final report

Project Code: NAP3.218

Prepared by: A.D. Noble and P. Nelson
CSIRO Land & Water

Date published: November 2001
ISBN: 1 74036 716 2

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

Sustainability of Stylosanthes based pasture systems in Northern Australia - Managing Soil Acidity

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

This publication is published by Meat & Livestock Australia Limited ABN 39 081 678 364 (MLA). Care is taken to ensure the accuracy of the information contained in this publication. However MLA cannot accept responsibility for the accuracy or completeness of the information or opinions contained in the publication. You should make your own enquiries before making decisions concerning your interests. Reproduction in whole or in part of this publication is prohibited without prior written consent of MLA.

TABLE OF CONTENTS

ABSTRACT

Accelerated soil acidification due to agricultural practices is recognised as a national soil degradation issue and brings into question the long-term sustainability of current production systems. Evidence of accelerated acidification under *Stylosanthes* dominant pasture systems was the catalyst behind this project. The main outcomes from this project include; recommendations on the management of *Stylosanthes*-based pasture systems that reduce the risk of *Stylosanthes* dominance; the development of a soil acidity risk map for the Dalrymple Shire and a simple field based tool kit to assess the predisposition of soils to acidification that will assist in the decision making process with respect to the establishment of improved legume pastures; quantification of the potential role of a diverse range of species in mediating acid input to these ecosystem based on their ash alkalinity; a clear understanding of the processes that contribute to the pattern of soil acidification under *Stylosanthes*-based pasture systems, these being nitrate leaching and excess cation uptake from deep in the profile; and finally several scientific publications that have either been or are in the process of being published in peer reviewed journals will contributed to our knowledge of acidity in semi-arid tropical environments.

EXECUTIVE SUMMARY

The inclusion of the *Stylosanthes* (stylos) has proved to be a low cost method of improving the quality of native pasture and legume-based cropping systems in Asia, Africa, South America, and northern Australia. This is due to the adaptability of the species to inherently infertile soils and climatic conditions ranging from the wet to the semi-arid tropics. Moreover, they have the potential to be more widely grown in the subtropics and tropics than those of any other genus currently being evaluated. Under the moderate to low rainfall regimes of northern Australia cultivars of *S. hamata* and *S. scabra* have been successfully established in agropastoral and seed production systems

Whilst use of leguminous plants to increase the fertility of farming systems is a fundamental practice in agricultural production systems throughout the world, the long-term negative impact of these production systems with respect to accelerated soil acidification is well recognised. Soil acidification is a naturally occurring phenomenon and is a result of long-term weathering and the leaching of exchangeable cations out of the soil horizon or profile. However, accelerated soil acidification in agricultural production systems is a consequence of increased product removal, the use of nitrogenous fertilisers and changes in the carbon and nitrogen cycles associated with legume introduction. Net acidification rates varied from 0.2 to 10.6 kmol H^+ ha^{-1} yr^{-1} for the range of sites sampled. The highest rate of acidification was observed under an irrigated *Stylosanthes* seed production system. Since differences between each of the paired sites were measured, the total acidification rate is likely to have been underestimated. The contribution from the export of meat products was estimated to be between 0.022 and 0.035 kmol H^+ ha^{-1} yr^{-1} on those sites with suitable records. Acidification occurred to a depth on all sites that exhibited accelerated acidification, making conventional remediation methods impractical in these extensive grazing systems.

The broad objectives of this project were as follows:

1. Establish permanent monitoring sites throughout northern Australia to assess long-term soil fertility and moisture trends under *Stylosanthes* and native pasture systems. Insight into the impact of these grazing systems on the soil resource base will assist in the development of sustainable beef production strategies.

2. Develop a soil acidity risk assessment map for the Dalrymple Shire at level that will assist resource managers in identifying areas most vulnerable to accelerated acidification. In addition, a simple field based tool-kit will be developed to assess soils for their sensitivity to accelerated soil acidification.

3. Evaluate the impact of different *Stylosanthes* management strategies implemented at Springmount, Mareeba, on the rate of acidification. This will facilitate the development of management strategies to minimise *Stylosanthes* dominance in improved pastures.

4. Conduct greenhouse and laboratory studies to ascertain the tolerance of grass and *Stylosanthes* species to acid soil infertility and assess the impact of ash produced after burning as an acid soil ameliorant.

5. Quantify the mineral nitrogen dynamics under a *Stylosanthes* dominant pasture in order to assess the contribution of nitrate leaching to acidification. Using published data attempt to establish a total nitrogen budget for pastures with and without *Stylosanthes*.

A further 9 permanent monitoring sites were added to a previous set of sites established under project NAP3.216. These sites covered an area stretching from northwest Queensland to the Northern Territory. The long-term objective of establishing these monitoring sites and undertaking initial chemical characterisation is that in 15-20 years these sites would be returned to and re-sampled in order to quantify soil chemical changes. Of the 9 sites sampled in this study, 7 were paired sites that contained a grass dominant system (unimproved) in close proximity to a Stylosanthes/grass pasture (improved pasture) where a comparison of the effects of *Stylosanthes* on soil chemical properties

could be undertaken. Five of these sites showed clear evidence of accelerated soil acidification under a *Stylosanthes* based pasture system thereby supporting earlier findings from both northern Australia and Thailand. The greatest degree of acidification under *Stylosanthes* was observed on a light-textured sand from the Northern Territory. It is important to note that accelerated acidification is a function of intrinsic soil chemical characteristics. On heavy textured soils with high organic matter, the ability of soils to resist shifts in pH is considerably higher than light textured, low organic matter soils. Whilst soil acidification is a factor in all production systems where there is product removal, the introduction of *Stylosanthes* has accelerated these processes through the introduction of fixed nitrogen. In the most extreme cases intensively managed systems (producing stylo hay and seed), considerable quantities of Ca, Mg and K are lost from the exchange complex of soils in plant material removed from the field. For example, a dry matter yield of 3t/ha/yr would result in a net loss of 46, 7 and 42 kg/ha/yr, respectively, of Ca, Mg and K.

Soil moisture monitoring undertaken at 4 sites in northwest Queensland have indicated that soil moisture decline was more rapid and to lower soil moisture contents under *Stylosanthes* dominant pastures than under improved grass pasture systems. However, a comparison between a *Stylosanthes* dominant pasture and native unimproved pastures indicated that there was greater consumption of soil moisture at 50 cm under the latter production system. Hence water use was greatest under unimproved native pasture followed by a *Stylosanthes* dominant pasture followed by an improved (cleared) pasture. These results would suggest that the inclusion of *Stylosanthes* into an improved grass pasture based system may counter increased deep drainage associated with the clearing of native vegetation and the promotion of a grass dominant pasture. In addition, observations made at the Thalanga monitoring site clearly indicated significant tree mortality under a Stylosanthes dominant pasture. These soils have a restricted rooting depth and there under drought conditions the legume pasture was able to out compete the tree component for limited soil moisture.

In an effort to assist producers and extension officers in identifying soils that are predisposed to accelerated acidification, an acidity risk map of the Dalrymple Shire in Queensland Australia was developed using information from a recently completed land resource survey. Validation of a previously derived pedotransfer function that predicts pH buffering capacity was undertaken using an independent set of soil samples collected from the Shire. Excellent agreement between measured and predicted pH buffering capacity was obtained. The pedotransfer function was used to estimate the pH buffering capacity of 44 soil associations in the Shire. These values were used to predict the number of years that it would take for soils to acidify from their current pH to 5.0 assuming a constant net acid addition rate of 2.1 kmol H^+/ha.yr. Approximately 62% of the total area of the Shire is predisposed to accelerated acidification and would take between 10-20 years to acidify to pH 5.0. In contrast, a relatively minor proportion of the total area of the Shire (17%) had significant internal buffering capacity. However, the degree of uncertainty associated with these estimations on certain soil associations may be too high to be of relevance.

For the majority of regions throughout northern Australia soil resource information is not at an appropriate scale for determining acidification risk. In addition, it may be argued that the acidity risk mapping is at a scale too coarse to be of value to the producer who manages a property at the paddock scale. To overcome this limitation a simple test based on the development of a two point buffer curve was developed to assist in assessing acidification risk. All that is required is a pH meter and two reagents (namely HCl and $CaCl_2$). A simple spreadsheet program has been developed that allows the operator to enter the two pH measurements, alter the bulk density of the soil and net acid addition rate, which is dependent on the degree of stylo dominance. The output consists of an estimated pH buffer capacity for the soil and the time it would take for the soil pH to decline to a predetermined critical pH value.

The acidity risk map clearly indicates areas within the Dalrymple Shire that are most sensitive to accelerated soil acidification and therefore could be used in broad decision-making by land managers. For example, by differentiating soils that are predisposed to accelerated acidification, a manager may strategically establish *Stylosanthes* in areas where the soils have the capacity to buffer acid inputs. In contrast, in areas of soils with low buffering capacity, managers, aware of the risk of accelerated acidification, can implement management strategies that minimise the risk of *Stylosanthes* dominance. These may include:

- Avoidance of excessive grazing pressure, particularly in summer, on native pasture that has been oversown with *Stylosanthes*. Selective and heavy grazing of palatable grasses like black speargrass (*Heteropogon contortus*) will weaken them and reduce their seed production. Over time this can lead to *Stylosanthes* dominance and the ingress of less palatable grasses. Rotational summer spelling is recommended for *Stylosanthes*-based pasture.

- Use of periodic early summer burning of native pasture with dense *Stylosanthes* so as to reduce *Stylosanthes* populations and promote grass.

- Including a 'grazing resilient' grass at the time of *Stylosanthes* planting. Grasses such as *Urochloa mosambicensis* and *Bothriochloa pertusa* compete strongly with *Stylosanthes* and can tolerate a heavy grazing pressure when needed.

- Use of phosphorus fertiliser (or a high fertility soil) to promote greater grass competition and use of nitrate before leaching, a significant contributor to acidification.

- Intensive management of *Stylosanthes* as a fodder crop on small areas may assist in reducing the risk of widespread acidification on individual properties. This would result in maximum productivity being achieved and allow for prophylactic applications of lime to be applied. Such systems are being used in southern China.

The ash alkalinity of a number of native grasses, trees, forbs and legume species was determined during the course of this study. This was undertaken to assess the potential acidification/alkalisation effects of these species. A high ash alkalinity is indicative of a species that has a net efflux of protons from the root and hence an acidifying impact on the rhizosphere. The potential consequence of this intrinsic characteristics of plant material is that on soils that are poorly buffered, the redistribution of alkalinity to surface horizons would be at the expense of significant acidification of the sub-surface horizons. However, on soils that are alkaline in deeper horizons (i.e. many duplex soils) the deposition of plant material on the soil surface would be highly beneficial. In both these cases it is assumed that plants take up nutrients from all the soil layers explored by roots. Consequently, plant material is simply a medium for redistribution of alkalinity that will have a significant role in the buffering of pH shifts as well as recycling nutrients. The results from this study clearly show that there are diverse ranges in ash alkalinities (*Sehima nervosum* 11.4 $CaCO_3$/kg dry matter to *Brunoniella acualis* 173 g $CaCO_3$/kg dry matter) between species that occur in pasture production systems. In the extensive grazing systems of northern Australia the introduction or retention of specific tree/forb species may modify the impact of soil acidification generated through product export and leaching of nitrate as a consequence of the increased N status following the establishment of legumes. It is important to realise that the potential increases in soil pH and associated changes in basic cation concentration on the exchange complex arising from litter additions, does not independently result in the synthesis of alkalinity. The litter is simply a medium for redistribution of alkalinity. The influence of contrasting litter materials was assessed in simple leaching column studies. All of the litters increased soil pH to depth regardless of their pre-treatments. Associated with increases in soil pH were increases in surface charge and the retention of cations. These results confirm the importance in litter materials in mediating acidity processes in the soil. Further research into the role of these species and their litter materials in mediating soil chemical changes should be encouraged.

Studies undertaken at two sites in Queensland (Springmount and Carfax) on the impact of different management strategies on soil acidification indicate that the introduction of more intensive management systems have resulted in declines in soil pH and other chemical attributes. These intensive management strategies included the use of GrasLan in reducing the tree component in a *Stylosanthes* based pastures and the introduction of *Stylosanthes* into native pasture systems with P additions. The greatest shifts in soil pH occurred where trees had been killed and *Stylosanthes* introduced. Associated with declining soil pH and increased acid soil infertility, it is highly probable that there will be a significant decline in pasture productivity. Relative growth reductions associated with acid soil infertility for grass and *Stylosanthes* species (*C. ciliaris, H. contorus, B. pertusa*, *U. mosambicensis*, Verano and Seca) was 99.7, 75, 66, 66, 61 and 52 % respectively from maximum growth observed under limed conditions. These results suggest that certain grass species are highly

sensitive to acid soil infertility and with progressive acidification would potentially be eliminated from the pasture. This clearly illustrates the sensitivity of both grass and legume species to acid soil infertility. Progressive acidification will drastically impact on pasture productivity and on species composition. Continued acidification of the soil resource will result in reduced thriftiness of the pasture, associated declines in productivity and pasture diversity, with acid soils promoting acid tolerant species.

A comprehensive study into the nitrogen dynamics under a Seca dominant pasture and an adjacent *U. mosambicensis* (Grass) pasture was undertaken at Lansdown Research. Monitoring of soil moisture show that *Stylosanthes* maintained lower water contents than grass throughout the monitored period and throughout the dry season, *Stylosanthes* maintained lower soil water contents than Grass.

Nitrogen concentrations were consistently highest in the Bare (control) topsoils, as dead roots and organic matter were mineralized. The Bare concentrations show the potential mineral N that becomes available for uptake by both grasses and legumes. Under pasture, the nitrate concentrations in the topsoil were consistently higher under *Stylosanthes* than under Grass. The difference was greatest at times of low nitrate concentration. In the subsoil however, the differences were much less, indicating that *Stylosanthes* and soil organisms were efficient at immobilizing or taking up the extra nitrate produced in the topsoil. Concentrations were lowest during the wet seasons, due to the combination of leaching loss, plant uptake, and possibly some gentrification during periods of waterlogging.

Nitrate concentration was also measured in soil solution, by vacuum extraction from ceramic suction cups. Over the three-year monitoring period the total loss of nitrate-N by leaching was 192 kg/ha under *Stylosanthes* and 110 kg/ha under Grass. From these results we were able to predict what leaching losses would be under *Stylosanthes* - or grass-dominated pastures on lighter or heavier textured soils in drier or wetter climates using the computer model HYDRUS. Loss of nitrate-N under *Stylosanthes* on a sandy loam soil in a wet year reached 225 kg/ha. Even under grass in a dry year on a clay soil, 10 kg/ha could be expected to be lost from the root zone by leaching. However, this amount would be compensated for by inputs from the atmosphere.

Total above-ground biomass of *Stylosanthes* was more than twice that of Grass over the whole monitoring period. Nitrogen content of the *Stylosanthes* biomass was 20-55% greater than that of Grass, the difference being greatest in the wet season. *Stylosanthes* biomass also had considerably higher ash alkalinity than the Grass.

Delta ^{15}N values indicate that during the wet season, a considerable proportion of N in the *Stylosanthes* originated from the atmosphere. However, during the dry season, when plants were not active, delta ^{15}N values were much lower in *Stylosanthes*. The dry season results from Lansdown were generally corroborated by the results for a range of other grasses and legumes sampled in the dry. Forbs stood out from grasses and legumes indicating that different pathways of uptake and loss occur. The grasses had a mean N content of 0.47%, the legumes 1.69% and the forbs 1.12%.

Stylosanthes drops most of its leaves in the dry season, and this may be a significant return of N to the soil. However, the mineralization of N from leaves of tropical legumes is often inhibited by organic compounds that bind to organic N compounds (proteins) and slow their decomposition. Mineralization of N in legume litter added to soil is inversely proportional to the lignin content, condensed tannin content and C:N ratio of the litter. Amongst other things, phenolic materials bind to proteins, inhibiting their decomposition in soils, but the nature of the materials and interactions involved are not fully understood. Two recently developed techniques may help elucidate the mechanisms concerned. Firstly, the ability of polyethylene glycol (PEG) to bind to condensed tannins is used to assess the effect of these materials on N mineralization in ruminant digestive tracts. Digestibility of N in a range of tropical legume shoots was more closely related to PEG binding than conventional measurements of condensed tannins. The lower the N digestibility of a plant sample, the greater it's PEG-binding capacity, and the greater the positive effect on N digestibility when PEG was added to the digestibility assay. Secondly, the total content of phenolic materials, including lignin and condensed tannins, may be estimated using C and N content and ^{13}C nuclear magnetic resonance (NMR) data. A study was undertaken to determine whether mineralization of N in litter of *Stylosanthes* and other tropical

legumes added to soil was related to their PEG-binding ability, or total phenolic material content by NMR.

The amount of N mineralised differed considerably between plant materials, with *Stylosanthes* litter having the lowest amount of mineralization. Mineralization of litter N was closely related to the PEG binding capacity of the litter and to the total content of phenolic materials. PEG binding capacity and total phenolic content was highly correlated. N mineralization was more closely related to PEG binding capacity and total phenolic material content than to N content, C:N ratio, lignin:N ratio or condensed tannin content by conventional means. These results suggest that *Stylosanthes* litter had lower N content and lower N mineralization than all of the fresh litters tested. Therefore *Stylosanthes* litter does not appear to add significant amounts of readily mineralisable organic N to the soil. It is possible that the plant relocates N from the leaves before dropping them. The results suggested that the low mineralization of N was due to binding of organic N compounds by phenolic materials including lignin and condensed tannins.

The *Stylosanthes*-dominated pasture had a considerable acidifying effect at the site, significantly lowering soil pH from the surface down to 0.4 m depth. The most acidified layer is at 0.05-0.10 m depth. Acid neutralizing capacity, or the amount of acid required to reduce pH from the existing value to pH 4, was also reduced under *Stylosanthes* compared to grass. It is the eventual decomposition of litter materials that leads to high soil nitrate concentrations, leaching and acidification. However, the *Stylosanthes* biomass, especially the leaves, also contained higher ash alkalinity than the grass biomass. The higher ash alkalinity of *Stylosanthes* is presumably due to greater transpiration of water, especially from depth. The return of this ash alkalinity to surface layers in litter and root death is presumably helping counter acidification in the very surface layers.

Quantification of uptake, mineralization and leaching of N under *Stylosanthes* and Grass-dominated pasture showed the potential for greater N inputs and losses under legumes. Leaching losses can be significant, particularly in wet years on light textured soils and that acidification of the soil under *Stylosanthes*-dominant pastures occurs due to a combination of cation uptake and nitrate leaching.

During the course of this project several peer reviewed scientific publications have been produced and are presented in full in an accompanying volume. In addition, strong linkages with outcomes from this project were established and maintained with Project NAP3.230 (Communication of Stylo management practices).

Acknowledgements

This work was funded by Meat and Livestock Australia (Project NAP3.218 ‘Sustainability of *Stylosanthes* based pasture systems in northern Australia: managing acidity’) for which we are grateful. We acknowledge valuable assistance of the following people: Terry Fitzgerald, Garry Swan and Peter Fitch installed and maintained an excellent data logging and telemetry system. Aaron Hawdon, Andrew Davidson, Marie-Dorothée Lapeyre Sue Berthelsen and Shelley Farr helped with the routine sampling and analysed the soil and water samples. The work on soil acidification and acid neutralizing capacity was carried out by Marc Marx, a German Honours student. We would like to express our sincere thanks to Mr R. Rebgetz (Thalanga Station), Mr John Rapisarda (Woodhouse Station), Mr Andrew Pemble (Myrralumbing Station) who collaborated in the project by allowing us to use their properties for the establishment of monitoring sites. Mr Bruce Rutherford and Jim Jones allowed us to carry out the experiments while they managed the Lansdown property. A special thanks is extended to Mr Col Middleton and Dr David Orr for their input into the project. Dr Freeman Cook assisted in the modelling associated with the computer program HYDRUS.

MAIN RESEARCH REPORT

1. Establishment of permanent monitoring sites for the assessment of soil fertility

Background

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. 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. However, there have been significant negative impacts to the soil resource base. For example, increased stocking rates have resulted in significant de-vegetation 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 prolonged drought periods, 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 (Noble *et al*., 1997; Noble *et al*., 1998). Statistically significant acidification to depth in soil profiles has been observed to have occurred on sites sampled throughout Queensland, the Northern Territory and Thailand (Noble *et al*., 2001) on soils that are dominated by *Stylosanthes*.

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 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 impacts.

When assessing the sustainability of grazing production systems, the soil resource base can be viewed as the component that provides the habitat in which pasture species grow. A favourable soil habitat will essentially maximise the chances of suitable surface cover and productivity being maintained. From a soils perspective, the primary requirement for productivity (i.e. grass production) is the availability of water and nutrients. Since rangeland soils, in general, are typically of a low fertility status and subject to unreliable rainfall, the supply of both water and nutrients to meet the needs of pasture species is critical to the productivity and long-term sustainability of these ecosystems.

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 inherent fertility and the soil water balance. There is a paucity of information on the long-term impact of current pasture production systems on the inherent fertility of soils as well as the soil moisture status under these production systems. At Redlands, north west Queensland, on a deep red earth the water extraction and root density distribution with depth were determined for the *Stylosanthes* cultivar Verano (Williams, 1980). This species was able to exploit water to depths in excess of 3 m. This would suggest that *Stylosanthes* dominant pastures may have a significant impact on the soil water balance and would probably explain the reported observations by 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 prolong drought period (C.H. Middleton and C.P. Miller, pers. comms).

The objective of this series of activities was to establish long-term soil fertility monitoring sites throughout northern Australia and on selected sites, monitor the soil water status under *Stylosanthes* dominant and improved/native pasture systems.

Methodology

Sites

Collection of soil samples was undertaken on sites stretching from north Queensland through to Katherine in the Northern Territory. Previous paired site surveys were undertaken of areas of central and south Queensland and the northern Territory and are reported elsewhere (MRC Project CS.277; Noble et al., 1997). A paired site approach was used on those sites where there was a *Stylosanthes* dominant pasture in close proximity (adjacent) to a native or improved pasture system. On sites that did not permit, soil samples were collected from the *Stylosanthes* pasture system and chemical attributes assessed. All of these sites would be returned to in 15 – 20 years to assess changes in the soil fertility status over this intervening period.

The selection of paired sites was based on the following criteria: (1) the existence of a grass dominated pasture (undeveloped area) in close proximity to a *Stylosanthes* dominated pasture (developed area) of known history; (2) a well defined boundary (i.e. fenceline) separating the two production areas; (3) the same soil type in both areas; and (4) little topographical difference (i.e. slope) between the two areas. Soil cores were collected from each of the sites by taking 50 mm diameter cores to approximately 70 cm depth at three positions in the plot approximately 10 m apart. Cores were sectioned into the following depth intervals: 0-10, 10-20, 20-30, 30-50 and 50-70 cm.

Soil analysis

Samples were air dried and sieved to pass a 2 mm mesh before pH was measured in both water (pH_w) and 0.01 *M* $CaCl_2$ (pH_{Ca}) using 1:5 soil:solution. The pH_{Ca} measurements are often preferred to that of pH_w because dilute salt solution assists in reducing seasonal effects due to variations in soil solution salt concentrations. Soil organic carbon was determined by the Walkley-Black method (Rayment and Higginson, 1992) and particle size as described by Coventry and Fett (1979). Basic exchangeable cations and CEC were determined by atomic absorption spectrometry after replacement with 0.1 *M* $BaCl_2/NH_4Cl$ as recommended by Gillman and Sumpter (1986). Exchangeable acidity was extracted with 1M KCl and the extract titrated to pH 8.0 using NaOH. The effective cation exchange capacity (ECEC) was calculated as the sum of basic cations (Ca+Mg+K+Na+Al+H). Mineral nitrogen (N) in the soil profile was determined by extracting 10 g of air dried soil in 50 mL 2 *M* KCl for 1 h. The extract was filtered and analysed for nitrate-N and ammonium-N using auto analyser techniques (Markus *et al*., 1985). Total N was determined by the standard Kjeldahl method of Rayment and Higginson (1992).

Results and discussion

The location of sites from where soils samples were collected is presented in Figure 1.1. The sites represent a diverse range of agro-ecotypes in which *Stylosanthes* has been introduced as a means of improving the dietary quality of native pastures. Included in these sites were the four soil moisture monitoring sites (to be discussed below) situated at Lansdown, Woodhouse Station, Thalanga Station and Myrralumbing Station. Chemical attributes of the samples collected are presented in Appendix 1 in table 1.1 to 1.20.

Lansdown:

The site selected comprised of two adjacent paddocks, an Urochloa and *Stylosanthes* dominant (mixture of Seca and Verano) system that were established to improved pasture in 1980 under a long-term grazing trial. By 1999 there was clear evidence that encroachment of *Stylosanthes* into the Urochloa dominant treatment pasture had occurred, requiring the manual removal of rogue plants from within the monitoring area so as not to compromise the study on nitrogen dynamics.

By comparing measured CEC (compulsive exchange method) and the ECEC (sum of basic cations) an indication of the uniformity of two profiles and hence the homogeneity of the soils can be assessed. It is clearly evident that the there is a uniform distribution of CEC's over depth down the down the rofile between the two paddocks thereby inferring homogeneity (Figure 1.2).

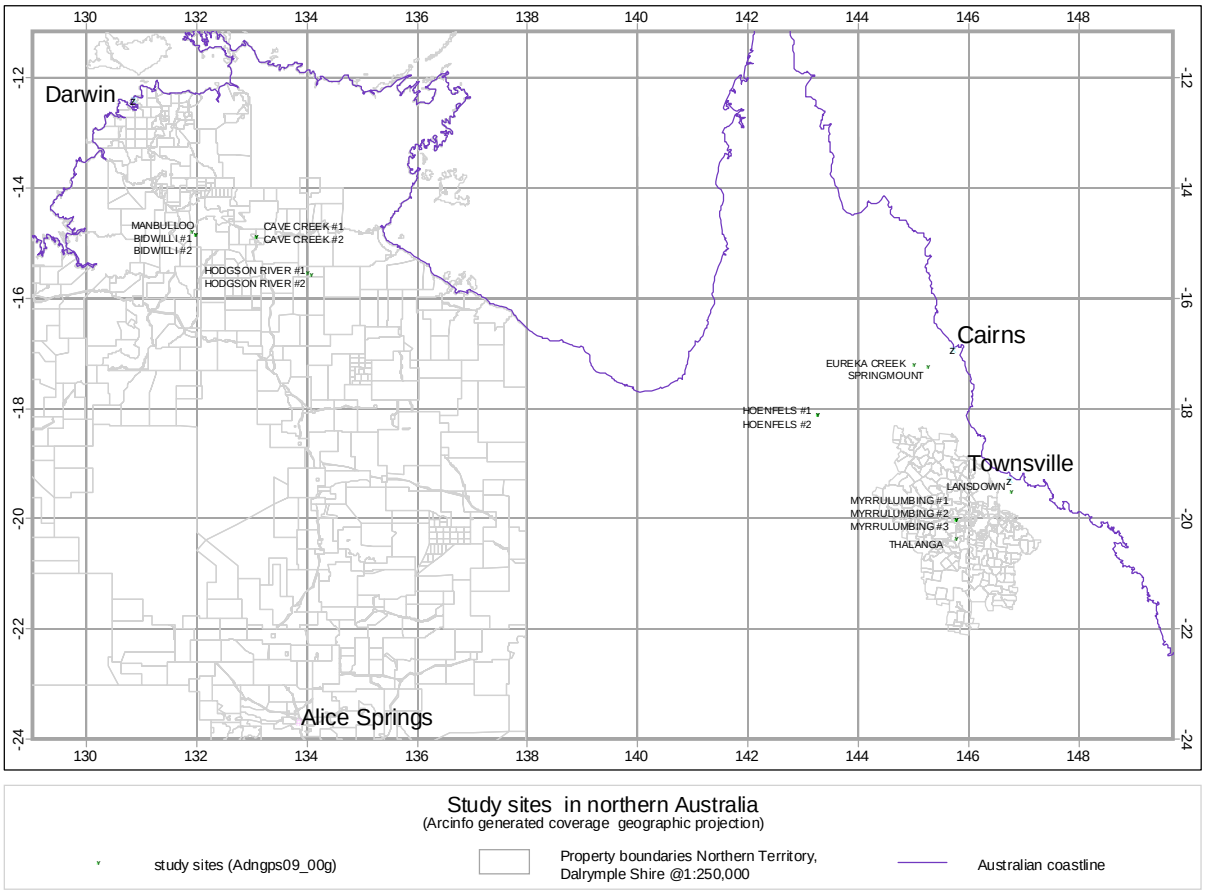


Figure 1.1. Map indicating the sites from which soil samples were collected.

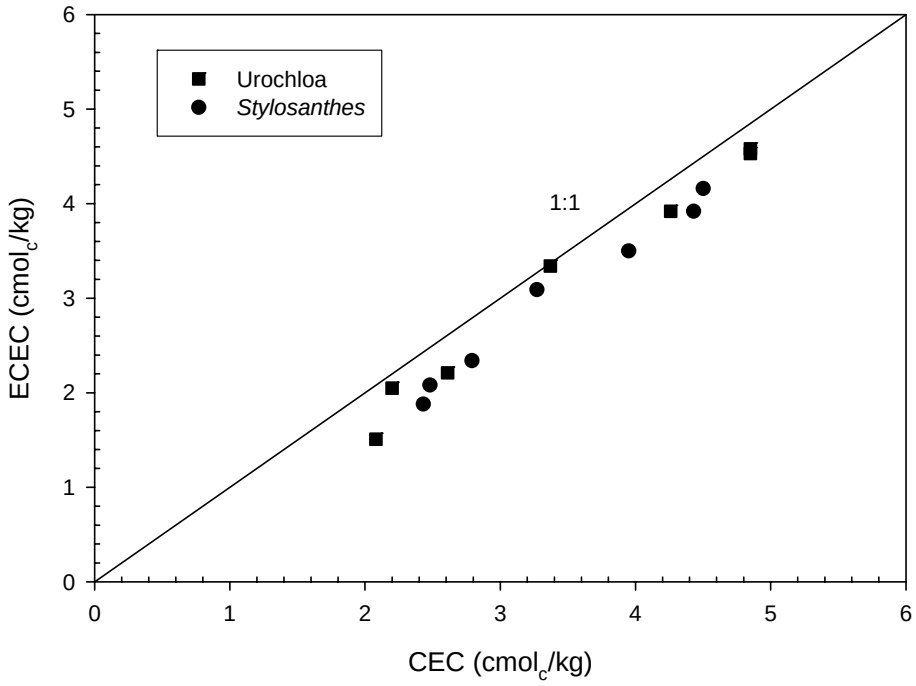


Figure 1.2. Relationship between measured CEC and ECEC for different depth intervals for an Urochloa and *Stylosanthes* dominant pasture at Lansdown, north Queensland.

In addition, the close proximity of points to the 1:1 line is indicative that the two methods of CEC determination are comparable. A comparison of soil pH measurements down the profile between the two systems clearly indicates that under the *Stylosanthes* dominant system, a greater degree of acidification has occurred to depth (Appendix 1 Tables 1.1 and 1.2). It is of note that mineral nitrogen levels (NH_4^+ and NO_3^-) were higher under the grass dominant system when compared to *Stylosanthes*. Slightly higher levels of soil organic carbon were measure in the 0-10 cm depth interval under Urochloa when compared to *Stylosanthes* however, these differences diminished with depth (Appendix 1 Tables 1.1 and 1.2).

Thalanga Station:

The site selected is a Producer Demonstration Site (PDS) established in the 1980's by Mr Peter Smith to demonstrate the advantages of incorporating *Stylosanthes* into native pasture systems (Figure 1.3). A paired site approach was used where a *Stylosanthes* dominant pasture was compared to an adjacent native pasture consisting of black spear grass and silver-leaved iron bark (*Eucalyptus shirleyi*). Due to the prolonged drought of the mid-1990's significant mortality of the tree component in the *Stylosanthes* dominant system was evident suggesting the greater ability of the species to extract water and to survive adverse drought conditions.

Figure 1.3. Producer demonstration site at Thalanga Station established as a permanent monitoring and soil moisture monitoring site. Note the extensive tree mortality under the *Stylosanthes* dominant system.

Selected soil chemical properties are presented in Appendix 1 Tables 1.3 and 1.4. Soils at the site have a soft to indurate plinthic layer that occurs at approximately 50-60 cm that restricts the vertical movement of percolating water. These soils are common throughout the Dalrymple Shire and typically suffer from waterlogging at certain times of the year. Soil pH was again higher (0-20 cm) under the grass dominant pasture when compared to the *Stylosanthes* system suggesting that accelerated acidification had occurred. It is of note that the pasture system had slightly higher clay contents in the surface horizons (16.4% versus 11.8%) that would explain the slightly higher CEC in the pasture system. There were no differences in mineral nitrogen between the two systems with only a slight increase in organic carbon in the 0-10 cm of the *Stylosanthes* system.

Myrrulumbing Station:

A paired site approach was adopted where improved pasture consisting of a combination of Urochloa, native grass species and *Stylosanthes* was separated from an adjacent property where little improvement had occurred by a fence. Results from the chemical analysis of samples collected are presented in Appendix 1 Tables 1.5 and 1.6. Soil pH_{Ca} was lower under the under the Stylosanthes pasture systems at all depth intervals other than the 0-10 cm where the pH was slightly higher than that under native pasture. NH_4^+ - N was extracted from all depth intervals from both production systems with no measurable difference between them. Slightly lower CEC values were observed under the *Stylosanthes* production system, this being attributable to the lower pH of the soil reducing the variable charge component.

Woodhouse Station:

The results of the paired site analysis are with presented in Appendix 1 Tables 1.7, 1.8 and 1.9. Woodhouse Station was one of the first properties to embrace the concept of introduced legumes into native pasture systems. As such, the property is the largest contiguous area of planted *Stylosanthes*

in Australia. In order to undertake a paired site comparison, an adjacent property was used as the control. The site is a gently sloping foot slope with large boulders and rocks interspersed both on the soil surface and throughout the profile. The soils are thus skeletal with effective rooting depth being compromised by rock material. The native pasture site was dominated by secondary re-growth and shrubby species and was over-grazed and poorly managed. There were no differences in soil pH between the *Stylosanthes* dominant system and the adjacent native pasture. Organic carbon in the surface horizon was higher under the *Stylosanthes*. The clay content under the *Stylosanthes* pasture was higher than the adjacent native pasture which would have contributed to a higher buffering capacity. This would effectively enhance the capacity of the soil to resist changes in soil pH.

Hoensfel Station:

Hoensfel Station, situated in the Gulf Country west of Georgetown, *Stylosanthes* was introduced into the properties production systems approximately 15 years ago. The results of a paired site analysis at 2 locations on the property are presented in Appendix 1, Tables 1.10, 1.11, 1.12 and 1.13. There was no clear evidence of *Stylosanthes* dominance in the pastures at sampling that occurred in late November at the end of the dry season. It would appear that there was an adequate grass component in these pastures. It is clearly evident from the data presented in Tables 1.10 – 1.13 that there is no evidence of accelerated under the *Stylosanthes* pasture. This would suggest that by maintaining an adequate grass component in a *Stylosanthes* pasture might reduce the risk of accelerated soil acidification.

