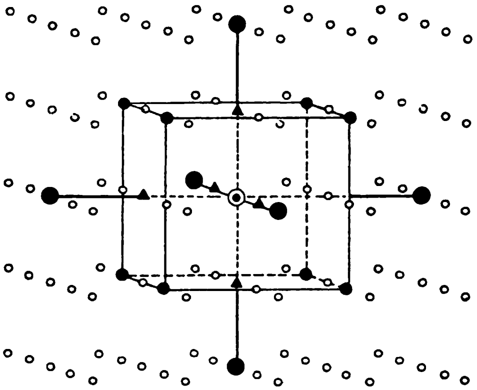

Figure 2. Central composite design (with additional design points) for three experimental variables within a 5^3 factorial grid. ● Factorial points 2^3; ◉ center point; ● axial points (2) (3); ▲ extra points (5).

The response surface contours which may be generated from this experiment are illustrated in Figures 3 and 4. The combined effect of grazing pressure and days rest on the growth rate of the pasture is illustrated by response contours (Figure 3), using a second order model, which shows a maximum growth rate when the pasture is given a rest interval of 25 days and residual dry matter of about 1.3 metric tons. Note that the 13 design points cover the region of the maximum fairly well. Contrast this with Figure 4 which illustrates the response surface for percentage of desmodium in the mixture. If a large percentage of desmodium is desirable then it appears that the 13 design points almost missed the region of interest. There was only one plot which had a rest period of 56 days which was the treatment giving the highest percentage of desmodium. These results show that the maximum (minimum) region of response may differ for different response variables. The direction in which the response may be at a maximum is also indicated. They also suggest that the selection of design points should be made with great care to ensure that the scale of each experimental variable is adequate to cover the range of interest.

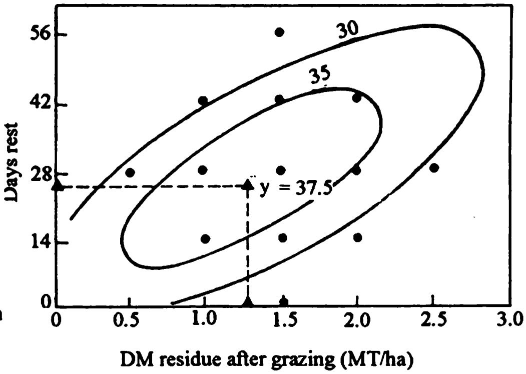

Figure 3. Contours of a fitted second-degree equation for growth rate (kg DM/ha per day) as a function of days rest and grazing pressure (residual DM, tons/ha). ● Design points; ▲ point of maximum response. (From Serrão, 1976.)

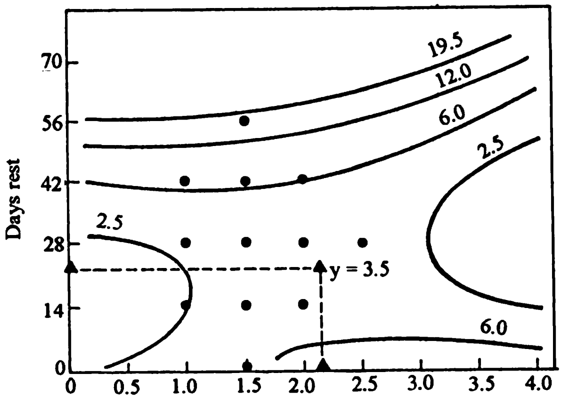

Figure 4. Contours of a fitted second-degree equation for percentage of desmodium in total aerial biomass as a function of days rest and grazing pressure (residual DM, tons/ha). ● Design points; ▲ response at stationary point. (From Serrão, 1976.)

Modification of the Central Composite Design

Littell and Mott (1975) suggested some modifications in the design and analysis of response surface experiments as applied to agronomy. Their research and studies conducted by graduate students at the University of Florida have resulted in design points being added to the central composite design. These additions have provided a more complete coverage of the response surface, especially at the extremes of the experimental region. They found that it was very easy to extrapolate the response surface well beyond the limits of the experimental region. The extra design points (corner points) have increased the scope of the experimental range without infringing on the integrity of the central composite design. Although the additional design points add to the total number of experimental units, the total units are considerably fewer than for the complete factorial (see Table 2).

Table 2. Number of design points in a central composite, modified central composite, and complete factorial (based on 5 levels of each experimental variable).

No. of experimental variables	No. of design points		
	Central composite	Modified central composite	Complete factorial
2	9	13	25
3	15	23	125
4	25	41	625

One example involving two components of grazing management, length of grazing cycle and grazing pressure is illustrated in Table 3 and Figure 5. This experiment is in progress during the current season (summer 1982) at the University of Florida. The pastures are being grazed by 250-300 kg yearling heifers. The number of animals is adjusted to defoliate each pasture to the projected grazing pressure (leaf dry-matter residue at end of grazing period) in each grazing cycle. Defoliation is accomplished in one or two days in each grazing cycle.

The response variables include estimation of leaf-and-stem dry matter/ha before and after grazing, tiller production, position and development of apical meristems, carbohydrate reserves, protein, and IVOMD of leaf-and-stem tissue before and after grazing. Each of these responses will be analyzed, using response surface methodology with a linear or nonlinear function.

The second example is a three-factor experiment in which days grazing, days rest, and grazing pressure are the experimental variables (Table 4 and Figure 6). This experiment is similar to the two-factor experiment discussed above, except the number of days grazing has been added as an experimental variable in the design. By adding treatment combinations in the corners of the design (2^3 factorial at ± 2 level), eight design points are added to the design, making a total of 23. When replications on certain design points are taken into account a total of 59 experimental units are included in the experiment.

