Know-how for Horticulture™

Understanding the use of chicken manure in vegetable production on sandy soil

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Bioscience Pty Ltd

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VG00006

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Final Report.

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Executive Summary

The prospect of banning the use of chicken manure on vegetable farms from 2001 in most production areas of Western Australia caused concern to many growers who were worried about increased costs and reduced production. Although many growers had come to rely on broiler litter as a reliable aid in crop production, information about the benefits it conferred was inadequate. This study aimed at providing information about chicken manure and its use by answering the following questions.

a) Nutritional Properties: Does broiler manure provide long term, sustained release of mineral nutrients to plant roots, and if so, what is the rate of nutrient release and what specific nutrients are of critical importance?
b) Soil Physical Properties: Does broiler manure provide a substrate to significantly increase water holding capacity, specific heat capacity or air filled porosity in sandy soils?
c) Soil Chemical Properties: Does broiler manure act as an ion-exchange medium to limit nutrient leaching from sandy soil, does it promote nitrification or does the breakdown process beneficially alter soil pH?
d) Microbiological: Does microbial degradation of broiler manure in soil influence soil properties, for instance by the generation of heat or the production of CO_2? Do the saprophytic organisms involved in decay inhibit otherwise harmful soil microflora?
e) Compositional Properties: Is broiler manure significantly different from layer manure or duck manure, and if so, does the type of sawdust used for broiler litter influence the beneficial properties.
f) Alternatives: Are alternative product able to emulate the desirable properties of chicken manure, and if so, at what cost?

The project involved both field and laboratory investigations. To initiate the study and to focus research on grower needs, interviews were conducted throughout the major production areas to determine how manure was used, at what rates and on what crops.

Field trials were undertaken to closely examine the influence of chicken manure on productivity. Crops grown were lettuce (5 trials), broccoli (2 trials) cabbage (1 trial) and sweet corn (1 trial). Laboratory trials examined the breakdown of manure and the release of nutrients. The influence of manure on soil microbiology was examined. An acidification amendment was developed and tested in an attempt to modify chicken manure so that fly breeding was reduced or stopped. A "synthetic" chicken manure was developed by combining greenwaste compost with mineral fertiliser to give the same elemental composition as chicken manure. This was compared to broiler litter in field and laboratory trials.

The major findings of the study were:

- Chicken manure provides a very cost effective and reliable means of supplying vegetable crops with nutrients, particularly nitrogen, phosphorus and potassium, but also calcium, magnesium and sulphur.

- When applied to soils, chicken manure breaks down quite rapidly by processes of microbial decay which leave little residue. The majority of nutrients are mineralised within a week of application, and there is little further release after two weeks. Chicken manure does not by itself promote the accumulation of organic carbon in soil, nor does it significantly alter soil pH or soil water holding capacity.

- Driven by the perception that surface-banded chicken manure breeds flies, most growers now incorporate manure into soil a week before planting. Planting earlier after application promotes root burning due to high levels of ammonia in soil and this hinders crop establishment.

- The current major usage method is inefficient and counter-productive, for under normal irrigation regimes, most of the applied nitrogen and potassium is lost before roots can absorb these nutrients, and incorporation breeds more rather than less flies. The loss of mineral nutrients without plant uptake has potentially undesirable environmental consequences.

- This study found that fly breeding potential of chicken manure use is related to application rate. Fly breeding was dramatically reduced when application rates are below 20 m^3 per hectare, and when manure is surface banded rather than incorporated.

- Pre-treatment of manure with mineral acid to reduce pH and ammonia volatilisation further reduces fly breeding potential. Such pre-treatment means crops can be planted immediately after application, thus a greater proportion of applied nutrients can potentially be absorbed by plants, thereby making usage more efficient and environmentally friendly.

- However fly breeding is highly seasonal, and the findings in this project needs to be studied in more detail and confirmed in areas and times when stable fly and house fly numbers are much higher than experienced during these trials.

- This study found that the major contribution to increasing organic carbon in soils used for vegetable production is crop trash rather than chicken manure residue. The healthier and more productive the crop, the greater the soil carbon accumulation, irrespective of fertiliser used.

- Compost application was found to cause a more durable increase in soil organic carbon than chicken manure, but contains far less nutrient elements in readily available form.

- "Synthetic" chicken manure made by blending compost with mineral nutrients produces a similar crop response to broiler litter, however the manufacturing cost means the price per tonne rises too high to be as economically attractive as broiler manure.

- Broiler litter promotes very significant changes in soil microbial activity, including a slight rise in soil temperature. This could be beneficial to plant growth during cool periods. The carbon dioxide evolved from decay of manure may also assist plant growth.

- Potential human pathogenic bacteria were not found in chicken manure or on crops treated with chicken manure.

- Cost effective and environmentally sustainable use of chicken manure to produce vegetable crops is a realistic possibility in Western Australia, but requires changes to current practice.

- Broiler producers should be encouraged to use screened, dried compost as an alternative litter to sawdust, as this will promote better soil organic carbon accumulation for vegetable producers as well as provide improvements in chicken health.

- Recovered broiler litter should be treated with phosphoric acid and dried to reduce pH and facilitate storage and used without breeding flies.

- Vegetable growers should apply chicken manures at rates of 15 m^3 per hectare or less, with repeat application every two weeks.

- The optimal usage which promotes high yield and quality vegetables and minimises environmental harm should involve incorporation of treated manure at 15 m^3 per hectare immediately before planting, then surface banded side dressing at 10 m^3 per hectare every two weeks until harvest.

- Such a regime still required the addition of mineral fertiliser, particularly magnesium and potassium depending on the specific crop, however the majority of nutritional needs of lettuce and Brassica crops can be provided through properly managed use of broiler litter.

Grower Summary

Chicken Manure has been used for decades as a fertiliser and soil amendment for growing a wide range of vegetable crops. With the dramatic expansion of chicken meat production starting in the mid 1960's, vast amounts of manure became available to growers. It is estimated in Western Australia that about 200,000 tonnes is now produced each year. Most of this has been used to produce leafy vegetable crops such as lettuce, cabbage, broccoli and cauliflower. Guidance on how to best use chicken manure was provided from the results of field trials undertaken by the then Western Australian Department of Agriculture.

Since the 1990's there has been increasing concern that the use of chicken manure has undesirable environmental consequences, particularly from nutrient contamination of groundwater, and because chicken manure has the potential to breed flies. In 1998, the Western Australian Government banned the application of chicken manure except during winter months as a means of reducing stable fly breeding.

Many vegetable growers in Western Australia expressed great concern that as they had come to rely heavily on chicken manure, their future prospects as growers were in jeopardy. Horticulture Australia Limited responded by funding a detailed study which was undertaken by the horticulture research company Bioscience Pty Ltd.

Study Objectives:

Growers report that chicken manure provides them with benefits beyond being a simple fertiliser, yet there is little information available on exactly how this can occur.

The study sought to answer the following questions.

a) Nutritional Properties: Does broiler manure provide long term, sustained release of mineral nutrients to plant roots, and if so, what is the rate of nutrient release and what specific nutrients are of critical importance?
b) Soil Physical Properties: Does broiler manure provide a substrate to significantly increase water holding capacity, specific heat capacity or air filled porosity in sandy soils ?
c) Soil Chemical Properties: Does broiler manure act as an ion-exchange medium to limit nutrient leaching from sandy soil, does it promote nitrification or does the breakdown process beneficially alter soil pH ?
d) Microbiological: Does microbial degradation of broiler manure in soil influence soil properties, for instance by the generation of heat or the production of CO_2, do the saprophytic organisms involved in decay inhibit otherwise harmful soil microflora ?
e) Compositional Properties: Is broiler manure significantly different from layer manure or duck manure, and if so, does the type of sawdust used for broiler litter influence the beneficial properties.
f) Alternatives: Are alternative products able to emulate the desirable properties of chicken manure, and if so, at what cost ?

Interviews:

The first part of the study involved interviewing 75 vegetable growers operating in the production area from Myalup in the south to Guilderton in the north. Growers were asked a range of questions about their experience with using chicken manure, how much they used, how they used it and what benefits they obtained. The interviews produced some surprising results:

- Although 93% of growers had experience using chicken manure, almost half of these (41% of all growers) had stopped using it. Of these, half (21%) had stopped using it because of impending government bans. The other half (20% of all growers) had stopped using it because they either no longer got the right results, or were now growing crops which did not benefit from using manure.

- Of growers interviewed, 52% believed it was a very useful material and wanted to keep using it. Over 2/3 of these growers had tried alternatives to chicken manure (such as conditioned manure and pelletised products) and most (but not all) thought the alternatives worked OK, but were much too expensive.

- The great majority of users only applied manure by incorporation before planting. Many had previously side-dressed their crops, but did not do so anymore because they were aware this bred too many flies. Only 15% of growers using manure still use side banded applications.

- The most common crops grown using manure were lettuce, followed by brassicas, but manure was also commonly applied to tomatoes and beans. Root crop growers did not use any manure.

- The amount used varied enormously, from a minium of 3 cubic meters per hectare to a maximum of 75 cubic meters.

- Although growers wanted to use manure on a year round basis, 21% reported they got better results from manure in winter compared to summer.

- A wide range of opinion was expressed about what benefits chicken manure gave. The great majority (87%) said it improved soil structure, while 37% reported they needed less irrigation water if they used manure. Users generally believed chicken manure was a safe, reliable and cheap way to produce high quality crops.

Growth Trials:

Bioscience conducted a total of 8 growth trials over a four year period. Although each trial was run slightly differently, exactly the same plots were used so we could study both the short and long term impact of using manure compared to mineral fertiliser or other organic based products.

Each trial involved using 6 different types or application methods of fertiliser (including pre-plant incorporation and side banding manure and top dressing with chemical fertiliser, manure only, “synthetic” manure made from compost and mineral fertiliser, or mineral fertiliser only.)

Each different application method was used at four different application rates, ranging from low, medium, medium high to quite high. Initial application rates were based around WA Dept of Agriculture recommendations for the particular crop. Throughout the four years these rates changed, generally becoming lower.