Bidwillii Station:

Bidwillii Station is south of Katherine, Northern Territory. The site sampled is unique in that Stylosanthes (Verano) is intercropped between immature mango trees. *Stylosanthes* is cut and baled and fed to livestock off farm. This practice would represent the most severe case of nett export of product. The mango orchard/*Stylosanthes* hay production system was established approximately 3 years previously. Selected soil chemical data are presented in Appendix 1 Tables 1.14 and 1.15. It would appear that acidification under the mango/*Stylosanthes* production system was confined to the surface 0-10 cm layer. The nett export of alkalinity in *Stylosanthes* from the site, assuming a conservative yield of 2 t/ha/yr, would amount to 108 kg $CaCO_3$ on an annual basis (Noble et al., 1997). This would represent the largest nett input of acidity associated with crop export.

Manbullo Station:

Manbullo Station had been previously sampled in an earlier survey of soil acidification (Noble et al., 1997). The site sampled on this occasion represents a single site sampled that will be returned to at a later date. There was little evidence of *Stylosanthes* dominance and the results of selected soil chemical analysis are presented in Appendix 1 Table 1.16.

Hodgen River Station:

Hodgen River Station was one of the initial properties in the Northern Territory where *Stylosanthes* (Verano and Seca) was introduced into native pasture systems. There was no evidence of *Stylosanthes* dominance in the pasture systems viewed and no clear boundary fences separating a *Stylosanthes* dominant pasture from a native pasture. Hence samples were collected from 2 sites on the property with the hope that they would be returned to in the future. The results of selected chemical analysis from the two sites are presented in Appendix 1, Tables 1.17 and 1.18. It is of note that the CEC on both sites is significantly larger that the other sites sampled in this survey. This would increase the soils ability to resist pH shifts and therefore reduce the risk of accelerated acidification. This may also explain the lack of *Stylosanthes* dominant in these pastures as with the higher nutrient content on these soils would favour the grass component.

Cave Creek Station:

Cave Creek is east of the township of Mataranka, Northern Territory. A fence line comparison between a *Stylosanthes* and native pasture dominant systems was possible at this site and results are presented in Appendix 1 Tables 1.19 and 1.20. *Stylosanthes* was introduced approximately 15 years prior to sampling into native pastures on light textured deep red sands. *Stylosanthes* (verano) had senesced so that a visual assessment of the extent of dominance could not be undertaken. However, results from the soil chemical data clearly indicate that accelerated acidification had occurred under the *Stylosanthes* dominant production system (Figure 1.4a). It is clearly evident that acidification has occurred to depth in the profile and that the profile is homogenous to depth as is evidenced by the consistently similar CEC down the profile (Figure 1.4b).

Of the 9 sites sampled, of which 7 were paired sites where a comparison of the effects of *Stylosanthes* on soil chemical properties could be undertaken, 5 of these sites showed clear evidence of accelerated soil acidification under *Stylosanthes* thereby supporting earlier findings. The greatest degree of acidification under *Stylosanthes* was observed on a light-textured sand from the Northern Territory. It is important to note that accelerated acidification will result where *Stylosanthes* dominance is allowed to occur for any extended period and is exacerbated on those soils that are predisposed through low internal buffering mechanisms. As discussed later in this manuscript, there are several management strategies that can be adopted by producers to minimise *Stylosanthes* dominance, one of which is prudent pasture management that would entail lighter grazing and resting phases. It was of note that pastures in the Northern Territory where significantly lighter grazed than those in Queensland and were subject to burning on a more frequent basis. Both of these strategies would reduce the risk of *Stylosanthes* dominance.

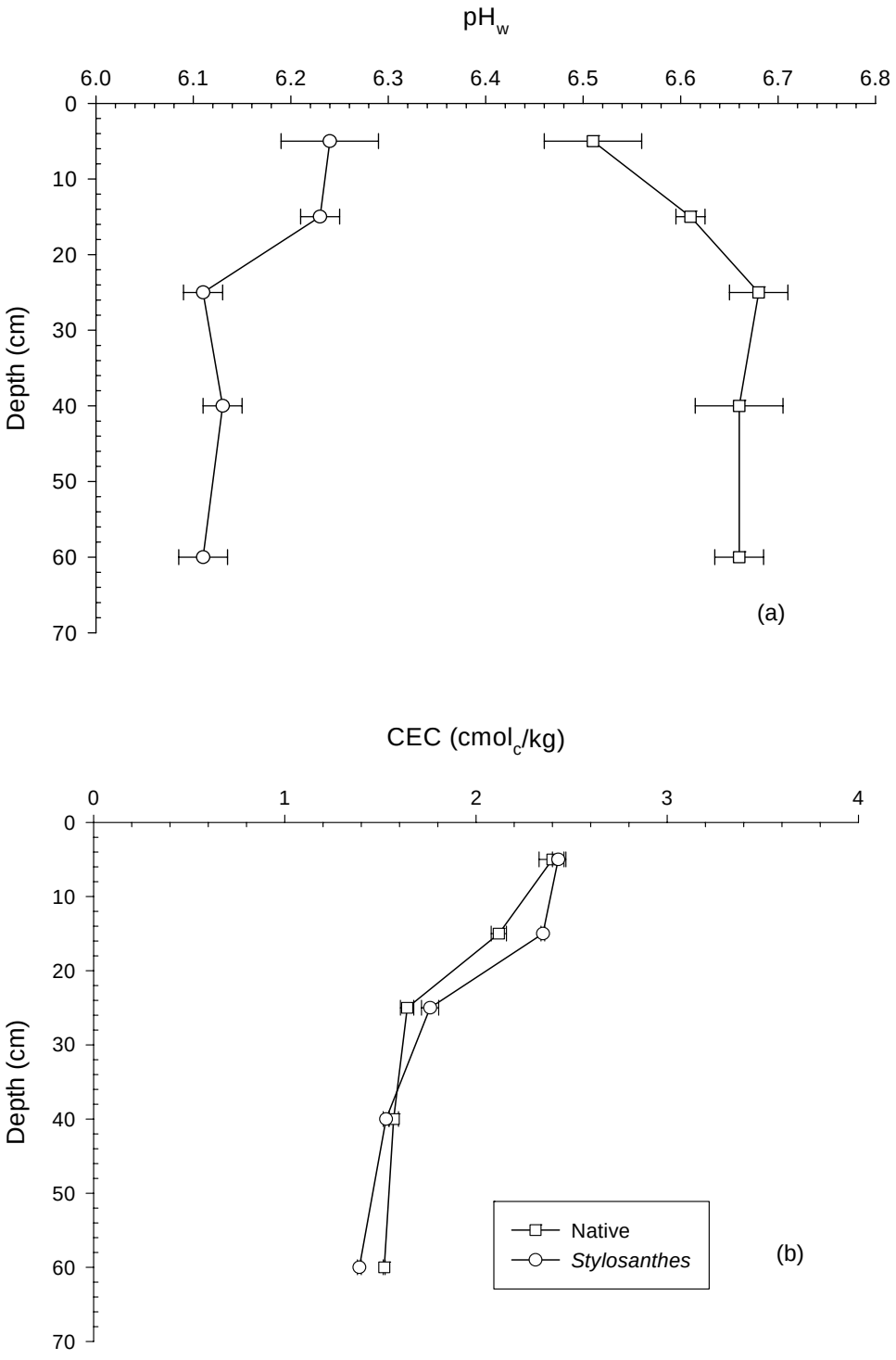


Figure 1.4. pH profile (a) and CEC (b) for a *Stylosanthes* and native pasture system collected at Cave Creek Station, Northern Territory.

2. Assessment of soil moisture consumption under *Stylosanthes* based pasture systems.

Background

The objective of this activity was to monitor soil moisture extraction patterns from the 0-50 cm depth interval under *Stylosanthes* dominant pastures systems to that under native pasture or improved pasture systems.

Methodology

Monitoring sites containing TDR probes and automatic rainfall gauges were established at Lansdown Research Station (CSIRO research Station), Thalanga Station (owner: Mr R. Rebgetz), Myrralumbing Station (owner: Mr A. Pemble) and Woodhouse Station (owner: Mr J. Rappasada). These systems comprise of TDR probes inserted at 2 positions in the profile of a *Stylosanthes* dominant pasture and an adjacent introduced/native pasture production system. The two production systems at each site were separated by a fence line. The site at Lansdown was also used in Activity v*i. Quantification of the mineral nitrogen dynamics under a Stylosanthes dominant pasture system in order to assess the contribution of nitrate leaching to acidification*. This site also was equipped with soil solution samplers and due to its proximity to digital mobile phone coverage was equipped with a modem and SIM card so that data could be automatically downloaded on a daily basis. The output from the TDR probes and rainfall are updated daily on the website at http://wwwfsig.tvl.clw.csiro.au/. This allowed for a rapid response with respect to placing soil solution cups under vacuum when a wetting front was detected. As for the other 3 sites, these were visited on a 3 monthly basis and data loggers downloaded manually.

Results and discussion

Soil moisture trends over the period of the project have been reported on an annual basis in Peer Review Reports or Annual Reports and for brevity will not be covered here. The reader is referred to these documents; however, the moisture consumption trends were similar over the entire duration of the study. For brevity the TDR traces and rainfall distribution for the 2000 season are presented for each of the depth intervals at the four monitoring sites in Figures 2.1–2.8. Mean annual rainfall for each of the sites is presented in Table 2.1.

Table 2.1. Mean annual rainfall (mm) for the each of the sites over the duration of monitoring. Note that sites were instrumented at different times and that in the case of Myrralumbing Station; intermittent faults were experienced with the rain gauge.

Site		**Year**		
	1998	**1999**	**2000**	**Jan-June 2001**
Lansdown	1130	672	2160	241
Thalanga	659	652	1308	275
Woodhouse	252	975	1554	226
Myrralumbing	-	-	565*	227

* Faulty rain gauge.

During the course of the study mean annual rainfall varied from relatively dry years (1999 and 2001) to above average rainfall in 2000. The soil moisture trends for the 2000 season are presented in Figures 2.1 – 2.8 and are similar to those reported previously (Noble, 1998; Noble and Nelson, 1999 and 2000). The rate of soil moisture draw-down under the *Stylosanthes* dominant pasture at Lansdown and Thalanga was greater than that under a pasture based system for both depth intervals (Figures 2.1 – 2.2). Whilst differences in clay content would account for the slight differences in steady state volumetric water content (point at which soil moisture is no longer available for plant uptake) the fact that the slope of the TDR curve is greater under *Stylosanthes* indicates that greater consumption of soil moisture has occurred over time. This is to be expected since *Stylosanthes* (Seca) grows actively throughout the year, although at a significantly reduced rate during the dry season. It is also of note that in the pasture systems at both of these sites, the perennial vegetation component at Lansdown was nonexistent whilst at Thalanga it was relatively sparse.

Root distribution profiles for each of the production systems were produced at the Thalanga site using the methodology of Nicoulland *et al*. (1994) and are presented in Figure 2.9. Although the site had an impervious lateritic layer at approximately 60 cm it is of note that roots of both grasses and *Stylosanthes* were able to penetrate to depth. The root distribution under *Stylosanthes* appears to be deeper and more extensive than under the native pasture (Figure 2.9). The greater root proliferation observed under *Stylosanthes* may account for the significantly higher tree mortality observed under the *Stylosanthes* production system. This observation supports previous findings where the rooting depth of Verano was determined to be in excess of 3 m on a deep red earth (Williams *et al*., 1980). It is also of note that on several occasions during the wet season significant drainage below the lowest monitoring depth occurred at all sites regardless of plant community, thereby contributing to profile recharge and deep drainage.

Contrasting the aforementioned discussion, the TDR moisture profiles for the Woodhouse and Myrralumbing sites showed similar trends in the surface 20 cm to that of the Lansdown and Thalanga sites, however, at depth there was a reversal of trends with greater consumption of moisture occurring under the native pasture systems (Figures 5-8). At both the Woodhouse and the Myrralumbing sites no evidence of tree clearing was observed. Probert and Williams (1986) found that water use under natural open savannah woodlands was greater than under an established Seca pasture which was greater than under cleared native pastures.

There are strong similarities between the water balances of Mediterranean and monsoonal tropical regions. As 70% of the annual rainfall is concentrated over 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). In this respect 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. The establishment of improved pasture systems can have a significant impact on the hydrological cycle leading to increased leaching and hence acidification associated with a disjunction of the nitrogen cycle in the case of *Stylosanthes* pastures. As discussed in a later chapter, nitrate leaching does occur in these environments.

Not only are perennial *Stylosanthes* 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). 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 leaves of Verano were near desiccation although when placed in free water these leaves fully regained their turgor. In contrast, the leaf water potential of Seca at the same time was –2.4 MPa suggesting that the root system of Seca was in contact with soil water. These results of Williams and Probert (1984) clearly support the deep rooted nature of Stylosanthes, particularly Seca, and therefore its ability to compete effectively for stored soil moisture. It could also be argued that due to the annual nature of Verano, (leaf senescence in the dry season), there is not the requirement for a deep rooted system to survive the dry season.

These results would suggest that the inclusion of *Stylosanthes* into an improved grass pasture based system may counter increased deep drainage associated with the clearing of native vegetation and the promotion of a grass dominant pasture. Clear the establishment of *Stylosanthes* on soils that have a restricted rooting depth will resulted in increased competition for soil moisture and can lead to increased tree mortality under drought conditions. This factor should be recognized when planning the establishment of improved *Stylosanthes* pasture.

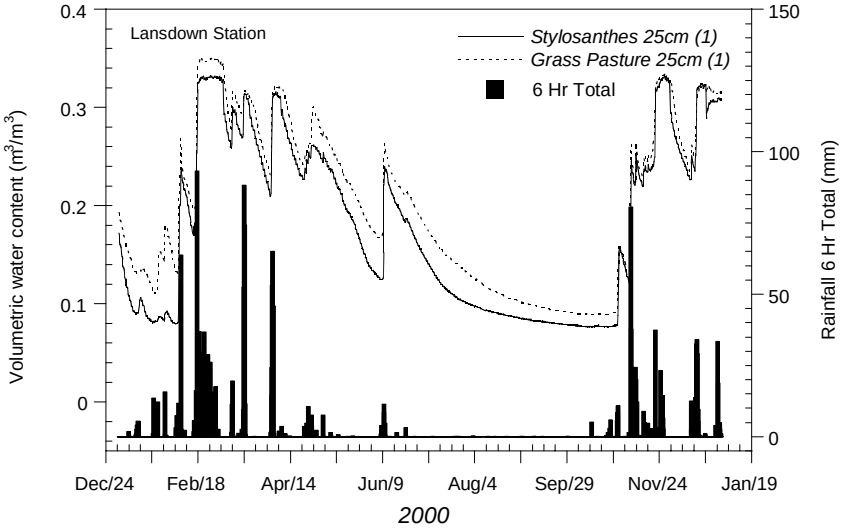


Figure 2.1. Comparison of the soil moisture and rainfall trends at 25 cm under a *Stylosanthes* and Urochloa dominant pasture at Lansdown for the 2000 season.

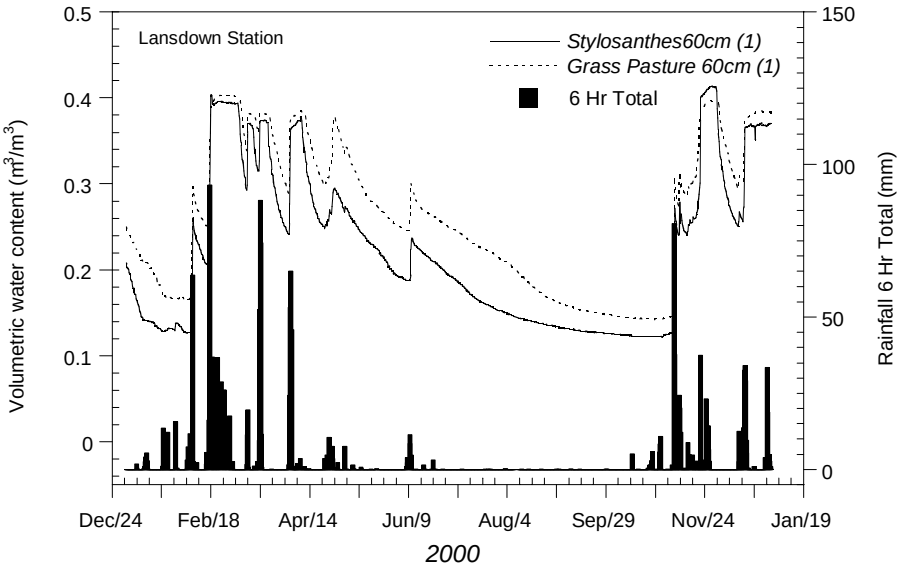


Figure 2.2. Comparison of the soil moisture and rainfall trends at 60 cm under a *Stylosanthes* and Urochloa dominant pasture at Lansdown for the 2000 season.

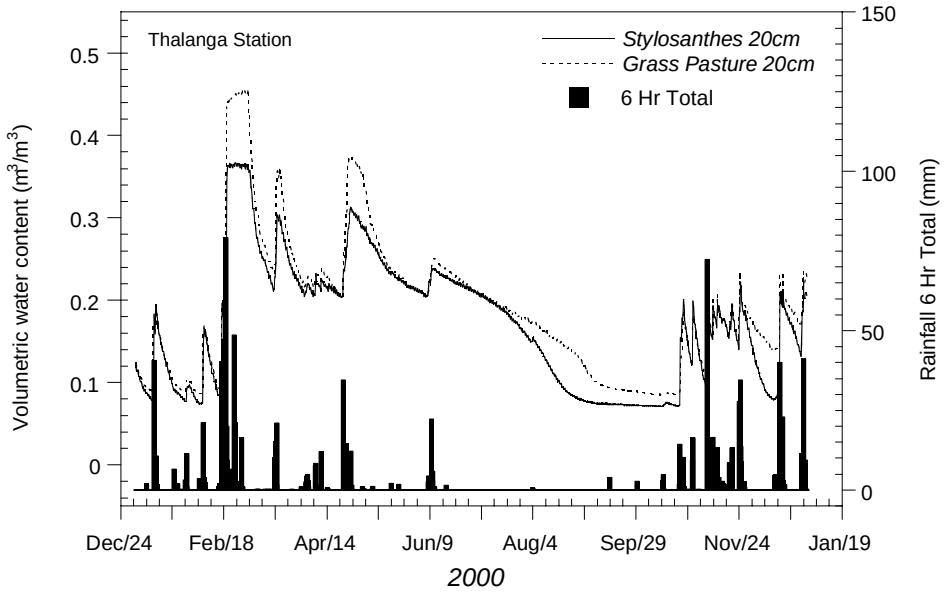


Figure 2.3. Comparison of the soil moisture and rainfall trends at 20 cm under a *Stylosanthes* and native pasture at Thalanga for the 2000 season.

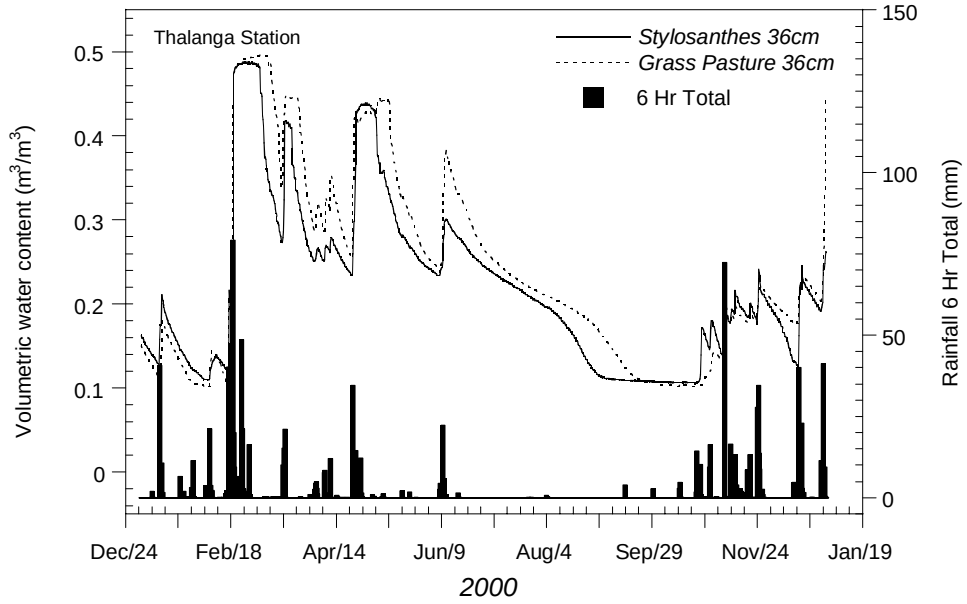


Figure 2.4. Comparison of the soil moisture and rainfall trends at 36 cm under a *Stylosanthes* and native pasture at Thalanga for the 2000 season.

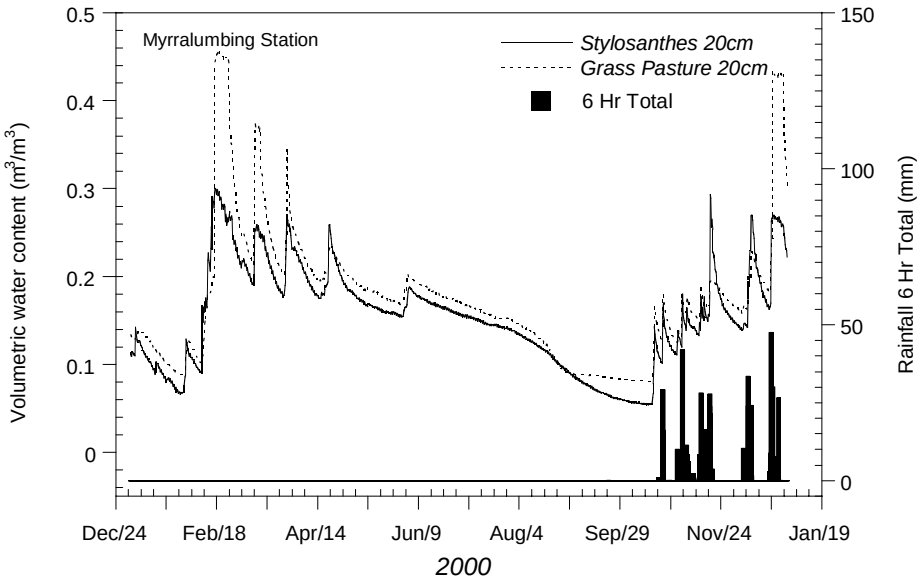


Figure 2.5. Comparison of the soil moisture and rainfall trends at 36 cm under a *Stylosanthes* and native pasture at Myrralumbing for the 2000 season. Note problems with the automatic rain gauge were experienced during the wet season of 2000.

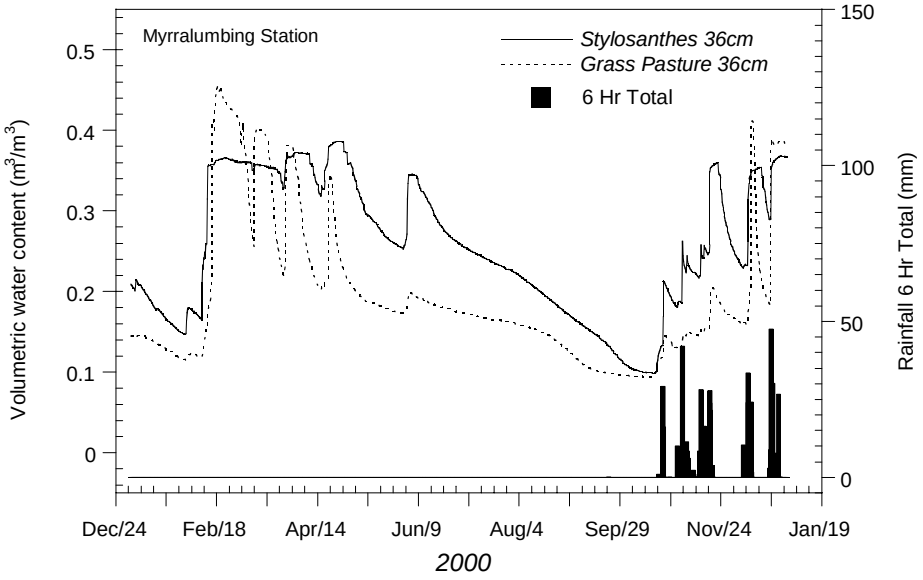


Figure 2.6. Comparison of the soil moisture and rainfall trends at 36 cm under a *Stylosanthes* and native pasture at Myrralumbing for the 2000 season. Note problems with the automatic rain gauge were experienced during the wet season of 2000.

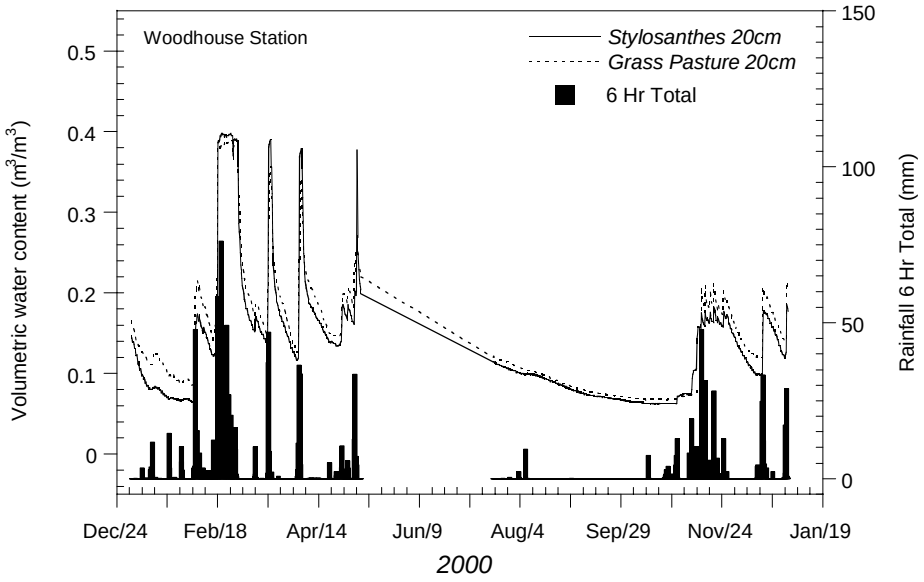


Figure 2.7. Comparison of the soil moisture and rainfall trends at 20 cm under a *Stylosanthes* and native pasture at Woodhouse for the 2000 season.

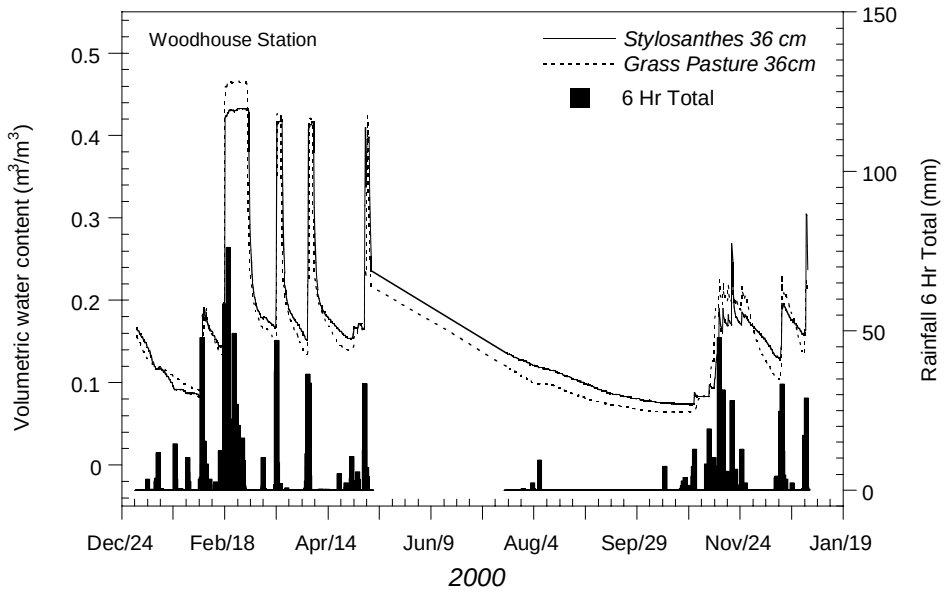


Figure 2.8. Comparison of the soil moisture and rainfall trends at 36 cm under a *Stylosanthes* and native pasture at Woodhouse for the 2000 season.

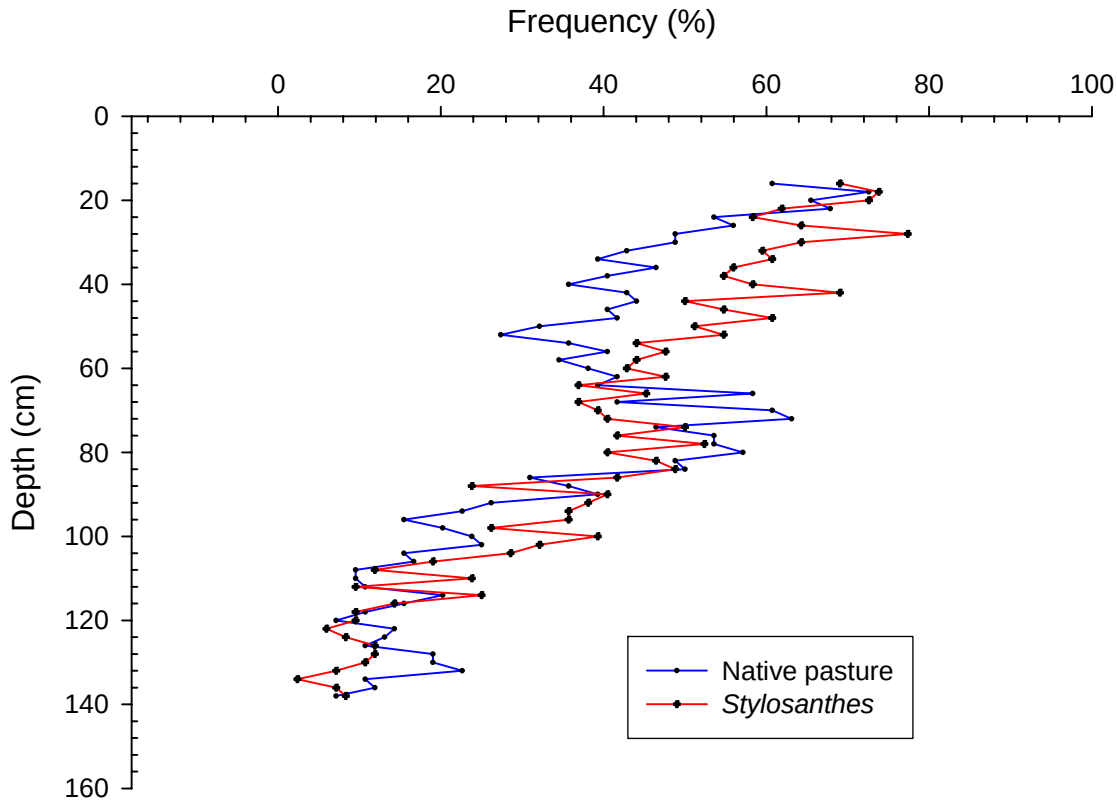


Figure 2.9. Frequency distribution of roots on the face of pits established in a Stylosanthes dominant and native pasture at Thalanga. Each point is the mean of two observations.

3. Predicting the risk of acidification

i. Development of an acidity risk map for the Dalrymple Shire.

Background

The inclusion of the *Stylosanthes* (stylos) has proved to be a low cost method of improving the quality of native pasture and legume-based cropping systems in Asia, Africa, South America, and northern Australia (Miller *et al.* 1988, 1991). This is due to the adaptability of the species to inherently infertile soils and climatic conditions ranging from the wet to the semi-arid tropics. Moreover, they have the potential to be more widely grown in the subtropics and tropics than those of any other genus currently being evaluated. Under the moderate to low rainfall regimes of northern Australia and south east Asia cultivars of *S. hamata* and *S. scabra* have been successfully established in agropastoral and seed production systems, as well as intercropped in plantations of rubber and coconuts and in some annual cropping systems. Indeed such has been the success of stylos that they form an integral component in the production of beef, poultry and pig industries in Australia and southeast Asia and in the reclamation of 'wastelands' in India (Jayan 1995; Michalk *et al*. 1993; Liu Goudoa *et al.* 1997; Pinstrup-Andersen and Pandya-Lorch 1994).

Soil acidification is a naturally occurring phenomenon and is a result of long-term weathering and the leaching of exchangeable cations out of the soil horizon or profile. However, accelerated soil acidification in agricultural production systems is a consequence of increased product removal, the use of nitrogenous fertilisers and changes in the carbon and nitrogen cycles associated with legume introduction (Helyar and Porter 1989). Whilst use of leguminous plants to increase the fertility of farming systems is a fundamental practice in agricultural production systems throughout the world, the long-term negative impact of these production systems with respect to accelerated soil acidification has been well recognised (Haynes 1983; Helyar and Porter 1989; Moody and Aitken 1997). In many agricultural production systems the inclusion of legumes in crop rotations is a corner stone of arable-crop farming systems. In general, these production systems could be classified as sustainable if there are external inputs of fertilizer and liming materials at some phase in the rotation. However, there is considerable evidence to show that under permanent legume/pasture systems in south east Asia and Australia there has been a gradual decline in soil pH (Chartres *et al.* 1990; Noble *et al.* 1998; Noble 1998).

Evidence from a series of surveys across northern Australia and southeast Asia (Noble *et al*. 1997; Noble *et al*. 1999) of legume-based pasture systems has shown that significant accelerated acidification has occurred on light textured low fertility soils with a low inherent buffering capacity. Under these environments *Stylosanthes* becomes the dominant species in the sward resulting in a significant decline in the grass component. In these extensive low input production systems, applications of liming materials are not economically viable and therefore alternative strategies are required (Middleton and Noble 1998). Thus the introduction of *Stylosanthes* in a pasture production system is a potential hazard, the consequence of which is acidification.

This study focused on the role of soil survey information in the identification of areas at risk of accelerated soil acidification associated with *Stylosanthes* dominance. This would assist land and resource managers in the processes of decision-making associated with the establishment of *Stylosanthes* pasture systems on an extensive basis. The Dalrymple Shire in north Queensland was selected as the target area for the development of a surface soil acidity risk map. This selection was based on the existence of a recently completed comprehensive land resource assessment of the Shire (Rogers *et al*. 1999). In order to develop a risk map, an estimate of a soil's ability to resist shifts in soil pH had to be undertaken. In a previous survey of *Stylosanthes* based pasture systems across northern Australia, Noble *et al*. (1997) developed several pedotransfer functions to predict soil pH buffering capacity. These functions were based on intrinsic characteristics of the soil, namely soil organic carbon, clay and silt content. However, no validation of these functions was undertaken using an independent set of samples. Consequently, the first stage of this exercise was to validate the pedotransfer function developed for surface soils on a range of dominant soils in the Dalrymple Shire.

The second stage was the production of a risk map for the Shire and finally, the development of a field-based toolkit that could be used by producers and extension personnel to determine a soils predisposition to accelerated soil acidification.

