Effects of green manure crops on short-term nitrogen availability in organic sweet corn systems

A thesis presented in partial fulfilment of the requirements
for the degree of

MASTER OF APPLIED SCIENCE
in
Soil Science

at Massey University,
Palmerston North, New Zealand

James Anthony Hanly

2000

This thesis is dedicated to my wife Jolanda.

Your encouragement of me during my tertiary education,

and your support, understanding and faithfulness

have made all the difference.

Thank you!

Abstract

In the Gisborne Region of New Zealand (NZ) many organic sweet corn growers use a range of winter green manure crops as a means of maintaining and improving soil fertility, particularly the availability of soil N. Some debate exists as to the most suitable green manure crops and their effectiveness at improving short-term N availability for subsequent sweet corn crops.

Two field trials were conducted in the Gisborne Region to assess the effectiveness of four winter green manure crops using a subsequent sweet corn crop to evaluate N availability. Two sites, Site-A at Tekaraka and Site-B at Tolaga Bay, with BIO-GROW NZ organic certification were used in this study. A Latin Square trial design was used at each site consisting of 25 plots made up of five replicates of each of the following five treatments: control (bare soil), blue lupin (*Lupinus angustifolus*), mustard (*Brassica sp.*), mustard/blue lupin mix and annual ryegrass (*Lolium multiflorum*).

Just prior to the soil incorporation of green manure treatments (early-mid September 1997), the lupin crop had the highest N concentration and N accumulation levels of 2.1% N and 156 kg N ha^{-1}, respectively, at Site-A and 2.1% N and 173 kg N ha^{-1}, respectively at Site-B. Soil incorporation of green manure treatments significantly influenced soil (0-150 mm) mineral N (nitrate and ammonium) levels measured at sweet corn emergence (30 November 1997) and at 5½ weeks post emergence. At sweet corn emergence the lupin, mustard/lupin mix, mustard, control and ryegrass treatments resulted in soil mineral N values of 68, 66, 57, 51 and 29 $kg.N.ha^{-1}$, respectively, at Site-A and 118, 118, 91, 81 and 54 $kg.N.ha^{-1}$, respectively, at Site B. At both sites, the lupin and mustard/lupin mix treatments resulted in soil mineral N levels significantly higher than the control treatment. In contrast, the ryegrass treatment resulted in soil mineral N levels significantly lower than the control treatment. These treatment effects were related to green manure crop N concentrations just prior to soil incorporation. On average over both sites, the lupin and mustard/lupin mix treatments, which had high DM yields (7900 kg and 6500 $kg.DM.ha^{-1}$ respectively), had the highest N concentrations (2.0% and 2.1% N respectively). The ryegrass treatment, which also accumulated a high average DM yield (6200 $kg.DM.ha^{-1}$), contained the lowest average N concentration of only 1.1 % N.

Sweet corn N accumulation at harvest was also significantly influenced by green manure treatments. At both sites, ryegrass significantly reduced sweet corn N accumulation compared with all other treatments, being 44% and 36% lower than control treatment value of 117 kg.N.ha^{-1}. At Site-A, the lupin, mustard/lupin and mustard treatment effects on sweet corn N accumulation were not different from that of the control treatment at final harvest. However, at Site-B the lupin and mustard/lupin mix treatments did produce sweet corn N accumulation levels significantly higher than the control treatment; being 21% and 18% higher than the control value of 102 kg.N.ha^{-1}, respectively.

Compared to the control treatment sweet corn yield (17.3 t ha^{-1} averaged over both sites), none of the four green manure treatments improved sweet corn yield even though the lupin and mustard/lupin mix treatments both increased soil N availability and sweet corn N accumulation. Soil moisture limitations probably restricted yield potentials. However, the ryegrass treatment detrimentally affected sweet corn yields at both sites. When compared to the control treatment reductions of 64% and 48% at Site-A and Site-B, respectively, were measured.

Soil mineral N (0-150 mm) tested early in the sweet corn growing season gave a better relationship with sweet corn N accumulation and yield compared with the incubation tests used. Short-term soil incubation tests, conducted under aerobic and anaerobic conditions, were not useful as indicators of net N mineralisation as they did not relate well to actual soil N mineralisation or crop response.

Although both the lupin and the mustard/lupin mix treatments had similar effects on soil N availability and sweet corn N accumulation, of the two the lupin treatment achieved a higher level of estimated N fixation. On average the estimated N fixation in the lupin treatment (98 kg N ha^{-1} averaged over both sites) was higher than N losses in harvested sweet corn ears (77 kg N ha^{-1} averaged over both sites). This positive N balance would help compensate for other possible N losses from the soil-plant system (ie. ammonia volatilisation or nitrate leaching).

Overall, the lupin green manure treatment appears be the best crop in terms of improving short-term N availability for the subsequent sweet corn crop and for maintaining an N balance in the soil–plant system. But ultimately, the benefit of lupin as a green manure crop will also depend on environmental conditions and management practices.

Acknowledgments

I would like to express my gratitude to the following people and organisations for their support and contribution to this thesis:

My supervisor, Associate Professor Paul Gregg, for giving me excellent guidance and support.

Mr Lance Currie, Associate Professor Mike Hedley and Professor Russ Tillman for providing me with this opportunity to study and improve my qualifications.

The Foundation for Research, Science and Technology, Massey University and Heinz-Wattie Australasia for providing funding for this project.

The staff of Heinz-Wattie Australasia, in both Gisborne and Fielding, for providing assistance and information.

Gayne and Eve Ellmers, and Mike and Bridget Parker for providing sites for the field trials and for their kind hospitality and helpful advice.

The staff and postgraduate students of the Soil and Earth Science Group for their encouragement and assistance. Include; Mike Bretherton, Tin Maung Aye, Bob Toes for help with field-work and providing company on the long drives to Gisborne; Mike Bretherton for providing climate information; Ian Furkert, Ross Wallace, Glenys Wallace, Anne West, Andrew Mitchell and Saman Bowatte for their helpful advice and assistance with laboratory work; and Dr. Loga Loganathan for proof-reading this thesis and providing useful comments.

My family and friends for their encouragement and support. My parents, Brain Hanly and Anita Mulay, and my parents-in-law, Martin and Pita Wouters, for their immense support; Mariska Wouters (my sister-in-law) and Scott Cameron for proof-reading this thesis; John Koolaard for providing helpful statistical advice; and Marty Wouters (my brother-in-law) for assisting me with the final harvest at very short notice.

I especially want to thank my wife Jolanda for helping me with field-work and for being a tremendous support; and my children, Nicholas and Jasmine, for being patient and understanding, particularly during the final stages this thesis.

Ultimately, I thank our Creator for bringing into existence the astonishingly wondrous and beautiful world and universe we live in. In every realm I observe compelling evidence of design, purpose, beauty, complexity and order, which not only make scientific inquiry possible but also fascinating and meaningful. I also thank Him for bestowing on our culture, through His Son, the values of integrity, unity and grace, which are the prerequisites for effective and meaningful scientific research.

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Chapter 1 ~ Introduction

1.1 Background

In the Gisborne Region of New Zealand (NZ), organic* sweet corn is grown under BIO-GRO NZ (BGNZ) certification for processing and marketing by Heinz-Wattie Ltd. Growers of BGNZ certified sweet corn are required to manage their farming systems using practices that maintain or improve soil quality and productivity over time. In organic cropping systems soil fertility is considered a key to successful production.

In crop production, when supplies of soil water are adequate, nitrogen (N) is most commonly the key yield-limiting factor (Meisinger, 1984). Sweet corn particularly needs a good supply of plant available N to meet plant growth and yield requirements (Anderson *et al.*, 1985; Nel *et al.*, 1996), as it partitions more N to the grain than any other nutrient derived from the soil (Steele *et al.*, 1982; Marschner, 1986). Consequently, successful 'organic' sweet corn production requires careful management of organic N sources.

Organic sweet corn is grown in Gisborne in both mixed and continuous cropping systems. In both these types of systems annual winter green manures are commonly used as a low cost method of maintaining or improving soil organic matter (SOM) and soil N fertility. Green manuring is an old and established arable-farming practice in which undecomposed green plant material is incorporated into the soil in order to increase its immediate productivity (Meelu *et al.*, 1994). Legumes are the plant species most commonly used as green manures because of their ability to bring N into the soil plant system via symbiotic fixation of atmospheric N (N_2) (Ebelhar *et al.* 1984; Doran and Smith, 1991). This is an important process as N is continually lost from the soil system via leaching, volatilisation and losses in product (Keeney and Gregg, 1982).

Keeney and Gregg (1982) affirmed that the development of sound farm management programs requires an understanding of the reactions of N in the soil, of sources of nitrogen for plant growth other than fertiliser, and of pathways of loss of N from the system. The amount of N actually contributed by green manure crops to following crops varies considerably, and is dependent on environmental conditions, carbon to

*(In general, the term 'organic' as it is used in the context of this study means producing food without the use of manufactured fertiliser, herbicides, fungicides or pesticides. A more ideological definition for 'organic' production is given in Section 2.1.)

nitrogen (C:N) ratios of the crop residues, soil available N concentration and soil microbial activity. Therefore, it is important to assess how much N the green manure crop provides and whether the time course of release of inorganic N from the decomposing residues coincides with subsequent crop N demand (Shennan, 1992).

1.2 Objective

The objective of this study was to determine how effective green manure crops, currently grown by organic producers in the Gisborne Region, are at improving soil N fertility and yield of a subsequent sweet corn crop. To achieve this objective a review of relevant research literature was carried out and field trials, evaluating a range of green manure crops, were conducted at two sites in the Gisborne Region.

Chapter 2 ~ Literature Review

2.1 Sustaining organic crop production ~ *an introduction*

Organic sweet corn grown in the Gisborne Region of NZ for processing by Heinz-Wattie Ltd is certified by BGNZ. BGNZ is the trading name of the NZ Biological Producers & Consumers Council Inc who have developed a set of production standards for organic agriculture and certify organic production for domestic and export markets. Their inspection and certification systems have been evaluated and accredited by International Federation of Organic Agriculture Movements (IFOAM) to ensure that their standards comply with the IFOAM International Standards (http://www.biogro.co.nz).

As defined by IFOAM, organic agriculture includes all agricultural systems that promote the environmentally, socially and economically sound production of food and fibres. These systems take soil fertility as a key to successful production. By respecting the natural capacity of plants, animals and the landscape, it aims to optimise quality in all aspects of agriculture and the environment. Organic agriculture dramatically reduces external inputs by refraining from the use of chemo-synthetic fertilisers, pesticides and pharmaceuticals (http://www.ifoam.org). Growers of organically certified products are required to show that the practices they are using are sustainable. In general, this means that practices used by growers should not lead to a decline in soil quality or productivity over time.

Careful management of SOM is critical to the sustainablity of organic cropping systems. SOM influences many physical, chemical and biological properties related to soil quality. As well as maintaining SOM over the long-term, these systems also need to ensure that nutrient availability is sufficient to meet cash crop requirements in the short-term. Organic cropping systems rely heavily on nutrient cycling from SOM and organic amendments for crop nutrition, particularly nitrogen (N) nutrition.

Mixed cropping (pasture/arable) systems are commonly practised in many parts of NZ. In these systems, grazed ryegrass/white clover pastures are generally grown for 2-5 years, followed by 2-5 years of arable crops. The major source of improved N fertility

in these systems is via symbiotic N_2 fixation by clover during the pasture phase of the rotation (Francis *et al.*, 1994). In some cases, however, growers operate continuous cropping organic systems producing a cash crop each year without spells into pasture. Maintaining or improving SOM and soil N fertility in these systems is more challenging than in mixed cropping systems (Magdoff, 1993). Correctly designed and implemented crop rotations are at the core of sustainable organic crop production in continuous cropping systems. These rotations contain the following key elements:

- Provide sufficient crop nutrients and minimise their losses.
- Provide nitrogen through leguminous crops.
- Aim to control weeds, pests and diseases.
- Maintain the soil structure and organic matter content.
- Provide a profitable output of organic cash crops and / or livestock.

In the Gisborne Region, annual winter green manures are commonly grown in crop rotation with organic sweet corn. Assessment of green manure crops, in terms of their effectiveness at improving soil N availability for the subsequent sweet corn crop, requires an understanding of:

i. Managing soil N fertility with green manure crops;
ii. Methods of assessing plant available soil N;
iii. N requirements of sweet corn.

This chapter reviews and discusses the scientific literature related to these three topics.

2.2 Managing soil nitrogen fertility with green manure crops

2.2.1 What are green manures?

Green manuring is an arable-farming practice in which undecomposed green plant material is incorporated into the soil in order to increase its immediate productivity. Legumes *(leguminosae)* are plant species most commonly used as green manures. Use of legumes in crop rotations, to improve soil fertility and to increase crop production, is one of the oldest agricultural practices recorded. The Greek and Chinese civilisations documented 2,500 years ago that legumes improved yields of subsequent crops (Pieters, 1927; as cited by Martin and Touchton, 1983). While green manure crops, especially lupin (*Lupinus* ssp.), were common in southern Europe before the birth of Christ, crop rotations were unknown in northern Europe until the 16th century (Pearson, 1967). Lord Townsend, of Norfolk County (UK), introduced the "Norfolk" rotation to England in the 1730s (Pearson, 1967). The Norfolk rotation was a four-year rotation of wheat, turnip, barley and red clover. This rotation was responsible for raising average wheat yields in England from 540 kg to 1350 kg ha^{-1} by the early 19th century (Reeves, 1994).

Doran and Smith (1991) list the multitude of benefits green manure crops provide in crop rotations:

- Provide cover and protect the soil from wind and water erosion.
- Serve as sinks for plant nutrients that might otherwise be lost via leaching or volatilisation.
- Provide weed control through competition and allopathy.
- Assist in control of disease and insects by increasing crop diversity.
- Act as a source of supplemental N (legumes) and slow release nutrients.

The value of legumes as green manures comes primarily from their ability to bring N into the soil-plant system via symbiotic fixation of atmospheric N (N_2) (Ebelhar *et al.* 1984). This is an important process as N is continually being lost from the soil system via leaching, volatilisation and losses in product. When the legume residues decompose in the soil the N they contain are mineralised for use by the subsequent crop (Matin and Touchton, 1983).

During the first half of the 20th century green manure crops were used extensively. This was evident in the U.S.A. where an estimated 5 million hectares of legumes were planted as green manures in 1940. (Rogers and Giddens, 1957; as cited by Martin and Touchton, 1983). However, since the 1940s, when inexpensive N fertiliser became widely available, there has been less need for N-fixing crops in rotations, particularly in the wealthier economies. Consequently, interest and research in the use of legumes as green manures declined. However, since the late 1970s there has been renewed interest in green manure crops (Blevins *et al.*, 1990). Smith *et al.* (1987) state that this renewed interest is mainly due to:

- Increases in the prices of N fertiliser, experienced in the 1970s and early 1980s, due to large increments in the cost of fossil fuels and the perception that over the long-term these commodities are likely to become more expensive or more limited in supply.
- Greater concern about soil erosion and more general concerns about the effects of agricultural practices on environmental quality (ie. nitrate leaching).
- An upsurgeance in organic crop production due to general concern over food safety and quality, which has seen markets for organically produced foods grow rapidly worldwide in recent years.

This review will focus on the effectiveness of legume green manures as a source of N for subsequent summer crops. The capacity of green manure residues to serve as an effective source of nutrients for subsequent crops depends largely on the legume characteristics, soil properties, tillage management and climate.

2.2.2 Legume characteristics

Two important characteristics of legume plants, relating to their effectiveness as a source of N for subsequent crops, are their N content and C:N ratio at the time they are incorporated into the soil as green manures. Reeves (1994) cites a list of references giving the N contents of a number of winter grown legumes. Reported N values ranged from 36 kg to 226 kg N ha^{-1} with the average N content of above–ground residues being 120 kg N ha^{-1}. Research in Canterbury (NZ) by Burtt and Hill (1981) measured the equivalent of 330 kg N ha^{-1} in a standing lupin (*L. angunstifolius*) crop. Later work by McKenzie and Hill (1984) found 150 kg N ha^{-1} in a less productive crop of lupin. Some researchers have reported N contents of legumes to be as high as 350 kg N ha^{-1}

(Holderbaum *et al.*, 1990). These studies have shown that legume crops vary greatly in their N contents, but in some cases can accumulate large quantities of N.

Rapid legume residue decomposition is important in organic cropping systems because of their reliance on the release of N from these residues to supply N to the subsequent crop. C:N ratio is a plant characteristic which influences the rate of N mineralisation from residues after incorporation into the soil. The C:N ratio of residues is really just another way of looking at the percentage of nitrogen (Figure 2.1). A high C:N residue has a low percentage of N. A low C:N residue has a relative high percentage of N.

Crop residues are usually close to 40% carbon and this figure does not change much from plant to plant (Magdoff, 1993). On the other hand, nitrogen content varies greatly depending on type of plant and stage of growth. It is generally believed that net N mineralisation of plant residues occurs when the N content of residues is above 2.0%-2.5% N (C:N ratio < 20:1) (Haynes *et al.*, 1993; Reeves,1994). Crop residues with N contents less than approximately 1% N (C:N ratio > 40:1) will result in short term reduction in nitrogen availability (immobilisation). Residues with N contents between 1% and 2% N will not have much effect on N immobilisation or mineralisation (Magdoff, 1993). The magnitude to which crop residues influence total soil net N mineralisation or immobilisation will depend on the quantity of residues added to the soil.

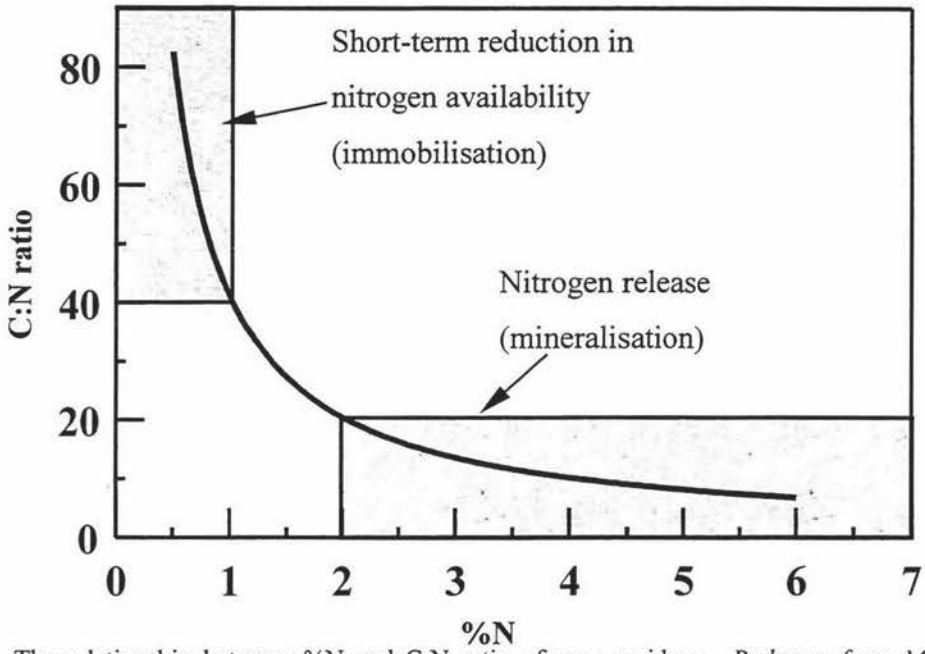


Figure 2.1. The relationship between %N and C:N ratio of crop residues. *Redrawn from Magdoff (1993), original source Vigil and Kissel (1991).*

For comparison, the C:N ratio of SOM is usually in the range of about 10-13:1 and C:N of soil microorganisms is around 5-7:1(Magdoff, 1993). Microorganisms using materials containing 1% or less N, need extra N for their growth and reproduction. They will take the needed N from the surrounding soil, diminishing the amount of nitrate and ammonium available for crop use. When microorganisms and plants compete for scarce nutrients, microorganisms have the advantage because they are well distributed in the soil. Plant roots are in contact with only 1-2% of the entire soil volume while microorganisms populate almost the entire soil (Magdoff, 1993).

There are large variations in values reported for N content and C:N ratios of green manure crop residues. This variability relates to differences in crop uptake of soil N, total dry matter (DM) yields and N fixation. Timing of green manure crop termination also affects its C:N ratio by its influence on N partitioning within the plant. For example, a legume crop which is not incorporated into the soil until after pod fill will have most of its N translocated into the seed, as much as 90% of total plant N (Burtt and Hill, 1981), resulting in a high C:N ratio throughout the majority of the plant. Climate and management factors also influence the N content of winter legume crops (Reeves, 1994). Practices that promote early establishment of a green manure crops results in greater DM yield and consequent N production.

To understand N cycling in these systems, it is important to know not just total N accumulation, but also the quantity of N provided from fixation. This is particularly important for organic cropping systems where N fixation may represent the main N input into the soil-plant system to counteract N losses via leaching, volatilisation and product removal.

Legumes vary widely in their ability to fix atmospheric N_2 due to both species differences and variations in field conditions under which they are grown (ie. soil factors, time of crop termination and climate). There are no direct measurements of the fraction of green manure N that is derived from atmospheric N_2 fixation versus that derived from soil N. The main methods for estimating N fixation by legumes are:

- Legume crop total N accumulation.
- Comparing total N accumulated by a legume crop with N accumulated by either a non-legume, non-nodulating legume or an uninoculated legume on the same soil.
- N^{15} isotopic dilution.
- Acetylene reduction.

A detailed review of methods of estimating N fixation by crops is given in LaRue and Patterson (1981) who state that much of the work reported in the literature on estimating fixation cannot be extrapolated to field conditions. A very common practice, especially when isotopic N is used, is to grow legumes in small pots, often in a green house. The published results of fixation as a percentage of total plant N may, however, serve in estimating a realistic figure for fixation in farm crops. LaRue and Patterson (1981) assert that there is no strong evidence that any legume crop satisfies its entire N requirements by fixation. The highest estimates (~ 80%) are typical of legumes growing in low-fertility soil or soil artificially made N-deficient by C amendment.

Estimates for legume N_2 fixation cited by LaRue and Patterson (1981) ranged from 10-220 kg N ha^{-1}. Burns and Hardy (1975) averaged many published estimates to arrive at an average figure of 140 kg N fixed per year per hectare for arable land under legumes. White (1989), a New Zealand researcher, lists estimates of N fixed by a range of legume species. The values ranged from as low as 10 kg N ha^{-1} for chickpeas to as high

as 250 kg N ha^{-1} for lupins and faba beans. The range within the one species was also wide. However, clear trends were apparent with lupins (60-250 kg N ha^{-1}) and faba beans (80-250 kg N ha^{-1}) fixing the highest amounts of N, followed by peas (60-200 kg N ha^{-1}), lentils (10-190 kg N ha^{-1}), chickpeas (10-120 kg N ha^{-1}), and soya beans (75-90 kg N ha^{-1}). Some of these estimates were derived by assuming that N fixation was equal to 50% of total N accumulated. Therefore, these values should be interpreted with caution. While the estimates for total N fixed by legumes tend to be wide, being influenced by the level of dry matter production, the percentage (%) of N derived from fixation generally is not as variable. Smith *et al.* (1987) cite estimates of legume N fixation by various researchers. In cases where legume growth was good, the amount of N that was apparently derived from fixation ranged from 67% to 84% of the total N accumulated by the legumes.

These studies indicate that legume crops vary greatly in their ability to fix N. This observation highlights the importance of careful selection and management of legumes for use as green manures. White (1989) states that, in general, legumes will tend to use soil mineral N or fertiliser N if it is available in preference to fixing their own. Consequently, fixation of N is likely to be greatest when legumes follow soil N depleting crops such as cereals. The time of termination of legume crops also influences the level of N fixation. The rate of N fixation is slow during early vegetative growth, when soil mineral N sources may be sufficient for crop requirements, but increases later parallel with the crop growth rate. Maximum rates are reached during flowering and early pod fill. A rapid decline in N fixation coincides with decreased crop growth rate, decreased green leaf area, lodging, and the initiation of translocation of N from vegetative organs to seed (White, 1989). Hardy *et al.* (1973) reported that early flowering soybean (*Glycine max*) cultivars fixed less total N than later maturity groups. Therefore, the price for early maturation may be a relatively reduced potential to fix N_2. The season in which a crop grows also affects the amount of N fixed. Autumn or winter sown legumes generally fix more N than spring-sown crops because they are growing for longer, and often in moister soil conditions which are better suited to optimum N fixation (White, 1989).

