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CROP NUTRITION RESEARCH FOR DOUGLAS DALY

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K THIAGALINGAM
Crop Nutrition Agronomist

CONTENTS

SUMMARY

Mineral nutrient stress is a major limitation to crop production on the sandy and loamy red earths of the Douglas Daly area. Major factors that influence crop nutrition are:

(1) Climate - rainfall intensity and distribution
(2) Soil - physical, chemical and biological properties
(3) Management

The main problem facing farmers and researchers at Douglas Daly is how to maintain high yields on soils with low cation exchange capacity (CEC), poor buffering, low nutrient retention, unreliable rainfall distribution, high erosion and in some cases, inefficient management.

Economic crop production will be enhanced by increasing fertilizer efficiency by selecting genotypes that make better use of nutrients or by suitable management practices (conservation tillage) that optimise moisture and nutrient uptake.

For the Douglas Daly area nitrogen, phosphorus, sulphur and zinc are the major nutrients limiting crop production. However, potassium and magnesium are emerging as potential problems. There is no data available on the manganese and boron levels and their influence on crop production.

Many experiments conducted on Blain and Tippera soil families failed or were inconclusive due to adverse climatic conditions, unsuitable sites, lack of basic soil or climatic data and inexperienced technical/management personnel.

An outline of future research is proposed with the main emphasis on defining responses, examining factors affecting efficiency, especially nitrogen fertilizer use through land management (rotation, tillage, green manure crops or intercropping). To achieve the most economic use of fertilizers a data base with information on soil, climate, fertility and crop management should be established. The following research is suggested for the red earth soils in order of priority.

1. Fertilizer response studies

   Experiments to evaluate and construct yield response curves for N, P, S and K under known moisture conditions.

2. Fertilizer efficiency studies

   A. Management of Fertilizer

      - time of application
      - source of fertilizer
      - method of application

   B. Monitoring of nutrients lost by

      - leaching
      - erosion
      - volatilization
      - uptake by crops

The above losses can be minimised through residue management (no till or minimum till), use of inhibitors or slow release fertilizers.

C. Methodology Development

- P and S sorption and desorption studies
- use of mycorrhiza to increase P efficiency
- appropriate soil test for P and S

3. Land Management Studies

Improving nitrogen efficiency through rotation i.e. Assessment of nitrogen contribution from rotations involving:

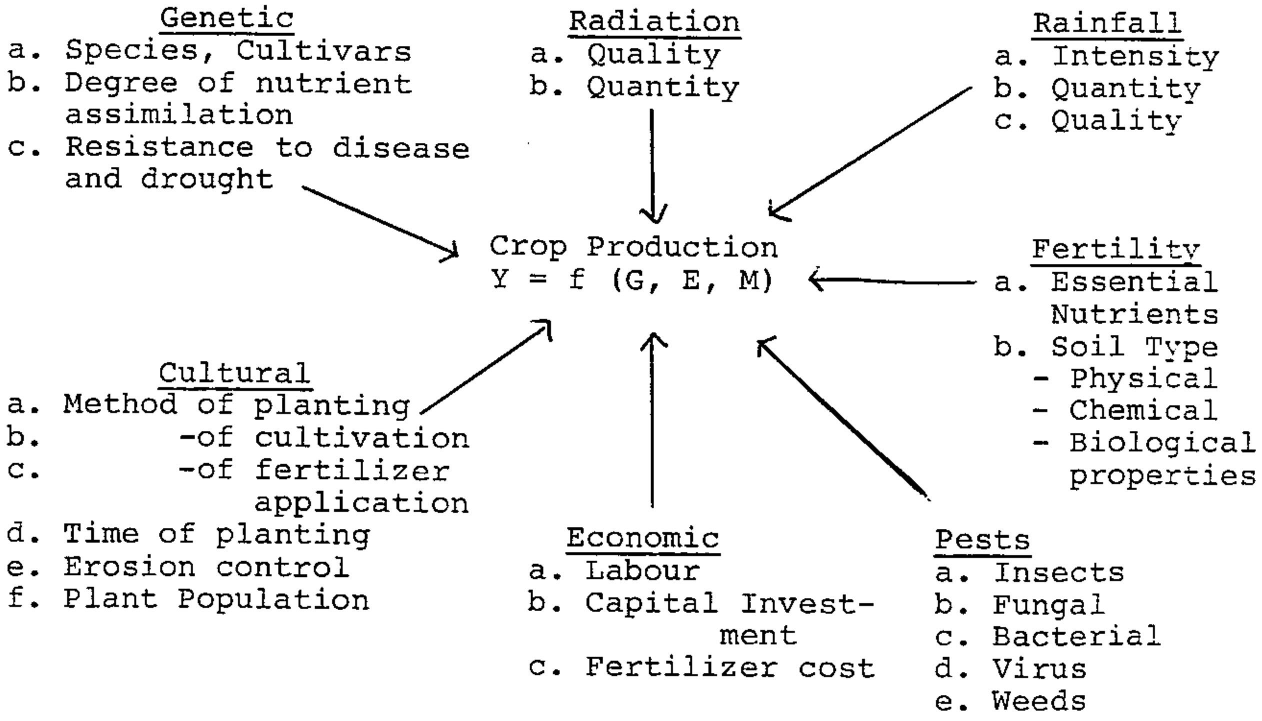
(a) grass leys
(b) grain legumes
(c) pasture legumes
(d) tree crops

1. INTRODUCTION

Soils provide physical support for plants and act as a medium to retain and release water and nutrients essential for plant growth and development. The productive capacity of a soil depends not only on its physical, chemical and biological properties, but also on various climatic and management factors. Soil fertility is the potential of a soil to supply nutrients in the most available forms and appropriate proportions. If the fundamentals of fertility control are not understood, this will lead to inefficient use, or misuse of fertilizers and result in a reduction of yield or efficiency. New lands brought into use will present special problems, while new cultivars or crops may require different amounts of fertilizers and times of application.

Improved yields can be attained by using suitable varieties, appropriate fertilizer management, or better control and management of water through appropriate tillage methods. Use of acidulated rock phosphate, sulphur and nitrogen compounds and N-fixing legumes may play a major role in the development of crop nutrient research in the Douglas Daly area. A better understanding of soil fertility factors is needed to take full advantage of biological N-fixation and to improve the efficiency of fertilizer nitrogen.

A knowledge of the chemistry and interaction of macro and micro nutrients in soils, and an understanding of the factors that determine the availability of these elements in soils, is important for good fertilizer and nutrient management. Crop nutrition plays a major role in crop production. However, it should be recognised that for economical and successful crop production, factors other than nutrients play a key role. Crop production should be viewed as a function of Genetic (G), Environmental (E) and Management (M) factors in which soil nutrient status forms a part of environmental and management factors. This is illustrated as follows:



y = yield f = function of genetics, environment and management

In the Douglas Daly area, one of the major factors causing low and variable crop yield is the frequent occurrence of suboptimal soil moisture regimes. Mollah (1986) established that rainfall variability within seasons can contribute to great variability in yields. He concluded that researchers should develop farming systems, crops and cultivars, that can cope with the range of prevailing conditions e.g. nutrient availability and its efficiency for crop development and growth, that are mainly dependent on rainfall and other associated environmental factors. The objective of this paper is to review and define the nutrient status and problems associated with crop production on the red earth soils (Tippera and Blain families) in the Douglas Daly area, and to propose research for the future.

2. REVIEW OF PHYSICAL AND CHEMICAL CHARACTERISTICS OF BLAIN AND TIPPERA SOILS (PALEUSTALFS)

Several attempts were made to classify the soils of the Douglas Daly basin for crop production, Stewart (1956), Van de Graaff (1965) and Aldrick (1972). Lucas et al., (1985) revised and proposed a more detailed classification in which they identified four families within the red earth group namely:

(a) Daly fine Sandy levee
(b) Edith fine loamy levee
(c) Blain sandy
(d) Tippera loamy

All the Agricultural Development and Marketing Authority (ADMA) farms and the Douglas Daly Research Farm are on the loamy and the sandy surfaced Tippera and the Blain families. The physical, chemical and morphological characteristics of the two soil families have been well documented by Day (1977), Lucas (1983) Price and Garside (1984, 1985). A summary of the physical and chemical properties of both soils are presented and discussed in Table 1.

TABLE 1: SOME PHYSICAL AND CHEMICAL CHARACTERISTICS OF BLAIN AND TIPPERA SOILS **

Soil Property	Blain	Tippera
<u>Texture</u>		
Surface	Sand to loamy sand	Clay loam
Immediate subsurface (10-30cm)	Sand to sandy loam	Sandy clay loam Clay loam, light clay
Sub soil (1.5m)	Clay loam or sandy clay or as heavy as medium clay with sand	light clay or heavier
Structure	Massive	Massive
Clay Minerals %		
Kaolinite	50 - 65	45
Illite	20 - 30	40
Quartz		10
Haematite	20 - 30	
pH	5.8 - 6.6	5.3 - 7.9
Available Moisture %	2.5 - 4.0	4.9 - 11.5
Total N %	0.026 - 0.06	0.037 - 0.135
Organic C %	0.42 - 1.07	0.45 - 2.50
C.E.C. (m.e/100g)	2.5 - 6	2.27 - 15.6
Exchangeable Cations (m.e/100g)±		
Ca	0.15 - 1.50	1.47 - 9.00
Mg	0.33 - 0.96	0.27 - 2.42
K	0.13 - 0.24	0.07 - 0.69
Available P ($NaHCo_3$) ppm	1 - 7	1 - 10
S (Phosphate) ppm	1 - 5	1 - 12
Zn (EDTA) ppm	0.2 - 1.0	0.1 - 1.2
Cu (EDTA) ppm	0.2 - 1.1	0.2 - 4.4

** Source: Day (1977); Lucas (1983); Price (1984, 1985, 1986)

± To convert m.e Ca to ppm multiply by 200
K to ppm multiply by 390
Mg to ppm multiply by 120

2.1 Blain Family (Venn, Tipperary, Willeroo and Ruby - profile class)

The soils of this family are very deep (7-12m), massive and earthy with weak profile development and good drainage. Surface consistency of these soils is loose or moderately weak.