Methodology

Study area

The Dalrymple Shire occupies 68 000 km^2 in north Queensland, roughly corresponding with the upper Burdekin River catchment. Average annual rainfall ranges from 500 to 1600 mm, with 80% occurring between November and April (De Corte *et al*. 1994). Although potential evoptranspiration is high (2000-2500 mm/year), the concentration of rain over a 5 - 6 month period leads to the filling of the soil profile and localised water logging every 3 years on average (Coventry and Williams 1984). The landscape over most of the Shire is characterised by level to undulating plains with long slopes and low gradients. Mesas, low range plateaus, and valleys constitute the major relief elements. Soils in the region exhibit a complex pattern but generally, parent material and geomorphic history are the dominant factors controlling the character and distribution of soils (Isbell and Murtha 1970; Bui *et al*. 1996). The most common catena consists of red and yellow earths on uplands, sodic and related soils with abrupt textural contrast on the intermediate slopes and cracking clay soils, often sodic in nature, with gilgai micro-relief in the lower portions (Bui *et al*. 1996). The proportions of broad soil groups have been reported by Rogers *et al*. (1999) as follows:

Sandy surfaced soils (sands to sandy loams) cover 45% of the Shire, with uniform sandy soils covering 21%, gradational sandy soils 6% and texture contrast soils occurring over 18% of the Shire. Loamy surface soil (sandy clay loams to clay loams) cover 44% of the Shire, with uniform loamy soils covering 1%, gradational loamy soils 22%, and texture contrast soils occurring on 21% of the Shire. Clay soils cover 9% of the Shire, with massive surface soils covering 1%, structured (blocky) 2.5%, and self-mulching clays occurring on 5.5% of the Shire. Rock outcrop (Basalt flow lines and sandstone outcrops) occupy 1% while < 1% of the Shire is flooded by natural or man-made lakes.

More than 90% of the Shire is used for extensive beef production with most properties being between 10 000 and 50 000 ha (Rogers *et al*. 1999). The Dalrymple Shire land resource map, at a scale of 1:250 000, provides soil information at a higher resolution than previously available (i.e. pH of surface soils 1:5 000 000 Ahern *et al.* 1994). This map was used as the basis of the risk map.

Validation of pedotransfer function

Validation of the surface soil pedotransfer function of Noble *et al* (1997) was undertaken on a independent set of 27 surface A horizon soils of variable depth collected from the Dalrymple Shire and archived at CSIRO Townsville laboratory (Table 3.1). The samples included the major soil series within the Shire as determined in the land resource survey of Rogers *et al*. (1999).

Table 3.1. Selected soil chemical and physical properties of surface soil samples (A horizon) used in the validation studies.

T Series No.	Depth	% of Shire	Clay	Silt	[A] OC	pHw	pH buffer capacity	
	(cm)						Predicted	Measured
			%				(mmol H^+/kg.pH)	
8	0-4	4.86	15	11	0.86	6.4	11.01	13.70
47	0-10	2.38	72	15	1.06	6.8	32.29	28.02
59	0-10	0.89	9	9	0.49	6.1	8.10	10.03
80	0-10	0.89	24	12	10.30	5.5	48.57	53.52
99	0-10	5.91	21	7	0.54	6	9.26	12.47
145	0-10	5.91	13	6	0.35	6.1	7.53	8.99
152	0-5	5.91	5	6	0.50	6.7	7.53	8.08
163	0-10	2.92	31	30	2.57	6.5	35.50	37.88
168	0-10	2.92	42	23	1.60	6.4	32.90	27.64
173	0-10	2.92	38	29	2.01	6.7	37.98	35.21
331	0-10	5.89	22	10	1.00	6.5	12.57	13.25
335	0-10	5.89	14	5	0.53	6	8.01	11.25
339	0-10	5.91	16	11	1.08	6	12.05	16.36
340	0-10	0.37	16	7	0.64	6.5	9.13	13.98

[A] Organic C content

Table 3.1. cont'd.

T Series No.	Depth	% of Shire	Clay	Silt	[A]OC	pHw	pH buffer capacity	
	(cm)						Predicted	Measured
			%				(mmol H^+/kg.pH)	
503	0-10	4.69	7	6	1.00	6.39	9.52	9.67
507	0-10	1.1	6	7	0.60	6.32	7.99	10.37
521	0-10	2.44	3	3	1.30	6.04	10.56	15.63
528	0-10	0.72	27	16	0.70	8.29	16.31	10.01
533	0-10	2.48	21	20	1.00	5.63	17.08	17.48
534	0-10	2.37	17	14	0.70	5.89	11.91	13.17
536	0-10	2.48	14	20	1.80	5.88	16.62	14.63
542	0-10	0.65	35	13	0.60	6.91	16.23	13.10
545	0-10	3.17	2	1	0.20	5.56	6.70	7.71
575	0-3	1.01	43	17	0.48	7.5	22.54	14.37
579	0-2	4.04	32	36	2.50	6.7	40.84	33.97
580	0-10	2.92	36	23	1.70	6.6	29.79	32.49
583	0-8	0.18	24	9	0.81	8.2	11.69	16.48

[A] Organic C content

The pedotransfer function for the 0-20 cm depth interval (Noble *et al*. 1997) is:

pH_{BC} = 6.28 - 0.11×clay % + 3.71×OC % - 0.16×silt % + 0.03×silt%×clay % (n = 50) (1)

r^2 = 0.844

where pH_{BC} is the pH buffering capacity (mmol H^+/kg.pH), clay, silt and organic carbon (OC) are the percentage of each of these variables in the soil. pH buffering capacity (pH_{BC}) measurements were made on each sample using the method of Aitken and Moody (1994). In brief, titration curves were established by adding incremental amounts of HCl to soil suspended (1:5) in water. For each titration 5g of soil was weighed into each of six polyethylene tubes and appropriate amounts of deionised water were added such that the final volume was 25 ml. The acid solution was 0.04 *M* (standardised) and for each soil additions of 0, 0.15, 0.25, 0.5, 1.0 and 2.0 ml were made. Additions of 1.0 ml of 0.05 *M* $CaCl_2$ were made to each tube to minimise variations in ionic strength as well as 0.25 ml of chloroform and the suspensions were equilibrated for 24 h at 25°C on an end-over-end shaker. The suspensions were then removed from the shaker and left to equilibrate for a further 6 days at 25°C. Re-suspension of the samples was undertaken on a daily basis by shaking for a 2 min period. After a total of 7 days the pH was measured and pH buffer capacity calculated from the inverse of the slope for the plot of pH versus acid added. Soil organic carbon was determined by the Walkley-Black method (Rayment and Higginson 1992) and particle size as described by Coventry and Fett (1979).

Development of acidity risk map

The rate at which a soil acidifies in a *Stylosanthes* - based pasture system is a function of the percentage of legume in the pasture. Previous measurements of accelerated acidification have shown significantly higher rates under *Stylosanthes* dominant pasture when compared to those exhibiting an equal proportion of both grass and legume (Noble *et al*., 1997). There are numerous factors that influence species dominance in a sward. In the case of *Stylosanthes* it has been suggested that it is a function of management (intensity of grazing and fire), rainfall, inherent soil chemical properties (i.e. pH buffering capacity and soil P content), and the productivity of the pasture (Partridge *et al*. 1996).

In the development of an acidity risk map for the Dalrymple Shire, it was assumed that the establishment of *Stylosanthes* based pastures was confined to areas within the Shire with an average annual precipitation of $\geq$ 500mm. Using the aforementioned pedotransfer function, pH buffering capacities were assigned to selected soil associations that had been identified within the Dalrymple Shire resource assessment survey that is based on the 1:250,000 soil map of Rogers *et al*. (1999). A total of 44 soil associations out of 57 had laboratory data sets that allowed for the calculation of pH buffering capacity using equation 1 (Table 3.2). Using a modification of the model proposed by Helyar and Porter (1989) the following equation was used to calculate the time (T) in years for the pH of the surface soil to drop from its current pH to a pH of 5.0.

$$T = [(pH_i - 5.0) \times pHBC \times BD \times V]/NAAR \quad (2)$$

where T is time in years; pH_i is the current measured soil pH; pHBC is mean pH buffering capacity of the soil association (kmol H^+/kg.pH); BD is the mean soil bulk density calculated for each soil association using the method of Rawls (1983); V is volume of soil in the 0-15 cm depth interval; and NAAR is net acid addition rate (kmol H^+/ha. year) which was assumed to be 2.1 kmol H^+/ha.year based on pastures that are stylo dominant (> 80% stylo) (Noble *et al*. 1997).

Table 3.2. Soil associations of the Dalrymple Shire used in the construction an acidity risk map for the region. Values represent the means of surface horizons ± s.e.

Soil association	Depth (cm)	pH_w	P^A (mg/kg)	OC (%)	Silt (%)	Clay (%)	Time to reach pH 5.0 (year)	pH buffer capacity[B] (mmol H^+/kg.pH)
Amity	0-10	7.20 ± 0.68	24.9±29.1	1.40±0.26	19.0±10.3	43.6±18.0	59.6±28.1	28.5±21.4
Bluff	0-10	6.48±0.50	5.31±3.82	1.02±.0.64	12.6±6.6	11.1±4.6	16.6± 5.4	11.0±4.8
Boston	0-4	6.02±0.57	3.72±2.61	0.57±0.19	7.1±2.5	14.0±4.8	9.8± 4.8	8.7±1.9
Burra	0-10	6.13±.0.65	2.47±1.77	0.66±0.20	6.2±1.8	9.8±3.5	10.1± 5.1	8.5±1.2
Burdekin	0-10	6.46±0.52	23.63±16.46	0.60	7.0	6.0	12.7	7.9
Conjuboy	0-10	6.50±0.44	80.02±60.85	1.84±0.34	24.3±5.7	37.8±3.9	44.0± 15.2	32.7±9.3
Ceaser	0-8	6.59±0.84	8.92±6.74	0.83	12.0	8.0	15.5	9.4
Carse O'Gowrie	0-5	6.50±0.72	4.78±6.65	0.98±0.96	6.00±4.0	4.6±1.5	13.9± 7.4	9.3±3.6
Creek	0-25	6.42±.0.42	6.93±7.57	0.16	2.0	3.0	9.6	6.4
Conolly	0-15	6.48±0.65	8.66±9.88	1.00	6.5±0.7	6.5±0.7	14.2	9.5
Cape	0-10	6.52±0.61	15.35±17.42	2.05±0.35	29.5±13.4	21.5±10.6	34.4± 11.4	25.8±16.2
Corea	0-8	6.24±0.54	2.70±2.59	0.61±0.33	7.6±3.3	11.3±4.7	11.5± 4.5	8.6±2.4
Charters Towers	0-10	6.81±0.52	5.44±3.74	1.07±0.46	7.1±2.1	16.0±5.3	20.3± 6.5	10.7±2.9
Dalrymple	0-10	6.63±0.47	6.70±3.24	0.95±0.28	10.2±2.8	15.7±8.4	19.1± 5.4	11.2±3.6
Dotswood	0-10	6.30±0.44	11.93±18.76	0.66±0.35	20.0±9.8	11.5±0.7	15.3 ± 4.2	11.1±3.4
Egera	0-17	8.01±0.80	2.60±1.18	0.86±0.33	15.5±0.7	49.0±12.7	70.9± 23.2	24.3±6.7
Fanning River	0-10	6.35±0.70	19.36±14.72	0.80±0.14	7.6±2.0	11.6±4.7	13.3±6.0	9.4±1.4
Felspar	0-10	6.76±0.27	85.77±95.87	1.75±0.44	25.8±3.1	45.6±7.8	58.6±19.1	38.9±10.6
Glencoe	0-11	6.66±0.55	62.10±55.01	1.80	34.0	46.0	69.0	49.3
Greenvale	0-10	6.35±0.57	8.50±13.24	0.76±0.40	10.3±1.1	9.0±2.6	13.0±4.9	9.2±2.1
Hillgrove	0-10	6.65±0.27	74.86±90.10	1.49±0.69	33.3±3.0	40.0±7.0	59.9±14.8	42.0±11.9
Lolworth	0-10	6.76±0.41	10.64±11.98	1.68±0.87	17.0±2.8	64.5±10.6	53.2±19.5	35.5±12.5
Liontown	0-10	6.29±0.51	3.54±1.95	0.61±0.31	8.0±4.8	11.5±7.6	12.0±4.4	8.7±3.1
Maryvale	0-10	7.94±0.62	6.72±4.72	0.49±0.02	15.5±2.1	55.5±17.6	72.2±27.2	25.3±9.5

Table 3.2 cont'd.

Soil association	Depth	pH_w	P[A]	OC	Silt	Clay	Time to reach pH 5.0	pH buffer capacity[B]
	(cm)		(mg/kg)	(%)	(%)	(%)	(year)	(mmol H^+/kg.pH)
Mingela	0-10	6.53±0.63	3.38±1.07	0.36±0.15	7.6±2.5	10.3±2.5	13.0±4.8	7.6±1.2
Manoa	0-10	5.89±0.61	23.00±14.14	1.43±0.58	22.6±2.5	41.3±17.6	25.5±16.1	31.5±14.9
Mount Ravenswood	0-14	7.41±0.69	4.44±1.71	0.95±0.20	10.0±1.0	29.6±8.9	34.8±10.8	13.8±3.1
Nosnillor	0-10	6.38±0.70	4.27±2.50	0.70±0.62	4.0±3.5	9.2±5.6	12.4±6.6	8.3±2.8
Pandanus	0-12	6.75±0.47	6.46±4.38	0.45	4.0	7.0	13.5	7.3
Pentland	0-10	6.09±0.55	4.45±2.27	0.91±0.45	7.5±3.1	15.8±6.8	11.8±5.6	10.2±3.4
Pallamana	0-10	6.09±0.61	5.27±7.21	0.54±0.23	5.6±2.3	9.4±5.3	9.0±4.7	7.9±1.4
Paynes	0-5	5.99±0.26	7.60±8.35	1.80	5.0±0.0	8.0±2.8	11.0	12.4
Powlathanga	0-10	6.79±0.83	5.32±3.07	0.84±0.29	17.0±6.4	31.2±4.3	35.1±16.0	19.1±7.8
Rangeview	0-4	6.29±0.56	18.57±20.01	2.30±0.42	17.5±2.1	22.0±5.6	24.3±9.6	21.1±4.9
Rishton	0-10	6.51±0.60	3.61±2.23	0.20	1.0	2.0	10.8	6.7
Rangeside	0-9	6.08±0.67	4.30±3.58	1.11±0.35	5.5±3.0	14.5±8.9	11.5±6.6	10.3±2.6
Scartwater	0-10	6.06±0.45	6.86±2.53	1.23±0.62	11.0±3.9	15.2±4.7	13.2±5.4	12.4±4.5
Two Creek	0-14	6.43±0.79	12.36±11.66	1.05±0.64	10.6±5.5	10.0±7.0	15.4±7.9	10.5±4.6
Tuckers	0-10	6.12±0.94	8.10±7.62	3.93±3.49	11.2±4.2	27.2±4.9	21.4±18.8	25.2±16.8
Victoria Downs	0-5	7.11±0.75	7.96±6.36	1.36±0.45	15.6±1.1	43.0±14.0	48.8±19.9	24.2±8.0
Wambiana	0-10	6.42±0.61	3.30±3.20	0.50	19.0	45.0	36.6	25.7
Wattle Vale	0-10	6.25±0.60	4.08±4.90	0.83±0.83	7.1±6.1	10.0±5.6	12.0±6.2	9.2±4.5
Yarraman	0-10	7.09±0.92	14.62±7.48	1.36±0.47	17.6±4.0	48.3±10.2	54.7±28.2	28.8±11.2

[A] Bicarbonate-extractable P (Colwell 1963)

[B] pH buffer capacity calculated using the following relationship: pH_{BC} = 6.28 - 0.11×clay % + 3.71×OC % - 0.16×silt % + 0.03×silt%×clay %

Development of a field based toolkit

In an effort to develop a simple method of determining the pH buffer capacity of soils in the Dalrymple Shire on a paddock point scale, pH buffer capacity was estimated using a two point pH method. Soils used in this study were the same as those previously described in the validation test. Soil (5 g) was weighed into each of 2 polyethylene tubes. Distilled water was added to the tubes; 24 mL to the first and 23.5 mL to the second. 0.5 mL of 0.04 *M* HCl was added to the second tube and 1.0 mL of 0.05 *M* $CaCl_2$ was added to both tubes. Each tube was shaken manually for approximately 30 s before being left to stand. pH measurements were undertaken at 1, 2, 4, 6 and 24 h. Prior to pH measurements, tubes were manually shaken for approximately 30 s. pH buffer capacity was calculated as follows:

$$\text{pH buffer capacity (mmol } H^+\text{/kg.pH)} = 1/((pH_c - pH_a)/C_a)) \quad (3)$$

where pH_c and pH_a are the pH values for the control and acid addition treatments respectively; C_a is the amount of acid added (mmol/kg) to the soil; this is a constant (40 mmol H^+/kg).

Results

Validation of pedotransfer function

Selected soil properties of the archival soils used in the validation process are presented in Table 3.1. Within the set of samples, clay and organic carbon contents ranged from 2-72% and 0.2-10.3%, respectively, thereby giving an adequate range of these two parameters to test the pedotransfer function. The previously derived pedotransfer function uses clay, silt and organic carbon content to predict pH buffering capacity (see Eqn 1). A highly significant linear regression (predicted pH buffer capacity (mmol H^+/kg.pH) = 0.977($\pm$0.034) measured pH; n = 27, r^2 = 0.885) was observed between measured and predicted pH buffering with no significant deviation of the slope from the 1:1 line (Figure 3.1). This clearly indicates that the previously developed pedotransfer function is effective in predicting pH buffering capacity for the suite of surface soils used in this study.

Development of acidity risk map

In the initial conceptualisation of acidification risk, it was assumed that low soil P status is a factor contributing to *Stylosanthes* dominance in pastures systems. Consequently, soil P status could be used as a variable in differentiating between soils with respect to vulnerability *Stylosanthes* dominance. However, variability in soil P was so high (Table 3.2) at this scale it was not considered to be a meaningful parameter in delineating risk of *Stylosanthes* dominance. Using pH buffering capacity, a map of the Shire was produced at a 1:250 000 scale indicating the potential risk of acidification (Figure 3.2). This map is based on the number of years required to reach a pH of 5.0 in water and a net annual input of 2.1 kmol H^+/ha.year. It should be noted that time taken to reach this pH is dependent on the pH buffer capacity, NAAR, soil bulk density and the initial pH. Therefore alterations to any of these parameters will influence the time to reach some critical pH.

Development of a field assessment tool kit

In order to use the previously discussed pedotransfer function, soil properties of clay silt and organic carbon content are required to predict pH buffering capacity. In general, these measured soil properties are not available at a paddock scale where the assessment of risk is most desirable from a management perspective. Therefore a quick and simple method of estimating soil pH buffering capacity is required to be of relevance at a property/paddock scale.

The results of the different equilibration times associated with the determination of pH buffer capacity using two points are presented in Table 3.3. The estimated pH buffering capacity based on differing equilibration times (1 – 24 h) was regressed against values measured after a 7 day equilibration period. With increasing time the relationship between the aforementioned methods improved, with the

slope of the regression curves decreasing from 4.031 after 1 h to 1.634 after 24 h. From a practical perspective an equilibration of time of 6 h or greater was deemed to be satisfactory in the estimation of pH buffering capacity. Substituting the estimated pH buffering capacity calculated for the (i.e. 6 or 24 h) equilibration period, the pH buffer capacity associated with a 7 day equilibration period could then be predicted and this value substituted along with the measured soil pH into Eqn 3.

Discussion

Based on the data of Gramshaw and Walker (1988) it is estimated that approximately 1 M ha of native pastures have been over-sown to *Stylosanthes* in Queensland. The effect of stylo in these native pastures has been to enhance animal performance and in some cases, increase the carrying capacities of certain pastures. Based on the data of Miller *et al.* (1997) and current beef prices, this translates into a contribution of around $20 - 25M annually to the beef industry (Noble *et al*. 2001).

Table 3.3. Relationship between pH buffering capacity (mmol H^+/kg.pH) as estimated using a short-term equilibration period (x) with that measured after 7 days (y)

Equilibration time (h)	Equation	R^2
1	y = 4.031(±0.705)x – 5.423(±5.495)	0.671
2	y = 3.459(±0.417)x – 6.225(±3.948)	0.811
4	y = 2.562(±0.239)x – 3.463(±2.561)	0.814
6	y = 2.203(±0.196)x – 2.337(±2.359)	0.829
24	y = 1.634(±0.140)x + 0.159(±2.109)	0.841

However, increased use of stylos with accompanying management practices, such as intensive seed/fodder production (with the associated export of plant material), has resulted in accelerated soil acidification and nutrient depletion (Noble *et al*. 1997; Noble *et al*. 1999). In addition, there is clear evidence to suggest that with declining soil pH, the productivity of both native and introduced grass species declines (Noble *et al*. 2001). Consequently, the long-term impact of accelerated acidification associated with stylos may be significant both from an economic and biological perspective. Due to the extensive nature of these production systems, remediation by liming is extremely costly and impractical (Noble *et al*. 1997; Moody and Aitken 1997; Noble *et al*. 1999).

The map in Figure 3.2 clearly shows that a high percentage (62% to acidify to pH 5.0 in 10-20 years) of the Shire has soils that are predisposed to soil acidification. The reason is that a significant proportion of the southern region of the Shire is dominated by light textured surface soils that have a low internal capacity to buffer acid additions. In contrast, the basalt derived soils that predominate in the central northern region of the Shire and the scattered isolated pockets of Vertosols that occur throughout Shire have considerably higher internal buffering capacities and hence would take longer to acidify (> 50 years). It should be borne in mind that the absolute values that are presented in the map and Table 3.2 should be treated with caution since we have assumed a constant rate of acid addition and have not taken into account management factors that may influence the rate of acidification. In addition, there is a high degree of uncertainty associated with some of the estimated values for particular soil associations (Table 3.2). It is quite feasible that rates of acidification will decline as decreases in soil pH reduce nitrogen fixation by the legume component. In addition, pasture species composition may change due to elevated nitrogen levels in the soil thereby influencing rates of acid addition (Coates *et al.* 1997). All of these parameters would influence the time taken to reach some predetermined value. Notwithstanding this, the map clearly indicates areas

within the Shire that are most sensitive to accelerated soil acidification and therefore could be used in broad decision-making by land managers. For example, by differentiating soils that are predisposed to accelerated acidification, a manager may strategically establish *Stylosanthes* in areas where the soils have the capacity to buffer acid inputs. In contrast, in areas of soils with low buffering capacity, managers, aware of the risk of accelerated acidification, can implement management strategies that minimise the risk of *Stylosanthes* dominance (Middleton and Noble, 1998). These may include:

1. Avoidance of excessive grazing pressure, particularly in summer, on native pasture that has been oversown with *Stylosanthes*. Selective and heavy grazing of palatable grasses like black speargrass (*Heteropogon contortus*) will weaken them and reduce their seed production. Over time this can lead to *Stylosanthes* dominance and the ingress of less palatable grasses. Rotational summer spelling is recommended for *Stylosanthes*-based pasture.

2. Use of periodic early summer burning of native pasture with dense *Stylosanthes* so as to reduce *Stylosanthes* populations and promote grass.

3. Including a 'grazing resilient' grass at the time of *Stylosanthes* planting. Grasses like *Urochloa mosambicensis* and *Bothriochloa pertusa* compete strongly with *Stylosanthes* and can tolerate a heavy grazing pressure when needed.

4. Use of phosphorus fertiliser (or a high fertility soil) to promote greater grass competition and use of nitrate before leaching, a significant contributor to acidification.

5. Intensive management of *Stylosanthes* as a fodder crop on small areas may assist in reducing the risk of widespread acidification on individual properties. This would result in maximum productivity being achieved and allow for prophylactic applications of lime to be applied. Such systems are being used in southern China (Liu Goudoa *et al.* 1997).

Whilst it may be argued that the mapping exercise is at a scale too coarse to be of value to the producer who manages a property at the paddock scale, the development of a simple test based on the development of a two point buffer curve may assist in assessing risk at this scale. All that is required is a pH meter and two reagents (namely HCl and $CaCl_2$). A simple spreadsheet program has been developed that allows the operator to enter the two pH measurements, alter the bulk density of the soil and net acid addition rate, which is dependent on the degree of stylo dominance.

For the majority of regions throughout northern Australia soil resource information is not at an appropriate scale for determining acidification risk. A simple equilibration test is proposed and a computer-spreadsheet program has been developed to estimate the time taken to reach some predetermined pH level. Whilst accelerated soil acidification under *Stylosanthes*-based pasture systems is a potential risk to long-term sustainability, knowledge of the risk, coupled with appropriate management strategies could minimize acidification rates.

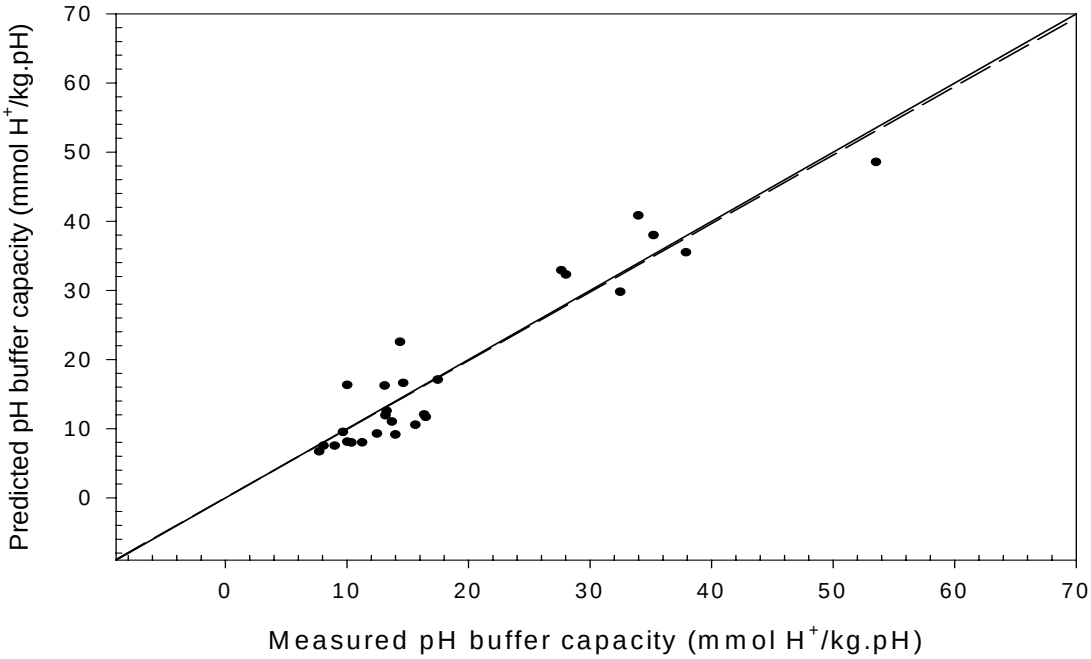


Figure 3.1. Validation of predicted pH buffering capacity against measured values for 27 surface soil samples (A horizon) from the Dalrymple Shire. Equation for the solid line forcing the intercept through zero is: $y = 0.978(\pm 0.035)\ x$; $r^2 = 0.885$; n = 27. Dashed line is the 1:1 line.

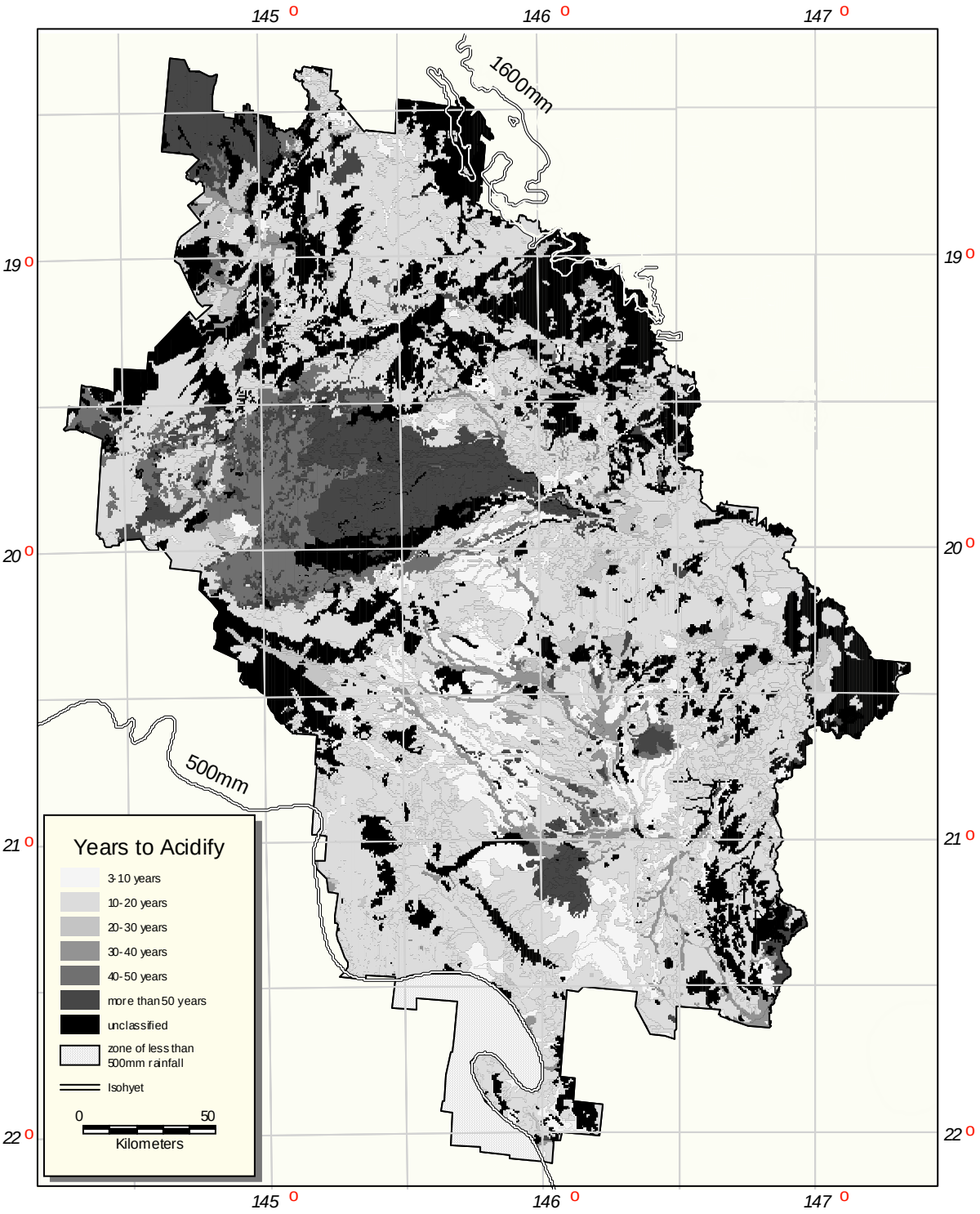


Figure 3.2. Acidification risk map for the Dalrymple Shire based on the time required for the soil pH to decline to 5.0. The grids show latitude (ºS) and longitude (ºE).

ii. Field Based Tool Kit for the Assessment of Acidity Risk

Background

The development of a simple tool kit to assess the predisposition of soils to accelerated soil acidification would significantly assist managers in planning the establishment of legume based pasture systems. Of importance in assess the predisposition of soils to accelerated soil acidification is quantification of the pH buffer capacity (pHBC). Soil pHBC is an intrinsic property of a soil that effectively describes its ability to resist shifts in soil pH. It is generally agreed that this property is a function of soil pH and clay and organic matter content. Often the pHBC is approximately constant within the pH range 4.5 – 6.0 (Magdoff and Bartlett, 1985) and therefore a single value is used.

Quantification of soil pHBC is undertaken using several different methodologies that include laboratory and field based assessments. In the initial development of a field based tool kit to assess acidity risk, the key functions associated with this method was the measurement of soil pH using a field electronic pH meter and the determination of field based soil texture. A concern that we had with this method was that the use of field texture precluded any assessment of the contribution of soil organic carbon to buffering capacity. Since a large number of soils exhibiting accelerated soil acidification are light textured, the contribution of soil organic matter to buffer capacity is significant. In an effort to rectify this deficit a simple method of determining directly the pHBC of soils is proposed.

Methodology

The most direct method of assessment of buffering capacity is by measuring pH changes through the addition of either acid or base. In previous studies pH buffering capacity measurements have been made on a range of samples the method of Aitken and Moody (1994). This method entails a 7 day equilibration period. As discussed previously, modifications were made to the method where by a significant relationship between a 7 day equilibration period over a range of acid inputs was found with that of a 2 point determination undertaken over a 6 hr period. In this study we have expanded the range of soils tested to include a set of 50 soil samples submitted to our laboratory for buffer capacity determination by Mr M. McCaskill of Victoria Agriculture. These samples were collected from an MLA funded study and processed in a similar fashion as previously discussed to determine pHBC over 16 hr and 7 days respectively. These data were then combined with the Dalrymple data to form a comprehensive data set from which regression analysis was undertaken to derive a unifying equation that estimates pHBC at 7 days from a 2 point 6 hr determination A highly significant linear correlation was observed the 2 point measured pHBC and the 7 day equilibration measure (Figure 3.3). With this information a simple Excel Spreadsheet program was developed by which requires the following steps to be undertaken to generate data for input into the spreadsheet. There are three stages in this process of assessment and detail to precision and accuracy should be strictly adhered to.

Step 1. Collection of a representative soil sample and preparation;

Step 2. Measurement of pH;

Step 3. Using pH measurements, an assessment of acidification risk is made using the calculator.

Step 1. Collection of soil

1. Take a clean bucket into the paddock and collect surface soil samples (0-15 cm) using a soil auger or spade.

2. Collect samples randomly from a minimum of 5 locations in the paddock that exhibit uniform soil characteristics and place them in the bucket.

3. Spread the soil in a thin layer on a clean plastic sheet taking care to break up clods. Allow the soils to air dry, which may take several days.

4. Mix the soil thoroughly once it is dry making sure there are no clods. If possible pass the soil through a 2 mm screen to give a uniform particle size.

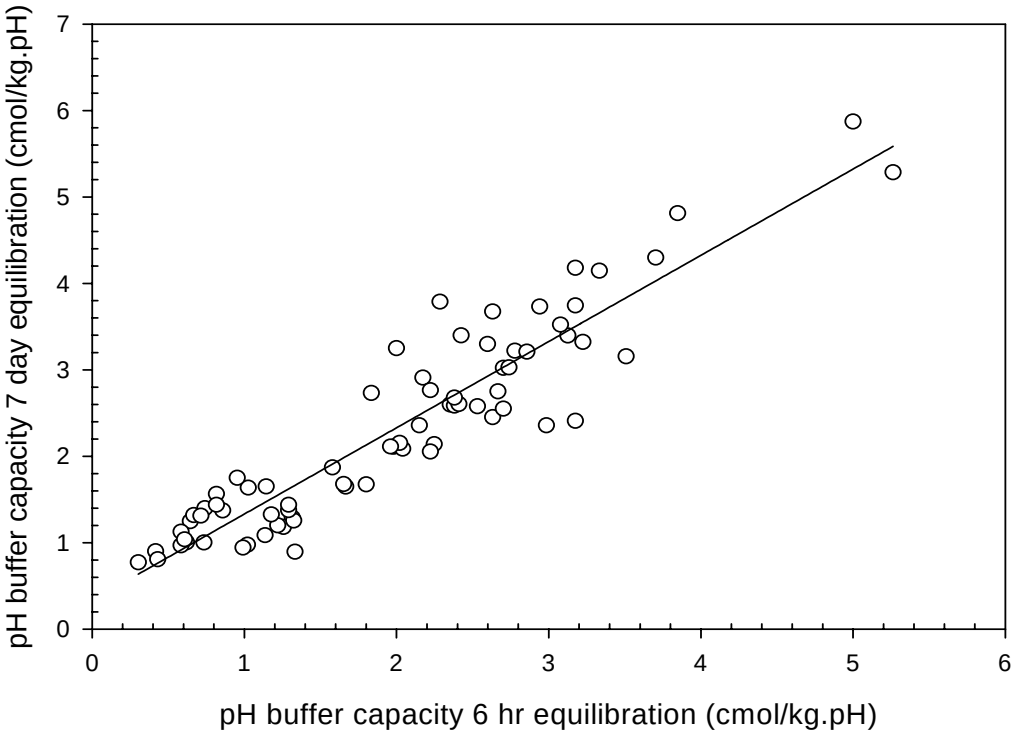


Figure 3.3. Relationship between 2 point determination of pH buffer capacity and that measured after a 7 day equilibration period using combined data from the Dalrymple Shire and southern Australia. Equation: y =0.332 + 0.998x; r^2 = 0.867; n = 74.

