final report

Project code: NAP3.203

Prepared by: John G. McIvor, Andrew D Noble, David M Orr
CSIRO Tropical Agriculture, CSIRO Division of Soils, Department of Primary Industries

Date published: December 1996

ISBN: 9781741917444

PUBLISHED BY
Meat & Livestock Australia Limited
Locked Bag 991
NORTH SYDNEY NSW 2059

Review of Stability and Productivity of Native Pastures Oversown with Tropical Legumes

NAP Occasional Publication 1

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Disclaimer

Contents

Preface

The Meat Research Corporation acknowledges the excellent work of Dr John G. McIvor of CSIRO Tropical Agriculture, Dr Andrew D. Noble of CSIRO Land and Water and Dr David M. Orr of the Queensland Department of Primary Industries, who conducted this review and submitted their report to the MRC in November 1996.

Following on from this report, a major research and extension program has been established, with CSIRO Land and Water and the Queensland Department of Primary Industries, to address problems of the instability and decline of native pastures associated with legume dominance and increasing soil acidification. This work is jointly funded by the Meat Research Corporation and the Land and Water Resources Research and Development Corporation, under the MRC's North Australia Program. The four projects in this program are –

- Workshop on the management of native pastures oversown with *Stylosanthes* spp. (NAP3.216) – Barry Walker and Judy Lambert, Meat Research Corporation.

- Sustainability of *Stylosanthes* based pasture systems in northern Australia: Managing soil acidity (NAP3.218) – Andrew Noble, CSIRO Land & Water.

- Communication of stylo management practices (NAP3.220) – Col Middleton, Queensland Department of Primary Industries.

- Management of native pastures oversown with stylos (NAP3.221) – Deryk Cooksley, Queensland Department of Primary Industries.

A Producer Panel is associated with this work and will continue to meet annually to review progress.

Barry Walker
Program Coordinator
MRC's North Australia Program

Forward

With the increasing use of *Stylosanthes* spp. in northern Australia (c. 1.2 M ha) and the accompanying management practices, such as the use of fertilisers and supplements, Brahman cattle and increasing stocking rates, the problems of the instability and decline in condition of the native pastures with associated legume dominance, have emerged as important issues for the beef industry of northern Australia. It is important for these issues to be further investigated.

In September 1996 the MRC commenced a review with the following terms of reference:

1. To collate, review, critically assess and document current information on the issues of the instability of native pastures oversown with tropical legumes and clearly outline the major issues and problems.

2. To identify and outline appropriate management practices/strategies based on current knowledge, which can be immediately adopted by industry.

3. To identify critical deficiencies in the current knowledge and practices and outline potential actions and R&D activities to overcome them.

4. To prepare a draft report by 18 October and present this report to an industry group of 6 to 8 producers and agri-business people.

5. Following these consultations, compile a final report to the NAP3 Resource Program Coordinator by 28 November 1996.

6. Following an assessment of the report by NAP management, to prepare a short report of up to 8 pages, which would be published by the MRC and widely circulated to industry, R&D agencies and personnel.

The review team consisted of:

Dr John McIvor (Principal Investigator), Senior Principal Research Scientist with CSIRO Tropical Agriculture, Brisbane, who has conducted extensive research on the stability of tropical pastures oversown with stylos.

Dr David Orr, Principal Pasture Agronomist with QDPI in Rockhampton, who has conducted extensive research in the dynamics of native pastures in response to management and climatic variables. More recently he has worked with the dynamics of native pastures oversown with *Stylosanthes* species.

Dr Andrew Noble, Principal Research Scientist with the CSIRO Division of Soils in Townsville. Dr Noble has conducted extensive research on soil acidification problems with temperate legumes in southern Australia. He has recently completed a study for MRC on "Soil acidification research in the semi-arid tropics" (Project CS.277).

The team met in Brisbane with Dr B. Walker (NAP Technical Coordinator) on August 29 to plan the review procedures, divide up the various tasks and responsibilities for conducting the review and determine the structure and content areas for the report.

Drs McIvor and Orr visited Mareeba on September 16 and 17 to inspect QDPI experiments and to discuss relevant issues with local staff. The review was written jointly by the three investigators and submitted to Dr Walker on October 15. The Executive Summary was copied to a number of producers (see Appendix 3) prior to a producer consultation meeting held in Townsville on November 7 to obtain producer input and get feedback on the review.

The authors thank all those who contributed to our discussions, particularly the producers at the Townsville meeting for their inputs.

Abstract

Native pastures oversown with introduced legumes are an important component of beef production systems in northern Australia. These pastures can give greater animal production than native pastures but there are increasing concerns about the stability and productivity of these systems. It is important for these issues to be further investigated and in September 1996 the MRC commenced a review to document current information on the issues, clearly outline the major issues and problems, identify and outline appropriate management practices/strategies based on current knowledge, identify critical deficiencies in the current knowledge and practices and outline potential actions and R&D activities to overcome them.

The results of the review are contained in this report. The impacts of oversown pastures on soil, vegetation and animal production are reviewed. Most oversown legume pastures have been developed by sowing the seed on the soil surface with no soil disturbance after burning or heavily grazing the existing native pasture. Establishment is usually slow and the legumes frequently contribute little to the sward in the initial years. However in most situations the legume increases with time and in many cases comes to dominate the sward. This may result in reduced biodiversity but this area requires more research to adequately assess the impacts. Animal production is higher from legume-based pastures than native pastures with most advantage occurring during the late wet and early dry seasons. Legume-based pastures can increase soil fertility but serious declines in soil pH have been measured under tropical legume pastures bringing into question the long term productivity of these systems.

The population biology of tropical legumes and grasses is discussed along with factors (seasonal conditions, soil type, fertiliser, animal supplements, grazing pressure, fire, associate grass, tree clearing, legume species/cultivar, geographic location, plant competition, spatial distribution) affecting the composition and stability of legume-based pastures.

Practices currently available to manage botanical composition in legume augmented pastures are burning to promote perennial grasses and manage legume populations, grazing management to favour the grass or the legume, sowing a grazing tolerant grass when sowing stylos, and choosing soils with a high phosphorus level or applying superphosphate.

Current knowledge gaps are listed and recommendations made for future research and development (a detailed inventory of existing commercial pastures; a grazing trial to examine combinations of levels of pasture utilisation, pasture spelling, fire and sown grasses on the stability and productivity of pastures which are currently legume dominant; suitable information systems be developed to capture knowledge of the performance and management of pasture species, and to make this widely available to users; continued monitoring of fertility decline and soil pH changes).

Executive Summary

With the increasing use of *Stylosanthes* spp. in northern Australia and the accompanying management practices, such as the use of fertilisers and supplements, Brahman cattle and increasing stocking rates, the problems of the instability and decline in condition of the native pastures with associated legume dominance, have emerged as important issues for the beef industry of northern Australia. It is important for these issues to be further investigated.

In September 1996 the MRC commenced a review with the following terms of reference:

1. To collate, review, critically assess and document current information on the issues of the instability of native pastures oversown with tropical legumes and clearly outline the major issues and problems.

2. To identify and outline appropriate management practices/strategies based on current knowledge, which can be immediately adopted by industry.

3. To identify critical deficiencies in the current knowledge and practices and outline potential actions and R&D activities to overcome them.

4. To prepare a draft report by 18 October and present this report to an industry group of 6 to 8 producers and agri-business people.

5. Following these consultations, compile a final report to the NAP3 Resource Program Coordinator by 28 November 1996.

6. Following an assessment of the report by NAP management, to prepare a short report of up to 8 pages, which would be published by the MRC and widely circulated to industry, R&D agencies and personnel.

Background

Native pastures support the bulk of the cattle in northern Australia, but their deficiencies in terms of herbage yields and quality have been well known for many years. A great deal of effort has gone into introducing and evaluating exotic legumes which could overcome (at least partially) these deficiencies and increase animal production. Of these, *Stylosanthes* is the most important genus and has been sown extensively with consequent increases in animal production, but a number of other legumes are also available.

The widest use of legumes has been to oversow into existing native pastures with the aim of developing stable grass-legume mixtures. Although productive pastures have been developed, there are increasing concerns about the dominance of legumes in some pastures and fluctuations in composition from year to year - both grasses and legumes are important for animal production, and legume dominance may influence both soil and vegetation resources. Legume dominance is not yet widely identified by most producers as a problem. Nevertheless, some producers have become concerned and there are also questions being asked of the weed potential of introduced legumes.

Most of the experimental and commercial experience with legume-native grass pastures is with stylos and this report is dominated by studies of stylo pastures. However, other legume species are considered where information is available.

Soil Impacts

The use of leguminous plants to increase the fertility of farming systems is a fundamental practice in agricultural production systems throughout the world. The introduction of *Stylosanthes* into pasture production systems of northern Australia has resulted in a significant increase in the productivity of native pasture systems and profitability of the livestock industry as a whole. The positive impacts of legume introduction on the soil resource base are evident in the increase in the inherent fertility of the soil through the fixation of nitrogen and its subsequent transfer to the soil, and through the addition of superphosphate. However, there have been significant negative impacts to the soil resource base. For example, increased stocking rates have resulted in significant devegetation with a concomitant loss in desirable soil surface structural features which has resulted in accelerated soil loss. The aforementioned negative impacts are largely associated with overstocking and the prolonged drought, and can therefore be rectified to a large degree by improved management.

More recently there is conclusive evidence to suggest that the introduction of *Stylosanthes* to pasture systems in northern Australia has resulted in a significant decrease in soil pH, and associated base stripping. Statistically significant acidification to depth in soil profiles has been observed to have occurred on sites sampled throughout Queensland and the Northern Territory on soils that are dominated by *Stylosanthes*. The net acidification rate of the 11 sites sampled range from 0.31 to 2.91 kmol H^+ ha^{-1} yr^{-1}, with a mean of 0.92 kmol H^+ ha^{-1} yr^{-1}. The highest rate of acidification was observed under an irrigated *Stylosanthes* seed production system. This production system is characterised by a monoculture of *Stylosanthes*, which is irrigated and the entire crop removed at harvest. In contrast, there was no significant shift in pH at a site at Meadowbank which can in part be ascribed to the higher soil pH buffering capacity of these basalt derived soils and the lack of legume dominance in the sward due to the inherently high P levels in these soils. At a site at Wrotham Park soil pH's were compared between samples collected in 1971 and 1996. Surface soil pH_w had declined by 1.05 (grass dominant pasture) and 1.78 units (stylo dominant pasture) over a 25 year period. This clearly indicates the impact of improved grazing systems on the soil resource over a relatively short period of time. In addition, this result would suggest that acid addition rates discussed above may be conservative and that rates of acidification may be higher than those calculated through paired site analysis. The potential cost of applying lime to remediate soil acidification was estimated to be between \$15.50 and \$145.50 per ha over a 10 year period. However, it is questionable whether the addition of surface applications of lime will effectively neutralise subsurface acidity.

The long-term impacts of continued soil acidification on the resource base are numerous. A continual decrease in pH will result in the soil exchange complex becoming dominated by acid cations (Mn^{2+}, Al^{3+} and H^+) at the expense of basic cations (Ca^{2+}, Mg^{2+} and K^+). This could lead to significant changes in biodiversity where the plant communities would be dominated by species having a relatively high tolerance to acid soil infertility. In addition, increased acidification may result in possible nutritional (Mo, Ca^{2+} etc.) deficiencies, the dissolution of clay platelets resulting in a reduction in the basic cation exchange capacity of the soil and an increased likelihood of aluminium and manganese toxicity. It is suggested that increased soil acidification could lead to decreased pasture productivity with a concomitant decrease in animal performance. In addition, declining soil cover may result in accelerated soil loss and therefore off site degradation.

The importance of maintaining plant cover to reduce runoff and soil loss is well recognised: it intercepts and absorbs the kinetic energy of falling rain drops; it impedes the flow of runoff water thereby increasing infiltration; and it reduces the erosive force of flowing water. Impacts of legume pastures on soil loss will depend on the utilisation rates used; the increased herbage growth of legume-based pastures can increase ground cover and reduce soil loss, but if high utilisation rates are used there will be increased soil loss due to the resultant low cover.

Vegetation impacts

Most oversown legume pastures have been developed by sowing the seed on the soil surface with no soil disturbance after burning or heavily grazing the existing native pasture. The absence of soil disturbance, low seeding rates (generally less than 2 kg/ha), and competition from the native pastures usually results in slow establishment and the legumes frequently contribute little to the sward in the initial years. However in most situations the legume increases with time and in many cases comes to dominate the sward.

Although there is little detailed information, exotic pasture species have attracted considerable criticism for their impacts on biodiversity and a number have been listed as environmental weeds. They may cause changes to faunal habitat as well as changes to vegetation. These changes can lead to a loss of biodiversity as native species decline or are displaced with suggested causes including changed nutrient supply levels, altered fire regimes, competition, changed drainage flows, restricted access. In recent years, Verano and Seca have become conspicuous species on many roadsides in northern Australia, in some cases forming almost pure stands. Reductions in biodiversity are possible but there have been no studies to determine which communities or plants (if any) are under threat.

Animal production

The annual live weight gain advantage for cattle grazing oversown pastures compared to native pastures is usually in the range 30 to 60 kg/head with average annual liveweight gains of 160 kg/head. There is a general pattern of diet selection throughout the year for cattle grazing stylo-grass pastures. In the early wet season cattle have a marked preference for young green grass. As the season progresses, cattle select an increasing proportion of stylo with stylo proportion reaching a maximum in the late wet or early dry seasons. Stylo proportions generally decline in the dry season and grass is again preferred by the late dry season. This renewed preference for grass coincides with leaf fall and increasing stem:leaf ratios in the stylo and has been attributed to spoilage of the dry stylo by mould which is encouraged by heavy dews, high humidity and periods of overcast and rainy weather. This basic seasonal pattern is modified by amount and distribution of rainfall, grass/legume proportions in the pasture, soil fertility, and stylo and grass species. Selection against stylo in the early wet seems stronger for Townsville stylo and Verano than Seca.

The changes in diet selection relate to differences in animal production from stylo- and grass-dominant pastures at different times of the year. In the late dry and early wet period liveweight losses on strongly stylo dominant pastures are greater than those from pastures with perennial grasses. The detrimental effect of stylo dominance is likely to be less with perennial shrubby stylos such as Seca due to greater leaf retention in the dry season, more rapid growth after the first rains from the perennial plants than from seedlings, and the better acceptance of Seca by cattle in the early wet season. In contrast to these early wet season results, animal growth is greater from stylo pastures than grass pastures in the late wet and early dry seasons.

Population biology of tropical legumes and grasses

The invasive legumes, stylos and Wynn cassia, are free seeding and set large amounts of seed at a time when these species are relative unpalatable compared with the associated native grasses such that grazing management has only a minor role in plant persistence. In contrast, grazing management is critical to the persistence of the non-invasive Siratro and this difference is closely related to differences in their population biology.

Comparing the population biology of native grasses and legume in legume/grass pastures, native grasses are disadvantaged because:
(1) native grasses produce much less seed (particularly in the north) and this is exacerbated by the lack of a persistent seed bank such that seed must be produced each summer for seedling recruitment to occur in the subsequent summer.
(2) most native grass seedlings emerge following the first major rainfall each summer and the subsequent survival of these seedlings is dependent on further rainfall. This contrasts with legume seedling emergence which occurs progressively through the summer as hardseededness is overcome.
(3) because of (1) and (2), grasses are less able than legume to increase density and, combined with the fact that grasses are further disadvantaged by being selectively grazing over summer (when they are susceptible to defoliation while the legumes are ungrazed or only lightly grazed), then it is not surprising that legumes, in the longer term eventually dominate these pastures in the absence of some management intervention.

Factors affecting the composition and stability of legume-based pastures

Seasonal conditions Much of the research dealing with Seca/Verano/grass dynamics has been conducted during the last 15 years. In many cases, this period has experienced some of the driest years on record. Has drought weakened the perennial grasses relative to legumes such that perennial grasses will become more competitive with a return to more "normal" seasons? Had seasonal rainfall been more "normal", would legume dominance have developed sooner? Botanical composition of pastures containing perennial species is likely to be less variable than that of pastures dominated by annual species as conditions during germination can markedly affect the proportions of annual species.

Soil type Both Verano and Seca are better adapted to lighter soils and are less competitive on heavy clays. Clay soils are also often associated with depressions at the bottom of slopes where frosts are a consideration in central and southern Queensland. Because of the effect of soil type on Seca distribution, commercial paddocks in central and southern Queensland are likely to have more mosaics of different proportions of Seca than paddocks in northern areas.

Fertiliser Phosphorus deficiency is widespread in northern Australia and superphosphate is the most widely used fertiliser. Effects of available P on stylo and grass growth are: at very low P levels (<3 ppm) legume growth is usually poor and botanical changes are slow; at low P levels (3-8 ppm) legume growth is enhanced and pastures become stylo dominant, especially with Seca; at higher P levels (>8 ppm) growth of legume is further increased but where introduced grasses are used the higher P levels are more advantageous to the grass and grass dominance is promoted.

Animal supplements Supplementing animals represents a significant input of P into pasture systems and has influenced the botanical composition of experimental pastures (e.g. *Alysicarpus vaginalis* increased from 10% to 25% at Katherine and Urochloa increased from <5% to 27% at Lansdown).

Grazing pressure Cattle select grass over stylos and Wynn cassia during the growing season. This dietary preference for grass in summer favours the legume in terms of both adult plant survival and seed set together with seedling establishment. In general for Verano/native grass pastures, increased stocking rates lead to an increase in Verano and a decrease in native perennial grasses; this can produce nearly pure Verano at high stocking rates. Annual grasses and forbs may also increase as stocking rate rises. Stocking rate responses on Seca/native grass pastures are more variable with Seca able to dominate over a range of stocking rates.

Fire Fire has been used successfully to control increasing Seca dominance in central Queensland. However, there is no clear understanding of when or how often fire can be used successfully. The response to fire depends on the response of mature plants and the soil seed bank. Considerable variation exists between stylo species in their ability to survive fire. Although many factors influence plant survival (fire intensity and duration, plant age, physiological state and health) the species rank for survival in order *S. scabra, S. hamata* and *S. guianensis.*

The ability of individual plants to withstand fire depends on how well protected are the growth sites within the different plants and individual Seca plants resist fire because of their ability to regrow from underground growth buds. Similarly, fine stem stylo can recover from fire because the plant crown is underground where it is protected from fire.

Fire also influences seedling regeneration. Although fire kills up to 40% of the seed bank on the soil surface, a considerable quantity of hard seed is softened and can lead to germination and seedling establishment. Before fire is used as a management tool, care should be taken to ensure that is sufficient seed is present in the soil seed bank.

Tree clearing Tree clearing or killing usually leads to increased grass growth and a consequent decrease in stylo due to increased grass growth.

Geographic location In northern Australia where the dry season moisture stress is greatest, the perennial grasses are inherently more susceptible to heavy grazing. With adequate soil fertility, heavy grazing leads to the replacement of perennial grasses by broadleaf weeds (e.g. *Hyptis* and *Sida*) and annual grasses (e.g. *Digitaria, Dactyloctenium* and *Brachiaria)*. Under conditions of heavy grazing, the addition of a sown legume accentuates the loss of perennial grasses and consequent legume dominance. Further south, the period of dry season moisture stress is less and perennial grasses are more resilient and tend form a more stable mix with oversown legumes.

Management strategies to maintain or alter botanical composition

Maintaining a productive legume-perennial grass mixture over the long term presents a considerable challenge. Many plant, climate, management and edaphic factors interact with the demographic features of each species so that simple recipes for management are unlikely to have widespread success; productive stylo/grass pastures are most likely to persist when managers know what to do and when. Legume dominance is a very real issue in legume-native grass pastures. There are potential management factors currently available to manage botanical composition in legume augmented pastures.

Fire Burning in spring followed by spelling /reduced grazing pressure can promote perennial grasses, especially *H. contortus*, and manage legume populations. Fire can kill mature legume plants so that the legumes need to reestablish from seed. Such burning practices can be advocated where the pasture is well established and has sufficient soil seed reserves for the maintenance of the legume population.

Grazing management Based on an understanding of the diet selected by cattle, grazing management can be manipulated to:
(i) favour the grass by spelling or reducing grazing pressure during the summer to promote the growth and seed production of perennial grasses;
(ii) favour the legume by grazing heavily during the summer;
(iii) increase seed ingestion and aid spread of the legume;
(iv) minimise legume spread by grazing animals elsewhere on the property when legumes are carrying their highest seed loads.

Sow a grazing tolerant grass when sowing stylos A suitable introduced grass could be sown at the same time as the legume. In general the stylos are more grazing tolerant than the native grasses and a grazing tolerant grass would make maintenance of balanced pastures an easier task in variable environments. Planting a grass species that has the ability to capture nitrate before it is leached would significantly reduce the rate of acidification. At this stage *Urochloa mosambicensis* and *Bothriochloa pertusa* seem to be the most suitable grasses for wide areas; *Cenchrus ciliaris* is also adapted but may be too competitive to form long-term legume-grass mixtures.

Soil phosphorus level and superphosphate application In legume dominant swards the addition of P may assist in balancing the pasture. Conversely, the planting of *Stylosanthes* could be confined to soils that have a high inherent P status so as to prevent legume dominance occurring. Since accelerated acidification is a function of both legume dominance and associated climatic and edaphic factors, the planting of *Stylosanthes* into native pastures should be confined to soil having a high inherent buffering capacity and an adequate P status that would maintain a significant grass component in the sward.

Area sown Given that managing oversown pastures can be difficult, many people suggest planting only small areas (say 10-30% of properties) to legume and managing these areas intensively. Such a plan may be compatible with using areas of high P/high buffering capacity soils and with producing cattle for particular markets.

Current knowledge Gaps

The review and discussions with experienced pasture scientists revealed a number of knowledge gaps which have been grouped as follows:

- *Geographic variation*: there is a need to establish a matrix of geographic location x legume species x stocking rate interactions to define the general trend for grazing tolerance and community stability to increase from the north-west to the south-east.
- *Management practices*: how to use fire in managing Seca populations, promoting companion grasses (both native and sown), and controlling woody species (including regrowth). What is the impact of resting pastures in the early wet season or deferring grazing to favour grasses in legume/grass mixtures? Management requirements for the recently released *Stylosanthes* sp. aff. *scabra* cultivars.
- *Soil studies*: legumes can fix nitrogen but what are the cycling and transfer processes in tropical pastures? Nutrient budgets of pasture systems. What is the impact of legume pastures on the soil resource? What are possible methods of remediation of acid soils in northern Australia? What impact do legumes have on soil surface condition and structure? What is the role of grasses in preventing/ameliorating soil acidification?
- *Animal production*: what impact does proportion of legume in the pasture have? Contributions of different pasture components to animal diets and their value for animal production.