Arndt et al., (1963) reported high infiltration rates and concluded that water seems to remain available at depth for a longer time during the dry period than the loamy red earth. Because of the sandy top soil there is no capillary movement of water from sub soil to top soil. The available water content at the surface is very low ranging from 2.5% to 4.0%.

Lucas (1983) reported a variation in the sub soil texture among the different soil series of this family. These textural differences will not only influence water retention and movement but also nutrient retention and release in the sub soils.

Cation exchange capacity (CEC) of the surface Blain soils are very low ranging from 2.5 to 6.0 m.e/100g. This can be attributed to the dominance of kaolinite (50% to 65%), low organic carbon content (0.42% to 1.07%) and low clay content.

Total nitrogen is very low ranging from 0.026% to 0.06% and with the low organic carbon this soil may need more nitrogen than soil with high organic carbon.

Soil pH indicates the relative availability of plant nutrients which reach maximum or near maximum availability in the pH range of 6 to 7. The pH of the Blain family falls within desirable pH range for most crops. Whenever calcium is desired gypsum is the best source of calcium. Because of the poor buffering capacity of the soil, application of large amounts of calcium carbonate or dolomite will induce micronutrient deficiencies due to sudden changes in pH.

Calcium dominates the exchange complex followed by magnesium and potassium. Calcium levels in virgin soils range from 0.15 to 1.50 m.e/100g. However, the application of fertilizers, burning, tree clearing and cropping have increased the calcium levels to more than 3.0 m.e/100g (Price 1985).

Exchangeable magnesium levels range from 0.33 to 0.96 m.e/100g and is within the sufficiency levels. For field crops an exchangeable magnesium level higher than 0.20 m.e./100g is desired.

Exchangeable potassium is marginal to deficient and ranging from 0.13 to 0.24 m.e/100g. Most field crops do not respond to potassium application when the exchangeable potassium is greater than 0.21 m.e./100g for sandy and loamy sands, 0.25 m.e./100g for sandy loams or loams, 0.32 m.e/100g for silt loams or clays.

Available phosphorus (sodium bicarbonate extractable P) ranges from 1 to 7 ppm and is well below the critical level for most crops. Poor buffering capacity of the soil and high erosion risks, necessitates frequent small applications of phosphorus.

Sulphur, zinc and copper levels in the soils are low ranging from 1 to 5 ppm for sulphur, 0.2 to 1.0 ppm for zinc and 0.2 to 1.1 for copper. There is no data on available or total manganese and boron in Blain soil.

2.2 Tippera Family (Oolloo, Kintore, Hayes, Emu, Fenton and Tindall - profile class)

Lucas et al., (1985) described the soils of this family as having variable depth (1-6m), being massive and earthy through the profile and having abundant clayskins in high clay content sub soils. The profile is weakly developed with good drainage. Surface consistency is firm with a higher clay content in the surface than the Blain family. However, Oolloo series have a sandy top soil with an increase in clay content in the immediate subsurface.

The main physical problem associated with these soils are surface sealing after cultivation and their high erodibility. The available water content ranges from 4.9% to 11.5%.

Cation exchange capacity of the Tippera ranges from 2.27 to 15.6 m.e./100g which is higher than in the Blain family, due to high clay content and hence the Tippera family is able to retain more nutrients than the Blain family.

pH of the soil is acid to neutral ranging from 5.3-7.9. Total nitrogen levels are low and range from 0.037% to 0.135%. The carbon content is higher than the Blain soil ranging from 0.45% to 2.50%. Nitrogen content is very low and will limit crop production.

Exchangeable Ca, Mg, K levels are adequate on virgin sites, however the balance of nutrients should be watched as poorly fertilized continuous cropping will lead to deficiencies.

Available P, Zn, S and Cu levels are low to marginal. Data is lacking on the available Mn and boron in the Tippera family.

Both soils have limitations and methods to increase the efficiency of nutrient use need to be developed.

3. NUTRITIONAL EXPERIMENTS CONDUCTED ON THE BLAIN AND TIPPERA SOILS

A summary of experiments reviewed are presented in Appendix 1. Some experiments failed due to adverse climatic conditions, unsuitable sites, lack of basic soil and climatic data, or technical or management problems.

3.1 Nitrogen, Phosphorus, Potassium and Sulphur

In the tropics large nitrogen losses are attributed to ammonia volatilization, leaching and denitrification. The volatilization losses will be even greater under dryland conditions for surface applied urea. In soils with low cation exchange capacity, low soil moisture levels, high pH and high temperature, an overall loss of 40% to 50% could be anticipated with low recovery of applied nitrogen. There is limited local data available to quantify the above. Myers (1983) reported denitrification losses up to 14% within first few weeks when the soil was periodically waterlogged.

Day (1977) and Wetselaar (1962) have reported high losses of nitrogen by leaching on red earth in the Douglas Daly basin and Katherine both under crops and bare fallow. Nitrate nitrogen was leached to between 45cm to 105cm depth in Tindall, 60cm to 105cm in Emu and 75 to 180cm in Blain. Day was able to recover only 21% of applied ammonium at 0cm to 30cm depth in Blain soil 12 days after fertilizer application. This he attributed to rapid mineralization and leaching. The results of this study emphasise the importance of N-fertilizer efficiency through the selection of deep rooted crops, timing of N application, slow release fertilizers or selecting the most appropriate rotation so that the N fixed by a legume will be used by the succeeding cereal crop.

Madin (1975) reported N response in maize of up to 120kg N ha^{-1} and concluded that N applications of about 80-100kg N ha^{-1} is adequate for mid-late season maturing hybrids (provided that the soil has adequate P) at a harvest population of 40 000 plants ha^{-1}. Higher rates of N depressed yields. In another study the same author reported that higher rates of N and P did not increase yield. However, increasing P depressed yields and it was concluded that 20kg P ha^{-1} was adequate for previously fertilized paddocks. Bio-super was unsuitable for maize as insufficient P was released to meet the P needs of a fast growing crop.

Day (1977) reported a significant response to nitrogen and phosphorus application by grain sorghum on Blain and Tindall red earths. The magnitude of the responses varied markedly in different seasons and he concluded that this variation is due to differences in leaching of nitrate, soil moisture stress and native mineral N supply in relation to the stage of the crop growth. Further, Day concluded from his two year N x P studies that a pasture species might be better adapted to utilise the longer growing season afforded by the sub soil moisture storage than would a crop with a high nutrient requirement.

Sulphur contents of the soils are low and the effect of sulphur on yield is difficult to assess from one or two experiments. To provide more accurate prediction of the fertilizer requirements for sorghum grown on red earths, a number of growing seasons need to be monitored incorporating the crop-legume rotations. Also a wide range of soil and climatic variables need to be monitored to accurately assess soil productivity. He did not find any response to potassium or sulphur by sorghum.

Garside and Buchanan (1985) studied the effect of 'starter' and supplementary N on growth and yield of soybeans. They reported that grain yield was not improved by either 'starter' or supplementary N, though both treatments increased the number of pods per plant and reduced seed size. As the soil in this experiment had an initial nitrate level of 100ppm the authors concluded that the negative response to starter N was due to the high residual nitrogen. Nodule attributes were not measured and the affect of high initial N on nodulation is unknown. As this is the only experiment involving nitrogen fertilization on soybeans, a firm conclusion cannot be drawn. Several experiments on both soils will be required before meaningful conclusions can be drawn about the profitability of using starter N on soybeans in the Douglas Daly region.

Williams et al., 1983-84 reported the results of a nitrogen X phosphate factorial experiment using urea and ammonium sulphate in combination with triple super phosphate and rock phosphate with maize on Blain soil. Both urea and ammonium sulphate increased yield with increasing N application. However, ammonium sulphate produced better yields due to its sulphur, since the urea treatment was not balanced with respect to sulphur. Phosphorus significantly increased yields of maize with maximum yields obtained with low levels of superphosphate (15kg P ha^{-1}) and high levels of rock phosphate (1 t P ha^{-1}).

Eighteen field trials were proposed by Williams 1982-83 to monitor fertility trends over a number of years with different sources and rates of nitrogen and phosphorus. The proposed trials were either discontinued or never initiated.

Day et al., (1983) in their P rate and sorption studies with six soils reported a very low P sorption in Blain red earth with 90% of the maximum yield of *Stylosanthes hamata* being obtained with 15kg P ha^{-1} from Douglas Daly Blain, 35kg P ha^{-1} for Katherine Tippera and 50kg P ha^{-1} for Mt Bundy yellow earth. They concluded that the different responses to P application on these soils was due to differences in their P sorption capacity. Soils with poor P buffering capacity will need frequent applications of P rather than large applications, especially on Blain soil in which excess P may be lost by erosion.