Step 2. Measurement of pH

1. For each of your surface soil samples weigh out two 5g lots of soil into two clean 50 ml polyethylene centrifuge tubes labelled "control" and "acid" that have screw tops.

2. 24 ml of distilled water is added to one of the tubes (control) and 23.5 ml added to the other (acid). 0.5 ml of 0.04 M HCl is added to the tube labelled "acid" and a further 1.0 ml of 0.05 M CaCl2 is added to both tubes. Replace the screw tops and shake each tube vigorously for approximately 30 sec. Allow to stand for 6 hr.

3. After 6 hrs, again vigorously shake the tubes before measuring the pH using a calibrated pH meter.

Step 3. Calculation of acid risk

1. Input the pH measurements after 6hr incubation into the Excel Spreadsheet in order to calculate the pH buffer capacity of the soil and the time to acidify to some predetermined pH.

The calculator spreadsheet to input the pH measurements is as follows:

Estimation of rate of acidification using a pH measurement technique.				
Inputs:			Outputs:	
1. What is the depth from which the sample was collected? Input depth from which the soil sample was collected i.e. 15 cm	15.00		1. Estimated pH buffering capacity from short-term incubation. Units: mmol H/kg.pH	14.81
2. Estimate the bulk density of the soil. This value will range from 1.2 - 1.5 g/cm3. For a lose, sandy loam the bulk density will be approximately 1.2 g/cm3, whilst a compacted surface soil may have a bulk density of 1.5 g/cm3.	1.50		2. Estimated pH buffering capacity after 1 week incubation. Units: mmol H/kg.pH	15.12
3. What is the pH of the "control" soil after 6 hr equilibration?	5.51		3. Time in years for the soil pH to drop to target pH	**6.87**
4. What is the pH of the soil labelled "acid" after 6 hr equilibration?	5.24			
5. What is the target pH that the soil is allowed to decrease to? Suggested pH value is 5.0	5.00			

6. What is the Net Acid Addition Rate? See Table 1 for suggested values.	2.50			
Table 1. Rates of annual acid addition for different production systems				
	NAAR (kmol H/ha/yr			
1. *Stylosanthes*/grass pasture with < 50 % Stylos	0.50			
2. *Stylosanthes*/grass pasture with > 50 % Stylos.	2.50			
3. *Stylosanthes* seed production system.	10.60			

This test is designed for use by either graziers or extension personnel and focuses on the establishment of a risk index, which is a measure of the number of years for the soil at its current pH to decline to a base pH of 5.0 in water. By varying the inputs such as bulk density and degree of *Stylosanthes* dominance, an estimate of the time required to achieve a predetermined pH at a set input of acid can be calculated.

This simple test has been shown to be robust and simple to use. It is suggested this methodology of directly determining the pHBC of a soil will enable producers to make informed decisions as to the establishment of legume based pasture systems.

4. Development of Sustainable Legume Based Production Systems

i. Assessing the impact of selected management systems currently used in Stylosanthes *pastures on rates of acidification.*

Background

Assessment of acidification under *Stylosanthes* based pasture systems both in Australia and southeast Asia has been confined to evaluating extreme situations i.e. either *Stylosanthes* dominance or native pastures. From a grazing perspective these two cases do not represent the desirable combination of species in a sward. In general, there are several different pasture/legume/tree combinations that exist on properties and experimental sites throughout northern Australia that represent what could be termed the norm or current practice. In this respect, an assessment of changes in soil chemical properties associated with these different production systems may give insight into their long-term impact on the soil resource base. An evaluation of the influence of these different pasture/legume/tree combinations on soil chemical properties needs to be assessed in order to devise sustainable pasture legume production systems for the semi-arid tropics.

The objective of this activity is to evaluate the impact of different *Stylosanthes* management strategies implemented at two locations Carfax (Central Queensland) and Springmount Mareeba (north Queensland), on the soil chemical properties. In the first case a less comprehensive assessment of the effect of different management strategies on soil properties was undertaken at the request of Dr Bill Burrows (DPI Rockhampton).

Methodology

'Carfax' site Central Queensland

The property 'Many Waters' (previously part of Carfax) is owned by Mr K. Jepperson. It was established as a PDS trial site in 1981/82 when it was sown to Fitzroy stylos. Two 100 ha paddocks were burnt in December 1981 and 1 kg ha^{-1} of Fitzroy stylo was flown on. The strike was poor and another 1 kg ha^{-1} was flown on in December 1982. In October 1987 another 1 kg ha^{-1} of *Stylosanthes scabra* mixture (including Seca) was sown by hand broadcasting because the Fitzroy stylo had succumbed to anthracnose. In November 1988 one half of each paddock was treated with 'GrasLan'. The treatments selected for comparisons were:

1. GrasLan (grass dominant)

2. *Stylosanthes* + GrasLan

3. *Stylosanthes* + Trees

A paired pasture area approach was used to estimate the effect of *Stylosanthes* pasture on rates of soil acidification. The selection of sites was based on the following criteria: (1) the existence of a grass dominated pasture (undeveloped area) in close proximity to a *Stylosanthes* dominated pasture (developed area) of known history; (2) a well defined boundary (i.e. fence line) separating the two production areas; (3) the same soil type in both areas; and (4) little topographical difference (i.e. slope) between the two areas. Samples were taken at five points in each area along a transect at right angles to the fence line. Sampling points were 10 m apart and at each point three individual soil cores (diameter 50 mm) were taken and bulked to form a composite sample for that point. Cores were sectioned into the following depth intervals; 0-5, 5-10, 10-15, 15-20, 20-30, 30-50, 50-70 and 70-90 cm except where a horizon change occurred or where parent material/bedrock was encountered. In the former case, the sample was split between horizons.

Soil analysis

Samples were air dried and sieved to pass a 2 mm mesh before pH was measured in both water (pH_w) and 0.01 *M* $CaCl_2$ (pH_{Ca}) using 1:5 soil:solution. The pH_{Ca} measurements are presented in preference pH_w because dilute salt solution assists in reducing seasonal effects due to variations in soil solution salt concentrations.

Statistical analysis

Statistical analysis of the data was undertaken using Genstat5. Preliminary analysis of the pH data was undertaken to determine whether transformation was required to standardise the variances. A simple ANOVA was used to analyse the data at a site by individual depth interval basis. In the case of the 'Carfax' site the distance between sampling paired sites in the *Stylosanthes* + Tree treatments was considerable, therefore an ANOVA was undertaken on samples collected from different sites (sites 3 and 5 Table 1) to determine whether there were significant differences between sampling points within this treatment. No significant differences due to sampling position in the paddock were observed therefore an analysis incorporating all three treatments was undertaken.

'Springmount' site north Queensland

Soil samples were collected in December 1998 from selected treatments within replication II of a long-term grazing trial established in 1982 at Springmount, Mareeba. Six treatments were selected from the suite of treatments applied on the basis of the fertilizer strategies imposed and the vegetation composition. These treatments were as follows:

1. Native pasture (T1)

2. Native pasture + *Stylosanthes* (T2)

3. Native pasture + *Stylosanthes* + 10 kg P ha^{-1} applied initially (T4)

4. Native pasture + *Stylosanthes* + 25 kg P ha^{-1} initially + 5 kg P ha^{-1} yr^{-1} thereafter (T6)

5. Native pasture + *Stylosanthes* + 5 kg P 2 yr^{-1} + P supplement (T7)

6. Native pasture + *Stylosanthes* + 10 kg P ha^{-1} applied initially + P supplement (T8).

Soil samples were collected from each of the aforementioned treatments by taking 50 mm diameter cores to approximately 70 cm depth at three positions in the plot each sampling point being approximately 10 m apart. Cores were sectioned into the following depth intervals: 0-10, 10-20, 20-30, 30-50 and 50-70 cm.

Samples were air dried and sieved to pass a 2 mm mesh before pH was measured in both water and 0.01 *M* $CaCl_2$ using a 1:5 soil:solution ratio. Basic exchangeable cations and CEC were determined by atomic absorption spectrometry after replacement with 0.1 *M* $BaCl_2/NH_4Cl$ as recommended by Gillman and Sumpter (1986). The effective cation exchange capacity (ECEC) was calculated as the sum of basic cations (Ca^{2+} + Mg^{2+} + K^+ + Na^+). On the basis of the soil pH in water being greater than 5.5, exchangeable acidity was not determined on samples. Soil organic carbon was determined by wet oxidation using the Walkley and Black method as modified by Rayment and Higginson (1992). Mineral nitrogen (N) in the soil profile was determined by extracting 10 g of air dried soil in 50 mL 2 *M* KCl for 1 h. The extract was filtered and analysed for nitrate-N and ammonium-N using auto analyser techniques (Markus *et al*., 1985). Total N was determined by the standard Kjeldahl method of Rayment and Higginson (1992). Bicarbonate P was determined on all samples using the methodology as described by Rayment and Higginson (1992).

Results and discussion

'Carfax' site

The impact of selected treatments imposed on the PDS site at Carfax are presented in Figure 4.1. The introduction of *Stylosanthes* in combination with an application of GrasLan has resulted in significant declines in soil pH_{Ca} to depth when compared to the grass dominant treatment. The retention of the tree component in the presence of *Stylosanthes* did not significantly differ from the grass dominant system although there was a general decline in soil pH_{Ca} with depth (Figure 4.1).

The results from this initial assessment of contrasting vegetation management clearly indicate that the introduction of *Stylosanthes* and subsequent dominance of this species in a pasture has resulted in a measurable and significant decline in soil pH over a relatively short period of time. These results confirm previous observations in pastures that have been sown to *Stylosanthes* (Noble *et al*, 1997). It would appear from these results that the retention of trees in a paddock oversown to *Stylosanthes* had less of an impact than where the trees had been killed through the application of GrasLan. In managing soil acidification in the presence of legume dominant pastures the retention of the tree component may assist in reducing accelerated acidification, however, it is suggested that this may be at the expense of increased productivity.

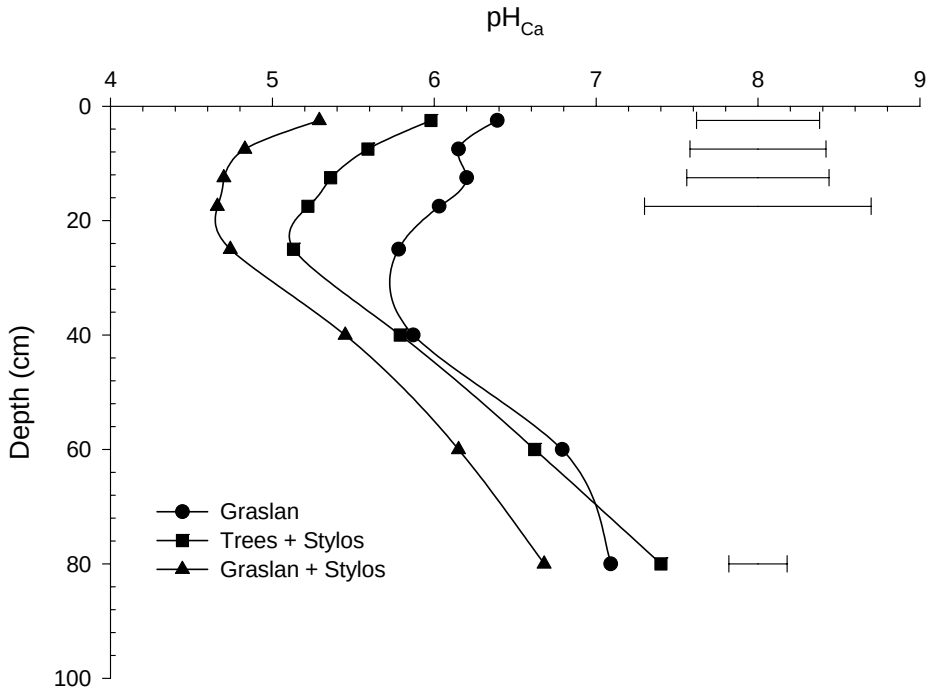


Figure 4.1. Changes in soil pH under contrasting vegetation management strategies associated with the introduction of *Stylosanthes* at Carfax, Central Queensland.

'Springmount' site

Changes in soil chemical properties.

The effect of different pasture management strategies on selected soil chemical properties is presented in Tables 4.1-4.6. In an effort to pictorial represent changes in selected chemical attributes of soils under different management regimes, the following relationship was calculated and plotted graphically in Figures 4.2: $(T1-T_i)$

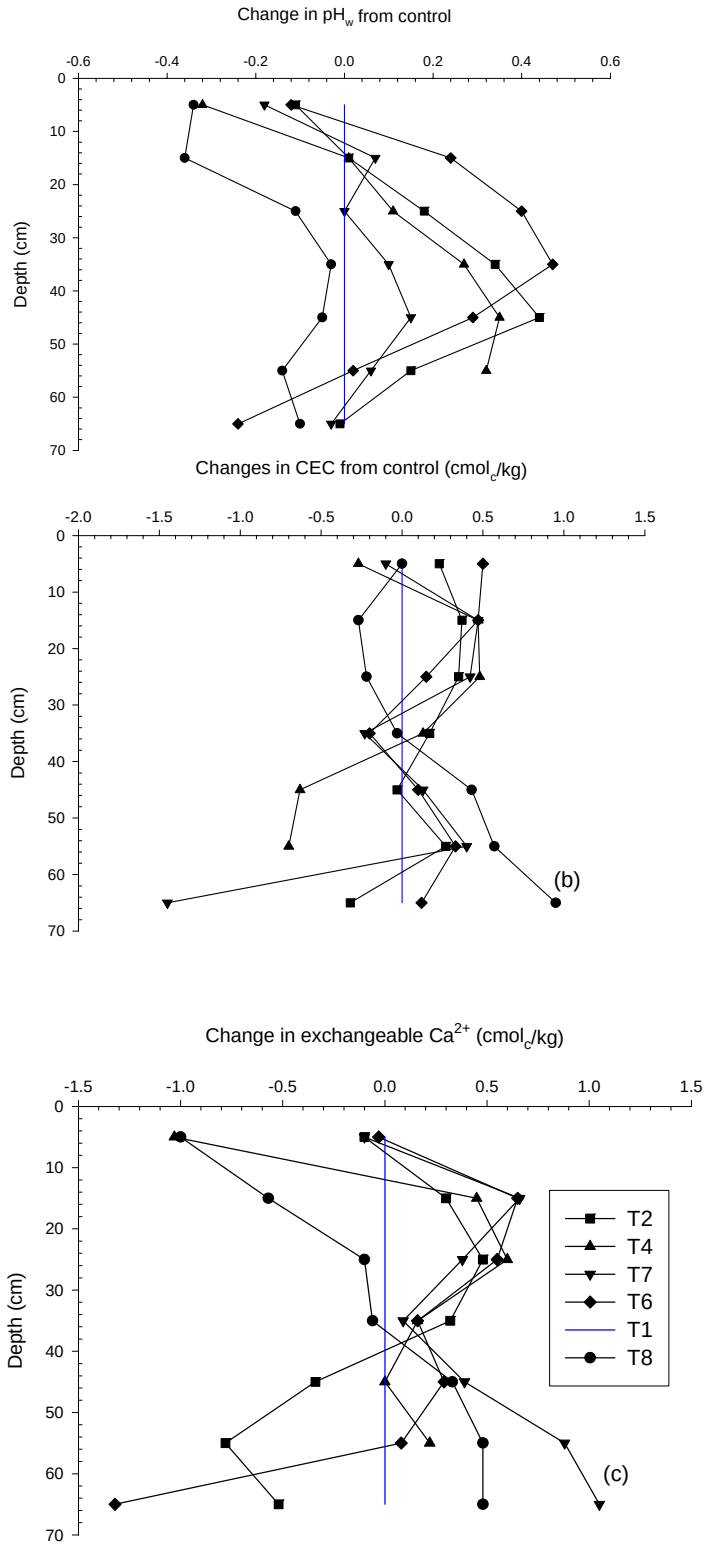


Figure 4.2. Changes is soil (a) pH; (b) CEC and (d) exchangeable Ca^{2+} from the control (native pasture T1 blue line i.e. T1 - T_i) associated with contrasting vegetation management strategies. A negative value indicates a higher value for the attribute in treatment T_i, whilst a positive value indicates a higher value in control (native pasture T1).

where T1 is the value of the parameter under consideration for the native pasture treatment (T1) and T_i is the same parameter as measured in the treatment under consideration.

Charges in soil pH, CEC and exchangeable Ca^{2+} from the control (native pasture) are presented in Figure 4.2. Note that a positive value indicates a higher value in the control treatment. The greatest decline in pH was observed over the depth interval 15-60 cm with treatment T6 (Native pasture + *Stylosanthes* + 25 kg P ha^{-1} initially + 5 kg P ha^{-1} yr^{-1}) showing the greatest degree of pH decline. Other than treatment T8, all other treatments showed a decline in pH associated with changed management strategies. However, it should be noted that those treatments exhibiting a decline in pH, this decline ranged from 0.05 to 0.45 pH units (Figure 4.2). The fact that surface (0-10 cm) samples in all treatments had higher pH values than the native pasture control can largely be attributed to the increased soil organic matter content that would increase the buffering capacity of the soil (Table 4.1-4.6).

In contrast, changes in CEC and exchangeable Ca^{2+} were confined to the 15-35 and 15-25 cm respectively. It is of note that there is a degree of variability with respect to CEC between treatments, however, this would not entirely explain the decline in soil pH at depth associated with the imposed management systems. It would appear from these results that improved management systems have had an effect on soil chemical properties with respect to increased acidity at depth and declining exchangeable Ca^{2+}.

Table 4.1. Selected soil chemical properties of treatment T1 (Native pasture) 16 years after changed land management. Figures in parenthesis are the standard error of the mean (SE).

Depth				Exchangeable cations				Exchange capacity		Total N	NO_3 - N	NH_4 - N
(cm)	pH_w	pH_{ca}	OC	Ca^{2+}	Mg^{2+}	K^+	Na^+	ECEC	CEC			
			(%)	($cmol_c$/kg)				($cmol_c$/kg)		(%)	(mg/kg)	(mg/kg)
0-10	6.12(0.03)	5.11(0.04)	0.89(0.02)	2.27(0.20)	0.41(0.02)	0.21(0.02)	0.03	2.91(0.23)	3.77(0.28)	0.05	0.70(0.13)	1.98(0.25)
10-20	6.13(0.04)	5.10(0.06)	0.56(0.04)	1.63(0.24)	0.31(0.03)	0.16(0.01)	0.03	2.13(0.27)	2.73(0.22)	0.04	<1	1.48(0.26)
20-30	6.23(0.09)	5.14(0.08)	0.47(0.04)	1.44(0.28)	0.33(0.08)	0.15(0.02)	0.03	1.95(0.35)	2.32(0.29)	0.03	<1	1.63(0.45)
30-40	6.35(0.12)	5.29(0.10)	0.33(0.04)	1.25(0.22)	0.32(0.06)	0.15(0.02)	0.03	1.75(0.28)	2.10(0.24)	0.03	1.53(1.03)	1.20(0.32)
40-50	6.36(0.11)	5.35(0.09)	0.30(0.04)	1.56(0.31)	0.46(0.07)	0.20(0.03)	0.03	2.25(0.40)	2.50(0.33)	0.03	1.55(1.05)	0.92(0.31)
50-60	6.26(0.11)	5.34(0.10)	0.30(0.05)	2.12(0.22)	0.72(0.05)	0.25(0.02)	0.03	3.12(0.24)	3.03(0.30)	0.03	<1	0.60(0.10)
60-70	6.14(0.18)	5.27(0.20)	0.24(0.03)	2.52(0.23)	0.88(0.07)	0.28(0.02)	0.04	3.72(0.24)	3.68(0.11)	0.03	<1	0.68(0.18)

Table 4.2. Selected soil chemical properties of treatment T2 (native pasture + *Stylosanthes*) 16 years after changed land management. Figures in parenthesis are the standard error of the mean (SE).

Depth (cm)	pHw	pHca	Organic C	Exchangeable cations				Exchange capacity		Total N	NO_3 -N	NH_4 - N
				Ca^{2+}	Mg^{2+}	K^+	Na^+	ECEC	CEC			
				($cmol_c/kg$)				($cmol_c/kg$)		(%)	(mg/kg)	(mg/kg)
0-10	6.23(0.21)	5.57(0.19)	0.86(0.11)	2.37(0.43)	0.50(0.06)	0.26(0.04)	0.023(0.003)	3.15(0.49)	3.53(0.47)	0.043(0.007)	0.50	1.60(0.17)
10-20	6.12(0.03)	5.34(0.03)	0.45(0.01)	1.33(0.12)	0.36(0.04)	0.17(0.02)	0.023(0.003)	1.88(0.18)	2.37(0.18)	0.020	0.50	0.50
20-30	6.05(0.02)	5.26(0.02)	0.35(0.01)	0.96(0.02)	0.30(0.00)	0.14(0.01)	0.023(0.003)	1.42(0.02)	1.97(0.07)	0.013(0.003)	0.50	0.90(0.21)
30-40	6.01(0.03)	5.20(0.03)	0.28(0.02)	0.93(0.13)	0.33(0.07)	0.16(0.02)	0.033(0.003)	1.45(0.21)	1.93(0.19)	0.008(0.002)	0.50	0.50
40-50	5.93(0.07)	5.17(0.08)	0.34(0.04)	1.90(0.25)	0.69(0.13)	0.28(0.02)	0.033(0.007)	2.91(0.40)	2.53(0.64)	0.012(0.004)	0.50	0.50
50-60	6.11(0.03)	5.37(0.06)	0.36(0.02)	2.90(0.10)	1.10(0.10)	0.35(0.04)	0.033(0.003)	4.38(0.07)	2.77(0.74)	0.010	0.50	0.70(0.20)
60-70	6.15(0.07)	5.53(0.04)	0.34(0.04)	3.03(0.22)	1.20(0.20)	0.36(0.04)	0.097(0.062)	4.69(0.49)	4.00(0.26)	0.010	1.13(0.63)	1.20(0.70)

Table 4.3. Selected soil chemical properties of treatment T4 (Native pasture + *Stylosanthes* + 10 kg P ha $^{-1}$ applied initially) 16 years after changed land management. Figures in parenthesis are the standard error of the mean (SE).

Depth				Exchangeable cations				Exchange capacity		Total N	NO_3 - N	NH_4 – N
(cm)	pH_w	pH_{ca}	Organic C	Ca^{2+}	Mg^{2+}	K^+	Na^+	ECEC	CEC			
				($cmol_c$/kg)				($cmol_c$/kg)		(%)	(mg/kg)	(mg/kg)
0-10	6.44(0.23)	5.76(0.29)	1.11(0.16)	3.30(0.72)	0.48(0.10)	0.19(0.01)	0.023(0.003)	4.00(0.82)	4.03(0.43)	0.667(0.014)	0.5	2.63(0.12)
10-20	6.12(0.28)	5.40(0.36)	0.48(0.06)	1.18(0.36)	0.25(0.03)	0.16(0.02)	0.017(0.003)	1.61(0.38)	2.27(0.30)	0.027(0.009)	0.5	0.80(0.30)
20-30	6.12(0.13)	5.28(0.24)	0.35(0.06)	0.84(0.03)	0.24(0.01)	0.17(0.03)	0.017(0.007)	1.26(0.04)	1.83(0.17)	0.023(0.007)	0.5	0.50
30-40	6.08(0.08)	5.27(0.11)	0.32(0.04)	1.09(0.16)	0.53(0.17)	0.25(0.07)	0.023(0.003)	1.90(0.39)	1.97(0.23)	0.016(0.003)	0.5	0.50
40-50	6.01(0.16)	5.29(0.05)	0.34(0.03)	1.56(0.39)	0.89(0.31)	0.27(0.06)	0.030(0.000)	2.76(0.75)	3.13(0.42)	0.020(0.006)	0.5	0.50
50-60	5.94(0.12)	5.27(0.06)	0.37(0.05)	1.90(0.42)	1.14(0.36)	0.29(0.06)	0.037(0.003)	3.37(0.83)	3.73(0.52)	0.023(0.003)	0.5	0.50

Table 4.4. Selected soil chemical properties of treatment T6 (Native pasture + *Stylosanthes* + 25 kg P ha^{-1} initially + 5 kg P ha^{-1} yr^{-1} thereafter) 16 years after changed land management. Figures in parenthesis are the standard error of the mean (SE).

Depth				Exchangeable cations				Exchange capacity		Total N	NO_3 - N	NH_4 - N
	pHw	pHca	OC	Ca	Mg	K	Na	ECEC	CEC			
(cm)				($cmol_c/kg$)				($cmol_c/kg$)		(%)	(mg/kg)	(mg/kg)
0-10	6.24(0.20)	5.29(0.11)	1.02(0.14)	2.30(0.32)	0.49(0.07)	0.41(0.11)	0.02	3.22(0.42)	3.87(0.39)	0.05(0.01)	<1	3.23(0.52)
10-20	5.89(0.08)	4.90(0.05)	0.50(0.03)	0.98(0.17)	0.18(0.02)	0.27(0.04)	0.02	1.45(0.21)	2.27(0.18)	0.03	<1	1.93(0.28)
20-30	5.83(0.13)	4.92(0.07)	0.40(0.03)	0.88(0.06)	0.20(0.03)	0.20(0.03)	0.02	1.30(0.10)	1.90(0.40)	0.03	<1	1.93(0.38)
30-40	5.88(0.05)	5.07(0.02)	0.33(0.06)	1.09(0.15)	0.31(0.03)	0.14(0.01)	0.02(0.01)	1.57(0.17)	2.33(0.15)	0.03	<1	1.67(0.33)
40-50	6.07(0.08)	5.26(0.05)	0.35(0.06)	1.27(0.12)	0.45(0.06)	0.17(0.04)	0.02	1.91(0.18)	2.37(0.09)	0.02	<1	1.90(0.87)
50-60	6.24(0.12)	5.46(0.10)	0.34(0.05)	2.03(0.13)	0.81(0.06)	0.22(0.02)	0.02	3.08(0.06)	2.63(0.20)	0.03	<1	0.80(0.30)
60-70	6.38(0.23)	5.62(0.21)	0.53(0.19)	3.83(1.18)	1.33(0.13)	0.28	0.03	5.48(1.32)	5.13(1.16)	0.03	<1	1.40(0.45)

Table 4.5. Selected soil chemical properties of treatment T7 (Native pasture + *Stylosanthes* + 5 kg P 2 yr^{-1} + P supplement) 16 years after changed land management. Figures in parenthesis are the standard error of the mean (SE).

Depth (cm)	pH_w	pH_{ca}	Organic C	Exchangeable cations Ca^{2+}	Mg^{2+}	K^+	Na^+	Exchange capacity ECEC	CEC	Total N	NO_3 - N	NH_4 - N
				($cmol_c/kg$)				($cmol_c/kg$)		(%)	(mg/kg)	(mg/kg)
0-10	6.30(0.18)	5.43(0.16)	1.01(0.20)	2.370.32	0.55(0.08)	0.34(0.03)	0.020(0.006)	3.28(0.42)	3.27(0.03)	0.05(0.01)	0.5	1.23(0.73)
10-20	6.06(0.14)	5.17(0.10)	0.53(0.07)	0.970.13	0.31(0.05)	0.25(0.04)	0.023(0.003)	1.55(0.14)	2.27(0.13)	0.04	0.5	1.43(0.48)
20-30	6.23(0.08)	5.31(0.06)	0.39(0.02)	1.060.28	0.33(0.06)	0.21(0.05)	0.017(0.003)	1.61(0.27)	2.17(0.22)	0.03	0.5	0.67(0.17)
30-40	6.25(0.13)	5.40(0.13)	0.38(0.03)	1.160.18	0.49(0.07)	0.22(0.05)	0.020	1.89(0.17)	2.30(0.06)	0.02	0.5	0.50
40-50	6.21(0.10)	5.43(0.10)	0.38(0.04)	1.170.03	0.92(0.14)	0.24(0.04)	0.020	2.34(0.19)	2.40(0.10)	0.03	0.5	0.50
50-60	6.20(0.06)	5.49(0.05)	0.31(0.01)	1.230.09	1.20(0.12)	0.27(0.05)	0.023(0.003)	2.72(0.23)	2.70(0.29)	0.02	0.5	0.50
60-70	6.17(0.08)	5.47(0.07)	0.31(0.04)	1.470.07	1.33(0.09)	0.36(0.04)	0.033(0.003)	3.19(0.07)	3.57(0.03)	0.02	0.7(0.2)	0.50

Table 4.6. Selected soil chemical properties of treatment T8 (Native pasture + *Stylosanthes* + 10 kg P ha $^{-1}$ applied initially + P supplement) 16 years after changed land management. Figures in parenthesis are the standard error of the mean (SE).

Depth				Exchangeable cations				Exchange capacity		Total N	NO_3 - N	NH_4 - N
	pHw	pHca	OC	Ca	Mg	K	Na	ECEC	CEC			
(cm)				($cmol_c$/kg)				($cmol_c$/kg)		(%)	(mg/kg)	(mg/kg)
0-10	6.46(0.08)	5.59(0.10)	1.09(0.14)	3.27(0.62)	0.48(0.03)	0.24(0.01)	0.02	4.01(0.63)	3.77(0.42)	0.07(0.01)	0.86	2.73(0.18)
10-20	6.49(0.06)	5.55(0.22)	0.63(0.11)	2.20(0.60)	0.39	0.18(0.04)	0.03	2.79(0.56)	3.00(0.30)	0.05(0.01)	0.80	2.65(0.15)
20-30	6.33(0.14)	5.37(0.18)	0.49(0.08)	1.53(0.24)	0.37(0.02)	0.16(0.01)	0.02	2.09(0.25)	2.53(0.07)	0.04	<1	1.27(0.38)
30-40	6.38(0.24)	5.35(0.24)	0.40(0.07)	1.31(0.32)	0.37(0.08)	0.15(0.01)	0.03	1.86(0.39)	2.13(0.23)	0.03(0.01)	<1	1.07(0.30)
40-50	6.41(0.21)	5.40(0.20)	0.29(0.03)	1.23(0.12)	0.45(0.09)	0.18(0.02)	0.03	1.89(0.21)	2.07(0.09)	0.03	<1	1.00(0.26)
50-60	6.40(0.14)	5.44(0.19)	0.32(0.05)	1.63(0.34)	0.67(0.08)	0.25(0.04)	0.03	2.58(0.42)	2.47(0.23)	0.03	<1	0.67(0.17)
60-70	6.24(0.18)	5.40(0.18)	0.38(0.07)	2.03(0.32)	0.96(0.02)	0.27(0.01)	0.04	3.30(0.35)	2.73(0.37)	0.04	0.93	0.97(0.47)

ii. Assessing the long-term impact of soil acidification on chemical properties and the amelioration of acidity through litter ash additions in soil columns.

a. Determination of the ash alkalinity of **Stylosanthes***, grass and tree species.*

Background

Soil acidification and its associated impacts, both on and off site, have been identified as a major limitation to sustainable crop and pasture production. Helyar (1991) suggested a number of broad approaches in the management of soil acidity to prevent acidification and treat acid soil. These included (i) minimising net acid production in an ecosystem by reducing acidifying inputs, reducing unnecessary product and by-product removal and reducing nutrient losses that are associated with acid accumulation in soils; (ii) the growing of species adapted to the current soil acidity so as to maximise the recycling of soil nutrients and water; (iii) the addition of liming materials to neutralise the acidity; (iv) the growing of tolerant plants using inputs such as tolerant rhizobia and molybdenum, in order to maintain production on acid soils.

Where it is economically feasible, amelioration of acid soil with lime is generally the preferred option. However, in many low input/output production systems, addition of liming materials does not increase gross margins sufficiently to make the practice economic. This occurs in many situations, including some extensive, legume-based grazing systems of both southern and northern Australia, where production has been maintained with relatively tolerant species after correcting gross deficiencies of phosphorus and trace elements (Williams and Andrew, 1970). However, the soils under these pastures have continued to acidify because the acidity generated through product export and through mineralization of organic N followed by nitrate leaching, has not been neutralised. In the past decade, attention has been paid to strategies which may reduce rates of acid addition such as the use of deeper rooted perennial grass species in pasture instead of annuals, in order to reduce losses of nitrate by leaching (Ridley et al*.,* 1990).

The benefits of incorporating organic matter into acid soils are well recognised (Thomas and Hargrove, 1984; Hue and Amien, 1989). However, until recently, there has been relatively little attention paid to the direct role of organic matter in acidification-alkalisation reactions in the soil (Noble et al., 1996; Yan et al., 1996; Pocknee and Sumner, 1997). With respect to soil pH, conflicting reports of the effects of organic matter are contained in the literature. There are reports of both an increase (Bessho and Bell, 1992; Tyson and Cabrera, 1993) and decrease (Tyson and Cabrera, 1993; Bevacqua and Mellano, 1994) in soil pH with the addition of organic matter. Given the diversity in composition of soil organic matter it would be presumptuous to assume that all organic matters react in a similar fashion. Previous studies have suggested that the mechanisms involved with associated decreases in soil pH are: (i) the generation of protons from nitrification and the subsequent loss of NO_3^- (Helyar and Porter, 1989; Bolan et al., 1991); (ii) the release of protons from organic anions (Helyar and Porter, 1989); and (iii) an increase in the cation exchange capacity of the soil with a corresponding increase in exchangeable acidity (Williams and Donald, 1957). In contrast, processes that have been reported to increase pH include; (i) the consumption of protons during the oxidation of organic anions (Helyar and Porter, 1989; Noble et al., 1996; Yan et al., 1996; Pocknee and Sumner, 1997); (ii) the presence of reducing conditions due to an increase in microbial biomass during rapid decomposition (van Breeman, 1987; Miller et al., 1985); (iii) proton adsorption onto exchanges sites generated due to organic matter incorporation (Hoyt and Turner, 1975); (iv) hydroxyl displacement from sesquioxidic surfaces by organic anions (Hue and Amien, 1989); (v) basic cation addition (Bessho and Bell, 1992); (vi) the production of NH_3 during decomposition (Hoyt and Turner, 1975);

The work described in this section examines the potential role of plant species in the recycling of nutrients and amelioration of acidity. In this respect the focus was on the ash alkalinity of a diverse range of plant species collected from the semi-arid tropics. Associated with this activity, the effect of the water-soluble organic component emanating from selected surface applied plant materials on the mobility of cations and the remediation of acidity was assessed. In addition, the chemical composition of the water-soluble leachate prior to and after leaching through soil columns was compared.

Methodology

Assessment of ash alkalinity of Stylosanthes accessions.