- *Legume characteristics*: What is the rate and seasonal timing of legume seed production and how much is transferred through grazing animals? What are the root profiles of legumes, grasses and trees? Impact of legumes (particularly Seca) on tree survival/mortality.
- *Sown grasses*: what is the influence of grass species, soil type, geographic location, sowing methods, pasture management, etc. on the performance of sown grasses after legume dominance has been attained? Are other grasses needed? Are other grass genera (e.g. *Digitaria, Bothriochloa, Dichanthium*) of value? Can Seca be grown in mixtures with Indian couch grass?
- *Biodiversity*: sown pastures and their associated management (fertiliser, increased stocking rates, cultivation, tree clearing) can have marked effects on species diversity but the detail of these changes is not known.
- *Legume use*: need to define the situations where Wynn cassia should be used. Are there more suitable legume species in current evaluation programs and recent South American collections (e.g. *Aeschynomene*)?
- *Information/indicators*: uncollated (and often unpublished) knowledge about the performance and management of sown pasture species needs to be synthesised and made available - computer-based formats may be the most suitable method. Early warning signs (indicators) need to be developed for managing pastures to control composition by preventing pastures from crossing thresholds from which it will be impossible (or very difficult) to recover.

Identification of issues for future R&D

- There is a need for long term information on the stability and productivity of oversown pastures that can best be determined from a detailed inventory of, and "snap shot" experiments on, existing commercial pastures. Such information would include extent and condition of existing pastures; producers' views on management, legume dominance, etc; soil acidification; impacts on biodiversity; persistence of sown species; impacts on soil surface condition.
- Use current data to model the risk of acidification for certain climatic conditions and soil types. This would be important in designating sites/regions where the introduction of legumes would have their least impact on the soil resource base. A relatively robust model based on inherent soil chemical properties, climate and productivity of the pasture could be developed to predict the risk of acidification and be a key component in predicting the financial implications of accelerated acidification from a resource economist's perspective.
- A clear understanding of nutrient inputs and outputs from these production systems. An estimate of nett proton accumulation due to product export can be made using regression equations and the determination of the ash alkalinity of material exported. Quantification of the contribution to the total proton pool by nitrate leaching and organic matter accumulation needs to be assessed over a wide range of soil types from the well drained red earths to the texture contrast soils. This could be achieved by measuring fluxes of protons entering and leaving the soil using a theoretical framework. In addition, the long-term impact of these improved pasture systems on the soil resource base is unknown. Research into nutrient budgets under improved pastures would assist in predicting the long-term impacts.
- Alternative methods of ameliorating acid soil infertility. Preliminary CSIRO research with a small range of tree species has shown wide differences in the ash alkalinities, and basic cation contents of leaf litter. In addition, it has been shown that the leaf litter of the tree species *Melia azedarach* (common name: white cedar), which has a high ash alkalinity, is able to neutralise substantial acidity when mixed with an acid soil. Current research is centred around evaluating the efficacy of trees and shrubs as biological nutrient "pumps" in

reducing and ameliorating soil acidification, based on their ability to redistribute nutrients from depth to the soil surface through litterfall and the production of organic anions. To date this research has focused on initial characterisation of species with respect to their chemical composition. There is a paucity of information on the role of deep roots and their ability to capture and redistribute nutrients on the soil surface. No work of this nature has yet been attempted in tropical Australia.

- Seasonal grazing pressure. We already know some of the dynamics of grass-legume interactions and diet selection patterns: the challenge is to devise and test some strategies to vary seasonal grazing pressure to maintain the grass-legume balance. The MRC CS197 Sub-project 5 trial at Eureka Creek will provide some of this information; a similar type of experiment should be established in central or southern Queensland.
- Suitable information systems should be developed to capture knowledge of the performance and management of pasture species, and to make this widely available to users.
- Spatial arrangement studies with grass and legume plants in field replacement arrangements and harvested over time (years) to understand the interactions between legumes and grasses.
- What is a reasonable compromise/balance between maximum proportion of legume for animal production and what is best for grass maintenance. How do geographic location and soil type influence this balance?

Recommendations

Recommendation 1. A set of management guidelines as described in 2.4 be developed and the information be extended widely.

Recommendation 2. There needs to be continued monitoring of fertility decline and soil pH changes. This should include permanent monitoring sites that could be returned to at some later date (5-10 years), sampling of sites where there is a desirable mix of grass/tree/legume in the pasture, and an assessment of the risk of acidification under various soil, climate and pasture production systems.

Recommendation 3. A more ecological approach be taken to the oversowing and subsequent management of introduced legumes stressing responsible management of natural resources through the considered use of appropriate grazing management and fire. In particular, recognise the pivotal role of perennial grasses in providing a source of forage to grazing animals, minimising nitrate leaching, and in protecting the soil surface against soil erosion.

Recommendation 4. A detailed inventory of, and "snap shot" experiments on, existing commercial pastures be conducted to gather long term information on the stability and productivity of oversown pastures.

Recommendation 5. A grazing trial should be established in central or southern Queensland to examine combinations of levels of pasture utilisation, pasture spelling, fire and sown grasses on the stability and productivity of pastures which are currently legume dominant.

Recommendation 6. Suitable information systems be developed to capture knowledge of the performance and management of pasture species, and to make this widely available to users.

Project Report

1. Background

In recent years there has been much discussion about the sustainability of agricultural production systems with concerns about the state of the natural resources (particularly soils and vegetation) as well as economic aspects. Particular emphasis has been placed on effects of high grazing pressure on native pastures leading to loss of perennial native grasses, invasion or increase in woody weeds, and reduced soil cover and increased soil erosion. In northern Australia grazing pressure has increased with higher cattle numbers, increased proportions of Brahman cattle, widespread use of feed supplements, and disease control; these increases have been exacerbated by below average rainfall in much of the area during the 1990s. These sustainability concerns are now a major issue for the northern beef industry.

Native pastures support the bulk of the cattle in northern Australia but their deficiencies in terms of herbage yields and quality have been well known for many years. A great deal of effort has gone into introducing and evaluating exotic legumes which could overcome (at least partially) these deficiencies and increase animal production. Townsville stylo (*Stylosanthes humilis*) became naturalised over a wide area (Humphreys 1967) and there were early reports of increases in animal production from Townsville stylo pastures (Norman and Arndt 1959; Shaw 1961). Other legume genera (*Macroptilium, Cassia, Centrosema, Aeschynomene*) have been used and while *Stylosanthes* is the most important genus, a number of legumes are now available (Oram 1990). These have been sown extensively (Clements 1996) with consequent increases in animal production. Tropical legumes are adapted (to at least some degree) to areas north of the NSW/Queensland border in an arc to the Kimberleys in WA in areas receiving more than 500 mm annual rainfall although their greatest use has been in areas receiving 650-700 mm or more.

Many authors have made estimates of the area suitable for sown pastures in northern Australia and the impact sowing this area might have on the value of animal production. For example in Queensland there have been estimates of 50-60 M ha (Davies and Eyles 1965; Ebersohn and Lee 1972; Weston *et al.* 1981) potentially suited to sown pastures although Walker and Weston (1990) reduced these values to 22 M ha for easily attainable pasture potential of which over 40% has been developed. Estimates of the present level of stylo development range from 700 T to 1.2 M ha and development over the next five years is expected to be in the range 30 to 40 T ha per year. This is a decline from past levels reflecting low beef prices and the impact of widespread drought in much of the area in Queensland suited to stylos.

Benefits of sown pastures include increased beef production through more and better quality feed, wider market access, increased profitability, better stock control and reduced handling costs, and increased management flexibility as sown pastures can be used to ease grazing pressure on native pastures. A recent examination (Chudleigh, personal communication) has estimated the net present value (5% discount rate) of the increases in beef production over the period 1960 to 2020 due to exotic pasture species at over $700M. This value was determined after allowing for costs of research, development and extension; costs of establishing, maintaining and utilising the pastures; and the costs of investing in additional stock. There are additional financial benefits to the dairying and wool industries.

In addition to their value to the grazing industries, sown species have contributed to crop production by increasing soil fertility during a ley phase in cropping systems. They also provide soil cover in orchards, and are used for revegetating bare areas, e.g. mine sites, roadsides, irrigation channels, railway lines and housing developments to reduce soil erosion and loss.

Legumes may be sown on cultivated seed beds with associate grasses, particularly in higher rainfall areas, but the widest use of legumes has been to oversow into existing native pastures with the aim of developing stable grass-legume mixtures. Although productive pastures have been developed, there are increasing concerns about the dominance of legumes in some pastures and fluctuations in composition from year to year - both grasses and legumes are important for animal production, and legume dominance may influence both soil and vegetation resources. Stability in this report is discussed in terms of changes in botanical composition of the pastures i.e. changes in the proportions of different species in the herbage. Changes in composition of pastures are to be expected with variable environments and management differences, and are not necessarily "good' or "bad" in themselves.

Few pastures in the tropics/sub-tropics are in equilibrium with their management and environment. In areas where they are adapted, legumes increase in density but the rate of increase varies from north to south and east to west - the switch in species dominance occurs at a slower rate in the south but the still inevitable increase in density of species such as Seca (*Stylosanthes scabra)* has to be managed as high legume biomass (>50% composition by weight) exposes animals in frost susceptible areas to the real risk of severe feed shortages in cold dry winters.

Legume dominance is not yet widely identified by most producers as a problem. (This contrasts strongly with the run down of available nitrogen in brigalow pastures where the impacts on animal production are apparent.) Nevertheless, some producers have become concerned and there are also questions being asked the weed potential of introduced legumes.

Most of the experimental and commercial experience with legume-native grass pastures is with stylos and this report is dominated by studies of stylo pastures. However, other species are considered where information is available.

2. Review of current information

This review concentrates on published information but reports, unpublished data, and expert opinion have also been included where relevant.

2.1. Impacts of tropical legumes

Most studies have been concerned with impacts (particularly pasture yield and composition, animal production, soil changes) where legumes have been sown, but where off-site impacts are a concern these are also considered.

2.1.1. Soil impacts

In discussing the potential impact of *Stylosanthes* pasture systems on the soil resource base it is pertinent to review other production systems where soil degradation has been reported. The use of leguminous plants to increase the fertility of farming systems is a fundamental practice in agricultural production systems throughout the world. In many such systems the inclusion of legumes in crop rotations is a corner stone of arable-crop farming. Whilst in general, these productions systems could be classified as sustainable on the basis that there are external inputs of fertiliser and soil conditioners (liming materials) at some phase in the rotation, there is considerable evidence to show that under permanent grass/legume pasture systems of eastern, southern and south western Australia there has been a gradual decline in soil pH and fertility with the introduction of subterranean clover (*Trifolium subterraneum*) (Donald and Williams 1954; Russell 1960; Rixon 1966; Flemons and Siman 1970; Kohn *et al.* 1977; Lee 1980; Williams 1980). Although it may take from 25 to 50 years for the pH to decrease by one unit, in the long-term such a decrease in pH has led to severe reductions in pasture or subsequent crop production. These have been due to the build up of phytotoxic levels of soluble and exchangeable aluminium (Al) and manganese (Mn) in the soil (Flemons and Siman 1970; Williams and David 1976; Osborne *et al.* 1978; Cregan *et al.* 1979; Lee 1980). Estimates of the lime ($CaCO_3$) required to balance acidification rates for temperate legume-based agricultural systems vary from 40 to 250 kg $CaCO_3$ ha^{-1} yr^{-1} and are dependent of the exploitive nature of the production system (Helyar and Porter 1989; Ridley *et al.* 1990a, b). For example, high rates of acidification would be expected in a system where there is significant nitrogen fixation, leaching and product removal as is common in the production of lucerne (*Medicago sativa*) hay in southern Australia. Analogous to this type of system in northern Australia would be the production of *Stylosanthes* seed, where the crop is irrigated, has a high nitrogen fixation ability, is baled for hay and the seed vacuum harvested (Noble 1996).

Without going into detail on the mechanisms of soil acidification and fertility decline due to legumes, a brief synopsis of the influence of legumes on soil chemical properties is presented here for completeness. It is important to grasp the complexity of the processes initiated with the introduction of legumes into a production system so that possible areas of intervention can be delineated where the negative impact of the legume on the soil resource base can be minimised. For a comprehensive outline of the processes and mechanisms involved the reader is referred to the discussion of Helyar and Porter (1989).

The growth of nodulated legumes fixing N_2 involves excess uptake of nutrient cations over anions with a consequent net efflux of H^+ ions from the plant root to the soil. In contrast, the growth of most crop plants (in agricultural soils where NO_3^- is the major form of mineral N) results in excess uptake of anions and the net efflux of OH^- or HCO_3^- ions to the soil. Consequently, the growth of legumes tends to decrease rhizosphere pH while that of other plants tends to raise the pH (Haynes 1983). The acidifying effect of legumes would, in the long-term, result in the acidification of the bulk soil causing the downward leaching of exchangeable cations and a decrease in base saturation. However, the processes leading to soil acidification under leguminous pastures is complicated by the characteristic cycling of nutrients and build-up of organic matter in the surface soil which occur under temperate pastoral conditions. The deep-rooting ability of some pasture legumes plus the characteristic cycling of nutrients which occurs under pasture conditions (Mott 1974) can result in an increase in the concentrations of exchangeable cations in the surface soil under leguminous pastures even though the soil pH is declining (Table 1). However, the accumulation of organic matter results in the CEC increasing at a faster rate than the sum of exchangeable cations (Table 1). It should be noted that the measurement of CEC (ie. at pH 7.0) (Table 1) may not be strictly comparable for such soils with differing organic matter contents; the CEC of organic matter is itself highly pH dependent. Such a measurement overestimates the CEC of the soil by a variable amount depending on the initial pH. There is, therefore, a progressive decline in percentage base saturation and soil pH.

Table 1. Some chemical properties of two podzolic soils from New South Wales after 26 years under subterranean clover pasture in comparison with undisturbed sites (from Williams and Donald 1957).

Soil Treatment	pH	CEC (pH 7.0) (meq kg^{-1})	Exchangeable cations (meq kg^{-1}) Ca	Mg	K	Na	Total
Undisturbed	5.96	79.3	48.4	10.7	3.2	1.0	63.3
Pasture	5.32	136.0	55.8	15.8	5.8	1.3	78.7
Undisturbed	5.80	62.4	24.6	8.4	2.9	0.8	36.7
Pasture	5.15	114.9	34.7	12.6	3.7	1.2	52.2

The build-up of organic matter, with consequent increases in soil CEC and exchangeable acidity, is an important contributing factor to the decrease in surface soil (0-10 cm) pH when virgin sites are sown to legume based pastures. This however, does not explain the progressive decrease in soil pH to depths below 10 cm. The efflux of H^+ ions from the growing legume could have an important acidifying effect on the soil under such conditions. The loss of symbiotically fixed N from the system through the leaching of NO_3^--N may also contribute to soil acidification below legume based pastures. The various factors that tend to promote a decline in soil pH in legume pasture systems is summarised in Figure 1.

It is obvious that the acidifying effect of legume growth should be recognised and borne in mind when legumes are used as components of pasture production systems. This is particularly the case when these improved production systems are implemented on poorly buffered, slightly acidic soils. The results of soil acidification are likely to be solubilisation of phytotoxic amounts of Al and Mn, dissolution of clay minerals and a subsequent decline in plant growth and yields. A reduction in plant cover can predispose the soil surface to rainfall impact and is associated with structural instability resulting in reduced infiltration rates and therefore excessive soil loss. The decrease in pH could also induce a deficiency in molybdenum which is a particularly important micronutrient in terms of nodulation and active N_2 fixation by rhizobium bacteria (Munns 1977).

2.1.1.1 Fertility and soil water balance

The introduction of *Stylosanthes* can result in an increase in the inherent fertility of the soil resource base through the fixation of nitrogen and its subsequent transfer to the soil, and through the addition of superphosphate. The suite of cultivars currently marketed are well adapted (ie. persistence and vigour) to lighter textured surface soils having a low inherent phosphorus (P), nitrogen (N) and sulphur (S) status. It is generally recommended that the oversowing of native pastures with *Stylosanthes* is accompanied by the addition of between 50 and 100 kg superphosphate ha^{-1}. However, this practice of applying superphosphate in the establishment of *Stylosanthes* pastures in not commonly undertaken by commercial producers (C.H. Middleton and C.P. Miller, pers. comms). With the addition of superphosphate one can infer that the inherent P status of the soil is increased along with the S and calcium status as these are components of the fertiliser. This constitutes a nett input into the system although a minor addition. *Stylosanthes* tends to have an advantage over most pasture species due to their greater ability to extract P from low phosphorus soils (Andrew and Robins 1969). However,

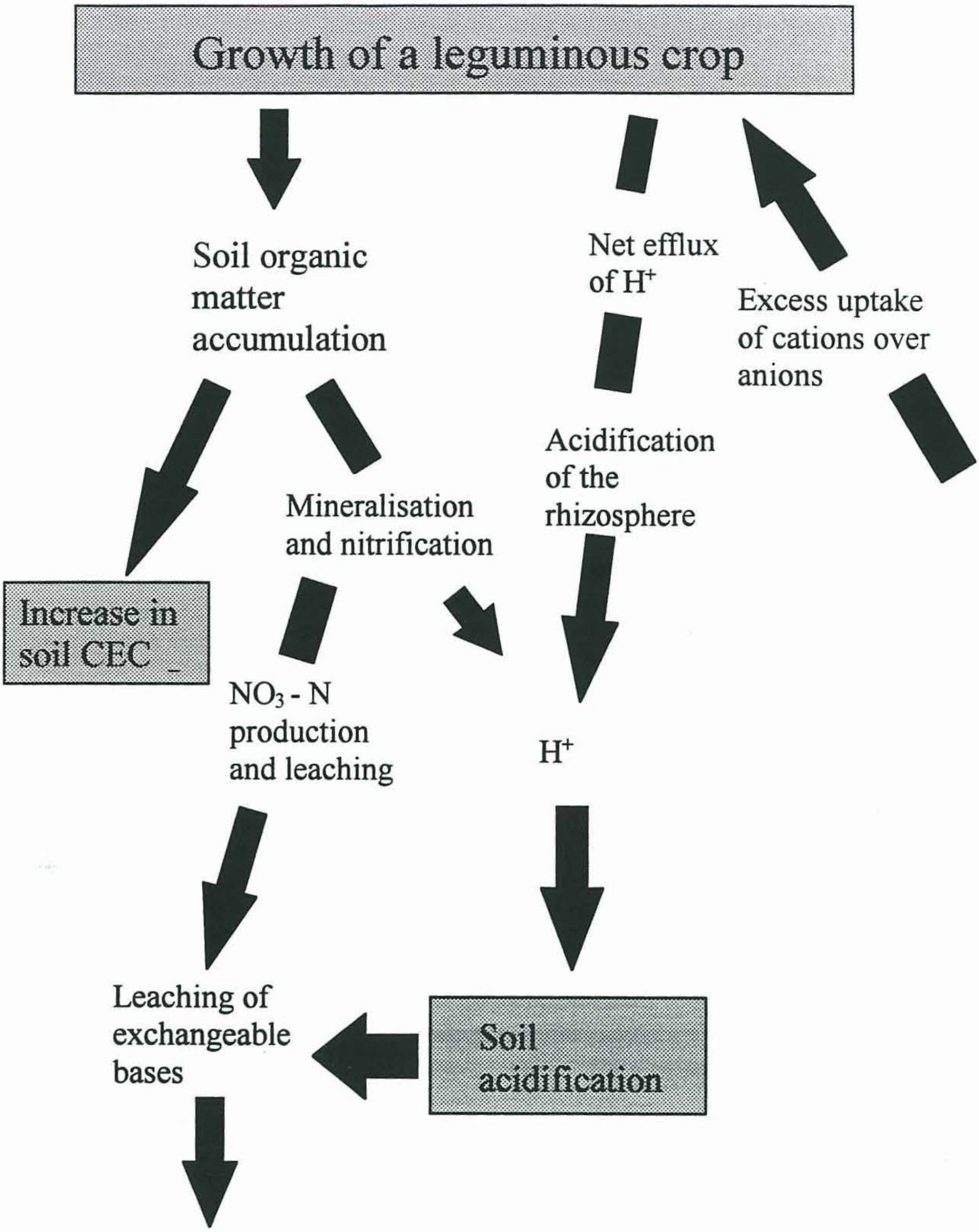

Figure 1. A summary of the major factors leading to soil acidification under legume based production systems.

Stylosanthes responds positively to phosphorus application under these conditions and is able to effectively compete with the normal growth of other species (Winter and Gillman 1976; McLean *et al.* 1981). However, in contrast to sub-tropical legumes, applying superphosphate to grazed *Stylosanthes*-grass pastures has frequently resulted in a large increase in grass content and corresponding decline in the legume component (Teitzel and Middleton 1979). The move to grass dominance may be attributed to (i) the application of small amounts of superphosphate to deficient soils can change the animal preference from grass to *Stylosanthes* thereby favouring the grass component (McLean *et al.* 1981); and (ii) while *Stylosanthes* responds to P in pure stands, they do not respond or grow as vigorously as most grasses and many tropical weeds (Torssell 1976). This aspect in the dynamics of the legume - grass mix as a result of P fertilisation may be a possible management strategy to exploit.

This interaction of species with P in legume-grass pastures can be of considerable importance in the management of pastures to achieve a desired botanical composition. For example *Urochloa-S. hamata* pastures became *S. hamata* dominant at low P fertilisation over 4 years (McIvor 1984). The increasing dominance of *Urochloa* with time was probably also associated with the increase in available soil N. Although the genus *Stylosanthes* are recognised as being especially efficient in utilising soil P there is considerable variation between species and accessions within the genus. On the basis of response to applied P on a soil with 12 ppm available p (0.1 N H_2SO_4 extractable) Jones (1974) was able to classify 30 accessions of *Stylosanthes* into 6 groups. There were large differences between the groups in terms of yield and P uptake in response to P fertilisation. This genotypic variability with respect to P requirement can best be demonstrated by the fact that *S. scabra* cv. Seca has a relatively lower P requirement (7-8 ppm, Gilbert and Shaw 1987) than that of *S. hamata* cv. Verano (10-12 ppm, Probert and Williams 1985).

With the introduction of adapted legume species and their associated effective nodulation to native pasture systems, significant increases in the nitrogen status of the soil system have been shown to occur, thereby providing a source of readily available nitrogen for the grass component in the pasture (Vallis 1985). Henzell (1968) estimated that average legume growth in the tropics under a mowing or intermittent grazing regime yields 40-210 kg N ha^{-1} yr^{-1} and good legume growth yielded 336 kg N ha^{-1} yr^{-1}. However, it would appear that in grazed pasture systems containing *Stylosanthes* the amount of N contained in the above ground biomass ranges from 30-80 kg N ha^{-1} (Gardener 1980a). The effects of legumes on the supply of soil N are important for the grass-legume balance and total productivity of the pasture. Changes in total and available soil N are not expected to be constant but fluctuate temporally as symbiotic fixation responds to edaphic, environmental and management changes. Vallis (1972) observed that under 10 year old *Stylosanthes*-speargrass pasture soil N decreased by 30 kg ha^{-1} yr^{-1} during drought years but increased by 30 kg ha^{-1} yr^{-1} over a three year period when rainfall was higher. Wetselaar and Norman (1960) found that at Katherine soil N increased to 110 kg ha^{-1} after seven years of *Stylosanthes* and suggested that most of this increase occurred in the first few years and that thereafter there was sufficient N in the system to suppress effective N fixation. Probert and Williams (1986) showed that the contribution of Verano with a dry matter yield of 1 t ha^{-1} yr^{-1} to the overall nitrogen pool was of the order of 33 kg N ha^{-1} on a red earth and 38 kg N ha^{-1} on a yellow earth averaged over a five year period.