Garside and Buchanan 1981-82 evaluated the effect of different rates of P and S on growth and yield of soybeans on virgin Tippera clay loam, they reported a significant grain yield response to phosphorus and sulphur. Highest yield was obtained with a combination of 80kg P and 20kg S ha^{-1}. Response of maize and soybeans to residual phosphorus in the 1981-82 plots was studied but due to adverse climatic conditions no data was collected.

The above experiment was used to study the residual effects of P and S and showed that soybean yield increased with increasing rate of P application. Eighty kilogram of P ha^{-1} applied in the 1981-82 season was adequate for 1983-84 planting. The authors concluded that if the soil available P is > than 14 ppm fertilizer P is not necessary.

Soil potassium levels presented in reports of Lucas et al., (1983), Day (1977) and Price (1984) indicate levels are adequate for crop production in the loamy red earths (56-385 ppm) and low to marginal (14 to 130 ppm) in the sandy red earths. Few studies were conducted on K nutrition. With cropping on lighter soils, K may emerge as a potential nutritional problem.

Day (1977) reported a non-significant response to K on sorghum grown on Blain, Tindall and Emu soil series. Flint (1982-83) reported that no response by peanuts to K application on the Blain soil (soil K = 108 ppm) and suggested that further research work is needed to accurately define the critical levels of K.

Some legumes grown on Blain and Tippera soils may need innoculation with specific bacteria for N-fixation. Garside and Buchanan (1985) reported a yield increase of 1 t ha^{-1} when soybean seeds were innoculated with Rhizobium japonicum (Strain B 1809). Effectiveness of nodulation and N-fixation and the activity of nodulating organisms for soybeans, peanuts and other legumes in both soil types especially on soils which have been cleared and burnt needs to be evaluated.

Williams 1982-83 investigated the effect of N, P, K on Tippera clay loam (Fenton) and sandy loam (Oolloo) and reported no response to potassium. Because of adverse climatic conditions, poor experimental site (windrow), late start to the wet season, variable plant population, results were inconclusive and no grain yield was recorded. Studies showed that moisture holding properties of both the soils are similar throughout the profile.

Flint (1982-83) studied the effect of P x S on Blain soil with peanuts and reported a response to P application. Maximum yield was obtained at 40kg P ha^{-1} when extractable P was 7 ppm. No response to sulphur was obtained as high levels of S were found in the irrigation water (30kg ha^{-1}). The above experiment was used to study residual P in the 1983-84 season and the author reported a residual P response at high P levels (13 ppm soil extractable P).

Garside and Buchanan (1985) assessed the nutrient deficiencies in Blain soil using the missing nutrient technique with maize, soybean and sword bean as indicator crops. The results were confounded by chloride toxicity but indicated possible deficiencies of N, P, K, S and Zn.

3.2 Calcium and Micronutrients

Few experiments have been conducted on problems associated with Ca or micronutrients in field crops in the Douglas Daly Region.

Flint (1982-83) studied the effect of calcium source and rates for peanut production on the Blain soil. His results revealed no response to any of the calcium and gypsum combinations or alone. The results were not conclusive due to high calcium content in the irrigation water and variability in Ca application rates.

Garside and Buchanan (1985) reported a negative response by soybeans to zinc on virgin Tippera soil which had an extractable zinc content of 0.35 ppm.

Flint (1983-84) reported low Zn and Mo levels in maize grown on Blain soil. Further studies using other crops are needed to establish critical levels of zinc and molybdenum for the Blain soil.

Day et al., (1983) used *Stylosanthes hamata* to evaluate the nutrient status of Tippera and Blain soil. Both soils responded to zinc and sulphur. Zinc responses were greater where sulphur was applied. Response to copper and potassium were smaller than P, S and Zn. There was no evidence of Ca, Mg, Mn, Mo, B or Fe deficiency on either the soils. Critical levels for these nutrients on varying crops need to be established.

Cameron and Ross (1986) reported zinc and molybdenum responses in Blain using *Stylosanthes hamata* with the best yield obtained at 5kg Zn ha^{-1} and 400g Mo ha^{-1}. The same Authors also found responses to S application up to 40kg S ha^{-1} for the above species.

4. REVIEW OF NUTRITIONAL AND OTHER PROBLEMS IN THE ADMA FARMS

The cropping areas of the ADMA farms and the Douglas Daly Research Farm are located on two main soil families (Tippera and Blain). Schultz and Garside (1983), Price and Garside (1984) and Price (1985) in their comprehensive reports have identified several problems associated with cropping on both soils. Even though the level of fertility of these soils is low, most of the nutritional problems experienced are associated with other environmental factors and management as is outlined below:

A. SOIL

1. Erosion - loss of soil and nutrients
2. Surface sealing and crusting
3. Low moisture retention and supply
4. Low CEC and buffering
5. Imbalance of nutrients
6. Low levels of nutrients (a) Immediate - N, P, S, Zn
   (b) Potential - K, Mg, B, Mn
7. Loss of nitrogen by leaching, volatilization and denitrification.

B. CROP

1. Seed Quality (Maize
   (Soybeans
2. Crop establishment population and distribution
3. Crop adaptation

C. CLIMATE

1. Distribution of rainfall
2. High soil temperature
3. Variable cloud cover

D. MANAGEMENT

1. Machinery
2. Difficulty in dispensing Urea
3. High fertilizer cost
4. Efficiency of fertilizer use
5. Method and time of fertilizer application
6. Lack of specific fertilizer recommendation
7. Weed control

There is inadequate information on the fate of applied fertilizers on farms. Soil samples have been collected and analysed every year since 1983 from farms by Price, to serve as a guide for fertilizer recommendations. This only indicates nutrient status at the time of sampling and the following information should be taken into consideration when making fertilizer recommendations:

1. Crop type and species
2. Soil and its buffer capacity
3. Planting density and fertilizer rate
4. Method of fertilizer application
5. Climate and sowing date
6. Expected yield levels

However, improved fertilizer recommendations will depend on good fertilizer research directed towards determining the efficiency of different rates, methods and forms for different crops and soils. Information on all of the above is lacking on the ADMA farms and future research programmes should address these issues. A summary of current nutrient status in soils of some of the ADMA farms are presented in Appendices 2 to 6.

4.1 Current Nutrient Status of the ADMA Farms:

Ceres Downs (T & C Royle)

The main soil type on this farm is Tippera clay loam (Fenton) and Tippera sandy loam (Oolloo) and crops grown are maize, sorghum, mungbean and soybeans. The soil is generally poor in N, P, S and Zn. With continuous cropping and application of fertilizers the P status in paddocks S_2 and S_3 has increased. Care should be taken not to over fertilize with P which could induce Zn and Fe deficiencies and displace sulphur.

High pH and Calcium were evident in samples collected in and around windrow areas in paddock S_2. Soybeans planted on these spots showed poor growth and nodulation (Thiagalingam and Watson, 1987). The soil is highly variable and the grey soil in paddock S7 is low in K and Mg along with N, P and S. It is therefore essential to fertilize this paddock with K and Mg.

The soil N levels are generally low and there is inadequate information to predict economic N application rates. The amounts of fertilizer N, P and S applied over the five years for maize and sorghum range from 35 to 114kg N ha^{-1}, 30 to 40kg P ha^{-1} and 2 to 62kg S ha^{-1}. The average rate of N seems to be 80kg N ha^{-1} applied at sowing and 35 days after sowing with 30kg P and 40kg S ha^{-1}. Summary of soil analysis is presented in Appendix 2.

Kumbychants (M Dawes)

The main soil type on this farm is Tippera (Fenton and Kintore) with areas of poorer drained Tippera (Hayes) and grey surfaced gravelly yellow earth (Jindare) and crops grown are maize, sorghum, sesame and soybean. Nitrogen and Sulphur are low in all the paddocks, specific data on N is lacking.

In many areas of this farm poor drainage caused waterlogging (Price 1984) especially the grey coloured soils. He also reported that crops grown on the grey patches were poor in growth and yield. There is evidence of P build up in most of the paddocks. Maize and sorghum yields were high where good rainfall distribution and early planting was experienced. The amount of N, P and S fertilizer applied to maize and sorghum range from 60 to 114kg N ha^{-1}, 20 to 50kg P ha^{-1} and 3 to 84kg S ha^{-1} with an average of 80N, 30P and 30S (Kg ha^{-1}) for both maize and sorghum.

The current nutrient status (Appendix 3) indicate a pH range of 5.7 to 7.5 with adequate exchangeable Ca, Mg and K. Cassia and Sida are prevalent weed problems and will compete with the crops for nutrients.

Bonalbo (J Vidler)

The main soil type on this farm is Blain and crops grown are maize, sorghum, sesame and peanuts. The soil is low in N, P, S and low to marginal in K and Mg. Response to K and Mg will depend on the crop and the Ca:Mg:K ratio. In all the paddocks sulphur deficiency is emerging as a major nutrient problem because of high leaching and low soil buffering capacity.

Annual applications of sulphur containing fertilizers are necessary or alternatively elemental sulphur could be used on a long term basis. However, it is essential to carry out detailed studies on the fate of applied S fertilizers on this soil. With high applications of Calcium for peanuts it is advisable to monitor the Ca:B balance.