Leaf samples of *Stylosanthes* accessions/species were collected from an introduction trial established at the CSIRO Lansdown Research Station (19.5° S, 146.8° E), 50 km south west of Townsville, Queensland, Australia. Lansdown has a mean annual rainfall of 836 mm that is highly summer dominant (November to April). Samples were collected during the active growth period of December/January 1997/1998.

With respect to the *Stylosanthes* a total of 17 accessions/species with three replications were collected (Tables 4.7). The leaf material was dried in a forced draft oven at 65°C for 48 hr and ground to a fine powder. The elemental composition of the leaf material was determined by XRF spectrometry (Norrish and Hutton, 1977). Ash alkalinity was determined on all samples using two methods, namely the methodology of Jarvis and Robson (1983) and by difference between the sum of cations and anions calculated on an equivalence basis: $\Sigma (Ca^{2+} + Mg^{2+} + K^{+} + Na^{+}) - \Sigma (SO_4^{2-} + H_2PO_4^{-} + Cl^{-})$.

The soils on which the *Stylosanthes* accessions were grown are described as a Lansdown sandy loam (Murtha and Crack, 1966). It is characterised as having a very strongly bleached sandy loam A1 - A2 over mottled yellow or olive heavy clays (Table 4.8). It is classified as a Hypocalcic, Hypernatric, Brown Sodosol (Isbell, 1996).

Assessment of ash alkalinity of a range of grass, shrubs, forbs and trees endemic to the Charters Towers region of north Queensland.

A comprehensive collection of grasses, forbs, legumes and selected trees from the Charters Towers area was analysed for ash alkalinity by the cation difference method. Plant material was oven dried at 60ºC and ground to a powder. The elemental composition was determined by x-ray fluorescence spectrometry (Norrish and Hutton, 1977). The ash alkalinity was determined by difference between the total cations and anions: $\Sigma (Ca^{2+} + Mg^{2+} K^{+} + Na^{+}) - \Sigma (SO_4^{2-} + H_2PO_4^{-} + Cl^{-})$. Ms Fiona Houlston originally collected the plant material as part of a PhD program under the supervision of Dr Andrew Ash.

Results and discussion

Assessment of ash alkalinity of Stylosanthes accessions.

The simplest method of determining the ash alkalinity of plant material is by titration of an acidified solution containing the ashed sample with standardised base (Jarvis and Robson, 1983). Whilst this method is sufficient in most cases to give an accurate assessment of this parameter, it has the inherent potential error associated with the volatilisation of S and Cl during the ashing process (Kennedy, 1992; Jungk, 1968). Under such circumstances, losses of these anions would result in an over-estimation of the ash alkalinity. A more accurate assessment of ash alkalinity can be achieved by subtracting the total equivalent cations from the total equivalent anions: $\Sigma(Ca^{2+} + Mg^{2+} + K^{+} + Na^{+}) - \Sigma(SO_4^{2-} + H_2PO_4^{-} Cl^{-})$. A simple linear regression was undertaken relating these two parameters for *Stylosanthes* accessions. A highly significant correlation coefficient was observed between the two measured parameters with the slope of the regression lines equal to 1.05, confirming the almost 1:1 relationship between these two parameters (Figure 4.3).

The elemental compositions of the 17 *Stylosanthes* accessions are presented in Table 4.7. The data set comprises a total of 4 different species, namely *S. scabra*, *S. seabrana* (syn. *S. aff. scraba*), *S. hamata* and *S. viscosa*. For the purpose of comparison, the genus was divided into two groups, namely the *S. seabrana* versus the rest. This was undertaken on the basis that *S. seabrana* is well adapted to heavy textured soils whilst the three other species are commonly grown on light textured soils.

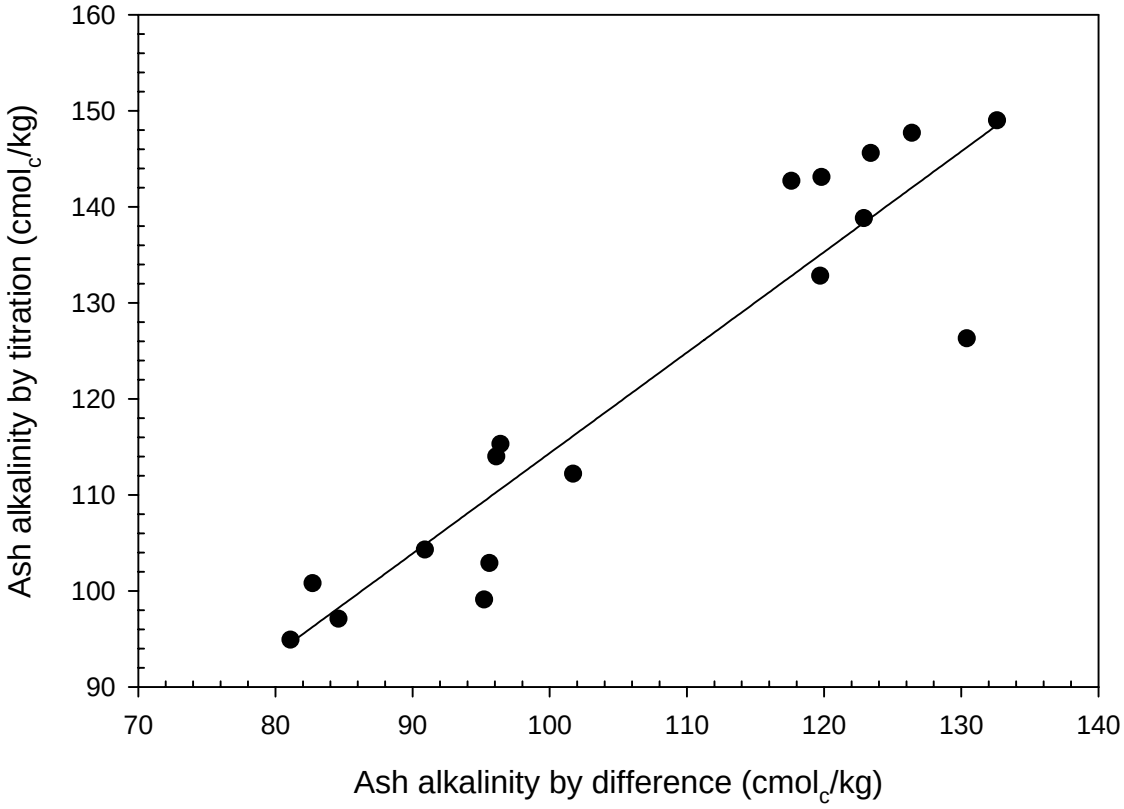


Figure 4.3. Relationship between ash alkalinity measured by difference and that by ashing for different *Stylosanthes* accessions collected at Lansdown. y =9.65(±11.53) + 1.05(±0.11)x; R^2 = 0.865; n = 17).

A simple correlation matrix was established for each of the variables analysed (Table 4.9). Ash alkalinity was highly positively correlated with elemental Ca and Mg but negatively correlated with K. From these results it is evident that 96% of the variance in the determination of ash alkalinity by difference can be explained on the elemental Ca concentration. In this respect, the ash alkalinity (y cmol$_c$/kg) was related to the Ca concentration (x mg/g) by the following relationship: y = 21.53 (± 5.89) + 4.68 (±0.31)x; n = 17; r = 0.967***).

An interesting feature of the two groupings is that the *S. seabrana* accessions have higher Ca and Mg concentrations as well as higher ash alkalinities than the rest of the *Stylosanthes* species (Table 4.7). These differences may be indicative of adaptability of this species to neutral / alkaline soils whilst the second group is more tolerant to acid infertile soils.

It is clearly evident from the previous discussion that Ca concentration in the plant material can be used to predict with a high degree of accuracy the ash alkalinity within species. This confirms previously observed relationship between these two parameters over a wide range of tree species (Noble *et al*., 1996). Since Ca is a relatively immobile constituent in the plant, it would therefore not be subject to transient changes. This observed relationship may suggest the existence of a genetically controlled mechanism whereby the uptake and accumulation of Ca is controlled by physiological processes that are unique to the species (Mengel and Kirkby, 1982).

Assessment of ash alkalinity of a range of grass, shrubs, forbs and trees endemic to the Charters Towers region of north Queensland.

The oxidation of organic anions during the decomposition of leaf material will influence the net proton pool in the soil. A direct measure of a litter materials impact on the proton pool is the ash alkalinity. In this respect the ash alkalinity of the litter material can be expressed as $CaCO_3$ equivalents if it is assumed that 1 mole H^+ requires 50 g $CaCO_3$ to be neutralised. The $CaCO_3$ equivalent values reflect the amount of alkalinity deposited in the plant material (i.e. fresh plant material) on a dry matter basis. It should be noted that these samples were collected as fresh plant material and may not reflect the composition of litter due to 'internal' recycling that occurs prior to senescence. The same would apply to the previously discussed *Stylosanthes* accessions. A considerable range (11.4 to 178.5 g $CaCO_3$/kg DM) in acid neutralization capacity of these plant materials, reflects the potential mediating role of these species in both nutrient cycling and acid/base reactions (Table 4.10). Whilst the potential role of these species in the remediation of soil acidity in *Stylosanthes* based pasture systems may be limited due to the propensity of a particular species in a paddock, the functionality of these species in mediating biological pumping needs to be assessed.

A highly significant linear relationship was observed between ash alkalinity and the Ca concentration of the plant material in all species other than *Salsola kali* and two *Portulaca oleracae* collections (Figure 4.4). In the case of these 2 species, extremely high concentrations of K were measured in the plant material. It is of note that both of these species are tolerant to salinity. Consequently, it is proposed that an estimate of ash alkalinity over a wide range of plant species commonly found in the semi-arid tropics can effectively be determined using the aforementioned relationship.

In general, plant materials contain an excess of cations over inorganic anions. Internal charge balance is maintained by synthesis of organic anions. When oxidised by burning or through decomposition, the organic anions are destroyed and the resulting ash is alkaline. The observed differences in the ash alkalinity of plant materials suggest that there are significant differences between species with respect to their ability to: (i) differentially take up cations and anions from the soil and/or (ii) internally recycle nutrients. If uptake differences are significant, it can be assumed that the more alkaline the material the greater the acidification generated at the root-soil interface. The cycling of nutrients through the soil/plant system and the redistribution of alkalinity within the soil profile through nutrient uptake and the deposition and decomposition of litter on the soil surface will have important implications for soil acidification. This process of "biological pumping" would have different consequences on the soil depending on the buffering capacity of the various soil horizons. On soils that are poorly buffered, the redistribution of alkalinity to surface horizons would be at the expense of significant acidification of the sub-surface horizons. However, on soils that are alkaline in deeper horizons (i.e. many duplex soils) the deposition of litter on the soil surface would be highly beneficial. In both these cases it is assumed that the plants take up nutrients from all the soil layers explored by roots. They can certainly extract significant amounts of water from the subsoil as previously discussed and the well recognised role of trees in altering the hydrological balance. In contrast to the movement of nutrients from depth to the soil surface by plants acting as biological pumps, there is the potential for the water soluble fraction or by-products of litter decomposition to complex cations and facilitate their downward movement by leaching. Litter products can form stable organometallic complexes thereby controlling primary and secondary mineral equilibria in soils (Browne, 1995). The presence of these organometallic complexes may allow an increase in the rate of processes resulting in podzolisation and thereby increase the potential for nutrient loss and the degradation of the soil resource.

In the extensive grazing systems of northern Australia the introduction or retention of specific tree species in these pasture systems may modify the impact of soil acidification generated through product export and leaching of nitrate as a consequence of the increased N status following the establishment of legumes. It is important to realise that the potential increases in soil pH and associated changes in basic cation concentration on the exchange complex arising from litter additions, does not independently result in the synthesis of alkalinity. The litter is simply a medium for redistribution of alkalinity.

Table 4.7. Elemental composition of *Stylosanthes* accessions from an introduction trial at Lansdown, Nth Qld. Each value is the mean of three replications & the LSD's pertain to the entire data set.

No.	Species	Accession No. (cultivar)	Ca	Mg	Na	K	S	Cl	P	Total N	Ash difference	Ash titration
						mg/g						$cmol_c/kg$
55	S. scabra	ATF2342	20.3	1.9	0.5	15.0	1.9	6.5	2.3	25.7	119.7	132.8
56	S. seabrana	ATF2517	21.5	3.4	0.2	10.4	2.3	7.0	2.0	24.3	122.9	138.8
57	S. seabrana	ATF2519	22.6	3.3	0.2	13.1	2.3	7.6	2.0	25.0	132.6	149.0
58	S. seabrana	CPI115994	22.0	3.3	0.3	12.6	2.0	7.5	1.9	25.4	130.4	126.3
59	S. seabrana	CPI115995	21.9	2.9	0.3	12.7	2.1	10.1	1.9	23.9	119.8	143.1
60	S. seabrana	(Unica)	22.4	3.7	0.3	11.2	2.3	9.6	2.5	20.9	123.4	145.6
61	S. seabrana	CPI110370C	21.8	3.5	0.3	12.6	2.2	9.0	2.0	24.2	126.4	147.7
62	S. seabrana	(Primar)	21.5	3.1	0.3	11.9	2.0	10.2	1.9	21.4	117.6	142.7
63	S. scabra	(Seca)	15.4	2.3	1.8	14.0	2.2	9.9	2.0	18.4	90.9	104.3

64	S. scabra	(Siran)	16.9	2.0	0.7	18.0	1.9	12.6	2.0	23.3	96.4	115.3
65	S. hamata (tetraploid)	(Amiga)	12.6	1.8	0.2	14.2	2.1	5.1	1.9	20.5	81.1	94.9
66	S. hamata (tetraploid)	(Verano)	13.1	1.8	0.4	14.6	2.3	5.1	1.8	20.6	84.6	97.1
67	S. hamata (diploid)	CPI110066	16.2	2.2	0.2	15.0	1.9	5.3	3.2	20.1	101.7	112.2
68	S. hamata (diploid)	CPI61670	16.3	2.4	0.3	13.0	2.6	4.5	3.5	16.5	95.6	102.9
69	S. viscosa	CPI34904	13.3	1.8	0.6	16.8	2.2	7.8	2.8	24.6	82.7	100.8
70	S. viscosa	CPI61675	18.1	1.7	0.1	16.2	2.4	9.6	2.9	30.2	96.1	114.0
71	S. guienensis	(Oxley)	14.3	2.1	0.0	17.3	1.9	5.0	3.8	21.4	95.2	99.1

Table 4.9. Correlation of chemical attributes with ash alkalinity as determined by difference.

Chemical attribute	*Stylosanthes*
Ash titration	0.930**
Ca	0.967**
Cl	0.262
K	-0.644**
Mg	0.847**
N	0.356
Na	-0.266
P	-0.315
S	-0.109

** correlation is significant at the 0.01 level.

Table 4.10. Ash alkalinity and $CaCO_3$ equivalents for selected grass, forbs and tree material collected in the Charters Towers area of north Queensland.

Species	**Ash alkalinity ($cmol_c$/kg)**	**$CaCO_3$ equivalent (g $CaCO_3$/kg DM)**
Sehima nervosum	22.8	11.4
Themeda triandra	24.8-36.9	12.4-18.4
Heteropogon triticeus	27.8	13.9
Sorghum plumosum	27.9	13.9
Bothriochloa ewartiana	30.7	15.3
Aristida hycrometrica	30.9	15.4
Enneapogon polyphyllus	31.5	15.7
Aristida calycina	31.5	15.7
Aristida muricata	31.8	15.9
Chrysopogon fallax	32.7-46.4	16.3-23.2
Tripogon lolliformis	35.1	17.5
Sehima nervosum	35.6	17.8
Dicanthium fecundum	36.1	18.0
Eragrostis sp	38.8	19.4
Heteropogon contortus	39.4	19.7
Bothriochloa decipiens	39.8	19.9
Sporobulus australicus	40.8	20.4
Dicanthium fecundum	41.4	20.7
Bothriochloa ewartiana	42.5	21.2
Enneapogon polyphyllus	44.6	22.3
Chrysopogon fallax	46.4	23.2
Sorghum plumosum	48.3	24.1
Digitaria ammophila	48.7	24.3

Sporobulus australicus	48.9	24.4
Heteropogon triticeus	50.1	25.0
Panicum decompositum	51.1	25.5
Scleria sp	53.2	26.6
Lomandra multiflora	53.3	26.6
Brachyachne convergens	53.4	26.7
Melenis repens	59.3	29.6
Alloteropsis semialata	59.6	29.8
Heteropogon contortus	62.6	31.3
Tragus australianus	65.0	32.5
Bothriochloa pertusa	65.1	32.5
Bloodwood leaves	69.1	34.5
Phyllanthus maderspatensis	71.7	35.8
Dactyloctenium radulans	77.5	38.7
Urochloa mosambicensis	78.7	39.3
Euphorbia mitchelliana	78.8	39.4
Digitaria ciliaris	83.5	41.7
Cenchrus ciliaris	87.2	43.6
Cajanus confertiflorus	95.6	47.8
Vernonia cinerea	97.4	48.7
Euphorbia drummondii	98.3	49.1
Phyllanthus maderspatensis	102.4	51.2
Urochloa mosambicensis	107.1	53.5
Stylosanthes scabra	109.6-148.2	54.8-74.1
Cajanus confertiflorus	114.1	57.0
Crotalaria medicaginea	114.6	57.3
Evolvulus alsinoides	117.7	58.8

Ipomea eriocarpa	121.6	60.8
Hybanthus enneaspermus	123.1-351.7	61.5-175.8
Ipomea polymorpha	127.2	63.6
Macroptilium atropurpureum	128.4	64.2
Stylosanthes hamata	128.7	64.3
Euphorbia drummondii	129.2	64.6
Crotalaria juncea	131.3	65.6
Grewia retusifolia	131.8-132.7	65.9-66.3
Ironbark leaves	132.9	66.4
Spermacoce brachystema	134.5	67.2
Glycine tomentella	134.5	67.2
Melhania oblongiflora	138.5	69.2
Indigofera pratensus	140.9	70.4
Portulaca filifolia	144.2	72.1
Sida acuta	145.7	72.8
Trianthema triqueta	146.4	73.2
Glycine tabacina	157.2	78.6
Hibiscus sp.	157.6	78.8
Euphorbia mitchelliana	177.8	88.9
Boerhavia schoenburgii	199.8	99.9
Wedelia spilanthoides	208.9	104.4
Indigofera colutea	210.0	105.0
Uraria sp.	216.6	108.3
Tribulus pentanelrus	234.8	117.4
Salsola kali	236.2	118.1
Evolvulus alsinoides	243.4	121.7
Tribulus terrestris	249.5	124.7

Portulaca oleracae	263.7-282.5	131.8-141.2
Heliotropium sp	294.8	147.4
Justicia procumbens	306.1	153.0
Indigofera linnifolia	309.7	154.8
Justicia procumbens	310.0	155.0
Indigofera linnaei	340.6	170.3
Hibiscus sp.	341.7	170.8
Brunoniella acualis	346.5	173.2

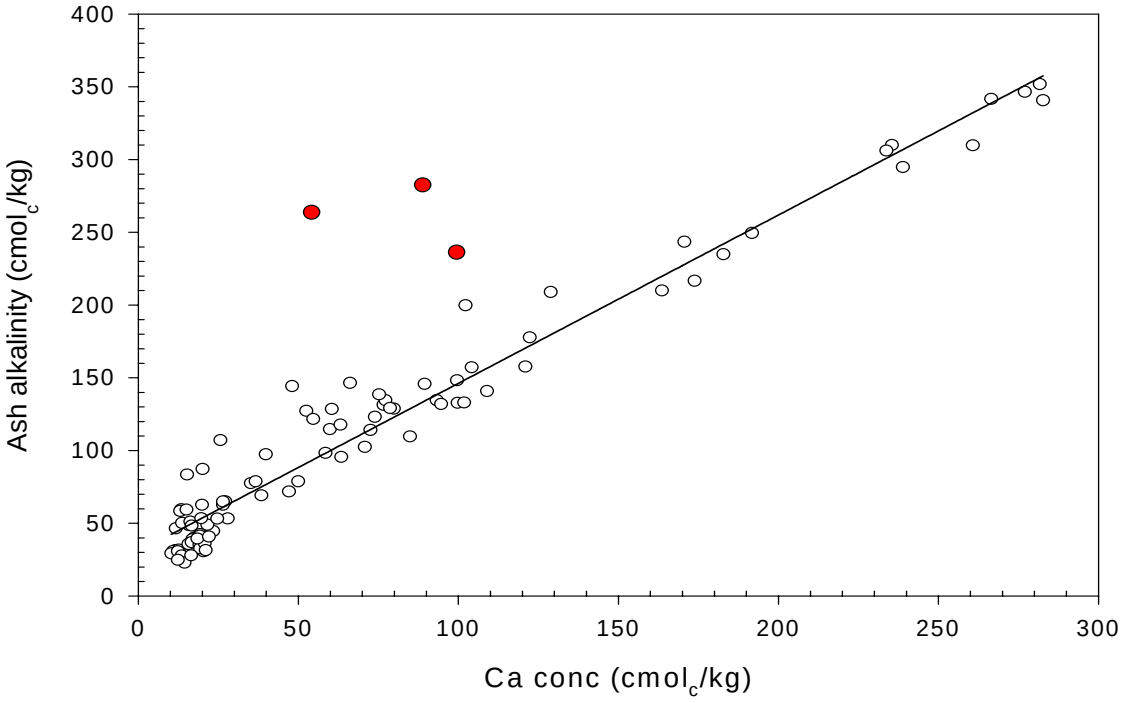


Figure 4.4. Relationship between Ca content in plant material and ash alkalinity. The red outliers are Salsola kali and two collections *Portulaca oleracae*. Regression equation: y = 30.52 + 1.15x; r^2=0.958 n = 93.

iii. Assessment of the acid neutralization capacity of litter materials from selected species.

Background

As indicated in the previous discussion organic acids are released in large quantities and great diversity during decomposition of plant materials on the soil surface thereby strongly affecting the mobility of cations in acid soils. However, there is a lack of information on the role of litter materials in northern pasture production systems in the neutralization of surface acidity and the movement of cations to depth.

The objectives of this activity are to:

Assess the effect of water soluble organic components emanating from selected surface applied plant materials on the mobility of cations and remediation of acidity.

Ascertain the efficacy of ashing plant material on the aforementioned parameters. This was undertaken to simulate the possible effects of burning.

Compare the changes in chemical composition of the water-soluble leachate component prior to and after leaching through a soil column.

Methodology

Plant residues used in this study and the region from where they were collected are presented in Table 4.11. The species were diverse in that they represent different plant orders. In this respect the grasses (monocots) are represented by *Urochloa mosambicensis*; leguminous dicots represented by *Stylosanthes* collected from the semi-arid tropics; and freshly fallen leaf litter material collected from the tree species *Melia azedarach.* In the latter case *Melia azedarach* was used as a benchmark species since it has been recognised as having a high ash alkalinity and acid neutralising capacity (Noble et al., 1999).

Table 4.11. Type and collection location of plant residues used in leaching studies.

Plant material	**Collection location**
1. *Urochloa mosambicensis*	Lansdown, north Queensland
2. White cedar (*Melia azedarach*) senesced leaf material.	Canberra, ACT
3. *Stylosanthes* (Seca) whole plant material	Lansdown, north Queensland

The treatments imposed for each of the litter materials consisted of the following:

1. Unamended litter ground to pass a 2 mm sieve.

2. Litter ashed at 500°C

3. Litter incubated for 21 days at 25°C in a sand matrix.

Preparation of leaching columns

The surface 0-15 cm of an acid light textured sand collected from the Herbert River District, north Queensland was used in all studies. Particle size analysis showed that soil was dominated by sand

and was classified as having a sandy loam texture. Leaching columns consisted of 15 cm long Perspex tubes with an internal diameter of 2.5 cm. Columns were packed to a depth of 12 cm at a uniform bulk density of 1.48 g/cm^3. Each column contained 87 g of soil and a total pore volume of 18.61 cm^3. Prior to packing the column, a 2.5 cm Millipore GF filter pad was placed at the bottom of the column to prevent soil from falling out of the column. Once the column was packed a Millipore GF filter was placed on to of the soil surface in order to distribute incoming solution and to prevent surface compaction.

Preparation of the litter material

In the unamended litter treatment, a mixture of litter and acid washed sand was placed on the top of the Millipore GF filter. This mix consisted of 1.227g (equivalent to 50 t/ha dry matter) oven dried (65°C) litter ground to pass a 2 mm sieve and 5 g of acid washed sands thoroughly mixed. A third Millipore GF filter was placed on top of the surface of the litter/sand mix to distribute the distilled water evenly and prevent surface impact. Columns were leached with distilled water over an 8 hr period with a total of 5.4 pore volumes. After this leaching phase, the surface placed litter/sand mixture was carefully removed from the surface of the column to expose the GF filter. A further 20 ml of distilled water was passed through the column as a means for flushing any entrained litter leachate.

During the leaching phase, the effluent emanating from the bottom of the column was collected and the pH and EC measured at the completion of the leaching phase. The aforementioned procedure was undertaken for each of the litter materials and was replicated 3 times. In addition, a sample of the litter/sand mixture was leached with 5.4 pore volumes of distilled water and the leachate collected. This represented the composition of the leachate emanating from the litter/sand mixture prior to passing through the soil column. As a control treatment, columns were prepared with only soil and leached as described previous with distilled water.

With respect to the ashed treatment, 1.277 g of oven dried litter of each of the materials was ashed in a muffle furnace at 500°C for 5 hrs, allowed to cool to room temperature and incorporated into 5 g of acid washed sand and subjected to the same leaching regime as described above. In the cases of the incubated treatment, a water extract was prepared by placing 20 g of soil in 100ml of distilled water and placing on an end-over-end shaker 1hr. The sample was then centrifuged and 20 mls of the supernatant was applied to the sand:litter mix consisting of 1.277g of oven dried litter and 5 g of acid washed sand. Samples were placed in containers covered with Gladrap and placed in a constant temperature room for 21 days. At the conclusion of the incubation period, the sand:litter mix was dried at 65°C and treated in the same manner as previously described.

Soil and leachate analysis

At the completion of the leaching phase, the columns were allowed to drain free and the soil gently blown out of the columns. The columns were sectioned into 2 cm sections from the top to the bottom. Soils were dried at 40°C in a forced draft oven for 48 hr and passed through a 2mm sieve.

Soil pH and EC was measured in a 1:5 soil:water solution matrix. Exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) were extracted using 0.1 M $BaCl_2/NH_4Cl$ (Gillman and Sumpter, 1986) and determined by atomic absorption spectroscopy. Exchangeable Al^{3+} was determined on the same extracts using Al^{3+} using the pyrocatechol-violet method (Bartlett *et al*., 1987).

The leachate extract was stored at 4°C until analysis. The dissolved organic carbon was determined using the modified Mebius method of Yeomans and Bremner (1988). The cation concentration was determined by atomic absorption spectroscopy.

Results and Discussion

Soil chemical characteristics after leaching

Changes in soil pH associated with different imposed treatments on the plant materials are presented in Figure 4.5. Melia unamended litter had a greater impact on the depth to which pH changes were observed when compared to the other two plant materials (Figure 4.5a). In all cases significant increases in soil pH to depth were observed in all treatments. However, the extent of pH shift was largest in the ashed material (Figure 4.5c). In the case of the unamended and incubated treatments, the degree of pH shift can in part be explained by the presence of soluble organic compounds that are able to transport alkalinity as well as complex exchangeable Al. Contrasting this, the pH response for the ashed sample can be attributed to inorganic alkalinity movement that is dependent on the pH of the system. Under such conditions alkalinity movement is dependent on the pH of the system being >5.5. Clearly these results indicate that regardless of the treatment of these materials, increases in soil pH can be achieved. As to be expected the greatest degree of pH shift occurred in the surface 0-2 cm. With respect to the individual plant species, in general Urochloa had a greater impact on soil pH changes to depth regardless of treatment followed by Melia. *Stylosanthes* consistently resulted in less of an impact on soil pH than the other two species.

Changes in exchangeable Ca, Mg, K, Al and ECEC associated with each of the plant species and applied treatments are presented in Tables 4.12-4.16. Exchangeable Ca was significantly increased from the control with all treatments imposed (Table 4.12). The greatest increases in Ca were observed in the surface horizons of the column and diminished with depth in the case of *Stylosanthes* and Melia. With respect to the unamended treatment, Melia had the greatest impact on exchangeable Ca, whilst the two other plant materials had similar effects down the column (Table 4.12). In the incubated plant material treatments, Melia increased the Ca content in the 0-2 cm but thereafter its effect diminished rapidly to a constant level. This contrasts the effects observed in both the unamended and ashed treatments for Melia. The influence of Urochloa contrasted that of the two other species in that there was an increase in Ca with depth down the column regardless of litter treatment.

Exchangeable Mg levels after the leaching were either little changed or had undergone a slight decrease (Table 4.13). Increases in exchangeable Mg were confined to the 0-2 cm depth interval and was observed in the unamended Urochloa, incubated and ashed Melia treatments respectively. Exchangeable K was increased in all treatments from the control with the greatest effects being observed in the 0-2 cm depth interval (Table 4.13). Urochloa appeared to have the greatest influence on exchangeable K this being a function of the composition of the leachate. Increases in soil pH and the complexing ability of organic compounds emanating from the litter will influence the amount of exchangeable Al on the exchange complex (Table 4.14). The greatest reduction in exchangeable Al was observed in the 0-2 cm depth interval. With increases in exchangeable cations and soil pH there was a concomitant increase in the ECEC (Table 4.15). This increase in charge capacity is associated with the generation of variable charge associated with the addition of organic compounds in the case of the unamended and incubated plant materials. In the case of the ashed treatments, increases in ECEC are associated with the generation of variable charge on existing inorganic and organic surfaces in the soil (Table 4.16). With increases in ECEC it is plausible that greater amounts of cations will be retrained from leaching and hence associated acidification.

Leachate composition

The composition of the leachates before and after passing through the soil column for each of the treatments is presented in Tables 4.17-4.19. Composition of the incoming leachate reflects the observed changes in the cation composition on the exchange complex. It is of note that the composition of the leachates with respect to cation composition and organic carbon differed significantly between species and treatments. When comparing the composition of the unamended and ashed incoming leaches, it would appear that ashing resulted in a decrease in the solubility of cations (Tables 4.17-4.18).

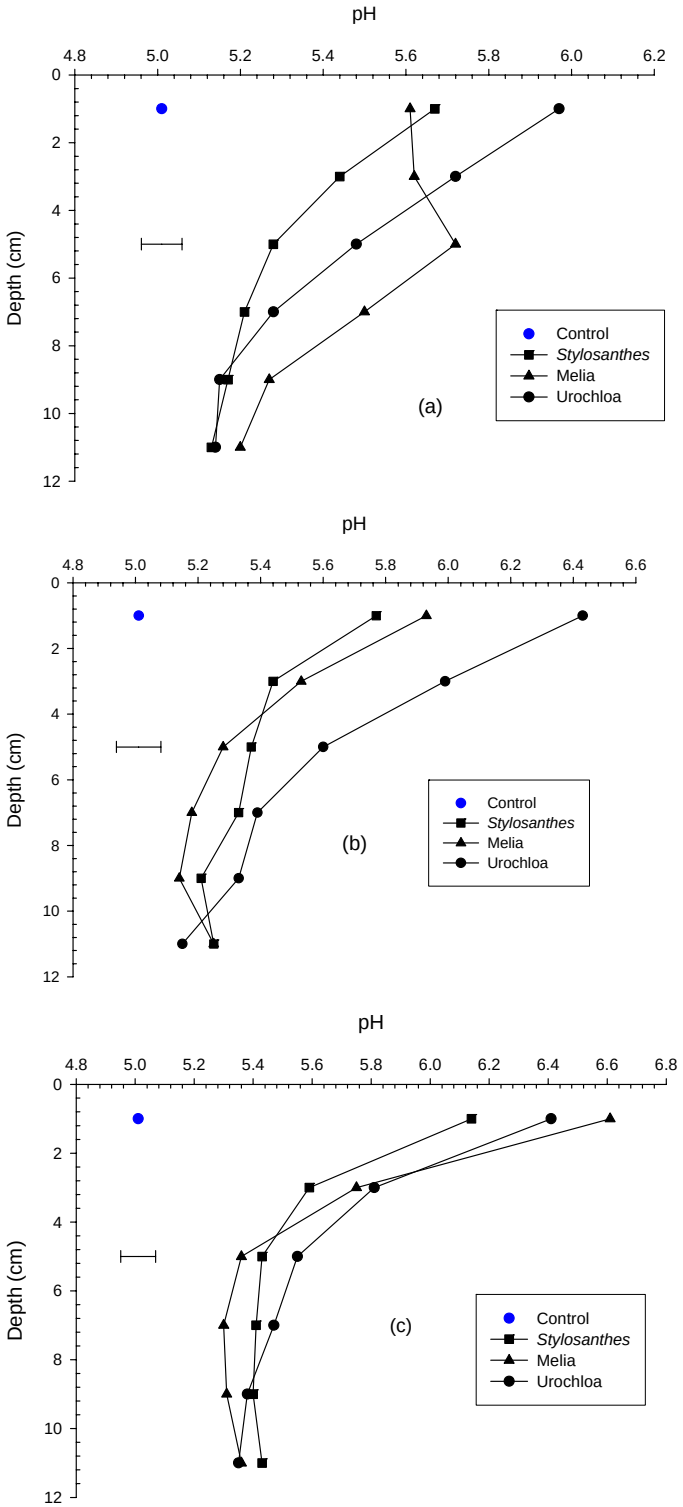


Figure 4.5. Changes in soil pH associated with the leaching of (a) unamended, (b) incubated and (c) ashed litter material from three contrasting plant materials. Horizontal line represents the LSD (0.05) between treatments over all depth intervals.

Table 4.12. Changes in exchangeable Ca ($cmol_c/kg$) after leaching with oven dried, incubated and ashed material from contrasting plant materials through a mini soil column.

Plant material			**Depth (cm)**			
	0-2	2-4	4-6	6-8	8-10	10-12
			Fresh material			
Control	0.133					
Stylosanthes	0.419	0.228	0.286	0.274	0.264	0.253
Melia	1.727	1.424	1.320	1.197	0.934	0.857
Urochloa	0.339	0.374	0.501	0.609	0.603	0.691
LSD (0.05)	0.197					
			Incubated			
Stylosanthes	0.364	0.243	0.243	0.241	0.230	0.249
Melia	1.140	0.303	0.251	0.246	0.253	0.294
Urochloa	0.413	0.493	0.668	0.639	0.681	0.688
LSD (0.05)	0.066					
			Ashed			
Stylosanthes	0.742	0.599	0.635	0.628	0.615	0.647
Melia	1.200	0.728	0.692	0.628	0.615	0.667
Urochloa	0.598	0.511	0.611	0.647	0.608	0.652
LSD (0.05)	0.13					

Table 4.13. Changes in exchangeable Mg ($cmol_c/kg$) after leaching with oven dried, incubated and ashed material from contrasting plant materials through a mini soil column.