Of importance in assessing the beneficial impact of *Stylosanthes* in a mixed pasture system is a clear understanding of the fate of fixed and subsequently mineralised nitrogen. Probert and Williams (1985) observed that the yields of associated grasses was small and unaffected by imposed phosphorus fertiliser treatments until the fifth year after establishment. Thereafter, plots that had received the higher rates of phosphorus application and produced the higher yields of legume became invaded by grass. Such fluctuations in the botanical composition of

Stylosanthes pastures are a normal occurrence (Gillard *et al.* 1980) and there can be little doubt that they are due in part to variations in soil nitrogen supply and/or soil P levels. The fluctuation in population dynamics in response to changes in fertility may indicate that legume dominance, as is often observed in these pasture systems, is a transient state in the agro-ecosystem and that grass dominance will occur once the fertility status of the soil has reached an adequate threshold.

In terms of soil acidification (see below), the leaching of exchangeable bases is an important consequence since it results in a permanent decrease in the base saturation and an increase in exchange acidity of the soil. In non-saline soils, even under irrigation, there is generally little downward movement of Ca^{2+} and Mg^{2+} unless there is a significant accumulation of NO_3^--N in the soil (Viets *et al.* 1967). Then these cations move downward as counter ions for the very mobile NO_3^- anions. Thus the downward movement of NO_3^- can be a dominant factor determining the quantity of exchangeable bases leached (Haynes 1981). Nitrification (the microbial conversion of NH_4^+-N to NO_3^--N) and the subsequent downward movement of NO_3^--N have been shown to have an acidifying effect on the surface soil. During the process of nitrification H^+ ions are released:

$$NH_4^+ + 2O_2 + H_2O \rightarrow 2H^+ + NO_3^-$$

Thus, where N is added to the soil in forms that are eventually nitrified (urea-N, NH_4^+-N or organic N, eg. legume residues) the leaching loss of NO_3^- will have a net acidifying effect on the soil. Exchangeable cations move downwards as counter ions with NO_3^- resulting in a decrease in base saturation. It can clearly be seen from the aforementioned discussion that if there is spatial disjunction between the production of NO_3^- and its subsequent uptake by the plant, the result is an accumulation of H^+ at point of production and net alkalisation due to the uptake of NO_3^- by the plant at some other point in the profile. The uncoupling of these two processes results in nett proton accumulation at one point in the profile and nett alkalisation at some other point. This conceptualisation of the process of acidification due to nitrate leaching brings into question whether the planting of perennial grass species will reduce the risk of acidification. As long as nitrate is taken up at point of production the outcome is neutral. However, if nitrate is allowed to leach down the profile and is subsequently taken up at depth by the roots of a grass species the result is as previously discussed.

The accumulation of nitrogen in the system is a function of the carbon/nitrogen cycle operative under the prevailing edaphic and climatic conditions. Based on the observations of Crack (1972) and Probert and Williams (1986), savanna environments, although having a semi-arid moisture regime, do have episodic leaching events. Crack (1972) observed that there was a significant increase in the transfer of nitrogen from the legume component in a pasture once the population density of the legume had increased to > 47%. This occurred largely during the dry season and is similar to what has been observed under legume based pastures in temperate regions of southern Australia where there is marked rainfall seasonality (Simpson 1962). In these semi-arid environments it is assumed that the accumulation of nitrogen commences at the end of the wet season and proceeds during the dry winter when the grass component is dormant. Any unseasonal rainfall events of significance during winter or at the onset of the rainy season when the grass component is dormant will result in nitrate being leached from surface horizons. Probert and Williams (1986) have shown that drainage in excess of 25 mm will occur at least 1 year in 3 in these semi-arid well drained soils and suggest that in the Katherine environment leaching would occur more frequently. Furthermore Williams and Probert (1984) presented data on the redistribution of applied nitrate and ammonium N on a red earth in 35 days during which 518 mm of rain fell. Almost 60 % of the applied ammonium-N had been nitrified and the peak nitrate concentration had leached to 75 cm. The recovery of the applied-N in the soil was 95% from which it was inferred that there had been little loss to the atmosphere. Consequently, it can be assumed that these semi-arid environments are in fact "leaky" systems.

The fate of fixed nitrogen from the legume component in the pasture system and its subsequent role in improving the soil nitrogen status is thought to have a positive influence on the protein content of the feed. However, the few data that are available show that total soil nitrogen does not build up to any great extent under tropical pastures, even when they contain a substantial legume component. Furthermore, efforts to utilise such nitrogen by cropping have found that its effect is short lived, being largely restricted to the first season after a ley (R. K. Jones and R. L. McCown, pers. comm. quoted by Williams and Probert 1984). This is in contrast to the temperate regions of southern Australia, where soil organic matter and nitrogen continue to build up for long periods with the presence of subterranean clover. It seems likely that any differences in the nitrogen status must result from higher rates of mineralisation in these tropical environments and the subsequent removal from the profile through leaching. Assuming that the downward movement of nitrogen is the main loss mechanism in such systems, there are important implications. Obviously a growing plant will have to trap its nitrogen before it is leached beyond the root zone. As will be discussed below the leaching of nitrate produced through mineralisation under legume based production systems will result in soil acidification. In addition, the widespread establishment of legume based pasture systems in these environments may result in increased nitrate concentrations in the groundwater.

In evaluating the long-term impact of *Stylosanthes* based pastures systems on the fertility status of the soil it is pertinent to consider that noticeable changes will only become evident after a considerable period of time. Consequently, due the relatively young age of the current suite of trials it is unlikely that significant changes in the base status of the soil would be evident. However, one can possibly use other low input production systems that incorporate a legume component in assessing the potential long-term impact on the fertility status of the soil. In this respect, the production of crops under an alley cropping system incorporating *Leucaena leucocephala* has been extensively studied (Lal 1989a, b, c, d, e). Significant declines in pH and basic cation concentrations were observed along with a concomitant increase in exchangeable acidity over time. It is generally agreed that continuous cropping in the presence of an alley crop is unsustainable, on soils with an inherently low base status, without the addition of fertilisers, in particular phosphorus. On all but the most fertile soils, productivity decreases with the intensity of soil use unless nutrients are imported to replace those that are leached or removed through product removal. These production systems containing a legume component have in the past been lauded as "sustainable". However, in the light of recent findings it is generally agreed that alley cropping as currently undertaken is "ecological pie in the sky" (Ong 1994). In a study undertaken at Lansdown near Townsville, the impact of a 22 year old Leucaena (*Leucaena leucocephala*)/Sabi grass (*Urochloa mosambicensis*) pasture production system on soil acidification and selected soil chemical properties was compared to an adjacent unfertilised *Urochloa mosambicensis* area. Significant acidification and cation depletion was observed to 70 cm under the Leucaena when compared to the Sabi system. With the introduction of *Stylosanthes* based pasture systems it should be borne in mind that with the increase in productivity through higher annual animal turn off, there is a greater nett export of nutrients and an associated risk of nutrient leaching, both contributing to a decline in inherent soil fertility.

Soil Water Balance

When examining the potential risk of nutrient leaching it is important to realise that even in semi-arid tropical regions of Australia substantial deep drainage and leaching of salts occur (Chapman 1963; Williams and Coventry 1979, 1981; Wetselaar 1980; Probert and Williams

1986; Jones *et al.* 1991). There are strong similarities between the water balances of Mediterranean and monsoon tropical regions. As 70 % of the annual rainfall is concentrated over the three months of the wet season the opportunity exists for a close sequence of rainfall events to fully recharge the profile and generate water movement deep into the profile beyond the root zone (Williams and Chartres 1991). Probert and Williams (1986) showed that there was a 50 % probability of deep drainage exceeding 25 mm per year when trees are removed and replaced with *Stylosanthes* pasture and native grasses. Their data showed clear experimental evidence of substantial movement of nitrate down the profile.

It is of note that the experimental work on NO_3^- leaching has been confined to well drained soils. However, there is a paucity of information on the movement of NO_3^- on texture contrast soils. McCown *et al.* (1976) observed that on poorly drained soils there was a buildup of salts at depth in the profile due to the prevailing leaching conditions. A close relationship between the observed depth of wetting and the depth to the salt bulge was found. This would suggest that on these soil types vertical leaching would be limited and the presence of basic salts would impart a relatively large buffering capacity.

Figure 2 sets out the effect of tree killing and pasture development on the water use at the study site reported by Probert and Williams (1986). The large amount of water remaining in the profile at the end of the wet season as a consequence of tree killing is available to contribute to deep drainage. Clearly the establishment of improved pasture systems can have a significant impact on the hydrological cycle leading to increased leaching of nutrients to below the effective rooting depth.

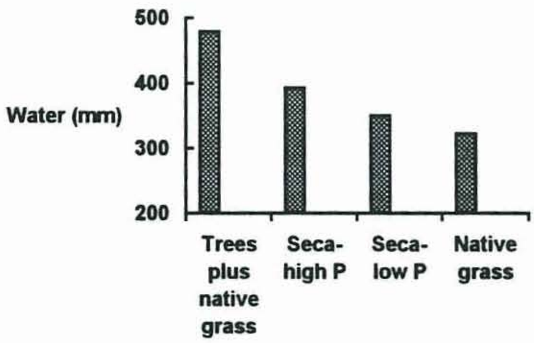

Figure 2. A comparison of water use by woodland and the effect of tree killing and pasture development on water use at Redlands near Charters Towers (Probert and Williams 1986).

The aforementioned discussion has concentrated on leaching under these tropical environments. However, of importance in evaluating the long-term impact of *Stylosanthes*-native pasture systems on the soil resource base is the influence of the pasture production system on the soil water balance. At Redlands on a deep red earth the water extraction and root density distribution with depth were determined for Verano (Williams *et al.* 1980). This deep-rooted species was able to exploit water to depths in excess of 3 m. Not only are the perennial *Stylosanthes spp*. able to root deeply, they appear to be able to extract water to potentials considerably < -1.5 MPa traditionally associated with the lower limit of available water. Williams and Probert (1984) measured the soil and pre-dawn leaf water potentials beneath and on well established swards of Verano and Seca. At a leaf water potential of -7.6 MPa the leaf of Verano was near desiccation although when placed in free water, leaves fully regained their turgor. In contrast, the leaf water potential of Seca at the same time was -2.4 MPa. They concluded that the root system of Seca must be in contact with soil water with a potential greater than -2.4 MPa. Water at a depth of > 4.0 m would meet these conditions. They point out that on these red earths large changes in water potential are associated with only small changes in water content and therefore this decrease in potential below -1.5 MPa is not associated with large quantities of water. However, these quantities are apparently sufficient for plant survival, if not for growth (Williams and Probert 1984). These results clearly show the resilience of *Stylosanthes* to water deficits and their ability to extract water from significant depths in the profile. This would probably explain the reported observations of several individuals that in swards of *Stylosanthes* dominant pastures established on lighter textured soils there has been a noticeable increase in tree mortality when compared to adjacent native grass woodlands over the present drought period (C.H. Middleton and C.P. Miller, pers. comms).

2.1.1.2. pH

Soil acidification occurs at a slow rate in natural ecosystems. The acids produced in the organic and inorganic nutrient cycles are involved in forming soils from parent rocks, and in releasing to the soil solution the nutrients contained in those rocks. Once in solution they are available for absorption by plants and for leaching by water flowing through the profile. Soils that have been acidified in natural ecosystems are more prevalent in areas of higher rainfall, especially where soils are old and where the parent material are low in basic minerals (eg. carbonates and Ca and Mg silicates) that buffer the soil pH against acidification (Williams and Chartres 1991).

Accelerated acidification of soils under agricultural ecosystems results from increases in the losses of products of acid reactions in the biological carbon and nitrogen cycles (Helyar 1976). In this respect the issue of accelerated soil acidification under temperate legume based pasture production systems in southern Australia is well recognised. In brief the processes which lead to soil acidification include (1) accumulation of organic matter and a consequent increase in CEC and exchangeable acidity, (2) mineral acid generation during the nitrification process and the subsequent leaching of nitrate along with basic cations, (3) carbonic acid production from CO_2 derived from the respiration of soil flora and fauna, (4) release of H^+ ions from plant roots due to excess uptake of cations over anions by plants and (5) inputs of acidifying substances from the atmosphere. Irrespective of the cause of soil acidification, several effects are generally observed to accrue including (1) leaching losses of basic cations, (2) mobilisation of Al^{3+} and Mn^{2+} ions, (3) reduction in the availability of Mo, (4) a reduction in the negative charge exhibited by variable charge colloids and (5) changes in biological activity. However, acidification of the soil does not occur as long as the buffering capacity keeps the pH and base saturation constant. Therefore the sensitivity of a soil to acidification is inversely related to the buffering capacity, being greatest on poorly buffered soils.

Until recently, little attention had been paid to potential acidification that may occur under legume based pasture systems in the semi-arid tropics of northern Australia. Early evidence of acidification after 5 years under pure swards of *Stylosanthes* was suggested by Probert (quoted by Williams and Chartres 1991). However, recent surveys of *Stylosanthes* spp. dominant grazing trials have conclusively shown that there has been significant downward shifts in soil pH in pasture systems that are dominated by legume when compared to unimproved pastures (Noble 1996). In a survey undertaken of *Stylosanthes* dominant pastures from southern Queensland to the Northern Territory statistically significant acidification due to the introduction of a legume component in pastures has been observed. The pH profiles of selected sites are presented in Figures 3a-e. It should be noted that the legume sites were dominated by *Stylosanthes* with very little evidence of a grass component and therefore can be assumed represent an extreme situation from a grazing management perspective. The extent of acidification due to the introduction of a legume component in these pastures is a function of (i) the farming system; (ii) soil and climate; and (iii) the population density of *Stylosanthes*. The highest rate of acidification was observed under an irrigated *Stylosanthes* seed production system (Figure 3b). This production system is characterised by a monoculture of *Stylosanthes*, which is irrigated and the entire crop removed at harvest. All these factors would potentially lead to enhanced nitrogen mineralisation and the consequent leaching of nitrate and, in addition, the removal of all above ground biomass at harvest would represent a nett export of alkalinity from the site. This type of production system is similar in several respects to the production of irrigated lucerne hay in southern Australia which has been observed to be one of the most acidifying agricultural systems (Chartres *et al.* 1990). In contrast, the lack of any significant shift in pH in the case of the Meadowbank site (Figure 3c) can in part be ascribed to the higher soil pH buffering capacity of these basalt derived soils and the lack of legume dominance in the sward due to the inherently high P levels in these soils (see previous discussion). Between these two extremes lies the majority of sites all of which exhibit some degree of accelerated acidification (Figure 3).

A problem with paired site comparisons is finding adequate areas in close proximity that are suitably contrasting in their treatments and that do not have a high degree of soil heterogeneity. For example, during the aforementioned survey of sites it was extremely difficult to find suitable contrasting sites at Wrotham Park due to fences separating different treatments having been removed and the spatial variability of the soils. Consequently, an area within the confines of the original experiment that was dominated by Sabi grass (*Urochloa mosambicensis*) was selected for sampling. The pH under the *Stylosanthes* dominant pasture was significantly more acid than under the Sabi grass pasture area (Figure 3e). The mean pH values under the Sabi dominated pasture were significantly greater than under the *Stylosanthes* dominant pasture especially in the 0-20 cm depth interval (Figure 3e). In 1971, a survey of the trial site was undertaken by Mr Ray Isbell and two sets of surface (0 - 10 cm) samples collected from each of the six blocks in the trial. A comparison of the pH_w of the 1971 samples with that of the current samples collected in 1996 from grass and *Stylosanthes* pastures over the same depth interval, indicated mean values of 6.71 (n=12), 5.66 (n=10) and 4.93 (n=10) respectively. Under each of the grazing regimes surface soil pH_w had declined by 1.05 and 1.78 units over a 25 year period. This clearly indicates the impact of improved grazing systems on the soil resource over a relatively short period of time. In addition, this result would suggest that acid addition rates discussed below are conservative and that rates of acidification may be higher than those calculated through paired site analysis.

From a management perspective it would be advantageous to predict those soils that are most predisposed to accelerated acidification. In this respect research is currently underway to determine pedotransfer functions that can estimate important soil characteristics that are key determinants in soil acidification (ie. a pedotransfer functions to predict pH buffering capacity). These pedotransfer functions along with other environmental parameters could then be used to produce GIS coverages of soils at highest risk. It is speculated that the scale of such maps will probably be at best, on a catchment/regional basis owing to the lack of detailed soil mapping on a property basis. However, as our understanding of the environmental and edaphic factors that determine accelerated acidification become clearer, the degree of sensitivity mapping will, it is assumed, become more refined. In addition, it may be appropriate as a first approximation to use broad soil textural classes to differentiate between sensitive sites. This would essentially assume that soils of light texture are more susceptible to accelerated acidification than those of a heavy texture.

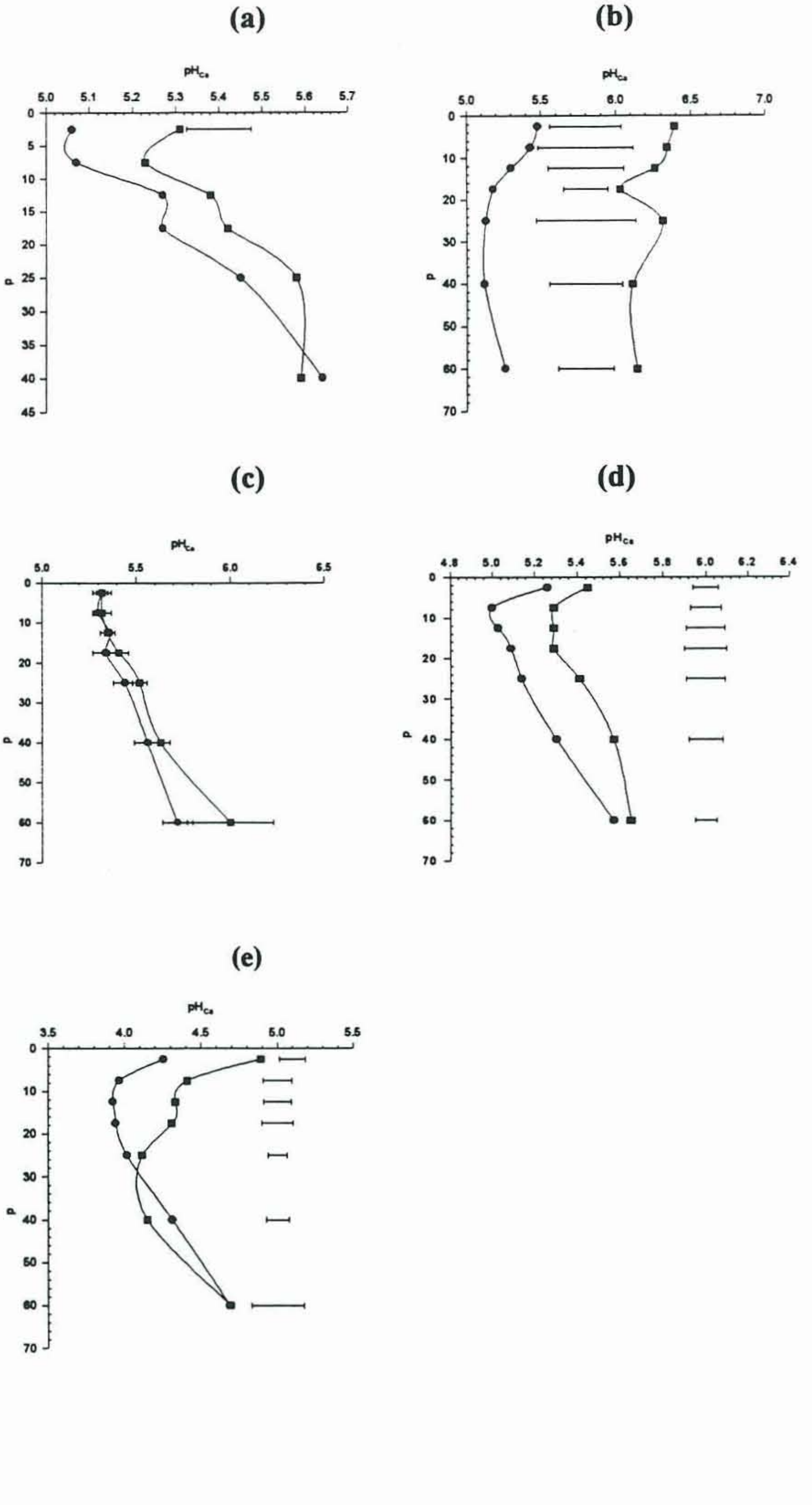

Figure 3. Relationship between soil pH_{Ca} and depth for *Stylosanthes* (■) dominant pasture and adjacent grass (●) pastures at (a) Wycheproof, (b) John Rains seed production paddock Mareeba, (c) Meadowbank, (d) Manbulloo, (e) Wrotham Park. Horizontal bars represent lsd (p<0.05).

The net acidification rate of the 11 sites sampled ranges from 0.31 to 2.91 kmol H^+ ha^{-1} yr^{-1}, with a mean of 0.92 kmol H^+ ha^{-1} yr^{-1}. Assuming that the equivalent of 50 kg $CaCO_3$ neutralises 1 kmol of H^+ the range in rates of acidification would equate to 15.5 to 145.5 kg $CaCO_3$ ha^{-1} yr^{-1} . At a nominal cost of $80 per ton of lime spread and assuming the liming source has a neutralisation capacity of 80%, the cost of neutralising the acidity generated by legumes over a 10 year period would be equivalent to $15.50 to $145.50 per ha respectively. The costs incurred in spreading lime will be a function of distance from liming source and the topography over which the lime is to be spread. However, it is questionable whether the addition of surface applications of lime will effectively neutralise subsurface acidity. Certainly the experiences from southern Australia would suggest that surface applications of lime are relatively ineffectual in neutralising subsurface acidity.