As well as bringing N into the soil-plant system via fixation, legumes also reduce N loss via nitrate-N (NO_3^--N) leaching by depleting both soil NO_3^--N and soil water (Hoyt

and Mikkelsen, 1991). This occurs most actively in late winter and spring when the potential for leaching is the greatest in most climates (Smith *et al.*, 1987). Meisinger *et al.* (1991) reviewed eleven studies on the effectiveness of cover crops to reduce N leaching. The percentage reduction of mass N leached averaged 25% for legumes (6-45% range). On average legumes were less than 50% as effective as either grasses or brassica at reducing N leaching losses. These studies support the hypothesis that legume crops reduce winter N leaching losses compared to bare fallow soil. However, in general, legume crops may not be as effective as some other crop species that derive their entire N requirements from soil mineral N.

2.2.3 Soil properties and tillage management

Productivity of an individual legume species can vary greatly due to differences in soil properties alone. Soil properties also affect the rate at which legume residues decompose and mineralise. The soil factors that typically have the largest influence on residue decomposition and mineralisation are soil moisture and soil temperature because they greatly influence the biological processes involved. Other important soil properties include clay content, pH, aeration and nutrient status. Smith *et al.* (1987) discuss in detail the influence soil properties have on the effectiveness of legumes as green manures.

One way growers can influence the decomposition of green manure residues is by choice of tillage method. Smith *et al.* (1987) found substantial evidence from earlier studies that decomposition and mineralisation of N is slower from plant residues left on the soil surface compared with soil incorporated residues. This effect is commonly attributed to lower moisture and nutrient availability for residues left on the soil surface. Varco (1986) observed that with conventional tillage the half-life for hairy vetch residue degradation was less than 15 days compared with 45-75 days from no-tillage. Other studies (Wilson and Hargrove, 1986; Varco *et al.*, 1989; Utomo *et al.*, 1990) have provided further evidence to support the hypothesis that conventional tillage (soil incorporation of residues) increases the rate of N released from legume residues compared with no-tillage (surface residues). In general, soil incorporated residues may decompose 3-5 times faster than for residues left on the soil surface. However, this relative difference will be climate and soil dependent.

2.2.4 Climate

It should be possible to grow annual legumes throughout much of the temperate and subtropical regions of the world. Yet the locations where reasonable production can be expected and where they are likely to be beneficial, as green manures, are considerably more restricted (Smith *et al.,* 1987). Doran and Smith (1991) observed that considerably greater quantities of N are accumulated in winter legumes in the humid temperate environments of east and south-east USA than in legumes grown in the subhumid western Corn Belt and eastern Great Plains of the USA. Winter legume crops commonly accumulate from 65 kg to 170 kg N ha^{-1} in east and southeast as compared with 35 kg to 45 kg N ha^{-1} in the drier, cooler climates of Iowa and Nebraska. New Zealand has a humid temperate climate, which supports good legume growth and rapid decomposition of plant residues over a large area.

2.2.5 Green manure N contribution to subsequent crop

As discussed previously, the N contribution from winter legumes is their most commonly observed benefit. Direct measurements of N actually transferred from the green manure crop to the summer crop are not easily made and there is only limited data available (Smith *et al.*, 1987). Many studies provide an indirect measurement of the N contribution by comparing yield response of the following crop to fertiliser-N with and without green manures. The "fertiliser-N equivalence" of a legume green manure is often calculated as the quantity of fertiliser-N that must be applied to the winter bare-soil or grass cover treatments to attain a summer crop yield equal to the yield of a crop that has received a green manure treatment. Smith *et al.* (1987) lists twelve studies that calculated values in this way. These values ranged from approximately 40 kg to 200 kg N ha^{-1}, but more typically were between 75 kg and 100 kg N ha^{-1}. Estimating the N contribution in this way is reasonable in a management context, in that the value of the cover crop is assessed in terms of crop yield and fertiliser rate, both easily priced commodities.

However, in a research context, this approach is misleading for it cannot be assumed that the fertiliser-N equivalence value accurately estimates the quantity of N transferred from a legume green manure to a summer crop (Smith *et al.*, 1987). This approach also implies that all of the yield response is due to N contribution, while in reality it is clear that the green manure may have beneficial or detrimental effects even when N is non-

limiting; these include: changes in rooting, soil structure, soil water, soil temperature, and weed control. Smith *et al* (1987) suggest that N accumulation difference rather than yield would be a better indicator of the N contribution made by the green manure.

Reeves (1994) stated that there are only a few studies with N^{15} isotope have been used to determine the contribution of legume crop residues to following crops. In pot and field studies, recovery of N labelled legume residue has ranged from 5-32% (Ladd *et al.*, 1983, Azam *et al.*, 1985, Westcott and Mikkelsen, 1987, Varco *et al.*, 1989). While this may only represent a small proportion of the N added to the soil in legume residues, the effect of this on N availability for the subsequent crop may be greater. The addition of legume residue with a low C:N ratio (high N concentration) to the soil can increase the rate of N mineralisation from resident SOM. This effect is known as priming.

2.2.6 Summary

Winter legume green manures are an effective source of N for subsequent crops. In the best recorded cases, green manures can be as effective as 200 kg fertiliser-N ha^{-1} at improving yield of the following summer crop. However, effectiveness of green manures are highly variable because legume N fixation and accumulation, and rates of N mineralisation from residues are greatly influenced by field conditions. Consequently, the values recorded for these characteristics have wide ranges associated with them. However, general guidelines can be developed for optimising the effectiveness of green manure crops. These include:

- A warm, humid climate that supports good annual legume crop growth from autumn to early spring and rapid decomposition and mineralisation of legume residues in spring.
- Fertile productive soils.
- Effective and inexpensive legume species capable of fixing and accumulating high levels of N, such as blue lupin.
- Termination of legume crop after flowering but before pod fill to maximise N fixation and accumulation and minimise C:N ratio in the vegetative tissues.
- Soil incorporation can increase the rate of crop residue decomposition by up to 3-5 times compared with surface applied residues.

Management can improve the success of green manures through its influence on the factors mentioned. However, the climate will ultimately be highly influential by its effect on legume growth, residue decomposition and N leaching losses during spring.

2.3 Methods of assessing plant available soil nitrogen

2.3.1 Background

N is a major essential nutrient and is required by plants in substantial quantities. When supplies of soil water are adequate, N is most commonly the key limiting factor for crop production (Meisinger, 1984). In agricultural land, surface soils commonly contain between 0.08% and 0.4% total N, almost entirely in the organic form (Bremner, 1965b). Greater than 90% of total soil N is contained in SOM, which can be equivalent to anywhere from 2,000 kg to 12,000 kg N ha^{-1}. N in SOM exists in highly complexed, poorly defined compounds, which slowly become available to plants through microbial decomposition. Soil N in the clay-fixed fraction, which is not normally available to plants, can represent from 100 kg to 500 kg N ha^{-1}. The amount of soil mineral N, which is the fraction that is immediately available to plants, is seldom greater than about 100 kg N ha^{-1} (Keeney and Gregg, 1982).

Prior to the widespread use of fertiliser N, agricultural production of cereal crops and pasture grasses relied on mineralisation of N from legume residues, animal manures, and SOM. As discussed in Section 2.2.2, during the period 1940 to 1963 numerous biological and chemical methods attempting to provide a simple and reliable indicator of N availability were proposed. With the advent of inexpensive N fertiliser, interest in the practical use of N availability indices declined. However, economic and environmental concerns have lead to renewed interest in methods of accurately assessing soil N availability for crops.

For farmers who receive premium prices for growing crops 'organically', without the use of fertiliser N, their ability to accurately assess and maximise soil N availability is a critical component of their management system. Keeney and Gregg (1982) affirmed that the development of sound farm management programme requires an understanding of the reactions of N in the soil, of sources of nitrogen for plant growth other than fertiliser, and of pathways of loss of N from the system.

Goh and Haynes (1986) outlined the main factors determining the soil's capacity to supply N for crop use as:

- the amount of residual inorganic N present in the potentially active root zone in the season before crop growth commences;
- the amount of potentially mineralisable N present in the soil;
- the proportion of potentially mineralisable pool of soil N that is mineralised during the growing season;
- and the amount of residual and mineralised N that is subsequently immobilised or lost from the plant-soil system by leaching or volatilisation.

Dahnke and Johnson (1990) outlined the problems associated with developing a test for available N. Firstly, the rate at which microorganisms decompose SOM is dependent on temperature, moisture, aeration, type of SOM, pH and other factors. Secondly, the mineral forms of N produced are subject to leaching, fixation, denitrification and other losses. Thus, it is difficult to predict either when N will become available or how much will become available over a growing season.

2.3.2 Methods of assessing the plant availability

Most methods of assessing the plant availability of soil N involve measuring either residual mineral N or the potential mineralisation of N from SOM. This review summarises and discusses those methods that have gained the widest acceptance and shown the greatest promise for application in the field for assessing plant available N.

Residual Mineral N

Comprehensive reviews on mineral N tests can be found in Bremner (1965a) or Keeney and Nelson (1982). There are no widely accepted methods of testing soils for mineral N other than measuring for residual NO_3^--N and ammonium-N (NH_4^+-N), which together make up the largest pool of mineral N in most soils.

McCracken *et al.* (1989) investigated various soil N tests to determine which would provide the best index of plant available N in maize (*Zea mays* L.) cropping systems. From this study it was observed that potassium chloride (KCl) extractable NO_3^-N, measured in soil collected 2 weeks after planting, had the highest correlation with maize yield, and therefore, was the best N availability index. However, inclusion of

KCl extractable NH_4^+-N resulted in negligible improvement in the correlation over KCl extractable NO_3^--N alone. Neither KCl extractable NH_4^+-N nor NO_3^--N were influenced significantly by tillage, though both were influenced by past N rate and past cover crop use.

Steele *et al.* (1982) conducted a number of experimental trials in NZ, located in the Bay of Plenty, Hawkes Bay, Hauraki Plains, Manawatu, Waikato, Poverty Bay (Gisborne) and South Auckland, investigating the determination of available soil N and the prediction of maize grain yield increase to applied fertiliser-N. Prior to planting, twenty soil (0-60 cm) cores were collected at random from each experimental area. Field moist soil samples were passed though a 4 mm sieve fresh, sub-sampled, and NH_4^+ and NO_3^- extracted using 2*M* KCl (60 minute extraction; 1:10 soil:solution ratio). The concentrations of NH_4^+-N and NO_3^--N were determined using an autoanalyser. The soil samples were then dried for 18 hours at 33°C, in a forced air oven, ground to pass through a 2 mm sieve and NH_4^+-N and NO_3^--N were re-determined.

Steele *et al.* (1982) observed that the amount of mineral N (0-60 cm) in field moist soils before planting varied from 25 kg to 145 kg ha^{-1} with a mean of 79 kg ha^{-1}. On sites following cultivation of pasture much of the mineral N was present in the upper 15 cm, but under continuous cropping regimes at least 70 % was below 30 cm. The mean mineral N in field moist soils from the Poverty Bay was 60 kg ha^{-1}. NO_3^--N was the dominant form of mineral N present in the majority of soils examined, on average comprising 74% of total mineral N in the Poverty Bay soils. The relationship between the mineral N present in moist soil and yield of control maize without fertiliser N was poor and showed little promise for predictive work. For all the areas sampled, the mean amount of mineral N (0-60 cm) in dry soil (33°C) was 103 kg ha^{-1} (range 34-199 kg). A relationship was found between the mineral N present in dried soil and the grain yield of the control maize crops. Another New Zealand researcher, Francis *et al.* (1994) observed that maize grain yield, grain N yield and total N yield were significantly related to the mineral N content of soils sampled following the early spring period, when leaching losses of mineral N were less likely.

Testing soils for NO_3-N to determine their N status has mainly been limited to subhumid regions (Roberts *et al.*, 1980) as climate is less variable. However, Heckman *et al.* (1995) recognised that the pre-sidedress soil nitrate test (PSNT) was gaining widespread acceptance in humid regions for use on field corn. The PSNT is an in-season soil test that measures the concentration of NO_3-N in the surface 30 cm of soil when corn plants are 20-30 cm tall (Magdoff, 1991).

Heckman *et al.* (1995) in a study examined the relationship between relative yield of sweet corn and soil mineral N just prior to sidedressing in sweet corn fields from a diversity of soils, climates, and management histories in New Jersey, USA. In this study, PSNT samples were taken by collecting eight cores (2 cm diameter x 30 cm deep) between rows of each control plot when plants were 30 cm tall at the whorl. The soil cores were composited by plot and spread in a thin layer (1cm thick) to air-dry at room temperature for 48 hours immediately after collection. Relative sweet corn yields (yields without sidedress N expressed as a percentage of the maximum yield with sidedress N) were calculated for fresh weight of 'marketable' ears (marketable ear lengths $\geq$ 17 cm). Heckman *et al.* (1995) concluded that the widespread use of the PSNT on field corn can be extended to use with sweet corn and stated that the PSNT would be most useful on manured soils or other soils with a potential to mineralise significant amounts of N.

2.3.3 Mineralisable N

While the amount of N mineralised from SOM during a growing season will seldom meet the total N needs of cereal crops, in some soils this source can provide a considerable portion of a crop's N requirement. A review of the various laboratory methods for measuring mineralisable N is found in Keeney and Bremner (1966). The main class of soil N mineralisation tests are biological incubation methods.

Laboratory incubation methods have been studied most intensively and are the most widely used. They are based on the incubation of soils under controlled laboratory conditions for a short-term (1 to 6 weeks) or long-term (30 weeks) period. Short-term incubation methods involve incubating soils in the laboratory under constant temperatures (25°, 30°, or 40°C) either aerobically for a period of two to six weeks or anaerobically for one to two weeks. Under anaerobic conditions only ammonium is

released and this is measured, while under aerobic incubation both ammonium and nitrate N are measured (Goh, 1983). Biological incubation methods provide a valid relative measure of soil N mineralisation potential but can be impractical for routine use because of the time required for incubation (Keeney, 1982).

Thicke *et al.* (1993) tested the hypotheses that maize grain yield and whole plant N accumulation could be predicted from N mineralisation tests of soil samples containing representative amounts of incorporated residues from the previous crop. Over all locations (Minnesota, USA), topsoil mineral N and one week of aerobic incubation explained between 65% and 81% of the variability in grain yield and total N accumulation of non-fertilised corn. For fertilised corn, N application rate alone accounted for the majority of variability in grain yield and total N uptake. In contrast, McCracken *et al.* (1989) observed in a maize study that the results of the anaerobic incubation method failed to correlate significantly with any crop parameter. It was observed that this indicator was significantly affected by past N-fertiliser and cover-crop treatments, but not in ways mirrored by crop response.

Soil Sample Collection and Preparation

The results of incubation tests are extremely sensitive to incubation conditions and methods of sampling, drying, grinding, sieving and storage of soil samples (Bremner, 1965a). Thus a satisfactory method can only be found if the conditions of sample collection, preparation and incubation are rigidly standardised and controlled. Critical factors which influence the success of a soil testing programme are: the time of sampling, the depth of sampling, the number of samples collected; and the way in which the samples are treated before testing.

Ward (1971) recommended sampling as close to planting time as possible. In more humid areas, the best sampling time may be after the crop has started to grow (Magdoff *et al.* 1984). Binford *et al.* (1992) sampled in late spring when maize plants were 15 cm to 30 cm high. This sampling time was chosen because it was late enough to minimise the influence of spring weather conditions and early enough so that fertiliser-N could still be added if required.

The desired sampling depth is the crop root zone, however, for some crops like maize this can be up to 1.5 m deep (Herron *et al.*, 1971). In practice, recommendations for sampling depth vary from 0.6-0.8 m (Keeney, 1982). This variability exists due to different crop rooting depths, soil types, soil conditions and previous history. Olson *et al.* (1976) observed that, as an average for all locations sampled in their study, distributions of mineral N were fairly uniform throughout the top 180 cm of the soil profile. In more recent studies (Magdoff *et al.* 1984; Binford *et al.*,1992) have shown good correlations between maize yields and concentrations of NO_3^--N in the surface 30 cm of soil when maize plants are 15 to 30 cm tall. Binford *et al.* (1992) observed in N response trials conducted in Iowa (USA) that the predicability of the soil test was only slightly improved by sampling to 60 cm instead of 30 cm. However, during this three year long study weather conditions were drier than normal, with severe drought occurring in one of the years. In more humid climates, where the chance of N leaching is greater, deeper sampling may be required depending on soil type, which will influence plant rooting depth and water movement (Dahnke and Johnson, 1990).

Peterson and Calvin (1965) defined the best sampling plan as the one that gives the lowest sampling error at a given cost or the lowest cost at a given sampling error. NO_3^--N levels vary as much over a relatively short distance as they do over long distances particularly in the field (Dahnke and Johnson, 1990). The spatial pattern of NO_3^--N can be just as important as the mean value, especially for crops that suffer yield or quality reductions at high N rates. Meisinger (1984) states that it is common to find that over 50% of the variability present within one hectare (ha) is already present in a few square meters. Consequently, it is quite unlikely that a field sample mean NO_3^--N level can be estimated to better than ± 20 % of the actual mean without an extensive sampling program (Meisinger, 1984).

Reuss *et al.* (1977) observed that the number of samples required for a 90% confidence interval of about ± 15 % of the mean, was 82 per field, whereas for ± 26 % of the mean at least 20 samples per field would be required. Swenson *et al.* (1984) indicated it is necessary to take approximately 20 subsamples per field in North Dakota to obtain an accuracy of ± 15 % for NO_3^--N at a precision level of 80%. The number of subsamples needed for that accuracy and precision varied little as field size increased from 10 ha to 40 ha. In practice, in many fields an error of ± 30 % will not affect N fertiliser

recommendations (Reuss et al.,1977). However, for research purposes a narrower confidence limit may be required, although trial design (plot size, number of treatment replicates and sampling depth) will also influence the number of cores needed for a required level of confidence.

Soil samples collected for mineral N analyses should be treated to stop mineralisation soon after they are collected. One of the most practical ways to stop mineralisation in the long term is to air dry each sample by spreading it out in a thin layer. Other methods that have been used are freezing or the addition of a biological inhibitor, such as toluene (Dahnke and Johnson, 1990). Steele *et al.* (1982) conducted a number of experiments in the Poverty Bay region (NZ) investigating the determination of available soil N and the prediction of maize grain yield response to applied fertiliser-N. They collected 20 soil cores (5 cm diameter) to a depth of 60 cm from each experimental area prior to planting in early October. Samples were transported to the laboratory in insulated boxes containing ice blocks and stored overnight at 2°C. Both fresh and dried (18 h in a forced air oven at 33°C) samples were analysed. On average the mineral N content increased by 24 kg ha^{-1} (range –16 kg to +86 kg) during the drying process. Drying soils under forced air for 18 hours at 33°C acted as a short term incubation, the soils which showed the largest increase in mineral N content being those that released the largest amounts of N during short term incubation. While drying soils is a practical way of stopping N mineralisation in the long-term, some mineralisation will occur during the drying process.

Dahnke and Johnson (1990) described how climatic conditions influence which soil test would be most suitable as a N availability test or indicator in a particular area. In cold humid conditions, SOM content is high and mineralisation of organic N can supply a significant portion of the total crop requirement. In these situations, SOM could be expected to provide a suitable N availability indicator. In hot, dry conditions, where cultivated crops tend to be irrigated and high yielding, SOM levels are very low (<1.0%) and mineralisable N provides only a small portion of the total N required for high yielding crops. In these situations, a test of soil NO_3-N is a good direct measure of available N. Between these two extremes there are a range of conditions under which available soil N may be identified by combinations of indirect and direct measures.

2.3.4 Summary

Testing for soil mineral N and/or the use of short-term biological incubation procedures have been shown to be important components in the evaluation of plant available N for agricultural crops. However, the success of either of these methods is influenced greatly by climatic conditions and methods of sample collection and preparation. In some cases, even the best application of existing tests may provide only poor measure of available N. Also, while analysis of soil samples for soil mineral N or mineralisable N may relate well to yield and N uptake by a crop in a given year, variability among years may preclude general use for predictive purposes.

Therefore, when utilising N availability tests for use either to assist with fertiliser recommendations or for research work, it is critical to take a holistic approach to improve the likelihood of success. This primarily involves selecting the appropriate test(s) for the climatic conditions, standardising a soil sampling and preparation programme, and researching the soil types and the crop and fertiliser histories of the areas to be tested. This will optimise the chances of developing successful relationships between soil N tests and crop yield parameters.

2.4 Nitrogen requirements of sweet corn

2.4.1 Background

Sweet corn is created by an endosperm gene mutation of maize. Traditional sweet corn is known as the sugary 1 (*su1*) mutation. In the last 25 years relatively new endosperm gene mutations, particularly shrunken2 (*sh2*) and sugary enhancer1 (*se1*), have been used to develop new commercial sweet corn hybrids with significant improvements in yield, quality, seedling vigour and adaptation to mechanisation (Wolfe *et al.,* 1997). Although maize and sweet corn are the same species (*Zea mays* L.) there are differences between them that need to be considered when comparing research findings for the two crops. Unlike maize, sweet corn is harvested when the kernels are immature so that sweetness and pericarp tenderness are optimum for fresh consumption (Wolfe *et al.*, 1997). Therefore, sweet corn has a shorter growing season than maize. Also, sweet corn yield is measured on a fresh weight basis as 'harvestable' or 'marketable' ear yields, whereas maize yields are measured on a dry kernel weight basis.

Sweet corn and maize partition more nitrogen (N) to their grain than any other nutrient derived from the soil (Steele *et al.*, 1982; Marschner, 1986). Therefore, a good supply of plant available N is needed to meet plant growth and yield requirements (Anderson *et al.*, 1985; Nel *et al.*, 1996). Requirements of sweet corn for fertiliser-N vary greatly from field to field (Heckman *et al.,* 1995). Many existing N fertiliser recommendations in New Zealand are based on grower experience, fertiliser history and the number of years a field has been continuously cropped (Steele *et al.*, 1982). For conventionally grown sweet corn in Gisborne, current agronomic practice involves the use of between 100 kg and 150 kg N ha^{-1} incorporated into the soil in two applications (Hansen, 2000). The first application occurs at sowing with about 75 kg N ha^{-1} drilled with seed. A further 75 kg N ha^{-1} in side-dressed at the V3-V5 stage of growth. However, Hansen (2000) states that there is no experimental evidence which demonstrates that this regime maximises sweet corn yield and the efficiency with which fertiliser N is used under Gisborne conditions. Recommending fertiliser-N without information about the N-supplying capacity of the soil may result in using excess N, which can contribute to NO_3^--N leaching or not supplying enough N for economic yield (Heckman *et al.*, 1995). An understanding of sweet corn N requirements and the need to monitor soil N

availability are also important for organic cropping systems, as this information is critical for the development of effective green manure management practices.

This section of the literature review first aims to review the N requirements of sweet corn and assess at what soil mineral N level sweet corn yield is not likely to respond to fertiliser-N. Secondly, it will determine whether sweet corn cultivars differ in their N requirements. If cultivars with lower N requirements and harvest N losses could be selected this would be an advantage for organic cropping systems.

2.4.2 Sweet corn N requirements

The total quantity of N that has accumulated in a high yielding crop gives an indication of its N requirements. Table 2.1 shows figures for sweet corn above-ground N accumulation from various locations. These figures show that when conditions are suitable for high yields the above-ground N accumulation of sweet corn can range from 130-240 kg N ha^{-1}. N accumulation in roots is often not greater than 5% of total sweet corn plant N accumulation, while the yield components (shank, rachis, kernels and husk) can contain as much as 65% of total plant N (Hansen, 2000). Therefore, a substantial quantity of N is removed when the crop is harvested; as much as 150 kg N ha^{-1} in some cases.