Plant material			**Depth (cm)**			
	0-2	2-4	4-6	6-8	8-10	10-12
			Fresh material			
Control	0.370					
Stylosanthes	0.222	0.112	0.130	0.142	0.144	0.147
Melia	0.216	0.204	0.216	0.231	0.213	0.220
Urochloa	0.596	0.121	0.098	0.132	0.141	0.169
LSD (0.05)	0.038					
			Incubated			
Stylosanthes	0.256	0.188	0.208	0.200	0.192	0.215
Melia	1.156	0.386	0.235	0.191	0.225	0.234
Urochloa	0.317	0.124	0.170	0.189	0.209	0.218
LSD (0.05)	0.050					
			Ashed			
Stylosanthes	0.261	0.136	0.154	0.148	0.154	0.154
Melia	0.629	0.123	0.133	0.133	0.146	0.142
Urochloa	0.251	0.103	0.109	0.122	0.117	0.151
LSD (0.05)	0.034					

Table 4.14. Changes in exchangeable K ($cmol_c/kg$) after leaching with oven dried, incubated and ashed material from contrasting plant materials through a mini soil column.

Plant material			**Depth (cm)**			
	0-2	2-4	4-6	6-8	8-10	10-12
			Fresh material			
Control	0.131					
Stylosanthes	0.555	0.359	0.258	0.210	0.187	0.179
Melia	0.327	0.438	0.474	0.414	0.416	0.391
Urochloa	0.820	0.715	0.450	0.274	0.175	0.159
LSD (0.05)	0.081					
			Incubated			
Stylosanthes	0.735	0.307	0.227	0.201	0.172	0.200
Melia	0.484	0.522	0.378	0.252	0.225	0.206
Urochloa	1.424	0.749	0.323	0.195	0.164	0.163
LSD (0.05)	0.088					
			Ashed			
Stylosanthes	0.736	0.169	0.132	0.136	0.132	0.135
Melia	0.997	0.398	0.188	0.139	0.149	0.141
Urochloa	0.963	0.359	0.292	0.215	0.150	0.148
LSD (0.05)	0.050					

Table 4.15. Changes in exchangeable Al ($cmol_c/kg$) after leaching with oven dried, incubated and ashed material from contrasting plant materials through a mini soil column.

Plant material			**Depth (cm)**			
	0-2	2-4	4-6	6-8	8-10	10-12
			Fresh material			
Control	0.350					
Stylosanthes	0.475	0.553	0.587	0.684	0.710	0.718
Melia	0.093	0.112	0.142	0.206	0.094	0.105
Urochloa	0.152	0.030	0.124	0.117	0.093	0.087
LSD (0.05)	0.083					
			Incubated			
Stylosanthes	0.092	0.176	0.223	0.215	0.209	0.255
Melia	0.040	0.129	0.324	0.243	0.284	0.366
Urochloa	0.046	0.111	0.201	0.240	0.253	0.224
LSD (0.05)	0.106					
			Ashed			
Stylosanthes	0.056	0.177	0.226	0.191	0.182	0.209
Melia	0.022	0.216	0.315	0.267	0.309	0.276
Urochloa	0.038	0.175	0.268	0.253	0.190	0.212
LSD (0.05)	0.089					

Table 4.16. Changes in exchangeable ECEC ($cmol_c/kg$) after leaching with oven dried, incubated and ashed material from contrasting plant materials through a mini soil column.

Plant material			**Depth (cm)**			
	0-2	2-4	4-6	6-8	8-10	10-12
			Fresh material			
Control	0.877					
Stylosanthes	1.730	1.313	1.341	1.369	1.357	1.350
Melia	2.385	2.200	2.171	2.073	1.677	1.602
Urochloa	1.953	1.282	1.222	1.175	1.055	1.170
LSD (0.05)	0.306					
			Incubated			
Stylosanthes	1.473	0.930	0.918	0.872	0.817	0.937
Melia	2.882	1.386	1.2343	0.972	1.041	1.146
Urochloa	2.302	1.558	1.435	1.318	1.363	1.355
LSD (0.05)	0.217					
			Ashed			
Stylosanthes	1.820	1.105	1.168	1.131	1.112	1.181
Melia	2.871	1.489	1.345	1.242	1.396	1.256
Urochloa	1.988	1.213	1.317	1.259	1.088	1.186
LSD (0.05)	0.244					

Table 4.17. Leachate and extract composition before and a passing through a soil column of the unamended plant materials.

Values in parenthesis represent the SE of the mean.

Plant material	OC		Al		Ca		Mg		K	
	Extract	Leachate	Extract	Leachate	Extract	Leachate	Extract	Leachate	Extract	Leachate
	(%)	($cmol_c/L$)								
Control	na	0.024	na	0.110	na	0.119	na	0.071	na	0.133
Melia	0.67	0.562	0.15	6.330	7.23	1.422	2.56	1.693	4.23	1.832
Stylosanthes	0.06	0.115	0.09	0.230	0.12	0.234	0.10	0.253	0.84	0.314
Urochloa	0.24	0.175	0.16	0.650	0.03	1.174	0.59	0.583	3.21	0.843
LSD (0.05)	na	0.031	na	1.016	na	0.618	na	0.105	na	0.684

Table 4.18. Leachate and extract composition before and a passing through a soil column of the ashed plant materials.

Values in parenthesis represent the SE of the mean.

Plant Material	OC		Al		Ca		Mg		K	
	Extract	Leachate	Extract	Leachate	Extract	Leachate	Extract	Leachate	Extract	Leachate
	(%)					($cmol_c/L$)				
Control	na	0.024	na	0.110	na	0.119	na	0.071	na	0.133
Melia	0.000	0.006	0.002	0.014	0.237	0.430	0.220	0.122	1.378	0.094
Stylosanthes	0.006	0.012	0.007	0.011	0.309	0.347	0.140	0.092	0.765	0.074
Urochloa	0.000	0.008	0.003	0.013	0.258	0.857	0.156	0.364	2.143	0.143
LSD (0.05)	na	ns	na	0.012	na	0.077	na	0.020	na	0.035

Table 4.19. Leachate and extract composition before and a passing through a soil column of the incubated plant materials.

Values in parenthesis represent the SE of the mean.

	OC(%)		Al		Ca		Mg		K	
	Extract	Leachate	Extract	Leachate	Extract	Leachate	Extract	Leachate	Extract	Leachate
						($cmol_c/L$)				
Control	na	0.024	na	0.110	na	0.119	na	0.071	na	0.133
Melia	0.151	0.187	0.004	0.616	1.267	0.545	1.569	0.492	1.530	0.412
Stylosanthes	0.018	0.044	0.003	0.068	0.145	0.187	0.045	0.155	0.663	0.207
Urochloa	0.078	0.040	0.003	0.012	0.117	1.082	0.215	0.415	3.573	0.179
LSD (0.05)	na	0.134	na	0.107	na	0.166	na	0.134	na	0.117

iv. Evaluate the tolerance to acid soil infertility within selected grass and Stylosanthes *species.*

Background

Coates *et al.* (1997) and Miller *et al.* (1997) reviewed the performance of cattle grazing native pasture-stylo pasture systems. In general, the higher nutritive value of stylo relative to native grass for most of the year results in faster growth rates, higher turnoff weights, improved breeder and weaner performance and reduced drought risk. In growing cattle, the inclusion of legumes results in a better overall live weight performance for most of the year and reduced (or even eliminated) live weight loss in the dry season compared with native pasture. The yearly advantage over native grass ranges from 30-60 kg/animal (Coates *et al.* 1997) depending on soil type, length of growing season and stocking rate. In central Queensland, with conservative stocking and adequate mineral supplements when needed, it is possible to produce a 600 kg live weight animal at 42 months of age from a stylo-native grass pasture. These responses are contingent on being able to grow adequate quantities of higher quality feed.

It has been clearly shown that increased use of stylos with accompanying management practices, such as intensive seed/fodder production (with the associated export of plant material), has resulted in accelerated soil acidification and nutrient depletion (Noble et al., 1998). Of importance in assessing the long-term impact of accelerated soil acidification is the influence of changes soil chemical properties on the productivity of pasture species. In this study the effects of acid soil infertility on root elongation of selected legume species were assessed in a rapid root elongation study. In addition, the productivity of selected grass and *Stylosanthes* varieties was assessed under contrasting acid conditions in a greenhouse pot study.

Materials and Methods

Root elongation study

A rapid technique to assess the impact of acid soil infertility on root elongation of selected *Stylosanthes* species (*S. macrocephala*, *S. hamata* (verano), *S. seabrana* (928338B) and *S. seabrana* (Primer)) was undertaken. In order to verify the technique as being effective in assessing the responsiveness to acid soil infertility, the technique was initially tested on two wheat varieties known to be either tolerant or sensitive to acid soil infertility (Carazinho and Egret). An acid infertile soil (pH water: 4.62; Exchangeable acidity 4.35; Acid saturation: 66.4%) was collected from the Herbert district of north Queensland, air dried and ground to pass a 2mm sieve. Varying rates of $Ca(OH)_2$ (0, 0.59, 1.18, 2.36 and 4.74 g/kg) was thoroughly mixed into 2 kg lots, watered to field moisture capacity and allowed to incubated for 4 weeks. After incubation the soils were air dried and ground to pass through a 2 mm sieve. 100g lots of each of the five treatments were weighed out into polystyrene cups, each treatment being replicated 4 times.

Seeds of each of species tested were placed on moistened filter paper set in petri dished and allowed to germinate in the dark. After approximately 4 days 8 uniform seedlings were transplanted into the treated soils and water to field moisture capacity. The polystyrene cups were placed in the dark in an incubation chamber set at 25°C for a further 7 days. At the completion of this phase, the soils containing the seedlings were carefully removed from the polystyrene containers and roots of each of the 8 seedlings extricated from the soil. Root length was measured and the mean for each pot calculated.

Greenhouse pot study

Further to the root elongation studies a greenhouse pot trial was conducted to ascertain the tolerance of selected grass and *Stylosanthes* varieties to varying degrees of acid soil infertility. The study included the following species:

- *Urochloa mosambicensis*

- *Bothriochloa petusa*
- *Cenchrus ciliaris*
- *Stylosanthes* Verano
- *Stylosanthes* Seca

The same acid infertile soil as used in the root elongation study was used. Varying rates of lime ($CaOH_2$) were applied to the soil and allowed to incubate over a 4 week period at field moisture capacity. These imposed treatments resulted in a range of pH_w (4.55-7.23) values. Three seedlings of the aforementioned species were transplanted from agar plates and grown in each treatment for a period of 6 months. Four consecutive harvests were undertaken over this period. Plant material was oven dried at 65°C and dry mater production determined. In order to compare contrasting species, relative dry matter production was calculated for each species.

Results and discussion

Root elongation study

The wheat varieties Egret and Carazinho where used as model plants to assess the efficacy of this technique in differentiating between tolerance and sensitivity to acidity since these varieties are know to be sensitive and e tolerant to acid soil infertility. The effects of remediating acid soil infertility are clearly shown with respect to Egret, a sensitive variety to acid soils, whilst in the case of Carazinho there was no significant response to increasing additions lime (Figure 4.6a). In the case of Egret, root elongation increased from 37 to 106 mm with decreasing acidity. Contrasting this Carazinho root growth increased from 80 to 95 mm with decreasing acidity (Figure 4.6a). These results suggest that the soil used in this screening process was adequately acid to elicit a response.

It is clearly evident that all of the *Stylosanthes* varieties tested showed significant responsiveness of lime additions (Figure 4.6b-e). In addition, root elongation in the unamended treatments is extremely poor suggesting that these species are highly sensitive to acidity. *S. macrocephala* showed the least responsiveness to increasing lime additions, whilst Verano exhibited the greatest. Clearly these results indicate that under severe acid conditions root elongation in these *Stylosanthes* species is dramatically reduced. It is probable that under these conditions there will be a decline in annual recruit of these species that would drastically reduce the legume component in the pasture. This could significantly impact on productivity particularly if the associated grass component is similarly affected.

Similar bioassay tests were attempted using different grass species. However, problems associated with seed germination were encountered and in the end was abandoned.

Greenhouse pot study

Severe growth reduction was observed in all species grown on the unamended soil, with *Cenchrus ciliaris* being unable to survive under severely acid conditions (Figure 4.7). As a means of assessing an individual species susceptibility to acid soil infertility, the relative growth at the first level of lime was determined for each species based on cumulative yield over the four harvests. The relative growth of *C. ciliaris, H. contorus, B. pertusa*, *U. mosambicensis*, Verano and Seca was 0.3, 25, 34, 34, 39 and 48 % respectively in the control treatment. The responsiveness to lime additions varied between species with B. petusa *U. mosambicensis* and Verano showing a gradual response to lime additions whilst *H. contorus* and Seca exhibited rapid response to lime additions (Figure 4.7). This would suggest that in the latter two species responses to acidification would be dramatic with a rapid decline n productivity, whilst the former species these changes would be gradual. These results suggest that certain grass species are highly sensitive to acid soil infertility and with progressive acidification would potentially be eliminated from the pasture.

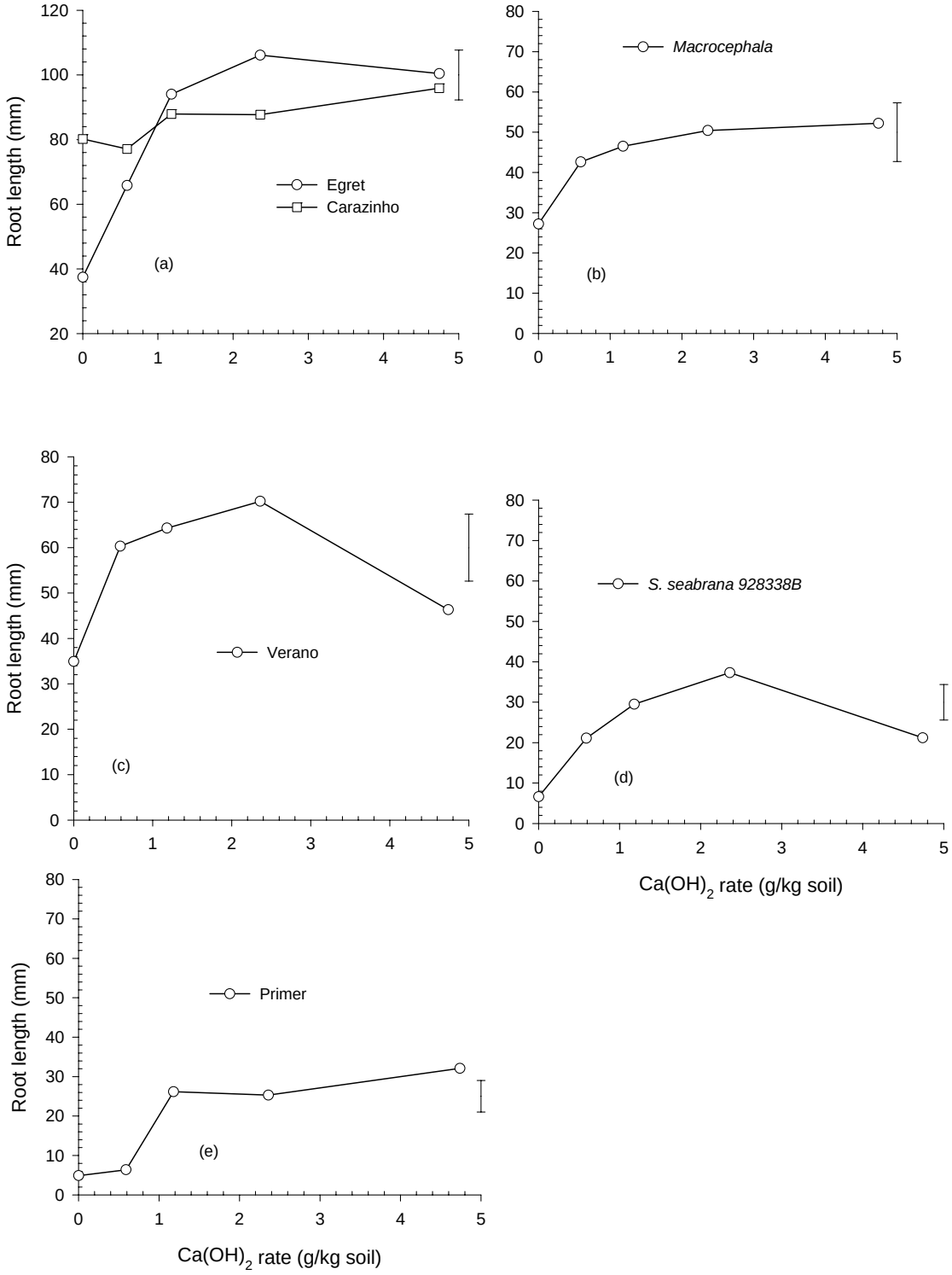


Figure 4.6. Root elongation in the presence of lime in (a) the wheat varieties Egret and Carazinho, and *Stylosanthes* varieties/species (b) *S. macrocephela*, (c) Verano, (d) *S. seabrana* 92838B and (e) Primer. Vertical bars represent the LSD between treatments at P<0.05.

These results clearly illustrate the sensitivity of both grass and legume species to acid soil infertility. Progressive acidification will drastically impact on pasture productivity and on species composition. Similar effects on pasture productivity have been observed in southern subterranean clover pastures. Continued acidification of the soil resource will result in reduced thriftiness of the pasture, associated declines in productivity and pasture diversity, with acid soils promoting acid tolerant species.

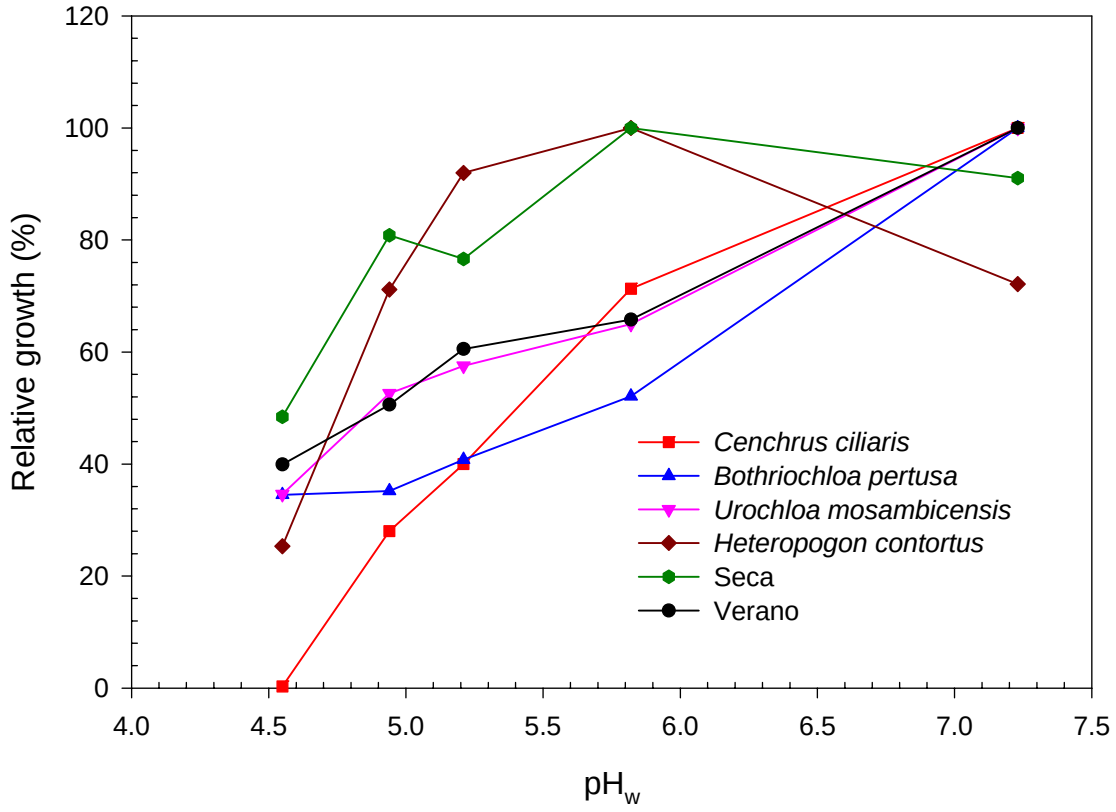


Figure 4.7. Relationship between soil pH measured in water and relative growth of different grass and *Stylosanthes* species.

5. Quantify the mineral nitrogen dynamics under a Stylosanthes dominant pasture system in order to assess the contribution of nitrate leaching to acidification and attempt to develop a total nitrogen budget for both a grass and legume dominant system respectively.

Background

The following section describes the work done towards this objective, mostly at Lansdown. The site was instrumented, measurements of quantities and fluxes of water were taken, the mineralisability of N in stylo litter was determined, nitrate leaching losses estimated, and the effects of stylo and grass on the acidity and buffering capacities of the soil were determined.

Methods

Site and soil properties

The experimental site (Lansdown, 146° 50' E, 19° 38' S) consists of two adjacent fields, one dominated by *Stylosanthes* (hereafter referred to as the Stylo plot) and the other by *Urochloa mosambicensis* (hereafter referred to as the Grass plot). The plots were established in 1986; the Stylo plot was sown to *Stylosanthes hamata* and the Grass plot to *Urochloa mosambicensis*. Since then the Stylo plot became dominated by *Stylosanthes scabra*. In 1999, *Stylosanthes scabra* was starting to appear in the Grass plot. It was removed by hand and prevented from re-establishing by adding superphosphate fertiliser, and by occasional hand-pulling and spraying with selective broadleaf herbicide (Starane). Within the Stylo plot, a Bare plot (5 m x 5 m) was established by hand pulling on 10 November 1999, and maintained bare of all vegetation by occasional spraying with glyphosate.

The soil is sandy loam over clay, classified in the Australian Soil Classification (Isbell, 1996) as a Yellow Subnatric Sodosol. Rainfall (tipping bucket) and soil water content (duplicate time domain reflectometry probes at 0.25 and 0.6 m depth) were monitored between 2 February 1998 and 11 April 2001. Data was stored in a Campbell data logger and downloaded to the laboratory daily by mobile phone telemetry. Soil water retention properties, unsaturated hydraulic conductivity and bulk density were measured in the laboratory using cores (70 mm diameter, 50 mm depth) taken from the 0-0.05, 0.075-0.135 (bulk density only) and 0.4-0.45 m depth layers (6 replicates for each depth in each plot). Saturated hydraulic conductivity was measured in the field using ring infiltrometers (Bouwer, 1986) with 0.3 m diameter placed at 0, 0.1 and 0.4 m depth (3 replicates for each depth in each plot).

Sampling and analyses

Nitrate content of the soil (5 replicates, depth increments of 0-0.1, 0.1-0.2, 0.2-0.4, 0.4-0.6 and 0.6-0.8 m) was measured regularly between 1999 and 2001. Nitrate content of the soil solution was measured occasionally during periods of high soil water content by taking samples from ceramic suction cups placed at 0.25 and 0.5 m depth (6 replicates). Plant biomass samples (5 quadrats of 0.25 or 1 m^2 in each plot) were taken on three occasions; in the dry season (9/6/99), at the start of the wet (9/12/99), and in the middle of the wet (14/2/00) (Table 2). On 14/2/00, roots were also washed from the soil on a 2 mm sieve.

Plant samples were analysed for total Kjeldahl N, ^{15}N content and ash alkalinity.

A range of plant species collected in October 2000 at Cornishmen's Creek in the Burdekin catchment were also analysed for N content and delta ^{15}N. They included grasses (*Themeda triandra, Chloris guyana, Bothriochloa decipiens, Bothriochloa pertusa, Chrysopogon fallax, Arundinella nepalensis, Melenis repens, Echinochloa colona, Heteropogon contortus, Dicanthium sericium*), forbs (*Pteracaulon radulans, Ageratum conzoides, Ludwigia octaivalis, Sida subspicata, Hyptis suaveolons, Sida cordifolia, Waltheria indica*) and legumes (*Glycine tomentella, Indigofera linnae, Rhyncosia minima, Crotolaria verrucosa, Crudigofera colutea, Crotolaria novae-hollandae*)

Over the 1999 dry season (9/6/99 to 8/12/99), litter was collected in 10 traps on either side of the fence, and weighed.

Mineralization of N in stylo litter

Eight plant materials, *Leucaena leucocephala* cv. Cunningham (1), *L. pallida* (2), *L. diversifolia* (3), *Calliandra calothyrsus* (4), *Gliricidia sepium* (5), *Acacia boliviana* (6), *Panicum maximum* (7) and *Stylosanthes scabra* (8) (all freeze-dried leaves, except for *Stylosanthes*, which was leaf litter collected from the ground), were treated with PEG (200 mg PEG /g litter) or not, and mixed thoroughly with Lansdown soil (0-10 cm depth) in incubation jars (300 mg litter, 20 g soil). A control treatment (0), in which no plant materials were added to the soil, was prepared and incubated with and without PEG. The jars, which were kept in the dark at 25º, were opened periodically to maintain aeration, and water was added to maintain water content at 80% of field capacity. At 0, 7, 14, 28 and 56 days, 3 jars of each treatment were removed from the incubation and analysed for ammonium and nitrate N in a 2 *M* KCl extract. Plant samples were analysed for total C and N content, condensed tannin content (conventionally using butanol/HCl extracts), total phenolic material content (Nelson and Baldock, submitted), and PEG binding capacity using radioactively labelled PEG (Jones and Palmer, 2000).

Calculation of nitrate fluxes

Drainage below the root zone was calculated for the period between 1998 and 2001 using the Hydrus model and the rainfall, soil water retention and conductivity data collected at the site. Soil hydraulic properties are shown in Table 5.1. Root distributions of grass and stylo were estimated from measurements made at Thalanga. Pan evaporation data from nearby (Lansdown station) was used and a crop factor of 0.7 assumed. Based on the soil hydraulic conductivity, rainfall characteristics and field observations, it was also assumed that no run-on or run-off occurred. Nitrate flux below the root zone during the 1999-2001 period was calculated by multiplying nitrate concentration in the 0.6-0.8 m depth layer (interpolated between analysis dates) with water flux. Nitrate leaching over the 1998-2001 period was estimated using 3-monthy mean nitrate concentrations derived from the period when nitrate was measured. Predictions of nitrate leaching were then made for pasture dominated by Stylo or grass on uniform sandy loam or clay soils in wet or dry years. The wet and dry years were simulated using data from the site

Results

Rainfall and soil water content

Rainfall and soil water content at the site are shown in Figure 5.1. Similarly to all the other sites, Stylo maintained lower water contents than Grass throughout the monitored period. The saturated water content is approximately 0.32 m^3/m^3 at 0.25 m depth and 0.40 m^3/m^3 at 0.50 m depth. During very wet periods, the water content under Stylo was similar to that under Grass. After rainfall events, Stylo extracted water more rapidly than Grass. Throughout the dry season, Stylo maintained lower soil water contents than Grass.

Nitrate content in soil and water

Soil nitrate concentrations for the deepest and shallowest depths under stylo and grass are shown in Figure 5.2. They were consistently highest in the Bare topsoil, as dead roots and organic matter were mineralized. The Bare concentrations show the potential mineral N that becomes available for uptake by both grasses and legumes. Under pasture, the nitrate concentrations in the topsoil were consistently higher under Stylo than under Grass. The difference was greatest at times of low nitrate concentration. In the subsoil however, the differences were much less, showing that Stylo and soil organisms were efficient at immobilizing or taking up the extra nitrate produced in the topsoil. Immobilization by soil microorganisms was particularly evident in the Bare plot, where a large amount of the nitrate was produced in the topsoil during the 2000 dry season, but was not leached; it was immobilized back into organic matter before the wet season. Nitrate concentrations were generally highest at the start of the 1999/00 wet season and at the end of the wet season. Those high concentrations were the result of high mineralization rates and low uptake rates. The soil being wet enough to support microbial activity but not plant growth. Concentrations were lowest during the wet

seasons, due to the combination of leaching loss, plant uptake, and possibly some denitrification during periods of waterlogging.

Nitrate concentration was also measured in soil solution, by vacuum extraction from ceramic suction cups (Table 5.2). When the soil was at or close to saturation, a suction of 80 kPa was applied, and the solutions extracted from the cups the following day. In December, soil solution nitrate concentration was much higher under stylo than under grass. As the wet season progressed, nitrate concentrations dropped markedly, reaching similarly low concentrations under both Stylo and Grass.

Nitrate leaching

Over the three-year monitoring period the total loss of nitrate-N by leaching was 192 kg/ha under Stylo and 110 kg/ha under Grass. From these results we were able to predict what the leaching losses would be under Stylo- or grass-dominated pastures on lighter or heavier textured soils in drier or wetter climates. Simulated drainage and nitrate leaching losses are presented and predicted losses are presented in Figure 5.3. Loss of nitrate-N under Stylo on a sandy loam soil in a wet year reached 225 kg/ha. Even under grass in a dry year on a clay soil, 10 kg/ha could be expected to be lost from the root zone by leaching. However, this amount would be compensated for by inputs from the atmosphere. Predicted annual losses are shown in Table 5.3.

Biomass, fixation and uptake of nitrogen

Total above-ground biomass of Stylo was more than twice that of Grass over the whole monitoring period (Table 5.4). Nitrogen content of the Stylo biomass was 20-55% greater than that of Grass, the difference being greatest in the wet season. Stylo biomass also had considerably higher ash alkalinity than the Grass.

On the 14/02/00 sampling, the total dry mass of roots, to 0.2 m depth, was 664 kg/ha under stylo, and 685 kg/ha under grass. Stylo roots had higher N content and higher ash alkalinity than whole Stylo tops (Table 5.4). Stylo leaves however had by far the highest N content and ash alkalinity of all samples. In Grass, both N content and ash alkalinity were lower in the roots than the tops.

Delta ^{15}N values (Figure 5.4) indicate that during the wet season, a considerable proportion of N in the Stylo originated from the atmosphere, the values being close to zero. However, during the dry season, when plants were not active, delta ^{15}N values were much lower in Stylo and were close to zero in Grass. Loss of N from the biomass during the dry season seemed to be having the opposite effect on isotopic composition than fixation in the dry. The dry season results from Lansdown were generally corroborated by the results for a range of other grasses and legumes sampled in the dry. Forbs stood out from grasses and legumes indicating that different pathways of uptake and loss occur. The grasses had a mean N content of 0.47%, the legumes 1.69% and the forbs 1.12%.

Under stylo, the total litter fall over the 1999 dry season (9/6/99 to 8/12/99) was 574 kg/ha, of which 458 kg/ha was stylo leaves and flowers, and 116 kg/ha was other species.

Mineralization of N in stylo litter

Stylo drops most of its leaves in the dry season, and this may be a significant return of N to the soil. However, the mineralization of N from leaves of tropical legumes is often inhibited by organic compounds that bind to organic N compounds (proteins) and slow their decomposition. Mineralization of N in legume litter added to soil is inversely proportional to the lignin content, condensed tannin content (Palm and Sanchez, 1991) and C:N ratio of the litter (Seneviratne, 2000). Amongst other things, phenolic materials bind to proteins, inhibiting their decomposition in soils, but the nature of the materials and interactions involved are not fully understood. Two recently developed techniques may help elucidate the mechanisms concerned. Firstly, the ability of polyethylene glycol (PEG) to bind to condensed tannins is used to assess the effect of these materials on N mineralization in ruminant digestive tracts. Digestibility of N in a range of tropical legume shoots was more closely related to PEG binding than conventional measurements of condensed tannins (Jones and Palmer, 2000). The lower the N digestibility of a plant sample, the greater it's PEG-binding capacity, and the greater the positive effect on N digestibility when PEG was added to the digestibility assay. Secondly, the total content of phenolic materials, including lignin and condensed tannins, may be estimated using C and

N content and ^{13}C nuclear magnetic resonance (NMR) data (Nelson and Baldock, submitted). In this experiment we set out to determine whether mineralization of N in litter of stylo and other tropical legumes added to soil was related to their PEG-binding ability, or total phenolic material content by NMR.

The amount of N mineralized differed considerably between plant materials, with stylo litter having the lowest amount of mineralization (Figure 5.5). Greater mineralization in the presence of PEG, or a positive PEG effect, was exhibited by samples 4 and 6, which had low N mineralization, high PEG binding and a large response to PEG in terms of in-vitro N digestibility. A negative PEG effect was noted for samples having high N mineralization (samples 1, 2 and 5). It appeared that in these samples, mineralised N was immobilised by microbes decomposing PEG.

Mineralization of litter N was closely related to the PEG binding capacity of the litter and to the total content of phenolic materials (Figure 5.6). PEG binding capacity and total phenolic content were highly correlated (r^2=0.88). N mineralization was more closely related to PEG binding capacity and total phenolic material content than to N content, C:N ratio, lignin:N ratio or condensed tannin content by conventional means.

In conclusion, stylo litter had lower N content and lower N mineralization than all of the fresh litters tested. Therefore stylo litter does not appear to add significant amounts of readily mineralisable organic N to the soil. It is possible that the plant relocates N from the leaves before dropping them. The results suggested that the low mineralization of N was due to binding of organic N compounds by phenolic materials including lignin and condensed tannins (of which stylo had the third highest content).

Effects on soil acidity and buffering capacity

Stylo-dominated pasture has had a considerable acidifying effect at the site, significantly lowering soil pH from the surface down to 0.4 m depth (Figure 5.7). The most acidified layer is at 0.05-0.10 m depth. Acid neutralizing capacity, or the amount of acid required to reduce pH from the existing value to pH 4, was also reduced under stylo compared to grass (Figure 5.7). The difference between the treatments is not significant, because it was measured at low ionic strength. Most of the acidification and loss of acid neutralizing capacity has occurred as a change in exchangeable rather than solution acidity, which is expressed more strongly in extracts with high ionic strength (eg. 0.1 M $CaCl_2$ as in Figure 5.7a) than extracts with low ionic strength (eg. in water or 0.002 M $CaCl_2$, as in Figure 5.7b). The decrease in acid neutralizing capacity under stylo relative to grass was a result of the difference in pH rather than differences in organic matter content, which were not significantly different. The only exception was the litter layers, which had very high and significantly different organic matter contents, which resulted in large differences in acid neutralizing capacity. The stylo litter had pH 6.26, organic C content of 19.2% and acid neutralizing capacity of 201 cmol H^+/kg, compared to the grass litter, which had pH 6.65, organic C content of 3.7% and acid neutralizing capacity of 83 cmol H^+/kg.

The acidifying effects of stylo were apparent from comparison the N contents and C:N ratios of the stylo and grass biomass components (Table 5.5). Tops, roots, and especially leaves of stylo had high N contents. It is the eventual decomposition of these materials that leads to high soil nitrate concentrations, leaching and acidification. However, the stylo biomass, especially the leaves, also contained higher ash alkalinity than the grass biomass. The higher ash alkalinity of stylo is presumably due to greater transpiration of water, especially from depth. The return of this ash alkalinity to surface layers in litter and root death is presumably helping counter acidification in the very surface layers.

Incubating the stylo and grass biomass components with the grass and stylo soils over 27 days did not significantly change the buffering capacity of the soils.

Conclusions

Quantification of uptake, mineralization and leaching of N under Stylo and Grass-dominated pasture showed the potential for greater N inputs and losses under legumes. The leaching losses can be significant, particularly in wet years on light textured soils. Acidification of the soil under Stylo-dominant pastures occurs due to a combination of cation uptake and nitrate leaching.