The amount of N, P and S fertilizer applied varies from 110 to 115kg N ha, 30 to 40kg P ha^{-1} and 32 to 42kg S ha^{-1} for maize and 59 to 111kg N ha^{-1}, 30kg P ha^{-1} and 32 to 41kg S ha^{-1} for sorghum. Soil erosion and waterlogging in patches occurs in some paddocks and suitable methods are necessary to alleviate this problem. A Summary of soil analysis is presented in Appendix 4.

Theona (D Donovan)

The main soil type is Blain with approximately 1/3 of the area being sandy surfaced Tippera and crops grown are maize, sorghum and peanuts. The farm has a severe erosion problem and likely that some paddocks have poorly drained and compacted areas.

The soil is low in N, P, K, S with marginal to low levels of magnesium in some paddocks. The levels of P in all the paddocks have increased with cropping and further large single applications of P may induce zinc deficiency. Because of the poor buffering and low CEC of this soil small frequent applications of P, K and Mg are better than one large single application.

The amount of fertilizer applied by the farmer ranged from 78 to 110kg N ha^{-1}, 20 to 40kg P ha^{-1} and 5 to 29kg S ha^{-1} for maize and 64 to 120kg N ha^{-1}, 29 to 42kg P ha^{-1}, 6 to 70kg S ha^{-1} for sorghum. A Summary of soil analysis is presented in Appendix 5.

Ruby Downs (Buchanan and Calvert)

The main soil type in this farm is 2/3 Blain and 1/3 Tippera and crops grown are sorghum, sesame and peanuts. The extractable S is low in all paddocks whereas P is also low in all paddocks except Tippera. Extractable K and Mg in Blain paddocks are low to marginal and can be a potential problem for cereals in the future. Zinc and copper levels are low in the Blain soil but adequate in Tippera. From the summary of the soil analysis data in Appendix 6, it is clear that the main nutritional problems are with N, P, S, Zn and Cu. However, K and Mg and other micronutrients will be a potential problem in the future.

Therefore soil and plant analysis should form part of the extension programme to determine critical levels and fertilizer efficiency.

5. MAJOR AVENUES FOR CROP NUTRITION RESEARCH

It is evident from the review that the major constraints that influence crop nutrition and hence crop production are:

1. Climate - rainfall intensity and distribution
   - temperature
2. Soil - physical, chemical and biological properties
3. Management

5.1 Climate

As pointed out earlier climate, especially rainfall, is the major factor influencing crop establishment, growth and development, nutrient availability and losses. Rainfall distribution is more important than total rainfall as regards nutrient availability through mineralisation of N and S, diffusion of nutrients to the root zone and uptake of nutrients. A five year summary of total rainfall, distribution pattern and yield of crops on some Douglas Daly ADMA farms indicates a relationship exists between yield and distribution of rainfall rather than total rainfall. (Table 2)

Intensity of rainfall influences soil erosion resulting in nutrient losses. Therefore, soil erosion is the next major constraint which affects nutrient availability. Both Blain and sandy surfaced Tippera (Oolloo) are prone to high erosion because of their low organic matter content and poor structural stability. Many poor patches of crop observed on the farms are due either to poor drainage, compaction and water logging or removal of nutrients by erosion.

Because of poor soil physical properties within the climatic constraint, water retention is another factor affecting crop nutrient use efficiency. The question is: can the efficiency of moisture use be increased? This could be achieved through:

1. Use of conservation tillage practices.
2. Retention of mulch.
3. Use of appropriate machinery - to reduce compaction which results in erosion and nutrient loss.
4. By selecting varieties with a good root system, better nutrient assimilation and by the use of legume leys or supplementary irrigation at critical stages of growth.

5.2 Soil Fertility and Management

The review has clearly shown that, next to climate, soil fertility plays a major role in crop production. Soil fertility is viewed as a function of physical, chemical and biological properties of the soil inter-acting with climate and management. An understanding of basic processes that follows is essential to formulate appropriate management practices.

- Nutrient transformations
- Nutrient movements
- Plant availability and absorption of nutrients
- Soil buffering capacity
- Soil structure and bulk density
- Soil, water retention

The main problem facing the farmers and researchers at Douglas Daly is how to maintain high yields on soils with low CEC, poor buffering, poor nutrient retention, unreliable rainfall distribution and in some cases inefficient management. Crop production will be improved only with proper soil amendment, crop management practices and suitable genotypes which are tolerant to adverse climatic conditions especially moisture stress. Because of the high cost of fertilizer and other energy-related operations, efficiency of fertilizer use needs to be increased. Fertilizer use efficiency can be viewed as a function of soil, climate, crop and management.

Response to N fertilizer application on Blain and Tippera soil will depend greatly on seasonal rainfall. Because of the erratic nature of the rainfall pattern, low organic matter and N status, generalised pattern of fertilizer N application cannot be prescribed. Minimum quantities should be applied at sowing and additional application could be based on rainfall pattern. From the experiments conducted at the Douglas Daly research station and from farmer's experience, 60 to 100kg N ha^{-1} in split applications seems adequate for maize and sorghum.

The rate of nitrate mineralisation in Blain and Tippera soil will depend on the C:N ratios, intensity of dry periods, soil properties and moisture in the profile. Therefore, the amount of NO_3 immediately after rainfall will depend on the above factors. In general, there will be a slow build up of NO_3 in the top soil during dry season with large quantities immediately after rains with rapid decline during monsoonal rains. This has a number of practical implications for fertilizer application, especially sulphur nutrition on sandy soils. Hence immediately after or during onset of rains Blain and Tippera soils will be likely to have a high NO_3 content and there are no data available on the "nitrate" flush or seasonal changes in nitrate levels in the Douglas Daly soils. The sudden appearance of large amounts of nitrate will have a bearing on the availability of SO_4 for crops. High nitrate will compete with SO_4 ions and induce temporary sulphur deficiency. This will depend on the $NH_4:SO_4$ ratio in which higher $NH_4 : SO_4$ ratio will not induce sulphur deficiency. However, when the $NO_3 : SO_4$ ratio is high, plants will show signs of sulphur deficiency.

The microbial characteristics of Blain and the Tippera soils have not been studied and it is important to determine the predominant microbial population in relation to soil physical, chemical, moisture and temperature conditions.

TABLE 2: RAINFALL DISTRIBUTION AND AVERAGE CROP YIELDS IN THE ADMA FARMS 1981-1986*

FARM	1981-82 (Rainfall) O	N	D	J	F	M	A	Rainfall Total (mm)	Crop Yields Kg ha^{-1} Maize	Sorghum	Soybean	Mungbean
Ceres Downs	55	263	205	413	263	214	10	1423	2600	2600	-	-
Kumbychants	48	332	151	455	205	105	14	1355	2230	2150	-	-
	1982-83											
Ceres Downs	-	89	117	94	81	276	117	774	2150	2160	2400	666
Kumbychants	9	55	382	194	71	393	354	1458	313	2635	2000	854
Ruby Downs	-	-	-	104	186	331	89	710	2650	4140	2570	910
Bonalbo	-	15	47	150	107	243	2	564	-	2031	-	1320
Theyona	-	56	64	121	197	286	70	794	2190	2220	-	1230
	1983-84											
Ceres Downs	84	158	131	326	262	257	3	1221	2875	2545	1980	1085
Kumbychants	-	113	104	399	286	317	-	1219	3150	2520	1625	-
Ruby Downs	99	191	101	387	359	373	14	1524	-	-	2025	-
Bonalbo	23	138	89	423	317	390	7	1387	-	-	-	533
Theyona	54	188	41	484	427	256	6	1456	1045	287	-	-

TABLE 2: (cont'd) RAINFALL DISTRIBUTION AND AVERAGE CROP YIELDS IN THE ADMA FARMS 1981-1986*

FARM	1984-85 (Rainfall) O	N	D	J	F	M	A	Rainfall Total (mm)	Crop Yields Kg ha^{-1} Maize	Sorghum	Soybean	Mungbean
Ceres Downs	24	64	252	182	185	60	170	937	3935	3000	930	-
Kumbychants	-	110	373	205	269	114	340	1411	4325	2850	905	1440
Bonalbo	-	17	213	121	230	91	147	819	2135	3428	-	-
Theyona	-	102	375	129	319	133	172	1230	1795	1380	1000	1007
	1985-1986											
Ceres Downs	-	153	52	333	71	81	67	757	1170	1840	865	570
Kumbychants	-	226	167	398	117	123	77	1108	1270	-	640	-
Ruby Downs	13	134	113	299	78	96	79	812	-	1290	710	-
Bonalbo	44	114	108	223	59	98	79	725	520	2765	-	530
Theyona	23	46	65	259	99	52	57	601	-	1690	-	-

* SOURCE: T Price

For example, if high levels of Actenomycetes are present, this will inhibit the rhizobium species which are important for legume nodulation. Another aspect of concern is the survival rate of soybean rhizobia under high temperatures. There is also a lack of information on the effect of phosphorus and sulphur on nodulation and N-fixation by soybeans. Inhibiting the symbiotic relationship would interfere with nitrogen nutrition of the plants. Effects of moisture stress on N-fixation in soybeans is also unknown for the Douglas Daly area.

Research should be aimed at increasing the efficiency of N, P and S fertilizer use through the following practices:

1. Rotation
2. Tillage
3. Green manure crops
4. Inter cropping or alley cropping

5.2.1 Rotation

The review clearly indicates that P and S research on the Blain and Tippera for legumes is inadequate. There is no evidence to suggest that grain legumes provide enough N for the succeeding cereal crop or improve soil structure significantly in one or two years. Sometimes soil mineralisation of residues from the first crop may inhibit nodulation of the second legume crop.