Four different crops were grown; lettuce (5), broccoli (2), cabbage (1) and sweet corn (1). Generally standard grower practice was employed, however to eliminate any influence due to herbicide use, no herbicides whatsoever were applied during the four years, with weed control solely by cultivation and hand or tool weeding.

The trial field was white Bassendean sand, and it was irrigated by 12 m spaced double jet knocker sprinklers. Irrigation water was high quality Oakford groundwater which is 200 ppm total dissolved salts.

Before, during and after trials, soil from each bed was sampled and analysed for a range of things, including pH, nutrient content and organic carbon content. Before each trial, soil pH was adjusted to the range 6.8 – 7.0 by the addition of ground limestone. Leaf tissue was collected from each bed and analysed in the laboratory for nutrient content. At harvest, both the quality and quantity from each test bed was carefully measured. All harvesting was undertaken manually.

During some trials, additional analysis was undertaken in the field, including measuring the amount of microbial activity in soil, and changes in soil temperature and moisture.

Laboratory trials:

Chicken manures from both broiler and egg production was tested in the laboratory to develop an understanding of variation between batches and between seasons.

Leaching columns were used to study what happens to chicken manure and fertiliser over time in soil in the absence of plants. As in the field, chicken manure was applied at different rates, either mixed into the soil, or placed on the surface. Other columns had synthetic manure, compost or mineral fertiliser added.

Each day for up to three weeks, water was applied to the top of each column, and the leachate from the bottom of the column was analysed for nutrient ions. At the completion of leaching, soil was removed from the columns and analysed so we could learn exactly how chicken manure breaks down to release nutrients to plants, and what long term changes it makes to soil properties.

Fly Breeding:
Because chicken manure use was banned on the basis of a perception it caused excessive breeding of flies, during the growth trials fly breeding within beds was measured. During the course of the study, it became apparent that it was feasible to treat raw chicken manure a number of ways to prevent fly breeding. These treated chicken manures were tested in the last three growth trials.

Major Findings:

1) Rate of chicken manure breakdown.
The study demonstrated both in the laboratory and the field that chicken manure breaks down quite rapidly in soil. Although there were slight differences between individual nutrients, most nutrients were released within 14 days of application, however the majority was released in the first 7 days. The amount of each nutrient released was directly proportional to the original composition. Nitrogen release involved firstly the release of ammonium ions, but after about 7 days, most nitrogen was released in the form of nitrate. There was very little difference in release pattern when chicken manure was incorporated into soil, or applied on the soil surface, but when applied on the surface, released nutrients take longer to leach under the root zone.

2) Impacts on soil water properties.
Incorporated chicken manure had a minor influence on soil water holding capacity. The increase was relatively minor, equating to about the same volume of additional water storage as volume of manure added. At addition rates of 30 cubic meters per hectare, the soil was initially able to hold 22% water at saturation (field capacity) whereas untreated soil was able to hold 20.5%. The increase in soil water holding capacity declined as chicken manure broke down so that after three weeks, there was no difference between plots treated with chicken manure compared to plots treated with mineral fertiliser.

Banded chicken manure did not alter soil water holding capacity, however it did influence soil moisture immediately under the band, in the top 75 mm. This was attributed to a mulching effect of the manure, slowing the evaporation of water from the soil surface after watering. This effect was more lasting than incorporate manure, because a greater residue of chicken manure remained on the surface compared to manure which had been buried.

3) Impacts on soil microbiology.
The addition of incorporated chicken manure caused a very significant increase in soil microbial respiration, increasing carbon dioxide formation by 150 – 180% at high application rates. Even small additions of chicken manure (5 cubic meters per hectare) caused a significant increase in microbial activity.

The study found that soil respiration increased as crops developed, reaching a higher level as crops matured, then reached the highest levels as crop trash was ploughed back into soil. The increase in respiration associated with crop growth meant that crops grown with mineral fertiliser eventually developed the same soil respiration rates as those grown using pre-plant manure. The overall impact of manure application on soil respiration was thus restricted to the first two to three weeks of crop growth.

The significant increase in soil respiration was associated with a small but discernable increase in soil temperature in the top 150 mm of soil. The maximum temperature increase found was 2.4^{O} C when manure was incorporated at 45 cubic meters per hectare. Although this is quite small, in one trial during winter when severe frosts were experience over a week, lettuce grown with chicken manure experienced somewhat less frost damage, but subsequent sclerotina damage was significantly reduced.

Surface banding also influenced soil temperature, however this effect was by slowing the rate of heating and cooling, rather than by changing the minimum and maximum soil temperature. Surface banded beds also had less frost damage than mineral fertiliser beds.

4) Organic carbon accumulation in soil.
Laboratory analysis showed that chicken manure organic carbon content was consistently in the range 37 – 39%. Immediately after manure incorporation in soil, soil organic carbon increased proportional to the amount of manure which had been added, however it started to decline as the chicken manure broke down.

After the first crops were harvested (before trash was ploughed in) the organic carbon in manure treated beds was barely higher than mineral fertiliser beds. Once the harvested field were ploughed, the difference became insignificant. After the second crop, again the manure treated beds had slightly more soil carbon. In the longer term, after four crops (two years) soil organic carbon had increased slightly in all trial plots, and there was no longer a significant difference between manure and mineral fertiliser treated plots.

Later trials using compost based litter showed that the organic carbon increased to higher levels where more compost had been added.

The conclusion is that vegetable production by itself marginally increases soil organic carbon content, but the greatest contribution is from crop trash residue rather than manure residue.

5) Air filled porosity.
Chicken manure had no significant influence on soil air filled porosity throughout the trial program. Porosity was highest immediately after rotary hoe ploughing before planting, and was reduced steadily as crops grew. The rate of decrease was faster in winter compared to summer.

6) Yield and quality improvement.
When crops were grown on nothing other than chicken manure, very high application rates were required to obtain commercial yields, but quality was generally poor. Leaf tissue analysis of these beds showed crops were deficient in magnesium and potassium.

Lettuce crops grown on chicken manure, but supplemented by top dressing with magnesium and potassium produced consistent and good quality crops. Brassica crops likewise required additional magnesium and potassium, however higher top dressing rates were needed to achieve high yields and high quality.

The best crops grown using chicken manure as the major fertiliser had initial pre-plant applications, followed by side banding of more manure every two weeks. These crops grew as well, and in most lettuce trials, better than beds fertilised by weekly applications of mineral fertiliser.

By amending chicken manure with phosphoric acid, pH was reduced so that ammonia was not produced. This meant crops could be planted sooner after incorporation into soil.

The study concluded that generally too much manure was being applied, and much of the potential nutrient value was being lost. Trials showed that good results can be obtained using small amounts applied frequently.

7) Fly Breeding.

The study confirmed previous work which showed that chicken manure can breed flies in large numbers. However we found that incorporation of manure produced more adult flies than side banding. When manure was used at rates of 15 m^3 per hectare or less, fly breeding was reduced to insignificant levels. At higher levels, depending on the time of year, flies could rapidly breed to very large numbers.

When manure was treated with phosphoric acid and dried, there was a significant reduction in fly breeding. This is believed to be due to acidification of manure reducing the conversion of nitrogen to ammonia which attracts flies to lay eggs. However egg laying did not stop completely, and phosphate in manure also seems to reduce the ability of maggots to survive to adulthood.

Because phosphate amended manures do not release as much ammonia, crops can be planted much sooner, if not immediately after incorporation. This means plant roots are exposed for a longer period to the minerals released from manure in the first two weeks

8) Conclusions.

Chicken manure can confer significant benefits to growers, as it a cheap and reliable means of improving production. The main reason is it provides plant nutrients at low cost, but it also confers other benefits including rapid establishment, increased soil bacterial activity and slightly elevated soil temperatures. Counter to what is widely believed, it does not seem to provide long term improvements in soil by increasing organic carbon content or water holding capacity, rather the benefits are short term.

The way chicken manure has been traditionally used has two major problems. It wastes valuable nutrients which are lost to the environment and potentially cause groundwater pollution, and it can breed flies.

The outcome is this work is to propose a new, efficient and environmentally sustainable way to use chicken manure.

- Broiler litter should be treated with 1.5 – 3% phosphoric acid, then dried. This reduces fly breeding and shortens the time between application and planting.
- Pre-plant, treated broiler litter should not be incorporated into soil at rates greater than 15 m^3 per hectare.
- After crops are established, treated manure should be applied as a side band dressing at 5 – 10 m^3 per hectare.
- Additional magnesium and potassium should be applied to lettuce during winter.

A further recommendation for this study is to encourage the broiler production industry to consider using dry, screened greenwaste-based compost as a bedding material. This would produce manure which has lower fly breeding capacity, and provide growers with a material which combines the long term benefits of compost with the short term benefits of broiler manure.

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1. Poultry Manure Use in Horticulture

1.1 Introduction:

Since the earliest days of mixed agriculture when animals were housed indoors, it has been recognised that the manure produced is best managed by applying it to land in order to improve plant productivity. The literature on manure usage thus goes back to the earliest texts on agriculture. This literature review does not seek to revisit this early history, but rather to provide a current appraisal of the existing focus on the use and management of animal manure, especially broiler manure, with a particular emphasis on the hypotheses being tested in this project.

A major feature of the last two decades has been a shift in the structure of agricultural activity, with production of chicken and pig meat becoming almost exclusively by intensive feedlot operations where uniform, high quality feeds are fed *ad libitum.* This has resulted in vast quantities of animal manures being produced. (Edwards and Daniel, 1992, Smith *et. al.*,1994, Hatfield and Stewart, 1998). Moore (1998) estimates that 13 million tonnes of poultry litter are produced annually in the USA, while in Western Australia it is estimated to be around 200,000 tonnes (Gerritsen 1997), which would nationally translate to around 2 million tonnes.