Table 5.1. Hydraulic properties of the Lansdown soil

	Grass	Stylo	Grass	Stylo	Grass	Stylo
Depth (cm)	**0**	**0**	**10**	**10**	**40**	**40**
			Bulk density (g/cm3)			
	1.48	1.68	1.74	1.62	1.54	1.62
Suction (cm)			**Volumetric water content (m3/m3)**			
1	0.386	0.332			0.376	0.352
10	0.372	0.329			0.370	0.334
20	0.350	0.320			0.339	0.304
50	0.309	0.285			0.299	0.265
100	0.270	0.256			0.276	0.244
306	0.152	0.137			0.216	0.194
3060	0.089	0.091			0.192	0.176
5100	0.083	0.086			0.188	0.172
15300	0.075	0.078			0.190	0.166
Suction (cm)			**Unsaturated hydraulic conductivity (mm/hr)**			
4	2.40	2.67			7.92	7.12
2	3.08	3.73			14.64	11.26
Head (cm)			**Saturated hydraulic conductivity (mm/hr)**			
10-14 cm	652	235	64	83	102	158

Table 5.2. Quality of water extracted from suction cups (mean values)

		Depth (m)	28/12/99	09/02/00	24/02/00	09/11/00	02/12/00
pH	Grass	0.25	6.42	6.17	6.21		
		0.50	6.49	6.25	6.25		
	Stylo	0.25	5.67	5.69	6.05		
		0.50	6.40	6.33	6.34		
Electrical conductivity	Grass	0.25	0.15	0.13	0.16		
(dS/m)		0.50	0.25	0.21	0.24		
	Stylo	0.25	0.34	0.16	0.07		
		0.50	0.27	0.06	0.09		
Nitrate-N*	Grass	0.25	0.57	0.43	< 0.3	0.05	0.06
(mg/L)		0.50	0.68	0.38	< 0.3	0.01	0.02
	Stylo	0.25	14.47	0.66	< 0.3	-	0.67
		0.50	10.19	0.44	< 0.3	1.92	0.47

* Nitrate makes a significant contribution to EC under stylo on the first sampling date (0.10 dS/m at 0.25 m and 0.07 dS/m at 0.5 m).

Table 5.3. Estimated loss of nitrate by leaching under various scenarios

Dominant pasture species	Climate	Soil texture	Estimated annual nitrate-N loss (kg/ha)
Stylo	Wet	Sandy loam	225
Stylo	Wet	Clay	163
Grass	Wet	Sandy loam	75
Grass	Wet	Clay	51
Stylo	Dry	Sandy loam	50
Stylo	Dry	Clay	25
Grass	Dry	Sandy loam	20
Grass	Dry	Clay	10

Table 5.4. Mean biomass, N content, proportion of N fixed, cation content and ash alkalinity of above-ground plant material from the Stylo and Grass plots.

Plot	Biomass	N	Ca	Mg	K	Na	Ash alkalinity
	(kg/ha)	(%)	($mmol_c$/kg)				
Stylo 9/6/99*	12,606	0.88	448	69	128	19	563
9/12/99	10,618	1.10	386	78	125	17	490
14/2/00	12,894	0.95	363	77	152	15	469
Grass 9/6/99*	5,497	0.73	255	180	256	87	533
9/12/99	5,340	0.78	248	117	115	52	402
14/2/00	5,567	0.61	201	120	206	55	414

*On 9/6/99, mean biomass composition of the Stylo plot was 81% *Stylosanthes* with 0.95% N, 14% grass with 0.65% N and 5% other materials with 1.12% N. Mean biomass composition in the Grass plot was 87% grass with 0.67% N and 13% Stylosanthes with 1.12% N. For cation and anion analysis, pure *Stylosanthes* samples were used from the Stylo plot and pure grass (*Urochloa*) samples were used for the Grass plot. In the subsequent two samplings, there was less grass in the Stylo plot and virtually no *Stylosanthes* in the Grass plot.

Table 5.5. Ash alkalinity and N content of above- and below-ground plant materials

		Dry season 9/6/99	Wet season, 14/2/00		
		Ash alkalinity (cmol/kg)	Ash alkalinity (cmol/kg)	Total N content (%)	C:N ratio
Stylo	Tops	51.8	35.9	0.72	60.2
	(Leaf)	(153.9)	(113.9)	(2.48)	(17.0)
	Roots		46.5	0.94	46.5
Grass	Tops	67.8	43.3	0.46	90.9
	Roots		21.5	0.40	106.0

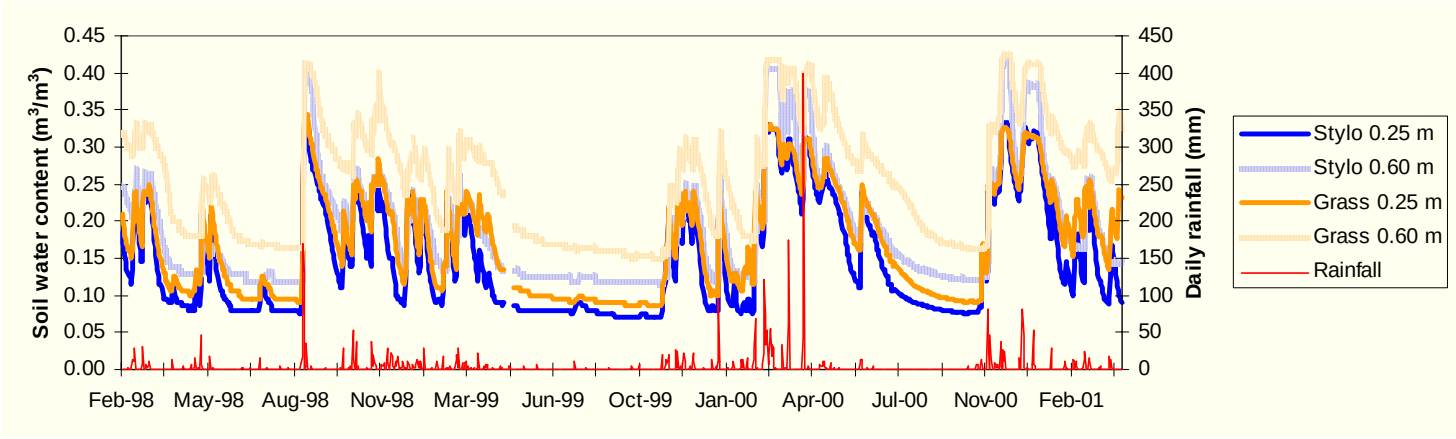


Figure 5.1. Rainfall and soil water content at the Lansdown site over the monitoring period.

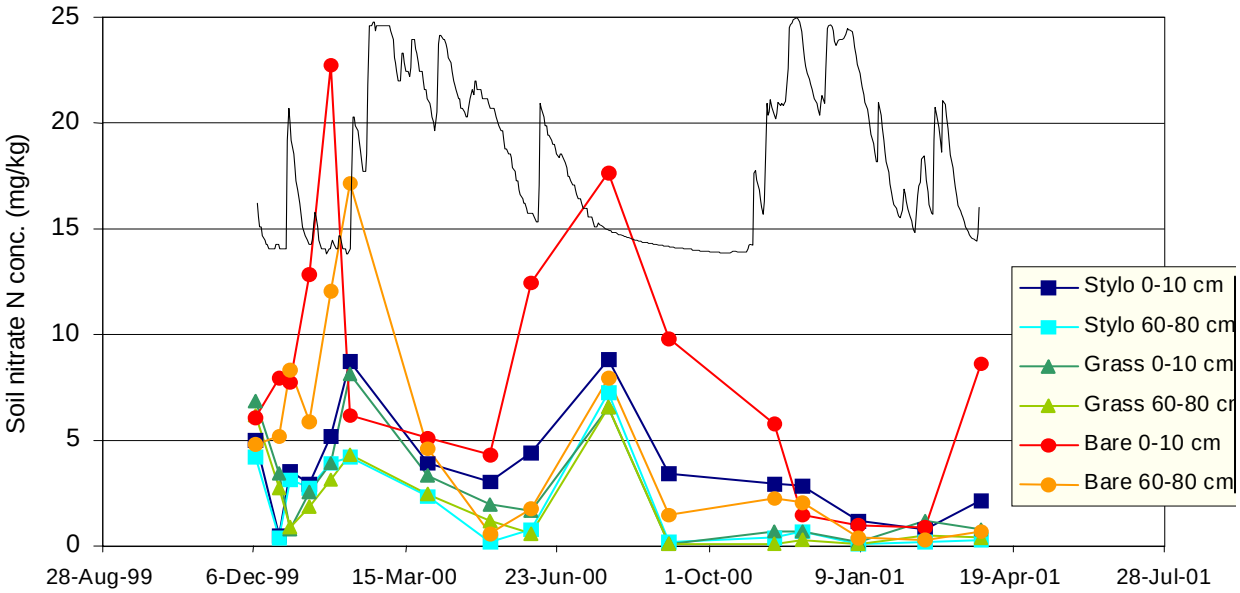
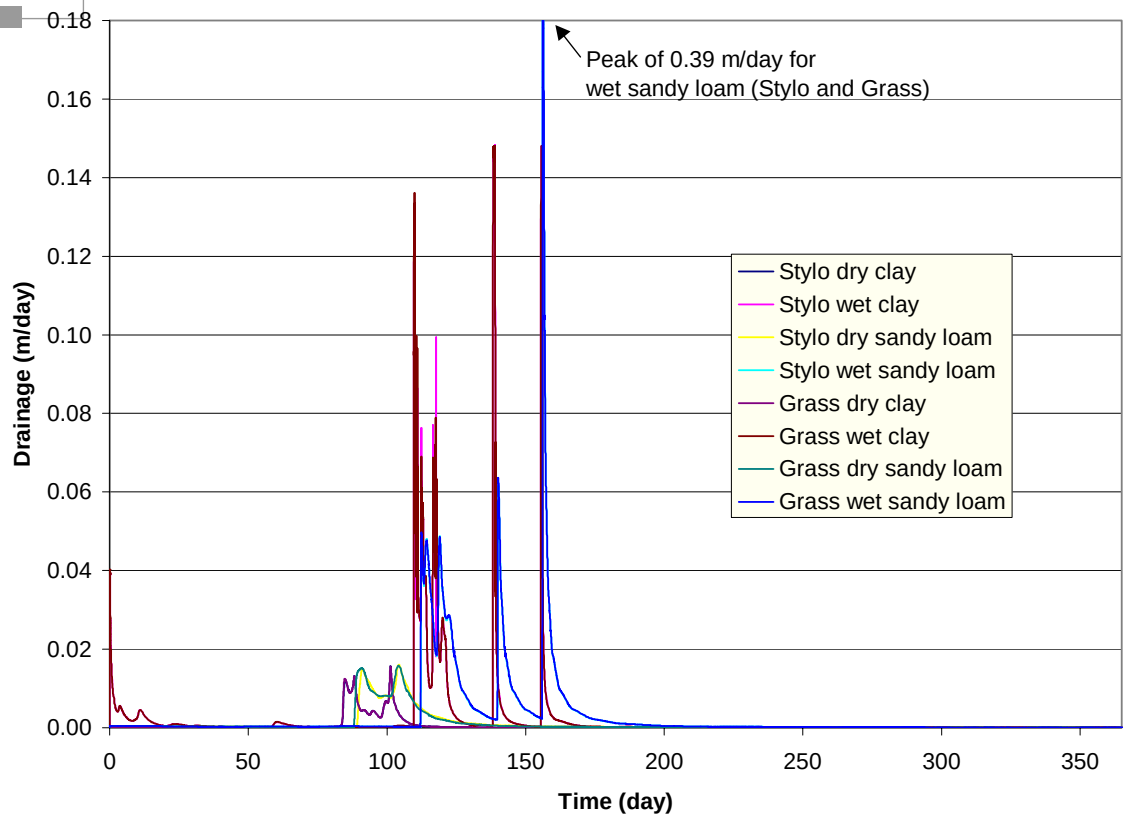


Figure 5.2. Concentration of soil nitrate-N from December 1999 to April 2001. The black line shows soil water content.



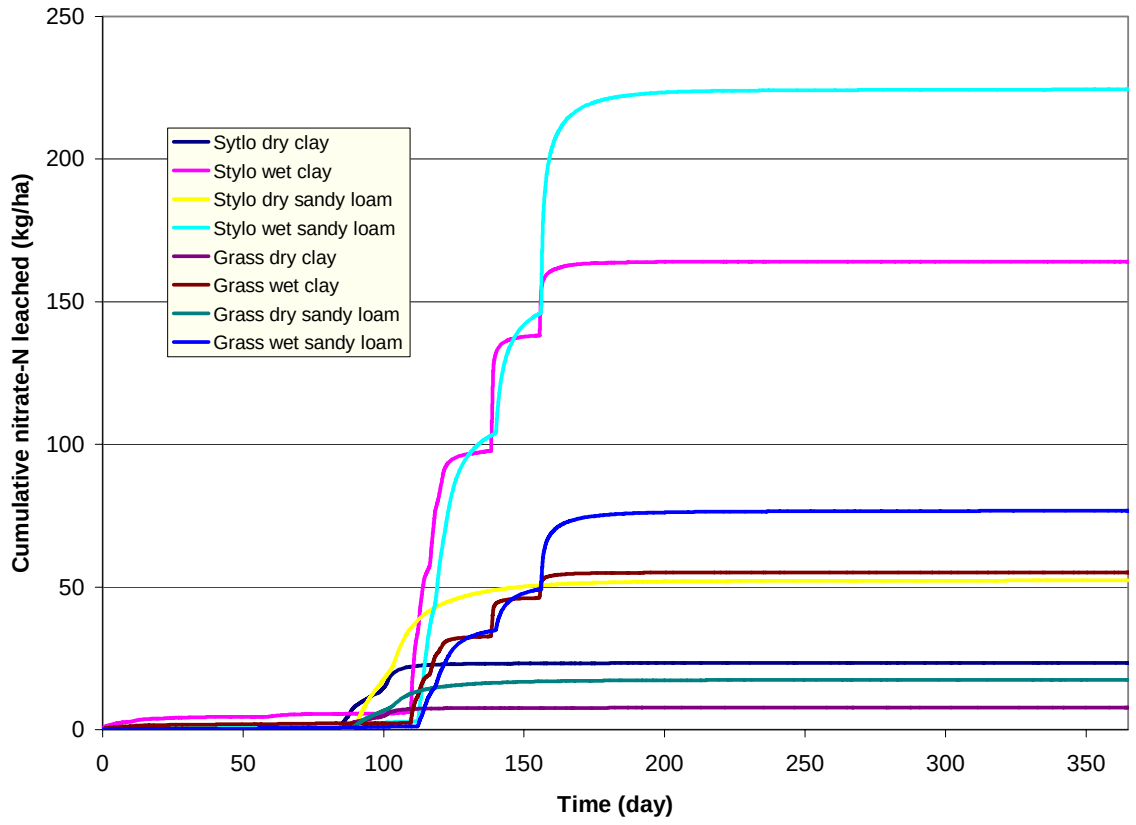


Figure 5.3. Simulated drainage and nitrate leahing under Stylo and Grass in wet or dry years on a sandy loam or clay soil.

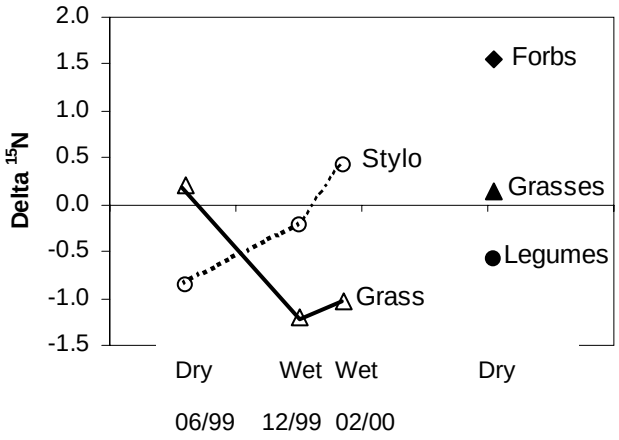


Figure 5.4. Delta 15N values for Stylo and grass at Lansdown and for a range of other rangeland understorey species from the Burdekin catchment.

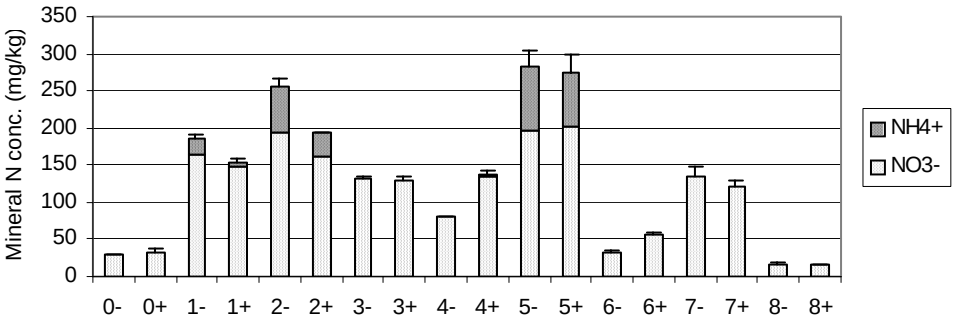


Figure 5.5. Mineral N concentration in soil after 56 days of incubation with various litter samples. Numbers indicate litter sample (Number 8 is stylo litter, see text for the others), "-" indicates no added PEG, "+" indicates PEG addition, and error bars are standard deviations of total mineral N concentration.

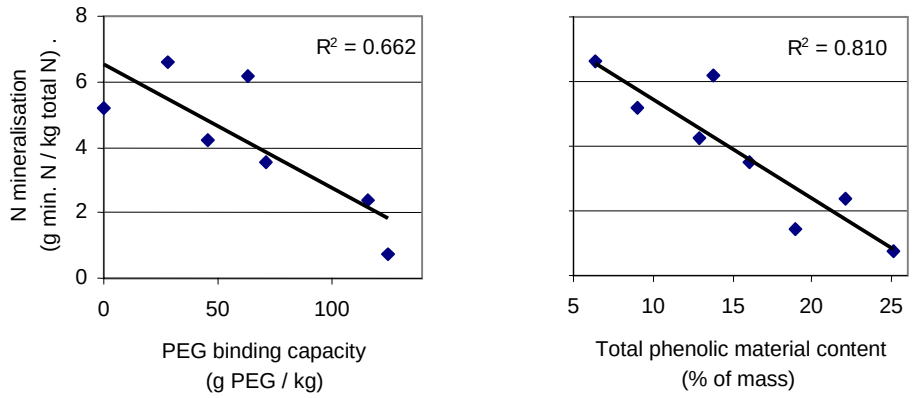


Figure. 5.6. N mineralization, after 56 days of incubation without added PEG, as a function of PEG binding capacity, and total phenolic material content of the litter.

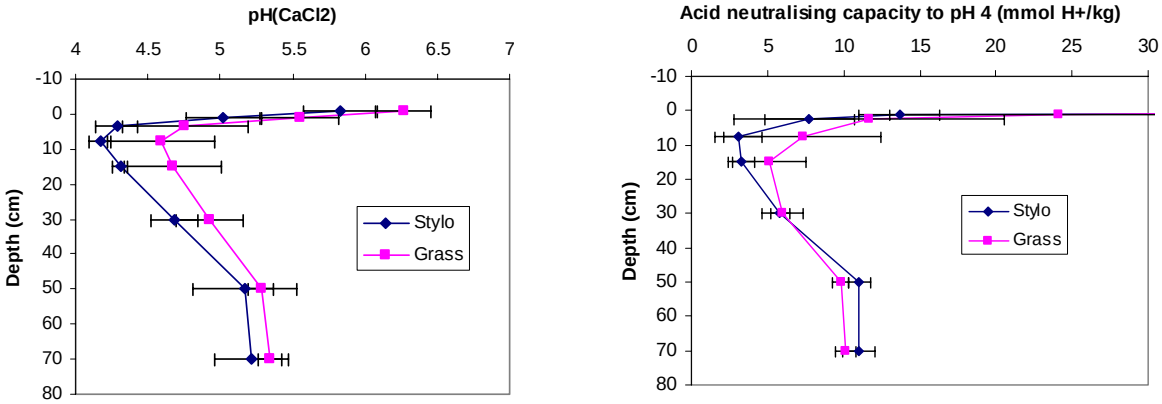


Figure 5.7. a) Soil pH and b) acid neutralising capacity profiles.

References

Ahern, C. R, Weinard, M. M. G. and Isbell, R. F. 1994. Surface soil pH map of Queensland. *Australian Journal of Soil Research* **32,** 213-227.

Aitken, R. L. and Moody, P. W. 1994. The effect of valence and ionic strength on the measurement of pH buffer capacity. *Australian Journal of Soil Research* **32,** 975-984.

Bartlett, R. .J., Ross, D. S. and Magdoff, F. R. 1987. Simple kinetic fractionation of reactive aluminum in soil "solution". *Soil Science Society of America Journal,* **51,** 1479-1482.

Bessho, T. and Bell, L. C. 1992. Soil solid and solution phase changes and mung bean response during amelioration of aluminium toxicity with organic matter. *Plant and Soil* **140,** 183-196.

Bevacqua, R. F. and Mellano, V. J. 1994. Cumulative effects of sludge compost on crop yield and soil properties. *Communications in Soil Science and Plant Analysis* **25,** 394-406

Bolan, N. S., Hedley, M. J. and White, R. E. 1991. Process of soil acidification during nitrogen cycling with emphasis on legume based pastures. In: Wright RJ, Baligar VC and Murrmann PR. (eds) Plant-Soil Interactions at Low pH, pp 169-170. (Kluwer Academic Publishers, Dordrecht).

Bouwer, H. 1986. Intake rate: Cylinder infiltrometer. In 'Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. Vol. 1.' (Ed Klute A.) pp. 825-844. (American Society of Agronomy, Soil Science Society of America: Madison, Wisconsin.)

Browne, B. A. 1995. Toward a new theory of podzolization. In: McFee WW and Kelly JM (eds) Carbon forms and functions in forest soils, pp 253-273. (Soil Science Society of America Inc., Madison, WI).

Bui, E. N., Smettem, K. R. J., Moran, C. J. and Williams, J. 1996. Use of soil survey information to assess regional salinization risk using geographical information systems. *Journal of Environmental Quality* **25**, 433-439.

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 Soil Research* **28**, 539-548.

Clowell, J. D. 1963. The estimation of the phosphorus fertilizer requirements of wheat in southern New South Wales by soil analysis. *Australian Journal of Experimental Agriculture and Animal Husbandry* **3,** 190-198.

Coates, D. B., Miller, C. P., Hendricksen, R. E. and Jones, R. J. 1997. Stability and productivity of *Stylosanthes* pastures in Australia. II. Animal production from *Stylosanthes* pastures. *Tropical Grasslands* **31**, 494-502.

Coventry, R. J. and Williams, J. 1984. Quantitative relationships between morphology and current soil hydrology in some Alfisols in semiarid tropical Australia. *Geoderma* **33,** 191-218.

Coventry, R. J. and Fett, D. E. R. 1979. A pipette and sieve method of particle-size analysis and some observations on its efficacy. CSIRO Division of Soils Divisional Report No. 38, Townsville, QLD.

De Corte, M., Cannon, M. G., Barry, E., Bright, M. and Scanlan, J. 1994. Land degradation in the Dalrymple Shire: A preliminary assessment of methods and results. Project report series QO 93023. (Queensland Department of Primary Industries: Brisbane)

Gillman, G. P. and Sumpter, E. A. 1986. Modification of the compulsive exchange method for measuring exchange characteristics of soils. *Australian Journal of Soils Research* **24**, 61-66.

Gramshaw, D. and Walker, B. 1988 Sown pasture potential in Queensland. *Queensland Agricultural Journal* **114**, 93-101.

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

Helyar, K. R. 1991. The management of acid soils. In: Wright RJ, Baligar VC and Murrmann PR. (eds) Plant-Soil Interactions at Low pH, pp 365-382. (Kluwer Academic Publishers, Dordrecht).

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

Hoyt, P. B. and Turner, R. C. 1975. Effects of organic materials added to very acid soils on pH, aluminium, exchangeable NH_4, and crop yields. *Soil Science* **119,** 227-237

Hue, N. V. and Amien, I. 1989. Aluminium detoxification with green manures. *Communications in Soil Science and Plant Analysis* **20,** 1499-1511

Isbell, R. F. (2000) The Australian Soil Classification. (CSIRO: Collingwood, Australia)

Isbell, R. F. and Murtha, G. G. 1970. Soils – Burdekin – Townsville Region (Queensland). Resources Series. (Department of National Development, Geographic Section: Canberra)

Jarvis, S. C. and Robson, A. D. 1983. The effects of nitrogen nutrition of plants on the development of acidity in Western Australian soils. II Effects of differences in cation/anion balance between plant species grown under non-leaching conditions. *Australian Journal of Agricultural Research* **34,** 355-365.

Jayan, P. K. 1995. Fodder resources and their development in peninsular India. (IGFRI Regional Station, Dharwad India.)

Jones, R. J. and Palmer, B. 2000. In vitro digestion studies using ^{14}C-labelled polyethylene glycol (PEG) 4000: Comparison of six tanniniferous shrub legumes and the grass *Panicum maximum*. *Animal Feed Science and Technology* (in press)

Jungk, A. 1968. Die Alkalinität der Pflanzenasche als Maß für den Kationenüberschuß in der Pflanze. *Z. Pflanzenernähr. Bodenkd.* **120**, 99-105.

Kennedy, I. R. 1992. Acid Soils and Acid Rain. pp 254. John Wiley and Sons Inc., New York

Liu Goudoa, Phaikaew, C. and Stur, W. W. 1997. Status of *Stylosanthes* development in other countries. II *Stylosanthes* development and utilisation in China and southeast Asia. *Tropical Grasslands* **31**, 460-466.

Magdoff, F. R. and Bartlett, R. J. 1985. Soil pH buffering revisited. *Soil Sci. Soc. Am. J.* **49:** 145-148.

Markus, D. K., McKinnon, J. P., and Buccafuri, A. F. 1985. Automated analysis of nitrite, nitrate and ammonium N in soils. *Soil Science Society of America Journal* **49**, 1208-1215.

Marschner, B., Marx, M. and Nelson, P. 2001. N-mineralisation and soil acidification in soils under grass and legume-improved pasture in Northeastern Australia. (Geotrop)

Mengel, K. and Kirkby, E. A. 1982. Principles of Plant Nutrition. pp 593. International Potash Institute, Berne, Switzerland.

Michalk D. L, Fu Nan-Ping and Zhu Chin-Ming. 1993. Improvement of dry tropical rangelands on Hainan Island, China. 2. Evaluation of pasture grasses. *Journal of Rangeland Management* **46,** 339-345.

Middleton, C. H. and Noble, A. D. 1998. Accelerated soil acidification under legume based pasture systems of northern Australia: Promotion of management strategies to minimise acidification. Proceedings National Soil Acidification Conference, Coolum, Sunshine Coast, 15-17 July, 1988.

Miller, C. P., Wildin, J. H., Cooksley, D. G. and Lowe, K. F. 1988. Augmenting native pasture with sown species. In 'Native pastures of Queensland'. Eds WH Burrows, JC Scanlan, MT Rutherford. pp. 160-173. (Queensland Department of Primary Industries: Brisbane)

Miller, C., Anning, P., Winter, W. and Wildin, J. 1991. Developing and managing pastures. *In* 'Sown pastures for the seasonally dry tropics'. Eds IJ Partridge, CP Miller. pp. 25-34. (Queensland Department of Primary Industries: Brisbane)

Miller, C. P., Rains, J. P., Shaw, K. A. and Middleton, C. H. 1997. Commercial development of *Stylosanthes* pastures in northern Australia. II. *Stylosanthes* in the northern Australian beef industry. *Tropical Grasslands*, **31**, 509-514.

Miller, W. P., Martens, D. C. and Zelazny, L. W. 1985. Effects of manure amendment on soil chemical properties and hydrous oxides. *Soil Science Society of America Journal* **49,** 856-861.

Moody, P. W. and Aitken, R. L. 1997. Soil acidification under some tropical agricultural systems. 1. Rates of acidification and contributing factors. *Australian Journal of Soil Research* **35,** 163-174.

Nelson P. N., and Baldock, J. A. 2001. Common biomolecules can explain the chemical composition of natural organic materials from diverse sources. *Organic Geochemistry*. (submitted)

Nicoulland, B., King, D. and Tardieu, F. 1994. Vertical distribution of maize roots in relation to permanent soil characteristics. *Plant and Soil* **159**: 245-254.

Noble, A. D. 1997. Soil Acidification research in the Semi-arid Tropics. MRC Report. Project CS.277.

Noble A. D., Irene Zenneck and Randall P. J. 1996. Leaf litter ash alkalinity and neutralisation of soil acidity. *Plant and Soil* **179**, 293-302

Noble A. D. and Randall, P. J. 1999. Alkalinity effects of different tree litters incubated in an acid soil of N.S.W. Australia. *Agroforestry Systems* **46,** 147-160.

Noble, A. D. 1998. Sustainability of *Stylosanthes* based pasture systems in northern Australia: managing soil acidity. In The North Australia Program 1998 Annual Peer Review of Sown Pasture Species Development and Legume Dominance and Soil Acidification Projects ed. B. Walker. pp.63-75. NAP Occasional Publication No. 6.

Noble, A. D. 1998. Soil acidification under legume based pastures of northern Australia: The problem. National Soil Acidification Conference, Sunshine Coast, Queensland. 15-17 July.

Noble, A. D., Thompson, C. H., Jones, R. J. and Jones, R. M. 1998. The Long-term impact of two pasture production systems on soil acidification in southern Queensland. *Australian Journal of Experimental Agriculture* **38**, 335-343.

Noble, A. D., Ruaysoongnern, S., Willett, I. R. and Palmer, B. 1999. Soil acidification under *Stylosanthes* seed production systems in Northeast Thailand and northern Australia: A potential constraint to long-term sustainability. In '2nd International Land Degradation Conference: Meeting the challenges of land degradation in the 21st century' pp 49. (Khon Kaen, Thailand)

Noble, A. D., Orr, D. M., Middleton, C. H. and Rogers, L. G. 2001. Legumes in native pasture - asset or liability! A case history with stylo. *Tropical Grasslands* **34**, 199-206.

Noble, A. D. and Nelson, P. 1999. Sustainability of *Stylosanthes* based pasture systems in northern Australia: managing soil acidity. In 1999 Peer Review of Resource and Whole Property Management Projects ed. J. Lambert. pp 60-70. NAP Occasional Publication No. 10.

Noble, A. D. and Nelson, P. 2000. Sustainability of *Stylosanthes* based pasture systems in northern Australia: managing soil acidity. In 1999 Peer Review of Resource Management Projects ed. J. Lambert. pp 107-115. NAP Occasional Publication No. 11.

Noble, A. D., Cannon, M. and Muller, D. 1997. Evidence of accelerated soil acidification under *Stylosanthes*-dominated pastures. *Australian Journal of Soil Research* **35**:1309-1322.

Noble, A. D., Ruaysoongnern, S., Willett, I. and Palmer, B. 2001. Soil acidification under Stylosanthes seed production systems in Thailand and Australia. In Response to Land Degradation eds. E. M. Bridges, I. D. Hannam, L. R. Oldeman, F. W. T. Penning de Vries, S. J. Scherr and S. Sombatpanit. p147. Science Publishers Inc. UK.

Norrish, K. and Hutton, J.T. 1977. Plant analysis by X-ray spectrometry. 1. Low atomic number elements, sodium to calcium. *X-Ray Spectrometry* **6,** 6-11

Palm, C. A. and Sanchez, P. A. 1991. Nitrogen release from the leaves of some tropical legumes as affected by their lignin and polyphenolic contents. *Soil Biology and Biochemistry* **23**, 83-88.

Partridge, I., Middleton, C. and Shaw, K. 1996. Stylos for better beef. Information Series QI96010. (Department of Primary Industries: Brisbane)

Pinstrup-Andersen, P. and Pandya-Lorch, R. 1994. Enough food for future generations? In 'Choices. The Magazine of Food, Farm, and Resources' Issues . No. 3, pp13-16.

Pocknee, S. and Sumner, M. E. 1997. Cation and nitrogen contents of organic matter determine its soil liming potential. *Soil Science Society of America Journal* **61,** 86-92

Probert, M. E. and Williams, J. 1986. The nitrogen status of red and yellow earths in the semi-arid tropics as ininfluenced by Caribbean stylo (*Stylosanthes hamata*) grown at various rates of applied phosphorus. *Australian Journal of Soil Research* **24**, 405-421.

Rawls, W. J. 1983. Estimating soil bulk density from particle size analysis and organic matter content. *Soil Science* **135**, 123-125.

Rayment, G. E. and Higginson, F. R. 1992. 'Australian Laboratory Handbook of Soil and Water Chemical Methods'. (Inkata Press: Melbourne)

Ridley, A. M., Slattery, W. J., Helyar, K. R. and Cowling, A. 1990. Acidification under grazed annual and perennial grass based pastures. *Australian Journal of Experimental Agriculture* **30,** 539-544

Rogers, L. G., Cannon, M. G. and Barry, E. V. 1999. Land Resources of the Dalrymple Shire. (Department of Natural Resources: Brisbane.)

Seneviratne, G. 2000. Litter quality and nitrogen release in tropical agriculture: a synthesis. *Biology and Fertility of Soils* **31**, 60-64.

Thomas, G. W. and Hargrove, W. L. 1984. The chemistry of soil acidity. In: Adams F. (ed) Soil acidity and liming, pp 3-56. (Agronomy Monograph 12 ASA, CSSA and SSSA, Madison, WI).

Tyson, S. C. and Cabrera, M. L. 1993. Nitrogen mineralisation in soils amended with composted and uncomposted poultry litter. *Communications in Soil Science and Plant Analysis* **24,** 2361-2374.

van Breeman, N. 1987. Effects of redox processes on soil acidity. *Netherlands Journal of Agricultural Science* **35,** 271-279

Williams, C. H. 1980. Soil acidification under clover pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **20**: 561-567.

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,** 179-189

Williams, C. H. and Andrew, C. S. 1970. Mineral nutrition of pastures. In: Moore RM. (ed) Australian Grasslands. pp 321-338. (ANU Press, Canberra).

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

Williams, J. and Probert, M. E. 1984. Characterisation of the soil-climate constraints 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 for soil water measurements. In National Conference Publication 80/9. pp 96-100. November 1980. (Institution of Engineers: Adelaide).

Yan F., Schubert, S. and Mengel, K. 1996. Soil pH increase due to biological decarboxylation of organic anions. *Soil Biology and Biochemistry* **28,** 617-624

Yeomans, J. C., and Bremner, J. M. 1988. A rapid and precise method for routine determination of organic carbon in soil. *Communications in Soil Science and Plant Analysis* **19**, 1467-76

APPENDICES

Site 1: Lansdown Research Station, north Queensland. Owner, CSIRO Sustainable Ecosystems. Previous site of T333 of Mr D. Coates.

Location:

Pasture Composition and History: Site previously used in a grazing study evaluating P and S additions in the presence of improved pasture (*Urochloa mozambicensis* and *Stylosanthes* (Secca and Verano)). The area was cleared and ploughed, and sown to a mixture of S. hamata cv Verano, S. scabra cv Seca and U. mozambicensis cv Nixon Sabi without fertilizer in December 1980. The soil is classified as a Yellow Subnatric Sodosol (Isbell, 1996). Pasture dominated by Urochloa whilst the legume pasture dominated by Secca and Verano. Evidence of weedy species encroaching into the Stylosanthes pasture.

Table 1.1. Selected soil properties for the Lansdown permanent monitoring site for the Urochloa dominant pasture.