In the Douglas Daly area mungbean, soybean and peanuts are grown in rotation with maize and sorghum. Herridge (1981) reported that with irrigated soybean 64 to 164kg N ha^{-1} is lost from the soil. However, pasture legumes are reported to increase soil N and the possibility of rotating pasture legumes and integrating animal production with crop production, as suggested by McCown et al., (1985), needs to be investigated.

Rotating cereal crops with legumes will not only reduce erosion risks but also increase fertilizer efficiency through build up of organic matter, improved soil structure, increased soil moisture retention and increased surface charge. The question is the type of legume to use in rotation? The type of legumes available can be divided into three groups:

(a) Grain legumes
(b) Pasture legumes
(c) Tree legumes

The choice of legume will depend on a number of factors. Little information exists on the amount of residue, amount of N lost or retained after a grain legume crop in Blain and Tippera soils. Tree legumes have not been used in rotation in the Douglas Daly area and legume leys have been shown to provide succeeding crops with the equivalent of 50 to 75kn N (McCown et al., 1985).

5.2.2 Tillage

The red earths of Douglas Daly possess a clay horizon and sometimes effective rooting depth is limited by compaction especially on sandy surfaced soils where the lighter surface soil is eroded. This mechanical impedance has caused water logging in patches resulting in poor growth.

This mechanical impedance should be controlled by tillage. Therefore, deep ploughing will open up hard soil layers and increase infiltration or improve profile moisture storage. Sometime when we have uneven land surface, it will result in poor seed placement. For efficient nutrient utilisation, a profuse root system is essential and achieved by either improving soil structure through high levels of organic matter build up or by primary tillage operations. When we develop or design experiments related to tillage we should consider the nature and properties of the individual soil types. Mechanised land clearing and use of heavy machinery for cultivation in the Blain and Tippera soils along with high intensity rainfall has resulted in compaction and erosion.

Tillage research at Douglas Daly is still at the infancy stage however experiments conducted to date have suggested a positive response to no till and nitrogen. But it is too early to reach any conclusions. There is no doubt that the efficiency of fertilizer use can be improved by increasing the soil moisture through no tillage. However, care should be taken in using large quantities of herbicides because of likely residual effects on soil and ground water. Currently we do not have a cheap broad spectrum herbicide for effective and economic weed control.

A need exists to document the economic and long term effects of no tillage on soil physical, chemical and biological properties, nutrient availability, pest problems under broad acre cropping systems. Research is needed to assess the economic benefits of crop rotation under no till systems. In the semi-arid environment the type of legume used in rotation is important.

5.2.3 Green Manure

The potential for a fast growing legume as a green manure crop has not been exploited under broad acre agriculture or cropping systems in the semi-arid tropics of the Northern Territory. A green manure crop could be sown immediately after harvest to make full use of the residual moisture or grown separately during the wet season and ploughed in after harvest.

This system may not appeal to farmers but has beneficial economic implications for N build up in soil, improved soil structure, water storage and increased surface charge. Under existing climatic conditions 60% to 70% of its N will be mineralised and made available for the succeeding crop. There is ample scope to test not only its ability to increase soil N but also a method of building up soil organic matter.

5.2.4 Inter-cropping and alley cropping

The possibility of increasing nutrient efficiency through sub soil fertility needs to be pursued. Because of high leaching, sulphate and nitrate ions moved to the sub soil can be recovered by the use of deep rooted crops like pigeon pea and leucaena in rotation with cereal crops. Tree crops not only act as a means to recover nutrients from depth but also act as a wind break and reduce evapotranspiration.

Therefore, experiments should be established in the use of:

(a) Pigeon Pea
(b) Leucaena
(c) Pearl Millet

Intercropping systems with cereals or other legumes which not only increase the level of nutrient use efficiency but also increase the surface charge of the Blain and the Tippera soil through organic matter addition from leucaena.

The review also points out that there are no long term studies related to nutrient retention, nutrient build up or nutrient availability. It is essential to conduct multifactor experiments in order to study interactions. As an example, it can be pointed out that there is interaction between Calcium and Boron uptake.

6. FUTURE RESEARCH

Mineral nutrient stress is one of the major limitations of crop production in the sandy and the loamy red earths of the Douglas Daly region. The degree of this stress will depend on rainfall (intensity, quantity and distribution), crop species, soil type, temperature and management.

The magnitude of this stress can only be defined through well conducted experiments. In order to develop a sound soil testing programme for farmers an enormous amount of background research is required. This should determine the significant chemical forms of the available nutrients and should correlate with yields and nutrient contents from simple statistically designed experiments. The research programme should establish critical values of soil and plant nutrients in the area to predict fertilizer needs of the crop.

Basic research should follow hand in hand with applied research. This could be achieved in collaboration with CSIRO and Conservation Commission. Greenhouse and laboratory experiments should form a part of the field research programme in order to accurately interpret data collected from field experiments. It will be difficult to pinpoint nutritional problems unless the farmer has adopted the recommended agronomic practices.

The aim of crop nutrition research in the Douglas Daly area is to achieve the most economic use of the fertilizers under the existing soil and climatic conditions. A data base needs to be developed comprising the following information:

A. Site factors

1. Soil classification
2. Soil depth
3. Soil physical, chemical and biological properties
4. Slope
5. Rainfall - intensity, distribution
6. Temperature
7. Solar radiation

B. Fertility factors

1. Source of fertilizer
2. Method, amount and time of fertilizer application
3. Cost of fertilizer
4. Residual effects

C. Crop Management

1. Planting date
2. Crop variety
3. Plant density
4. Pest and weed control
5. Plant and soil nutrient analysis
6. Harvest data

Sufficient interpretive data are lacking for most of the crops at different stages of growth under existing climatic and management practices. Data are needed to calibrate nutrient concentrations as low, sufficient or toxic. Currently, nutrient toxicity may not be a problem but with continuous cropping and with any one nutrient applied in excess toxicity may develop.

The difference in response to phosphorus and sulphur application depends on differences in P sorption and sulphur retention in soils. There is limited knowledge on P sorption, P retention, S sorption and retention, rate of N and S transformation and rate of leaching. Critical levels need to be established for basing fertilizer recommendations.

A major problem associated with plant nutrient deficiencies is nutrient imbalance. Research on the imbalance of nutrients in the soils and a programme to recommend a balanced application of nutrients is warranted. The key to the efficient, economic use of fertilizers is to add a balanced level of appropriate nutrients. For example, excess Ca^{++} will lead to poor K nutrition and excess NO_3 will interfere with SO_4 sorption. The use of unbalanced ratios of N, P and K will lead to disturbances of plant nutritional status and result in loss of yield.

Research emphasis should be on the efficient use of fertilizer especially on sandy soils and be geared towards maximising their availability at the most important growth stage.

Availability of nutrients from the soil can be maximised by:

(a) Increase organic matter levels
(b) Minimum tillage
(c) Proper planting time
(d) Better tillage conditions
(e) Adaptable variety

In this environment, selecting the right combination of cultivar, fertilizer and suitable tillage practice is important to produce the maximum economic yield.

Sulphur deficiency is emerging as a major problem in Blain and Tippera soils and priority should be given to establishing long term studies on sulphur source and rate of application in relation to cost and efficiency. Interaction of sulphur with other nutrients needs to be evaluated.

Nutrient management should be assessed for either average yield for the environment or the optimum economic yield. Cultivars need to be selected at plant densities suitable to prevailing environmental conditions and response to nutrients along with interactions should be assessed.

Fertilizer efficiency can be influenced by maintaining a good mulch on the surface or by build up of soil organic matter which keeps soil moist and cool avoiding high temperature stress and encourages better root development with increased nutrient uptake. Research should be designed to explore the use of green manure as a source of material for organic matter build up under broad acre cropping and explore improved residue management through no till.

Soil erosion is a major factor in the Blain and Tippera soils and assessment should be made on the loss of soil nutrients due to sediment transport especially on sandy soils to determine how much fertilizer is required to offset the losses by erosion.

The following research is suggested for the red earth soils in order of priority. Major emphasis will be to develop a low input fertilizer programme.

6.1 Fertilizer Response Studies

Current fertilizer recommendations are based on soil tests and farmer's experience. There is a need to understand nutrient uptake rates (especially N & S) and utilization by the crops grown in Douglas Daly. Nutrient response curves using supplementary irrigation will be useful for computer modelling for future fertilizer prediction. To develop an economic fertilizer recommendation initially, fertilizer response curves for:

(a) Nitrogen
(b) Phosphorus
(c) Sulphur
(d) Potassium

should be established for Blain and Tippera soils over a number of seasons for all the crops grown in the Douglas Daly area.

6.2 Fertilizer Use Efficiency

Fertilizer efficiency is a function of soil, crop, climate and management and will be evaluated under the following categories.

A. Fertilizer Management through:

- Time of application of fertilizers, i.e. splitting fertilizer application between sowing and at different stages of crop growth. This offers an option of applying fertilizer according to season and supplying nutrient when the crops requirements are high.

- Source of fertilizer: Different fertilizers will respond differently to climate, soil and crop. It is essential to evaluate the most economical and efficient fertilizer.

- Method of application, i.e. broadcasting, banding etc.

B. Monitoring of Nutrients lost by:

- leaching
- erosion
- volatilization

The above losses can be reduced by residue management through no till or minimum tillage, use of inhibitors to reduce the rate of nitrification or sulphur transformation, use of slow release fertilizers.