The long-term impacts of continued soil acidification on the resource base are numerous. A continual decrease in pH will result in the soil exchange complex becoming dominated by acid cations (Mn^{2+}, Al^{3+} and H^+) at the expense of basic cations (Ca^{2+}, Mg^{2+} and K^+). This could lead to significant changes in biodiversity where the plant communities would be dominated by species having a relatively high tolerance to acid soil infertility. In addition, increased acidification may result in possible nutritional (Mo, Ca^{2+} etc.) deficiencies, the dissolution of clay platelets resulting in a reduction in the basic cation exchange capacity of the soil and an increased likelihood of aluminium and manganese toxicity. It is suggested that increased soil acidification could lead to decreased pasture productivity with a concomitant decrease in animal performance. In addition, declining soil cover may result in accelerated soil loss and therefore off site degradation.

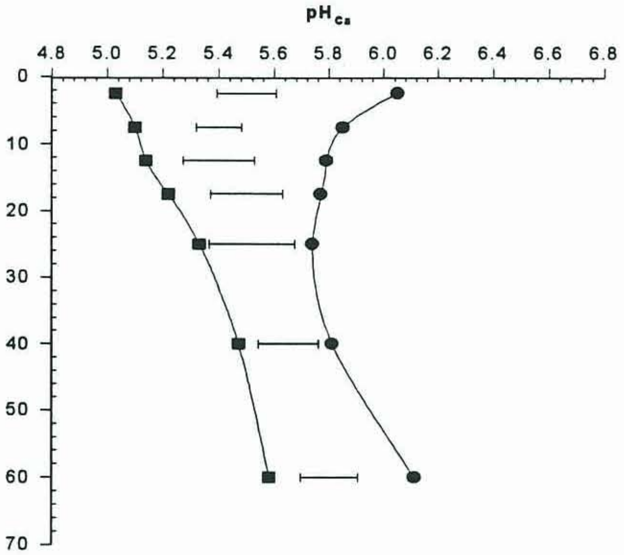

Figure 4. Relationship between soil pH_{Ca} and depth for grass (●) dominant pasture and Leucaena / grass (■) pastures at Lansdown, Queensland. Horizontal bars represent lsd ($p<0.05$).

It is important to point out that soil acidification due to the introduction of tropical legume species is not confined to *Stylosanthes* based pasture systems. There is significant evidence to suggest that soil acidification is accelerated with the introduction of Leucaena based pasture systems (Figure 4). For example the net acidification rate for a Leucaena pasture at Lansdown was estimated to be 2.73 kmol H^+ ha^{-1} yr^{-1} of which 0.17 kmol H^+ ha^{-1} yr^{-1} was estimated to have originated from animal product removal (Noble and Jones 1996). It is therefore suggested that the major contributing factor to acidification on these sites is nitrate leaching. These preliminary results bring into question the long-term sustainability of these legume based production systems on these soils

These soil chemical changes are permanent and remediation by conventional liming practices are relatively ineffectual and uneconomic. The challenge facing the industry is the management of these production systems in order to minimise the negative impact of accelerated acidification.

2.1.1.3. Biology

Relatively few studies have been undertaken to examine the changes in soil biological components associated with grazing and in particular with *Stylosanthes* based pastures. Soil organisms play a significant role in the cycling of plant nutrients and hence soil physical and chemical properties (Lal 1988). A change in abundance or activity of soil organisms as a result of agricultural practices will therefore affect both the soil water and nutrient status, and hence pasture growth and sustainability (Holt *et al.* 1996a). A study of the effects of grazing pressure on populations of two groups of arthropods [Acari (mites) and Isoptera (termites)] under native pastures in the semi-arid tropics of northern Queensland, found that heavily grazed treatments had significantly lower populations of these groups than lightly grazed pastures (Holt *et al.* 1996a). Termite species diversity and activity were significantly lower in the heavily grazed treatments than in the lightly grazed treatments. This change in species diversity was suggested to be associated with a reduction in availability of grass litter. Similarly, populations of mound-building termites were found to be significantly reduced after 14 years in pastures of *Urochloa mosambicensis* when compared to native semi-arid tropical woodland (Holt and Coventry 1988). This decline in certain species of termite was attributed to the lack of acceptable fodder resources.

The influence of grazing pressure on soil organic carbon, microbial biomass and selected enzyme activities of soils at several sites in northeastern Australia have been examined (Holt 1996). No changes in organic carbon levels were detected, but a significant reduction in soil microbial biomass carbon levels occurred at two sites after between 6 and 8 years of heavy grazing. In addition, peptidase and amidase activity was significantly reduced in soils that had been heavily grazed. The decline in these two enzyme groups would suggest that there has been a decline in the N mineralisation potential and hence nitrogen availability. Similarly, significant decreases in microbial biomass have been observed in bare patches (scalds) when compared to annual and perennial grass patches (Holt *et al.* 1996b).

The studies to date have been confined to native woodland/perennial grass based pasture systems that have undergone a high degree of degradation due to over stocking. No information on changes in soil biology due to the introduction of legume based pasture systems was found. It is plausible that changes in microbial biomass due to the establishment of *Stylosanthes* would be somewhat different to that observed under native mismanaged pasture production systems in that nitrifying components of microbial biomass would be enhanced.

2.1.1.4 Surface condition and structure

Overgrazing and the indiscriminate use of fire in the management of perennial tall grass pastures of northern Australia has resulted in significant degradation resulting in the appearance of large areas of bare soil commonly called "scalds" (Mott *et al.* 1979; Bridge *et al.* 1983). These areas show structural collapse and surface sealing, with considerable reduction in infiltration rates. The size of the bare areas ranges from 5-20 m in diameter and occupy 3-5% of the total area (Bridge *et al.* 1983). They have been observed in the Katherine region of the northern Territory and in the Torrens Creek area of central north Queensland (Mott *et al.* 1979; Coventry and Fett 1982). Revegetation under natural conditions is difficult and bare areas can persist for many years. The persistence of these bare areas is attributed to seed removal during runoff, to high temperatures and low water content in the sealed surface preventing seed germination and to mechanical impedance resulting in poor seedling emergence (Mott *et al.* 1979).

A speculative hypothesis of scald formation was outlined by Mott *et al.* (1979) which is as follows: if plants are killed by overgrazing or any disturbance, the carbon cycle between soil, plant and atmosphere is broken. During the hot moist conditions of the wet season, soil microorganisms would rapidly decompose soil organic matter, particularly the readily oxidised polysaccharides (Oades and Ladd 1977). These compounds are considered important in bonding clay domains and quartz particles together to form stable aggregates. Under these conditions, the structural bonds would disappear and soils would slake under raindrop impact leading to the formation of surface crust and seals. However, Bridge *et al.* (1983) showed that the sorptivity and hydraulic conductivity were significantly reduced within the first year of imposed treatments on these scalded areas and that micromorphological examination of these seals showed surface sealing and structural collapse without a significant decline in soil organic carbon content. They concluded that structural collapse was attributed to raindrop impact rather than loss of structural bonds in the soil.

Whilst most research to date has been directed at understanding the formation of scalds in grass pasture systems, there is a paucity of information on the impact of *Stylosanthes spp.* on soil surface physical properties. Bridge *et al.* (1983) studied the structure of soil under pastures sown on a former *Themeda australis* native grassland. Heavily grazed pastures containing Verano had more macropore space in the surface soil than a lightly grazed native grassland, while pastures containing Townsville stylo had as little macropore space as degraded areas. Macropore space in the Verano pasture increased between the third and fourth wet seasons after establishment when the pasture comprised 70-80% legume. Where macropore space was high, infiltration measurements showed that sorptivities were as high as those in the native grassland. Contrasting this, where macropore space was low, sorptivities were as low as those in degraded areas. However, all sown pastures showed low hydraulic conductivities equivalent to degraded areas, this being attributed to trampling during the wet season under higher stocking rates. All of these pastures had complete vegetative cover and substantial litter layers which would protect the soil surface from raindrop impact and prevent structural breakdown. It was speculated that heavily grazed pastures containing Verano were likely to be stable in the long-term, provided there is a layer of litter on the soil surface. However, in central Queensland this is unlikely to occur since heavily grazed pastures do not have a litter layer to offer protection from raindrop impact (M. Sallaway, pers. comm.).

Studies evaluating the potential use of *Stylosanthes* spp. in the re-vegetation of scalded areas have shown that the faster-germinating *S. hamata* could germinate successfully on the sealed area, but the slower-germinating *S. viscosa* and *Themeda australis* had poor establishment rates compared with the more favourable regime under grass cover (Mott *et al.* 1979).

Similarly, field observations have shown that these sites are often areas where rapidly germinating weeds become established. Movement of seed by run-off early in the wet season was considerable and over 90% of the seed sown onto sealed areas was washed to the edges before germination took place.

Soil surface cover is imperative in the maintenance and enhancement of surface physical properties. Whilst reducing the effects of raindrop impact and enhancing the soil organic carbon status thereby improving aggregate stability, the microclimate that is produced may provide a desirable habitat for soil macrofauna. Indeed, Bridge *et al.* (1983) observed a number of small beetles under the litter layer of pastures containing *S. hamata*. These beetles were not observed where there was no litter. Holt *et al.* (1996a) observed a deterioration in soil hydraulic properties in heavily grazed pastures and they associated this reduction to both increased trampling by cattle and decreased termite activity in the top 25 mm of soil.

2.1.1.5. Soil erosion and runoff

The importance of maintaining plant cover to reduce runoff and soil loss is well recognised: it intercepts and absorbs the kinetic energy of falling rain drops; it impedes the flow of runoff water thereby increasing infiltration; and it reduces the erosive force of flowing water (Osborn 1952; Gifford 1985).

The influence of pasture management on runoff and soil loss was measured on a neutral red duplex by McIvor *et al.* (1995). The pasture systems under investigation included native pasture with either the tree component alive or dead which was compared to improved sown pasture including Verano and Seca in the presence of either killed or cleared trees. Runoff and soil movement were greatest in native woodlands and least in developed pasture. Runoff and soil movement were both related to degree of cover present in the pasture. In small rainfall events (total <50 mm and intensity <15 mm h^{-1}), runoff and soil loss decreased rapidly as cover increased and only small cover levels (40%) were needed to reduce them to a low level. As the size of the rainfall event increased, greater cover levels were required, and for very large events (total >100 mm and intensity >45 mm h^{-1}) cover had no effect on runoff although it still reduced soil movement. McIvor *et al.* (1995) concluded that on these neutral red duplex soils, managers should maintain at least 40% groundcover, however this would still allow large losses of suspended sediment in large storms. It is therefore important to recognise that erosion is sporadic with the majority of soil loss occurring from a few large storms (Freebairn and Wockner 1986). This makes management very difficult in environments where large, intense rainfall events are experienced but are unpredictable.

Of importance when evaluating the impact of *Stylosanthes* spp. on soil erosion and runoff is the influence of the associated grass species in the pasture. In a study of Scanlan *et al.* (1996) investigating the effect of different percentage cover in pastures dominated by *Bothriochloa pertusa* (a stoloniferous naturalised grass) and *Heteropogon contortus* (a native tussocky perennial grass) on runoff, they found that pastures dominated by the former species had lower run-off and lower rates of soil movement than pastures dominated by the latter species at the same level of cover. It was suggested that the distribution of cover for the stoloniferous dominated sites enabled greater opportunity for infiltration, slowed the velocity of run-off or increased surface detention. One could infer from these observations that pastures dominated by *Stylosanthes* spp. but lacking the presence of a stoloniferous grass species would be more vulnerable to soil loss than a pasture with the same percentage cover but containing a stoloniferous species.

In a study in central Queensland, changes in species composition were related to changes in pore size distribution, with a loss of 1-3 mm pores under *Aristida* spp. or annual grasses (Sallaway and Waters 1994; Sallaway *et al.* 1993). Total runoff and peak runoff rates were reduced if *H. contortus* was maintained. Although these results pertain to a grass dominant system, they clearly indicate the importance of maintaining a desirable grass species in the sward to minimise soil loss.

Rainfall intensity and the magnitude of rainfall events are important components in the issue of soil loss. Studies undertaken at Galloway Plains and Glenwood in central Queensland on black speargrass (*Heteropogon contortus*) grazing lands showed a significant effect of stocking rate on soil movement within a landscape, even during the worst drought on record (Sallaway and Waters 1996). At one of the sites spatial variation in hydrology and soil movement within the landscape was recorded, although this was not translated into total soil loss from the catchment. The effect of this source/sink movement within a landscape will have important consequences for the future stability of the landscape and the vegetation states that occur and highlights the need for scaling approaches to catchment levels to assess the impact of these degradation processes.

2.1.2. Vegetation impacts

Oversowing legumes can have large impacts on the vegetation. Most studies have been concerned with the effects on the major herbaceous species with little study of minor or rare species or the tree layer.

2.1.2.1. Botanical composition

Most oversown legume pastures have been developed by sowing the seed on the soil surface with no soil disturbance after burning or heavily grazing the existing native pasture. The absence of soil disturbance, low seeding rates (generally less than 2 kg/ha), and competition from the native pastures usually results in slow establishment and the legumes frequently contribute little to the sward in the initial years. However in most situations the stylo increases with time (see example in Figure 5) and in many cases comes to dominate the sward. How long this dominance lasts depends on many factors (see Section 2.3) but pastures may remain stylo dominant for considerable periods, switch to perennial grass dominant, or become invaded by annual grasses and forbs.

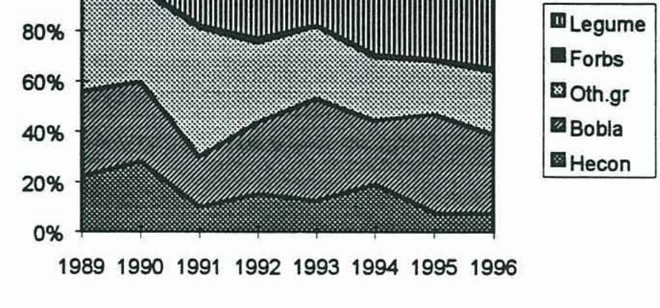

Figure 5. Botanical composition of stylo-grass pastures at Galloway Plains between 1989 and 1996.

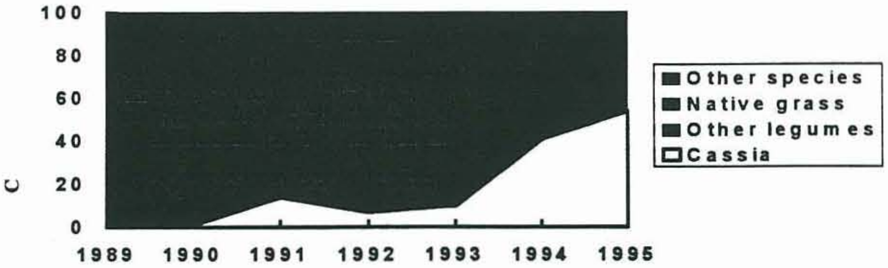

Figure 6. Composition changes in an oversown pasture at Narayen.

Pastures sown to legumes other than stylos may also become strongly legume dominant as demonstrated in Figure 6 for a Wynn cassia pasture at Narayen.

2.1.2.2. Biodiversity

Although there is little detailed information, exotic pasture species have attracted considerable criticism for their impacts on biodiversity and a number have been listed as environmental weeds. Environmental weeds are species which invade native communities and cause changes to the vegetation structure (species composition and abundance), and/or the function of ecosystems. These may result in changes in faunal habitat as well as changes to vegetation. These changes can lead to a loss of biodiversity as native species decline or are displaced with suggested causes including changed nutrient supply levels, altered fire regimes, competition, changed drainage flows, restricted access.

Eleven tropical pasture plants are listed as environmental weeds in Humphries *et al.* (1991) - nine grasses (*Andropogon gayanus, Brachiaria decumbens, B. mutica, Cenchrus ciliaris, Echinochloa polystachya, Hymenachne amplexicaulis, Hyparrhenia rufa, Melinis minutiflora* and *Pennisetum polystachyon)* and two legumes (*Leucaena leucocephala* and *Stylosanthes scabra*). Under appropriate conditions, these species are capable of forming almost mono-specific swards.

Although there have been few studies of the effects of pasture development on diversity, survival of native plant communities has usually been reduced by agricultural development (Leigh *et al.* 1984; Hobbs and Hopkins 1990; Kirkpatrick 1994). Shaw and Dale (1978) showed the balance of native species in pastures oversown with Townsville stylo at Rodds Bay was little affected but only the major species were studied - no analyses were made of the rarer species.

Pasture development usually includes some or all of the following components - tree clearing, cultivation before sowing, introduced species, fertiliser application and increased stocking rates. In such cases it is impossible to separate the contributions of the individual components but some assessment can be made in a study by McIvor (1997) at sites near Charters Towers. Impacts of sowing introduced grasses and legumes, superphosphate application, tree killing, cultivation and stocking rate on species density at the quadrat and plot level were measured.

Although the impacts were complex with effects varying between sites and years, and with the scale of measurement, some general trends were apparent. At the plot scale, species density was lower on the oversown plots than the native pasture plots, lower where the plots were cultivated before sowing, and higher at high stocking rates. Responses to tree killing and superphosphate were smaller and more variable.

In recent years, Verano and Seca have become conspicuous species on many roadsides in northern Australia. In some cases they may form almost pure stands and reductions in biodiversity are possible. However, there have been no studies to determine which communities or plants (if any) are under threat.

2.1.2.3. Nutrient content

As mentioned earlier in Section 2.1.1.1, legumes can increase the supply of available N in the soil raising the possibility of increased N levels in associate grass species. However, results have been variable. Wynn cassia (*Chamaecrista rotundifolia*) increased N concentration of the associated speargrass by 20% when unfertilised and by nearly 40% when fertilised (110 kg/ha of superphosphate at establishment and thereafter every second year) indicating that this legume can fix considerable amounts of N which are transferred to the grass (Partridge and Wright 1992). At Springmount near Mareeba, addition of P fertiliser did not increase nutrient concentration of grasses despite large yield responses by the legume (mainly Seca) (C.P. Miller, pers. comm.).

2.1.3. Animal production

Most experiments where animal production has been measured on oversown legume/native grass pastures have had a stylo as the legume or as part of a mixture so these results refer predominantly to stylo pastures. Gillard and Winter (1984) reviewed results from experiments to that time - the results were mainly from *Stylosanthes humilis* with some from *S. guianensis*. They showed that, compared with native pasture, oversown stylo pastures had higher carrying capacities and, when appropriate fertilisers were applied, annual liveweight gains per head of 150-170 kg could be obtained.

Coates *et al.* (1997) have reviewed more recent information on animal production from oversown stylo pastures based on Verano and/or Seca. The annual live weight gain advantage for cattle grazing oversown pastures compared to native pastures was usually in the range 30 to 60 kg/head with average annual liveweight gains of 160 kg/head.

A number of studies (Hunter *et al.* 1976; Gardener 1980a; Gardener 1984; Gardener and Ash 1994; Coates 1996; Coates *et al.* 1997) have demonstrated a general pattern of diet selection throughout the year for cattle grazing stylo-grass pastures (see Figure 7 for a typical example). In the early wet season cattle have a marked preference for young green grass. As the season progresses, cattle select an increasing proportion of stylo with stylo proportion reaching a maximum in the late wet or early dry seasons. Stylo proportions generally decline in the dry season and grass is again preferred by the late dry season (Coates 1996; Coates *et al.* 1997). This renewed preference for grass coincides with leaf fall and increasing stem:leaf ratios in the stylo and has been attributed to spoilage of the dry stylo by mould which is encouraged by heavy dews, high humidity and periods of overcast and rainy weather (Gardener 1980a; McCown and Wall 1981). This basic seasonal pattern is modified by amount and distribution of rainfall, grass/legume proportions in the pasture, soil fertility, and stylo and grass species. Selection against stylo in the early wet seems stronger for Townsville stylo and Verano than

Seca (Hunter *et al.* 1976; Gardener 1980a; Hendriksen *et al.* 1987; Gardener and Ash 1994; Coates 1996; Coates *et al.* 1997).

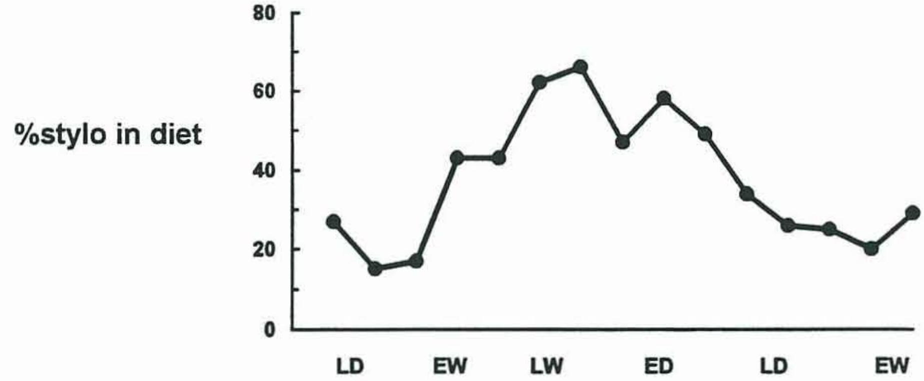

Figure 7. Seasonal pattern of diet selection for heifers grazing stylo-grass pasture at Lansdown, near Townsville. ED = early dry, LD = late dry, EW = early wet and LW = late wet seasons. (from Coates *et al.* 1997).

The changes in diet selection described in the previous paragraph relate to differences in animal production from stylo- and grass-dominant pastures at different times of the year. In the late dry and early wet period liveweight losses on strongly stylo dominant pastures are greater than those from pastures with perennial grasses (Liang *et al.* 1985; Winter 1988; Winter *et al.* 1989b). The detrimental effect of stylo dominance is likely to be less with perennial shrubby stylos such as Seca due to greater leaf retention in the dry season, more rapid growth after the first rains from the perennial plants than from seedlings, and the better acceptance of Seca by cattle in the early wet season (Coates *et al.* 1997). In contrast to these early wet season results, animal growth is greater from stylo pastures than grass pastures in the late wet and early dry seasons as demonstrated in Table 2.

Table 2. Seasonal live weight gain of steers grazing native pasture and Verano-native pasture at Lansdown near Townsville (from Gardener *et al.* 1993).

Season	Live weight gain	(g/steer/day)
	Native	Verano
Early wet	886	947
Late wet	321	572
Dry	-61	91
Transition	-171	-390
Annual	301	389

The quantity of legume required for animal production is unresolved but animal growth rates may be independent of botanical composition over quite wide ranges (20-80% stylo, Jones *et al.* 1997). However, extreme dominance by either grass or legume would be expected to result in lower animal performance - growth rates on legume dominant pastures would be lower during the transition between dry and wet seasons, and growth rates on grass pastures would be lower in the late wet and early dry seasons. Partridge *et al.* (1996) suggest that a 50% grass-50% legume mix is desirable while M. Quirk (pers. comm.) considered about 30-40% Seca was sufficient with 60% legume too close to the "flip" point where dense stands with little grass would develop. Considering that stylos can become extremely dominant, and noting and the changes to soils under stylo pastures, it could be expected there would be some declines in animal production from older pastures. None have been noted but this could be due to the wide variation between years in production due to climatic differences and the widespread droughts over the last five years, particularly in Queensland.