Table 3. Treatment combinations in a study of dwarf elephant grass. Two experimental variables: days of rest (X_1) and grazing pressure (X_2); 13 design points; 2 replications; and 26 experimental units were used.

No.	Treatments[a]				Size of experimental unit (m^2)
	Coded experimental variables X_1	X_2	Days in rotation cycle	Grazing pressure (kg of LDMR[b]/ha)	
1	1	1	42	1400	1000
2	1	-1	42	600	1000
3	-1	1	14	1400	1000
4	-1	-1	14	600	1000
5	2	2	56	1800	1000
6	2	-2	56	200	500
7	-2	2	0	1800	3500
8	-2	-2	0	200	1000
9	2	0	56	1000	1000
10	-2	0	0	1000	2000
11	0	2	28	1800	1000
12	0	-2	28	200	500
13	0	0	28	1000	1000

a. This study is currently being conducted by Jonas B. da Veiga and Luis R. Rodrigues, graduate research fellow, Brazil, 1982.

b. LDMR = Leaf dry-matter residue.

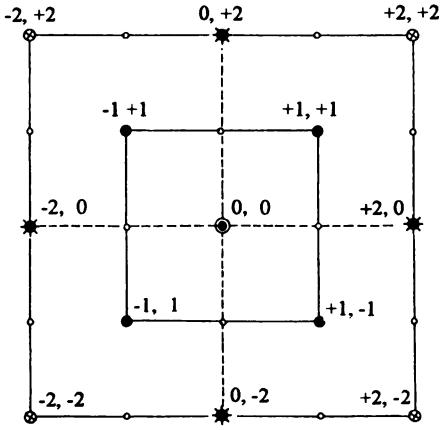

Figure 5. Central composite design in two experimental variables plus added corner points with 13 design points set in a 5^2 factorial grid. ● Factorial points 2^2; ⊗ corner points 2^2; ✱ axial points (2) (2); and ● center point.

Table 4. Treatment combinations in a study of a tropical legume-grass association, Pichilingue, Ecuador, 1979-1980. Three experimental variables: days of grazing (X_1), days of rest (X_2), and grazing pressure (X_3); 23 design points; variable number of replications, and 59 experimental units were used.

No.	Coded experimental variables			Treatments[a]			Estimated size of exp. unit (m^2)
	X_1	X_2	X_3	Days of grazing (X_1)	Days of rest (X_2)	Grazing pressure (X_3)	
1	-1	-1	-1	7	14	3.3	1000
2	1	-1	-1	21	14	3.3	1500
3	-1	1	-1	7	42	3.3	500
4	1	1	-1	21	42	3.3	1000
5	-1	-1	1	7	14	6.6	1500
6	1	-1	1	21	14	6.6	3000
7	-1	1	1	7	42	6.6	1000
8	1	1	1	21	42	6.6	1500
9	-2	-2	-2	1	0	1.6	3000
10	2	-2	-2	28	0	1.6	3000
11	-2	2	-2	1	56	1.6	500
12	2	2	-2	28	56	1.6	1000
13	-2	-2	2	1	0	8.3	6000
14	2	-2	2	28	0	8.3	6000
15	-2	2	2	1	56	8.3	500
16	2	2	2	28	56	8.3	2000
17	-2	0	0	1	28	5.0	500
18	2	0	0	28	28	5.0	2000
19	0	-2	0	14	0	5.0	4000
20	0	2	0	14	56	5.0	1000
21	0	0	-2	14	28	1.6	1000
22	0	0	2	14	28	8.3	1500
23	0	0	0	14	28	5.0	1000

a. The field data were recorded by Raul Santillán in Ecuador. He was a graduate student at the University of Florida, 1982.

The response variables include an estimate of aerial biomass on offer at the beginning of the grazing period and residual dry matter at the end of the grazing period. Botanical composition of the mixture

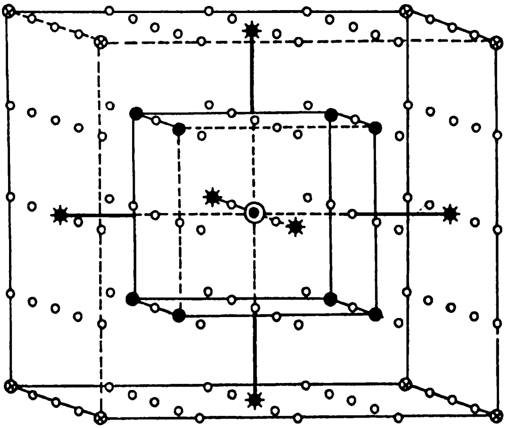

Figure 6. Central composite desingn in three experimental variables plus added corner points with 23 design points set in a 5^3 factorial grid.
● Factorial points 2^3;
⊗ corner points 2^3;
✱ axial points (2) (3);
◉ and center point.

was estimated for each treatment throughout the 2-year period of the experiment. Quality characteristics of the forage were also measured.

Discussion

In the evaluation of forage germplasm the investigator encounters a multitude of factors which may determine the success or failure of a group of accessions. His/her ability to select factors that are significant with respect to the environment and management to which a new cultivar will be subjected will determine its survival under farm conditions. Since no two farms or farmers are alike, it is imperative to screen forage germplasm over as wide a combination of circumstances as possible so as to provide information relative to the optimal operating conditions. The three steps in the evaluation scheme discussed in this paper actually represent a continuum with emphasis on simple designs in the early phases, followed by more complex designs to determine optimal management systems for persistence and yield. When components of grazing management are to be studied, the experimental units must be of sufficient size to accommodate at least two grazing animals for the designated number of days of grazing. The investigator may have to be satisfied with an estimate of the region of the optimum from designs which provide fewer design points than in the complete factorial. It is suggested that forage scientists investigate this family of designs.