Table 2.1. Above-ground N accumulation in high yielding sweet corn crops.

Location (source)	**Cultivar**	**Trial yield*** (t/ha)	**Aboveground N accumulation** (kg N/ha)
Florida, USA. (Sanchez *et al*, 1989)	*Florida Staysweet*	17.1	130
Tasmania, Australia. (Salardini *et al*, 1992)	*Jubilee*	23.1	240
Gisborne, NZ. (Hansen, 2000) **Study 1**	*Jubilee*[1]	22.5	165
Gisborne, NZ. (Hansen, 2000) **Study 1**	*SS42*[1]	23.4	125
Gisborne, NZ. (Hansen, 2000) **Study 2**	*Jubilee*[1]	20.4	225
Gisborne, NZ. (Hansen, 2000) **Study 2**	*SS42*[1]	22.2	200

**(criteria for 'yield' may differ between locations)*

[1](Planting density 70,000 plant/ha)

The length of a sweet corn growing season is usually in the range of 85-90 days (1200-1300 growing degree-days, GDD) depending on the cultivar grown. To ensure that

there is sufficient mineral N in the soil to meet crop demand it is useful to know when the crop has its greatest N requirement. Hansen (2000) observed that less than 10% of the total N accumulation in sweet corn (Jubilee) was taken up in the first-third of the growing season, whereas 60%-75% of the total N accumulation was taken up in the last third of the growing season. In summary, sweet corn N requirements are high and are greatest in the last month of the growing season.

2.4.3 Fertiliser N response studies

As sweet corn has high N requirements it is not surprising that many studies have shown good yield responses from applied fertiliser-N. Moss and Mack (1979) in a study in Oregon, U.S.A., observed that applications of fertiliser-N increased sweet corn marketable yield (husked ears $\geq$ 220 g) to a maximum yield of 17 tonnes (t) ha^{-1} (55% higher than the control yield) with an application rate of 56 kg N ha^{-1}. Smith (1984) reported that yield of sweet corn increased 35% as fertiliser-N rate increased from 0 to 112 kg ha^{-1}. However, neither of these studies gave values for soil mineral N status or sweet corn N accumulation. Without this information total crop requirements and total mineral N available to the crop can not be assessed.

Sanchez *et al.* (1989) summarised the results of studies conducted during five cropping periods to evaluate the response of sweet corn to fertiliser-N rate on organic soils (Histosols) in Florida. Sweet corn (Florida Staysweet cultivar) was planted to give a population of 58,000 plants ha^{-1}. Fertiliser treatments were 0 (control), 20, 40, and 60 kg N ha^{-1} and were applied at the 15-leaf (V15) stage. Sweet corn marketable yields (definition of 'marketable' not provided) were increased significantly by N fertilisation in four out of five experiments. Overall, yields were maximised between the 40 and 60 kg N ha^{-1} rates. The highest marketable yield was 17.1 t ha^{-1}. The yield increase between the control and the highest yielding treatment was on average 10% (range 5-15%) for the four responsive experiments. While this study did not provide any soil mineral N information it is likely that most of the N accumulated in the sweet corn in this study was derived from the soil. This can be assumed because at the highest yield total sweet corn N accumulation was 133 kg N ha^{-1}, which was more than double the fertiliser rate (40-60 kg N^{-1}) and only 18 kg N ha^{-1} higher than the sweet corn N accumulation measured for the control.

The following summaries of fertiliser-N response studies provide soil mineral N information and therefore are more useful for predicting sweet corn yield responsiveness to applied fertiliser-N. Roberts *et al.* (1980) presented the results of a USA study designed to calibrate soil test NO_3^--N for predicting relative yield (% of maximum yield) and the N-requirement index (NRI) of sweet corn. The study was conducted on a silt loam soil with 1% organic matter following a crop rotation of nonlegumes with a pretreatment level of soil (0-120 cm) NO_3-N of 5 parts per million (ppm). Near maximum (95% of maximum) yield of 25.1 tonnes unhusked sweet corn per hectare was achieved at a fertiliser-N rate of 255 kg N ha^{-1}. The 255 kg N ha^{-1} fertiliser rate was associated with a soil test NO_3-N level of 30 ppm NO_3-N, which was measured in soil samples collected after fertiliser application (exact sampling time and depth were not provided). This indicates that if soil NO_3-N levels are $\geq$30 ppm NO_3-N then N supply is likely to be adequate to achieve near maximum sweet corn yield without further additions of N to the soil-crop system. However, without knowing sampling time or depth this information is of limited value for predictive or comparative purposes.

Salardini *et al.* (1992) describe an experiment, conducted in Tasmania on a fine loamy clay krasnozem soil, in which the responses of sweet corn yield to basal and side-dressed N were assessed. The level of soil mineral N averaged for the surface 40 cm was 15 ppm NO_3^--N and 1.9 ppm NH_4^+-N prior to fertilisation and sowing. Fertiliser N rates used at sowing time were 0 (control), 25, 50, 100, 150 and 200 kg N ha^{-1}. The plots receiving basal applications of 50 and 100 kg N ha^{-1} also received either none, one or two sidedressings of 50 kg N ha^{-1}. The sidedressings were applied at 7 (cob initiation) and 12 (silking) weeks after sowing. The cultivar Jubilee was sown at a density of 60,000 seeds ha^{-1} that was thinned to 35,000 plants ha^{-1} a week after emergence. This was a typical density for production of large cobs in the region. The highest cob yield of 23.1 t ha^{-1} was attained from a basal application of 100 kg N ha^{-1} and two sidedress applications of 50 kg N ha^{-1}. Relative to the highest cob yield the 0, 50 , 100, 150 and 200 kg N ha^{-1} (basal application only) treatments achieved yields of 62%, 72%, 84%, 88% and 88% receptively. Splitting 200 kg N ha^{-1} into three applications produced 14% higher yield than when all the fertiliser-N was applied at sowing. Shoot and cob N accumulation was 240 kg N ha^{-1} for the highest yielding treatment and 125 kg N ha^{-1} for the control. The N supplied from the soil in the control

treatment was estimated to be equivalent to a fertiliser application rate of 150 kg N ha^{-1}. Despite high soil N availability in this study, sweet corn responded significantly to fertiliser-N. Salardini *et al.* (1992) concluded from the N-use efficiency results that Jubilee required an abundant N supply to produce high yields.

Heckman *et al.* (1995) provide experimental evidence that NO_3^--N and (NO_3^- + NH_4^+)-N levels in the surface 30 cm of soil, when sweet corn plants are 30 cm tall, can be used to predict whether a yield response to sidedress fertiliser-N is likely. Non-responsive sites (relative yields $\geq$ 92% without sidedressing) were associated with soil NO_3-N concentrations > 25 mg N kg^{-1} and soil (NO_3^- + NH_4^+)-N >31 N kg^{-1}. Including NH_4-N in the soil analysis did not improve the accuracy of the soil test for predicting whether sidedress N was needed. Other researchers (Magdoff *et al.*, 1984; Blackmer *et al.*, 1989; Fox *et al.*, 1989; Binford *et al.*, 1992; Meisinger *et al.*, 1992; Klausner *et al.*, 1993) working in humid regions with maize found that 20-25 ppm NO_3^--N was sufficient for near-maximum yield.

2.4.4 Cultivar Differences in Fertiliser-N Responsiveness

Hansen (2000) conducted detailed studies on the effects cultivar type, planting density and fertiliser-N rate had on yield, yield components and N partitioning of sweet corn grown in Gisborne, NZ. In the first study, harvestable ear yield was clearly responsive to plant density. However, the sweet corn cultivar SS42 (*sh2* mutant) and, to a lesser extent, Jubilee (*su1* mutant) were unresponsive to fertiliser-N. Hansen (2000) attributed the limited response to N rate to an abundant supply of soil mineral and mineralisable N. In this first study 90 kg of mineral N ha^{-1} (surface 15 cm, 60 ppm N assuming bulk density of 1 g/cm^3) were present in the soil 2 weeks prior to sowing and potentially mineralisable N provided a further 170 kg N ha^{-1}. Despite apparently high levels of soil available N, some Jubilee yield responses from fertiliser-N were recorded. With the 230 kg N ha^{-1} fertiliser treatment, harvestable ear yields of 23.6-24.4 t ha^{-1} (depending on density) were recorded, 4.1 t ha^{-1} greater than the control. In contrast, a yield of SS42 did not increase with any level fertiliser-N (highest rate 230 kg N ha^{-1}).

In a second study, Hansen (2000) observed that the maximum SS42 harvestable ear yield of 22.2 t ha^{-1}, recorded for the 162 kg N ha^{-1} fertiliser-N rate, was significantly higher than the 15.22 t ha^{-1} recorded for the control. However, almost all of the yield

increase was achieved between the 0 and 74 kg N ha^{-1} rates. Thus, although yield was maximised with 162 kg ha^{-1}, a yield of 21.5 t ha^{-1} with 74 kg N ha^{-1} was not significantly different. Maximum Jubilee yield of 20.4 t ha^{-1}, achieved with the 116 kg N ha^{-1} fertiliser-N rate, was 34% higher than the control. However, yield response with N rates between 74 and 172 kg N ha^{-1} was similar to that with 116 kg N ha^{-1}. Soil test values from the second Hansen (2000) study indicated that soil (0-15 cm) N availability was lower than in the first study. Soil mineral N was 38 kg N ha^{-1} and potentially mineralisable N was a further 170 kg N ha^{-1}. However, in the later study, the soils were sampled 8 weeks prior to sowing (Hansen, pers. comm.) and therefore may not have been indicative of soil N availability at establishment.

The objective of the second Hansen (2000) study was to compare the yield responses of Jubilee and SS42 to N rate. However, a high incidence of lodging for Jubilee confounded the results making it had to compare the cultivars. While the results from the second study did not strongly support the hypothesis that Jubilee was more responsive to N rate than SS42, Hansen (2000) concluded that the combined results from both studies collectively suggested that yield of Jubilee is more responsive to N availability than yield of SS42.

In numerous studies that have reported cultivar differences in the response to N rate (Smith, 1934; Dalby and Tsai, 1975; Tsai *et al.*, 1978b; Friedrich and Schrader, 1979; Pollmer *et al.*, 1979; Reed and Hageman, 1980; Eghball and Maranville, 1991; Tsai *et al.*, 1992; as cited by Hansen 2000), a common explanation for such differences was a difference in sink strength of the cultivars. Dalby and Tsai (1975) and Tsai et al. (1978b) reported levels of zein, a measure of sink strength (Russelle *et al.*, 1983; Tsai *et al.*, 1978a; as cited by Hansen 2000), to be 43-54% lower in the *sh2* mutants than in the *su1* mutants. Zein, the primary N storage protein in kernels of sweet corn and maize (Tsai *et al.*, 1983), becomes increasingly abundant as soil N fertility increases (Sauberlich *et al.*, 1953; Prince,1954; Keeney, 1970; Rendig and Jimenez, 1978; Tsai *et al.*, 1980; as cited by Hansen, 2000).

Further investigation by Hansen (2000) provided evidence to support the hypotheses that differences in N accumulation among genotypes were related to differences in zein accumulation, and thus kernel sink strength. Hansen (2000) confirmed that kernels of

Jubilee and SS42 differ in their sink strength not only for DM but also for N. Such higher sink strength was attributed to Jubilee (*su1* mutant) kernels accumulating significantly more (31%) zein than SS42 (*sh2* mutant) kernels. Thus Jubilee would be expected to require more N for maximum yield than SS42, consequently, would be a less suitable cultivar for organic production.

2.4.5 Summary

A review of the literature has shown that high yielding sweet corn can accumulate more than 125 kg N ha^{-1} over its growing season, with some sweet corn cultivars able to accumulate as much as 240 kg N ha^{-1}. Over 50% of this N accumulates in the last month of the growing season. Crop N removal at harvest is in the range of 80-150 kg N ha^{-1} (approximately 65% of plant total accumulated N).

Depending on soil mineral N levels, sweet corn yield is maximised by fertiliser-N rates of anywhere between 0-250 kg N ha^{-1}. Fertiliser-N response studies indicate that in humid climates the use of a PSNT can be used to reliably predict the responsiveness of sweet corn to fertiliser-N. In general, if soil (0-30 cm) NO_3-N levels are > 25 ppm, when sweet corn plants are 30 cm tall, then yield response to fertiliser-N is likely to be minimal.

The level of soil mineral N that is required to maximise sweet corn yield will be influenced by the cultivar grown. Evidence from studies supports the hypotheses that differences in N accumulation among cultivars are related to differences in zein accumulation, and thus kernel sink strength. This finding may have important implications for the management of these cultivars, particularly for organic sweet corn systems that are largely reliant on soil mineral N. Further research should be carried out to clarify these findings with the objective of selecting sweet corn cultivars most suitable for organic systems. This would involve identifying cultivars whose yields are less sensitive to variations in soil mineral N levels and can also maintain high yields with lower N content, with a smaller proportion of N being partitioned to yield components.

Chapter 3 ~ Materials and Methods

3.1 Introduction

The study described in this section consists of two field trials of similar design at two different sites. The commencement dates of the experiments at the two locations were one day apart. The following sections give details of the design, materials and methods used for this study.

3.2 Experimental design and trial establishment

3.2.1 Treatments

The green manure treatments used in this study are listed in Table 3.1. These treatments were chosen because they represent the main management strategies used by organic sweet corn growers over the winter period, except for annual ryegrass, which was included because of its ability to accumulate high levels of DM during the autumn/winter period.

Table 3.1 Green manure and control treatments

Treatment number	Treatments	Sowing rate (kg seed ha^{-1})
1	control (bare-soil)	-
2	blue lupin (*Lupinus angustifolus)*	60
3	mustard (*Brassica sp.*)	5
4	mustard / blue lupin mix	2 (mustard) / 50 (lupin)
5	annual ryegrass (*Lolium sp.*)	25

3.2.2 Experimental layout

For both field trials a Latin Square experimental design was used, which consisted of five replicates of each of the five treatments mentioned in the previous section. Each of the 25 plots used in the design measured 10m × 15 m. The experiment design layout is shown in Figure 3.1.

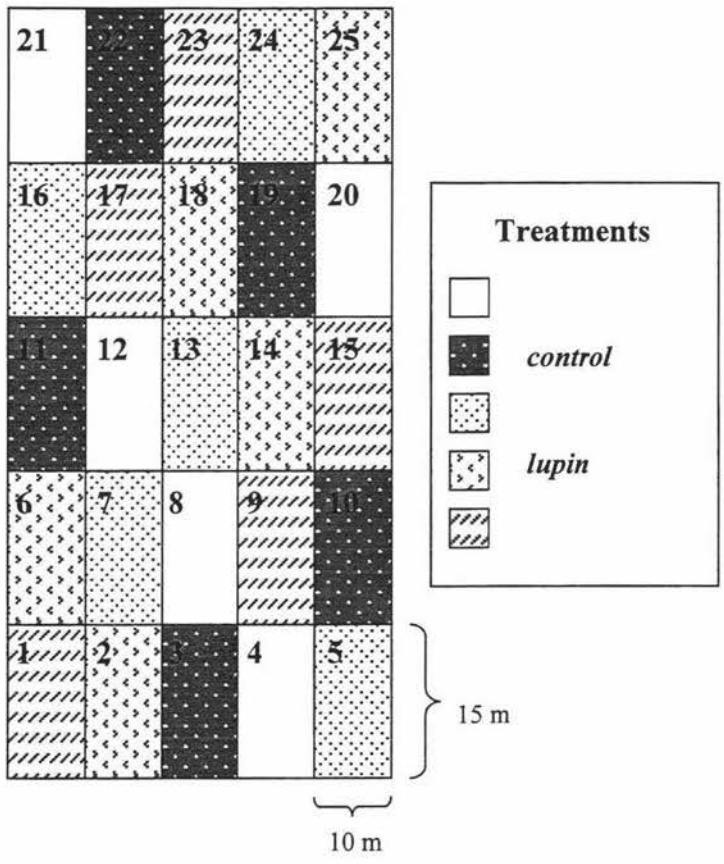


Figure 3.1 Trial design layout. *(mustard lupin mix)

3.2.3 Site selection

The two trial sites used in this study are BGNZ organic certified. The two sites also have contrasting crop management histories. The first trial site, hereafter Site-A, located near Tekaraka, about 40 km inland from Gisborne City (Figure 3.2), is part of a continuous cropping system, which has been cropped for the last 42 years. Annual winter green manure crops have been grown in crop rotation at Site-A since the late 1980s. The second site, hereafter Site-B, located near Tolaga Bay, about 50 km north of Gisborne City along the coast (Figure 3.2), is part of a mixed cropping system. The soils at Site-B had been cropped for three to four years before the start of this study and prior to that they had been in short-term pasture. Winter green manures are also used in crop rotation at Site-B. No chemical nitrogen fertiliser had been applied to either site for at least two years prior to the start of this study. A summary of site information is given below in Table 3.2.

Table 3.2 Trial site description

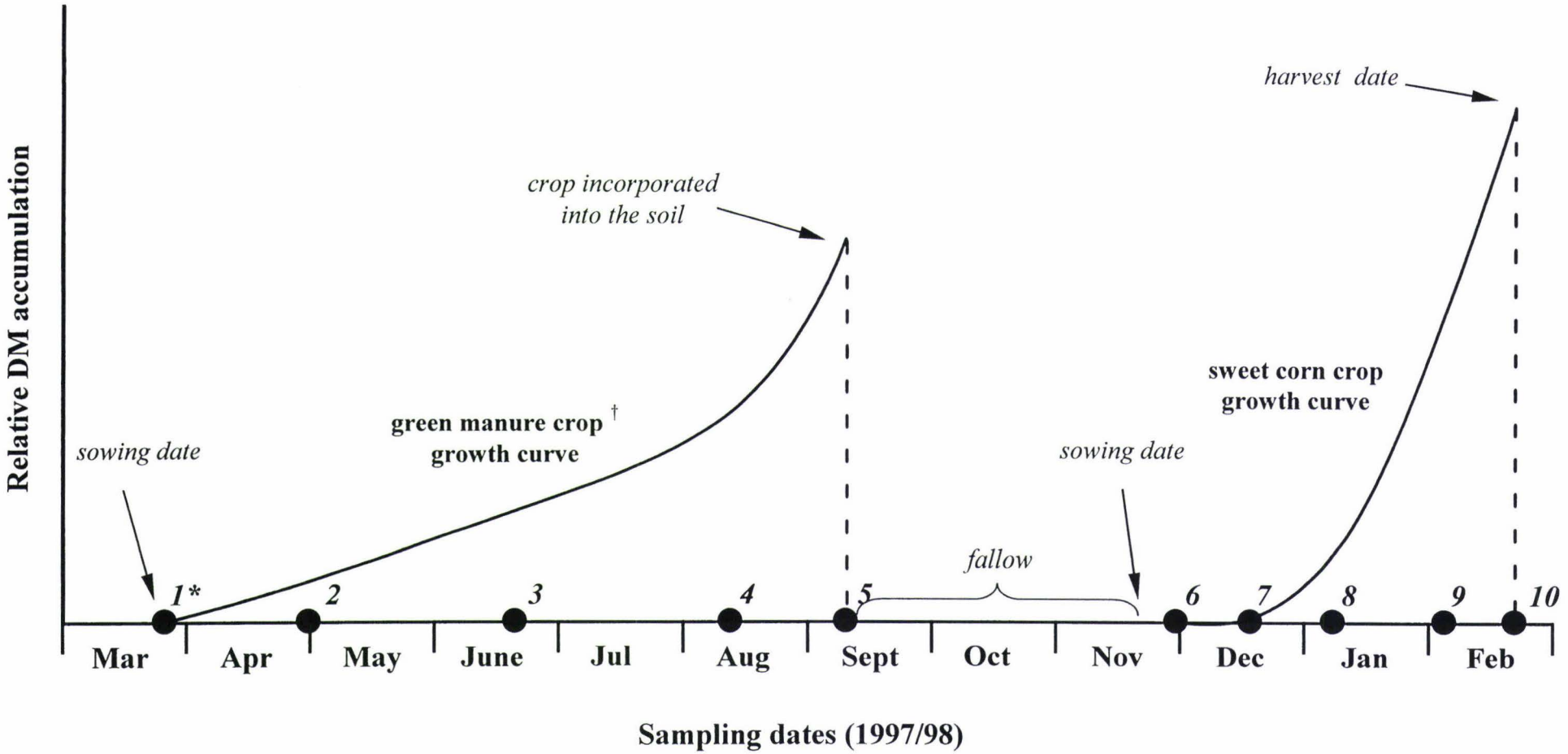
Location	Soil Type	Cropping History
Site-A (Tekaraka) (continuous cropping system)	Waipoa Silt Loam *(Recent Alluvium)*	42 years continuous cropping
Site-B (Tolaga Bay) (mixed cropping system)	Makari Silt Loam, *(Recent Alluvium)*	3-4 years crops, previously short-term pasture.

3.2.4 Field Trial Establishment

From 24-26 March 1997 both trial sites were laid out with the corners of all plots being marked with pegs and green manure treatments were sown (Table 3.1). The exact locations of plots were recorded with bearings taken from fence lines, to allow peg removal and replacement during cultivation. On 6 and 17 September 1997 green manure treatments were incorporated into the soil with tractor drawn discs. Both sites were then left fallow until 23-25 November 1997 when they were sown in sweet corn (cultivar 'Punch'). The sweet corn sowing rates were 65,000 seeds and 59,000 seeds ha^{-1} at Site-A and Site-B respectively. Sweet corn was harvested from these sites on 19-20 February 1998.

A schematic diagram of field trial sampling dates in relation to green manure and sweet corn crop DM accumulation is shown in Figure 3.3. The diagram gives an overall picture of the times when the trial was sampled.

Figure 3.2 Locations of the two field trial sites (Site-A, Site-B) used in this study.



* (● *1 – 10* represent sampling dates)

†(Average DM accumulation rate for the lupin treatment at Site-A)

Figure 3.3. A schematic diagram showing approximate soil (# 1, 5, 6, 8,-9) and herbage (# 2-5, 7-10) sampling times in relation to crop dry matter (DM) accumulation.

3.3 Soil sampling and analyses

3.3.1 Soil sample collection

Over the duration of the trial, soil samples were collected at five out of the ten sampling times (sampling times 1, 5, 6, 8 and 9 in Figure 3.3) at both trial sites. The first soil sampling was conducted at the start of the trial (25, 26 March 1997) when seed treatments were applied. The second sampling was made on 6, 17 September 1997 just prior to incorporation of the green manure treatments into the soil. The last four soil sampling times were made following sweet corn emergence (28-29 November 1997). At each soil sampling ten bulked soil cores (2.5 cm in diameter and to a depth of 0-15 cm) were collected from each treatment plot. At particular sampling times deeper soil cores were also collected. At some later sampling times, soil samples were only collected from three treatment blocks (15 plots) at each site (details provided in Table 3.3).

Table 3.3 Summary of soil sampling details

Date *(Sampling number)**	Site	Soil depth (mm)	Number of plots sampled
25, 26 March 1997	A	0-150	25
(1)	B	0-150, 150-300	25
6, 17 September 1997	A	0-150, 150-300, 300-450	25
(5)	B	0-150, 150-300, 300-450	25
30 November 1997	A	0-150	25
(6)		150-300	10
	B	0-150	25
		150-300	10
7, 8 January 1998	A	0-150	15
(8)	B	0-150	25
3, 4 February 1998	A	0-150	15
(9)	B	0-150	15

**(Sampling numbers refer to sampling dates that are numbered in Figure 3.3)*

At all sampling times conducted after sweet corn emergence, the soil-sampling procedure involved collecting five soil cores from in between sweet corn rows and another five cores from along the rows in each plot. This method of sampling was used to reduce within plot sampling variability caused by the effect of sweet corn row spacing.

3.3.2 Soil sample preparation

Soil samples collected from each trial plot were placed in plastic bags and stored in chilly-bins for transportation. Within 1-2 days after collection, soil samples were either immediately air-dried (30-35 °C) or were initially stored in a chiller (4 °C) and air-dried at a later stage. Once air-dry, the soils were ground and sieved to produce samples with particle size < 2 mm. Prepared soil samples were then used for analyses, as outlined in the following sections.