C. Development of Suitable Methods of Assessing

- P sorption and desorption of soils
- P sorption in relation to wetting and drying
- S sorption and desorption of soils
- N released by mineralization
- S released by mineralization
- Use of mycorrhiza to increase P efficiency
- Appropriate tests for sulphur and phosphorus

All of the above studies can be conducted under greenhouse and laboratory conditions to support field experiments.

6.3 Nitrogen Efficiency through Rotation

Assess the Nitrogen contribution from different crop rotation systems i.e.

(a) Grass leys
(b) Grain legumes - peanuts, soybeans, mungbean
(c) Pasture legumes - verano, siratro
(d) Tree crops e.g. leucaena, sesbania

Experiments should be designed which involve growing cereal crops after one, two or three years of legume rotation at different levels of nitrogen. From the nitrogen response curves, N contribution by the legume can be estimated. Similar work using legume leys has been conducted at CSIRO Katherine (McCowan et al., 1985).

6.4 Farm Surveys

- Soil testing
- Tissue analysis

Collection and analysis of soil and plant samples at

(a) Active vegetation stage,
(b) Active reproductive stage of crops,
(c) Harvest.

This along with field, laboratory and greenhouse studies would enable us to set out critical levels of nutrients for specific crops.

6.5 Evaluating Genotypes which make better use of nutrients, eg:

- drought resistant varieties
- varieties which can tolerate nutrient stress
- varieties with a better root system
- varieties showing increased adaptation to both moisture and nutrient stress

APPENDIX I : SUMMARY OF NUTRITIONAL EXPERIMENTS ON BLAIN AND TIPPERA SOILS

	Fertilizer Elements and their rates Kg ha-1	Soil	Crop	Summary of Response and Conclusions	Reference
1.	N (0, 40, 80, 120) Urea applied twice at planting and 26 days after planting	Tippera	Maize	Response to N application up to 120 Kg ha-1. Yields depressed after 120 Kg N ha-1. The author concluded that for Tippera soil an economic rate will be 80 - 100 Kg N ha-1 for mid late season maturing hybrid at a harvest population of 40 000 plants ha-1.	R W Madin 1973/74 File No. 572/1009
2.	N x P factorial N (0, 35, 70, 105 Kg ha-1) as $(NH_4)_2\ SO_4$ and Urea P (0, 30Kg P ha-1 TSP, 15Kg P ha-1 + 1tha-1 of RP, 15Kg ha-1 + 2 t P ha-1 RP)	Tippera	Maize	Both N sources increased yield. However, ammonium sulphate response was higher than urea. The urea treatment was not balanced with the amount of S in ammonium sulphate. Response to P application. No difference between P treatments. However, low levels of TSP (15Kg P ha-1) + 1 t P ha-1 of RP showed the highest crop P levels.	C N Williams et al 1984. DPP 82/1584
3.	Starter N (0, 15,30) Supplementary N (0, 100)	Tippera	Soybean	Seed yield was not improved by either Starter or Supplementary N. However, increased pod number per plant and decreased seed side. Residual soil N is 100ppm. Nodulation effect due to high levels were not measured. Moisture stress during grain formation.	Garside and Buchanan (1985)
4.	N x P Factorial N (0, 45, 67.5, 135) P (0, 20,40) Bio super at the highest N level (0, 20, 40Kg P ha-1)	Tippera	Maize	The results of this experiment was not conclusive due to differences in plant population within treatments. Increasing N and P had no effect on grain yield. Recommended 20Kg P ha^{-1} as a maintenance application on a previously fertilized area. Bio-super is unsuitable because of its slow release.	R W Madin 1973/74 J 72/1009

	Fertilizer Elements and their rates Kg ha-1	Soil	Crop	Summary of Response and Conclusions	Reference
5.	N (0, 35, 70, 105, 140) P (0, 20, 40, 60) K (0, 40)	Tippera (Oolloo)	Maize	The experiment was a failure due to: (a) Poor site (b) Late start of the wet season (c) Variable plant population (d) Different methods of fertilizer application within treatment (e) Method of sampling	C N Williams 82/83 DPP NR 82/1583
6.	N (0, 22, 56 112) P (0, 11, 28, 56) K (0, 67) S (0, 17, 45)	Blain Tindall Emu	Sorghum	No significant response was found to the addition of K and S to any of the three soils. All three soils responded to N and P. However, N and P responses were dependent on seasonal variations.	Day, 1977
7.	N (0, 112) treatments from a factorial expt was used to study leaching of nitrate	Blain Tindall Emu	Sorghum	Leaching displaced NO_3 to between 45-105cm in Tindall, 60-165cm in Emu and 75-180cm in Blain during the sorghum growing season. Rapid displacement in Blain	Day, 1977
8.	P (0, 10,20,40,80) S (0, 20,40) P - Placement S - Gypsum Broadcast (1981/82)	Tippera	Soybean	Significant grain yield response to P and S. Highest yield was obtained with a combination of 80Kg P and 20Kg S per ha. Most economic combination is 40Kg P and 20Kg S per ha.	Garside and Buchanan (1985)
9.	P (0, 20,40) applied in 1982-83 as sub plots after P x S rates being applied in 1981/82	Tippera	Soybean Maize	Experiment was a failure due to adverse climatic conditions	Garside and Buchanan 1985

	Fertilizer Elements and their rates Kg ha-1	Soil	Crop	Summary of Response and Conclusions	Reference
10.	The above experiment was planted with soybeans. Residual effects of S and P evaluated.	Tippera	Soybean	Yield increased with increasing rate of P applied in 1981-82. There was no yield increase from 1982-83 applied P when 80Kg/ha was applied in 1981-82. Available P > 14ppm. Concluded that no response due to high available P. No response to sulphur due to high leaching.	Garside and Buchanan (1985)
11.	P (0, 10, 20, 40, 80) S (0, 35, 70)	Blain	Peanuts	Response to P application. The best yield was obtained at 40Kg P/ha when the soil P was 7ppm. No response to sulphur was obtained because of high levels of S in the irrigation water.	C Flint 1982-83 Unpublished
12.	Residual P (1982) (0, 10, 20, 40, 80) Treatment P (0, 15, 30) (1983)	Blain	Peanuts	Yield response to residual P. Response to applied P over control.	C Flint 1983-84 Unpublished
13.	Response of Peanuts to minor and some major nutrients	Blain	Peanuts	No response to K application. No response to Mn and B. However, B content in Blain soil has never been assessed. Concluded that P, Zn, Cu, Mo is low. Not very conclusive.	C Flint 1982-83 Unpublished
14.	Minor Nutrient Expt. - K, Zn, Mn, Cu, Fe, B	Blain	Maize	Zinc was found to be the main nutrient deficient. Mo contents in kernels were low in the zero and minus Mo treatments.	C Flint 1983-84 unpublished

	Fertilizer Elements and their rates Kg ha-1	Soil	Crop	Summary of Response and Conclusions	Reference
15.	Calcium nutrition of Peanuts. Effect of rate and source. Lime (0, 300, 600, 1200) Gypsum (0, 250, 500, 1000)	Blain	Peanuts	No significant response to any of the Ca x Gypsum treatment combinations or Lime or Gypsum alone. This may be due to high Ca^{++} content in the irrigation water and problems associated with spreading of Lime and problems with machinery.	C Flint 1982/83 unpublished
16.	Zinc (0, 5, 10, 15, 20)	Tippera	Soybean	No soybean yield response to zinc. Initial soil zinc level is 0.35 ppm. Critical levels for each crop should be established.	Garside and Buchanan (1985)
17.	P (0, 12.5, 25, 50, 75, 100, 150) (Pot Expt)	Tippera (Katherine) Blain (Douglas/Daly)	Stylosanthes hamata Cv.Verano	Both soils responded to P application and 90% of the estimated maximum yield was obtained with 15Kg P ha-1 in Blain soil and 35Kg P ha-1 in the Tippera soil.	Day et al (1983)
18.	2^7 Factorial Experiment	Tippera (Katherine) Blain (Douglas/Daly)	Stylosanthes hamata Cv.Verano	Both soils responded to Zn and S applications. Zinc responses were greater where S is applied. Responses to K and Cu are smaller than P, S, and Zn. There was no evidence of deficiencies of Ca, Mo, Mg, Mn, B or Fe.	Day et al (1983)
19.	2^6 Factorial	Blain Oolloo	Stylosanthes hamata Cv.Siratro	Significant responses to Mo. Test species and design of the expt had deficiencies	B. Ross NR 84/170 unpublished

	Fertilizer Elements and their rates Kg ha-1	Soil	Crop	Summary of Response and Conclusions	Reference
20.	Zn x Mo Expt.	Blain	Stylosanthes hamata Cv.Verano	Response to zinc and molybdenum. Best response at 50Kg ha-1 of Zn and 400g Mo ha-1	A Cameron (Pastures)
21.	P x S Experiment	Blain	Stylosanthes hamata Cv.Verano	Response to S application up to 40 Kg ha-1	A Cameron (Pastures)
22.	Effect of innoculation on the yield of soybeans. (Rhizobium japaricum CB 1809)	Tippera	Soybean	A yield difference of one tonne/ha was obtained. (innoculated = 3450 Kg ha-1, not innoculated = 2414 Kg ha-1).	Garside and Buchanan (1985)
30.	Tillage (no till vs conv.till) x Rotation (Soybean, Maize) x Nitrogen (0, 20, 40, 80, 160)	Tippera	Maize Soybean	No major difference between treatments in 1984-85 season. However, 1985-86 season no tillage yields were higher than conventional tillage treatment. 1986-87 response to N application under no till.	N Gould (Unpublished)