Depth	Particle size distribution (%)				pH_w	pH_s	EC	Exchange properties ($cmol_c/kg$)						Ext P	OC	NO_3-N	NH_4-N
(cm)	C.S	F.S	Silt	Clay			(dS/m)	Ca^{2+}	Mg^{2+}	K^+	Na^+	Mn^{2+}	CEC	(mg/kg)	(%)	(mg/kg)	
								Urochloa mozambicensis									
0 - 10	31.3	45.3	13.2	10.2	6.30	5.07	0.05	1.02	0.45	0.45	0.13	0.02	2.20	3.00	0.70	6.39	11.29
10 - 20	31.4	43.7	12.8	12.1	5.81	4.74	0.03	0.78	0.47	0.18	0.08	0.03	2.08	2.00	0.37	0.90	3.46
20 - 30	30.6	40.1	10.0	19.3	6.07	5.08	0.02	0.98	0.98	0.16	0.09	0.03	2.61	1.50	0.34	0.90	2.45
30 - 40	30.2	31.6	8.2	29.9	6.22	5.32	0.03	1.22	1.83	0.15	0.14	0.01	3.37	1.00	0.35	0.90	1.59
40 - 50	29.3	25.6	9.1	35.9	6.31	5.44	0.03	1.18	2.39	0.15	0.20	0.01	4.26	1.00	0.31	0.90	1.25
50 - 60	26.6	25.1	9.0	39.4	6.26	5.45	0.04	1.11	2.95	0.18	0.29	0.01	4.85	1.50	0.28	0.90	2.14
60 - 70	27.9	26.0	7.5	38.6	6.23	5.47	0.04	0.90	2.95	0.19	0.54	0.01	4.85	1.00	0.26	0.90	2.15

C.S. = coarse sand; F.S. = fine sand; nd = not determined.

Table 1.2. Selected soil properties for the Lansdown (Site 1b) permanent monitoring site for the *Stylosanthes* dominant pasture.

Depth	**Particle size distribution (%)**				**pH_w**	**pH_s**	**EC**	**Exchangeable cations ($cmol_c$/kg)**						**Ext P**	**OC**	**NO_3-N**	**NH_4-N**
(cm)	**C.S**	**F.S**	**Silt**	**Clay**			**(dS/m)**	**Ca^{2+}**	**Mg^{2+}**	**K^+**	**Na^+**	**Mn^{2+}**	**CEC**	**(mg kg^{-1})**	**(%)**	**(mg kg^{-1})**	
								Stylosanthes									
0 - 10	nd	nd	nd	nd	6.05	4.84	0.04	1.15	0.42	0.44	0.07	0.04	2.48	3.00	0.67	4.74	1.09
10 - 20	nd	nd	nd	nd	5.78	4.61	0.02	1.07	0.53	0.25	0.03	0.05	2.43	2.00	0.41	1.85	1.00
20 - 30	nd	nd	nd	nd	5.90	4.83	0.02	1.17	0.86	0.25	0.06	0.04	2.79	2.00	0.41	0.90	0.99
30 - 40	nd	nd	nd	nd	5.90	4.91	0.02	1.37	1.39	0.25	0.08	0.05	3.27	1.50	0.36	0.90	0.90
40 - 50	nd	nd	nd	nd	6.01	5.02	0.02	1.36	1.91	0.19	0.04	0.03	3.95	1.00	0.32	0.90	0.90
50 - 60	nd	nd	nd	nd	6.13	5.13	0.02	1.24	2.24	0.17	0.27	0.03	4.43	1.50	0.31	0.90	0.90
60 - 70	nd	nd	nd	nd	6.20	5.26	0.03	1.31	2.43	0.20	0.22	0.02	4.50	1.50	0.29	0.90	0.90

Bulk density measurements made on *Stylosanthes* dominant site. Each point is the mean of 2 samples.

Depth (cm)	Bulk density (g/cm^3)	Depth (cm)	Bulk density (g/cm^3)	Depth (cm)	Bulk density (g/cm^3)	Depth (cm)	Bulk density (g/cm^3)
0-5	1.180	10-15	1.376	20-30	1.463	50-60	1.383
5-10	1.442	15-20	1.351	30-50	1.544		

Site 2: Thalanga Station, PDS site, north west Queensland. Owner Mr R. Rebgetz.

Location: 20° 21' 57.91" S; 145° 47' 38.27":

Pasture Composition and History: Site was a Producer Demonstration Site established by Mr Peter Smith in the early 1980's to expound the value of legume based pasture systems. The demonstration plots were oversown with a legume mix (*Stylosanthes* (Secca and Verano)) with the addition of P. Significant tree mortality is evident on the legume dominant site. Adjacent to the PDS is open woodland of silver-leaved ironbark (*Eucalyptus shirleyi*) and black speargrass (*Heteropogen contortus*). The soil is classified as a petroferric bleached orthic tenosol (Isbell, 1996).

Table 1.3. Selected soil properties for the Thalanga permanent monitoring site for a native dominant pasture. Samples collected 26/02/1997.

Depth	**C sand**	**F sand**	**Silt**	**Clay**	**pH_w**	**pH_s**	**Total N**	**EC**	**Exchangeable cations ($cmol_c$ kg^{-1})**					**CEC**	**Ext P**	**OC**	**NO_3-N**	**NH_4-N**
(cm)	**%**						**(%)**	**(dS/m)**	**Ca^{2+}**	**Mg^{2+}**	**K^+**	**Na^+**	**Mn^{2+}**	**($cmol_c$ kg^{-1})**	**(mg kg^{-1})**	**(%)**	**(mg kg^{-1})**	
									Native pasture									
0 - 10	42.1	32.9	8.6	16.4	5.91	4.91	0.016	0.02	1.45	0.49	0.24	0.04	nd	2.27	nd	0.57	<1	<1
10 - 20	37.8	35.9	8.5	17.8	6.07	5.02	0.015	0.02	0.99	0.43	0.35	0.05	nd	2.20	nd	0.38	<1	<1
20 - 30	32.3	33.9	7.4	26.4	5.16	4.27	0.013	0.01	0.99	0.57	0.15	0.04	nd	2.30	nd	0.30	<1	<1
30 - 40	38.8	25.0	6.2	29.9	5.36	4.48	0.012	0.01	1.40	0.85	0.07	0.06	nd	2.73	nd	0.28	<1	<1
40 - 50	40.7	20.6	5.4	33.3	5.58	4.74	0.013	0.01	1.67	1.10	0.05	0.06	nd	3.07	nd	0.30	1.6	<1

Table 1.4. Selected soil properties for the Thalanga permanent monitoring site for a *Stylosanthes* dominant pasture. Samples collected 26/02/1997.

Depth	**C sand**	**F sand**	**Silt**	**Clay**	**pH_w**	**pH_s**	**Total N**	**EC**	**Exchangeable cations ($cmol_c$/kg)**					**CEC**	**Ext P**	**OC**	**NO_3 -N**	**NH_4 -N**
(cm)	**%**						**(%)**	**(dS/cm)**	**Ca^{2+}**	**Mg^{2+}**	**K^+**	**Na^+**	**Mn^{2+}**	**($cmol_c$ /kg)**	**(mg/kg)**	**(%)**	**(mg/kg)**	
									Stylosanthes									
0 - 10	40.9	38.8	8.5	11.8	5.32	4.36	0.024	0.02	1.02	0.28	0.16	0.05	nd	1.63	nd	0.70	<1	1.9
10 - 20	42.2	38.5	8.1	11.2	5.13	4.23	0.011	0.01	0.54	0.22	0.08	0.05	nd	1.30	nd	0.30	<1	<1
20 - 30	35.4	36.4	7.5	20.8	5.23	4.26	0.013	0.01	0.85	0.43	0.07	0.06	nd	1.90	nd	0.38	<1	<1
30 - 40	36.2	29.5	6.5	27.9	5.41	4.44	0.013	0.01	1.12	0.78	0.05	0.07	nd	2.40	nd	0.27	<1	<1
40 - 50	38.8	23.2	5.2	32.9	5.75	4.76	0.014	0.02	1.52	0.99	0.04	0.09	nd	3.00	nd	0.32	<1	<1

Site 3: Myrrulumbing Station, north west Queensland. Owner Mr A. Pemble.

Location: 21° 01' 10.99" S; 145° 48' 05.27":

Pasture Composition and History: Stylosanthes pasture established approximately 15 years ago after clearing of native tree species. Native pasture on opposite side of the fence on an adjacent property. Pasture degraded in places with Aristida species, Indian couch and remnants of black speargrass (*Heteropogen contortus*) Trees present in pasture.

Table 1.5. Myrrulumbing Station native pasture dominant system. Values in parenthesis are the standard error of the mean.

Depth	pH_w	pH_{Ca}	EC	Organic	Total N	NO_3 -N	NH_4 - N	Charge Properties ($cmol_c/kg$)								Bicarb P
(cm)			(dS/m)	Carbon %	%	(mg/kg)	(mg/kg)	Ca^{2+}	Mg^{2+}	K^+	Na^+	H^+	Al^{3+}	CEC	ECEC	(mg/kg)
0-10	5.95(0.05)	4.71(0.15)	0.02	0.66(0.12)	0.04(0.01)	<1	1.90(0.17)	1.77(0.33)	0.56(0.06)	0.31(0.03)	0.04(0.01)	0.07(0.02)	0.00	2.90(0.29)	2.75(0.34)	4.33(0.88)
10-20	5.83(0.14)	4.82(0.15)	0.02	0.33(0.01)	0.02	<1	1.53(0.03)	1.17(0.09)	0.61(0.08)	0.25(0.03)	0.05(0.02)	0.11(0.01)	0.02(0.02)	2.40(0.44)	2.21(0.16)	3.33(0.88)
20-30	5.56(0.06)	4.65(0.14)	0.02	0.29(0.01)	0.02	<1	1.30(0.06)	1.09(0.07)	0.70(0.01)	0.26(0.02)	0.03	0.14(0.04)	0.04(0.02)	2.67(0.13)	2.26(0.01)	2.67(0.33)
30-40	5.58(0.16)	4.74(0.21)	0.02	0.29(0.02)	0.02	<1	1.43(0.19)	1.23(0.12)	0.82(0.01)	0.27(0.03)	0.04(0.01)	0.12(0.03)	0.06(0.05)	2.77(0.12)	2.53(0.02)	2.67(0.33)
40-50	5.74(0.37)	4.89(0.41)	0.02	0.32(0.05)	0.02	<1	1.70(0.10)	1.73(0.43)	1.05(0.07)	0.25(0.03)	0.07(0.02)	0.12(0.03)	0.09(0.03)	2.53(0.38)	3.31(0.37)	4.67(1.67)
50-60	5.65(0.28)	4.86(0.33)	0.02	0.29(0.03)	0.02	<1	1.60(0.12)	1.32(0.36)	1.06(0.04)	0.19(0.03)	0.05(0.01)	0.12(0.01)	0.08(0.05)	3.20(0.25)	2.83(0.36)	3.00(1.00)
60-70	5.62(0.03)	4.93(0.14)	0.02	0.27(0.03)	0.02	<1	1.40(0.10)	1.24(0.27)	1.37(0.07)	0.17(0.02)	0.06(0.02)	0.09(0.02)	0.01(0.01)	2.83(0.48)	2.93(0.19)	3.67(0.88)

Table 1.6. Myrrulumbing Station *Stylosanthes* dominant system. Values in parenthesis are the standard error of the mean.

Depth (cm)	pH_w	pH_{Ca}	EC (dS/m)	Organic Carbon %	Total N %	NO_3 - N (mg/kg)	NH_4 - N (mg/kg)	Charge Properties ($cmol_c/kg$)								Bicarb P (mg/kg)
								Ca^{2+}	Mg^{2+}	K^+	Na^+	H^+	Al^{3+}	CEC	ECEC	
0-10	5.86(0.06)	4.83(0.10)	0.02	0.60(0.12)	0.03(0.01)	1.30	1.67(0.27)	1.15(0.38)	0.31(0.05)	0.16(0.02)	0.03	0.06(0.01)	0.00	2.07(0.55)	1.70(0.41)	3.67(0.33)
10-20	5.54(0.08)	4.33(0.02)	0.01	0.30(0.04)	0.01	1.20	1.47(0.15)	0.43(0.08)	0.13	0.09(0.03)	0.02	0.14(0.02)	0.15(0.11)	1.60(0.15)	0.95(0.04)	3.33(0.88)
20-30	5.54(0.03)	4.35(0.07)	0.01	0.23(0.05)	0.01	<1	2.13(0.98)	0.27(0.06)	0.11(0.01)	0.07(0.02)	0.02	0.10	0.08(0.03)	1.37(0.07)	0.65(0.05)	2.67(0.33)
30-40	5.54(0.13)	4.41(0.17)	0.01	0.19(0.01)	0.01	<1	1.33(0.20)	0.21(0.07)	0.12(0.02)	0.09(0.04)	0.03	0.10(0.01)	0.10(0.05)	1.30(0.12)	0.65(0.08)	2.33(0.33)
40-50	5.47(0.16)	4.46(0.20)	0.01	0.18	0.01	<1	1.50(0.15)	0.30(0.10)	0.19(0.05)	0.11(0.03)	0.04 (0.01)	0.10(0.01)	0.13(0.07)	1.33(0.12)	0.87(0.17)	2.33(0.33)
50-60	5.42(0.16)	4.49(0.22)	0.02	0.21(0.01)	0.01	<1	1.20	0.49(0.20)	0.39(0.14)	0.07(0.02)	0.04	0.11(0.02)	0.14(0.07)	1.46(0.41)	1.25(0.31)	2.67(0.67)
60-70	5.66(0.18)	4.72(0.32)	0.02 (0.01)	0.23(0.02)	0.02	<1	1.27(0.22)	0.87(0.39)	0.83(0.27)	0.07(0.01)	0.07 (0.01)	0.09(0.02)	0.08(0.05)	2.47(0.60)	2.01(0.60)	3.33(0.33)

Site 4: Woodhouse Station, north Queensland. Owner Mr J. Rapisada.

Location:

Pasture Composition and History: The property was one of the first properties under the management of the AA company to introduce Stylosanthes in their production systems. The property is *Stylosanthes* dominant and hence an adjacent property was used in the assessment of native pasture.

Table 1.7. Consolidate analysis of samples collected from Woodhouse 24/09/99. Site dominated by *Stylosanthes*. Values in parenthesis represent the standard error of the mean.

Depth (cm)	pH_w	pH_s	EC (dS/m)	Organic Carbon (%)	Total N (%)	NO_3 - N (mg/kg)	NH_4 – N (mg/kg)	Charge Properties ($cmol_c/kg$)								P (mg/kg)
								Ca^{2+}	Mg^{2+}	K^+	Na^+	H^+	Al^{3+}	CEC	ECEC	
0-10	5.41(0.10)	4.35(0.08)	0.03	1.10(0.21)	0.08 (0.01)	1.93(0.07)	4.27(0.24)	1.45(0.51)	0.56(0.12)	0.34(0.05)	0.11(0.01)	0.16(0.01)	0.07(0.03)	2.77(0.50)	2.68(0.63)	3.33(0.88)
10-20	5.22(0.04)	4.09(0.04)	0.02	0.76(0.07)	0.05	0.50	2.93(0.23)	0.68(0.08)	0.45(0.01)	0.23(0.05)	0.11(0.02)	0.18(0.01)	0.35(0.03)	1.93(0.07)	2.00(0.12)	1.17(0.44)
20-30	5.18(0.03)	4.06(0.03)	0.02	0.57(0.08)	0.04	0.50	3.70(0.29)	0.57(0.03)	0.63(0.09)	0.20(0.04)	0.14((0.02)	0.19(0.01)	0.46(0.04)	2.13(0.07)	2.18(0.07)	1.17(0.44)
30-40	5.21(0.02)	4.08(0.02)	0.02	0.55(0.08)	0.04	0.50	3.87(0.69)	0.52(0.06)	0.87(0.04)	0.18(0.04)	0.13(0.01)	0.19(0.01)	0.47(0.04)	2.33(0.23)	2.36(0.08)	1.00(0.50)

Table 1.8. Consolidate analysis of samples collected from grass and woody tree/shrub dominant site at Woodhouse station (Site 4b) 24/09/99. Values in parenthesis represent the standard error of the mean.

Depth (cm)	pH_w	pH_s	EC (dS/m)	Organic Carbon (%)	Total N (%)	NO3 (mg/kg)	NH4 (mg/kg)	Charge Properties (cmol(c)/kg)								P (mg/kg)
								Ca^{2+}	Mg^{2+}	K^+	Na^+	H^+	Al^{3+}	CEC	ECEC	
0-10	5.22(0.17)	4.24(0.13)	0.02	0.44(0.02)	0.05 (0.01)	1.17(0.34)	2.27(0.18)	0.57(0.20)	0.24(0.05)	0.19(0.02)	0.10	0.17(0.01)	0.20(0.10)	1.37(0.03)	1.47(0.18)	0.67(0.17)
10-20	5.14(0.20)	4.14(0.14)	0.02	0.60(0.08)	0.03	0.50	2.07(0.12)	0.44(0.21)	0.25(0.08)	0.14(0.03)	0.10(0.01)	0.17(0.01)	0.37(0.17)	1.57(0.17)	1.47(0.15)	0.50
20-30	5.03(0.08)	4.04(0.04)	0.02	0.44(0.06)	0.03	0.50	1.63(0.09)	0.30(0.08)	0.34(0.01)	0.10(0.02)	0.11(0.02)	0.18(0.01)	0.50(0.11)	1.50	1.53(0.03)	0.50
30-40	4.99(0.06)	4.01(0.03)	0.02	0.33(0.02)	0.03	0.50	2.13(0.28)	0.30(0.11)	0.58(0.04)	0.09(0.03)	0.13(0.01)	0.19	0.60(0.09)	1.87(0.09)	1.90(0.06)	0.67(0.17)
40-50	5.02(0.04)	3.97(0.01)	0.02	0.39(0.03)	0.03	0.50	2.10(0.25)	0.31(0.10)	0.95(0.03)	0.09(0.02)	0.17	0.22(0.01)	0.87(0.08)	2.23(0.03)	2.61(0.04)	0.50
50-60	5.09(0.01)	3.95(0.01)	0.02	0.39(0.04)	0.04	0.50	2.20(0.17)	0.30(0.05)	1.37(0.09)	0.10(0.02)	0.20	0.24	0.99(0.07)	2.97(0.46)	3.19(0.09)	0.50

Table 1.9. Particle size distribution of bulked samples collected Site 4.

Depth	% of total				Vegetation
(cm)	C Sand	F Sand	Silt	Clay	Type
0-10	33.9	35.5	18.9	11.7	Stylosanthes dominant
10-20	29.6	34.1	20.3	16.0	
20-30	30.9	30.7	19.6	18.9	
30-40	30.3	27.5	19.2	23.0	
0-10	47.7	30.4	12.6	9.3	Shrubby native woodland
10-20	44.1	30.1	13.9	11.9	
20-30	45.4	27.9	12.6	14.2	
30-40	40.6	26.3	13.7	19.5	
40-50	34.9	21.4	14.3	29.5	
50-60	28.9	18.1	14.9	38.1	

Site 5: Hoensfel Station, Georgetown, Gulf region north Queensland. Owner Mr J. Bethel.

Location: Site 1: 18° 06' 35.9" S; 143° 16' 25.9": Site 2: 18° 06' 16.5" S; 143° 16' 26.9"

Pasture Composition and History:

Table 1.10. *Stylosanthes* dominant pasture at site 1 on the property Hoensfel, Georgetown. Values in parenthesis are the standard error of the mean.

Depth (cm)	EC	pH_w	pH_{ca}	OC	Exchange characteristics ($cmol_c/kg$)					
	(dS/cm)			(%)	Ca^{2+}	Mg^{2+}	K^+	Na^+	CEC	ECEC
0-10	nd	5.07(0.38)	4.38(0.41)	0.75(0.23)	0.47(0.31)	0.16(0.13)	0.13(0.07)	0.09(0.03)	0.81(0.53)	0.85(0.52)
10-20	nd	4.83(0.21)	4.11(0.21)	0.33(0.11)	0.14(0.07)	0.08(0.04)	0.06(0.02)	0.08(0.01)	0.77(0.27)	0.35(0.14)
20-30	nd	4.88(0.21)	4.09(0.17)	0.32(0.12)	0.14(0.08)	0.09(0.05)	0.06(0.02)	0.07	0.80(0.27)	0.36(0.15)
30-50	nd	4.83(0.21)	4.01(0.16)	0.32(0.04)	0.11(0.06)	0.08(0.04)	0.06(0.01)	0.08(0.01)	0.37(0.41)	0.33(0.12)
50-70	nd	5.18(0.52)	4.15(0.20)	0.29(0.02)	0.12(0.06)	0.29(0.15)	0.06(0.02)	0.15(0.05	0.95(0.37)	0.62(0.26)

Table 1.11. Grass dominant pasture at site 1 on the property Hoensfel, Georgetown. Values in parenthesis are the standard error of the mean.

Depth (cm)	EC	pH_w	pH_{ca}	OC	Exchange characteristics ($cmol_c/kg$)					
	(dS/cm)			(%)	Ca^{2+}	Mg^{2+}	K^+	Na^+	CEC	ECEC
0-10	nd	5.11(0.18)	4.21(0.09)	0.48(0.04)	0.17(0.08)	0.09(0.04)	0.08(0.02)	0.05(0.02)	0.69(0.20)	0.40(0.11)
10-20	nd	4.85(0.08)	4.10(0.04)	0.28(0.02)	0.08(0.01)	0.06(0.01)	0.05(0.02)	0.08(0.04)	0.57(0.08)	0.27(0.06)
20-30	nd	4.92(0.32)	4.12(0.22)	0.30(0.06)	0.08(0.01)	0.04(0.01)	0.07(0.04)	0.09(0.05)	0.52(0.21)	1.24(1.73)
30-50	nd	4.76(0.21)	4.03(0.14)	0.26(0.05)	0.05(0.03)	0.04(0.01)	0.06(0.02)	0.06(0.02)	0.63(0.14)	0.21(0.07)
50-70	nd	4.62(0.37)	3.87(0.13)	0.39(0.08)	0.08(0.06)	0.06(0.01)	0.09(0.03)	0.09(0.03)	0.38(0.56)	0.32(0.09)

Table 1.12. *Stylosanthes* dominant pasture at site 2 on the property Hoensfel, Georgetown. Values in parenthesis are the standard error of the mean.

Depth	EC	pH_w	pH_{ca}	OC	Exchange characteristics ($cmol_c/kg$)					
(cm)	(dS/cm)			(%)	Ca^{2+}	Mg^{2+}	K^+	Na^+	CEC	ECEC
0-10	nd	5.35(0.29)	4.33(0.36)	0.39(0.08)	0.31(0.05)	0.14(0.01)	0.19(0.10)	0.06(0.02)	0.76(0.39)	0.70(0.14)
10-20	nd	5.12(0.18)	4.18(0.12)	0.33(0.05)	0.28(0.06)	0.13(0.03)	0.13(0.04)	0.06(0.01)	0.72(0.37)	0.60(0.05)
20-30	nd	5.18(0.13)	4.16(0.10)	0.35(0.05)	0.28(0.03)	0.15(0.04)	0.12(0.05)	0.06(0.01)	0.96(0.07)	0.62(0.08)
30-50	nd	5.17(0.08)	4.23(0.01)	0.37(0.13)	0.40(0.09)	0.26(0.15)	0.14(0.05)	0.08	1.08(0.12)	0.89(0.19)

Table 1.13. Grass dominant pasture at site 2 on the property Hoensfel, Georgetown. Values in parenthesis are the standard error of the mean.

Depth	EC	pH_w	pH_{ca}	OC	Exchange characteristics ($cmol_c/kg$)					
(cm)	(dS/cm)			(%)	Ca^{2+}	Mg^{2+}	K^+	Na^+	CEC	ECEC
0-10	nd	5.09(0.26)	4.20(0.12)	0.54(0.15)	0.37(0.07)	0.19(0.03)	0.16(0.01)	0.09(0.01)	1.10(0.12)	0.82(0.10)
10-20	nd	5.02(0.12)	4.09(0.05)	0.37(0.04)	0.24(0.09	0.14(0.04)	0.14(0.03)	0.12(0.06)	0.91(0.13)	0.65(0.15)
20-30	nd	5.06(0.15)	4.04(0.02)	0.33(0.02)	0.16(0.06)	0.11(0.05)	0.11(0.03)	0.07(0.03)	0.92(0.09)	0.45(0.15)
30-50	nd	5.11(0.09)	4.07(0.07)	0.28(0.02)	0.27(0.11)	0.29(0.23)	0.10(0.02)	0.07(0.01)	0.96(0.30)	0.72(0.34)
50-70	nd	5.08(0.05)	4.12(0.12)	0.27(0.07)	0.21(0.24)	0.23(0.29)	0.08(0.04)	0.07(0.01)	0.73(0.30)	0.59(0.56)

Site 6: Bidwillii Station, south of Katherine, Northern Territory. Owner.

Location: 15° 33' 26.83"S; 134° 05' 39.93":

Pasture Composition and History: *Stylosanthes* grown as a cover crop between rows of mango trees. *Stylosanthes* cut and baled for livestock feed. This production was imposed approximately 3 years prior to sampling. Adjacent to the orchard was a remnant native dominant system. Soils were skeletal with a significant stone content.

Table 1.14. Bidwillii station site, *Stylosanthes* grown as a cover crop. Values in parenthesis are the standard error of the mean.

Depth (cm)	EC	pH_w	pH_{ca}	OC	Exchange characteristics ($cmol_c/kg$)					
	(dS/cm)			(%)	Ca^{2+}	Mg^{2+}	K^+	Na^+	CEC	ECEC
0-10	0.03	6.08(0.05)	5.32(0.06)	0.65(0.11)	2.36(0.42)	0.26(0.02)	0.09	0.03	2.53(0.51)	2.76(0.42)
10-20	0.02	6.16(0.13)	5.28(0.14)	0.39(0.07)	1.12(0.13)	0.17(0.02)	0.07(0.01)	0.03	1.42(0.15)	1.39(0.110
20-30	0.01	6.25(0.12)	5.31(0.13)	0.31(0.03)	0.86(0.14)	0.24(0.03)	0.07(0.01)	0.03(0.01)	1.44(0.07)	1.20(0.10)
30-50	0.01	6.35(0.08)	5.44(0.09)	0.36(0.01)	1.11(0.20)	0.65(0.05)	0.11(0.01)	0.03	1.93(0.11)	1.90(0.23)
50-60	0.01	6.03(0.14)	5.37(0.13)	0.32(0.01)	1.40(0.12)	1.04(0.05)	0.11(0.02)	0.04(0.01)	2.40(0.14)	2.58(0.12)

Table 1.15. Bidwillii station site, adjacent native trees and grass. Values in parenthesis are the standard error of the mean.

Depth (cm)	EC	pH_w	pH_{ca}	OC	Exchange characteristics ($cmol_c/kg$)					
	(dS/cm)			(%)	Ca^{2+}	Mg^{2+}	K^+	Na^+	CEC	ECEC
0-10	0.03	6.33(0.05)	5.43(0.05)	1.03(0.11)	3.32(0.39)	1.53(0.16)	0.25(0.04)	0.04	5.17(0.51)	5.14(0.54)
10-20	0.02	6.12(0.08)	5.08(0.12)	0.75(0.09)	2.42(0.32)	1.66(0.10)	0.19(0.02)	0.04	4.24(0.43)	4.31(0.42)
20-30	0.01	6.10(0.12)	5.07(0.16)	0.56(0.04)	2.22(0.20)	1.84(0.07)	0.14(0.02)	0.04	4.00(0.18)	4.24(0.21)
30-50	0.01	6.21(0.09)	5.27(0.11)	0.47(0.02)	2.15(0.13)	1.98(0.15)	0.12(0.02)	0.05	3.88(0.19)	4.30(0.03)
50-60	0.01	5.93	5.25	0.62	1.57	2.50	0.06	0.04	3.99	4.17

Site 7: Manbullo Station, west of Katherine, Northern Territory.

Location: 14° 47’ 35.39” S; 131° 56’ 25.45”:

Pasture Composition and History: Previous site of long-term grazing trial of CSIRO Tropical Crops and Pasture. A single sample was collected as a means of comparing changes in soil chemical attributes over time.

Table 1.16. Manbullo, previously *Stylosanthes* dominant site.

Depth (cm)	EC	pH_w	pH_{ca}	OC	Exchange characteristics ($cmol_c/kg$)					
	(dS/cm)			(%)	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	CEC	ECEC
0-10	0.03(0.01)	6.71(0.27)	5.98(0.31)	1.14(0.08)	7.03(0.91)	1.38(0.04)	0.64(0.05)	0.04(0.01)	8.77(0.43)	9.08(0.92)
10-20	0.03(0.01)	6.58(0.29)	5.83(0.30)	0.84(0.07)	5.31(0.55)	1.19(0.04)	0.62(0.11)	0.03	7.29(0.29)	7.15(0.61)
20-30	0.02(0.01)	6.55(0.25)	5.77(0.24)	0.58(0.04)	4.45(0.42)	1.06(0.05)	0.50(0.15)	0.03	6.25(0.33)	6.05(0.48)
30-50	0.02	6.47(0.12)	5.81(0.12)	0.39(0.03)	3.79(0.17)	1.02(0.02)	0.31(0.10)	0.03	5.51(0.26)	5.15(0.22)
50-70	0.02	6.64(0.04)	5.98(0.11)	0.39(0.04)	3.97(0.17)	1.02	0.22(0.03)	0.04(0.01)	4.97(0.36)	5.25(0.15)

Site 8: Hodgen River Station, Northern Territory. Owner Mr Ted Edwards.

Location: Site 1:14° 34' 31.00" S; 132° 28' 55.48": Site 2: 15° 33' 01.19" S; 134° 01' 21.90".

Pasture Composition and History: Hodgen River Station was on of the initial properties in the Northern Territory where *Stylosanthes* (Verano and Seca) was introduced in native pasture systems. There was no evidence of *Stylosanthes* dominance in the pasture systems viewed and on clear boundary fence separating a *Stylosanthes* dominant pasture from a native pasture. Hence samples were collected from 2 sites on the property with the hope that they would be returned to in the future.

Table 1.17. Hodge 1. *Stylosanthes*/grass pasture system

Depth (cm)	EC	pH_w	pH_{ca}	OC	Exchange characteristics ($cmol_c/kg$)					
	(dS/cm)			(%)	Ca^{2+}	Mg^{2+}	K^+	Na^+	CEC	ECEC
0-10	0.03	6.49(0.01)	5.75(0.03)	0.60(0.06)	11.20(0.50)	6.90(0.40)	0.47(0.05)	0.06(0.01)	17.98(0.94)	18.64(0.80)
10-20	0.02	6.82(0.05)	5.83(0.03)	0.39(0.04)	13.88(0.91)	7.74(0.23)	0.15(0.03)	0.08(0.01)	20.19(0.86)	21.86(1.08)
20-30	0.02	7.04(0.03)	5.94(0.03)	0.39(0.04)	16.05(0.87)	9.09(0.34)	0.10(0.02)	0.12(0.01)	22.65(0.51)	25.37(1.20)
30-50	0.02	7.31(0.06)	6.12(0.09)	0.34(0.04)	17.85(1.20)	10.02(0.31)	0.08(0.01)	0.17(0.03)	23.22(0.54)	28.13(1.24)
50-70	0.02	7.59(0.17)	6.36(0.13)	0.23	19.74(0.57)	9.94(0.45)	0.07(0.01)	0.26(0.06)	21.47(1.29)	30.02(0.96)

Table 1.18. Hodge 2. *Stylosanthes*/grass pasture system.

Depth (cm)	EC	pH_w	pH_{ca}	OC	Exchange characteristics ($cmol_c/kg$)					
	(dS/cm)			(%)	Ca^{2+}	Mg^{2+}	K^+	Na^+	CEC	ECEC
0-10	0.02	6.12(0.07)	5.28	0.49(0.10)	3.40(0.42)	1.55(0.18)	0.43(0.03)	0.04	5.64(0.47)	5.42(0.62)
10-20	0.02(0.01)	6.13(0.10)	5.31(0.10)	0.40(0.02)	3.99(0.28)	1.59(0.19)	0.39(0.03)	0.04(0.01)	6.13(0.38)	6.01(0.48)
20-30	0.01	6.12(0.13)	5.27(0.13)	0.33(0.01)	4.04(0.19)	1.75(0.21)	0.38(0.02)	0.05(0.01)	6.48(0.49)	6.22(0.42)
30-50	0.02	6.19	5.33(0.15)	0.29(0.03)	4.21(0.23)	1.80(0.23)	0.41(0.02)	0.04	6.62(0.54)	6.46(0.47)
50-70	0.02	6.31(0.14)	5.55	0.28	4.23	2.04	0.42	0.05	6.74	6.74

Site 9: Cave Creek Station, west of Mataranka, Northern Territory. Owner Mr Stockwell .

Location: 14° 53’ 23.28” S; 133° 05’ 18.41”

Pasture Composition and History: *Stylosanthes* was introduced to the property approximately 15 years prior to sampling. The soils are characterised as deep red sands. A paired site approach was adopted where a fence line separated an adjacent property that had not been established to *Stylosanthes*.

Table 1.19. Cave Creek grass dominant pasture system.

Depth	EC	pH_w	pH_{ca}	OC	Exchange characteristics ($cmol_c/kg$)					
(cm)	(dS/cm)			(%)	Ca^{2+}	Mg^{2+}	K^+	Na^+	CEC	ECEC
0-10	0.02	6.51(0.10)	5.70(0.06)	0.46(0.02)	2.03(0.14)	0.26(0.01)	0.06	0.03	2.40(0.14)	2.38(0.15)
10-20	0.02	6.61(0.03)	5.69(0.06)	0.36(0.01)	1.66(0.08)	0.25(0.01)	0.06	0.03	2.12(0.08)	2.01(0.08)
20-30	0.01	6.68(0.06)	5.65(0.10)	0.29(0.02)	1.11(0.07)	0.24(0.01)	0.06	0.02	1.64(0.07)	1.43(0.07)
30-50	0.01	6.66(0.09)	5.61(0.10)	0.25(0.01)	0.97(0.07)	0.24(0.02)	0.06	0.02	1.57(0.05)	1.30(0.08)
50-70	0.01	6.66(0.05)	5.58(0.07)	0.24(0.02)	0.86(0.03)	0.27(0.01)	0.09(0.01)	0.03(0.01)	1.52(0.01)	1.25(0.01)

Table 1.20. Cave Creek, *Stylosanthes* dominant pasture system.

Depth	EC	pH_w	pH_{ca}	OC	Exchange characteristics ($cmol_c/kg$)					
(cm)	(dS/cm)			(%)	Ca^{2+}	Mg^{2+}	K^+	Na^+	CEC	ECEC
0-10	0.02	6.24(0.10)	5.31(0.10)	0.44(0.06)	1.87(0.09)	0.29(0.02)	0.07(0.01)	0.03	2.43(0.06)	2.26(0.10)
10-20	0.01	6.23(0.04)	5.23(0.07)	0.44(0.05)	1.74(0.03)	0.27(0.01)	0.07(0.01)	0.03	2.35(0.02)	2.12(0.04)
20-30	0.01	6.11(0.04)	5.09(0.03)	0.34(0.05)	1.17(0.07)	0.20(0.02)	0.06	0.03	1.76(0.09)	1.46(0.08)
30-50	0.01	6.13(0.04)	5.07(0.01)	0.28(0.04)	0.97(0.01)	0.17(0.01)	0.06	0.03	1.53(0.03)	1.24
50-70	0.01	6.11(0.05)	5.14(0.05)	0.20(0.02)	0.80(0.02)	0.16	0.05	0.02	1.39(0.02)	1.04(0.02)