3.3.3 Soil analyses

At the start of this study, soil samples were collected from trial plots to characterise the soil chemical fertility at both trial sites. Soil analyses used to characterise the soils included total C and N, and routine soil chemical analyses for plant available nutrients (Olsen P, sulphate S, exchangeable cations) and pH. At all of the subsequent soil sampling times, samples were analysed for mineral N (NH_4^+, NO_3^-) only. The soil samples collected at sweet corn emergence were also analysed for potentially mineralisable nitrogen.

3.3.3.1 Total C and N

The total C and N of soil samples were determined using a LECO FP 2000 automated analyser, which measures C and N content by combustion in a resistance furnace.

An air-dry soil sample (<0.25 mm sieved), which weighed approximately 0.3 g, was introduced into the furnace where it was heated to 1,050 °C in a stream of pure oxygen. After passing through a thermoelectric cooler, which removed water, the resulting combustion gases are collected in a ballast tank. A sample of gas was passed through an infrared cell, which determined the C content. N content was then determined by thermal conductivity.

3.3.3.2 Sodium bicarbonate extractable phosphate (Olsen P)

Olsen P was determined using a method adapted from the method described in Olsen *et al.* (1954). This method involved accurately weighing 1 g of air-dry soil (<2 mm sieved) into a 50 ml polypropylene centrifuge tube, then adding 20 ml of 0.5 M $NaHCO_3$ solution (pH 8.5). The soil suspensions were shaken together for 30 minutes in an end-over-end shaker. This was followed by centrifuging at 8000 rpm for 1 minute and filtration through Whatman No.1 filter paper. Inorganic P was then

determined by the phosphomolybdate method adapted from the method described by Murphy and Riley (1962)

3.3.3.3 Phosphate extractable sulphate

Extractable sulphate was determined using a method adapted from the method described by Landers *et al.* (1983). This method involves accurately weighing 5 g of air-dry soil (<2 mm sieved) into a 50 ml polypropylene centrifuge tube, then adding 25 ml of 0.01 M $Ca(H_2PO_4)_2.H_2O$ solution. The soil suspensions were shaken together for 30 minutes, in an end-over-end shaker, followed by centrifuging at 8000 rpm for 3 minutes and filtration through Whatman No. 41 filter paper. The amount of extractable sulphate was measured using a Technicon II auto-analyser (Blakemore *et al.*, 1987).

3.3.3.4 Exchangeable cations

Exchangeable cations (K^+, Ca^{2+}, Mg^{2+}, Na^+) were determined by accurately weighing 1 g air-dry soil (<2 mm sieved) and mixing with 3 g of acid-washed sand. The mixed sample was placed in a leaching tube, which was blocked at the bottom with a piece of damp Whatman No. 41 filter paper. The sample in the tube was then leached with 50 ml of 1M NH_4OAc (pH 7) solution; containing either 1.26 g/L CsCl (measuring K^+, Na_{2+}) or 2.,4. G/L Sr $(NO_3)_2$ (measuring Ca^{2+}, Mg^{2+}). One ml of the collected leachate was diluted with 9 ml of the initial ammonium acetate solution and the concentration of cations in the solution were determined using an atomic absorption spectrometer.

To determine the cation exchange capacity of the soil, the quantity of H^+ ions in the leachate solution was also calculated by measuring the change in pH of the leachate solution compared to the initial ammonium acetate solution and using a predetermined calibration curve, which relates pH change to exchange acidity. Cation exchange capacity was then determined by summing the amounts of K^+, Ca^{2+}, Mg^{2+}, Na^+, H^+ measured in the leachate solution.

3.3.3.5 pH

Soil pH was determined by adding 25 ml of distilled water to 10 ml of air-dry soil (<2 mm sieved), mixing together thoroughly and leaving for approximately 16 hours. After 16 hours the sample was mixed again and left to settle for a further one hour. The pH of the suspension was then measured using a pH meter equipped with a glass/calomel combination electrode.

3.3.3.6 Mineral N

The method used for analysing mineral N involves accurately weighing 3 g air-dry soil (<2 mm sieved) into a centrifuge tube and adding 30 ml of 2 M KCl. The solution in the centrifuge tube was shaken in an end-over-end shaker for 1 hour and centrifuged at 8000 rpm for 2 minutes, followed by filtration through Whatman N. 41 filter paper. The amounts of nitrate (NO_3^-) and ammonia (NH_4^+) were measured using a Technicon II auto-analyser (Blakemore *et al.*, 1987).

3.3.3.7 Anaerobic mineralisable N

The method used for analysing anaerobic mineralisable N in this experiment was adapted from the method described by Waring and Bremner (1964). This method involves accurately weighing 5g air-dry soil (<2 mm sieved) into a centrifuge tube followed by an addition of 20 ml distilled H_2O. The tube was sealed with a lid and the sample was incubated at 30-35 °C for 15 days. At the end of the incubation period, 10 ml of 3M KCl was added to each tube and shaken in an end-over-end shaker for 20 minutes. After shaking, the tubes were centrifuged at 8000 rpm for 5 minutes, followed by filtration through Whatman No. 41 filter paper. The amounts of NO_3^- and NH_4^+ were measured using a Technicon II auto-analyser (Blakemore *et al.*, 1987). The level of net-mineralisable N is determined by subtracting the quantity of mineral N in the soil, prior to incubation, from the values measured in the incubated samples.

3.3.3.8 Aerobic mineralisable N

The method used for analysing anaerobic mineralisable N in this study was adapted from the method described by Keeney and Bremner (1967). This method involved accurately weighing 10 g air-dry soil (<2 mm sieved) and 30 g acid-washed sand into a 250 ml conical flask. The contents of the flask were stirred and 6 ml of distilled H_2O was added. The flask is then capped with aluminium foil. The sample in the flask was incubated at 30 °C for 14 days. At the end of the incubation period, 100 ml of 3M KCl was added to the sample and shaken with an orbital shaker for 1 hour. After shaking, the sample was given time to settle and then an aliquot was filtered through Whatman No. 41 filter paper. The filtered sample was then analysed for NO_3^- and NH_4^+ as described in Section 3.3.3.7.

3.4 Herbage sampling and analyses

3.4.1 Green manure herbage sampling

On 28-29 April 1997, green manure crop treatments were sampled at both trial sites to assess crop establishment numbers. A 0.5m x 0.5m quadrat was used to measure the establishment rate of plants in all green manure plots. For all treatment plots, except the control and ryegrass treatments, the quadrat was randomly placed ten times in each treatment plot and the number of plants within the area of the quadrat were counted. For the ryegrass treatment only five quadrat areas were counted per plot, because ryegrass had a much higher population density compared to the other green manure treatments.

On 18-19 June 1997, herbage samples were collected from all treatment plots except the control plots, at both trial sites. One 0.5m x 0.5m quadrat cut was collected from each plot and placed in a labelled paper bag. These samples were dried at 65 °C and the dry sample was weighed to determine DM yield.

On 10 August 1997 at Site-A only, further herbage samples were collected from treatment plots to assess within-plot variability of green manure treatment yields. No samples were collected from control treatment plots at this sampling time, as they were devoid of vegetation. Five quadrat cuts (ryegrass 0.5m x 0.5m quadrat; all other green manure treatments 1.0 m x 0.5 m quadrat) were randomly collected from each plot. The herbage collected from each quadrat was placed in a separate bag to give a total of five samples per treatment plot. These samples were dried at 65 °C and the dry sample was weighed to determine DM yield.

Final green manure crop sample collection, made just prior to soil incorporation, was made on 6 September 1997 at Site-A and on 17 September at Site-B. At these sampling times, five quadrat cuts (ryegrass 0.5m x 0.5m quadrat; all other green manure treatments: 1.0m x 0.5 m quadrat) were randomly collected from each plot. All five samples within each plot were combined and weighed on field scales to give a total fresh weight for the combined sample from each plot. The combined sample was mixed, and a sub-sample was selected and weighed on the field scales. These sub-samples were dried at 65°C and the dry samples were weighed to determine DM

percentage. DM percentage was used to calculate the total DM yield per plot. The dry samples were then finely ground and analysed for total N and P, as described in Section 3.5.3.1.

3.4.2 Sweet corn herbage sampling

Sweet corn (Zea mays L., cultivar 'Punch') was sown in this experiment at both trial sites between 23-25 November 1997 and the plants emerged 5-6 days later. Sweet corn plants were sampled at four different stages of growth following emergence, represented by the sampling times numbered 7-10 in Figure 3.3. All treatment plots were split in half to give two sub-plots per plot. One sub-plot was used for the first three sampling times and the other half was used for the fourth (final) sampling at crop harvest.

The first sweet corn samples were collected on 17-18 December 1997. At this sampling time ten corn plants, being cut at ground level, were collected from sub-plots at both sites. All plant samples were collected along a line running diagonal relative to sweet corn rows in each sub-plot. All plant samples collected in one sub-plot were placed together in a labelled paper bag and were taken to the laboratory where they were dried at 65°C then finely ground and analysed for total N and P, as described in Section 3.5.3.1. Sweet corn establishment rates in all plots were also counted. The method for assessing establishment involved counting the number of plants along a row over a distance of 13.3 m. This was measured on the three centre rows of all plots.

At the second sweet corn sampling (7-8 January 1998) five corn plants were collected from every plot at both trial sites. All five plants in each plot were placed in a labelled paper bag and transported back to the laboratory. The samples were dried at 65 °C then finely ground and analysed for total N and P, as described in Section 3.8.2.1. The third sweet corn sampling (3-4 February 1998) was conducted in the same way as the second sampling.

The fourth (final) sampling was made at the sweet corn harvest (19-20 February 1998). At this sampling all 'harvestable' ears (> 150 mm from butt to tip) were harvested from 20 'well guarded' plants from every plot at both sites. The weights of the whole ears were measured on a balance in the field. Also, six sweet corn plants were collected

from each plot at Site-A and five plants were collected from each plot at Site-B. The total fresh weight of the samples from each plot was measured on a field balance and the weight recorded. The sweet corn samples were then chopped up with either a garden shredder or with a knife and sub-samples were taken. The sub-samples were weighed in the field then taken to the lab, where they were dried at 65 °C, weighed again and finely ground for total N and P analysis.

3.4.3 Herbage Analyses

3.4.3.1 Total Phosphorus and Nitrogen

Total N and P in herbage samples were analysed using the Kjeldahl digest method adapted from the method described by McKenzie and Wallace (1954). This method involved accurately weighing 0.1000 ± 0.0010 g of finely ground herbage onto a piece of cigarette paper (glue strip removed), which is then placed into a 100ml Pyrex tube. Four mls of digest mixture (250 g K_2SO_4, 2.5 g Selenium, 2.5 L H_2SO_4) was added to each tube and heated in an aluminium block at 350 °C for 7 hours. The tubes were given time to cool and are then made up to 50 ml with distilled water and mixed thoroughly with a vortex mixer. P and N in the solution was determined using a Technicon II auto-analyser (Blakemore *et al.*, 1987).

Chapter 4 ~ Results and Discussion

4.1 Characterisation of soil chemical properties.

At commencement of this study (25-26 March 1997) soil samples were collected from the two trial sites and analysed to determine their chemical fertility. A summary of the soil test results is presented in Table 4.1.

Table 4.1 Summary of soil test results (soil depth 0-15 cm).

Soil Test	Site-A	Site-B
Total carbon (%)	1.9	1.7
Total nitrogen (%)	0.16	0.16
C:N ratio	11.9:1	10.6:1
pH	6.1	5.5
Olsen P (μg/g)	45	13
Sulphate-S (μg/g)	7.1	7.6
	(meq/100g)	(meq/100g)
Potassium (exchangeable K^+)	1.18	0.54
Calcium (exchangeable Ca^{2+})	20.6	10.5
Magnesium (exchangeable Mg^{2+})	3.29	1.90
Sodium (exchangeable Na^+)	0.27	0.08
Cation exchange capacity	30	19

At the beginning of the study, soil test results showed that soil total carbon (C), total N, C:N ratio and sulphate-S levels were similar for both trial sites whereas soil pH, Olsen P, exchangeable cations (K^+, Ca^{2+}, Mg^{2+}, Na^+) and cation exchange capacity (CEC) levels were higher at Site-A compared with Site-B. In general, Site-A soil test levels showed high availability of most nutrients. At Site-B, however, soil pH and Olsen P were at levels considered low and exchangeable potassium was marginally low for growing sweet corn (Wood *et al.*, 1986) unless supplemented by nutrient additions and liming.

McLaren and Cameron (1996) state that the C:N ratio of soil organic matter (SOM) appears to become stabilised between 8:1 and 16:1, mainly depending on climatic conditions. The C:N ratios of the upper 15 cm of the soils in this study were similar being 11.9:1 and 10.6:1 for Site-A and Site-B, respectively. Both of these soil C:N ratios were low enough to expect that soil N net mineralisation would occur at times when climatic conditions favoured high microbial activity.

4.2 Green manure growth and nutrient accumulation

4.2.1 Green manure establishment

The establishment levels of the green manure crop treatments were measured one month after they were sown (Appendix 1). Green manure treatments established well in all plots at both sites. For each green manure treatment type, the establishment levels at the two sites were similar. This outcome strengthens later comparisons made between the two sites. Visual assessment of overall establishment also indicated that crop treatments were even and generally well established with healthy plants at both sites (Plates 4.1 and 4.2).

4.2.2 Green manure dry matter between plot variation

A preliminary sampling (10 August 1997) of the green manure crops was conducted at Site-A to evaluate the effect that the number of samples taken per plot would have on DM yield between-plot variation. This evaluation compared DM yield between-plot variation using 3 quadrat cuts per plot, considered to be a minimum, with between plot variation using five quadrat cuts per plot. Five quadrat cuts were randomly collected from each green manure plot at Site-A. Quadrat area was 0.5 m x 0.5 m (0.25 m^2) for sampling ryegrass and 1.0 m x 0.5 m (0.5 m^2) for sampling each of the other green manure treatments.

Generally, there was only a small marginal decrease in DM yield between-plot variation when five samples were sampled per plot compared with using three samples. Using five samples per plot the between-plot coefficient of variation was 16.5%. Collecting only three samples from each plot gave an average between-plot coefficient of variation of 18.6% (range 16.9 %-20.8%; using different combination of 3 samples per plot). This result indicates the using more than 5 samples per plot is unlikely to result in large decreases in between-plot variation. Consequently, it was decided that 5 samples per plot would be sufficient for final green manure DM sampling.

Plate 4.1. Trial layout at Site A showing the established green manure treatment and control (bare soil) treatment plots.

Plate 4.2. Established lupin plants in a lupin treatment plot at Site-B.

4.2.3 Green manure dry matter accumulation

Final DM accumulation levels for green manure treatments were measured on 6 and 17 September 1997 just prior to their incorporation into the soil (Figures 4.1 and 4.2). At both sites, the lupin, mustard/lupin mix and ryegrass treatments showed similar trends of DM accumulation with the lupin treatment achieving the highest level at both sites. All these three treatments achieved DM levels considered high for winter grown crops ranging from between 5 - 8 t DM ha^{-1} at Site-A and 5 - 9 t DM ha^{-1} at Site-B (Plate 4.3 and 4.4).

At the earlier sampling times, the mustard treatment had similar DM levels compared with the other three green manure treatments. However, at the final sampling (6, 17 September 1997) mustard DM levels were substantially lower than the other green manure treatments, particularly at Site-B where the mustard DM levels were lower at final sampling than they had been at the previous sampling. Low DM yields measured for mustard were mainly due to early maturity and defoliation prior to final sampling. Mustard defoliation was most pronounced at Site-B where the majority of mustard plots had mainly only stems remaining (Plate 4.4). However, mustard in the mustard/lupin mix treatment did not lose its foliage to the same extent as was observed in the mustard only plots. Defoliation of mustard prior to final sampling has meant that the values obtained for mustard DM, N and P accumulation do not truly represent the actual levels for this treatment. Consequently, this should be considered when relating these parameters of the mustard treatment with other variables.

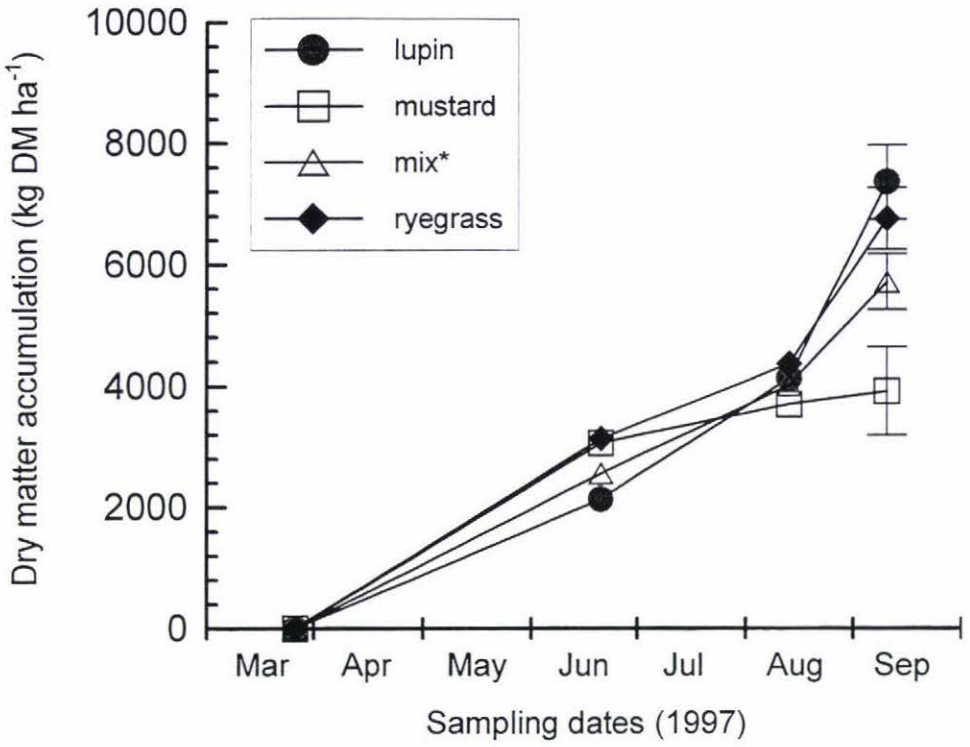


Figure 4.1: Green manure dry matter accumulation from sowing (25 March 1997) until just prior to soil incorporation (6 September 1997) at Site-A (vertical lines denote standard errors).
*(mustard/lupin mix treatment)

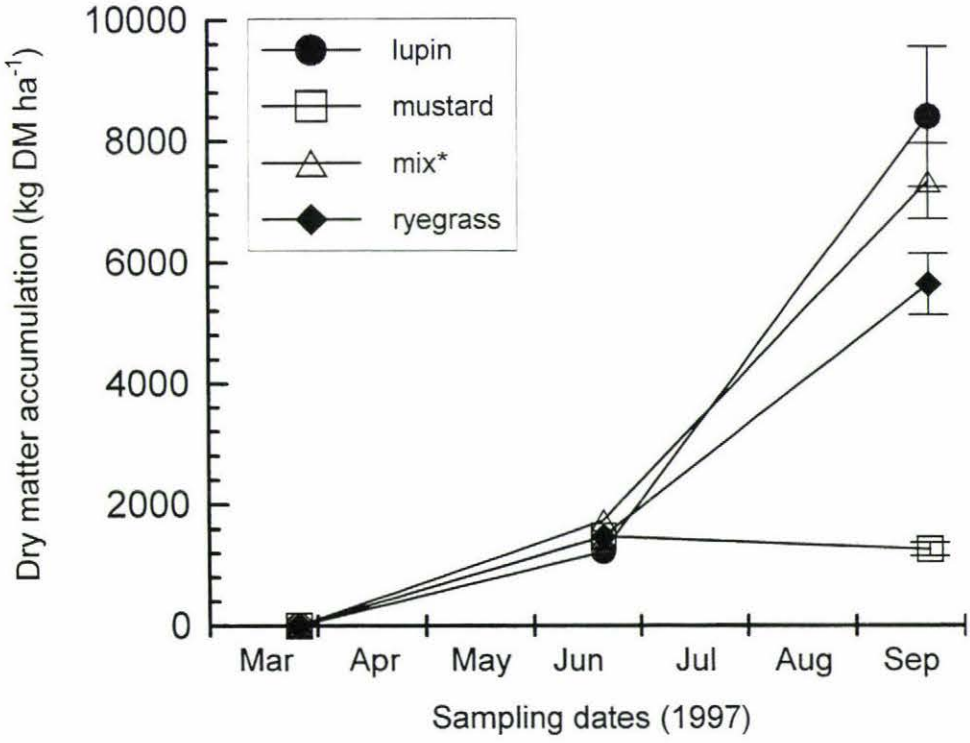


Figure 4.2: Green manure dry matter accumulation from sowing (26 March 1997) until just prior to soil incorporation (17 September 1997) at Site-B (vertical lines denote standard errors).
*(mustard/lupin mix treatment)

Plate 4.3. Green manure treatments (lupin, mustard, ryegrass) and control (bare soil) treatment just prior to soil incorporation (6 September 1997) at Site-A.

Plate 4.4. Green manure treatments (lupin, ryegrass, mustard) and control ('bare soil') treatment plots just prior to soil incorporation (17 September 1997) at Site B. (*Notice the weed cover on control treatment plot in the foreground and defoliated plants in the mustard plots*).

4.2.4 Green manure nitrogen and phosphorus levels and C:N ratios

The capacity of green manure crops to serve as an effective source of nutrients for a subsequent crop depends largely on the green manure crop characteristics, soil properties, tillage management and climate (Doran and Smith, 1991). Two important green manure crop characteristics relating to their effectiveness as a source of N for subsequent crops are total N accumulation and N concentration (or C:N ratio) of green manure residues at the time they are incorporated into the soil. Kumar and Goh (2000) cite many researchers who have reported highly significant correlations among crop residue N content, N release and biomass loss.

The results (Table 4.2) from the present field study showed that the lupin treatment achieved the highest N accumulation and N concentration (lowest C:N ratio) at both trial sites. On average over the two sites the N accumulation for the lupin treatment was 165 kg N ha^{-1}.

Table 4.2 Green manure nitrogen and phosphorus levels and C:N ratios.

Trial Site	Treatment	P (%)	N (%)	P accumulation (kg P ha^{-1})	N accumulation (kg N ha^{-1})	C:N ratio**
Site A	**Control**	-	-	-	-	-
(6/9/97)	**Lupin**	0.26	2.1	19	156	19:1
	Mustard	0.21	1.4	8	58	29:1
	Mix*	0.26	2.0	15	116	20:1
	Ryegrass	0.26	1.2	18	79	33:1
Site B	**Control**	-	-	-	-	-
(17/9/97)	**Lupin**	0.17	2.1	14	173	19:1
	Mustard	0.12	1.5	2	19	27:1
	Mix *	0.16	1.9	12	139	21:1
	Ryegrass	0.20	0.9	11	54	44:1

* (Mustard and lupin mix treatment)

** (C:N ratio calculated assuming plants have an average carbon (C) concentration of 40%; Magdoff, 1993; Reeves, 1994)

The treatment with the second highest N accumulation and N concentration was the mustard/lupin mix treatment at both sites. The high N accumulation and N concentrations measured in the mustard/lupin mix treatment were predominantly due to the contribution of the lupin component in the mix. The ryegrass treatment had the

third highest N accumulation level with the lowest N concentration (highest C:N ratio). Mustard had the lowest N accumulation level of all the treatments even though its N concentration was higher than ryegrass. As stated previously, the mustard treatment had low DM levels because of defoliation prior to sampling. Consequently, N accumulation for mustard was also low.

It is generally believed that net N mineralisation of plant residues occurs when the N content of residues is above approximately 2.0% N (below C:N ratio <20:1) and net N immobilisation when N content is below 1% N (above C:N ratio > 40:1) (Haynes *et al.*, 1993; Magdoff, 1993; Reeves, 1994). Using these guidelines it would be expected that soil incorporation of the lupin and mustard/lupin mix treatments, with their high average N concentrations (≥ 1.9% N), would result in rapid soil N net mineralisation at both sites. The mustard treatment containing 1.4% to 1.5% N was not expected to have much effect on either soil N net mineralisation or immobilisation compared to the control treatment. However, the ryegrass treatment with low N concentrations (≤ 1.1% N) would be expected to result in soil N net immobilisation.