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Chapter 11

Recommendations for Evaluating Germplasm Under Small-Plot Grazing

Osvaldo Paladines and Carlos E. Lascano

Introduction

The discussion and methodological recommendations that follow are the result of papers presented at this meeting and of the exchange of experiences and discussion of concepts during workshop sessions.

This contribution comprises four parts. In the first, the objectives of germplasm evaluation under grazing are discussed; in the second, some factors that affect germplasm evaluation under grazing are analyzed in summary form; in the third, fundamental aspects of grazing management in small plots are discussed; and in the last, methodological recommendations for germplasm selection and evaluation under small-plot grazing are given.

Objectives of Germplasm Evaluation Under Grazing

Expressed in simple terms, the objective of evaluating forage germplasm undergoing trampling and defoliation is to select forage

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plants with characteristics superior to those of germplasm currently available. This objective, simple at first sight, becomes more complex when we include the concept that the superior characteristics of the germplasm should, at the same time, be related to some specific objective, one that can be different at each region or site. At the regional level, germplasm would be selected for its adaptation to environmental conditions (climate, soils, and resistance to pests and diseases), and for its usefulness as forage (nutritive value). At the local level, there would be more specific selection objectives, because one would look for forage germplasm that would not only be adapted to the environment and be of high nutritive value, but would also link itself to the production system in which it would be employed. As pointed out by Toledo (see Chapter 1, p. 5-9) and Gardner (see Chapter 7, p. 140-142), this attitude will have implications for the evaluation methodology that is to be applied.

Forage germplasm selection programs have traditionally employed cutting evaluation techniques. This type of evaluation plays a very important role because it ascertains the degree of germplasm adaptation to the environment and its production potential. Nevertheless, particularly in grass-legume associations, there is a selective effect created by the grazing animal that cannot be reproduced entirely by cutting. The animal should, therefore, be incorporated into the initial stages of germplasm evaluation for those forages that will be used for grazing.

Factors Affecting Germplasm Evaluation Under Grazing

Factors related to climate (temperature, solar radiation, or precipitation) and soil (accumulation of water and nutrients, or toxicities) that affect the adaptation and production of forage germplasm have been identified. These factors were discussed in Jones's paper (Chapter 2, p. 16-29). However, biotic factors (grazing, cutting, burning, pests, and diseases) also influence, to a large degree, the germplasm's adaptation to a given ecosystem. Humphreys (1981) discusses the effect of such biotic factors on tropical plants.

Presuming that forage germplasm evaluated under the animal's action is adapted to the environmental conditions of the test site, only plant factors directly or indirectly related to compatibility and persistence under grazing are analyzed. Grazing management related to forage germplasm evaluation is also discussed.

Plant factors

The formation of grass-legume mixtures should be based on the degree of compatibility among the plants in the association. Growth habit and between-plant competition for water, nutrients, and light determine plant compatibility. However, grass-legume compatibility can be modified by animal selectivity that, in turn, is affected by the palatability and growth habit of the species. These two factors interact with pasture management, modifying the balance of the mixture's components over time.

Degree of plant acceptance. It has been shown that animals select different plants, a preference that varies according to season and to the plant's morphological and chemical characteristics.

A model of selectivity during the year has been established, in which legume intake increases in the dry season while that of grass increases in the rainy season. This pattern interacts with the system or intensity of grazing, as will be described later, underlining the importance of grazing grass-legume associations under contrasting intensities and in different seasons.

Certain chemical characteristics of plants are directly or indirectly related to animal selectivity during grazing. It has frequently been observed that the alimentary bolus contains more protein and is more digestible than the forage available. The animal therefore selects those plants and plant parts of higher protein content and greater digestibility. Likewise, it is known that substances, such as tannins and alkaloids, present in forages affect their acceptability and their nutritive value. In some tropical legumes, tannins are found at levels that negatively influence intake. In addition, those levels have been associated in legumes grown on low-fertility soils, so that an interaction between legume acceptance and fertilization can be anticipated. The degree of animal acceptance must be taken into account when designing small-plot trials, as will be discussed later, and should be determined in previous trials.

Plant growth habit. The growth habits of the grass and legume species that form an association contribute to determining animal selection, and as a consequence, to the persistence of those species. In associations of erect grasses with legumes of erect growth habit, the animal can more easily select the component of greater acceptability. On the contrary, in mixtures of erect or decumbent grasses with legumes having a climbing growth habit, animal selection becomes difficult. These effects, not reproducible in cutting systems, can be modified by grazing intensity, taking into account that intense grazing reduces selection possibilities.

Grazing management in germplasm evaluation

Three principal factors are recognized in grazing management:

grazing intensity,
length of grazing period, and
length of rest period.

Grazing intensity. This can be expressed as stocking rate or grazing pressure. Stocking rate is the number of animals or total liveweight of animals that graze a given area at a given time, independent of forage availability. Stocking rate, therefore, relates three factors: animals, surface area, and time. Animals are usually expressed as "heads," "steers," or animal units (AU). The last expression is the most useful as it allows equivalence of different animal categories employed in one or more experiments. Regrettably, there is no unique criterion for AU and each researcher should define it in his experiment. Grazing area can be expressed in hectares or acres, and grazing period can be expressed in hours, days, weeks, months, or years.