APPENDIX 2 : SUMMARY OF FERTILIZER RATES AND SOIL NUTRIENT STATUS 1983 - 1986 (CERES DOWNS)
Source: T. Price

Paddock & Year		Soil Family	Crop		Fertilizer Rate (Kg ha-1) N	P	S	Soil Nutrient Status After Each Crop pH	P	K	Ca -ppm-	Mg	S	Zn	Cu
S_1	1983	Tippera	Sorghum Maize	81/82 82/83	92	35	5	6.2	5	199	955	187	9	0.2	2.0
	1984	Tippera	Maize	83/84	97	40	21	6.3	18	233	947	162	5	0.3	4.8
	1985	Tippera	Fallow	84/85	30	32	-	6.4	13	296	1070	145	7	0.3	4.9
	1986	Tippera	Mungbean	85/86	27	-	-	6.4	8	321	1092	138	5	0.3	3.2
S_2	1983	Tippera	Sorghum Soybean	81/82 82/83	5	34	32	6.8	6	266	1646	187	6	0.3	3.8
	1983	Tippera	Sorghum Maize	81/82 82/83	94	37	6	6.4	9	284	1704	179	13	0.4	2.6
	1984	Tippera	Maize Soybean	82/83 83/84	23	40	21	6.8	8	231	1978	148	5	0.2	4.7
	1985	Tippera	Soybean Maize	83/84	65	30	47	6.2	26	235	1459	232	9	1.1	6.4
	1986	Tippera	Maize Maize	84/85 85/86	86	30	39	7.2	25	279	2526	127	9	0.8	3.3
	1986	Tippera	Maize Maize	84/85 85/86	86	30	39	7.3	64	370	1906	111	9	1.1	2.5
	1986	Tippera*	Maize Maize	84/85 85/86	86	30	39	8.0	40	234	3722	95	8	0.9	2.1

* Windrow - Poor Growth

Paddock & Year		Soil Family	Crop		Fertilizer Rate (Kg ha-1)				Soil Nutrient Status After Each Crop						
					N	P	S	pH	P	K	Ca -ppm-	Mg	S	Zn	Cu
S_3	1983	Tippera (light)	Sorghum	82/83	35	30	2	6.6	8	177	1253	129	8	0.2	2.2
	1983	Tippera (light)	Mungbean	82/83	5	40	4	6.5	7	162	1170	133	8	0.3	1.5
	1984	Tippera	Sorghum Maize	82/83 83/84	114	40	57	6.5	21	118	772	89	9	0.8	2.1
	1984	Tippera	Sorghum Maize	82/83 83/84	48	40	52	7.2	28	100	1497	67	5	0.3	1.0
	1985	Tippera	Soybean Soybean	83/84 84/85	-	29	2	6.6	20	251	1178	121	10	0.8	3.3
	1986	Tippera	Soybean	85/86	-	29	2	7.1	33	293	1892	122	5	1.4	2.9
S_5	1983	Tippera (light)	Millet	82/83				6.9	5	112	755	117	7	0.8	2.0
	1984	Tippera (light)	Millet Sorghum	82/83 83/84	70	33	21	6.7	5	86	917	104	5	0.7	3.8
	1985	Tippera	Sorghum Sorghum	83/84 84/85	70	30	5	6.1	9	100	798	92	10	1.4	2.7
	1986	Tippera	Sorghum	85/86	65	30	62	6.2	15	134	854	86	5	2.7	2.9
S_6	1984	Tippera	Virgin Sorghum	82/83 83/84	95	33	21	7.1	9	122	1571	137	5	1.3	2.0
	1986	Tippera (red)	Maize Maize	84/85 85/86	86	30	39	6.2	14	142	845	115	5	3.5	1.6

Paddock & Year	Soil Family	Crop		Fertilizer Rate (Kg ha-1)			Soil Nutrient Status After Each Crop							
				N	P	S	pH	P	K	Ca -ppm-	Mg	S	Zn	Cu
S_7 1985	Tippera (grey)	Virgin Maize	83/84 84/85	84	45	7	6.4	5	30	395	44	6	0.9	1.5
1985	Tippera (red)	Virgin Sorghum	83/84 84/85	113	75	13	6.6	8	90	1142	175	9	1.9	5
1986	Tippera (grey)	Maize Mungbean	84/85 85/86	-	29	2	6.5	9	33	339	36	5	0.3	0.5
1986	Tippera (red)	Sorghum Mungbean	84/85 85/86	-	29	5	6.2	14	142	845	115	5	3.5	1.6

APPENDIX 3 : SUMMARY OF FERTILIZER RATES AND SOIL NUTRIENT STATUS (1983-1986) (KUMBYCHANTS)

Source: T. Price

Paddock & Year		Soil Family	Crop		Fertilizer Rate (Kg ha-1)			Soil Nutrient Status After Each Crop							
					N	P	S	pH	P	K	Ca -ppm-	Mg	S	Zn	Cu
H_1	1983	Tippera	Maize Maize	81/82 82/83	106	30	40	6.8	12	195	1698	130	7	1.3	8.8
	1985	Tippera	Sorghum Maize	83/84 84/85	101	29	15	6.2	25	194	1507	123	5	0.6	10.6
	1986	Tippera	Maize Maize	84/85 85/86	81	35	9	7.5	31	256	4332	123	14	1.5	7.8
H_2	1984	Tippera	Sorghum Maize	82/83 83/84	75	35	17	6.2	27	165	907	151	5	0.3	15.5
	1986	Tippera	Maize Maize	84/85 85/86	81	35	9	5.7	19	144	667	98	13	2.1	7.3
H_3	1983	Tippera (yellow)	Maize	82/83	60	30	40	6.6	5	235	1608	205	16	0.8	8.1
	1983	Tippera (red)	Maize	82/83	60	30	40	6.6	7	220	1430	138	7	0.7	7.6
	1984	Tippera (red)	Maize Sorghum	82/83 83/84	68	38	5	6.6	15	144	1160	103	5	0.7	3.1
	1985	Tippera (red)	Sorghum Maize	83/84 84/85	111	29	27	7.0	24	229	1641	117	5	0.4	4.9
	1986	Tippera (red)	Maize Maize	84/85 85/86	81	35	9	6.4	32	206	1046	81	15	3.2	4.2

Paddock & Year		Soil Family	Crop		Fertilizer Rate (Kg ha-1)			Soil Nutrient Status After Each Crop							
					N	P	S	pH	P	K	Ca -ppm-	Mg	S	Zn	Cu
H_4	1983	Tippera	Sorghum	83/84	114	45	25	7.0	13	216	1368	159	12	0.4	10.4
	1984	Tippera (red)	Virgin Sorghum	82/83 83/84	70	50	7	6.9	11	126	1890	185	5	0.3	4.1
	1985	Tippera (red)	Sorghum Sorghum	83/84 84/85	91	29	3	6.4	14	201	917	135	7	2.0	6.0
	1986	Tippera	Mungbean Sesame	84/85 85/86	42	15	4	6.8	11	146	694	90	5	0.6	5.5
	1986	Tippera	Maize Maize	84/85 85/86	81	35	9	6.1	9	202	936	134	22	1.7	3.8
H_5	1983	Tippera	Maize	82/83	110	45	84	6.3	4	208	1328	143	12	0.3	3.2
	1984	Tippera (red)	Virgin Sorghum	82/83 83/84	75	50	7	6.8	9	149	1912	121	5	0.3	11.8
	1984	Tippera (grey)	Virgin Maize	82/83 83/84	73	30	16	6.2	23	212	1329	135	5	0.6	3.5
	1984	Tippera (red)	Virgin Maize	82/83 83/84	73	30	16	6.3	5	182	890	174	5	0.4	3.8
	1985	Tippera (red)	Maize Soybean	83/84 84/85	-	35	38	6.3	11	213	1044	137	9	0.8	4.1
	1985	Tippera (grey)	Maize Soybean	83/84 84/85	-	35	38	6.5	9	239	1537	128	6	0.7	5.0
	1986	Tippera (grey)	Soybean Maize	84/85 85/86	81	35	9	6.4	12	244	947	133	9	2.9	1.8
	1986	Tippera (red)	Soybean Maize	84/85 85/86	81	35	9	6.4	12	214	988	111	11	1.5	2.3

Paddock & Year	Soil Family	Crop		Fertilizer Rate (Kg ha-1)			Soil Nutrient Status After Each Crop							
				N	P	S	pH	P	K	Ca -ppm-	Mg	S	Zn	Cu
H_6 1985	Tippera	Virgin Soybean	83/84 84/85	-	35	38	6.5	11	208	1244	145	7	1.1	4.3
1986	Tippera	Soybean Maize	84/85 85/86	81	35	9	6.0	9	158	934	117	17	2.7	3.1
A_1 1984	Tippera (grey)	Sorghum Sorghum	82/83 83/84	63	29	4	6.3	7	196	1856	212	5	0.4	2.1
1986	Tippera (grey)	Maize Maize	84/85 85/86	101	35	33	6.7	15	489	2071	250	5	2.5	2.1
1986	Tippera (red)	Maize Maize	84/85 85/86	101	35	33	6.1	28	175	711	50	5	1.9	3.2
A_2 1984	Tippera (grey)	Virgin Sorghum	82/83 83/84	63	29	4	6.4	21	200	1649	208	5	0.6	2.8
1986	Tippera (grey)	Virgin Soybean	84/85 85/86	-	25	28	6.7	16	283	2382	193	5	1.2	3.0
1986	Tippera (grey)	Sorghum Sesame	84/85 85/86	42	15	4	6.6	9	385	2766	320	5	2.5	2.1