The magnitude to which the lupin and mustard/lupin mix treatments influence net mineralisation and the ryegrass treatment influences net N immobilisation also depends on the quantity of residues incorporated into the soil. All three treatments had high DM yields (Figures 4.1 and 4.2) and were therefore expected to have a substantial impact on N availability after soil incorporation. This impact can be either negative or positive depending on N concentration.

Plant P accumulation and concentrations are similar for all green manure crop treatments at each site except for mustard (Table 4.2). Mustard had lower P concentration and accumulation levels compared to all the other green manure treatments. Lupin, mustard/lupin mix and ryegrass treatments all had similar levels of P at each site, however, they varied between sites. At Site-A green manure crop treatments contained higher levels of P compared to those grown at Site-B. This result is likely to be due to Site-A having a substantially higher soil Olsen P level than Site-B (Table 4.1), particularly since no P fertiliser was applied to either trial site during the study.

4.3 Effect of green manures on plant available soil nitrogen

4.3.1 Effect of growing green manures on soil mineral N in early spring

Soil mineral N was measured at three soil depths (0-15, 15-30 and 30-45 cm) just prior to green manure soil incorporation (6, 17 September 1997) to determine whether growing green treatments manures over the winter period had different effects on levels of soil mineral N in early spring. Soil NO_3^--N, NH_4^+-N and total mineral N (NO_3^--N and NH_4^+-N) were measured in all treatment plots at both trial sites.

The results (Figures 4.3 and 4.4) show that green manure treatments significantly ($p=0.0001$) influenced soil NO_3^--N at all three depths at Site-A. At Site-A, all green manure treatments resulted in soil NO_3^--N levels significantly lower than the control treatment with ryegrass being the lowest. At Site-B the effect of green manure treatments on soil NO_3^--N was only significant in the top depth (0-15 cm [$p=0.008$]). The ryegrass treatment reduced soil (0-15 cm) NO_3^--N compared to the control treatment at Site-B.

Although the ryegrass treatment reduced soil NO_3^-- N levels at both sites compared to the control treatment, the actual NO_3^--N levels were all very low (< 8 kg N ha^{-1}) with the size of the differences too small to be of agronomic significance. Furthermore, the effect of green manure treatments on soil NH_4^+-N and total mineral N levels were not statistically significant at either site (Appendix 3 and 4).

Green manure cropping during rainy periods on fallow fields has been shown to reduce nitrate leaching losses (Martinez and Guiraud, 1990; Macdonald *et al.*, 1996). In the present study the ryegrass crop, which derived its entire N from soil mineral N, accumulated 67 kg N ha^{-1} on average for the two sites. As mentioned previously, the level of soil (0-45 cm) total mineral N levels in early September were not statistically different for the ryegrass treatment compared to the control treatment. Consequently, there is likely to be as much as 67 kg more N ha^{-1}in the soil of the control plots below the upper 45 cm compared to the soils in the ryegrass treatment plots. If this additional soil mineral N in the control plots leaches below the root zone, which for some crops

like maize can be up to 150 cm deep (Herron *et al.*, 1971), then it will be unavailable to the subsequent sweet corn crop.

Deeper sampling (0-180 cm) in early spring, as suggested by Hoyt and Mikkelsen (1991), may have been useful to determine how far down the soil profile the additional mineral N in the control treatment plots had moved. However, the number of samples generated by sampling to a depth of 180 cm in increments of 15 cm to 30 cm would have been restrictive. Furthermore, the value of the information obtained would not have justified such intensive sampling as organic sweet corn growers in Gisborne are unlikely to leave their soils in bare fallow over the winter period.

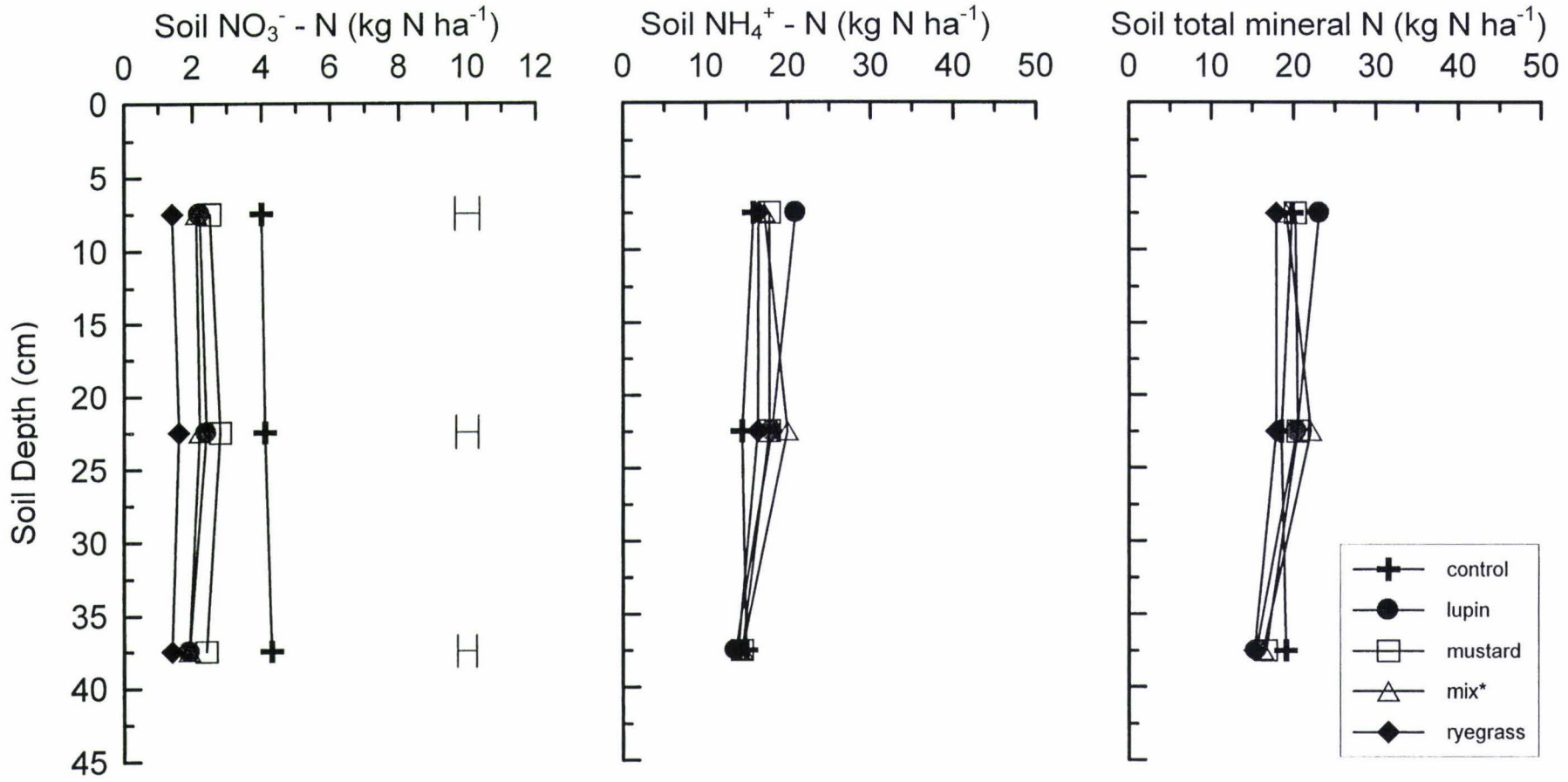


Figure 4.3. Effect of growing winter green manure crops on soil mineral N levels just prior to residue incorporation (6 September 1997) at Site-A (horizontal lines denote LSD values at a 5% significance level). * (mustard/lupin mix treatment)

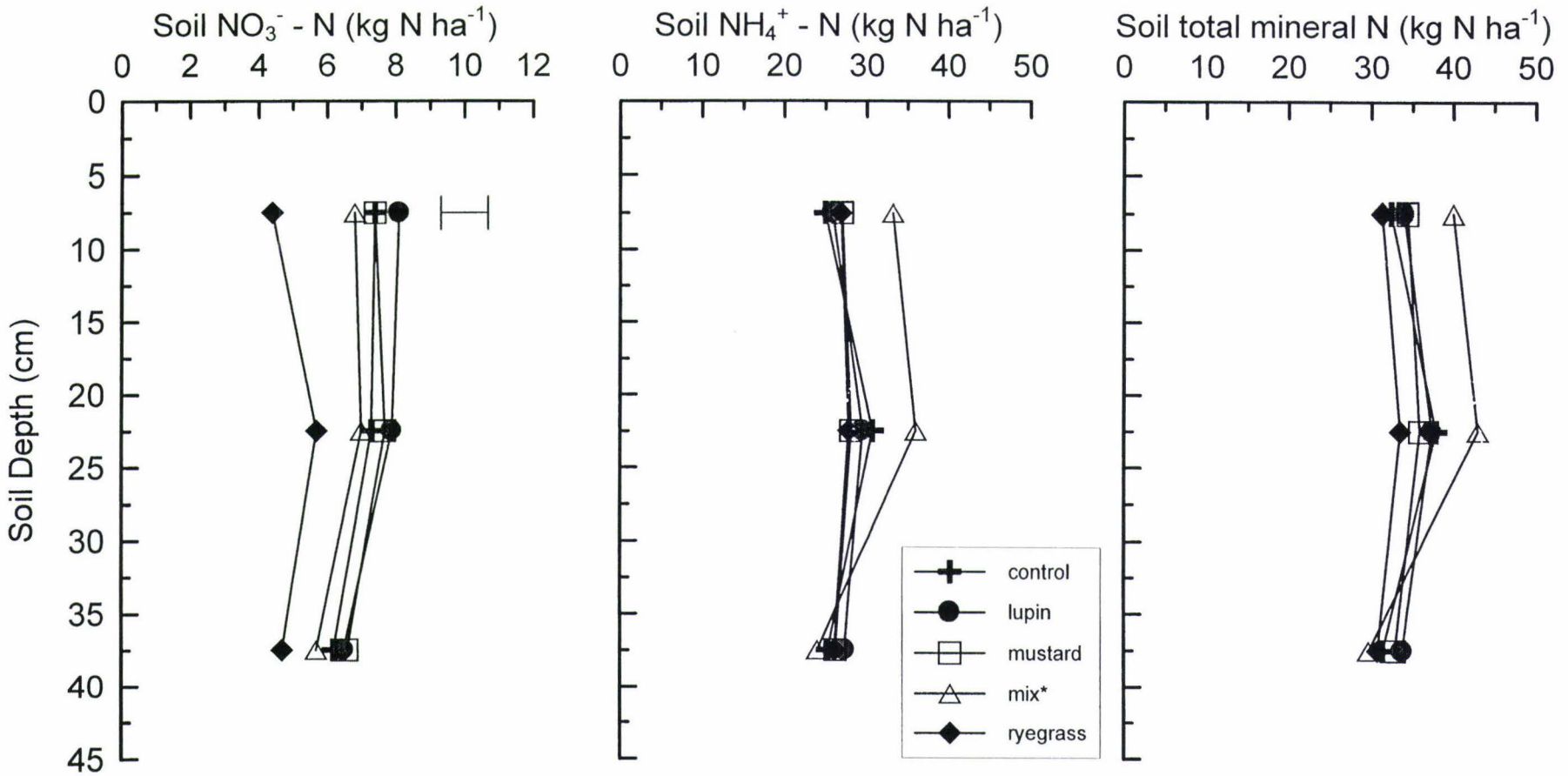


Figure 4.4. Effect of growing winter green manure crops on soil mineral N levels just prior to residue incorporation (17 September 1997) at Site-B (horizontal lines denote LSD values at a 5% significance level). * (mustard/lupin mix treatment)

4.3.2 Effect of incorporating green manure crop residues on soil mineral N levels over time

McCracken *et al.* (1989) observed that of various soil N tests investigated, the best indicator of plant available N in maize cropping was KCL extractable NO_3^--N and NH_4^+-N from soil sampled two weeks after sowing. In the present study, soil (0-150 mm) total (NO_3^--N and NH_4^+-N) mineral N levels were measured at three different sampling times over the sweet corn growing season (Figures 4.5 and 4.6):

1. sweet corn emergence (30 November 1997; one week after sowing),
2. 5½ weeks post-emergence (7-8 January 1998), and
3. 9½ weeks post-emergence (3-4 February 1998).

Statistical analysis showed that the effects of green manure treatment addition on soil (0-150 mm) total mineral N were significant at sweet corn emergence (10-11 week s after incorporation) and again 5½ weeks post-emergence (Figure 4.5 and 4.6). Results for soil NO_3^--N and NH_4^+-N levels separately are provided in Appendix 5 and 6.

Monitoring changes in soil mineral N, following crop residue soil incorporation, gives an indication of whether soil N net mineralisation or immobilisation occurs. The best time to monitor for changes in soil mineral N is close enough to planting of the subsequent sweet corn crop to allow time for the green manure residues to decompose, but before any significant N uptake by the subsequent crop has occurred. If soil mineral N levels are higher in green manure treated plots compared with control treatment plots then green manure treatment incorporation has resulted in net N mineralisation. Conversely, if levels are lower then net N immobilisation has occurred.

4.3.2.1 Soil total mineral N at sweet corn emergence

Soil mineral N levels at sweet corn emergence (30 November 1997) were monitored to provide an indicator of whether soil incorporation of green manure treatments caused soil N net mineralisation or immobilisation. At sweet corn emergence the effect of green manure treatments on soil (0-150 mm) total mineral N was highly ($p=0.0001$) significant for both sites.

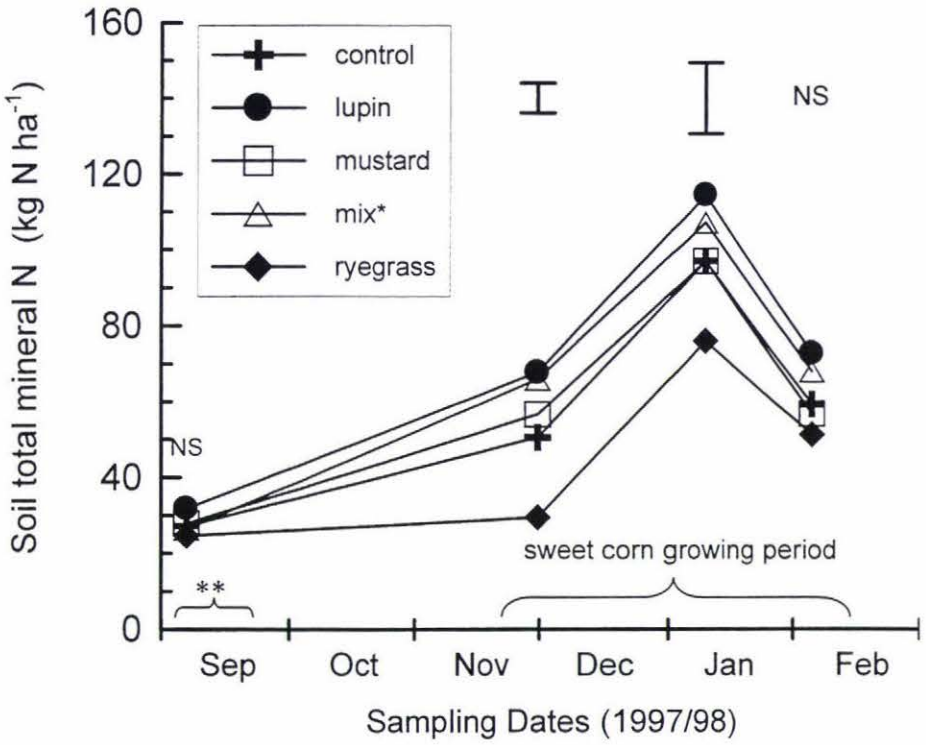


Figure 4.5. Effect of soil incorporation of green manure treatments on soil (0-150 mm) mineral nitrogen at Site-A (vertical bars denote LSD values at the 5% significance level; 'NS' denotes not significant). *(mustard/lupin mix treatment) **(soil incorporation of green manure treatments)

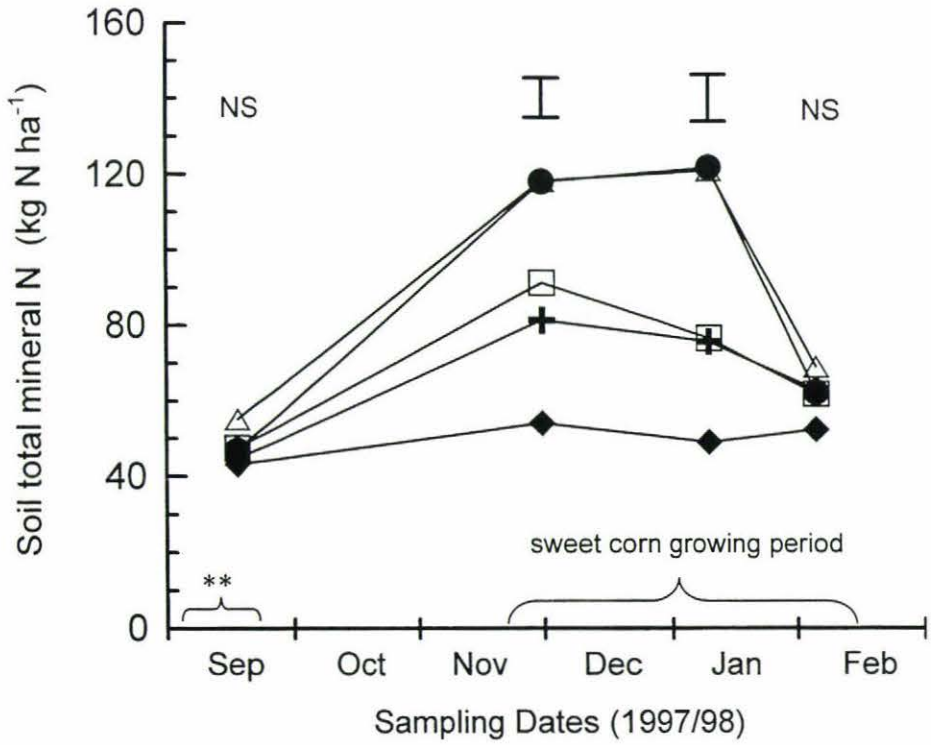


Figure 4.6. Effect of soil incorporation of green manure treatments on soil (0-150 mm) mineral nitrogen at Site-B (vertical bars denote LSD values at the 5% significance level. 'NS' denotes not significant). *(mustard/lupin mix treatment) **(soil incorporation of green manure treatments)

At Site-A, the lupin and mustard/lupin mix treatments significantly increased soil total mineral N by 34% and 31%, respectively, compared to the control treatment value of 50.4 kg N ha^{-1}. The effect of the mustard treatment on total mineral N levels was not significantly different from the control treatment. However, the ryegrass treatment decreased soil total mineral N by 41% compared to the control treatment.

The relative effects of green manure treatments on soil total mineral N, after they were soil incorporated, at Site-B were similar to Site-A. The lupin and mustard/lupin mix treatments significantly increased soil total mineral N by 45% compared to the control treatment value of 81.3 kg N ha^{-1}. The effects of the mustard treatment on total mineral N levels were not significantly different from the control treatment. Again, the ryegrass treatment decreased soil total mineral N, this time by 34% compared to the control treatment

In the present study, soil incorporation of the lupin and mustard/lupin treatments resulted in soil N net mineralisation. Soil incorporation of the mustard treatment resulted in neither net mineralisation nor immobilisation, while the ryegrass treatment resulted in net immobilisation (Table 4.3) compared to the control treatment.

Table 4.3. Balance of soil (0-15 cm) total mineral N as influenced by green manure treatments after subtracting control treatment effect (30 November 1997).

Green manure treatment	Balance soil (0-15 cm) total mineral N (kg N ha^{-1})	
	Site A	Site B
lupin	17	37
mustard**	6	10
mix*	15	37
ryegrass	- 21	- 27

*(mustard/lupin mix treatment) **(mustard treatment was not statistically different from the control).

As previously discussed, the N concentration of crop residues is an important crop characteristic influencing whether soil N net mineralisation or immobilisation results following soil incorporation (Reeves, 1994). A high N content of residues reduces competition of available N by microorganisms and consequently enhances the decomposition by maintaining high microbial activity (Kumar and Goh, 2000).

In the present study, just prior to residue soil incorporation the lupin treatment contained an average 2.1% N at both sites, while the mustard/lupin treatment contained an average of 2.0 % N. Both of these treatments resulted in increased soil N availability after soil incorporation. These results agree with guidelines (Haynes *et al.*, 1993) indicating that crop residues with N concentrations $\geq$ 2.0 % N will result in soil N net mineralisation.

The mustard treatment resulted in neither soil N net mineralisation nor immobilisation after residue incorporation. Just prior to soil incorporation the mustard crop contained 1.4% and 1.5 % N at Site-A and Site-B, respectively. These observations agree with the guidelines (Magdoff, 1993) that soil incorporation of crop residues containing between 1% to 2 % N are unlikely to influence short-term soil N availability.

The ryegrass N concentrations just prior to soil incorporation were 1.2% and 0.9% at Site-A and Site-B, respectively, and resulted in soil N net immobilisation. This result also agrees with the guidelines (Magdoff, 1993) that crop residues with N concentrations $\leq$ 1% will cause a short-term reduction in soil N availability.

The relative effects of green manure and control treatments on soil (0-150 mm) total mineral N were similar for the two sites, however, levels at Site-B were 60-85% higher than at Site-A. The difference in the magnitude of soil mineral N between the sites was also observed in the control treatment indicating that site differences in green manure crop characteristics or crop management are unlikely to be the main cause of higher soil mineral N levels at Site-B. Although an actual reason for the difference between sites was not identified, edaphic or climatic factors are more likely to be the cause. For example, both sites had the same soil (0-150 mm) total N levels (Table 4.1) at trial commencement, however, Site-B had a lower soil C:N ratio indicating a greater potential for N mineralisation.

4.3.2.2 Soil total mineral N at 5½ and 9½ weeks after sweet corn emergence

Soil (0-15 cm) total mineral N levels monitored after sweet corn emergence were influenced by N uptake of the growing sweet corn crop. However, the effect of green manure incorporation on soil (0-150 mm) total mineral N was still statistically significant 5½ weeks after sweet corn emergence (7-8 January 1998) at both sites (Site-A [p=0.0133], Site-B [p=0.0001]) (Figures 4.5 and 4.6). At Site-A, ryegrass significantly decreased soil (0-150 mm) total mineral N levels by 22% compared to the control treatment, but no other green manure treatment was significantly different from the control at Site-A. At Site-B the lupin and mustard/lupin mix treatments significantly increased soil total mineral N by 60% compared to the control treatment. Also, the ryegrass treatment reduced soil total mineral N by 35% compared to the control treatment.

At the subsequent sampling, 9½ weeks after sweet corn emergence (3, 4 February 1998), the effects of green manure treatments on soil (0-150 mm) total mineral N levels were no longer significant at either site. Since deeper samplings were not carried out the effect of green manure treatments on mineral N at deeper depths could not be evaluated.

4.3.3 Relationship between green manure N concentrations and soil total mineral N at sweet corn emergence

The results from Section 4.3.2 showed that soil incorporation of green manure treatments had a significant influence on soil total mineral N over the period sweet corn was grown. As previously discussed, the research literature (Haynes *et al*, 1993) supports the view that the N concentration of soil incorporated crop residues is an important determinate of subsequent soil N availability. Therefore, the strength of the relationship between green manure N concentrations (6, 17 September 1997) and the subsequent effect on soil (0-150 mm) total mineral N (30 November 1997) was investigated.

For both sites regression analysis shows a strong linear relationship between green manure N concentrations just prior to soil incorporation and subsequent soil total mineral N levels at both sites (Figures 4.7 and 4.8). The strength of this relationship shows that green manure N concentrations were a major factor influencing soil mineral N availability.