Such large volumes of waste require a sustainable management strategy, and although alternatives such as animal feeds (Bagley *et. al.* 1996) or combustion fuel for electricity have been explored, the vast majority is applied to agricultural fields as fertiliser/soil conditioner (Moore, 1998)

2. Chicken Manure as Fertiliser:

The most commonly employed and abundant form of chicken manure is from broiler production. It consists of a litter material, mainly wood chips or saw dust, and the accumulated fecal matter, feathers and spilled feed from an entire production batch. The elemental composition of broiler manure has been extensively examined (e.g. Smith *et. al.* 1994, Asiegbu and Oikeh 1995, Nicholson *et. al.* 1996, Moore 1998) and been shown to contain significant volumes of all the major, minor plant nutrients and trace elements. The actual concentration depends on the broiler production method and the rations fed, but typically contains around 3.5% N, 1.6% P and 1.8% K (all w/w on a dry weight basis). Composting or drying chicken manure causes some changes in chemical composition, most typically by reduction in total nitrogen (Mondini *et. al.*1996, Atkinson *et. al.* 1996).

Because of the high content of plant nutrients and the relatively cheap cost, a large part of the literature on the use of poultry manure focuses on the content and availability of those mineral nutrients most widely used in agriculture, being nitrogen and phosphorus. There are many studies reported on the plant availability of N and P following application of broiler manures, such as Sims (1987), N'Dayegamiye *et. al.* (1997), Robinson and Sharploy (1996) and Smith *et. al.* (1998). Because of this focus on N and P, the appropriate application rate of chicken manure for field crops is generally calculated from the N or the P requirement of the crop, as in Eghball and Power (1999).

Although receiving less attention, minor and trace element composition (Ihnat and Fernandez 1996) and availability have been studied in clay (Li *et. al.* 1996) and loam

(Cummings and Xie 1995a, 1995b). It is clear that post-production processing of manure can influence bioavailability through diversion from microbially-bound or soil-bound forms (Entry *et. al.* 1997).

The majority of field trials reported grew cereals and pasture crops, however vegetable crops such as lettuce (Flynn *et. al.* 1995), eggplant (Opara and Asiegbu 1996), peas (Vazquez *et. al.* 1996) tomatoes (Brown *et. al.* 1995) and brassicas (Mahimairaja *et. al.* 1995) have all been shown to respond well to poultry manure. The uncontrolled or poorly managed use of poultry manure can create problems for both the grower and the environment. The forms of nitrogen in manures are important. A significant but variable proportion of the nitrogen is present in the form of ammonia or ammonium (Moore 1998). When pH is high, ammonium ions form ammonia which can be lost by volatilisation, thereby reducing plant available N. This process also causes major problems in the chicken shed due to ammonia vapour. In the USA it is common to amend litter with chemicals to reduce volatilisation (Moore 1995), whereas in Australia it is more common to remove litter from sheds after each batch so the problem is not as severe.

3. Environmental Concerns

When poultry manure is applied to soil there are a range of potential environmental problems which have received attention, including nitrate and phosphate leaching, carbon runoff, bacterial contamination, nuisance insect breeding and greenhouse gas emissions.

Nitrate leaching occurs from the process of mineralisation wherein organically-bound nitrogen is released as nitrate ions which are highly mobile through soil and can potentially contaminate groundwater (Vervoort *et. al.* 1998, Liebhardt *e.t al.* 1979). When application rates are matched to crop requirements and mineralisation rates are considered, leaching is usually less than the maximum set by environmental regulations (Moore 1998).

Phosphorus leaching was not considered as serious in earlier literature, particularly from countries where P binding onto soil clay and organic fractions is common, however more recently it was realised that organically bound P is more mobile through soil (Lucero *et. al* 1995). It is now generally recommended that application rates to cereal crops should be determined by the P requirement rather than N, as the latter results in P accumulation in soil (Sharpley A.N. 1996). Phosphorus leaching is a noted problem on sandy soils (Vervoort *et. al.* 1998, Shepherd and Withers 1999, Smith *et. al.* 1998) where leaching can lead to eutrophication of water ways.

The major constituent of poultry manure is organic matter with a significant energy content, much of which becomes soluble as it is broken down by soil microbes. If such soluble organic matter enters waterways it can increase biological oxygen demand (BOD) and cause negative impacts on aquatic life (Moore 1998). High irrigation rates should thus be avoided where poultry manure is used near aquatic ecosystems (Shreve *et. al.* 1995). A related problem is bacterial runoff, where it has been noted that fecal coliform levels from land receiving manure treatments are often high (Baxter-Potter and Gilliland 1988). Later work showed that fecal bacterial survival was reduced when chicken manure was incorporated into soil, irrespective of the manure loading (Zhai *et. al.* 1995).

The potential for poultry manure to breed flies is the principle reason for community concern in WA, even though there is evidence that phosphate addition, by reducing the volatility of ammonia, reduces the incidence of egg laying (Barnard *et. al.*1995).

An environmental concern of increasing importance is the impact of using poultry manure on greenhouse gas emissions. Agriculture presently contributes 20% of Australia's greenhouse emissions (Australian Greenhouse Office, 1998). Chicken manure can potentially have positive or negative impacts on greenhouse gas inventories, depending on how much of the biomass becomes stabilised as soil organic matter, whether ammonia nitrogen is volatilised or incorporated into soil fractions, and whether mineralised nitrogen is converted to plant biomass or lost to the atmosphere as NO_x (as demonstrated by Coyne *et. al* 1995 and Ferm *et. al.* 1999). By the year 2008, depending on international negotiations on accounting for agricultural inputs, this could have a major economic impact on production costs. This topic is now gaining momentum in the international literature, as witnessed by entire volumes devoted to such issues as "Soil as a carbon sink" (Volume 49 (1998) *Nutrient Cycling in Agroecosystems*) and "NO_x Emissions from Soil" (Volume 52 (1999) *Nutrient Cycling and Agroecosystems*).

4. Soil Organic Matter

Whilst much of the older literature looked upon manure merely as cheap fertiliser, it is becoming increasingly recognised that the contribution to soil organic matter dynamics may be just as important.

A recent review looking at the effect of manure-derived organic matter on soil water holding capacity (Haynes and Naidu, 1998) which showed the picture is far from simple. For example, although water holding capacity of manure-treated soils increase, so does the wilting point, resulting in no net increase in plant available water.

The turnover rate of soil organic matter derived from chicken manure also appears to be quite complex. Gijsman and Sanz (1998) showed that a large part of the organic fraction is protected from microbial oxidation by forming soil aggregates. This is consistent with the findings of Gerzabek *et. al.*(1997) who found the organic matter turnover of manure amended soils to be much slower than expected from mineralisation data. It is noteworthy that in these studies which used chicken manure there was minimal soil disturbance, whereas work by Sauerbeck (1982) and Rochette and Gregorich (1998) used cattle manure and conventional tillage practice, and resulted in much faster organic matter turnover. Entry *et. al* (1997) studied organic matter turnover in more detail and found the protein and cellulose content of the manure had significant impacts on organic matter turnover and mineralisation.

Holland and Coleman (1987) showed that the placement of poultry litter has an impact on organic matter dynamics. There has been little recent attention to the effect of placement on the effects of poultry manure, however it seems likely to be important as Ferm *et. al.* (1999) showed significant differences in the breakdown of pig manure when it was broadcast or banded, and these differences were very dependent on soil moisture and temperature.

Temperature may be an important consideration on the organic matter dynamic under Australian conditions. Whereas much of the published work is from Europe, studies in arid environments suggest soil temperature is more important than soil moisture on organic matter turnover (Abdel Magid *et al.* 1993).

A real problem in comparing data on soil organic matter turnover is the analytical methods employed. Debate amongst soil scientists working on greenhouse gas implications of soil organic matter have highlighted the need for consistent methodology. Rayment and Higginson (1992) point out that the most common methods, wet oxidation and weight loss after combustion suffer from underestimates (former) or overestimates (latter) depending on the form of organic matter, the concentration and the soil type. The preferred method uses combustion furnaces with direct measurement the CO_2 liberated using IR, albeit after prior acid treatment to remove carbonates.

Another important development in the study of soil organic matter is the recognition that different fractions of organic matter confer separate functional properties on soil. Of relevance is the recent finding of Ellerbrock *et. al.* (1999) that the application of manure to soil changes molecular weight distribution of soil organic matter with a relative increase in higher molecular weight fractions.

5. Soil Microbiology:
Although it is well understood that the breakdown of manure organic matter, and the subsequent processes of mineralisation of nutrients and uptake by plants are mediated by soil bacteria and fungi, surprisingly few direct studies of the impact of manure addition on microbial populations and activity have been undertaken.

There have been many studies where changes in soil properties often associated with microflora have been observed, such as improved infiltration and porosity (Haynes and Naidu, 1998), increased soil respiration and CO_2 evolution (Rochette and Gregovich, 1998, Abdel Magid *et. al.*1993) and increased nitrogen mineralisation and turnover rates (Johnson and Wolf 1995, N'Dayegamiye *et.al.* 1997, Ferm *et. al.* 1999), however direct studies on microflora populations and activity are rare. Indirect assessment of microbial enzymatic activity have been undertaken using composted cattle manure (Lalande *et. al.* 1998) mixed farmyard manure (Gogal *et. al.*1993) and poultry manure (Cooper and Warman 1997).

The direct enumeration of soil microorganisms is generally considered to be of dubious benefit (Lynnette Abbott - personal communication) because any plating or dilution method is very selective, and what grows in the laboratory may only constitute a tiny fraction of the total microbial population.

One new approach which may have merit for this study has recently been described by van Bruggen and Semenov (1999) as a means of developing indicators of root disease suppressive soils. The method recognises that bacteria which proliferate under conditions of high energy availability (termed "copiotrophs") increase in numbers after organic amendment to soil, and thereafter decline. Bacteria adapted to low energy availability ("oligotrophs") decline after organic amendment, and thereafter increase. The new method determines the ratio of copiotrophic bacteria to oligotrophic bacteria by plating soil on carbon rich and carbon poor media. The actual ratio found is not considered particularly important, however it is the change in the ratio over time which forms a fairly convenient measure of the microbial diversity and functional redundancy.

The concept of increasing biodiversity of soil microbes by the addition of chicken manure for the control of root disease has already been described by Ringer *et. al.* (1997) who demonstrated good control of Pythium, but somewhat poorer control of Rhizoctonia.