Paddock & Year		Soil Family	Crop		Fertilizer Rate (Kg ha-1)			Soil Nutrient Status After Each Crop							
					N	P	S	pH	P	K	Ca -ppm-	Mg	S	Zn	Cu
D_2	1984	Tippera (red)	Maize Maize	82/83 83/84	80	30	16	6.6	21	219	1414	143	5	0.7	8.6
	1984	Tippera (grey)	Maize Maize	82/83 83/84	80	30	16	6.3	15	256	1134	150	5	0.4	3.3
	1985	Tippera (red)	Maize Maize	83/84 84/85	101	29	15	6.5	19	186	1094	100	5	0.4	3.7
	1985	Tippera (grey)	Maize Maize	83/84 84/85	101	29	15	6.4	12	211	1219	131	5	0.4	3.7
	1986	Tippera (red)	Maize Maize	84/85 85/86	101	35	33	7.0	13	34	295	14	5	0.2	0.4
	1986	Tippera (grey)	Maize Maize	84/85 85/86	101	35	38	6.0	12	148	671	92	9	2.6	3.1
D_3	1983	Tippera	Maize Soybean	81/82 82/83	-	26		6.7	9	231	1817	165	14	1.1	3.3
	1984	Tippera	Soybean Soybean	82/83 83/84	23	39	6	6.8	15	202	1136	135	5	0.9	5.2
	1985	Tippera	Soybean Maize	83/84 84/85	101	29	15	6.6	19	233	1537	139	5	1.5	4.2
	1986	Tippera	Maize Maize	84/85 85/86	81	35	9	6.1	15	285	1510	121	19	1.4	3.5

APPENDIX 4 : SUMMARY OF FERTILIZER RATES AND SOIL NUTRIENT STATUS (1985 - 1986) (BONALBO)

Source: T. Price

Paddock & Year	Soil Family	Crop		Fertilizer Rate (Kg ha-1)			Soil Nutrient Status After Each Crop							
				N	P	S	pH	P	K	Ca -ppm-	Mg	S	Zn	Cu
V_1 1985	Oolloo	Mungbean Sorghum	83/84 84/85	59	30	41	7.1	20	50	621	41	7	3.7	1.2
1986	Oolloo	Sorghum Sorghum	84/85 85/86	85	30	33	6.5	14	136	446	50	5	3.4	1.5
V_2 1985	Oolloo	Mungbean Sorghum	83/84 84/85	59	30	41	6.6	14	24	474	27	7	3.3	1.0
1986	Oolloo	Sorghum Sorghum	84/85 85/86	85	30	33	7.1	44	77	625	66	5	1.6	0.7
V_3 1985	Oolloo	Fallow Maize	83/84 84/85	110	36	41	6.7	11	60	603	34	6	1.0	1.1
1986	Oolloo	Maize Maize	84/85 85/86	110	30	32	6.3	10	120	536	59	6	1.5	0.8
V_4 1985	Oolloo	Virgin Maize	83/84 85/86	114	40	42	6.4	9	56	550	49	6	1.2	1.2
1986	Oolloo	Maize Maize	84/85 85/86	111	30	32	6.4	20	112	494	41	8	4.2	2.0
V_5 1985	Oolloo	Virgin		-	-	-	7.0	6	50	607	60	6	0.4	1.0

Paddock & Year		Soil Family	Crop		Fertilizer Rate (Kg ha-1)			Soil Nutrient Status After Each Crop							
					N	P	S	pH	P	K	Ca -ppm-	Mg	S	Zn	Cu
V_6	1985	Oolloo	Virgin Maize	83/84 84/85	115	40	36	6.0	12	24	350	30	8	1.6	0.6
	1985	Oolloo	Virgin Maize	83/84 84/85	115	40	36	6.3	18	14	249	32	8	1.6	0.6
	1986	Oolloo	Maize Sorghum	84/85 85/83	111	30	32	6.2	14	45	283	29	5	5.9	0.5
V_7	1985	Oolloo	Virgin Soybean	83/84 84/85	-	38	3	6.4	8	28	409	59	6	0.6	0.8
	1986	Oolloo	Virgin Peanuts	84/85 85/86	-	38	4	6.7	14	50	428	53	7	0.8	0.5
V_8	1985	Oolloo	Virgin Soybean	83/84 84/85	-	38	3	6.8	7	39	478	44	8	0.5	0.7
	1986	Oolloo	Soybean Mungbean	84/85 85/86	19	39	10	6.7	24	61	434	46	5	2.1	0.5
V_9	1985	Oolloo	Virgin		-	-	-	6.4	1	30	326	53	6	0.3	0.8
	1986	Oolloo	Millet		-	-	-	6.5	5	46	368	63	5	0.8	0.6

APPENDIX 5 : SUMMARY OF FERTILIZER RATES AND SOIL NUTRIENT STATUS (1984 - 1986)
(THEYONA)

Source: T. Price

Paddock & Year		Soil Family	Crop		Fertilizer Rate (Kg ha-1)			Soil Nutrient Status After Each Crop							
					N	P	S	pH	P	K	Ca -ppm-	Mg	S	Zn	Cu
Liddys	1984	Oolloo	Virgin Maize	82/83 83/84	97	50	15	7.4	9	65	608	56	5	1.6	0.9
	1984	Oolloo	Soybean Maize	82/83 83/84	97	40	15	6.6	12	55	494	47	5	2.6	1.1
	1985	Oolloo	Maize Sorghum	83/84 84/85	64	34	5	6.8	20	111	705	64	5	1.4	1.4
	1985	Oolloo	Maize Maize	83/84 84/85	101	34	5	5.8	18	44	428	25	5	1.4	1.4
	1986	Oolloo	Sorghum Maize	84/85 85/86	78	20	27	6.4	20	121	534	53	11	1.3	0.5
Bucknell	1985	Oolloo	Maize Soybean	83/84 84/85	20.5	58	3	6.8	15	35	498	40	5	0.8	0.9
	1986	Oolloo	Soybean Sorghum	84/85 85/86	78	42	6	6.5	17	85	740	57	5	2.3	0.6
Front	1984	Oolloo	Virgin Maize	82/83 83/84	97	40	15	6.8	23	90	902	76	5	0.4	0.9
	1985	Oolloo	Maize Mungbean	83/84 84/85	20	29	27	6.6	33	200	930	93	7	0.3	1.4
	1986	Oolloo	Mungbean Sorghum	84/85 85/86	120	30	70	6.8	29	144	1055	92	5	2.0	1.3

Paddock & Year		Soil Family	Crop		Fertilizer Rate (Kg ha-1)			Soil Nutrient Status After Each Crop							
					N	P	S	pH	P	K	Ca -ppm-	Mg	S	Zn	Cu
Flemming	1985	Oolloo	Virgin Sorghum	83/84 84/85	70	40	29	6.9	14	146	986	133	5	1.1	1.1
	1985	Oolloo	Sorghum Maize	83/84 84/85	82	53	29	6.7	14	117	767	83	5	0.7	1.8
	1986	Oolloo	Sorghum Maize	84/85 85/86	78	20	27	6.7	38	154	909	98	11	1.6	1.4
	1986	Oolloo	Maize Maize	84/85 85/86	78	20	27	6.7	35	136	600	50	8	0.8	0.5
Centre	1985	Oolloo	Maize Maize	83/84 84/85	84	34	23	5.0	23	43	387	22	6	1.3	1.6
	1986	Oolloo	Maize Maize	84/85 85/86	78	20	27	6.2	29	89	454	33	8	4.4	2.3

APPENDIX 6 : SUMMARY OF FERTILIZER RATES AND NUTRIENT STATUS (1986)
(RUBY DOWNS)

Source: T. Price

Paddock & Year		Soil Family	Crop	Fertilizer Rate (Kg ha-1)			Soil Nutrient Status After Each Crop							
				N	P	S	pH	P	K	Ca -ppm-	Mg	S	Zn	Cu
Species	1986	Blain	Virgin 84/85 Sorghum 85/86	69	40	45	6.6	5	51	599	47	5	0.3	0.4
Trial	1986	Blain	Virgin 84/85 Sesame 85/86	68	40	42	7.7	5	109	792	62	7	0.2	1.9
House	1986	Blain	Virgin 84/85 Sesame 85/86	68	40	42	6.7	7	41	443	37	5	1.5	0.3
Tippera	1986	Tippera	Soybean 84/85 Soybean 85/86	-	38	12	6.3	21	159	505	80	5	1.0	2.5
Intro	1986	Blain	Virgin 84/85 Sorghum 85/86	69	40	45	6.6	5	40	391	29	5	0.3	0.4
Peanut (Old)	1986	Blain	Peanut 84/85 Peanut 85/86	-	29	3	7.9	9	77	756	36	5	0.5	0.4
Peanut (New)	1986	Blain	Virgin 84/85 Peanut 85/86	-	35	42	8.6	6	105	1878	67	5	0.3	0.5
Species (Ruby end)		Blain	Virgin 84/85 Sorghum 85/86	69	40	45	8.5	5	71	1596	65	5	0.8	0.4

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