Grazing pressure relates the quantity of forage available in a pasture to the liveweight of the grazing animals. The simplest way to consider these variables is to relate the kilograms of dry matter—or of green dry matter—available per 100 kg of liveweight, per day. Once a grazing pressure is defined, the stocking rate fluctuates over time; the opposite happens when stocking rate is set.

For germplasm evaluation, grazing pressure is conceptually more logical than stocking rate, because it relates animal numbers to available forage, which in turn, is an inherent function of germplasm, season, and grazing management. Nevertheless, using grazing pressure entails making many measurements that are not always possible because of limited resources.

One fundamental characteristic that is searched for in forage germplasm is its capacity to persist under grazing in a productive manner during a certain time. This survival capacity is related, in part, to some plant characteristics and to the grazing intensity that is employed. Given that grazing intensity does not have a uniform effect on forages, it is important to evaluate germplasm under contrasting intensities to determine its innate capacity to survive under a wide variety of managements.

As indicated earlier, grazing intensity influences selection of components of a grass-legume association. In general, animal preference is for grasses during the rainy season. The excessive consumption of grasses causes a dominance of legumes, particularly when grazing intensities are high and legumes aggressive and of low palatability. With low grazing intensities, however, grasses can dominate the association, reducing the legume because of excessive competition for light and nutrients. In the dry season, a high grazing intensity can bring about the disappearance of certain legumes and a general deterioration of pasture, especially if grazing in the previous rainy season was also intensive.

Grazing and rest periods. The combinations of grazing and rest days of a field are part of all grazing systems that range from no rest (continuous grazing) to systems of rotation with variable grazing and rest periods.

The grazing and rest periods of a given grazing system are of undeniable importance, particularly when evaluating grass-legume associations, because they can exercise a large influence on the persistence and balance of the mixture's components over time. Once again, given that animals normally prefer grass over legume in the rainy season, a system of continuous grazing may favor the legume. If the legume has an aggressive growth habit and low palatability in relation to the accompanying grass, it can dominate the mixture. In these cases, some system of rotation will favor the grass and so help maintain the balance of the species in the mixture.

With the objective of being able to define the most suitable grazing and rest periods for the persistence of forage species under rotational grazing, the possibility that grazing management and germplasm (being evaluated) may interact should be remembered.

Grazing period interacts with grazing intensity (stocking rate or pressure) to define the degree of utilization of forage "on offer" with regard to the species in association, as well as to plant parts. With a grazing intensity and grazing period that allow selection, animals tend to consume tender leaves and stems first, while consuming lignified stems and dead material later. In grass-legume associations, selectivity toward the legume usually increases with the number of grazing days, which is, in turn, associated with a lower availability of green dry matter of the accompanying grass. Grazing period and grazing intensity also influence the quantity of residual forage left after each grazing, which, in turn, affects the quantity of photosynthetic tissue and carbohydrate reserves in the plant. These reserves, the grazing period and grazing intensity, together with the soil seed reserves, modify the pasture's persistence.

The **rest period** interacts with the grazing period, grazing intensity, and season to determine, in a large part, the degree of accumulation—and quality—of the phytomass available to the grazing animal. The rest period can have, in addition, an effect on the botanical composition of grass-legume associations. Prolonged rest periods can result in excessive growth of erect grasses which can sometimes result in a prejudicial shading that reduces the persistence of some legumes. The rate of growth and maturity of the associated species should be the criteria for establishing rest periods for grass-legume associations in rotation.

Grazing Management in Small Plots

When experiments are planned to select and evaluate germplasm in small plots, it is important to consider some aspects of grazing inherent in this type of test, as well as illustrate how these management factors can be manipulated by the researcher.

Aspects inherent in small-plots testing

When designing an evaluation system for small-plot grazing, the researcher should choose a simulated grazing system. A "simulated system," is an experiment which contains only a small-scale part of a grazing system. The small experimental plot is one of several of a rotation, the others not existing. The animals remain outside the experiment during the plot's rest period—which is why it is difficult to simulate a continuous grazing system on small plots: the dimensions of the plot would have to be modified proportionately for it to be grazed permanently.

Nevertheless, two options for simulating continuous grazing have been proposed:

> Graze the plot frequently, for example, with intervals of one or two weeks; and
>
> Include all germplasm to be evaluated in small plots within a field large enough to allow continuous grazing.

None of the methods for simulating rotational and continuous grazing has been properly tested and, as a result, their validity has not been demonstrated.

The researcher should take into account that, according to the variables of grazing management, designs for germplasm evaluation in small plots can acquire such dimensions that it is difficult to finance, establish, and manage them.

For example, a design with three grazing intensities, three grazing periods, and three rest periods, with three replications, requires 81 experimental plots per germplasm treatment (3 x 3 x 3 x 3). If each plot is 500 m^2, the experiment will require 4.05 ha, 5 km of fencing, 42 watering places, and a high labor demand for sampling. To simplify the magnitude of grazing trials on small plots, the use of nonfactorial surface response designs, belonging to the family of composite central designs (see G. O. Mott, Chapter 10, p. 200-209) has been proposed.

When one plot contains germplasm of different palatabilities, there is a risk that animals will preferentially graze some entries, even to the extreme of overgrazing, while undergrazing others. This risk—very frequent in the evaluation of tropical germplasm—seems inevitable in a system of common grazing where, to reflect a situation of normal grazing, periods of permanence of several days in the plot are established.