The control treatment soil mineral N levels relate to green manure N concentrations of approximately 1.45 % N and 1.30% N for Site-A and Site-B, respectively. These green manure N concentrations were near the middle of the range of the Magdoff (1993) guideline of 1% to 2% where neither soil N net mineralisation of immobilisation occurs.

Although the N concentration (C:N ratio) of crop residues is useful in predicting residue decomposition rates, it should be used with some caution as it reveals little of the C and N available to microoganisms from the soil (Kumar and Goh, 2000), which also influences residue decomposition rates. The information generated from laboratory studies, which are conducted in different environmental conditions compared to the field, could provide misleading estimates of threshold C:N ratios or may even overestimate the impact of N content on field residue decomposition. The following section discusses the effect of green manure treatments on soil N net mineralisation as predicted by two laboratory soil incubation tests.

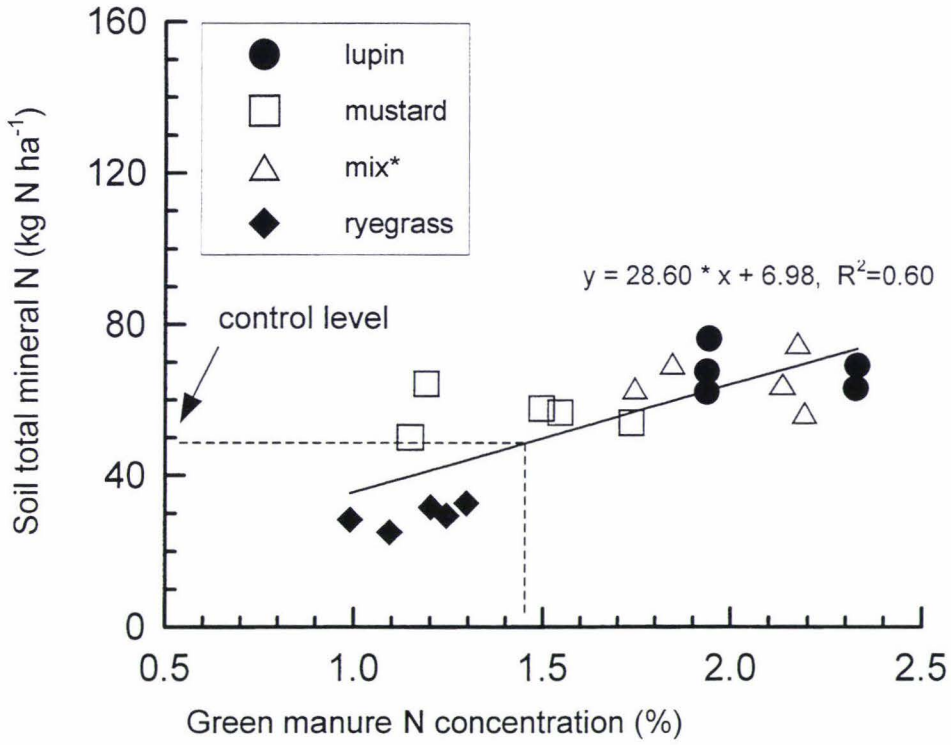


Figure 4.7. Relationship between green manure N concentrations just prior to soil incorporation (6 September 1997) and the subsequent soil (0-150 mm) total mineral N levels at sweet corn emergence (30 November 1997) at Site-A.

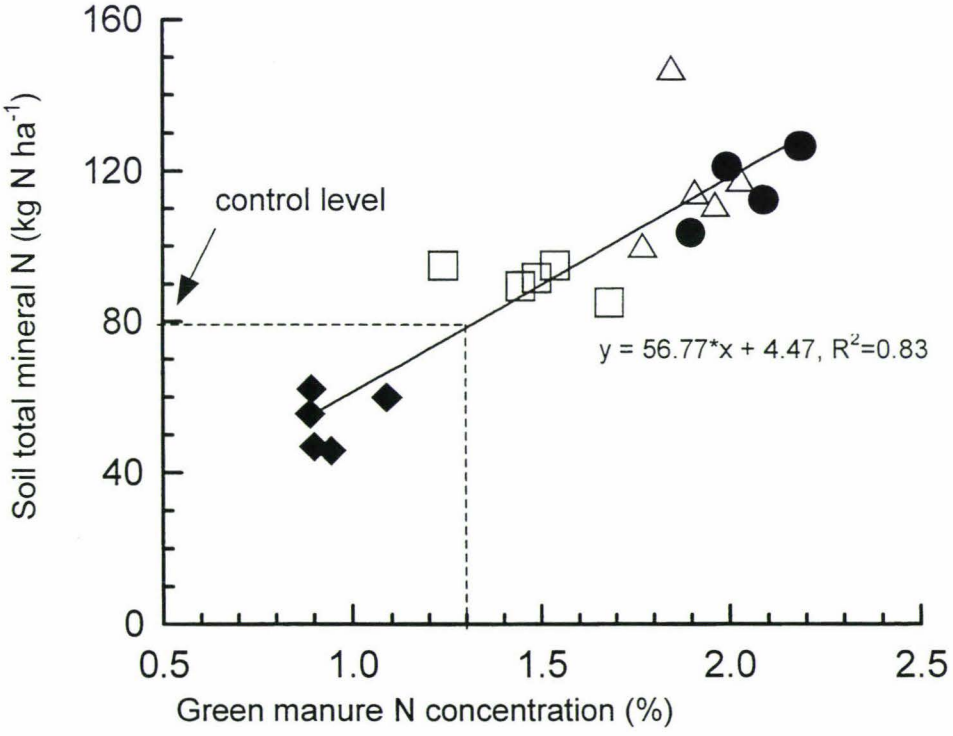


Figure 4.8. Relationship between green manure N concentrations just prior to soil incorporation (17 September 1997) and the subsequent soil (0-150 mm) total mineral N levels at sweet corn emergence (30 November 1997) at Site-B.

4.3.4 Effect of green manure treatments on soil N net mineralisation

Two laboratory incubation tests, one under aerobic conditions and another under anaerobic conditions (details in Sections 3.3.3.7 and 3.3.3.8), were used to predict soil N net mineralisation in samples collected at sweet corn emergence (30 November 1997). The following sections investigate whether green manure treatments influenced soil N net mineralisation as predicted by the two soil incubation tests and compares them with 'actual' net mineralisable soil N (Figures 4.9 and 4.10).

4.3.4.1 Aerobic soil incubation test

Green manure treatments significantly (Site-A [p=0.0351], Site-B [p=0.0106]) influenced net mineralisable soil N as predicted by the aerobic soil incubation test (Figures 4.9 and 4.10). At both sites the lupin and mustard/lupin mix treatments resulted in test values significantly higher than the control treatment. At Site-A the lupin and mustard/lupin mix treatment values were 30% and 23% respectively higher than the control treatment value of 160 kg N ha^{-1}. While at Site-B the lupin and mustard/lupin mix treatment values were 24% and 27% respectively higher than the control treatment value of 98 kg N ha^{-1}. The effects of the mustard and ryegrass treatments were not statistically different from the control treatment at either site.

4.3.4.2 Anaerobic soil incubation test

Green manure treatments also significantly (Site-A [p=0.0004], Site-B [p=0.0001]) effected net mineralisable soil N as predicted by the anaerobic soil incubation test. At both sites the ryegrass treatments resulted in test values significantly higher than the control treatment. The ryegrass treatment value was 97% higher than the control treatment value of 45 kg N ha^{-1} at Site-A, and 70% higher than the control treatment value of 60 kg N ha^{-1} at Site-B. At Site-A no other green manure treatment effect was statistically different from the control treatment. However, at Site-B the lupin, mustard and mustard/lupin mix treatments all resulted in anaerobic incubation test values significantly lower than the control treatment.

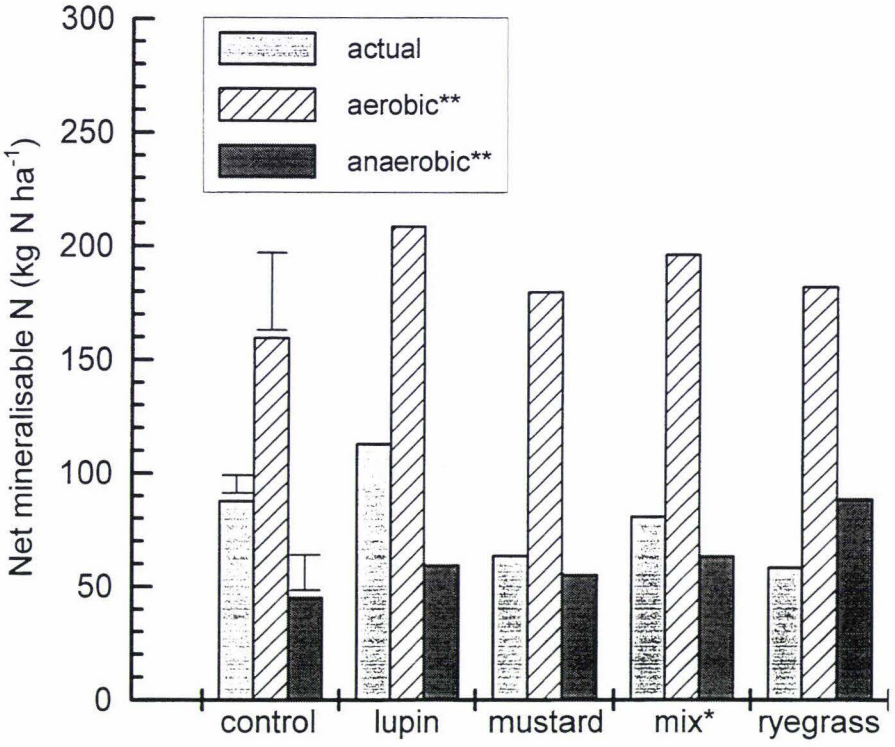


Figure 4.9. Effect of green manure treatments on 'actual' net mineralisable soil N and two indicators of net mineralisable N **(aerobic and anaerobic soil incubation tests) at Site-A (vertical lines denote LSD values at 5% significance level). *(mustard/lupin mix treatment)

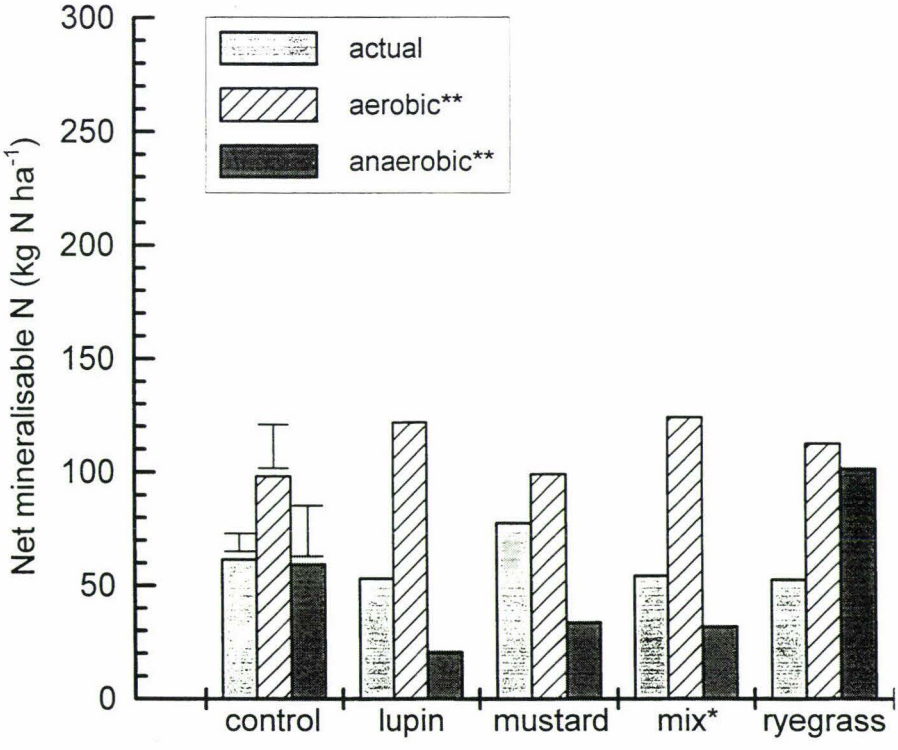


Figure 4.10. Effect of green manure treatments on actual net mineralisable soil N and two indicators of net mineralisable N **(aerobic and anaerobic soil incubation tests) at Site-B (vertical lines denote LSD values at 5% significance level). * (mustard/lupin mix treatment)

Keeney (1982) states that more N is mineralised in anaerobic conditions in a given period than under aerobic conditions. However, in the present study the anaerobic soil incubation test overall gave lower values for net mineralisable soil N than the aerobic test. The results from earlier soil incubation tests made on these samples had been discarded due to nitrogen contamination of the KCL used to make the extracting solutions. Therefore, the results presented here were obtained from air-dried soils that had been stored for over 24 months following sampling. One explanation why the aerobic test gave a higher estimate for N mineralisation could be due to the long storage time of the samples. In an earlier study by Keeney and Bremner (1966) long-term storage (24 - 48 weeks) of air-dried soil samples reduced the level of N mineralised by the anaerobic incubation test and increased the level of N mineralised by the aerobic test. However, short-term storage for 4-24 weeks increased the levels of N mineralised by both incubation tests in the Keeney and Bremner (1966) study.

4.3.4.3 'Actual' soil N net mineralisation

'Actual' net mineralisable soil N was calculated as follows:

$$a = (b+c)-d$$

Where;

a = 'actual' net mineralisable N

b = soil (0-15 cm) total mineral N (9½ weeks after sweet corn emergence [3, 4 February 1998])

c = sweet corn N accumulation (9½ weeks after sweet corn emergence [3, 4 February 1998])

d = soil (0-15 cm) total mineral N (sweet corn emergence [30 November 1997])

Deriving net mineralisable soil N in this way assumes that all N accumulated by the sweet corn was sourced from the 0-150 mm soil depth. However, sweet corn plants are likely to source some N from soil below 150 mm. Consequently, this method is likely to over-estimate the amount of N mineralised in the surface 0-150 mm of the soil. Leaching losses were also not accounted for in this estimate, however, as the late-spring and summer rainfall (Table 4.6) was very low the leaching losses would likely to have been minimal or nil during this period.

'Actual' soil N net mineralisation was significantly influenced by green manure treatments at both sites (Figures 4.9 and 4.10). However, there were no strong direct relationships (Appendix 6) between 'actual' net mineralisable soil N and the values obtained from either of the two soil incubation tests. The aerobic test gave values

considerably higher than the 'actual' values including the ryegrass treatment. However, the real effect of the ryegrass treatment was to cause N immobilisation compared to the control treatments at both sites as discussed in Section 4.3.2.

In general, the anaerobic soil incubation test gave values lower than 'actual' values for all treatments except the ryegrass treatment at both sites. Ryegrass resulted in the highest net mineralisable soil N predicted by the anaerobic incubation test. As with the aerobic test, the anaerobic test overestimated the effect ryegrass had on soil N mineralisation.

In summary, the two incubation tests used did not prove reliable as indicators of net mineralisable soil N because they did not show good agreement with each other or with 'actual' net mineralisation. This helps to explain why these tests did not relate well with sweet corn yield responses (as discussed in the next section). Also, the relationships between incubation test values and sweet corn crop responses, as discussed later in this chapter (Section 4.5), were either weak or negatively correlated.

4.4 Net mineralisable soil N as a predictor of sweet corn response

Results of this study have shown that sweet corn DM and N accumulation, and 'harvestable' ear yields were all significantly influenced by the impact green manure treatments had on soil N availability (details given in subsequent sections). Regression analysis was carried out to determine how well conventional tests for soil mineral N and net mineralisable N, measured at sweet corn emergence, related to sweet corn crop responses. Of the tests used the soil mineral N test gave the best direct relationship with sweet corn crop responses (Appendix 8). Therefore, the use of the mineral N test, as a predictor of sweet corn crop responses, will be discussed in subsequent sections that deal with sweet corn crop responses and only net mineralisable soil N tests are discussed here.

Net mineralisable soil N was determined by the aerobic and anaerobic soil incubation tests (details in Sections 3.3.3.7 and 3.3.3.8). Test levels were plotted against sweet corn DM accumulation, N accumulation, and 'harvestable' ear yield. Initially linear

relationships were investigated (Appendix 8) then those that indicated possible quadratic relationships were assessed.

Net mineralisable N as assessed by the aerobic method failed to show a strong relationship with any of the sweet corn crop response parameters (Appendix 8). Net mineralisable soil N as assessed by the anaerobic incubation method did not have a strong relationship with either sweet corn DM accumulation or N accumulation. However, there was a moderately strong but negative relationship between net mineralisable N (anaerobic) and 'harvestable' ear yield at both sites. The negative relationship is almost entirely due to the effect of the ryegrass treatment. The ryegrass treatment scored high on the anaerobic test but had low ear yields.

Conditions in the anaerobic soil incubation must have favoured N mineralisation by the ryegrass treatment in spite of ryegrass having a low N concentration. One explanation for this is that the lupin and the mustard/lupin mix treatments resulted in greater mineralisation of green manure N earlier in the season and therefore had less potential to mineralise N after sweet corn emergence compared to the ryegrass treatment. The aerobic and anaerobic soil incubation tests did not prove useful as indicators of net mineralisable soil N and consequently did not relate well to sweet corn crop responses either.

4.5 Sweet corn response to green manure treatments

The results discussed in Section 4.3 showed that green manure treatments significantly influenced soil N availability over the period sweet corn was grown. The next stage is to determine whether sweet corn productivity was responsive to the effects of the green manure treatments on soil N availability. Sweet corn N and DM accumulation, and 'harvestable' ear yield were all monitored to determine sweet corn response to green manure treatment effects.

4.5.1 Sweet corn N accumulation

The effect of green manure treatments on sweet corn N accumulation was monitored at four different times over the growing period:

- *First sampling* -2½ weeks post emergence (17-18 December 1997),
- *Second sampling* - 5½ weeks post-emergence (7-8 January 1998),
- *Third sampling* - 9½ weeks post-emergence (3-4 February 1998), and
- *Fourth sampling* - final harvest (19-20 February 1998).

At the first sampling, very low N accumulation values existed; therefore, only results from the last three sampling times will be discussed in this section. At Site-A the effect of green manure treatments was significant at 5½ weeks ($p=0.0002$) and 9½ weeks ($p=0.0002$) post-emergence and at final harvest ($p=0.0127$) (Figure 4.11). Ryegrass was the main green manure treatment effect influencing sweet corn N accumulation. Ryegrass significantly reduced sweet corn N accumulation compared to the control treatment and all other green manure treatments. At final harvest, the ryegrass treatment reduced sweet corn N accumulation by 45% compared to the control treatment value of 117 kg N ha^{-1}. However, no other green manure treatments achieved sweet corn N accumulation levels statistically different from the control treatment at final harvest.

At Site-B, the effect of green manure treatments was significant at 5½ weeks ($p=0.0091$) and 9½ weeks ($p=0.0016$) post-emergence and at final harvest ($p=0.0001$) (Figure 4.12). At these three sampling times the ryegrass treatment also significantly reduced sweet corn N accumulation compared to the control treatment and all other green manure treatments. At final harvest the ryegrass treatment decreased sweet corn N accumulation by 36% compared to the control treatment value of 103 kg N ha^{-1}. Also, the lupin and mustard/lupin mix treatments significantly increased sweet corn N accumulation by 21% and 18%, respectively, compared to the control treatment.

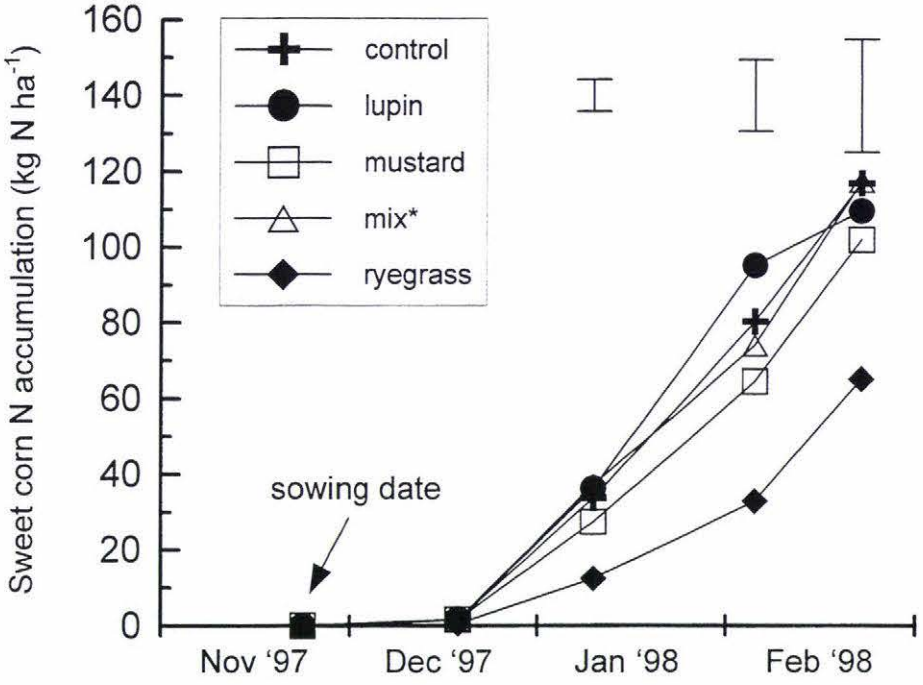


Figure 4.11. Effect of green manure treatments on sweet corn N accumulation at Site-A (vertical bars denote LSD values at 5% significance level). *(mustard/lupin mix treatment)

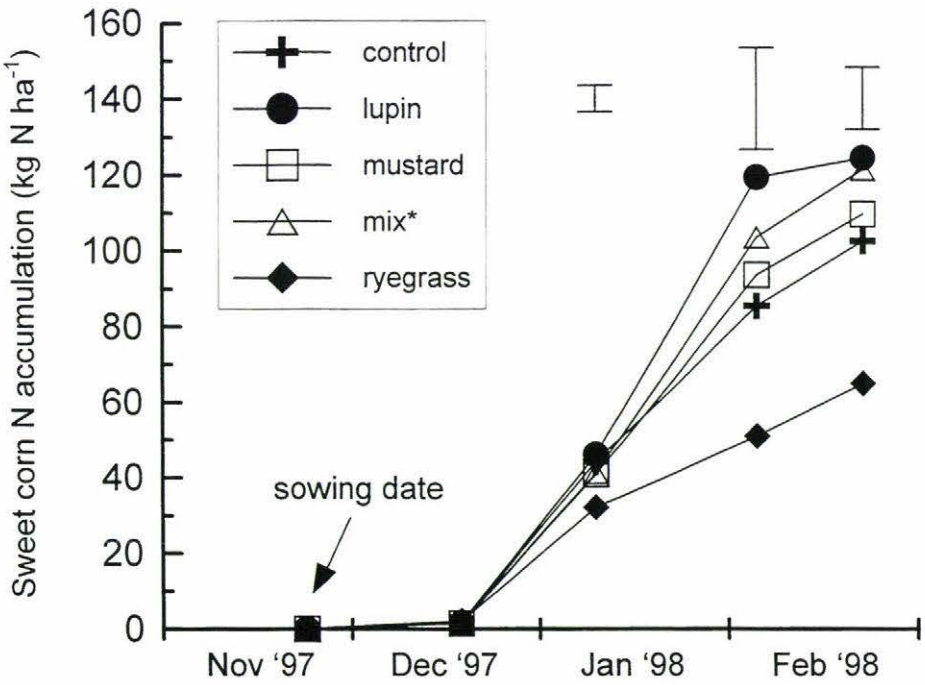


Figure 4.12. Effect of green manure treatments on sweet corn N accumulation at Site-B (vertical bars denote LSD values at 5% significance level). *(mustard/lupin mix treatment)

At final harvest (19-20 February 1998), sweet corn N accumulation also showed a relationship with soil (0-150 mm) total mineral N measured at sweet corn emergence (30 November 1997). This relationship was strongest at Site-B (Figures 4.13 and 4.14). At Site-B, as the level of soil total mineral N at sweet corn emergence is increased the amount of N accumulated by sweet corn increases, however, there is very little further increase in sweet corn N accumulation above a soil mineral N level of about 80 kg N ha^{-1}.