Another potentially important biocontrol impact of poultry manure on soil microflora is the observed suppression of nematode populations (Marull *et. al.* 1997). This suppression is believed to be related to the increased microbial diversity creating greater predation pressure for plant parasitic nematodes (Porazinska and Coleman 1995) from nematophageous fungi and nematodes. Other researchers suggest increasing bacterial populations are responsible (Riegel *et. al.* 1996).

The proposed study puts forward a hypothesis that microbial degradation of manure may provide CO_2 to increase photosynthesis. Interestingly this idea is not so new, as it has recently been examined in England (Adams *et. al.* 1997) albeit in greenhouse crops.

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MANURE AND FLIES: Amendment of poultry manure to prevent fly breeding.

1) Background

Poultry manure usage in crop production has been identified as the major source of both stable fly (*Stomoxys calcitrans*) and house fly (*Musca domestica*) breeding on the Swan Coastal Plain. Raw poultry litter, when used as either a pre-plant or sideband/top-dressing, is capable of producing in excess of 200,000 stable flies and 1.5 million house flies per hectare (Cook *et al*. 1999). Stable flies rarely develop in pure, dry poultry manure, however broiler litter, which is a combination of poultry manure and sawdust (organic material) produced as a by-product of the poultry meat industry, provides an ideal medium (Sutherland 1978; Williams et al. 1980; Boire et al. 1988). Significant stable fly breeding events are also associated with rotting crop residues and other situations where rotting organic matter is exposed to flies.

In response to complaints about the impact of stable fly on both people and livestock, the WA Government has recently banned the use of poultry manure for commercial horticulture through amendments to the Health Act Regulations. In most shires with significant horticultural activity, poultry manure application is prohibited unless the material has been treated using an approved process. Currently approved processes are composting and pelletizing, but both add considerable cost to the user and are thus not attractive to commercial growers.

The ban has caused concerns to vegetable farmers who have come to rely on broiler litter as a cheap, effective fertiliser and soil conditioner.

Bioscience has argued that this approach to stable fly control is poor policy, not only because it can seriously damage the vegetable production industry, but also because it does not address any of the broader economic, environmental or community interests raised by the current poor management of poultry manure.

Instead, we are proposing a new approach that not only eliminates an important source of stable fly and house fly breeding; it provides substantial productivity benefits to the poultry industry. It allows vegetable producers to continue using manure and obtain improved fertiliser performance. It eliminates a major source of community concern about poultry shed operations. It reduces the threat to groundwater pollution and it reduces the need for landfill.

This review provides the theoretical framework underlying the Bioscience proposal. It seeks to involve both the poultry and vegetable industry into a collaborative approach to research and development to ensure both the poultry and vegetable production industries develop practical and integrated ways to obtain the maximum benefits from the technology.

2) Poultry Manure Chemistry

Broiler litter is a combination of sawdust and chicken faeces. Chickens excreta is a combination of waste from both the kidneys and the gastrointestinal tract, with much of the water removed before elimination. Depending on the specific rations fed to birds, manure contains high levels of all plant nutrients, particularly nitrogen (3.5-5%), phosphorus (0.8 – 1.5%) and potassium (0.7 – 0.9%). The majority of manure mass is organic matter consisting of undigested carbohydrate and protein, fiber and commensal microbial biomass. The carbon content of manure is typically 40%, equating to about 90% organic matter. This organic matter in manure is in a reduced form, thus contains considerable energy (about 10,000 Btu per kilo, or nearly 1/3 the energy content of coal).

Because of the abundance of available metabolic energy and nutrient ions, when poultry litter has moisture levels over about 15% w/w it is rapidly degraded by bacteria. The carbon to nitrogen ratio is initially about 8 – 12, thus microbial metabolism within manure rapidly leads to reduced oxygen concentration and the establishment of anaerobic conditions. With an excess of nitrogen to carbon relative to bacterial needs, nitrogen, hydrolysed during the breakdown of protein and peptidoglycan into ammonium ions is not all captured by the bacteria.

Under aerobic conditions, the breakdown of organic matter produces CO_2 which, combined with water, promotes acidic conditions. In the absence of oxygen as an electron acceptor (i.e. under anaerobic conditions) depending on the bacteria involved, the medium can become alkaline. Under alkaline conditions, ammonium loses a hydrogen ion to hydroxide and forms water and ammonia gas.

Ammonifying bacteria such as *Bacillus subtilis, B. cereus, B. megatherium, Proteus sp, Pseudomonas sp,* and *Escherichia coli* increase broiler litter pH and the concentration of ammonia gas both within and around poultry farms (Ivanov 2001). In Poultry litter, volatilisation of ammonia has been attributed to microbial decomposition of principally the nitrogenous compound uric acid (Burnett and Dondero 1969; Carlile 1984). However, ammonia release from animal manures is highly pH dependent (Ivos et al. 1966), where ammonia release is substantial when pH is >8.0, but very small when manure pH is <7.0. Hence, reducing the pH to below 7 is a very effective way of reducing both ammonia volatilisation and microbial counts (Ivanov 2001).

The treatment of broiler litter with organic acids has been shown to decrease the harmful effect of both ammonia and bacteria on broiler chickens (Ivanov 2001), reducing the environmental, feed and poultry meat contamination with *Salmonella*, *Campyloribacteria* and *E.coli* (Shane 1998). Addition of phosphoric acid to manures can result in a virtually 100% reduction in ammonia emission, whilst increasing the fertilizer value of the manure (Andersson 1996).

The treatment of broiler litter with organic acids reduces costs associated with removing ammonia gas especially over the early brooding period (Shane 1998). Pure acids such as nitric, sulphuric and phosphoric are more cost effective than acidic salts such as superphosphate or calcium sulphate (gypsum) due to their greater solubility. Chemicals that reduce nitrification (ammonia/nitrogen loss) from livestock manures subsequently reduce fly breeding (Sweeney *et al*. 1996). These chemicals either inhibit microbial growth or combine with and neutralize the released ammonia.

Bioscience has conducted many hundreds of analyses of broiler litter for the West Australian composting and mushroom industries. The results show moisture content from WA shed is highly variable, ranging from 19.5 – 40%. The pH is in the range 7.2 – 8.9, and the ammonium concentration is typically 5,000 – 9,000 ppm. As such, almost all broiler litter leaves sheds with a chemical composition that promotes anaerobic decomposition, produces offensive odour and provides ideal fly breeding habitat.

3) Fly Breeding

Flies as a group exploit a remarkably wide range of breeding sites and breeding media. The most likely primitive larval medium is rotting vegetable matter where larvae feed on the microorganisms involved in decomposition (Ferrar 1987). Consequently, many fly species are associated with carcasses, manure and other by-products of human activity. Most flies have one thing in common; they use an ephemeral resource in which to lay their eggs (oviposition) or larvae (larviposition). Substrate quality affects both larval development rate and the eventual size of the emerging adult fly. Independent of substrate quality is season, which has the most profound affect on patterns of fly abundance.

Synanthropic flies begin life in a milieu teeming with microorganisms. For example, the stable fly (*Stomoxys calcitrans*), while breeding in a range of manures and rotting organic material, use the microorganisms associated with decomposition. For this reason, fly larvae cannot survive and grow in the absence of bacteria (Hollis et al. 1985), illustrated by the fact that anti-microbial compounds retard larval growth and that addition of bacteria to sterile breeding media improves growth of fly larvae. Fly larvae are particle feeders and bacteria in manure are the principal source of food for maggots (references in Barnard et al. 1995). Stable fly larvae require bacteria to complete development, including *Acinetobacter sp., Aeromonas sp., Empedobacter breve, Flavobacterium odoratum* and *Serratia marcescne*, especially mixed cultures of the bacteria rather than pure bacterial cultures (Lysyk et al. 1999).

Flies respond to variations in the physical and chemical properties of manure. For example, the pH of putrescible materials is considered crucial in determining the species of fly larvae found utilising that material (Brues 1946). In essence, flies select a certain microbial profile indicative of a particular environment. They achieve this through both olfactory stimulation and contact chemoreception. Fly larvae cannot survive and grow in the absence of bacteria (Hollis *et al*. 1985), hence anti-microbial compounds retard larval growth and addition of bacteria to sterile breeding media improves larval growth. Bacteria in manure are the principal source of food for maggots (references in Barnard *et al*. 1995). It is possible to regulate bacterial populations in animal faeces to control the development of nuisance flies (Barnard *et al*. 1995).

Attraction to Oviposition (egg-laying) sites.
Cattle odour, fresh cattle dung, expired human breath, acetone and 1-octen-3-ol all produced positive EAG's (electroantennograms) in *S.calcitrans*. Acetic acid vapour

caused a reversal of the usual EAG response in stable flies, indicating inhibition (Warnes and Finlayson 1986).

Increasing numbers of gravid female stable flies visited cattle dung as it aged and peaked when the manure was approx 2 weeks old. (Broce and Haas 2000). Female *S.calcitrans* prefer to lay eggs on a moist medium with a 5% ammonium hydroxide solution (Killough and McKinstry 1965). Acetic acid causes a reversal in the usual positive (EAG) response of female *S.calcitrans* looking to lay eggs (Warnes and Finlayson 1986).

Glutamic acid consistently caused a marked reduction in the amplitude of ovarian compressions in gravid *S.calcitrans* females (Cook and Peterson 1989) Octanoic acid elicited the poorest EAG response from adult *S.calcitrans* (Schofield et al 1995).

Oviposition
S.calcitrans females laid eggs on a black velvet pad moistened with a 5% ammonium hydroxide solution (Killough and McKinstry 1965).

Sorbic acid added to ovipositional media reduced egg survival. The more acidic the pH of the media, the smaller the dose of sorbic acid required for the same effect. The sorbic acid was found to adversely affect the dietary mutualistic microorganisms of *S.calcitrans* (Dunkel and Read 1991).

Octopamine produced large increases in the amplitude of spherical compressions at 10^{-7} M. The neuropeptide proctolin (10^{-9} M) caused changes in both the frequency and amplitude of ovarian contractions. Glutamic acid consistently caused a marked reduction in the amplitude of ovarian compressions (Cook and Peterson 1989). Gravid house fly females may avoid potential oviposition sites that are rich in anti-microbial compounds such as linalool, a component of pine oil (Maganga et al. 1996). Female house flies (M.domestica) clearly avoid ovipositing on poultry manure with borate residues (disodium octoborate tetrahydrate) when given a choice of untreated poultry manure (Mullens and Rodriguez 1992).