Pastures containing legume species other than stylos also give increased animal production. Steers grazing Wynn cassia pastures near Gin Gin gained an average of 35 kg/animal/year more than those on native pasture (and 45 kg/animal/year more where superphosphate was applied) (Partridge and Wright 1992). At Gayndah, steers grazing native pasture had annual live weight gains of 62 kg/animal compared to 167 kg/head by animals grazing fertilised fine stem stylo/native grass pasture (Bowen and Rickert 1979). Animal production from fertilised Siratro (*Macroptilium atropurpureum*)/native pasture at Narayen was 4-10 times higher (on an area basis) than from native pasture, with 40+% increases in production per animal (Tothill 1974).

There are no published results for animal production from the newer stylos. In areas where their growth is similar, animal production from Amiga and Siran would be expected to be similar to that from Verano and Seca respectively. Where their growth is superior, they could be expected to have greater impacts on animal production although there are suggestions that animal production may not be increased where stylo yields exceed 600-750 kg/ha (Gillard *et al.* 1980; Gillard and Winter 1984). The recently released *Stylosanthes* aff. *scabra* cultivars (Primar and Unica) may find their greatest use on the more fertile clay soils and their impacts on animal production are more difficult to predict.

2.2. Population biology of tropical legumes and grasses

Virtually all population studies have concentrated on the legumes and a relatively comprehensive understanding exists on the population biology of *Stylosanthes scabra* cv. Seca, *S. hamata* cv. Verano, *Macroptilium atropurpureum* cv. Siratro (Siratro) and *Chamaecrista rotundifolia* cv. Wynn (Wynn cassia) at a range of sites where they are either well or marginally adapted (McIvor *et al.* 1993). Further information on *S. guianensis* var. *intermedia* (Oxley fine stem stylo) is available from Brian Pastures Research Station. Because of this understanding, it is possible to summarise the individual population biology of each of these legumes.

Seca

Individual plants are relative long lived with measured life spans of at least 8 years at both Lansdown (Gardener 1984) and Galloway Plains (D.M. Orr, unpublished data). A comparison of the life spans of successive cohorts from Galloway Plains (Figure 8) suggests that increasing plant competition from already established Seca plants reduces the life spans of later emerging cohorts.

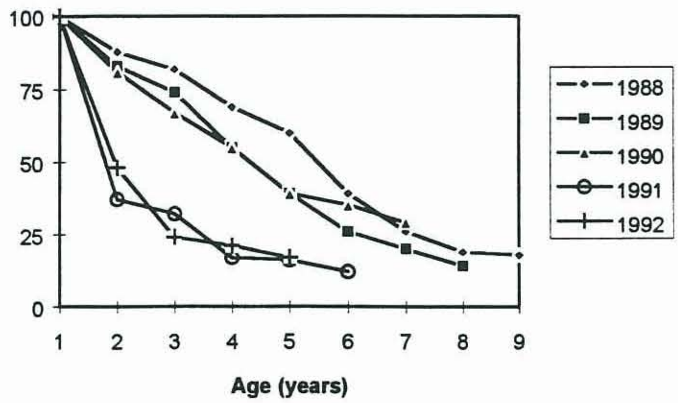

Figure 8. Survival (%) of annual cohorts of *S. scabra* cv. Seca between 1988 and 1996 at Galloway Plains.

Populations of Seca usually increase slowly because seed production following sowing is slow compared with the other stylos, such as Verano, which have short life spans (see below). At Galloway Plains, plant density increased faster at the low compared with the high stocking rate because more seed was set at the low stocking rate (Orr and Paton 1993). Maximum plant density figures recorded include 145 plants/m^2 (mixed *S. scabra* and *S. viscosa*) at Manbulloo (Mott *et al.* 1989) and 100 plants/m^2 at Galloway Plains (Orr and Paton 1993; see also Figure 9).

At Narayen, Seca persistence is limited by frost although Jones *et al.* (1993a) suggest that the increasing incidence of rainfall during late autumn and winter with increasing latitudes may limit the adaption of shrubby stylos such as Seca in addition to cool season temperature *per se*. Further south in the Darling Downs/Maranoa areas, Seca does not persist because seedlings do not survive (R.G. Silcock, pers. comm.).

Verano

Individual plants are relative short lived with measured lifespans for individual plants of up to three years at both Lansdown (Gardener 1982, 1984) and Galloway Plains (D.M. Orr, unpublished data). However, most plants fail to persist into their second summer. Plant density at Lansdown between 1972 and 1979 varied widely with the highest density of 350 plants/m^2 recorded in a fertilised, heavily grazed pasture. However, at Galloway Plains, the highest density recorded between 1988 and 1996 has been only 5 plants/m^2 (D.M.Orr, unpublished data) reflecting the fact that Verano is much less suited to central than northern regions.

Fine stem stylo

Individual plants of Fine stem stylo have survived for more than five years at Brian Pastures although most plants die within three years. Seedling survival is strongly related to the seasonal rainfall pattern following recruitment and consequently longer lifespans appear to be associated with improved seasonal rainfall particularly during seedling growth. Between 1987 and 1992, plant density at two stocking rates ranged from 15 to 50 plants/m^2 and reflected both the survival of existing plants and variation in the recruitment and survival of seedling cohorts (D.M. Orr, unpublished data).

Dynamics of stylo seed banks

A characteristic of all stylos sown into native grass pastures is that they have relatively large seed banks. The seed bank for a number of stylos at a number of sites is given in Table 3.

Table 3. Seed banks (seeds/m^2) of a range *Stylosanthes* spp. at a range of locations.

Species	Location	Seed bank (seeds/m^2)	Notes	Reference
Verano	Lansdown	8560	P fertilised, heavy grazing	Gardener (1982)
	Hillgrove	3000	Light - moderate grazing	J.G. McIvor (unpublished)
	Cardigan	9000	Light - moderate grazing	J.G. McIvor (unpublished)
Seca	Hillgrove	2000	Light - moderate grazing	J.G. McIvor (unpublished)
	Cardigan	7000	Light - moderate grazing	J.G. McIvor (unpublished)
	Galloway Plains	600	Light grazing	D.M. Orr (unpublished)
Fine stem stylo	Brian Pastures	10000	Light grazing	D.M.Orr, (unpublished)

In addition to their relatively large size, these seed banks are persistent such that seed viability is retained beyond the first summer and seed can continue to germinate in subsequent summers once hardseededness has been overcome. Hardseededness is overcome by exposure to increasing soil temperature which usually occurs early in the summer period in the northern regions but often throughout the summer in the more southern regions (Mott *et al.* 1981). Thus, large and persistent seed banks together with seedling emergence "spread" over a number of seasons "buffer" plant recruitment resulting in large increases in plant density (see Figure 9).

Development of stylo populations

Small seedlings of stylo can survive long dry periods (Partridge *et al.* 1996). Success of sowings will depend on the weather experienced and may be low for some sowings (Gramshaw *et al.* 1993) but even sowings during the late wet season can be successful if the following dry season is not too long and arid (McIvor 1983). Observations (D.M.Orr) at Galloway Plains, where there is some component of winter rainfall, suggest that Seca seedlings recruited as late as autumn and early winter can survive the winter to contribute to the population. However, discussions at Mareeba suggest that a similar situation may not exist in north Queensland because the prolonged dry season may limit the survival of seedlings. Therefore, it is speculated that Seca dominance in pastures may become more of a problem in central regions than further north. However, any increase in Seca survival has to be countered with improved persistence of native grasses in central compared with northern regions (see Section 2.3.10). Nevertheless, Orr and Paton (1993) recorded higher seedling recruitment of Seca under light compared with heavy grazing and this finding has implications for the management of newly sown Seca pastures. In the case of Seca, field populations are likely to contain plants of a wide range of age classes because of continuing recruitment and the prolonged life span of individual Seca plants.

Wynn Cassia

A conceptual model for the persistence of *Chamaecrista rotundifolia* cv. Wynn (Wynn cassia) (Jones *et al.* (1993b) focuses on seed production, soil seed banks and seedling recruitment because of the inherent short life span of individual plants (usually less than 1 year?). Rainfall pattern is the major factor influencing populations rather than stocking rate, possibly because this species is relatively unpalatable to livestock. Favourable rainfall during the growing season is necessary to ensure satisfactory seed set and seedling recruitment to maintain plant populations. In this way, persistence relies on a favourable soil seed bank to counter seasonal fluctuations in rainfall.

Soil seed bank measurements include 10000-12000 seeds/m^2 at Samford (mean annual rainfall 1100 mm) (Jones and Bunch 1995), 7500 seeds/m^2 near Gin Gin (mean annual rainfall 1070 mm) and 15000 seeds/m^2 near Rockhampton (mean annual rainfall 860 mm) (C.H. Middleton, unpublished data). Mature plant and seedling densities of 50 and 135 plants/m^2 at Samford and 15 and 164 plants/m^2 at Gin Gin indicated that Wynn cassia persistence is high. In contrast, at Narayen (mean annual rainfall 715 mm) near the dry limit of its adaptation, Wynn cassia showed reduced plant density from 50 plants/m^2 to 1 plant/m^2 associated with a series of drought years. During this drought, isolated rainfall events promoted major seedling germination events without seed production and followed by rapid seedling death resulting in a substantial reduction in the soil seed bank (Jones 1993).

Comparative population biology of the invasive stylos and Wynn cassia with the non-invasive Siratro in relation to grazing management

The invasive legumes, stylos and Wynn cassia, are free seeding and set large amounts of seed at a time when these species are relative unpalatable compared with the associated native grasses such that grazing management has only a minor role in plant persistence. In contrast, grazing management is critical to the persistence of the non-invasive Siratro and this difference is closely related to differences in their population biology. Individual plants/stolons of Siratro have a lifespan of up to 10 years and seed banks are low (usually less than 250 seeds/m^2) relative to stylos and Wynn cassia and high stocking rates reduce the contribution of Siratro to the pasture.

Because of its high palatability, plants are usually heavily selected during flowering and seed set so that careful grazing management is necessary for Siratro to persist (Jones and Bunch 1988). This difference in population biology suggests that heavy grazing while plants of stylos and Wynn cassia are seeding may reduce seed set. However, the effectiveness of such a grazing strategy would depend on the extent of increased grazing pressure on the associated native perennial grasses. Wynn cassia in particular is known to be unpalatable on some soil types.

Grasses

In contrast to the legumes, data on the population biology of perennial grasses are few (McIvor and Orr 1991) and are generally restricted to *Heteropogon contortus*. Therefore, the population biology of native grasses is summarised in terms of the components of the population biology.

Longevity

Fewer than 10% of plants of *H. contortus* survived for 5 years at 2 sites near Charters Towers although plants of *Chrysopogon fallax* (golden beard grass) and of *Bothriochloa ewartiana* (desert mitchell grass) displayed greater longevity (McIvor *et al.* 1994). At Galloway Plains (Orr and Paton 1993) and Narayen (D.M. Orr, unpublished data), *H. contortus* displayed similar longevity to that near Charters Towers. At Galloway Plains, increasing grazing pressure reduced plant longevity but this trend was not apparent at Narayen.

Seed production

At Narayen, seed production of *H. contortus* ranged from 200 to 2500 seeds/m^2 over a series of drought years and was consistently higher in the silver leaf than in the narrow leaf landscape position. The major factor influencing seed production was inflorescence density while the viability of this seed differed between years with a positive relationship between seed viability and rainfall occurring during March when that seed was produced (D.M. Orr, unpublished data).

At Lansdown, seed production of *H. contortus* and *Themeda triandra* in ungrazed pasture averaged 4600 and 1200 seeds/m^2 compared with 63000 seeds/m^2 for *B. pertusa* over a three year period of "average" rainfall (Howden 1988). However, in grazed pastures, seed production for each of the native grasses *H. contortus, C. fallax* and *T. triandra* measured over three years averaged <100 seeds/m^2 compared with that for *B. pertusa* and *Chloris inflata* which averaged 1000 and 1700 seed/m^2. Seed production of the three native grasses declined with increasing stocking rate whereas the two naturalised grasses produced most seed at the medium stocking rate (McIvor *et al.* 1996).

Soil seed banks

At Narayen and Galloway Plains, the highest germinable seed banks of *H. contortus* measured at the start of summer were 400 and 200 germinable seeds/m^2 with large differences between seasons being apparent (Orr *et al.* 1995). There was a consistent trend at both sites for the highest germinable seed banks to be recorded at the lightest grazing pressures (Orr and Paton 1993, D.M. Orr, unpublished data). Comparisons of the germinable seed banks of *H. contortus* at Galloway Plains under native pasture and native pasture augmented with Seca stylo at the same stocking rates (0.25 and 0.375 steers/ha) between 1989 and 1993 indicated no differences between these treatments. However, since the 1994-95 summer, germinable seed banks of *H. contortus* have been significantly lower in stylo augmented treatments than in the native pasture treatments (D.M. Orr, unpublished data). This result further emphasises the necessity to understand the long term population biology of perennial grasses in legume augmented pastures.

In the northern region, a soil seed bank of 60 seeds/m^2 for *H. contortus* was reported at Lansdown (McIvor 1987). Further studies of twenty communities with a wide range of compositions near Collinsville (McIvor and Gardener 1994) demonstrated the small numbers of native perennial grass seeds present in the soil seed bank (< 5% of the total seed bank) irrespective of grazing history and indicated that soil seed banks were dominated by forb species. Such reports are consistent with reports of increasing occurrence of forb species in these pastures as native perennial grasses disappear. At Katherine, a pasture dominated by *Themeda triandra* had a soil seed bank of 8 *T. triandra* seeds/m^2 (Mott and Andrew 1985).

The problem of low seed production and soil seed banks is further accentuated by the lack of a persistent seed bank. Studies of the persistence of *H. contortus* seed banks from Galloway Plains indicates that more than 95% of the total seed recovered over four successive years was recovered in the first year (D.M. Orr, unpublished data).

Seedling recruitment

Seeds of native grasses remain dormant from the time of production in one summer until the start of the following wet season when dormancy has been overcome by exposure to increasing soil temperatures at the end of the dry season (Mott 1978). Seedling emergence of up to 300 seedlings/m^2 for *H. contortus* was reported under regular spring burning in southern Queensland (Shaw 1957) because burning in spring causes seed to overcome dormancy (Campbell 1995).

Studies of seedling emergence patterns in both northern (McIvor and Gardener 1991) and southern (Orr and Paton 1997) *H. contortus* pastures indicate that most *H. contortus* seedlings emerge with the first summer rainfall event and emergence then decreases as the summer progresses.

The pattern of subsequent seedling survival following emergence is strongly influenced by rainfall. For example at Katherine, 5 seedlings/m^2 of *T. triandra* emerged (mean of burnt and unburnt treatments) and 20% of these survived until the end of the summer but all seedlings subsequently died during the following dry season (Mott and Andrew 1985). In contrast, at Brian Pastures Research Station, 60-80 seedlings/m^2 of *H. contortus* emerged following spring burning, 40-70% of these survived until the end of the summer and 20-60% of this total seedling emergence had survived until the second summer (Orr and Paton 1997).

In the absence of fire, seedling recruitment of *H. contortus* at the end of summer at Galloway Plains and Narayen was usually less than 15 seedlings/m^2 with highest recruitment usually occurring at the lightest stocking rate and with large variation between years due to seasonal variation in rainfall (Orr and Paton 1993, D.M. Orr, unpublished data).

Rainfall was considered more limiting than soil seed bank in determining *H. contortus* seedling recruitment at both Galloway Plains and Narayen (Orr *et al.* 1995). Furthermore, there is little evidence that recruitment of *H. contortus* at both Galloway Plains and Narayen was affected by differences in stocking rate (D.M. Orr, unpublished data).

Plant density

Plant density of *H. contortus* at Galloway Plains and Narayen has fluctuated from 5 to 30 and from 10 to 25 plants/m^2 respectively under a wide range of seasons and stocking rates (D.M. Orr, unpublished data). Such fluctuations are consistent with the relative short plant longevity and variable recruitment reported above. In contrast to *H. contortus* , the complete lack of seedling recruitment of *T. triandra* at Katherine indicates that populations of *T. triandra* depend on the longevity of individual tussocks (Mott and Andrew 1985).

Comparison of the population biology of native grasses and legumes

Comparing the population biology of native grasses and legumes in legume/grass pastures, native grasses are disadvantaged because:

(1) native grasses produce much less seed (particularly in the north) and this is exacerbated by the lack of a persistent seed bank such that seed must be produced each summer for seedling recruitment to occur in the subsequent summer
(2) most native grass seedlings emerge following the first major rainfall each summer and the subsequent survival of these seedlings is dependent on further rainfall. This contrasts with legume seedling emergence which occurs progressively through the summer as hardseededness is overcome.
(3) because of (1) and (2), grasses are less able than legume to increase density and, combined with the fact that grasses are further disadvantaged by being selectively grazing over summer (when they are susceptible to defoliation while the legumes are ungrazed or only lightly grazed), then it is not surprising that legumes, in the longer term eventually dominate these pastures in the absence of some management intervention.

This eventual legume dominance is illustrated by plant density data for *H. contortus* in native pasture and native pasture plus Seca treatments at Galloway Plains between 1988 and 1996 (Figure 9). which shows the inevitable increase in Seca density, particularly between 1992 and 1996.

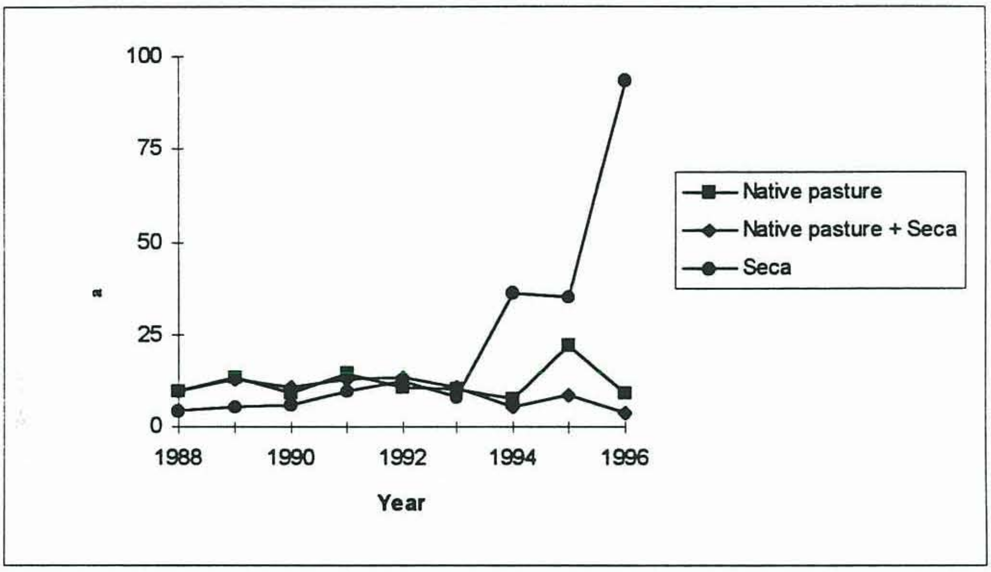

Figure 9. Changes in the density of *Heteropogon contortus* in native pasture and native pasture augmented with Seca stylo between 1988 and 1996 at Galloway Plains. Note the rapid increase in Seca stylo density after 1993. The density of *H. contortus* is significantly reduced in 1995 and 1996 (D.M. Orr, unpublished data).

2.3. Factors affecting the composition and stability of legume-based pastures

It is important to consider the time scale over which botanical composition changes have been measured when discussing pasture stability. Jones *et al.* (1995) reviewed some long term studies where botanical composition was measured and highlighted the time lag involved in adequately describing species change. Reasons for these time lags include rainfall variability, changing soil fertility, plant longevity and the cumulative effects of different stocking rates. These authors also pointed to the misleading results that would have occurred in the absence of long term measurements. For population studies, Jones and Mott (1980) concluded that populations should be studied for sufficient time to record the death of plants recruited to the study and not just the original individuals. By way of example, four years of recording botanical composition at Gin Gin (Partridge and Wright 1992) failed to detect any shift towards Wynn cassia dominance. In view of the concern now being expressed in that area (see survey reported in Appendix 1), it is interesting to speculate that had botanical composition been measured over a longer time frame that Wynn cassia dominance may have developed.

2.3.1. Seasonal conditions

Much of the research dealing with Seca/Verano/grass dynamics has been conducted during the last 15 years. In many cases, this period has experienced some of the driest years on record. This fact raises two important questions regarding legume dominance in pastures. Firstly, has drought weakened the perennial grasses relative to legumes such that perennial grasses will become more competitive with a return to more "normal" seasons? However, this scenario presupposes that sufficient grass tussocks and/or viable seed remain available to respond to improved rainfall conditions. Or secondly, had seasonal rainfall been more "normal", would legume dominance have developed sooner? It can be expected that during a run of wetter years stylo growth would be greater but this could be offset by increased fire frequency.

Botanical composition of pastures containing perennial species is likely to be less variable than that of pastures dominated by annual species (Gardener and McIvor 1985) as conditions during germination can markedly affect the proportions of annual species (Torssell and McKeon 1976; Gardener 1982). Annual species tend to avoid drought by remaining dormant but drought conditions may reduce overall seed production.

2.3.2. Soil type

Both Verano and Seca are better adapted to lighter soils and are less competitive on heavy clays in north Queensland. In a glasshouse trial involving Verano and Seca with Sabi grass and Indian couch grass, the grasses were more competitive on a clay loam than a sandy clay loam and contributed a greater proportion of the mixtures (Hu 1995).

Similarly, Seca does not grow as well on clay soils (where *Bothriochloa bladhii* is common) as on other soil types in central Queensland. Differences in Seca density due to soil type is indicated at Galloway Plains where Seca contributes 40% of the botanical composition (mean of three stocking rates) on the duplex soil compared with 30% on the clay soil. However, this soil association effect may be confounded with landscape position as the clay soils are associated with depressions at the bottom of slopes where frosts are a consideration in central Queensland. Further south at Narayen, Seca stylo has its highest plant density in the spotted gum landscape position where the incidence of frost is lowest (Taylor and Cook 1993). Jones *et al.* (1993a) recorded widespread death of Fitzroy plants at Narayen during winter following a period of very wet conditions in late autumn and early winter.

Because of the effect of soil type on Seca distribution, commercial paddocks in central and southern Queensland are likely to have mosaics of different proportions of Seca throughout the paddock.

Soil P levels are considered in the next section (2.3.3).

2.3.3. Fertiliser

Phosphorus deficiency is widespread in northern Australia and superphosphate is the most widely used fertiliser. Results from a number of trials examining the response of stylo pastures to superphosphate are given in Table 4. A general summary of the effects of available P on stylo and grass growth is (Coates *et al.* 1990; Jones *et al.* 1997): at very low P levels (<3 ppm) legume growth is usually poor and botanical changes are slow; at low P levels (3-8 ppm) legume growth is enhanced and pastures become stylo dominant, especially with Seca; at higher P levels (>8 ppm) growth of legume is further increased but where introduced grasses are used the higher P levels are more advantageous to the grass and grass dominance is promoted.