The sweet corn N accumulation results reflect the effect green manure treatments had on soil N availability, particularly at Site-B (Section 4.2.6.1). At both sites the lupin and mustard/lupin treatments increased soil N availability at sweet corn emergence, however, it was only at Site-B that these two treatments resulted in increased N accumulation compared to the control treatment. Again, this may be due to soil and climate difference between sites and higher sampling variability at Site-A compared to Site-B at final harvest.

Sweet corn growing in the lupin treatment plots accumulated 117 kg N ha^{-1} (above-ground N accumualtion) on average over the two trial sites. This level of N accumulation was just below the 125-225 kg N ha^{-1} range measured by Hansen 2000 in high yielding (20-23 t ha^{-1}) sweet corn crops (Jubilee and SS42 cultivars). In the present study, this is likely to indicate that the N status of the sweet corn grown in the lupin treatment plots was near levels required for achieving high yields.

The mustard treatment did not influence sweet corn N accumulation compared to the control treatment at either of the two trial sites. This result reflects the finding that the mustard treatment did not alter soil N availability compared to the control treatment. The ryegrass treatment, which resulted in soil N net immobilization, reduced sweet corn N accumulation at both sites compared to the control treatment. Sweet corn growing in the ryegrass treatment plots accumulated 65 kg N ha^{-1} at both trial sites, which was only about 50% of the lowest N accumulation value measured, by Hansen 2000, in high yielding sweet corn crops. In the present study, the relatively low level of N accumaltion measured in sweet corn growing in ryegrass plots would help to explain why the ryegrass treatment effect also substantially reduced sweet corn DM accumulation and 'harvestable' ear yield (results discussed in subsequent sections).

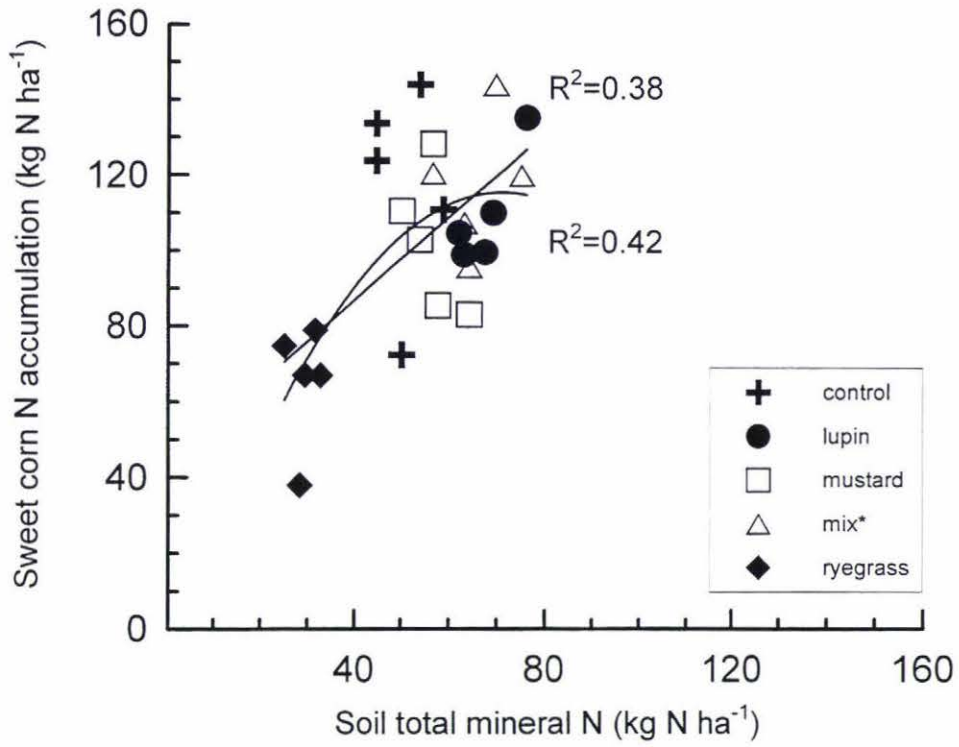


Figure 4.13 Relationship between soil (0-150 mm) total mineral N measured at sweet corn emergence, and sweet corn N accumulation at harvest (Site-A). *(mustard/lupin mix treatment)

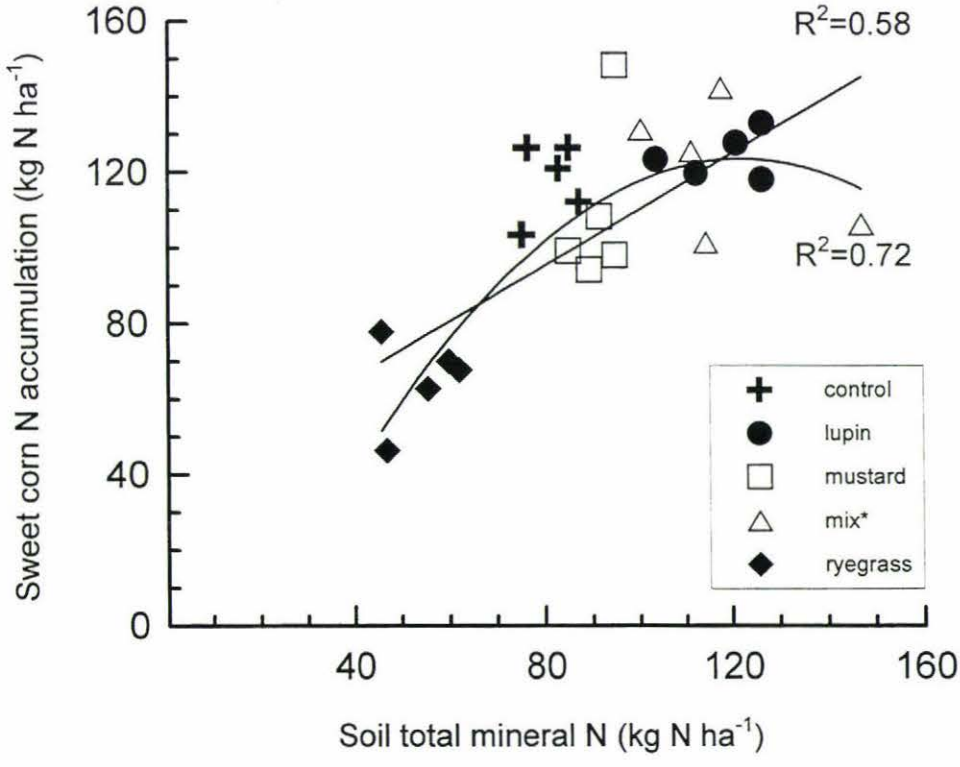


Figure 4.14 Relationship between soil (0-150 mm) total mineral N measured at sweet corn emergence, and sweet corn N accumulation at harvest (Site-B). *(mustard/lupin mix treatment)

4.5.2 Sweet corn P accumulation

Overall there was insufficient evidence to support a hypothesis that green manure treatments had a significant influence on P accumulation of the subsequent sweet corn crop (Appendix 7). Such an outcome is clearly expected for Site-A where the soils had high P availability (Olsen P = 45) at the commencement of the study. At Site-B, however, the soils had low P availability (Olsen P = 13). This suggests that green manure treatments were not effective at influencing P availability for the subsequent sweet corn crop even when soil P availability was low. As discussed in Section 4.2.4, green manure crop P accumulation and concentrations were similar for all green manure treatments except mustard. Mustard had lower P concentration and accumulation levels compared to all the other green manure treatments, although the actual levels for mustard were likely to be higher than the recorded values due to substantial defoliation prior to sampling.

Another reason why green manure treatments did not have a significant influence on sweet corn P content may be due to the behaviour of P in soils. Broadbent (1986) states that the influence of organic matter on P supply to plants is somewhat more difficult to evaluate than in the case of N, since plants derive a significant proportion of their P from inorganic sources. In addition, the release of P from organic forms may be followed by sorption and precipitation reactions, which alter the availability of the P mineralised.

4.5.3 Sweet corn dry matter accumulation

The effect of green manure treatments on sweet corn DM accumulation was monitored for the same four sampling times as with sweet corn N accumulation (Section 4.4.1). At Site-A, the effect of green manure treatments on sweet corn DM accumulation was significant at 2½ weeks ($p=0.0014$), 5½ weeks ($p=0.0002$) and 9½ weeks ($p=0.0006$) post-emergence, but not at final harvest (Figure 4.15). The treatment which influenced sweet corn DM the most during the initial three samplings times was ryegrass. The ryegrass treatment reduced sweet corn DM levels compared to the control treatment and all other green manure treatments. At the third sampling the ryegrass treatment resulted in sweet corn DM yield 42% lower than the control treatment value of 5,200 kg DM ha^{-1}.

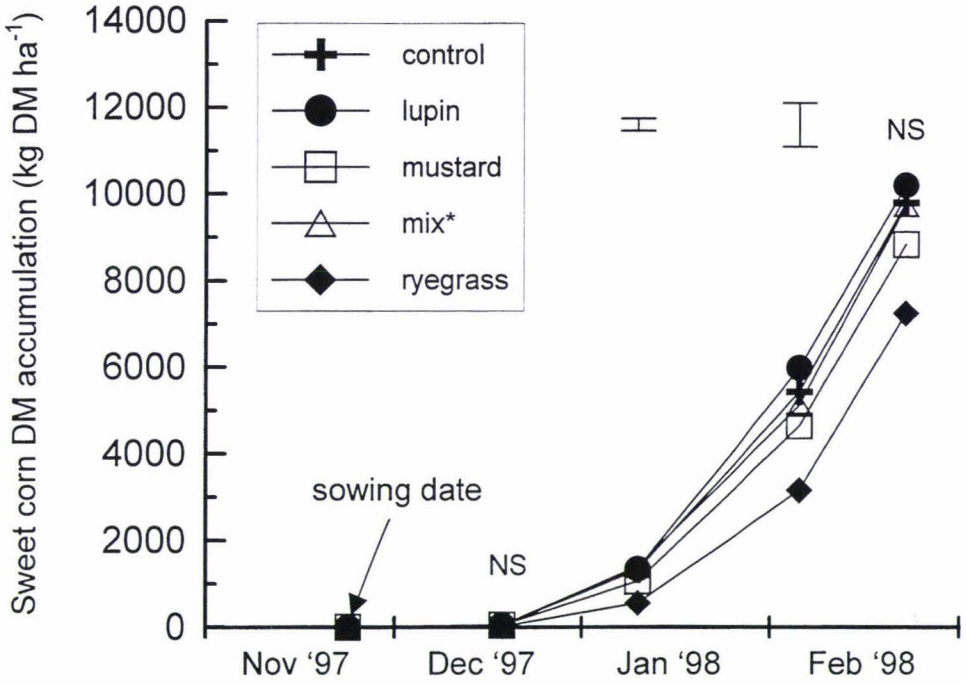


Figure 4.15 Effect of green manure treatments on sweet corn DM accumulation at Site-A (vertical bars denote LSD values at 5% significance level. 'NS' denotes not significant.) * (mustard/lupin mix treatment)

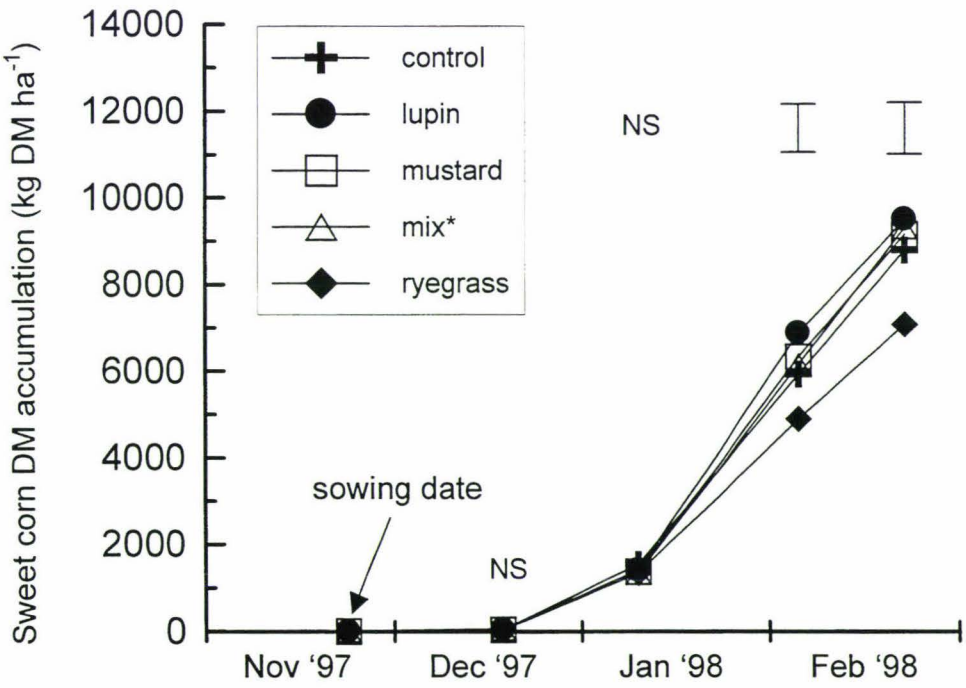


Figure 4.16 Effect of green manure treatments on sweet corn DM accumulation at Site-B (vertical bars denote LSD values at 5% significance level. 'NS' denotes not significant.). *(mustard/lupin mix treatment)

At Site-B, the effects of green manure treatments were significant (p=0.0051) at 9½ weeks (p=0.0246) after sweet corn emergence and again at final harvest (Figure 4.16). At final harvest, ryegrass was the only treatment producing sweet corn DM levels statistically different from the control treatment. The ryegrass treatment reduced sweet corn DM levels by 20% compared to the control treatment value of 8,800 kg DM ha^{-1}.

In summary, the ryegrass treatment substantially decreased soil N availability and consequently resulted in decreased sweet corn DM yields compared to the control treatment. Visually the effect of the ryegrass treatment on the development of the subsequent sweet corn crop was noticed as early as 2½ weeks after sweet corn emergence, particularly at Site-A (Plates 4.5 and 4.6).

At all four sampling times and at both sites the lupin, mustard/lupin mix and mustard treatments did not produce sweet corn DM yields significantly different from the control treatment. Although the lupin and mustard/lupin treatments did increase soil N availability this did not translate into increased sweet corn DM accumulation. This result suggests that either N availability in the control treatment was sufficient for optimum yield or some other factor was more limiting than N in all treatments except ryegrass. A drought experienced in Gisborne during the summer of 1997/98 is likely to have had a major impact on sweet corn growth and responsiveness to improved soil N fertility. The effect of climate on sweet corn yields is discussed further in subsequent sections.

Plate 4.5. Sweet corn growing in treatment plots 2½ weeks after emergence (17 December 1997) at Site A. Plots with poor growth show the effect of the ryegrass treatment.

Plate 4.6. Pale, stunted sweet corn plants 2½ weeks after emergence (17 December 1997) in a ryegrass treatment plot at Site A (ryegrass residues still visible).

4.5.4 Sweet corn harvestable ear yield

On 19-20 February 1998, sweet corn ears were harvested from treatment plots at both trial sites using the method described in Section 3.8.1.2. The effects green manure treatments had on sweet corn 'harvestable' ear yields were highly significant (p=0.0001) at both sites (Figure 4.15). However, ryegrass was the only treatment effect statistically different from the control treatment at both sites. Ryegrass significantly reduced sweet corn 'harvestable' ear yields by 64% and 48% at Sites A and B, respectively, compared to the control treatment.

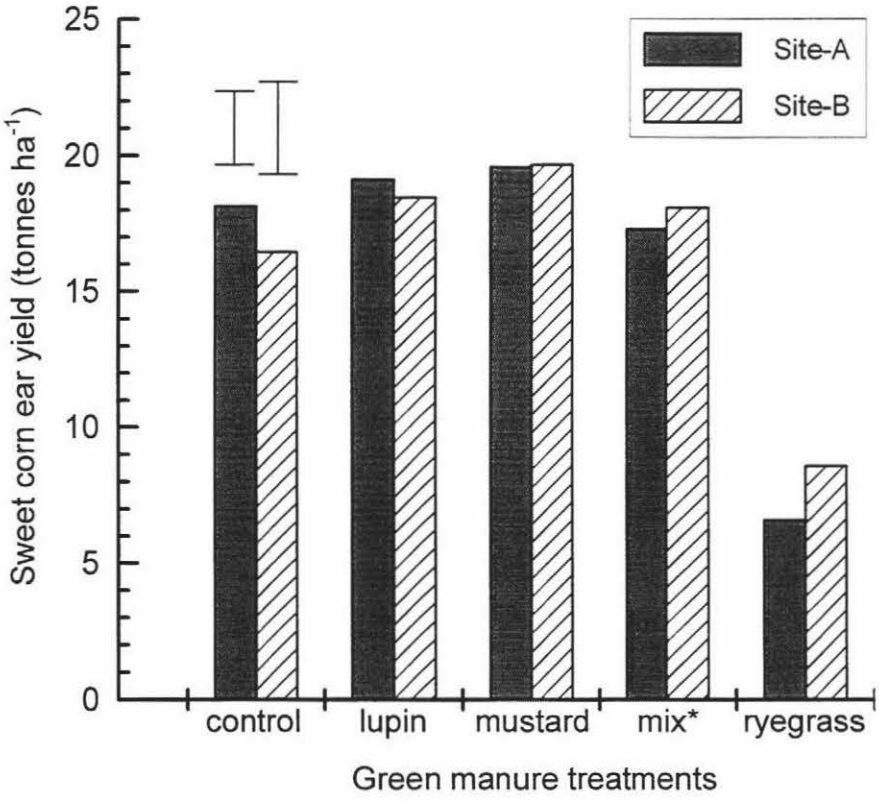


Figure 4.17 Effect of green manure treatments on sweet corn 'harvestable' ear yield at final harvest (19-20 February 1998) at Site-A and Site-B. (Vertical lines above the yield bars denote LSD values at the 5% significance level and relate to treatment comparisons at each site). *(mustard/lupin mix treatment)

Regression analysis indicated that there was a relationship between soil (0-150 mm) mineral N, at sweet corn emergence, and sweet corn 'harvestable' ear yields (Figures 4.18 and 4.19). Although, the strength of this relationship is predominantly due to the effect of the ryegrass treatment at both sites, it supports the hypothesis that ryegrass reduced sweet corn ear yields mainly due to its negative influence on soil N availability.

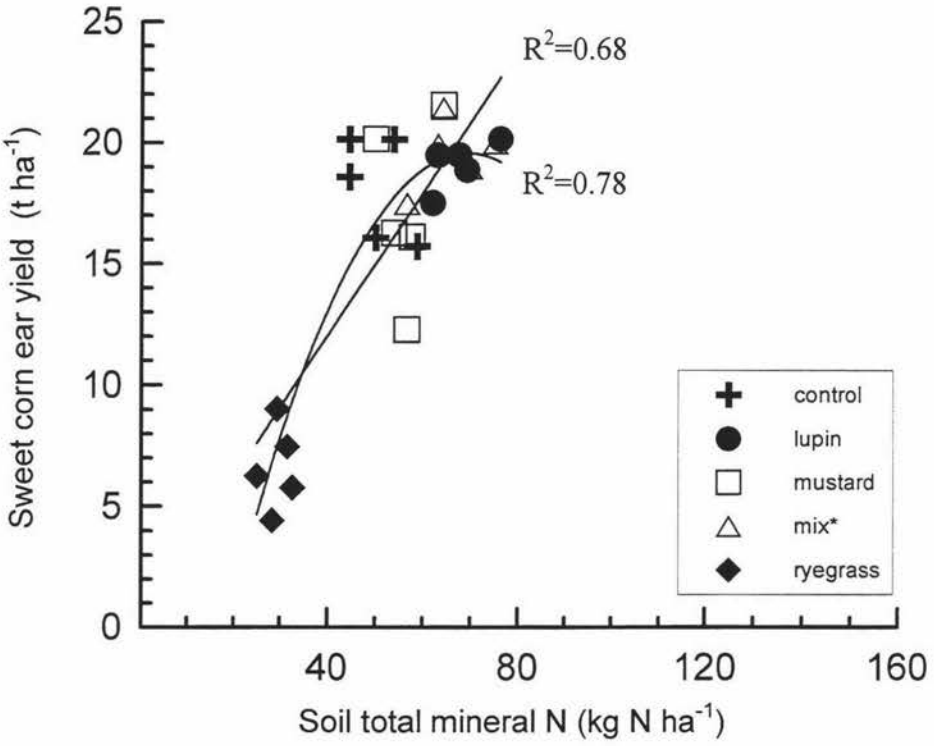


Figure 4.18 Relationship between soil (0-150 mm) total mineral N measured at sweet corn emergence, and sweet corn 'harvestable' ear yield at harvest (Site-A).

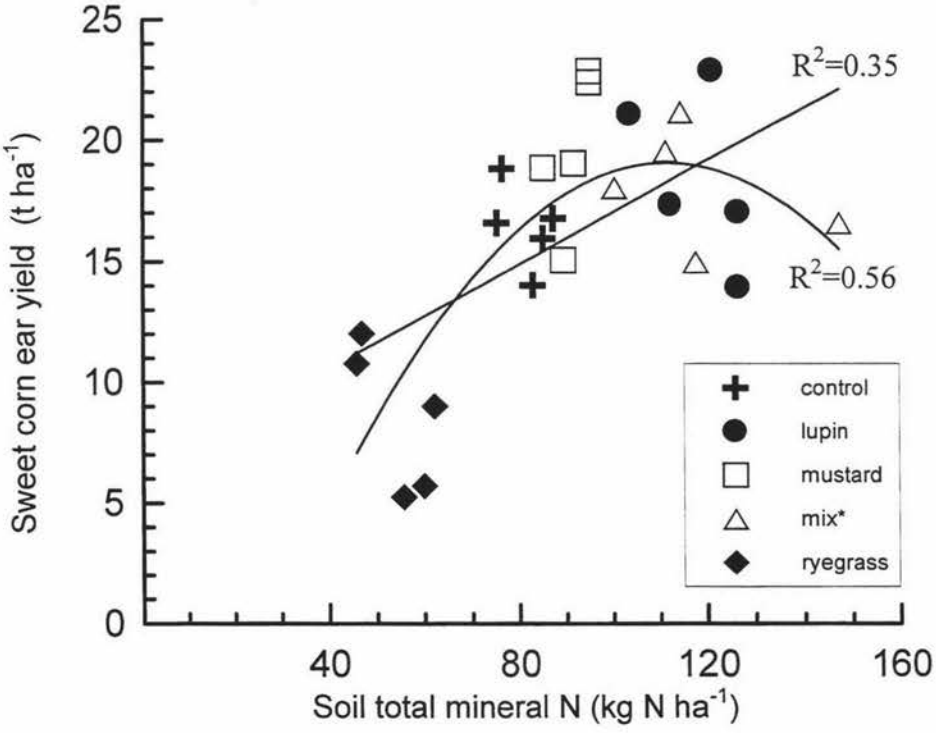


Figure 4.19 Relationship between soil (0-150 mm) total mineral N measured at sweet corn emergence, and sweet corn 'harvestable' ear yield at harvest (Site-B).

In general, fertiliser-N response studies (Magdoff *et al.*, 1984; Fox *et al.*, 1989; Binford *et al.*, 1992; Meisinger *et al.*, 1992; 1993; Heckman *et al.*, 1995) have shown that when soil (0-300 mm) NO_3-N levels are > 25 ppm when sweet corn plants are 300 mm tall then yield responsiveness to increased N availability is likely to be minimal. In the present study, soil (0-150 mm) samples collected 5½ weeks after sweet corn emergence indicated that at both sites only the ryegrass treatment had soil NO_3-N levels below 25 ppm, being 19 ppm and 23 ppm for Site-A and Site-B respectively (Appendix 4 and 5). Unfortunately, the 150-300 mm soil depth was not sampled, therefore, any comparisons with the above mentioned studies have limited value.