Larval Development
Calcium cyanamide added to a larval medium resulted in 100% control of stable fly larvae; this was not due to the increased nitrogen content of the fertilizer as neither urea nor ammonium nitrate at 1X or 2X the nitrogen content of CaCN affected larval mortality (Chamberlain and Matter 1986). Mortality was due to the cyanamide radical itself (references in op. cit.). Similarly, calcium cyanamide and acid phosphate added to horse manure resulted in >95% house fly mortality (Cook and Hutchison 1916; Howard 1926).

Changes in animal diet alter nutrient availability in manure and only affect fly larvae indirectly, as bacteria in manure are the principal source of food for maggots (references in Barnard et al. 1995). Bacteria are required for *S.calcitrans* larvae to complete development, including Acinetobacter sp., Aeromonas sp., Empedobacter breve, Flavobacterium odoratum and Serratia marcescne, especially mixed cultures of the bacteria rather than pure bacterial cultures (Lysyk et al. 1999). Living bacteria in bovine feces are essential to normal growth and development of face fly larvae (Hollis et al. 1985).

Larval survival, pupal size, adult emergence and fecundity of house flies (*M. domestica*) are not influenced by the levels of calcium or nitrogen in egg layer poultry manure, but increased manure phosphorus concentrations reduces pupal size, adult fly fecundity and natality (Barnard et al. 1995).

Development of face fly (*Musca autumnalis*) larvae was severely retarded in cattle dung from animals fed a diet high in grain (>60%) (Meyer at al. 1978; D'Amato et al. 1980; Grodowitz et al. 1987). Fecal pH dropped below 5.0, lactic acid levels and the numbers of lactobacilli were very high and coliform bacteria were destroyed (D'Amato et al. 1980); high levels of organic acids (VFA's and lactic)(Meyer etal. 1978) and large increases in osmolality (200 mmol/kg) were recorded (Grodowitz et al. 1987).

Salinity levels of 15 ppt have detrimental effects on stable fly larvae, and salinity levels of 40 ppt completely prevent larval development (Gaugler 1990).

Larvidical applications of boron compounds reduce numbers of immature house flies in animal wastes (Cook et al. 1914; Howard 1926; Midgley et al. 1943; Mullens and Rodriguez 1992). Borax (disodium tetraborate) and gypsum (calcium sulphate) had excellent larvicidal activity against house flies (>98% morality when 0.34kg borax and 0.14kg gypsum was added to 0.28 cubic metres (280 litres) of horse manure (Cook and Hutchison 1916).

Pupation
Wandering larvae (looking to pupate) of stable flies (*S. calcitrans*) pupated at the highest pH offered (9.3 versus 7.2, 6.4 and 5.2) and at the lowest osmolality (111 mmol/kg versus 254 and 609) (McPheron and Broce 1996).

Increased manure phosporus levels reduce pupal size, adult fly fecundity and natality in house flies (Barnard et al. 1995) and are likely to influence other muscoid fly larvae (such as stable flies) by altering either the manure chemistry, microflora or the ability of manure microorganisms to provide essential growth factors (Brookes and Fraenkel 1958). Similarly, calcium cyanamide and acid phosphate added to horse manure resulted in >95% house fly mortality (Cook and Hutchison 1916; Howard 1926).

Adult Fly Development
Addition of sodium bisulfate to horse manure reduced adult stable fly (*S. calcitrans*) populations and substantially decreased manure pH and ammonia concentrations (Sweeney 1996).

Stable fly larvae are only first found in cattle dung that is nearly 3 weeks old, whereas house fly larvae are found in fresh cattle dung (2 days old) (Broce and Haas 2000). Similarly, stable flies prefer to develop in more aged poultry litter (4-7 days old) whereas house flies were the exclusive fly species in fresh poultry litter (up to 4 days old) and did not utilise poultry litter that had aged for greater than 9 days (Cook et al. 1999).

SUMMARY
The addition of phosphoric acid to bedding used in broiler production has a range of potential benefits. Firstly, in the poultry shed it will lower the manure pH, thereby

reducing ammonia gas which is detrimental to bird health and productivity. It will also reduce the levels of pathogenic bacteria affecting both birds and food contamination. Secondly, the resultant manure removed from sheds will have minimal odour but an increased fertilizer value to the horticultural industry. Furthermore it will be a resource that is not favoured by key nuisance fly species, in particular stable flies and house flies.

Options available to decrease pH and increase manure phosphate levels include adding phosphates to feed, or treating bedding material with phosphoric acid prior to use. The former option is available to the egg production industry.

We anticipate the maximum impact at both broiler and vegetable production stages requires phosphoric acid addition to bedding prior to birds being introduced. The treatment is estimated to cost an additional 3.5c per bird. This cost can easily be recouped through both increased broiler production rates, and on-sale of a more valuable fertilizer to the horticultural industry.

Although it has not been specifically tested, the literature provides a host of reasons why treating poultry litter with phosphoric acid will reduce fly breeding. In the first instance, reduced pH will attract fewer gravid flies as there will be less ammonia and nitrogenous odour. Any flies present will have a reduced physiological stimulus to lay eggs. It will affect the nature of the bacterial population towards one that does not provide good substrate for larval food. Any larvae present will experience the deleterious impact of higher phosphate levels. Any pupae that are produced will be unable to find high pH microenvironments to complete development.

Low pH and high phosphate levels are inhibitory to fly development for apparently different reasons. Accordingly it is unclear which provides the better single option to control flies, however phosphoric acid combines both low pH and high phosphate levels, and is thus the preferred treatment.

4) Odour Control and Bird Health

The Department of Environmental Protection has consistently recorded odour as the cause of one third of all public complains received (DEP 2000) with the vast majority of these complaints being related to the cleaning of litter from broiler sheds.

The impact of odour on the general community has had a negative effect on the broiler industry, with planning and regulatory authorities requiring progressively larger buffer distances between new broiler farms and neighbours.

As has already been pointed out in the preceding sections, odour is caused by the decomposition of manure by bacteria under moist anaerobic conditions. Although ammonia may not be the main cause of offensive odour, the more offensive smelling odourants are concomitantly produced under the same conditions that produce ammonia, being high pH and high moisture.

Keeping the interior of shed completely dry is made practically difficult because of the need to provide adequate drinking water to growing birds, and because of the need to keep growing sheds at optimum temperature and humidity. Even the minimum levels measured in WA broiler litter are moist enough to enable bacterial activity. Carlile (1984) reviewed ammonia levels in poultry houses after addition of a range of chemicals to the manure to control or reduce ammonia production. These included paraformaldehyde, clinoptilolite, yucca sponin, acetic acid, propionic acid, sorbic acid, gentian violet and calcium propionate. Phosphoric acid has been shown to lower poultry litter pH and decrease ammonia concentration (Reece et al. 1980). Similarly, sodium bisulfate reduces ammonia and bacterial growth in poultry litter (Sweeney et al. 1996; Shane 1998) and reduces pH, ammonia levels and stable fly populations when added to horse manure (Sweeney *et al.*1996).

Ammonia production from broiler litter has a range of deleterious effects on broiler birds including decreased growth rate, increased mortality rate due to respiratory diseases (Bradbury 1999; Carrier 1999), eye irritation and keratitis (Ivanov 2001) and the development of pathogenic bacteria (Byrd 1999). However, ammonia release from animal manures is highly pH dependent (Ivos et al. 1966), where ammonia release is substantial when pH is >8.0, but very small when manure pH is <7.0. Hence, reducing the pH to below 7 is a very effective way of reducing both ammonia volatilisation and microbial counts (Ivanov 2001).

The potential benefits to the broiler industry from treating bedding material with phosphoric acid are thus improved animal health due to lower atmospheric ammonia, and better community relations through reducing the odour associated with shed clean out.

5) Fertiliser Value and Environmental Outcomes

Exactly why broiler litter is so popular with vegetable producers had not been clearly elucidated until this study commenced. Extensive interviews with growers throughout WA have also indicated how growers use manure and what benefits they achieve. Interviews have revealed that the majority of broiler litter is applied as a pre-plant treatment, typically 7 to 10 days before crops are sown. Laboratory leaching trials have shown that within this time interval, greater than 60% of the nutrients are likely to be lost due to leaching.

The reason growers leave manure in the ground before planting is to prevent burning. Plant roots are very sensitive to ammonia, and are sensitive to high concentrations of ammonium ions. Because fresh poultry litter is alkaline, much of the nitrogen is mineralized to ammonia and ammonium ions during the first 10 days.

Phosphoric acid pre-treatment of bedding will increase the utility of manure for two reasons. In the first instance, because nitrogen is not lost as ammonia in the growing shed, but rather is retained in litter, the manure has a higher initial concentration of nitrogen. Nitrogen response is the main benefit growers seek from poultry manure.

Bioscience estimates that the N content is likely to increase from the present average of 4 % to 5%. Likewise the amount of phosphorus in manure will be increased from the current mean level of around 0.9%, to greater than 2.5%. This increase in P will save growers money by reducing or eliminating the need to apply pre-plant phosphate fertilisers.

The second reasons for improvement results from reducing manure pH. If crops can be planted immediately after manure application, then the nutrient ions released by mineralisation in the first 10 days are available for root uptake. A low pH means excess ammonium ions, instead of forming ammonia gas, will form nitrate ions which plant roots can very effectively remove. This aspect has recently been tested in the field. Sweet corn (which being a monocot is particularly sensitive to ammonia) was transplanted immediately after incorporating phosphate amended poultry manure, and suffered no post-transplant burning.

In WA most vegetable growers produce 2.6 crops per year. Those using poultry manure are thus losing on average 26 days of productive time on their land. This equates to a 7% opportunity loss which would be saved by using low pH manure. The preservation of groundwater quality on the Swan Coastal Plane is seen as a major environmental concern, particularly as the population grows and dam reserves decline. The current pattern of poultry manure use suggests the majority of nutrient contained in the manure is lost to groundwater. By enabling growers to plant immediately after incorporating phosphate amended manure, a much greater proportion of this nutrient will be recycled as plant biomass.