Preferential selection by the animal is reduced as much as possible when the grazing period, as an experimental variable, is replaced by a system of rapid and intense grazing. This method, however, is criticized by many researchers as equivalent to using a mower.

Manipulation of grazing management factors on small plots

As mentioned earlier, the effects of grazing on forage germplasm can be evaluated through the use of differing intensities and frequencies of defoliation. Grazing intensities can be applied as either grazing pressure or stocking rate, concepts illustrated below by means of equations and examples.

If grazing pressure is used to generate different grazing intensities in tropical pastures, it should be remembered that a grazing pressure is high when the availability of green dry matter [(kg of (grass + legume)/100 kg of liveweight per day)] is 3 kg/day, or less; and a grazing pressure is low when the availability is 6 kg of green dry matter/100 kg of liveweight per day, or more.

To calculate the total liveweight of animals that should graze a plot, according to the grazing pressure chosen, the following equation is applied:

$$LW_t = \frac{GDM \times A \times 100}{D \times GP} \qquad (1)$$

where

LW_t = total liveweight of animals in the plot (kg/plot)

GDM = green dry matter (leaves + stems) available from the mixture (grass + legume) (kg/ha)

A = size of the plot (ha)

D = number of grazing days

GP = grazing pressure, defined as kg of GDM/100 kg of LW per day

The application of equation (1) is illustrated with the following example:

Green dry matter available at the beginning of grazing: 3000 kg/ha

Size of the plot: 0.05 ha

Grazing pressure chosen: 2.5 kg of GDM/100 kg of LW per day

Grazing period: 4 days

With the previous information, the researcher wishes to know what animal liveweight should graze the experimental plot. By applying equation (1), the value of the LW_t will be:

$$LW_t = \frac{3000 \times 0.05 \times 100}{4 \times 2.5} = 1500 \text{ kg}$$

As a result, in this example, 1500 kg of total liveweight for 4 days would result in a grazing pressure of 2.5 kg of GDM/100 kg of LW per day. If the average weight of the animals available is 250 kg, then six animals should be used (= 1500 kg of LW/250 kg of LW) per plot.

Equation (1) is applicable to situations where, because the grazing days are few, regrowth is minimal. If there are to be more than 4 grazing days in the experiment, then regrowth can affect the availability of daily forage; this regrowth should be included in the LW_t equation as follows:

$$LW_t = \frac{[GDM + (RGDM \times D)] \times A \times 100)}{D \times GP} \qquad (2)$$

where

RGDM = green dry matter of regrowth per hectare and per day

If stocking rate is used, then the following general equation applies:

$$SR = \frac{\sum_{i=1}^{n} (AU \times D)_i}{(GC)\,(A)\,(DEP)} \qquad (3)$$

where

> SR = stocking rate

$\sum_{i=1}^{n} (AU \times D)_i$ = sum of the product of the animal units that graze a plot—in the rotation system used—multiplied by the number of grazing days and i represents each grazing or rotation cycle

GC = number of grazings or rotation cycles

A = plot size in ha

DEP = days of evaluation period, that is, (grazing + rest) x number of grazings

Equation (3) can be simplified by eliminating the sum

$$\sum_{i=1}^{n} (AU \times D)_i$$

and the number of grazings (GC) when the animal units that graze a plot are constant in each cycle. Equation (3), when simplified, becomes:

$$SR = \frac{(AU)\,(D)}{(A)\,(DEP)} \qquad (4)$$

To find the number of animal units that should graze a plot, that is, to obtain an equivalent stocking rate desired per hectare, the following equation is used:

$$AU = \frac{(SR)\,(A)\,(DEP)}{(D)} \qquad (5)$$

The use of equation (5) is illustrated by the following examples:

Example 1. The objective is to evaluate the effect of two stocking rates: 2 and 3 AU/ha. There are three replications, that is, plots, 0.05 ha each, for each stocking rate treatment. A system of 4 days grazing and 28 days rest is applied. How many AU should be used for each stocking rate treatment to obtain equivalent stocking rates of 2 and 3 AU/ha, while maintaining the rotation cycle?

By applying equation (5):

2 AU/ha equivalent SR:

$$AU = \frac{(2)\,(0.05)\,(28 + 4)}{4} = 0.8$$

3 AU/ha equivalent SR:

$$AU = \frac{(3)\,(0.05)\,(28 + 4)}{4} = 1.2$$

Animal units used should be 0.8 and 1.2 to obtain equivalent stocking rates of 2 and 3 AU/ha, respectively, in a rotation system with 4 grazing and 28 rest days per plot.

Example 2. The objective is to evaluate the effect of grazing on an association by applying three rest periods (14, 28, and 42 days) in plots of 0.05 ha with a grazing period of 4 days and an equivalent stocking rate of 2 AU/ha, constant for all treatments. How many AU should be used to maintain an equivalent stocking rate of 2 AU/ha?

By using equation (5):

For 14 rest days:

$$AU = \frac{(2)\,(0.05)\,(14+4)}{4} = 0.45$$

For 28 rest days:

$$AU = \frac{(2)\,(0.05)\,(28+4)}{4} = 0.80$$

For 42 rest days:

$$AU = \frac{(2)\,(0.05)\,(42+4)}{4} = 1.15$$

Animal units used should be 0.45, 0.80, and 1.15, respectively, for 14, 28, and 42 rest days, to obtain an equivalent stocking rate of 2 AU/ha.

If differential stocking rates are applied according to season (for example, rainy and dry seasons), calculations are made for each season by applying equation (5) in the same manner. In such a case, to calculate the average stocking rate, it is necessary to use a weighted average according to the number of rotation cycles in each season.