Table 4. Effects of superphosphate on native pastures oversown with stylo in northern Australia. Treatment values are the amount of superphosphate (kg/ha) applied initially and annually.

Site	Treatment	Stylo (%)	Notes	Reference
Manbulloo	Nil	31	Legume content of	Winter *et al.*
	100/25/......	47-93	fertilised plots	(1989a)
Avail. P = 3.5			increased with	
			stocking rate	
Springmount	Nil	<2	Legume mix - 90%	Coates *et al.*
	50/0/0/50/0	45	of legume was Seca	(1990)
Avail. P = 2	50/200/50/100/1	60		
	00			
Lansdown	Nil	75	Verano, Seca,	Coates *et al.*
	0/100/0......	30	Urochloa mixture	(1990)
Avail. P=3-4	0/100/.......	25		
Manbulloo	Nil	25	Verano	Coates *et al.*
Avail. P = 3.5	100/25/.....	80		(1990)
Lansdown	Nil	29	Verano. Mean value	Gardener *et al.*
Avail. P = 18	300/.......	18	1973-85 (range =	1993
			10-61%)	
Lansdown	Nil	38	Verano, Seca and	McIvor (1984)
Avail. P = 4	200/........	25	Urochloa.	
Hillgrove	Nil	30	Verano, Seca, buffel	McIvor and
Avail. P = 50	100/.........	24	and Urochloa	Gardener (1995)
Cardigan	Nil	37	Verano, Seca, buffel	McIvor and
Avail. P = 6	100/......	42	and Urochloa	Gardener (1995)
Swans Lagoon	Nil	>95	Townsville stylo.	Winks (1973)
	125/......	10	Fertilised plots	
			dominated by annual	
			grasses	

While many soils in northern Australia are P deficient, responses to S have been recorded on euchrozems (Miller and Jones 1977; Gilbert and Shaw 1981; McIvor *et al.* 1988) and neutral red duplexes (Probert and Jones 1982). On a euchrozem at Meadowbank cv. Graham declined over the years after contributing 95% in 1975 to <1% in 1980 where no sulphur applied but the proportion of Graham increased where S was applied (Gilbert and Shaw 1981).

2.3.4. Animal supplements

Supplementing animals represents a significant input of P into pasture systems (10 g/an/day equals 2.5 kg/yr at a stocking rate of 1 an/ha). This can influence botanical composition as Winter (1988) showed *Alysicarpus vaginalis* increased from 10% in control plots to 25% in plots where animals were supplemented. On unfertilised pasture at Lansdown Urochloa increased from <5% to 27% when animals were supplemented (Coates *et al.* 1990; Coates 1994). Animal supplements can create a more complex situation in larger commercial paddocks where animals tend to concentrate nutrients in camps leading to the uneven distribution of nutrients.

2.3.5. Grazing pressure

Cattle select grass over stylos (Gardener 1984) and Wynn cassia (Quirk *et al.* 1992) during the growing season. However, Hendricksen *et al.* (1987) indicate that Seca is selected throughout the year although much less so in summer than in autumn after the grasses have seeded. This dietary preference for grass in summer favours the legume in terms of both adult plant survival and seed set together with seedling establishment. Furthermore, it is a fairly general view that producers have increased stocking rates when legumes have been oversown into native pastures because producers wish to recoup the additional cost of sowing the legume. Thus, the idea that legume oversowing *per se* leads to eventual legume dominance, must be interpreted with this general background of increased stocking rate.

Examples of stocking rate effects on the proportion of various stylos in pastures are shown in Table 5. In general for Verano/native grass pastures, increased stocking rates lead to an increase in Verano and a decrease in native perennial grasses; this can produce nearly pure Verano at high stocking rates as shown by Winter *et al.* (1989a). Annual grasses and forbs may also increase as stocking rate rises. Stocking rate responses on Seca/native grass pastures are more variable with Seca able to dominate over a range of stocking rates. However, at Springmount, the addition of Seca and Verano did not reduce perennial grass yields when these pastures were grazed at a light stocking rate even though Seca dominated the pasture (C.P. Miller, pers. comm.).

Table 5. Stocking rate effects on native pastures oversown with stylo in northern Australia.

Site	Treatment	Stylo (%)	Notes	Reference
Katherine Research Station	0.67 an/ha	58	Townsville stylo	Norman and Phillips (1970)
	1.00 an/ha	67		
	1.33 an/ha	75		
Manbulloo	0.6 an/ha	47	Verano with superphosphate	Winter *et al.* (1989a)
	0.8 an/ha	63		
	1.0 an/ha	93		
Hillgrove	0.2 an/ha	35	Verano, Seca, buffel and Urochloa	McIvor and Gardener (1995)
	0.33 an/ha	32		
	0.5 an/ha	34		
	1.0 an/ha	7		
Cardigan	0.2 an/ha	28	Verano, Seca, buffel and Urochloa	McIvor and Gardener (1995)
	0.33 an/ha	32		
	0.5 an/ha	48		
	1.0 an/ha	49		
Lansdown	0.6 an/ha	20	Verano	Gardener *et al.* (1993)
	1.2 an/ha	25		
Galloway Plains	0.25 an/ha	43	Seca (Verano) No fertiliser	Burrows *et al.* (Unpublished data)
	0.375 an/ha	22		
	0.5 an/ha	40		

In contrast, at Galloway Plains, the highest legume content occurs at the lowest stocking rate (Table 5) suggesting that at this site, the increase in the density of Seca has been highest at the lowest grazing pressure. Similarly, Orr and Paton (1993) reported that Seca density increased faster at low rather than at high stocking rate probably because heavy grazing reduced Seca seed production. Therefore, this difference in stocking rate effects on Seca density between northern and central Queensland may be related to a better environment for Seca seedling establishment in central Queensland (see Section 2.2.).

Bowen and Rickert (1979) showed that reducing grazing pressure reduced the density of fine stem stylo which, in turn, increased grass yield. This different reactions of fine stem stylo to reduced grazing pressure may be related to differences in plant longevity.

2.3.6. Fire

Fire has been used successfully to control increasing Seca dominance at The Springs and Wycheproof in central Queensland (C.H. Middleton, unpublished data). However, there is no clear understanding of when or how often fire can be used successfully. The response to fire depends on the response of mature plants and the soil seed bank.

Considerable variation exists between species in their ability to survive fire. At Lansdown, Gardener (1980b) recorded average survival values of 33% for Seca, 30% for Fitzroy, 12% for Verano and nil for Schofield (Schofield plants failed to survive even the coolest fire). Of the commercial lines only Seca survived the hottest fire. At Katherine, Fitzroy had the lowest mortality in young swards but its survival was poor in swards more than 3 years old; Verano plants survived only low intensity fires (Mott 1982). Although many factors influence plant survival (fire intensity and duration, plant age, physiological state and health) the species rank for survival in order *S. scabra, S. hamata* and *S. guianensis.*

The ability of individual plants to withstand fire depends on how well protected are the growth sites within the different plants and Gardener (1980b) demonstrated that individual Seca plants resist fire because of their ability to regrow from underground growth buds. Similarly, fine stem stylo can recover from fire because the plant crown is underground where it is protected from fire and also from heavy grazing (Stonard and Bisset 1970, Bowen and Rickert (1979). Nevertheless, Mott *et al.* (1989) demonstrated increased mortality of Seca plants older than 3 years and attributed this result to higher heat intensity in the older, ungrazed swards. J.M. Hopkinson (pers. comm.) maintains that fire, under the right conditions, can be used to achieve variation in age structure of Seca populations.

Fire also influences seedling regeneration in the following growing season. Although fire kills up to 40% of the seed bank on the soil surface, a considerable quantity of hard seed is softened and can lead to germination and seedling establishment (Mott 1982). However, before fire is used as a management tool, Mott (1982) cautioned that care should be taken to ensure that there is sufficient seed is present in the soil seed bank. Furthermore, Miller and Webb (1989) recorded regeneration of both Seca and Verano seedlings that was more than sufficient to replace those plants killed following a wildfire at Springmount.

H. contortus is known to be well adapted to fire. Recently, Orr *et al.*(1997) and Orr and Paton (1997) have shown that burning together with spelling/reduced grazing pressure can result in large increase in the density of *H. contortus*. This positive response of *H. contortus* to fire and reduced grazing pressure together with some negative effects on legumes appears to provide considerable scope for manipulating the grass/legume balance and further research is warranted.

2.3.7. Associate grass

Indian couch grass (*Bothriochloa pertusa*) is now naturalised over 1 M ha (mainly in north-east Queensland) in areas suitable for stylos. There have been suggestions that Verano and Indian couch grass may not form suitable pasture mixtures. In a grazing experiment at Lansdown, Jones (1992) measured lower Verano content in pastures with Indian couch grass than in pastures with Sabi grass (*Urochloa mosambicensis*). Hu (1995) examined reasons for this result and, in a glasshouse pot trial, showed that Sabi grass was more competitive than Indian couch grass in the seedling stage. However, when Verano was sown into field swards, competition was greater from Indian couch grass than from Sabi grass. Selective grazing further favoured the Indian couch. Legume contents in Indian couch grass pastures will vary considerable between years in response to seasonal conditions and management changes but both components seem able to persist together. While pastures of Indian couch and stylos (both Verano and Seca) have been developed, some problems have been observed with Seca reestablishing in Indian couch grass stands (Jones, pers. comm.).

Mixtures of Verano, Seca, buffel and Sabi grass oversown into native pastures at Hillgrove and on plots with superphosphate at Cardigan have become very strongly buffel grass dominant with only minor legume components (McIvor and Gardener 1995). Given the extreme competitiveness of buffel (particularly in drought conditions), survival of associated legumes is likely to be a problem where buffel is well adapted.

2.3.8. Tree clearing

Tree clearing or killing usually leads to increased grass growth and a consequent decrease in stylo due to increased grass growth (Table 6).

Seca stylo goes some way towards the leucaena model of a deep rooted perennial carrying green leaf into the early to mid dry season (Miller and Stockwell 1991). However, tree clearing or killing in the northern area usually leads to increased grass growth and a consequent decrease in stylo due to increased grass growth. In the central region, current recommendations are producers graze the "flush" of grass following timber treatment before sowing legumes (W.H. Burrows, pers. comm.).

Stylo pastures have been reported to have resulted in the death of eucalypt trees during recent drought years and observations at Springmount indicate that the presence of Seca does result in the death of trees. However, the death of eucalypts outside the experimental area suggests that tree death has occurred independently of Seca.

Trees may act as "nutrient pumps" bringing cations from the subsoil to the surface to counteract movement of these ions downwards during leaching and help reduce acidification.

Sowing stylos into native pastures in north Queensland has resulted in some producers not using fire for pasture management so as not to kill the legume. However, this lack of burning appears to have resulted in increasing timber regrowth problems (K. Shaw, pers. comm.).

Table 6. Tree clearing effects on native pastures oversown with stylo near Charters Towers.

Site	Treatment	Stylo (%)	Notes	Reference
Hillgrove	Live	36	Verano, Seca, buffel	McIvor and
	Killed	17	and Urochloa	Gardener (1995)
Cardigan	Live	49	Verano, Seca, buffel	McIvor and
	Killed	30	and Urochloa	Gardener (1995)

2.3.9. Legume species/cultivar

The P requirements of Verano (e.g. 10-12 ppm, Probert and Williams 1985) are higher than those of Seca (e.g. 7-8 ppm, Gilbert and Shaw 1987).

2.3.10. Geographic location

In northern Australia where the dry season moisture stress is greatest (Mott *et al.* 1985), even in the absence of sown legumes, the perennial grasses are inherently more susceptible to heavy grazing. With adequate soil fertility, heavy grazing leads to the replacement of perennial grasses by broadleaf weeds (e.g. *Hyptis* and *Sida*) and annual grasses (e.g. *Digitaria, Dactyloctenium* and *Brachiaria)*. Under conditions of heavy grazing, the addition of a sown legume accentuates the loss of perennial grasses and consequent legume dominance.

Further south, the period of dry season moisture stress is less and perennial grasses are more resilient (Mott *et al.* 1985) and tend form a more stable mix with oversown legumes. The results of Shaw (1978) indicated that perennial grasses were able to persist with oversown Townsville stylo even at heavy stocking rates.

Geographic variation in the resilience of perennial grasses to increased grazing pressure suggests that the management of botanical composition in legume augmented pastures may need to be geographically specific.

2.3.11. Plant competition

Little is known of the competitive interaction between native grasses and introduced legumes under field conditions. However, a preliminary pot trial using the "replacement series" approach indicated that Seca had no effect on *H. contortus* yield but increasing proportions of *H. contortus* progressively reduced the yield of Seca (Figure 10) (D.M. Orr, unpublished data). However, caution must be used to interpret this result because of the different architecture of the root systems of *H. contortus* and Seca. In the field situation, Seca develops a deep central tap root system compared with the comparatively shallow root system of perennial grasses and this difference may result in a different competitive outcome in the field situation.

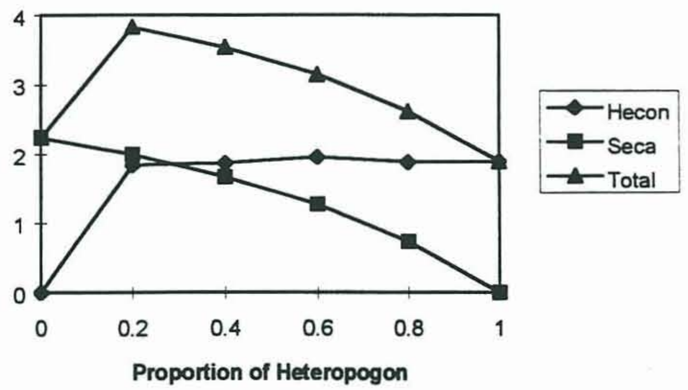

Figure 10. Replacement series diagram of competition between *H. contortus* and *S. scabra* cv. Seca.

2.3.12 Spatial distribution

Patches of Townsville stylo and perennial grasses (predominantly *H. contortus*) were shown to alternate over a two to three year time scale at Rodds Bay. This pattern was recorded under a regime of spring burning and some heavy grazing (due to drought) which tended to prevent a stable pattern from developing. This lack of constancy in the patch mosaic of legume/grass was considered to be beneficial because it resulted in improved nutrient cycling and availability (Hacker *et al.* 1982).

At Lansdown, McIvor *et al.* (1993) reported fluctuations in the occurrence of Verano in permanent quadrats between 1972 and 1979. Although plant frequency fluctuated between 60 and 80%, Verano was present in 36% of quadrats every year, 52% in some years but was absent from 12%. These data suggest that some degree of patch mosaic may be occurring in this pasture system.

Few data are available on the spatial distribution of other legume/grass combinations. Because of the short life spans of Townsville stylo and Verano, it is conceivable that the mosaic patterns reported above can occur over a relatively short time scale. In the case of Seca, with the longevity of individual plants and the tendency for seedlings to develop around seed producing plants, any patch mosaic patterns would be expected to occur over a much longer time frame. Such a consideration further emphasises the need for studies to be conducted over the life spans of the plant species being studied.

2.4. Management strategies to maintain or alter botanical composition

As shown in the preceding section, there are a number of management factors known to influence the botanical composition of oversown pastures. Maintaining a productive legume-perennial grass mixture over the long term presents a considerable challenge. Many plant, climate, management and edaphic factors interact with the demographic features of each species so that simple recipes for management are unlikely to have widespread success; productive stylo/grass pastures are most likely to persist when managers know what to do and when (Gardener 1984). Legume dominance is a very real issue in legume-native grass pastures. Furthermore, this issue is probably one that is not widely recognised outside the scientific community although individual producers are now expressing views that indicate that the issue is becoming increasingly recognised.

There are two stages of legume augmentation into native grass pastures. An establishment phase where it is important to increase the legume content in the pasture by managing to boost seed set and plant density. Subsequently, once a reasonable legume content has been achieved, careful management is required to maintain an appropriate grass/legume balance and particularly to prevent either the loss of the legume or legume dominance.

In any management strategy overall stocking rates need to be conservative to maintain both the pasture and the soil resources. From the results presented in Section 2.3. there are potential management factors currently available to manage botanical composition in legume augmented pastures.

a. Fire

Considerable scientific evidence and practical experience exists to support the use of fire and strategic rest in managing botanical composition. Burning in spring followed by spelling/ reduced grazing pressure can promote perennial grasses, especially *H. contortus*, and manage legume populations. Fire can kill mature legume plants so that the legumes need to reestablish from seed. Such burning practices can be advocated where the pasture is well established and has sufficient soil seed reserves for the maintenance of the legume population.

b. Grazing management

Based on an understanding of the diet selected by cattle, grazing management can be manipulated to:
(i) favour the grass by spelling or reducing grazing pressure during the summer to promote the growth and seed production of perennial grasses;
(ii) favour the legume by grazing heavily during the summer;
(iii) increase seed ingestion and aid spread of the legume. Heavy defoliation at the end of the wet season will have little adverse effect on stylo populations as stylo seed is ingested and spread and there will be little advantage to the grasses as soil moisture has been exhausted (Gardener 1984);
(iv) minimise legume spread by grazing animals elsewhere on the property when legumes are carrying their highest seed loads.

c. Sow a grazing tolerant grass when sowing stylos

In anticipation of perennial grass decline, a suitable introduced grass could be sown at the same time as the legume. In general the stylos are more grazing tolerant than the native grasses and a grazing tolerant grass would make maintenance of balanced pastures an easier task in variable environments. A major component in accelerated acidification observed under legume dominant pasture systems is thought to be NO_3-N leaching. Planting a grass species that has the ability to capture this NO_3^- before it is leached would significantly reduce the rate of acidification. At this stage *Urochloa mosambicensis* and *Bothriochloa pertusa* seem to be suitable grasses for wide areas. *Cenchrus ciliaris* is suited to the some of the more fertile soils in the region and can produce productive pastures with stylos but may prove too competitive as a long term companion grass.

d. Soil phosphorus level and superphosphate application

The application of superphosphate to *Stylosanthes*-grass pastures has frequently resulted in a significant shift in botanical composition from legume to grass dominance. In legume dominant swards the addition of P may assist in balancing the pasture. Conversely, the planting of

Stylosanthes could be confined to soils that have a high inherent P status so as to prevent legume dominance occurring. Results from high P basaltic soils at Meadowbank and Hillgrove show low levels of *Stylosanthes* in the sward (McIvor and Gardener 1995; C.P. Miller, pers. comm.). Since accelerated acidification is a function of both legume dominance and associated climatic and edaphic factors, the planting of *Stylosanthes* into native pastures should be confined to soil having a high inherent buffering capacity and an adequate P status that would maintain a significant grass component in the sward.

e. Area sown

Given that managing oversown pastures can be difficult, many people suggest planting only small areas (say 10-30% of properties) to legume and managing these areas intensively. Such a plan may be compatible with using areas of high P/high buffering capacity soils as discussed in (d.), and with producing cattle for particular markets. In some areas, edaphic (e.g. heavier soils, waterlogged areas) and environmental constraints (e.g. frosting) may limit the growth of stylos on parts of properties leading to mosaics of legume and native pastures.

3. Current knowledge Gaps

The above review and discussions with experienced pasture scientists (see Appendix 2) have revealed the following knowledge gaps. The points are in random, not priority, order.

3.1. There appears to be a general trend for grazing tolerance and community stability to increase from the north-west to the south-east (Mott *et al.* 1985; Tothill and Mott 1985). However, there is a need to establish a matrix of geographic location x legume species x stocking rate interactions including long term monitoring of vegetation "cycles" between grass and legume to define this general relationship. This would include monitoring commercial sown pastures in the long term as is already underway for native pastures.

3.2. The use of fire in managing Seca populations, promoting companion grasses (both native and sown), and controlling woody species (including regrowth). Issues include the role of soil seed banks to supply enough seed to regenerate; fire frequency and the fuel load required; the severity of fire/mature plant mortality relationships; financial impact of fire on stylo development, grass management, and timber control; education campaign on burning for legume control; managing pastures to enable enough fuel (grass) to be able to burn; incorporating burning into a property management plan. In some areas frost may prevent the accumulation of large, woody Seca plants (or at least reduce their rate of accumulation) but fire may still also have a role.

3.3. As described in Section 2.1.3, diet selection for grass is strong in the early wet season when the grasses are also most susceptible to defoliation (Mott 1987). What is the impact of resting pastures at this time or deferring grazing to favour grasses in legume/grass mixtures?

3.4. Legumes can fix nitrogen but what are the cycling and transfer processes in tropical pastures? How much N is fixed? What is the effect of different soil P levels? How much N is transferred to the grasses (or other species)? How much is leached? What are the differences between species? (Compare the effects of stylo and Siratro on pasture growth.) Are there long term soil changes which influence nutrient cycling?

3.5. Animal production from different proportions of legumes in pasture? Does animal production "fall away" when the proportion of grass is severely reduced?

3.6. What are the root profiles of legumes, grasses and trees?

3.7. Spread of legume seed in cattle dung is an important mechanism for species to colonise new areas. What is the rate and seasonal timing of legume seed production and how much is transferred through grazing animals? What is the impact of stocking rate?

3.8. Influence of grass species, soil type, geographic location, sowing methods, pasture management, etc. on the performance of sown grasses after legume dominance has been attained.

3.9. Sown pastures and their associated management (fertiliser, increased stocking rates, cultivation, tree clearing) can have marked effects on species diversity but the detail of these changes is not known. What are the species changes when pastures are sown? If pastures fail to persist, what happens - do communities revert to their prior composition or change to some new, altered state? Pasture sowing can involve a number of disturbances and may also alter soil biology and soil processes (nutrient, water and energy flows and cycles). What are the linkages between species diversity, soil processes and productivity? What are the short- and long-term effects? Which pasture species have colonised the greatest areas?

3.10. Nutrient budgets of pasture systems. Accelerated acidification and its concomitant impact on base saturation in legume pastures are assumed to be the result of increased product removal, nitrate leaching and organic matter accumulation. What is the relative contribution of these in tropical pastures?

3.11. What is the impact of legume pastures on the soil resource? What are the financial implications of accelerated acidification?

3.12. Conventional methods of remediation (lime application) of acid soils in southern Australia are uneconomic under present commodity prices. The same would apply to beef production systems in northern Australia. What are possible alternative methods?

3.13. Condition of the soil surface is critical for water entry and subsequent use by plants. What impact do legumes have on soil surface condition and structure?

3.14. The recently released *Stylosanthes* sp. aff. *scabra* cultivars are a possible means of overcoming problems with nitrogen supply on clay soils. Their management requirements (rhizobia, establishment methods, grazing, associate grasses, fertiliser) and impacts (animal production, nitrogen supply, persistence) need to be determined.