It is acknowledged that in most of the developed world, the intensive meat production industries are under considerable pressure to reduce, rather than increase phosphate content in animal manures. However it must be recognized there are significant difference in population densities of both people and livestock, and very different soil types are involved.

In the USA and Europe, manure has been applied to pasture as a source of nitrogen. The argillic, slow draining soils typically have a good supply of phosphate. Under such conditions, rain frequently dissolves surface soil phosphate which is carried into waterways causing eutrophication problems. Because of the soil type and the excess of phosphate, regulatory authorities have encouraged the intensive livestock industries to reduce phosphate levels in manures.

The situation on the Swan Coastal Plain is quite different. Manure is typically used by incorporating into soil for intensive horticulture rather than broadcast on the surface of pasture. Soils are very free draining sand, rather than argillic clay. They are acidic rather than neutral, and they are universally deficient in phosphate.

6) Economics

Trials have tested amending poultry litter with 1.5 and 3% phosphoric acid (weight/weight on a dry weight basis for manure). Assuming sawdust bedding constitutes 40% of broiler litter, this equates to 3.75 and 7.5% of the weight of sawdust. The cost of commercial quantities of technical grade orthophosphoric acid is currently around $1,000 per tonne. The bulk density of hardwood sawdust is typically 0.45 – 0.55 (average 0.5). The typical cost of bedding sawdust is $14 per cubic meter delivered. The materials cost of amending a cubic meter of sawdust is $18.75 to $37.50 for a total bedding cost of $32.75 - $51.50.

When treated sawdust is spread as a layer 25 mm deep, each cubic meter covers 40 square meters. At the standard density of 13.5 birds per meter, the treatment cost equals 3.47 or 6.94 cents per bird.

Irrespective of what productivity benefits the broiler farmer may get from improved shed atmosphere and control of bacteria, and what community benefits accrue from no longer being a potentially offensive neighbour, the broiler farmer may recover the expenditure due to the improved fertiliser value of the broiler litter.

Currently the vegetable production industry pays on average $13 per cubic meter of delivered broiler litter. The average application rates are 20 cubic meters or $260 per hectare. Vegetable growers would typically also apply about 1 tonne of superphosphate pre-plant ($190), then apply weekly applications of nitrogen and potassium fertiliser starting the week after planting (e.g. 100 Kg ammonium nitrate ($45) and 80 Kg potassium sulphate ($56) for about 12 weeks. The total fertiliser cost is around $1650 per hectare per crop.

With amended fertiliser having more N and P, and being applied immediately before sowing, the grower no longer needs to apply superphosphate, and can quite safely delay top dressing fertiliser for the first two weeks after planting. This reduces the mineral fertiliser cost by $291 per crop.

Using the assumption that one cubic meter of bedding sawdust eventually becomes 2.5 cubic meters of broiler litter (40% sawdust, 60% manure), the material has now cost the broiler grower $13.10 - $20.10 per meter.

If the vegetable producer pays twice the current rate, he is still $30 per hectare per crop better off, and the broiler grower has completely recovered the treatment cost. This analysis is of necessity simplified. In reality, the prices paid to broiler farmers and by vegetable growers changes according to supply and demand. Sometimes broiler farmers get nothing for their litter (albeit their sheds are cleaned for free by contract cleaners). Cleaning contractors are also key players in the buying and selling of poultry manure. In a free market, all three parties will try to negotiate a deal to their best advantage. The point to be made however is that the modest cost to the broiler producer can be offset by the direct production benefits to him as well as by the increased price to the vegetable grower.

7) Further Research Required

Horticulture Australia Ltd has funded a research program by Bioscience to examine the use of phosphate amended broiler litter for vegetable production as a continuation of the project examining the use of chicken manure in vegetable production on sandy soil (Project VG 00006).

The program involved field trials and laboratory work. The field trials grew vegetable crops through standard rotations, and compared production using different application rates of standard broiler litter, phosphate amended broiler litter and mineral fertilisers. Each trial involved extensive analysis of soil fertility, plant nutrient uptake, soil microbial metabolism and soil organic matter dynamics.

Throughout later trials, insect traps were set into each bed and emerging adult flies were trapped, identified and counted. A total of 144 traps are set per trial.

In addition to this field work, a further set of beds were used solely for fly breeding trials employing 12 large fly traps. These enabled a series of rapid (3 week) trials to be undertaken in the absence of growing crops.

Laboratory work examined the binding and release of phosphate to various materials that are suitable as bedding for broiler production, thereby to develop cost-effective and practical means of treating such material.
The objectives of the program were:

- To quantify the impact of phosphate amended manure on (all) fly breeding.
- To establish optimal application rates of manure and mineral fertiliser to produce export quality vegetables.
- To revise best practice guidelines for using poultry manure for the vegetable production industry.

Bioscience has developed methods to treat broiler litter with phosphoric acid and methods to simulate production of “treated” manure by treating sawdust, then blending it progressively with poultry manure and moisture as occurs within sheds.

Bioscience does not have the expertise or resources to determine the impacts of acid-treated bedding material on the health and productivity of broiler chickens. This research is best undertaken by the poultry industry.

Both the egg production and broiler industry should also re-examine the cost/benefit of increasing the phosphate content of feed.

Currently the standard layer ration contains 0.6% elemental P, derived mainly from meatmeal, which is included primarily for its protein and fat content. The standard broiler ration contains 0.4% elemental P, most of which comes from added calcium phosphate. Whist it is acknowledged that P levels can not be increased without considering the impact on C/P ratios and other factors influencing egg shell production in layers and bone development in broilers. Given that current prices for chicken feed are around $330 per tonne, whereas dicalcium phosphate is $600 per tonne, doubling phosphate content in broiler feed would cost an extra $5.50 per tonne. Because of relatively poor absorption of phosphate across the chicken gut, most of this addition would end up in manure.

Another issue to address is alternative to hardwood sawdust, as changes in forestry and logging practice brought about through the regional forests agreement may deplete the sawdust resource. The use of appropriately treated greenwaste is an alternative which should be considered. Treatment of such material with phosphoric acid can potentially eliminate any prospects for introducing pathogens into broiler shed. Because greenwaste is locally available, it may prove a cheaper source of bedding.

Alternatively, compost would likewise provide a suitable bedding material. Because it is produced under thermophilic conditions it is effectively pasteurised and free from pathogenic organisms. It has very high moisture holding capacity and can effectively absorb nitrogen. A manure based on compost litter would have added attraction to the vegetable production industry of providing a longer term improvement in soil by the addition of a stable carbon fraction.

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3 Grower Interviews

3.1 Introduction

At the beginning of this study there was little quantitative data available on how many vegetable growers used poultry manure, or the way it was commonly used. In order to focus the research program, it was important to understand usage patterns, application rates and reasons why growers chose to use manures. To gain this information growers were interviewed using a structured series of questions.

Prior to commencing interview, Bioscience had preliminary discussions with growers from their client base to get a general understanding of use, and to develop and test a questionnaire. Growers were forewarned of the interviews through publication of an article in WA Grower explaining the HAL-funded study and that interviews would be conducted by Bioscience staff.

3.2 Study Methodology.

The process used to select growers for interviews was based on Bioscience's knowledge of production areas in Western Australia ranging from the Myalup area about 150 Km south of Perth, to Lancelin, 90 Km north of Perth. The number of vegetable farms visited in each area was proportional to the level of activity in the area. This meant that about 40% of interviews were conducted south of Perth, and 60% were conducted to the north. Farms were also selected on the basis of size, so that both large (up to 200 Hectares) and small (2 Hectare) growers were interviewed.

The Interview process was deliberately kept informal. Bioscience staff would arrive unannounced on a farm and ask for the owner or farm manager, then explain who they were and what they wanted and how long the interview was likely to take. There were no instances where growers did not want to cooperate and assist with providing information, notwithstanding that most growers were busy at the time. In many instances, interviews were conducted against a tractor or in a packing shed.

Although each grower was asked the same questions and their response written on an interview form, the questions were put in a conversational mode and growers were encouraged to provide any additional information they thought was relevant. About 75% of growers interviewed seemed to genuinely appreciate that someone was taking an interest in their opinion, and generally interviews took longer than expected as growers generously shared various opinions and anecdotes.

An Interview form is present on the following page to highlight the structure of questions asked.

3.3 Questionnaire

CHICKEN MANURE INTERVIEW

1. Name:
2. Address:
3. Area used for production:
4. Soil Type:
5. How many years have you been growing:
6. How long has this site been used:
7. Crops Grown

What Crops	Summer	Autumn	Winter	Spring

8. Have You Used PM ? Do you still use it ? When did you stop ?
9. What type - broiler litter, layer, breeder
10. How is it applied (PP, Inc. BD, SB)
11. How much do you use.
12. How much do you pay for it.
13. Who do you usually buy from.
14. How much at a time.
15. What time of year does it work best.
16. What other fertilisers do you use, PP, TD ?
17. What benefit does it give you ? (Yield, Quality, Timing)
18. Have you used Dynamic Lifter, Organic 2000 ?
19. How do you receive, handle and store manure ?
20. Does it make a difference if it is fresh or old.
21. Does it differ batch to batch
22. Does using manure change the way you water beds
23. Do you get a carry over effect to the next crop
24. Does it help build up soil structure, organic matter etc.
25. Has it ever caused problems, given poor results.
26. Does it change the incidence of pests or disease.
27. Have you ever tried not using it and comparing results.
28. Have you neighbours ever complained to you.
29. Has anyone from the govt, shire ever spoken to you about using it.
30. Would banning it cost you money - how much.
31. Are you prepared to adopt new management methods (storage, application rate etc.) in order to keep using it ?

3.3 Results

Over a period of six weeks, 75 growers were interviewed. Of these, two interview sheets were subsequently discarded when further observation by the interviewer indicated the grower had not been frank with their answers. (In both cases the grower said they did not use poultry manure as they had no need, whereas piles of manure were seen on their properties).

Experience
A wide range of grower experience was encountered. One grower had been vegetable farming for just three months, and the oldest had been producing vegetables for 70 years. The average time in the industry was 22.4 years. The average time the particular farm had been in production was 18 years.