A final example illustrates how, starting from grazing pressure, values for stocking rate can be derived.

Example 3. An association is evaluated, using grazing pressures of 3 and 6 kg of GDM/100 kg of LW per day, in a rotation system of 4 grazing days and 28 rest days, using plots of 0.05 ha. After completing four grazings, the average stocking rate can be calculated by employing the following data:

No. of grazings (cycles)	Liveweight (kg of LW/plot) for pressure treatment[a] of:	
	3	6
1	800	600
2	700	500
3	500	300
4	400	200

a. In kg of GDM/100 kg of LW per day.

To calculate the equivalent stocking rate for each grazing, per hectare, the liveweight data are converted to AU (1 AU = 400 kg of LW):

No. of grazings (cycles)	Equivalent stocking rate (AU/plot for pressure treatment[a] of:	
	3	6
1	2.00	1.50
2	1.75	1.25
3	1.25	0.75
4	1.00	0.50

a. In kg of GDM/100 kg of LW per day.

To calculate the equivalent average stocking rate per hectare (AU/ha), once the four grazing cycles are finished, the general equation (3) is employed:

Grazing pressure: 3 kg of GDM/100 kg of LW per day.

Number of grazings or cycles, i: 4.

$$SR = \frac{\Sigma\,[(2.0 \times 4), (1.75 \times 4), (1.25 \times 4), (1.0 \times 4)]}{(4)\,(0.05)\,[(4 + 28)\,(4)]} = 0.94 \text{ AU/ha}$$

Grazing pressure: 6 kg of GDM/100 kg of LW per day.

Number of grazings or cycles, i: 4.

$$SR = \frac{\Sigma\,[(1.5 \times 4), (1.25 \times 4), (0.75 \times 4), (0.50 \times 4)]}{(4)\,(0.05)\,[(4 + 28)\,(4)]} = 0.62 \text{ AU/ha}$$

According to the previous calculations, the equivalent average stocking rate per hectare, once the four grazings are concluded, is 0.94 and 0.62 AU/ha for the pressures of 3 and 6 kg of GDM/100 kg of LW per day, respectively.

Methodological Recommendations for Evaluating Forage Germplasm in Small Plots

Type of test

Some methodological recommendations resulted from the meeting's discussion groups. The recommendations are directed toward two types of tests for evaluating germplasm according to the number of entries and the level of its characterization. The number of entries, together with their level of basic characterization, is considered to physically limit grazing tests. Such a limitation is, therefore, a good reason for differentiating the two types of tests, namely:

> Selection under grazing of a high number of germplasm entries whose previous characterization is limited.

Evaluation under grazing of germplasm in an advanced state of selection.

It was agreed that, within the International Tropical Pastures Evaluation Network (RIEPT), selection under grazing of a high number of entries will be carried out principally at major research centers located in main ecosystems. The evaluation under grazing of germplasm in an advanced state of selection was considered to be an activity that will be conducted at different locations within an ecosystem, with the possibility of extrapolating information from one location to another—or others—within the same ecosystem.

Definition of terms

Entry is understood as a unit of germplasm (genus, species, ecotype, or variety, or accession) that will be evaluated individually in a test. A **field** is a fenced grazing area—independent of its dimensions—that can contain one or several entries, planted on individual plots within the field. The **plot**, therefore, contains one entry and is the unfenced area of a field that may contain more than one entry. The **entry** in a plot is either a germplasm unit or a germplasm association.

Selection from a large number of entries

Since the group of researchers participating at the meeting decided not to include more than 30 entries in the same test, this figure should be understood only as a result of the experience and opinion of some researchers and not as a critical evaluation of the optimal or maximum number of entries.

The principal methodological recommendations for setting up these tests are the following:

(A) PREVIOUS KNOWLEDGE ABOUT THE GERMPLASM

Before beginning the test, knowledge about the following germplasm characteristics is necessary:

adaptation and potential productivity under the site's soil and climatic conditions,

resistance to pests and diseases, and

degree of relative palatability.

Information on germplasm adaptation and resistance to pests and diseases should have been obtained in previous agronomic trials (RIEPT Regional Trials A and B) carried out at the site or in a similar ecosystem. Palatability can be verified from information generated at major research centers, or locally through "cafeteria" type grazing of forage germplasm that has just been submitted for agronomic evaluation. Knowing the palatability will prevent mixing, in the same field, germplasm entries which have different levels of palatability.

(B) TEST OBJECTIVE

At this level of testing, the objective is to identify or select forage germplasm that will be productive and persistent under grazing.

(C) EXPERIMENTAL DESIGN

Commonly known designs such as complete randomized blocks, split plots, and others are applied in these tests.

It is very strongly recommended that the researcher consult specialists in biometrics before designing the experiment. With their help and as a function of the size of variance expected, the design and number of replications necessary to detect significant differences can be chosen.

(D) EXPERIMENTAL FACTORS

The following experimental variables can be included:

germplasm,
grass-legume associations,
grazing management, and
fertilization.

Germplasm. The number of germplasm entries in these tests is not to surpass 30 in the same field. When groups of germplasm differ because of their growth habit or palatability, similar entries should be grouped within the same field. This precaution is indispensable because it avoids invasion or contamination of some entries by others—some have an invading habit—and because it lessens the effect of selective grazing brought about by different levels of palatability.

Associations. Legume germplasm should be tested in association with grasses, considering the advantages that association brings to animal production. Legumes should therefore be associated with grasses of different growth habits to determine their range of compatibility. As an alternative, legumes in evaluation can be associated with the best grass in the adaptation tests (RIEPT Regional Trials A and B) and with the common grass of the site.