3.15. There is a wide range of opinion about the value of Wynn cassia (from happy with it to useless, weedy, etc) and a need to define the situations where it should be used. Is low acceptability associated with gross infertility?

3.16. Can more suitable legumes be developed? There is a wide range of material in the *S. scabra* collections; could any of this provide valuable cultivars which are less prone to dominate pastures than Seca? Are there more suitable species in current evaluation programs and recent South American collections (e.g. *Aeschynomene*)?

3.17. There are a number of issues concerning sown grasses. Sabi grass appears to be widely adapted and forms suitable mixes with legumes in many circumstances. Are other grasses needed? In mixed pastures at Lansdown live weight gains from pastures containing Sabi grass were higher than those from pastures with Indian couch grass in some years. Is this a general situation? Are other grass genera (e.g. *Digitaria, Bothriochloa, Dichanthium*) of value? Can Seca be grown in mixtures with Indian couch grass? Sabi grass appears to be colonising new areas including soils with low P levels. Is this due to mycorrhizal infections? What is the role of grasses in preventing/ameliorating soil acidification?

3.18. There is a lot of uncollated (and often unpublished) knowledge about the performance and management of sown pasture species. This needs to be synthesised and made available - computer-based formats with provision for updating with new information may be the most suitable method.

3.19. Managing pastures to control composition involves preventing pastures from crossing thresholds from which it will be impossible (or very difficult) to recover. Suitable indicators or early warning signs need to be developed so this can be prevented. This will involve knowledge of the population biology of the important species and likely influences of seasonal growth and management on plants of different ages.

3.20. Although the general patterns of diet selection are known, much remains to be learnt about the contributions of different pasture components to animal diets and their value for animal production. Techniques are now available (carbon ratios, alkanes, DNA markers, NIR) to enable this information to be collected.

3.21. Impact of legumes (particularly Seca) on tree survival - observations at Springmount show greater tree death in recent dry periods in Seca pastures than adjacent native pastures.

3.22. Pasture development philosophies. Should we consider planting legumes with sown grasses in small areas and managing them, or should we plant them into native pastures over whole properties? Should we recommend that stylos not be planted into native pastures so that the problem of grass maintenance does not arise? Is management for animal production compatible with pasture sustainability? What are the roles of perennial grasses in oversowing situations? What is the weed potential of introduced legumes such as stylo and Wynn cassia? What responsibility do we have to the environment by promoting these plants? (Leucaena is already a declared weed in some situations in Queensland). Should we be developing and promoting native grasses?

3.23. What impact will reduced soil pH have on animal production? As yet there do not appear to have been any measured impacts but it can be expected that below some critical level both pasture and animal production would greatly decline.

4. Identification of issues for future R&D

A large number of knowledge gaps were listed in the preceding section and many or all of these could be addressed by research. However, in this section we have concentrated on issues relevant to management of existing pastures and not on the development of new cultivars for the future although this may also have a role.

4.1. There is a need for long term information on the stability and productivity of oversown pastures that can best be determined from a detailed inventory of, and "snap shot" experiments (i.e. comparisons of pastures in equilibrium with different management/environmental conditions) on, existing commercial pastures. Such an approach would provide information on:
(a) extent and condition of existing pastures
(b) producers' views on management, legume dominance, etc.
(c) soil acidification

(d) impacts on biodiversity
(e) persistence of sown species
(f) impacts on soil surface condition

4.2. Soil acidity

(a) Use current data to model the risk of acidification for certain climatic conditions and soil types. This would be important in designating sites/regions where the introduction of legumes would have their least impact on the soil resource base. A relatively robust model based on inherent soil chemical properties, climate and productivity of the pasture could be developed to predict the risk of acidification and be a key component in predicting the financial implications of accelerated acidification from a resource economist's perspective.

(b) A clear understanding of nutrient inputs and outputs from these production systems. An estimate of nett proton accumulation due to product export can be made using regression equations and the determination of the ash alkalinity of material exported. Quantification of the contribution to the total proton pool by nitrate leaching and organic matter accumulation needs to be assessed over a wide range of soil types from the well drained red earths to the texture contrast soils. This could be achieved by measuring fluxes of protons entering and leaving the soil using a theoretical framework. In addition, the long-term impact of these improved pasture systems on the soil resource base is unknown. Research into nutrient budgets under improved pastures would assist in predicting the long-term impacts.

(c) Alternative methods of ameliorating acid soil infertility. Preliminary CSIRO research with a small range of tree species has shown wide differences in the ash alkalinities, and basic cation contents of leaf litter. In addition, it has been shown that the leaf litter of the tree species *Melia azedarach* (common name: white cedar), which has a high ash alkalinity, is able to neutralise substantial acidity when mixed with an acid soil. Current research is centred around evaluating the efficacy of trees and shrubs as biological nutrient "pumps" in reducing and ameliorating soil acidification, based on their ability to redistribute nutrients from depth to the soil surface through litterfall and the production of organic anions. To date this research has focused on initial characterisation of species with respect to their chemical composition. There is a paucity of information on the role of deep roots and their ability to capture and redistribute nutrients on the soil surface. No work of this nature has yet been attempted in tropical Australia.

4.3. Seasonal grazing pressure

We already know some of the dynamics of grass-legume interactions and diet selection patterns: the challenge is to devise and test some strategies to vary seasonal grazing pressure to maintain the grass-legume balance. The MRC CS197 Sub-project 5 trial at Eureka Creek will provide some of this information; a similar type of experiment should be established in central or southern Queensland to provide information from a different region.

4.4. Suitable information systems should be developed to capture knowledge of the performance and management of pasture species, and to make this widely available to users.

4.5. Spatial arrangement studies with grass and legume plants in field replacement arrangements and harvested over time (years)

4.6. What is a reasonable compromise/balance between maximum proportion of legume for animal production and what is best for grass maintenance. How does different geographic location influence this balance?

5. Recommendations

Recommendation 1. A set of management guidelines as described in 2.4 be developed and the information be extended widely.

Recommendation 2. There needs to be continued monitoring of fertility decline and soil pH changes. This should include permanent monitoring sites that could be returned to at some later date (5-10 years), sampling of sites where there is a desirable mix of grass/tree/legume in the pasture, and an assessment of the risk of acidification under various soil, climate and pasture production systems.

Recommendation 3. A more ecological approach be taken to the oversowing and subsequent management of introduced legumes stressing responsible management of natural resources through the considered use of appropriate grazing management and fire. In particular, recognise the pivotal role of perennial grasses in providing a source of forage to grazing animals, minimising nitrate leaching, and in protecting the soil surface against soil erosion.

Recommendation 4. A detailed inventory of, and "snap shot" experiments on, existing commercial pastures be conducted to gather long term information on the stability and productivity of oversown pastures.

Recommendation 5. A grazing trial should be established in central or southern Queensland to examine combinations of levels of pasture utilisation, pasture spelling, fire and sown grasses on the stability and productivity of pastures which are currently legume dominant.

Recommendation 6. Suitable information systems be developed to capture knowledge of the performance and management of pasture species, and to make this widely available to users.

6. References

Andrew, C. S. and Robins, M. F. (1969) The effect of phosphorus on the growth and chemical composition of some tropical legumes 1. Growth and critical percentages of phosphorus. *Australian Journal of Agricultural Research* **20,** 665-74.

Bowen, E.J. and Rickert, K.G. (1979) Beef production from native pastures sown to fine-stem stylo in the Burnett region of south-eastern Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry* **19,** 140-49.

Bridge B. J., Mott, J. J. and Hartigan, R. J. (1983) Dynamics of formation of degraded areas in the dry savannah woodlands of northern Australia. *Australian Journal of Soil Research* **21,** 91-104.

Burrows, W.H. (1991). Sustaining productive pastures in the tropics 11. An ecological perspective. *Tropical Grasslands* **25,** 153-58.

Campbell, S D. (1995) Plant mechanisms that influence the balance between *Heteropogon contortus* and *Aristida ramosa* in spring burnt pastures. PhD thesis, University of Queensland.

Chapman, T. J. (1963) Groundwater hydrology of the Weipa Peninsula, North Queensland. *Journal of the Institution of Engineers Australia*, July-August, pp. 181-86.

Chartres, C.J. Cumming, R.W., Beattie, J.A., Bowman, G.M. and Wood, J.T. (1990) Acidification of soils on a transect from plains to slopes, south-western New South Wales. *Australian Journal of Soils Research* **28,** 539-48.

Clements, R.J. (1996) Pastures for prosperity 3. The future for new tropical pasture species. *Tropical Grasslands* **30,** 31-46.

Coates, D.B. (1994) The effect of phosphorus as fertiliser or supplement on pasture and animal productivity in the semi-arid tropics of north Queensland. *Tropical Grasslands* **28,** 90-108.

Coates, D.B. (1996) Diet selection by cattle grazing *Stylosanthes*-grass pastures in the seasonally dry tropics: effect of year, season, stylo species and botanical composition. *Australian Journal of Experimental Agriculture* **36,** (in press).

Coates, D.B., Kerridge, P.C., Miller, C.P. and Winter, W.H. (1990) The effect of phosphorus on the composition, yield and quality of legume based pasture and their relation to animal production. *Tropical Grasslands* **24,** 209-20.

Coates, D.B., Miller, C.P., Hendricksen, R.E. and Jones, R.J. (1997) Animal production from stylo pastures. *Tropical Grasslands* (submitted).

Coventry, R. J. and Fett, D. E. R. (1982) Morphology and particle-size characteristics of the red, yellow, and grey earths and associated soils of the Torrens Creek area, central north Queensland. CSIRO Division of Soils Report.

Crack, B. J. (1972) Changes in soil nitrogen following different establishment procedures for Townsville stylo on a solodic soil in north-eastern Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry* **12,** 274-80.

Cregran, D., Sykes, J. A. and Dymock, A. J. (1979) Pasture improvement and soil acidification. *Agricultural Gazette of New South Wales*, **90,** 33-35.

Davies, J.G. and Eyles, A.G. (1965) Expansion of Australian pastoral production. *Journal of the Australian Institute of Agricultural Science,* **31,** 77-93.

Donald, C. M. and Williams, C. H. (1954) Fertility and productivity of a podzolic soil as influenced by subterranean clover (*Trifolium subterraneum* L.) and superphosphate. *Australian Journal of Agricultural Research* **5,** 664-97.

Ebersohn, J.P. and Lee, G.R. (1972) The impact of sown pastures on cattle numbers in Queensland. *Australian Veterinary Journal,* **48,** 217-223.

Flemons, K. and Siman, A. (1970) Goulburn lucerne failures linked with induced manganese toxicity. *Agricultural Gazette of New South Wales* **81,** 662-63.

Freebairn, D.M. and Wockner, G.H. (1986) A study of soil erosion on vertisols of the eastern Darling Downs, Queensland. 1. Effects of surface conditions on soil movement within contour bay catchments. *Australian Journal of Soil Research* **24,** 135-58.

Gardener, C. J. (1980a) Diet selection and liveweight performance of steers on *Stylosanthes hamata*-native grass pastures. *Australian Journal of Agricultural Research* **31,** 379-92.

Gardener, C.J. (1980b) Tolerance of perennating *Stylosanthes* plants to fire. *Australian Journal of Experimental Agriculture and Animal Husbandry* **20,** 587-593.

Gardener, C.J. (1982) Population dynamics and stability of *Stylosanthes hamata* cv. Verano in grazed pastures. *Australian Journal of Agricultural Research* **33,** 63-74.

Gardener, CJ. (1984) The dynamics of *Stylosanthes* pastures. *In* 'The Biology and Agronomy of *Stylosanthes*'. (Eds. H.M. Stace and L.A. Edye) pp. 333-57. (Academic Press: Sydney).

Gardener, C.J. and Ash, A.J. (1994) Diet selection in six *Stylosanthes*-grass pastures and its implications for pasture stability. *Tropical Grasslands* **28,** 109-19.

Gardener, C.J., McCaskill, M.R. and McIvor, J.G. (1993) Herbage and animal production from native pastures, and pastures oversown with *Stylosanthes hamata* 1. Fertiliser and stocking rate effects. *Australian Journal of Experimental Agriculture* **33,** 561-70.

Gardener, C.J., and McIvor, J.G. (1985). Pasture stability in the semi-arid tropics of north-eastern Australia. *In* 'Ecology and Management of the Worlds Savannas' (Eds. J.C. Tothill and J.J. Mott). pp. 314-17 (Australian Academy of Science: Canberra).

Gifford, G. F. (1985) Cover allocation in rangeland watershed management (A review). *In* 'Watershed Management in the Eighties'. (Eds E. B. Jones & T. J. Ward). pp. 23-31. (American Society of Civil Engineers: New York).

Gilbert, M.A. and Shaw, K.A. (1981) Residual effects of sulphur fertilizers on cut swards of a *Stylosanthes guianensis* and native grass pasture on a euchrozem soil in north Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry* **21**, 334-42.

Gilbert, M.A. and Shaw, K.A. (1987) Fertility of a red earth soil of mid-Cape York Peninsula. *Australian Journal of Experimental Agriculture* **27**, 863-68.

Gillard, P., Edye, L. A. and Hall, R. L. (1980) Comparison of *Stylosanthes humilis* with *S. hamata* and *S. subsericea* in the Queensland dry tropics: effects on pasture composition and cattle liveweight gain. *Australian Journal of Agricultural Research* **31**, 205-20.

Gillard, P. and Winter, W.H. (1984) Animal production from *Stylosanthes* based pastures in Australia. *In* 'The Biology and Agronomy of *Stylosanthes*'. (Eds H.M. Stace and L.A. Edye). pp. 405-32. (Academic Press: Sydney).

Gramshaw, D., McKeon, G.M. and Clem, R.L. (1993) Tropical pasture establishment. 1. A systems perspective of establishment illustrated by legume oversowing in the subtropics. *Tropical Grasslands* **27**, 261-75.

Hacker, J.B., Shaw, N.H. and 't Mannetje, L. (1982). More beef from spear grass country. CSIRO Division of Tropical Crops and Pastures, Report Number 2.

Haynes, R.J. (1981) Laboratory study of nutrient leaching from the surface of cultivated, grassed and herbicided orchard soil. *Soil and Tillage Research* **1**, 281-88.

Haynes, R. J. (1983) Soil acidification induced by leguminous crops. *Grass and Forage Science* **38**, 1-11.

Helyar, K. R. (1976) Nitrogen cycling and soil acidification. *Journal of Australian Institute of Agricultural Science* **42**, 217-21.

Helyar, K. R. and Porter, W. M. (1989) Soil acidification, its measurement and the processes involved. *In* 'Soil Acidity and Plant Growth'. (Ed. A. D. Robson) pp. 61-102. (Academic Press: Sydney).

Hendricksen, R.E., Punter, L.D. and Miller, C.P. (1987) Selection by cattle of Seca stylo from oversown native pasture in the dry tropics. *In* 'Herbivore Nutrition Research' (Ed. M. Rose) pp. 91-92. (Australian Society of Animal Production).

Henzell, E. F. (1968) Sources of nitrogen for Queensland pastures. *Tropical Grasslands* **2**, 1-17.

Hobbs, R.J. and Hopkins, A.J.M. (1990) From frontier to fragments: European impact on Australia's vegetation. *Proceedings of the Ecological Society of Australia* **16**, 93-114.

Holt, J. A. (1996) Biological and chemical properties of soils in semi-arid northeastern Australia: The impact of grazing pressure. *Applied Soil Ecology* (In press).

Holt, J. A. and Coventry, R. J. (1988) The effects of tree clearing and pasture establishment on the population of mound-building termites (Isoptera) in north Queensland. *Australian Journal of Ecology* **13**, 321-25.

Holt, J.A., Bristow, K.L. and McIvor, J.G. (1996a) The effects of grazing pressure on soil animals and hydraulic properties of two soils in semi-arid tropical Queensland. *Australian Journal of Soil Research* **34**, 69-79.

Holt, J. A., Grice, A. C. and Brown, J. R. (1996b). Patchiness in herbaceous vegetation: Relationships with soil microbial biomass. *In* 'The Australian Rangeland Society 9th Biennial Conference' (Ed. Hunt, L.P. and Sinclair, R.). September 24-27, 1996, Port Augusta, South Australia. pp. 143-44.

Howden, S.M. (1988) Some aspects of the ecology of four tropical grasses with special emphasis on *Bothriochloa pertusa*. PhD thesis, Griffith University.

Hu, F. (1995) Competition and allelopathic effects of the introduced grasses *Bothriochloa pertusa* and *Urochloa mosambicensis* when grown in association with *Stylosanthes hamata* cv. Verano and *Stylosanthes scabra* cv. Seca. PhD thesis, James Cook University of North Queensland (submitted).

Humphreys, L.R. (1967) Townsville lucerne: history and prospect. *Journal of the Australian Institute of Agricultural Science* **33,** 3-13.

Humphries, S.E., Groves, R.H. and Mitchell, D.S. (1991) Plant invasions: The incidence of environmental weeds in Australia. *Kowari* **2,** 1-134.

Hunter, R.A., Siebert, B.D. and Breen, M.J. (1976) The botanical and chemical composition of the diet selected by steers grazing Townsville stylo-grass pastures during a period of liveweight gain. *Proceedings of the Australian Society of Animal Production* **11,** 457-60.

Jones, R.J. (1992) The effect of grass species on animal performance. CSIRO Australia Division of Tropical Crops and Pastures Biennial Research Report 1991-1993. pp. 77-78.

Jones, R.J., McIvor, J.G., Middleton, C.H., Burrows, W.H., Orr, D.M. and Coates, D.B. (1997) Long term botanical changes and their implications in grazed stylo pastures. *Tropical Grasslands* (submitted).

Jones, R. K. (1974) A study of the phosphorus responses of a wide range of accessions from the genus *Stylosanthes*. *Australian Journal of Agricultural Research* **25,** 847-62.

Jones, R. K., Dalgleish, N. P., Dimes, J. P. and McCown, R. L. (1991) Sustaining multiple production systems 4. Ley pastures in crop-livestock systems in the semi-arid tropics. *Tropical Grasslands* **25,** 189-96.

Jones, R.M. (1993) Beef production from Cassia/Buffel grass pastures in subtropical Queensland. Final Report CSNAP.11.

Jones, R.M. and Bunch, G.A. (1988) The effect of stocking rate on the population dynamics of Siratro in Siratro (*Macroptilium atropurpureum*)-Setaria (*Setaria sphacelata*) pastures in south east Queensland 1. Survival of plants and stolons. *Australian Journal of Agricultural Research* **39**, 209-19.

Jones, R.M. and Bunch, G.A. (1995) Yield and population dynamics of *Chamaecrista rotundifolia* cv. Wynn in coastal south-eastern Queensland as affected by stocking rate and rainfall. *Tropical Grasslands* **29,** 65-73.

Jones, R.M., Jones, R.J. and McDonald, C.K. (1995) Some advantages of long-term grazing trials, with particular reference to changes in botanical composition. *Australian Journal of Experimental Agriculture* **35,** 1029-38.

Jones, R.M., Kerridge, P.C. and McLean, R.W. (1993a) Population dynamics of Siratro and shrubby stylo in south-east Queensland as affected by phosphorus, soil type, stocking rate and rainfall. *Tropical Grasslands* **27**, 65-74.

Jones, R.M., McDonald, C.K. and Bunch, G.A. (1993b) Persistence of roundleaf cassia in grazed pastures - a conceptual model. *Proceedings of the XVIIth International Grassland Congress*, pp. 1902-3.

Jones, R.M. and Mott, J.J. (1980) Population dynamics in grazed pastures. *Tropical Grasslands* **14**, 35-42.

Kohn, G. D., Osborne, G. J., Batten, G. D., Smith, A. N., and Lill, W. J. (1977) The effect of topdressed superphosphate on changes in nitrogen, carbon, sulphur, phosphorus and pH on a red earth soil during a long term grazing experiment. *Australian Journal of Agricultural Research* **28,** 147-58.

Kirkpatrick, J.B. (1994) *A Continent Transformed.* (Oxford University Press: Melbourne).

Lal, R. (1988) Effects of macrofauna on soil properties in tropical ecosystems. *Agricultural Ecosystems and Environment* **24,**101-16.

Lal, R. (1989a) Agroforestry systems and surface soil management of a tropical alfisol. *Agroforestry Systems* **8,** 1-6.

Lal, R. (1989b) Agroforestry systems and surface soil management of a tropical alfisol: I: Soil moisture and crop yields. *Agroforestry Systems* **8,** 7-29.

Lal, R. (1989c) Agroforestry systems and surface soil management of a tropical alfisol: II: Water runoff, soil erosion, and nutrient loss. *Agroforestry Systems* **8,** 97-111.

Lal, R. (1989d) Agroforestry systems and surface soil management of a tropical alfisol: III: Changes in soil chemical properties. *Agroforestry Systems* **8,** 113-32.

Lal, R. (1989e) Potential of agroforestry as a sustainable alternative to shifting cultivation: concluding remarks. *Agroforestry Systems* **8,** 239-42.

Lee, B. (1980) Farming brings acid soils. *Rural Research* **106,** 4-9.

Leigh, J., Boden, R. and Briggs, J. (1984) *Extinct and Endangered Plants of Australia.* (MacMillan: Sydney).

Liang, J.B., Murray, R.M. and Winter, W.H. (1985) The nature and causes of weight changes of cattle during the dry and early wet seasons in the seasonally-dry tropics of Australia. *Proceedings of the 3rd Asian-Australian Association of Animal Production Societies Animal Science Congress (Seoul).* pp. 1225-27.

McCown, R. L., Murtha, G. G. and Smith, G. D. (1976) Assessment of available water storage capacity of soils with restricted subsoil permeability. *Water Resources Research* **12,** 1255-60.

McCown, R.,L. and Wall, B.H. (1981) The influence of weather on quality of tropical legume pasture during the dry season in northern Australia II. Moulding of standing hay in relation to rain and dew. *Australian Journal of Agricultural Research* **32,** 589-98.

McIvor, J. G. (1983) The effect of seedbed preparation and sowing time on the establishment of perennial *Stylosanthes* species. *Tropical Grasslands 17, 82-85.*

McIvor, J. G. (1984) Effects of phosphorus and superphosphate on the growth of *Urochloa* species. *Australian Journal of Experimental Agriculture and Animal Husbandry* **24,** 571-78.

McIvor, J.G. (1987) Changes in germinable seed levels in soil beneath pastures near Townsville, north Queensland. *Australian Journal of Experimental Agriculture* **27**, 283-89.

McIvor, J.G. (1997) Pasture management in semi-arid tropical woodlands: effects on species diversity. *Australian Journal of Ecology* (submitted).

McIvor, J.G., Ash, A.J., Mott, J.J. and Andrew, M.H. (1994) Ecology of grazed tropical tallgrass rangelands in northern Australia. Biennial Conference, Australian Rangeland Conference, Katherine, pp. 115-124.