Soil types
Soil types used for vegetable production were invariably sandy soil, with 60% of farms being on white/grey sand of the Bassendean Dunes system, and 40% growing on yellow/brown Spearwood Dunes soils. The former soils are typically acidic with low clay content and low water holding capacity, whereas the latter soils have up to 5% clay, contain natural carbonates and are typically neutral pH.

Users
Of the growers interviewed, 93% had experience using poultry manure for vegetable production (68/73), but only 52% still used manure and wanted to keep doing so. Of those who had previously used manure, about half (14/30) had stopped in anticipation that the use of chicken manure was soon going to be banned. The rest (16/30) had stopped using manure because they had changed to root crop production, or had changed to using fertigation systems.

Type of Manure and Application mode
Of the current users, the vast majority (84%) used broiler litter only or breeder litter only (8%) whereas only two growers had used layer litter (5%).

Most growers only used chicken manure as a pre-plant soil preparation (60%) whereas 29% used manure both as pre-plant and as a side dressing. One grower only used manure as a side brand treatment, one used it only as a deep banded application, and one used manure as a broadcast top dressing.

Amounts Used
The minimum amount of chicken used per crop was 3 cubic meters per hectare and the maximum amount was 75 cubic meters. From all current users, the average use per crop was 20.7 cubic meters per hectare.

Growers paid difference prices for manures. One grower paid nothing, as he had invested in machinery to clean out a neighbour's broiler sheds. The minimum paid was $9 per cubic meter to a maximum of $16 per cubic meter. The average price paid was $13 per cubic meter.

The minimum volume purchased was 10 meter loads and the maximum volume was 386 meters per time. Most growers purchased chicken manure in quite large batches with the average purchase being 85 cubic meters.

Crops
The complete range of vegetable crops was produced by interviewed growers. Without exception, each crop had been grown with different amounts of poultry manure, however very few growers used manure directly on root crops, but many growers still used manure for leafy crops grown before root crops.

By far the most chicken manure was used on lettuce and brassica crops, however it was also commonly used for tomato, celery, bean, capsicum, sweet corn and cucurbit production. It was generally found that smaller vegetable farms produced a greater variety of crops, whereas larger farms were more specialised to fewer lines. The smaller farms were less selective in their use of chicken manure, whereas larger farms used it in particular circumstances, such as for just one crop, or at one time of year. Large farms growing lettuce and Brassica crops seemed to have the most sophisticated understanding of chicken manure use, and some had developed their own special equipment and techniques to use chicken manure.

Time for Best Effect
The majority of growers (63%) believed manure worked just as well in summer as in winter, whereas 21% believed it worked better in winter and 8% believed it worked better in summer. A further 8% didn't really know if there was any difference between the seasons.

Benefits Experienced
There was a wide range of opinion about the benefits of using chicken manure. The biggest group (45%) felt it simultaneously improved yield, quality and time predictability of cropping. The next biggest group (24%) believed it had other benefits including yield quality and timing, but the other benefits were very diverse, including quicker seedling establishment, better disease resistance, better frost protection, slower fertiliser release and reduced production cost. The next biggest group were "other" at 18%, but these growers did not believe there was improvement in yield, quality or timing. The remainder believed chicken manure only increased one of the three properties (yield, quality or timing) while 2 growers could not explain what benefit they derived from using manure.

Alternative Products.
When asked whether they had used alternatives such as pelletised or composted manure products, 68% of users said they had tried alternatives, however only three of these growers believed the alternatives were as good as standard manure. All users believed standard manure represented much better value than alternative manure-based products.

Receival and Storage
Most growers were very aware of regulations concerning the handling of chicken manure, with 47% using it immediately after delivery, and 34% covering material with plastic upon arrival. Only three growers admitted to leaving delivered manure uncovered prior to land application.

Product variation
In response to the question of whether fresh or aged manure was better, opinion was split with 42% believing fresh manure was better, 24% believing mature manure was better, 24% believing there was no difference and 10% not having any opinion.
When asked if each batch they received was the same, 42% said they were, 47% said they had noticed batch to batch variation and 10% made no comment. The biggest variation growers noticed was in moisture content. When manure was wet it made spreading more difficult due to clumps forming and blocking spreaders.

Impact on irrigation
This question also produced a diversity of opinion, but the biggest group (47%) said it made no difference whereas 36% believed they needed less water when they used manure. The rest believed chicken manure made them use more water or had no opinion.

Soil structure
There was almost uniform agreement among growers that chicken manure caused a significant improvement in soil structure with 87% agreeing, only 5% disagreeing and 8% not offering an opinion.
The duration of structure improvement was not so well agreed, with 42% believing the soil structure improvements carried through to the next crop whereas 50% believed there was no improvement at the next crop.

Problems caused
Although users believed using manure was beneficial, 24% reported that they had experienced problems associated with its use. The most common problem was transplanting seedlings too soon after incorporation which resulted in burned roots. Most growers believed the problems were their own fault and learned from their mistakes. A further 8% of growers had experienced problems of root disease which they associated with chicken manure. Occasional complaints from neighbours about smell were experienced by 18% of growers. Overall however, most growers believed using chicken manure caused few problems but rather was a cheap and reliable aid to crop production.

Consequences of a ban
All growers interviewed were aware that regulations had changed, or were about to change, and 87% of users felt the move would cost them money, either through lost production opportunities or because of increased production cost. Already 63% had been visited by shire health officers warning them that they could no longer use manure.

The great majority of users (82%) said they would adopt any management measured required in order for them to be able to keep using chicken manure.

Summary

In all, about 75% of vegetable producers interviewed either still used chicken manure or wanted to use it. The reasons were varied, but it was widely seen as being a cheap and reliable means of improving vegetable production. It was almost universally recognised as significant soil conditioner, improving soil structure and fertility.

Leaf vegetable growers, particularly lettuce growers were the largest users of chicken manure, followed by Brassica growers. However, manure had been used on a very wide range of crops, with the exception of most root vegetables.

There was considerable variation in the way it was used, but pre-plant incorporation had become the most common method. Growers recognised that surface banding was very beneficial, but had generally moved away from the practice because of their perception that it promoted fly breeding.

4. Field Trials

4.1 Overview

Reviews of the scientific literature and results of grower interviews suggested that chicken manure conferred a number of benefits to soil which improved productivity and commercial outcomes in vegetable production. What was not clear was whether the benefits were derived from simply the release of nutrients into soil, from changes in soil microbial activity, or from changes in soil physical structure. It was likewise unclear whether benefits were short term or long term, or whether repeated use of manure caused cumulative improvements in soil properties.

Given that increasing concern about environmental impacts of chicken manure was becoming evident, and that there was little clear information about the optimal amounts and means of applying chicken manure to maximise benefits to growers, a quite detailed trial program was required to provide data upon which to address as many of these issues as possible.

Grower interviews revealed that the majority of users only applied chicken manure as a pre-plant application, incorporated into soil 7-10 days before planting crops. However, some growers still applied chicken manure sided banded to crops after transplantation. Many others had used this practice in the past, but had stopped because they believed it promoted fly breeding.

As the objective of the study was to provide both scientifically rigorous data and practical advice to growers, trials emulated standard grower practice where this was possible.

The overall strategy adopted was to use six different soil treatment types with four different application rates for each treatment. Each treatment type and application rate would be repeated within the same experimental plot for the duration of the study, thereby allowing the collection of data on both short term and long term consequences of each treatment and application rate.

4.2 Trial Beds

Trials were undertaken at Oakford on Bioscience's field station which had been used for vegetable production trials for five years. The soil is deep white Bassendean sand which is prone to acidity (typical pH 4.5) and has low natural fertility and water holding capacity (typically 22% w/w at field capacity). The trial field had been fallow for 8 months before trials commenced.

Irrigation of the trial site is via twin tail knocker sprinklers ("Pope Premier") set at 12 m spacings. Although such systems had gone out of favour because of irregular delivery in high winds, the site is sheltered from prevailing winds by buildings to the west, and the trial was undertaken in the central part of a larger field. Irrigation water was high quality water abstracted from the superficial water table. The water is 200 ppm total dissolved salts of containing 30 ppm calcium and 120 ppm Sodium Chloride.

Beds were formed using a small rotary hoe 1.0 m wide which cultivated to a standard depth of 280 mm. The trial field was formed into 24 such rows, each of 35 meters length. Each row was then divided into three beds of 10 m length, with a 1 m buffer between each bed and a 1 m buffer on each end. The entire test field was surrounded by 2 extra beds which served as planted buffers.

Individual treatments in each bed were determined at the outset of the trials using a randomised block design. Each of the 24 individual treatments had three replicates, so each block was allocated a separate randomisation schedule. Once treatments were assigned, the same treatment number and location was retained for the duration of trials. This allowed the long term comparison of production based on chemical fertilisers alone compared to manure application. To prevent blending of soils between beds, each time the field was plowed, it was in the opposite direction to the previous time. To ensure mixing was not influencing sample collection, soil samples were collected from the middle 2/3 of each bed rather than the outside areas.

RANDOMISED BLOCK DESIGN
24 ROWS X 3 BEDS.
Row number 1 = West, 24 = East
Rows 1 - 8 = Block B1, 2 - 16 = Block B2 17 - 24 = Block B3.
Treatments A1 - 4, B1 - 4, etc.

Block B1	1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24
	C1	E2	B4	B2	A4	B3	D1	D4
	D2	A1	E1	C4	E3	C3	F2	A3
	B1	E4	D3	F1	F3	F4	C2	A2

Block B2	25-27	28-30	31-33	34-36	37-39	40-41	43-45	46-48
	A2	A3	D4	C2	F2	D1	F4	C3
	B3	F3	E3	A4	F1	C4	B2	D3
	E1	B4	E4	A1	E2	B1	D2	C1

Block B3	49-51	52-54	55-57	58-60	61-63	64-66	67-69	70-71
	E1	B3	A2	B4	F3	A3	E4	E3
	D4	A1	A4	C2	E2	F1	F2	B1
	C4	D1	D2	B2	F4	C1	D3	C3

4.3 General Treatment

Crop sowing densities were the same as conventional vegetable production practice for the particular crop. All beds were transplanted on the same day.