Even though the lupin and mustard/lupin mix treatments resulted in increased soil N availability and sweet corn N accumulation this did not result in increased DM accumulation or sweet corn ear yields compared to the control treatment. This result suggests that either N availability in the control treatment plots was sufficient to produce optimum yields or that some other yield limiting factor was more influential than soil N availability, for all treatments except ryegrass.

In the paddocks where field trials in this study were conducted, average paddock sweet corn yields during the 1997/98 season were substantially lower than the yields achieved during the 1994/95 season, particularly at Site-A (Table 4.4). Average district sweet corn yields during the 1997/98 season were also lower than normal, particularly for crops grown later in the season, as in this study.

Table 4.4 'Paid' weight of Bio-Grow NZ certified sweet corn processed by Heinz-Wattie Ltd, Gisborne.

Season (cultivar)	**Bio-Grow Gisborne District averages (t ha^{-1})**	**Site-A Average paddock yield (t ha^{-1})**	**Site-B Average paddock yield (t ha^{-1})**
1994/95	21.6 (Jubilee)	15.2 (Reliance)*	22.6 (Jubilee)
1995/96	12.3 (Jubilee)	15.0 (SS42)*	13.3 (Jubilee)
1996/97 (Jubilee)	9.0	10.0	14.4
1997/98 (Punch)	10.0	7.5 (8)**	14.0 (14.5)**

* (During the 1994/95 and 1995/96 seasons sweet corn was conventionally grown at Site-A).
**(Numbers in brackets are harvested ear gross field weight).

In the Gisborne region during the 1997/98 season, low sweet corn yields were attributed to drought conditions caused by lower than normal rainfall (Appendix 9) during the summer months (pers. comm. Walsh, 1998). Climate data was used to estimate evapotranspiration (Allen *et al.* 1998) and derive an estimate of soil water balance (Figure 4.20). The soil water balance shows that the sweet corn grown in this study were likely to have experienced water stress during the final stages of development. It is therefore likely that low soil moisture limited sweet corn yield in this study.

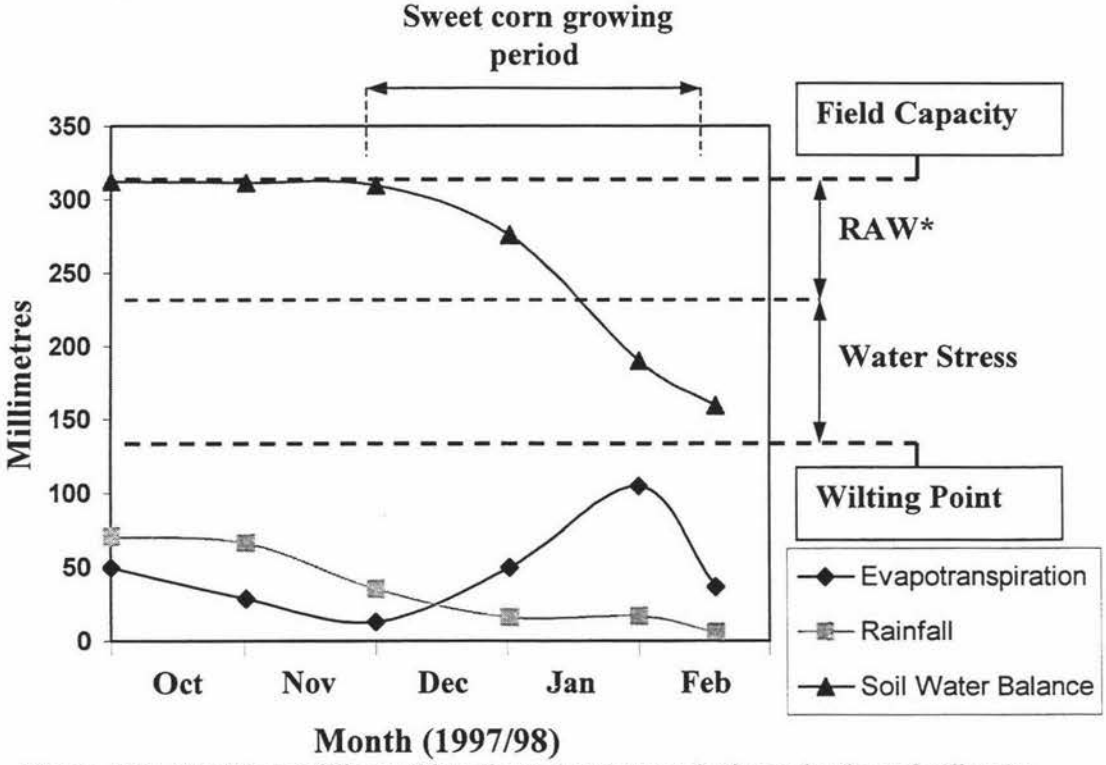


Figure 4.20. Monthly rainfall, monthly estimated evapotranspiration and estimated soil water balance (800 mm soil rooting depth; silt loam soil) for Gisborne. *(RAW = Readily Available Water)

Although, the sweet corn ear yields obtained for the control treatments in this study appear relatively high compared to the actual average paddock yields, this may be due to field variability and differences between sampling techniques used to assess ear yield in the trial and actual machine harvested ear yields. The trials were also located in parts of the fields that were likely to yield higher than field averages, particularly at Site-A. Both trial sites where located well away from fence lines to avoid headlands, which are usually lower yielding due to vehicle compaction. Also, Site-A was located on an area of the field where the soils where heavier textured and, therefore, were likely to have had greater water holding capacity compared to areas of lighter textured soils in the field.

4.6 Cropping system annual N balance.

The development of sound farm management programs requires an understanding of the reactions of N in the soil, of sources of N for plant growth other than fertiliser, and of pathways of loss of N from the system (Keeney and Gregg, 1982). Any substantial losses of N from a cropping system need to be replaced to maintain productivity. This section briefly compares known and estimated annual N inputs and losses in the green manure and sweet corn cropping systems used in this study.

Over the duration of this study the only significant input of N into the soil-crop system was from biological N fixation in the lupin crop grown both as a treatment on its own and in a mix with mustard. The 'difference method' (Williams *et al.*, 1977) was used to estimate N fixation in this study because more direct methods for assessing N fixation in field conditions (ie. N^{15} or acetylene reduction techniques) were not used. The 'difference method' involves subtracting the total N content of a non-fixing crop (derived solely from soil N) from the total N content of a N-fixing legume. The difference between the values is assumed to be the quantity of N derived by N fixation. In the present study, this estimate of N fixation was achieved by subtracting the amount of N accumulated by the ryegrass treatment from the amount of N accumulated by either the lupin or mustard/lupin mix treatments (Table 4.5).

Table 4.5 Estimates of N fixation using the 'Difference' method (LaRue and Patterson, 1981).

Trial Site	Legume treatment (N content kg N ha^{-1})	Non-legume treatment (N content kg N ha^{-1})	Difference (estimate of N fixation by legume in kg N ha^{-1})
Site A	Lupin (156)	Mustard (58)**	98
		Ryegrass (79)	**77**
	Mix* (116)	Mustard (58)**	58
		Ryegrass (79)	**37**
Site B	Lupin (173)	Mustard (19)**	154
		Ryegrass (54)	**119**
	Mix* (139)	Mustard (19)**	120
		Ryegrass (54)	**85**

* (Mustard and lupin mix treatment)

**(mustard treatment in this study is not a reliable estimate due to early defoliation prior to final sampling)

The estimates of N fixation in Table 4.6 assume that the legume (lupin) and the non-legume (ryegrass) green manures derived the same quantity of N from the soil and that an insignificant amount of the ryegrass N is derived from biological fixation. The first of these assumptions is admittedly questionable (Smith *et al.,* 1987), however, in the absence of a direct method to measure biological N fixation this estimate provides the best estimate of the N contribution made by biological N fixation.

The main N losses from the soil-crop system are from N lost in harvested corn, NO_3^- leaching and volatilisation (N_2 , N_2O , NO , NH_3 gaseous losses). Annual N leaching and volatilisation losses were not monitored in this study. However, Table 4.6 gives estimates for the levels of annual leaching and volatilisation N losses required before there are annual net N losses from these soil-plant systems.

Table 4.6 Annual N balance in green manure-sweet corn cropping systems at both trial sites.

Soil –plant system N inputs and losses	**Site-A**		**Site-B**	
	Lupin	*Mix**	*Lupin*	*Mix**
N Inputs	**(kg N ha^{-1})**	**(kg N ha^{-1})**	**(kg N ha^{-1})**	**(kg N ha^{-1})**
1. fertiliser/compost/animal manure	0	0	0	0
2. green manure N fixation[i]	77	37	119	85
A. TOTAL INPUTS	77	37	119	85
N Losses	**(kg N ha^{-1})**	**(kg N ha^{-1})**	**(kg N ha^{-1})**	**(kg N ha^{-1})**
3. leaching and volatilisation	x	x	x	x
4. sweet corn harvest losses[ii]	72	77	81	79
B. TOTAL LOSSES	$72 + x$	$77 + x$	$81 + x$	$79 + x$
NET GAIN (A– B)	$5 - x$	$-(40 + x)$	$38 - x$	$6 - x$

*(Mustard/lupin mix treatment)
[i](Estimated using the Difference Method)
[ii](Sweet corn N harvest losses where estimated as 65% [Hanson, 2000] of the total N accumulation in sweet corn)

For lupin at Site-A leaching and volatilisation losses need to exceed 5 kg N ha^{-1} before there is an annual net N loss. However, the mustard/lupin mix harvest losses (Site-A) exceeded the estimated N gains via fixation by 40 kg N ha^{-1} even before leaching and volatilisation losses are accounted for. At Site-B, annual leaching and volatilisation losses need to exceed 38 kg N ha^{-1} and 6 kg N ha^{-1} for the lupin and mustard lupin mix treatments respectively for an annual net N loss to occur.

Leaching losses were likely to have been minimal or nil over the sweet corn growing period in this study due to very low rainfall (Appendix 9). However, on an annual basis there will inevitably be some losses of N from the soil-plant system via leaching and volatilisation. The quantity of N lost via leaching and volatilisation are highly variable depending on rainfall intensity and frequency and quantity of mineral N available in the soil.

Winter green manures reduce NO_3^- leaching (Martinez *et al.*, 1990; Webster *et al.*, 1992) by depleting both soil NO_3^- and water while they are growing, however, some losses can still occur, being dependant on rainfall. In a study investigating NO_3^- leaching losses under autumn sown cover crops Macdonald *et al.* (1996) observed that in a wet winter (268 mm total drainage) leaching losses were 34 kg N ha^{-1} under bare fallow and 17-33 kg N ha^{-1} under cover crops. In the same study during a relatively dry winter (32 mm total drainage) nitrate leaching losses were lower, being 9 kg N ha^{-1} under bare fallow and 1-5 kg N ha^{-1} under cover crops.

At Site-A the estimated input of N via fixation for the lupin treatment is virtually the same as sweet corn harvest losses. However, for the mustard/lupin mix treatment the harvest N losses were substantially higher than estimated gains to the system via N fixation. These results indicate that if N losses via leaching and volatilisation were also included then it is likely that the continuous use of green manure and sweet corn crop rotations would lead to declining total soil N at Site-A over the long-term.

Alternating sweet corn with a cash crop that either fixes its own N or has lower N harvest losses can help to maintain a balance between N gains and losses over a two-year period. For example, at Site-A in some years vining peas are grown instead of sweet corn. Because vining peas are a leguminous crop they bring further N into the soil-plant system via biological N fixation. Another way to improve the N balance is to change from a continuous cropping to a mixed cropping system as is the case at Site-B, which uses a short-term pasture phase after every 3-4 years of continuous cropping. In a mixed cropping system the annual N balance in the cropping phase is supplemented over the longer-term by the contribution made by the clover based pasture phase. However, this also requires the use of an organically certified stock production system, which may be less acceptable to some organic crop growers.

Chapter 5 ~ Conclusion

Just prior to soil incorporation, the lupin crop contained the highest N concentration and N accumulation levels compared to the other green manure crop treatments used in this study. The mustard/lupin mix treatment also contained high levels of N, which were mostly due to its lupin component. Soil incorporation of green manures significantly influenced soil (0-150 mm) mineral N levels measured at sweet corn emergence and at 5½ weeks post emergence.

Compared to the control treatment none of the four green manure treatments used in this study improved sweet corn 'harvestable' ear yield, even though the lupin and mustard/lupin mix treatments both increased soil N availability and sweet corn N accumulation. Insufficient soil moisture over the growing period is likely to be the reason why the higher soil N availability, observed for the lupin and mustard/lupin treatments, did not result in increased sweet corn DM or 'harvestable' ear yields.

The ryegrass green manure treatment had a detrimental effect on sweet corn yields. This treatment significantly reduced sweet corn 'harvestable' ear yields by 64% and 48% at Site-A and Site-B, respectively, compared to the control treatment. Also, compared to the control treatment the ryegrass treatment substantially depressed sweet corn N and DM accumulation.

The negative impacts of the ryegrass treatment on sweet corn were related to its high DM yield and low N concentration just prior to soil incorporation, which caused net immobilisation of soil N. As a result soil N availability was considerably lower in the ryegrass treatment plots, compared to the control treatment plots, for the majority of time the subsequent sweet corn crop was developing. This result emphasises the importance of choosing the appropriate crop species for green manuring, particularly if fertiliser-N cannot be used, as is the case in organic cropping systems.

It is generally accepted that testing for soil mineral N and/or the use of short-term biological incubation procedures have been shown to be important components in the evaluation of plant available N for agricultural crops. In the current study, soil mineral N tested early in the sweet corn growing season gave a better relationship with sweet

corn N accumulation and yield compared with the incubation tests used. Short-term soil incubation tests, conducted under aerobic and anaerobic conditions, were not useful as indicators of net N mineralisation as they did not relate well to actual soil N mineralisation or crop response.

Although both the lupin and the mustard/lupin mix treatments had similar effects on soil N availability and sweet corn N accumulation, of the two the lupin treatment achieved a higher level of estimated N fixation. Therefore, the lupin treatment was likely to have provided greater gains of N into the soil-plant system. At both trial sites, estimated N fixation in the lupin treatment was higher than N losses in harvested sweet corn ears. This positive N balance would help to compensate for other possible N losses from the system (ie. ammonia volatilisation or nitrate leaching).

Overall, the lupin green manure treatment appears be the best crop in terms of improving short-term N availability for the subsequent sweet corn crop and for maintaining an N balance in the soil–plant system. But ultimately, the benefit of lupin as a green manure crop will also be dependant on environmental conditions and management practices. Also, this recommendation is based solely on the benefits lupin provides in terms of N supply in the soil-crop system and, therefore, further consideration needs to be given to any possible detrimental effects of growing lupin annually for many years (ie. crop disease problems).

This present study compared the relative agronomic effectiveness of a range of green manure crops using the same management practises. Future research could evaluate different management practices for improving the effectiveness of lupin as a green manure. This could include:

- length of fallow period following lupin soil incorporation,
- optimal nutrition for lupin to maximise its yield and biological N fixation,
- lupin residue management (ie. residue shredding versus disking).

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Appendices

Appendix 1. Green manure crop establishment

Treatment name		Number of plants (plants/ m^2)	
		Site-A	Site-B
lupin		22	22
mustard		29	32
mix:	*lupin*	10	9
	mustard	20	23
ryegrass		346	401

Appendix 2. Soil (mineral N levels (6 September 1997) at Site-A.

Soil depth	Treatment name	NO_3^--N *(kg N ha^{-1})*	NH_4^+ - N *(kg N ha^{-1})*	Total mineral N *(kg N ha^{-1})*
0-150 mm	**control**	4.0	15.8	19.8
	lupin	2.2	20.9	23.1
	mustard	2.5	17.7	20.2
	mix*	2.1	17.1	19.2
	ryegrass	1.4	16.4	17.8
	P value	*P=0.0001*	*NS*	*NS*
	LSD	*0.7*	-	-
150-300 mm	**control**	4.1	14.4	18.5
	lupin	2.4	18.0	20.4
	mustard	2.8	17.7	20.5
	mix*	2.2	19.9	22.1
	ryegrass	1.6	16.3	17.9
	P value	*P=0.0001*	*P=0.0465*	*NS*
	LSD	*0.7*	*3.5*	-
300-450 mm	**control**	4.3	14.9	19.2
	lupin	1.9	13.6	15.5
	mustard	2.4	14.4	16.8
	mix*	1.9	14.4	16.3
	ryegrass	1.4	13.9	15.3
	P value	*P=0.0001*	*NS*	*NS*
	LSD	*0.6*	-	-

**(mustard/lupin mix treatment)*

Appendix 3. Soil mineral N levels (17 September 1997) at Site-B.

Soil depth	Treatment name	NO_3^--N *(kg N ha^{-1})*	NH_4^+ - N *(kg N ha^{-1})*	Total mineral N *(kg N ha^{-1})*
0-150 mm	**control**	7.4	25.0	32.4
	lupin	8.1	25.9	34.0
	mustard	7.4	27.0	34.4
	mix*	6.8	33.2	40.0
	ryegrass	4.4	26.9	31.3
	P value	*P=0.0008*	*NS*	*NS*
	LSD	*1.3*	-	-
150-300 mm	**control**	7.3	30.7	38.0
	lupin	7.9	29.5	37.4
	mustard	7.7	28.1	35.9
	Mix*	7.0	36.0	43.0
	ryegrass	5.7	27.8	33.5
	P value	*P=0.0599*	*NS*	*NS*
	LSD	*1.3*	-	-
300-450 mm	**control**	6.2	25.3	31.5
	lupin	6.5	27.3	33.8
	mustard	6.6	26.2	32.8
	mix*	5.7	24.0	29.7
	ryegrass	4.7	26.1	30.8
	P value	*NS*	*NS*	*NS*
	LSD	-	-	-

**(mustard/lupin mix treatment)*

Appendix 4. Soil (0-150 mm) mineral N levels over sweet corn growing season at Site-A

Sampling Date	Treatment name	NO_3^--N *(kg N ha^{-1})*	NH_4^+ - N *(kg N ha^{-1})*	Total mineral N *(kg N ha^{-1})*
30 Nov 1997	**control**	30.6	19.8	50.4
(sweet corn emergence)	**lupin**	45.2	22.5	67.7
	mustard	34.4	22.1	56.5
	mix*	42.3	23.5	65.8
	ryegrass	9.2	20.3	29.5
	P value	*P=0.0001*	*P=0.0347*	*P=0.0001*
	LSD	*6.4*	*2.5*	*7.9*
7 January 1998	**control**	41.1	56.0	97.1
(5½ weeks post-emergence)	**lupin**	60.3	54.1	114.4
	mustard	46.9	50.1	97.0
	mix*	56.0	51.2	107.2
	ryegrass	28.3	47.6	75.9
	P value	*P=0.0001*	*NS*	*P=0.0133*
	LSD	*8.2*	-	*18.8*
3 February 1998	**control**	18.9	40.3	59.2
(9½ weeks post-emergence)	**lupin**	27.3	45.4	72.7
	mustard	14.9	41.8	56.7
	mix*	20.3	47.6	67.9
	ryegrass	10.5	40.7	51.2
	P value	*P=0.0341*	*NS*	*P=0.0620*
	LSD	*9.6*	-	*15.1*

**(mustard/lupin mix treatment)*

Appendix 5. Soil (0-150 mm) mineral N levels over sweet corn growing season at Site-B.

Sampling date	Treatment name	NO_3^--N *(kg N ha^{-1})*	NH_4^+ - N *(kg N ha^{-1})*	Total mineral N *(kg N ha^{-1})*
30 Nov 1997	**Control**	60.0	21.3	81.3
(sweet corn emergence)	**Lupin**	97.4	20.5	117.9
	Mustard	67.8	23.3	91.1
	mix*	95.0	23.1	118.2
	Ryegrass	33.1	20.9	54.0
	P value	*P=0.0001*	*NS*	*P=0.0001*
	LSD	*11.7*	-	*10.4*
8 January 1998	**control**	62.1	13.5	75.6
(5½ weeks post-emergence)	**lupin**	107.0	14.6	121.6
	mustard	62.3	14.2	76.5
	mix*	105.5	15.6	121.1
	ryegrass	34.9	14.2	49.1
	P value	*P=0.0001*	*NS*	*P=0.0001*
	LSD	*12.1*	-	*12.4*
4 February 1998	**control**	23.6	39.2	62.8
(9½ weeks post emergence	**lupin**	25.4	36.7	62.1
	mustard	22.5	39.2	61.7
	mix*	32.0	37.1	69.1
	ryegrass	13.1	39.2	52.3
	P value	*NS*	*NS*	*NS*
	LSD	-	-	-

**(mustard/lupin mix treatment)*

Appendix 6. Linear relationship between 'actual' net mineralisable N and two lab incubation methods in soils (0-15 cm) sampled at sweet corn emergence (November 30 1997).

	Aerobic incubation Net mineralisable N	Anaerobic incubation Net mineralisable N
'Actual' net mineralisable N		
Site-A	R^2=0.022	R^2=0.077
Site-B	R^2=0.080	R^2=0.008

Appendix 7. Effect of green manure treatments on sweet corn P accumulation.

Sampling date	Treatment name	Sweet corn P accumulation (kg P ha^{-1})	
		Site-A	**Site-B**
17-18 December 1997	**Control**	0.12	0.11
(2½ weeks post-emergence)	**Lupin**	0.13	0.11
	Mustard	0.14	0.10
	mix*	0.12	0.11
	Ryegrass	0.08	0.17
	P value	*NS*	*NS*
	LSD	-	-
8-9 January 1998	**control**	4.15	3.93
(5½ weeks post-emergence)	**lupin**	4.28	3.46
	mustard	3.27	3.48
	mix*	4.41	3.24
	ryegrass	2.49	3.69
	P value	*0.0030*	*NS*
	LSD	0.93	-
3-4 February 1998	**control**	11.25	9.42
(9½ weeks post-emergence)	**lupin**	13.28	12.60
	mustard	10.03	10.48
	mix*	10.80	10.64
	ryegrass	10.13	9.41
	P value	*NS*	*NS*
	LSD	-	-
19-20 February 1998	**control**	16.75	14.68
(Final harvest)	**lupin**	17.72	14.63
	mustard	16.17	14.12
	mix*	17.72	14.16
	ryegrass	18.95	11.98
	P value	*NS*	*NS*
	LSD	-	-

**(mustard/lupin mix treatment)*

Appendix 8. Linear relationships between soil N availability tests and sweet corn response.

	Sweet corn DM accumulation	**Sweet corn N accumulation**	**Sweet corn ear yield**
1.Soil total mineral N (emergence)			
Site-A	R^2=0.2192	R^2=0.3777	**R^2=0.6844**
Site-B	R^2=0.3336	**R^2=0.5757**	R^2=0.3451
2. Net mineralisable N (aerobic incubation)			
Site-A	R^2=0.0868	R^2=0.0168	R^2=0.0404
Site-B	R^2=0.0065	R^2=0.0020	R^2=0.0028
3. Net mineralisable N (anaerobic incubation)			
Site-A	R^2=-0.1526	R^2=0.0168	**R^2=-0.4900**
Site-B	R^2=-0.0510	R^2=-0.2117	**R^2=-0.5408**
1 + 2			
Site-A	R^2=0.1731	R^2=0.1278	R^2=0.2509
Site-B	R^2=0.1567	R^2=0.1924	R^2=0.3320
1 + 3			
Site-A	R^2=0.0003	R^2=0.0002	R^2=0.0040
Site-B	R^2=0.0374	R^2=0.0025	R^2=-0.0621

Appendix 9. Gisborne summer rainfall data (Source: *NZ Climate Digest*, NIWA Research Ltd.)

Period	Nov	Dec	Jan	Feb	Total (Nov-Feb)
'Normal'* summer rainfall (mm)	55	84	70	67	276
1997/98 summer rainfall (mm)	35	16	17	35**	103
1997/98 rainfall as a % of 'Normal'	64%	19%	24%	52%	37%

* ('Normal' summer rainfall is the average monthly rainfall for the period 1951-1980).
** (Only 6mm of the February 1998 precipitation fell prior to sweet corn harvest).