McIvor, J.G. and Gardener, C.J. (1991). Soil seed densities and emergence patterns in the seasonally dry tropics of north-eastern Australia. *Australian Journal of Ecology* **16,** 159-69.

McIvor, J.G. and Gardener, C.J. (1994) Germinable soil seed banks in native pastures in north-eastern Australia. *Australian Journal of Experimental Agriculture* **34,** 1113-19.

McIvor, J.G. and Gardener, C.J. (1995) Pasture management in semi-arid tropical woodlands: effects on herbage yields and botanical composition. *Australian Journal of Experimental Agriculture* **35,** 705-15.

McIvor, J.G., Jones, R.M. and Taylor, J.A. (1993) Tropical pasture establishment 4. Population dynamics of sown species in developing pastures. *Tropical Grasslands* **27,** 302-13.

McIvor, J.G. and Orr, D.M. (1991) Sustaining productive pastures in the tropics 3. *Tropical Grasslands* **25,** 91-97.

McIvor, J.G., Singh, V., Corfield, J.P. and Jones, R.J. (1996) Seed production by native and naturalised grasses in north-east Queensland: effects of stocking rate and season. *Tropical Grasslands* **30**, 262-69.

McIvor, J. G., Williams, J. and Gardener, C. J. (1995) Pasture management influences runoff and soil movement in the semi-arid tropics. *Australian Journal of Experimental Agriculture* **35,** 55-65.

McIvor, J.G., Probert, M.E., Gardener, C.J. and Smith, F.W.N. (1988) Nutrient requirements of *Stylosanthes hamata* cv. Verano on a euchrozem near Charters Towers, north Queensland. *Tropical Grasslands* **22,** 132-38.

McLean, R. W., Winter, W. H., Mott, J. J. and Little, D. A. (1981) The influence of superphosphate on the legume content of the diet selected by cattle grazing on *Stylosanthes*-native grass pastures. *Journal Agricultural Science* **96,** 247-49.

Miller, C.P. and Jones, R.K. (1977) Nutrient requirements of *Stylosanthes guianensis* pastures on a euchrozem in north Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry* **17,** 607-13.

Miller, C.P. and Stockwell, T.G.H. (1991) Sustaining productive pastures in the tropics 4. Augmenting native pasture with legumes. *Tropical Grasslands* **25,** 98-103.

Miller, C.P. and Webb, C.D. (1989) Recovery of Seca and Verano stylo from fire. *Proceedings of the Fourth Queensland Fire Research Workshop*, pp. 85-88

Mott, G. O. (1974) Nutrient cycling in pastures. *In* 'Forage Fertilisation'. (Ed. Mays D. A.) pp. 323-39. (American Society of Agronomy: Madison).

Mott, J.J. (1978) Dormancy and germination in five native grass species from savanna woodland communities of the Northern Territory. *Australian Journal of Botany* **26,** 621-31.

Mott, J.J. (1982) Fire and survival of *Stylosanthes* spp. in dry savanna woodlands of the Northern Territory. *Australian Journal of Agricultural Research* **33,** 203-11.

Mott, J.J., Winter, W.H. and McLean, R.W. (1989). Management options for increasing the productivity of tropical savanna pastures IV. Population biology of introduced *Stylosanthes* spp. *Australian Journal of Agricultural Research* **40,** 1227-40.

Mott, J.J. (1987) Patch grazing and degradation in native pastures of the tropical savannas in northern Australia. *In* 'Grazing-lands research at the plant-animal interface' (Eds F.P. Horn, J. Hodgson, J.J. Mott and R.W. Brougham) pp. 153-61. (Winrock International: Morrilton).

Mott, J.J. and Andrew, M.H. (1985) The effect of fire on the population dynamics of native grasses in tropical savannas of north-west Australia. *Proceedings of the Ecological Society of Australia* **15,** 231-39.

Mott, J.J., Bridge, B. J. and Arndt, W. (1979) Soil seals in tropical tall grass pastures in northern Australia. *Australian Journal of Soil Research* **17,** 483-94.

Mott, J.J., McKeon, G.M., Gardener, C.J. and 't Mannetje, L. (1981) Geographic variation in the reduction of hard seed content of *Stylosanthes* seeds in the tropics and subtropics of northern Australia. *Australian Journal of Agricultural Research* **32,** 861-69.

Mott, J.J., Williams, J., Andrew, M.H. and Gillison, A.N. (1985) Australian savanna ecosystems. *In* 'Ecology and Management of the World's Savannas.' (Eds J.C. Tothill and J.J. Mott) pp. 56-82. (Australian Academy of Science: Canberra).

MRC Project DAQ.080 (1996) Effects of stocking rate, legume augmentation, supplements and fire on the animal production and stability of native pastures. Technical Report, MRC.

Munns, D. N. (1977) Mineral nutrition and legume symbiosis. *In* 'A Treatise on Dinitrogen Fixation, Section IV: Agronomy and Ecology'. (Eds. R. W. F. Hardy & A. H. Gibson). pp. 353-91. (John Wiley: New York).

Noble, A. D. (1996) Soil acidification research in the semi-arid tropics. MRC Project CS.277.

Noble, A. D. and Jones, R. J. (1996) Long-term impact of Leucaena-based grazing system on soil acidity. Submitted to 18th International Grassland Congress, Canada 1997.

Norman, M. J. T. (1960) Performance of buffel grass and buffel grass-Townsville lucerne mixtures at Katherine, N. T. CSIRO Australia Division of Land Research and Regional Survey Technical Paper No. 11.

Norman, M.J.T. and Arndt, W. (1959) Performance of beef cattle on native and sown pastures at Katherine, N.T. CSIRO Australia Division of Land Research and Regional Survey Technical Paper No. 4.

Norman, M.J.T. and Phillips, L.J. (1970) Wet season grazing of Townsville stylo pasture at Katherine, N.T. *Australian Journal of Experimental Agriculture and Animal Husbandry* **10,** 710-15.

Oades, J. M. and Ladd, J.N. (1977) Biochemical properties: carbon and nitrogen metabolism. *In* 'Soil Factors Affecting Crop Production in a Semi-arid Environment'. (Eds. J.S. Russell and E.L. Greacen). (University of Queensland Press: Brisbane).

Ong, C. (1994) Alley cropping - ecological pie in the sky. *Agroforestry Today* 6:No. **3**:8-10.

Oram, R.N. (1990) Register of Australian Herbage Plant Cultivars. 3rd edition. (CSIRO: Melbourne).

Orr, D.M., McKeon, G.M. and Day, K.A. (1991) Burning and exclosure can rehabilitate degraded black speargrass (*Heteropogon contortus*) pastures. *Tropical Grasslands* **25**, 333-36.

Orr, D.M. and Paton, C.J. (1993) Impact of grazing pressure on the plant population dynamics of *Heteropogon contortus* (black speargrass) in subtropical Queensland. *Proceedings XVIIth International Grassland Congress* pp. 1908-11.

Orr, D.M., Paton, C.J., Rutherford, M.T. and Taylor, J.A. (1995) Does lack of rainfall or lack of seed limit the recruitment of *Heteropogon contortus*. *Proceedings Vth International Rangeland Congress* pp. 416-17.

Orr, D.M., Paton C.J. and Lisle, A.T. (1997). Using fire to manage species composition in *Heteropogon contortus* (black speargrass) pastures 1. Burning regimes. *Australian Journal of Agricultural Research* (submitted).

Orr, D.M. and Paton C.J. (1997). Using fire to manage species composition in *Heteropogon contortus* (black speargrass) pastures 2. Enhancing the effects of fire with grazing management. *Australian Journal of Agricultural Research* (submitted).

Osborn, B. (1952) Effectiveness of surface cover in preventing soil and water losses. *Proceedings of the 6th International Grassland Congress*. pp. 1079-84.

Osborne, G. J., Wright, W. A. and Sykes, J. (1978) Increasing soil acidity threatens farming system. *Agricultural Gazette of New South Wales* **89,** 21.

Partridge, I.J. and Wright, J.W. (1992) The value of round leaf cassia (*Cassia rotundifolia* cv. Wynn) in a native pasture grazed with steers in south-east Queensland. *Tropical Grasslands* **26,** 263-69

Partridge, I J., Middleton, C.H. and Shaw, K.A. (1996). Stylos for better beef. Information Series Q196010, Queensland Department of Primary Industries, Brisbane.

Probert, M.E. and Jones, R.K. (1982) Studies on some neutral red duplex soils (Dr2.12) in north-eastern Queensland 4. Field studies of nutrient responses with Caribbean stylo. *Australian Journal of Experimental Agriculture and Animal Husbandry* **22,** 382-90.

Probert, M. E. and Williams, J. (1985) The residual effectiveness of phosphorus for *Stylosanthes* pastures on red and yellow earths in the semi-arid tropics. *Australian Journal of Soil Research* **23,** 211-22.

Probert, M. E. and Williams, J. (1986) The nitrogen status of red and yellow earths in the semi-arid tropics as influenced by Caribbean stylo (*Stylosanthes hamata*) grown at various rates of applied phosphorus. *Australian Journal of Soil Research* **24,** 405-21.

Quirk, M.F., Wilson, R.J. and Blight, G.W. (1992) Wynn cassia (*Cassia rotundifolia* cv. Wynn) improves the feed intake and liveweight gain of cattle fed poor quality native pasture. *Australian Journal of Experimental Agriculture* **32,** 1005-09.

Ridley, A.M., Helyar, K.R. and Slattery, W.J. (1990a) Soil acidification under subterranean clover (*Trifolium subterranean* L.) pastures in north-eastern Victoria. *Australian Journal of Experimental Agriculture* **30,** 195-201.

Ridley A.M., Slattery, W.J., Helyar, K.R. and Cowling, A. (1990b) The importance of the carbon cycle to acidification of a grazed annual pasture. *Australian Journal of Experimental Agriculture* **30,** 529-37.

Rixon, A.J. (1966) Soil fertility changes in a red-brown earth under irrigated pastures I. Changes in organic carbon, carbon/nitrogen ratio, cation exchange capacity, and pH. *Australian Journal of Agricultural Research* **17,** 303-16.

Russell, J.S. (1960) Soil fertility changes in the long term experimental plots at Kybybolite, South Australia I. Changes in soil pH, total nitrogen, organic carbon and bulk density. *Australian Journal of Agricultural Research* **11,** 902-26.

Sallaway, M.M. and Waters, D.K. (1994) Spatial variation in runoff generation in granitic grazing lands. *In* 'Water Down Under '94'. pp. 485-90. Adelaide, Australia, November 1994.

Sallaway, M.M., Waters, D., Bridge, B. and Wandera, F.P. (1993) Variations in hydrological characteristics of the soils associated with grazed patches in granitic landscapes in northern Australia. Proceedings of the XVII International Grasslands Congress 1993: Rockhampton, Australia. pp. 1900-02.

Sallaway, M.M. and Waters, D.K. (1996) Spatial variation in land degradation due to changes in grazing pressure during drought. *In* 'The Australian Rangeland Society 9th Biennial Conference' (Ed. Hunt, L.P & Sinclair, R.). September 24-27, 1996, Port Augusta, South Australia. pp. 108-09.

Scanlan, J.C., Pressland, A.J. and Myles, D.J. (1996) Run-off and soil movement on mid-slopes in north-east Queensland grazed woodlands. *Rangeland Journal* **18**, 33-46.

Shaw, N.H. (1957) Bunch speargrass dominance in burnt pastures in south-eastern Queensland. *Australian Journal of Agricultural Research* **8**, 326-34.

Shaw, N.H. (1961) Increased beef production from Townsville lucerne (*Stylosanthes sundaica* Taub.) in the spear grass pastures of central coastal Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry* **1**, 73-80.

Shaw, N.H. (1978) Superphosphate and stocking rate effects on a native pasture oversown with *Stylosanthes humilis* in central coastal Queensland 1. Pasture production. *Australian Journal of Experimental Agriculture and Animal Husbandry* **18**, 788-99.

Shaw, N.H. and Dale, M.B. (1978) Superphosphate and stocking rate effects on a native pasture oversown with *Stylosanthes humilis* in central coastal Queensland 3. The balance of native species in the pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry* **18,** 808-16.

Simpson, J.R. (1962) Mineral nitrogen fluctuations in soils under improved pasture in southern New South Wales. *Australian Journal of Agricultural Research*, **13,** 1059-72.

Stonard, P. and Bisset, W.J. (1970) Fine stem stylo: a perennial legume for the improvement of subtropical pasture in Queensland. *Proceeding 10th International Grassland Congress* pp. 153-58.

Taylor, J.A. and Cook, S.J. (1993) Management and use of complex landscapes: some implications of spatial variation for pasture and animal production. *Proceedings of the 17th International Grassland Congress* pp. 1932-34.

Teitzel, J. K. and Middleton, C. H. (1979) New pastures for the wet tropical coast. *Queensland Agricultural Journal* **105,** 98-103.

Torssell, B. W. R. (1976) Drought resistance effects on species composition of an annual pasture in a dry monsoonal climate. *Journal of Applied Ecology* **13,** 943-53.

Torssell, B.W.R. and McKeon, G.M. (1976) Germination effects on pasture composition in a dry monsoonal climate. *Journal of Applied Ecology* **13,** 593-603.

Tothill, J.C. (1974) Catchment grazing experiment. CSIRO Australia Division of Tropical Agronomy Annual Report pp. 27-30.

Tothill, J.C. and Mott, J.J. (1985) Australian savannas and their stability under grazing. *Proceedings of the Ecological Society of Australia* **13,** 317-322.

Vallis, I. (1972) Soil nitrogen changes under continuously grazed legume-grass pastures in subtropical coastal Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry* **12**, 495-501.

Vallis, I. (1985) Nitrogen cycling in legume-based forage production systems in Australia. *In* 'Forage Legumes for Energy-Efficient Animal Production'. (Eds R.F. Barnes, P.R. Ball, R.W. Brougham, G.C. Marten and D.J. Minson). pp. 160-70. (USDA Agric. Res. Serv.: Washington, DC).

Viets, F.G., Humbert, R.P. and Nelson, C.E. (1967) Fertilizers in relation to irrigation. *In* 'Irrigation of Agricultural Lands'. Agronomy Monograph No. 9. pp. 1009-36. (American Society of Agronomy: Madison, Wisconsin).

Walker, B. and Weston, E.J. (1990) Pasture development in Queensland - A success story. *Tropical Grasslands,* **24,** 257-268.

Weston, E.J., Harbison, J., Leslie, J.K., Rosenthal, K.M. and Mayer, R.J. (1981) Assessment of the agricultural and pastoral potential of Queensland. Technical Report No. 27, Agricultural Branch, Queensland Department of Primary Industries, Brisbane.

Wetselaar, R. (1980) Nitrogen cycling in a semi-arid region of tropical Australia. *In* 'Nitrogen Cycling in West African Ecosystems.' (Ed. T. Rosswell). pp. 157-69. (SCOPE/UNEP: Stockholm).

Wetselaar, R. and Norman, M.J.T. (1960) Soil and crop nitrogen at Katherine, N.T. CSIRO Aust. Div. Land Res. Reg. Surv. Tech. Paper No. 10.

Williams, C.H. (1980) Soil acidification under clover pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry* **20**, 561-67.

Williams, C.H. and David, D.J. (1976) Effects of pasture improvement with subterranean clover and superphosphate on the availability of trace metals to plants. *Australian Journal of Soil Research* **14,** 85-93.

Williams, C.H. and Donald, C.M. (1957) Changes in organic matter and pH in a podzolic soil as influenced by subterranean clover and superphosphate. *Australian Journal of Agricultural Research* **8,** 179-89.

Williams, J. and Chartres, C.J. (1991) Sustaining productive pastures in the tropics. 1. Managing the soil resource. *Tropical Grasslands* **25,** 73-84.

Williams, J. and Coventry, R.J. (1979) The contrasting soil hydrology of red and yellow earths in a landscape of low relief. *In* 'The Hydrology of Areas of Low Precipitation'. pp. 355-95. AHS-AISH Publication No. 128.

Williams J. and Coventry, R.J. (1981) The potential for ground water recharge through red, yellow and grey earth profiles in central north Queensland. *Australian Water Resources Council, Conference Series* No. 3. pp 169-86. (Australian Government Printing Service: Canberra).

Williams, J. and Probert, M.E. (1984) Characterization of the soil-climate constraint for predicting pasture production in the semi-arid tropics. Proceedings of the International Workshop on Soils, Townsville, Queensland. pp. 61-75.

Williams, J., Wall, B.H. and McCown, R.L. (1980) Estimation of deep drainage and plant water extraction from soil water measurements. *In* 'National Conference Publication 80/9'. pp 96-100. November 1980. (Institution of Engineers: Adelaide).

Winks, L. (1973) Townsville stylo research at Swan's Lagoon. *Tropical Grasslands* **7,** 201-08.

Winter, W.H. (1988) Supplementation of steers grazing *Stylosanthes hamata* pastures at Katherine, Northern Territory. *Australian Journal of Experimental Agriculture* **28,** 669-82.

Winter, W.H. and Gillman, G.P. (1976) Plant nutrition studies on some red and yellow earth soils in northern Cape York Peninsula 2. Phosphorus plant response and soil retention. *Australian Journal of Experimental Agriculture and Animal Husbandry* **16,** 542-48.

Winter, W.H., Mott, J.J., McLean, R.W. and Ratcliff, D. (1989a) Evaluation of management options for increasing the productivity of tropical savanna pastures 1. Fertiliser. *Australian Journal of Experimental Agriculture* **29**, 613-22.

Winter, W.H., Mott, J.J. and McLean, R.W. (1989b) Evaluation of management options for increasing the productivity of tropical savanna pastures 2. Legume species. *Australian Journal of Experimental Agriculture* **29**, 623-30.

Winter, W.H., Mott, J.J. and McLean, R.W. (1989c) Evaluation of management options for increasing the productivity of tropical savanna pastures 3. Trees. *Australian Journal of Experimental Agriculture* **29**, 631-34.

7. Appendices

Appendix 1. Survey of Wynn cassis producers.

Comments on Wynn Cassia; summary responses to a survey of producers from 12 properties attending the Miram Vale Rural Sciences and Landcare field day in May 1996. Five questions were answered yes/no with the option for comment.

Question	Response		
1. Area planted to Wynn?	6 > 40 ha	5 10-40 ha	1 none
	YES	NO	UNCERTAIN
2. Has fertiliser been applied?	9	2	
3. A useful legume?	8	2	1
4. Will you plant more?	4	7	
5. Would you like a higher yielding type?	5	4	2

Comments from "No" voters to Q4: too aggressive, unpalatable, invasive, pest risk, now spreading naturally, better alternatives available.

Appendix 2. Pasture scientists consulted during the preparation of the report.

P. Anning	H.G. Bishop	A.J. Boorman	W.H. Burrows
D.F. Cameron	R.L. Clem	D.B. Coates	D.G. Cooksley
P. Filet	M.A. Gilbert	T.W.G. Graham	T.J. Hall
R.E. Hendricksen	J.M. Hopkinson	R.J. Jones	R.M. Jones
J.C. Kernot	C.K. McDonald	S. McIntyre	C.H. Middleton
C.P. Miller	K.J. Murphy	C. Olive	D.B. O'Sullivan
P.J. O'Reagain	I.J. Partridge	C.J. Paton	M.F. Quirk
K.A. Shaw	R.G. Silcock	I. Staples	J. Turner
R.W. Walker			

Appendix 3. Producer consultation meeting to discuss "Review of the stability and productivity of native pastures oversown with tropical legumes" held at CSIRO Davies Laboratory, June 5, 1998

A producer consultation meeting was held at the CSIRO Davies Laboratory on November 7 1996. A group of producers with experience with oversown pastures and from a wide geographic region (see below) were invited to the meeting. The investigators presented the important points from their report, followed by general discussion of the issues raised and other experiences and points of view. A summary of the main points from the meeting are given below.

The producers were:

Graham Acton	Marlborough
Rodney Barrett	Bowen
John Bethel	Georgetown
Don Heatley	Home Hill
Claire Olive	Marlborough
John Rains	Mareeba
Kev Shaw	QDPI, Mareeba

The following issues were raised during the discussion.

1. It is important that the report and any material prepared from it should be balanced and contain the positive aspects of the use of tropical legumes as well as any problems (present or potential) that may be experienced.

2. There is a growing awareness among producers of land and pasture issues and they are looking for information. There is a need to be proactive - we need to document what is happening, what are the likely impacts, and future proposed activities to address these issues.

3. Suggested future sowings of 100,000 to 150,000 ha per annum of stylos were considered overoptimistic and a value of 30,000 to 40,000 ha was more likely. Sowings have been limited by low cattle prices and poor seasonal conditions and producers will need time to recover from this situation before widespread sowings are likely. The concept of sown pastures is now well established but producers are concerned about the large up-front costs and the time to obtain a return from investment in pastures; these considerations are likely to prevent large scale sowings and future sowings are likely to be directed to establishing strategic areas and allowing spread to other areas via cattle.

4. Producers did not consider legume dominance a problem for animal production and felt the benefits out weighed any problems but they were very concerned about possible environmental impacts. Producers had not noticed any general decline in the productivity of stylo pastures - indeed most pasture were still improving.

5. The importance of management packages was stressed; individual aspects need to be brought together. There is a need to put available information together in a readable form - this could be done by setting out general principles followed by case studies of successful producers which documented what had been done and provided a scientific explanation of the results.

6. On property monitoring with scientific interpretations of observed changes was considered desirable.
7. A number of the management strategies which can be used to reduce stylo dominance and promote the grass component will also reduce the rate of acidification - a lower level of utilisation by animals will reduce the offtake of nutrients in animal products; fire will remove some nitrogen from the system; the higher phosphorus soils also generally have higher buffering capacities; and if the strategies are successful there will be a smaller legume component reducing the amount of nitrogen fixed.
8. Whilst soil pH may decline gradually, impacts on production may be nil or small until a threshold is reached when they decline rapidly.
9. A possible experimental approach to rapidly determine the impact of low soil pH would be to artificially lower the pH and to measure the effects.
10. The role of trees in any issues about stability, productivity or resource maintenance
11. need to be clearly established. e.g. How important is the role of trees as "nutrient pumps"?
12. Is there a role for intensive pasture development rather than (or as well as?) development of extensive pastures by oversowing?
13. The general level of knowledge of fire is poor, including the perception that fire will kill out a Seca pasture. It was suggested burning every four years would be a possible strategy as plants more than four years old had low leaf and seed productivity and were less acceptable to stock.
14. Although the direct costs of burning were low, if pastures needed to be spelled for a year to accumulate sufficient fuel and production was significantly reduced in the year following the fire, there was a substantial income reduction.
15. The recommendations as outlined in the report were supported in principle.
16. The composition and format of the producer consultation meeting was considered by all participants to be an effective reviewing process and was a model which the NAP should adopt more frequently.