Grazing management. At this level of evaluation, it is convenient to define the effect of grazing management on germplasm, especially as it refers to the compatibility and persistence of the association's components. Grazing management can be studied with two grazing intensities (stocking rate or pressure), as a minimum, or with two grazing frequencies. To choose either grazing intensity or frequency as a management factor will depend on the researcher. If the first is chosen, the grazing frequency should be maintained constant and will have been estimated by previous knowledge of growth rate and maturity of the grass. Nevertheless, rest periods of 3 to 4 weeks in rainy seasons, and from 5 to 6 weeks in the dry seasons, can be taken as a guide. If the researcher decides to use grazing frequency, it will be necessary to maintain a grazing pressure—or stocking rate—uniform in all frequencies. Grazing days should also be uniform.

Fertilization. It is not usually recommended that, at this level of germplasm evaluation and selection, fertilization be included as an experimental factor. Establishment fertilization should be based on the minimal requirements of the germplasm being tested and should be studied in trials of fertilization adjustment to agronomic level at each site.

If the researcher decides, when looking at trial objectives, to employ more than one fertilization level to evaluate recycling of nutrients and maintenance fertilization, he must consider the risk of fertility transfer from one plot to another when, within a field, plots are established with qualitative or quantitative differences of fertility. These risks can be diminished, but not eliminated, by employing a system of rapid defoliation that will impede the deposit of feces and urine coming from the same field. In addition, the animals that enter the field should come from an unfertilized pasture.

It is recommended that the fertilization treatments be distributed in separated plots, being careful not to move animals from plots with higher fertilization levels to those with lower levels. To avoid this, it is recommended to conserve an area outside the experiment with no or low fertilization that will serve to clean—in a lapse of 5 or 6 days—the animal's digestive tract. Alternatively, particularly in studies on nutrient recycling, rotating animals in plots that have received the same fertilization treatment is recommended.

(E) RESPONSE VARIABLES

The nature of selection tests with a high number of germplasm entries requires that responses to treatments established be measured in terms of qualitative and quantitative characteristics of the plants, without determining response in animal production.

The response variables that should be measured are:

> production of total dry matter and green dry matter of the mixture (grass + legume),
>
> botanical composition (grass + legume + weed), and
>
> ground cover.

Also important is to keep a detailed record of the presence of pests and diseases, without applying any pest, disease, or weed control.

To estimate the production of total dry matter and green dry matter, it is necessary to measure (on plots) the residue that is left after grazing and the forage available before the next grazing. When an experiment includes treatments with zero rest days (continuous grazing), the calculation of forage growth requires the use of movable exclusion cages.

Details for measuring and calculating yield of forage plants are found in recent papers by Hodgson et al. (1981), Shaw and Bryan (1976), and 't Mannetje (1978). Older, but still valid, studies are those by Brown (1954), the Grassland Research Institute (1961), and Lynch (1966).

The botanical composition of the pasture over time is a fundamental response variable that permits evaluation of survival of association components under different intensities or frequencies of trampling and defoliation produced by the animal. The specific methods to measure this botanical composition are found in 't Mannetje (1978).

The number of entries at this level of evaluation is large and, as a result, quantitative observations should be kept at a minimal, necessary, level. However, the researcher should exercise constant visual control over the germplasm being tested to detect changes that are produced in the associations during the year, the manner in which animals defoliate the diverse associations, the degree of the animal's seasonal selection of association components, and, as indicated earlier, the presence of pests and diseases.

(F) FREQUENCY OF OBSERVATIONS

The fundamental changes that are to be measured in these tests occur over time and, therefore, it is critical to take very precise measurements at the beginning and end of the tests. Evidently, when grazing pressures are used, it is necessary to measure the quantity of forage available before each grazing. If, however, animal stocking rates are used, periodic measurements are recommended, especially in the rainy season and in the transition season.

(G) DURATION OF TESTS

Species being tested should be grazed over a 2-year period, once they are well established and have received some grazings to make them uniform.

(H) SIZE AND DISPOSITION OF THE FIELDS AND PLOTS

The minimum sizes recommended are:

Fields:	500 m^2 (0.05 ha)
Plots within fields:	25 m^2 for erect plants
	50 m^2 for plants with decumbent growth habit or with stolons

The dimensions and size of fields should be such that they will allow establishment of the desired grazing management.

The fields should be separated by fences, either three- or four-wired-permanent fences or high-powered electric fences can be used. Watering points and mineral boxes should be installed in all fields. Access to water is frequently a problem that should be solved when working with small fields by developing field designs that will facilitate access to a watering point from several fields.

Plots within a field should be marked off clearly with permanent marks to outline their limits. This is best done, not by hammering stakes in the middle of the field, but by placing metal stakes at the edges of the field. Marking off the plots will help sampling.

Evaluation of germplasm in advanced state of selection

At this stage of germplasm evaluation, the researcher has germplasm with known characteristics that is almost ready for final evaluation where its animal production potential is measured.

(A) TEST OBJECTIVE

The objective of these tests in small plots is to obtain specific information on the effects of grazing management variables, and on their interactions with productivity, compatibility, and persistence of forage species, so that these tests will contribute to perfecting the design of subsequent animal production tests and to visualizing possible germplasm use in production systems.

(B) PREVIOUS KNOWLEDGE ABOUT THE GERMPLASM

Germplasm that has reached this stage of evaluation should have been characterized in detail during earlier evaluation stages for the following variables:

growth throughout the year;
fertilization requirements, at least for establishment; and
compatibility of grasses with legumes.

(C) EXPERIMENTAL DESIGN

Comments in section C (p. 228) apply equally to this type of test.

(D) EXPERIMENTAL FACTORS

The two experimental factors of greatest interest in these tests are germplasm and grazing management.

Each entry of a legume in association with grass occupies a field and undergoes individual grazing; however, when two or more entries are accessions of the same species, with similar morphological characteristics, time of flowering, and palatability, they can be grouped in the same field in which common grazing will be employed.

These advanced tests investigate new factors of grazing management. At least two intensities of grazing (grazing pressures or stocking rates) and at least two frequencies of defoliation should be considered as variables of grazing management. By including at least two levels of each management factor the range within which the interactions occur can be chosen by the researcher. This practice is fundamental for selecting germplasm capable of withstanding extreme grazing conditions that sometimes are very real. It can happen, for example, that of two legumes in association with a grass, one will be more productive than the other, and will persist only in conditions of low grazing intensity and with prolonged rest periods, while the other one, of lower production, will persist under a wide range of grazing managements. The first legume could be recommended to advanced producers who manage their pastures well and seek highly productive materials; the second legume could be widely recommended, without major management restrictions.

An additional alternative experimental design that explores a wider range of factors, and of levels within factors, of grazing management are response surface designs. These designs require greater availability of resources and a more extensive work area. The information obtained is in the form of response surfaces, which does not allow comparisons among individual means. A detailed description of these designs is found in Chapter 10 by G. O. Mott (p. 200-209).

(E) RESPONSE VARIABLES

Given that fewer entries are put on trial and that information generation is a necessary step before establishing grazing trials that will measure animal production, the greatest possible number of pasture attributes should be quantified at this stage. The important response variables are the same as those studied in the experiments with a high number of entries (section E, p. 230-231), emphasizing determinations of dynamics of botanical composition as a measurement of the association's stability.

It is recommended to periodically measure the quantity of green dry matter (leaves + stems) of the association's components. This measurement of phytomass, expressed as kg of GDM/ha, is related to animal production, and contrasts with the absence of correlation that is usually found between total dry matter and animal production.

(F) FREQUENCY OF OBSERVATIONS

The need for obtaining quantitative information requires an increase in the frequency of measurements. If stocking rates are used, it is recommended to measure forage availability at the beginning and end of a determined grazing period and at the beginning of the next grazing period to obtain (in representative seasons) an estimate of pasture growth, as was explained earlier (section E, p. 230-231). It is advisable to take these measurements in different seasons, coinciding with periods of minimum and maximum rainfall. If grazing pressure is used as a criterion of grazing intensity in each grazing cycle, forage availability should be measured before taking the animals to the field, to determine the number of animals that should be used. Forage availability should also be known, to calculate the grazing pressure resulting from the stocking rates used.

(G) SIZE AND DISPOSITION OF THE FIELDS

The minimal size of the experimental fields should be 500 m^2, as for tests with a large number of entries. However, in ecosystems where germplasm tends to show less productivity—because of soil fertility, prolonged dry season, or similar causes—this minimal area should be increased to allow greater flexibility in the use of animals, especially if stocking rate is to be used to generate grazing intensities.

When several entries of the same species are evaluated—with similar growth habit and palatability—they can be planted in plots within the field. Plots should be 25 m^2 for erect plants and 50 m^2 for prostate and stoloniferous plants.

(H) DURATION OF THE TESTS

As in tests with a large number of entries, these should last 2 to 3 years, discounting the establishment phase and pasture uniformity grazings.

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Annex I

Acronyms and Abbreviations

AU	Animal unit
C3, C4	Signify different methods by which plants obtain carbon dioxide for photosynthesis
CENARGEN	Centro Nacional de Recursos Genéticos, Brazil
CIAT	Centro Internacional de Agricultura Tropical, Colombia
CNIA	Centro Nacional de Investigaciones Agropecuarias, ICA, Colombia
CNPGL	Centro Nacional de Pesquisa de Gado de Leite, Brazil
CPAC	Centro de Pesquisa Agropecuária dos Cerrados, Brazil
CSIRO	Commonwealth Scientific and Industrial Research Organisation, Australia
DM	Dry matter
EEA	Estación experimental agropecuaria (i.e., Agricultural experiment station)
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária, Brazil
FAO	Food and Agriculture Organization of the United Nations, Italy
FONAIAP	Fondo Nacional de Investigaciones Agropecuarias, Venezuela
GDM	Green dry matter (leaves and stems of pastures)
IB	Intake per bite (by grazing animal)
ICA	Instituto Colombiano Agropecuario, Colombia
IDIAP	Instituto de Investigaciones Agropecuarias, Panama
IDRC	International Development Research Centre, Canada
IIZ	Instituto de Investigaciones Zootécnicas, FONAIAP, Venezuela
IVOMD	In vitro organic matter digestibility

LW	Liveweight
OM	Organic matter
RB	Rate of biting (by grazing animal)
RIEPT	Red Internacional de Evaluación de Pastos Tropicales (i.e., International Tropical Pastures Evaluation Network)
RTA, RTB, RTC, RTD	Regional Trials A, B, C, and D of RIEPT
UEPAE	Unidade de Execução de Pesquisa de Âmbito Estadual, Brazil
UNAM	Universidad Nacional Autónoma de México, Mexico
UNDP	United Nations Development Programme, France
WUE	Water-use efficiency (in plants)

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Index

In some cases, an entry begins with a preposition. To alphabetize the entries, these prepositions are ignored. Page references to figures are in italics.

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