Application of pesticides was by using Integrated Pest Management approaches. At least twice per week, crops were inspected and incidence of pests or disease was noted, and appropriate treatments instigated as soon as thresholds were reached. In general, quite low chemical inputs were used. Brassica crops were treated with B.t ("Dipel Forte") to control caterpillars. Lettuce crops were treated with copper oxychloride ("Coppox") and mancozeb to control mildew.

No herbicide applications were used. Weed control was generally by cultivation practice. Where this failed to achieve adequate control, weeds were removed manually until crops were well established.

Irrigation scheduling was varied according to crop requirements and the weather. The system was first calibrated by placing small beakers throughout the field. Generally crops were watered once per day in winter, twice per day in spring and autumn and three times per day in summer.

4.4 Nutrient Treatments.

For all trials undertaken, soil was first analysed in each bed to determine pH using both water and $CaCl_2$ extractants. Ground limestone was added to beds in order to achieve the target pH of 6.5 in $CaCl_2$ and 7 in water. At every second trial, to ensure no trace element deficiencies occurred, a chelated trace element mix ("Librel BMX") was added to soil at a rate of 1.5 Kg per hectare.

The trials sought to compare commonly used fertiliser application methods and rates. The following gives the broad outline of treatments, but some changes and variations were made as trials progressed.

Treatment A: Chicken manure was applied as a pre-plant application and incorporated by rotary hoe 7 days before planting. Beds were then top dressed every 10 days with mineral fertiliser until harvest.

Treatment B: either a) A trench was dug to 100 mm in the middle of the bed 7 days before planting, and chicken manure was buried in this trench which was then covered. Beds were top dressed with mineral fertiliser every 10 days until harvest, or b) Nutriplex was applied as a pre-plant application and incorporated by rotary hoe 1 day before planting. Beds were then top dressed with mineral fertiliser every 10 days until harvest.

Treatment C: Beds were treated with pre-plant mineral fertiliser ("Potato E") the day before planting. Chicken manure was surface banded beside the plants after 14 days.

Treatment D: Chicken manure was applied as a pre-plant application and incorporated by rotary hoe 7 days before planting. Chicken manure was surface banded beside the plants after 14 days.

Treatment E: Beds were treated with pre-plant mineral fertiliser ("Potato E") the day before planting. Beds were then top dressed with mineral fertiliser every 10 days until harvest.

Treatment F: Beds were treated with pre-plant mineral fertiliser ("Potato E") the day before planting. Chicken manure was surface banded beside the plants after 14 days. After a further 10 days bed were top dressed onto the surface band with mineral fertiliser every 10 days until harvest.

Note: In later trials, application of top dressing was every 7 rather than 10 days.

4.5 Fertiliser Application Rates

Fertiliser application rates were guided initially by the most recent recommendations by the Western Australian Department of Agriculture. Based on their rates for specific crops, the elemental composition was determined, and the weight equivalent of different materials (manure, mineral fertiliser or Nutriplex) was calculated.
Four different application rates were used for each treatment, and these equated to 50%, 75%, 100% and 125% of the rate (or equivalent elemental composition) recommended. As trials progressed, these rates were generally lowered as described for each trial.

4.6 Nutriplex

To examine whether organic-based fertilisers could be substituted for chicken manure, Bioscience developed a material it had initially devised for a commercial client. The material is based on compost blended with mineral fertilisers.

The compost used was based on greenwaste to which food waste (activated sludge from a malting company's waste treatment stream) had been added to give an initial carbon nitrogen ratio of 22 – 24 and a moisture content of 45 – 50% (w/w). Open windrows were turned every day for seven to eight weeks using a tractor-drawn windrow turner until thermophilic conditions abated. The material was then screened through a trommel system fitted with 8 mm screens. Uncomposted sticks and coarse material was removed and the fines became the basis of the "synthetic" chicken manure.

Chemical analysis of the screened compost showed it had a similar elemental composition to chicken manure in terms of calcium, magnesium and sulphur, but significantly less nitrogen, phosphorus and potassium. Accordingly, to emulate chicken manure, this material was amended by the application of phosphoric acid, and a solution of ammonium nitrate and potassium nitrate. The material was then dried in the sun to similar moisture content to chicken manure.

4.7 Phosphate Amended Manure

In order to test whether acidified chicken manure reduced the time required between application and planting, and reduced the incidence of fly breeding. Chicken manure was amended with phosphoric acid.

Chicken manure was dried by spreading as a thin layer of about 20 mm on black polyethylene plastic in the sun. When moisture content had fallen below 15% (w/w), the material was placed in a small cement mixer, and phosphoric acid (85% w/w, SG 1.66) was added at 1.5% w/w or 3% w/w. Treated manure was then again spread out to dry before application to fields. (Note: Caution is needed with this treatment, as phosphoric acid addition generates heat. This can promote combustion if large volume piles are created. Accordingly treated manures were immediately spread out as a thin layer for drying.)

4.8 Soil Analyses

Soils sampling of trial beds involved extracting 20 separate 30 mm diameter cores augered to 200 mm from each bed, then mixing the cores thoroughly before removing a 100 g mixed sample for laboratory analysis. The analyses were pH ($CaCl_2$ and H_2O), conductivity, Colwell extractable NH_4-N, P, and K, DTNP-exchangeable cations (Ca, Mg, K and Na,) and Organic Carbon and Sulfur (Leco Carbon Analyser). All analytical methods were as per Rayment and Higginson (1992) *Australian Laboratory Handbook of Soil and Water Chemical Methods,* Inkata Press.

4.9 Leaf Tissue and Manure Analyses

Leaf tissue and analyses were undertaken during early and mid phases of crop development. Manure analyses were undertaken for each batch received for trials. Collected leaves and manures were dried at 65^oC for 24 hours, ground in a hammer mill, then digested in concentrate sulphuric acid at 350^oC for four hours before the residue was decolorised with concentrated hydrogen peroxide and heated to 120^oC. Elemental analysis of the digested material used standard methods with P measured colorimetrically as the molybdate complex, N measured colorimetrically as a nitroferricyanide complex and the remaining elements by Atomic Absorption Spectroscopy (Varian SpectrAA110).

4.10 Hedonic Scoring

Non-parametric variables were measured using a hedonic scoring system. For growing crops this was used to measure crop establishment, disease incidence and frost damage. At harvest the system was used to measure product quality.

The scoring system involved firstly determining the overall range of the particular variable, then assigning the least or worst plants or beds a score of 1, and the greatest or best a score of 5. Individual plants or individual beds were then assigned a whole number score from one to five. This was done rapidly, and by at least three different people. Scores were then collated and averaged for each scorer.

4.11 Yield

Yield was determined at harvest by weighing each individual plant once processed for market presentation. For cabbage and lettuce this was the whole head. For broccoli, this was the head cut to "ice pack" size. For sweet corn this was the weight of the picked cob.

4.12 Statistical Analyses.

Statistical analyses of collected data was undertaken using Microsoft Excel Statistical Package, as contained within the "Office Professional" software suite.

Trial 1: Cabbage and Broccoli ***Comparing different broiler litter applications and mineral fertiliser.***

The purpose of the first field trial was to investigate the effect of poultry manure on cabbage and broccoli production in sandy soil over winter. Taking into account our findings from the interviews, alongside current fertiliser recommendations by Agriculture Western Australia, the following fertiliser treatments were employed and tested at 50%, 75%, 100% and 125% of the standard recommendations:

TREATMENTS

A: Manure incorporated pre-plant. Top dressing with NK every 10 days.
B: Manure deep banded. Top dressing with NK every 10 days.
C: Pre-plant Potato E. Manure surface banded at 2 weeks.
D: Manure incorporated pre-plant, Manure surface banded at 2 weeks.
E: Mineral only, pre-plant and top dressing every 10 days.
F: Pre-plant Potato E, Manure surface banded at 2 weeks, top dressed with NK onto band every 10 days.

Standard Fertiliser (100% rate): 1250 Kg Potato E per hectare pre-plant.
1200 Kg Agran per hectare in 6 x 10 day doses (200 Kg/Ha)
840 Kg Muriate of Potash in 6 x 10 day doses (140 Kg/Ha)
50 cubic meters of broiler litter taken as standard.

Hedonic Score

Two and five weeks after transplant, four individuals rated the size, uniformity and overall appearance of the plants in each bed. This was determined using a five point hedonic scale, whereby a score of '1' represented high quality/uniformity, and a score of '5' represented low quality/uniformity. Scores given for each bed were averaged to give a mean score for each treatment. The results are illustrated in Figures 4.1a – 1d. (Error bars are standard deviation in this and all subsequent graphs)

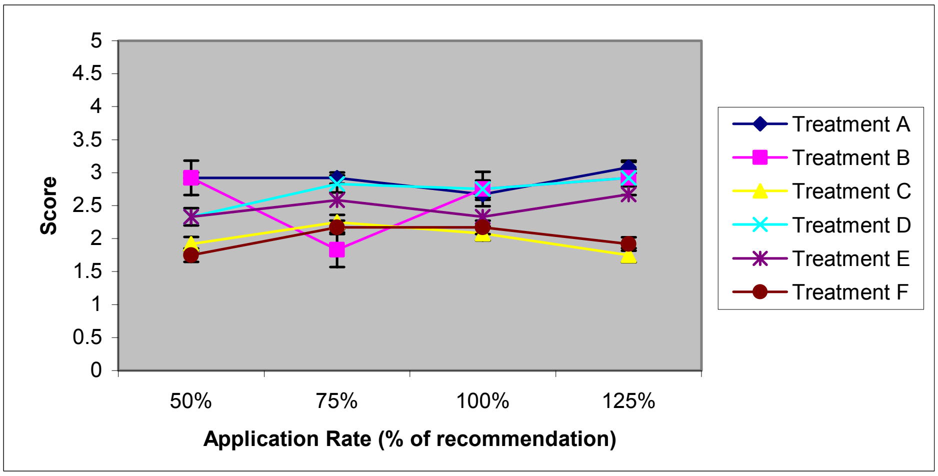

Figure 4.1a: Trial 1 broccoli hedonic score two weeks after transplant

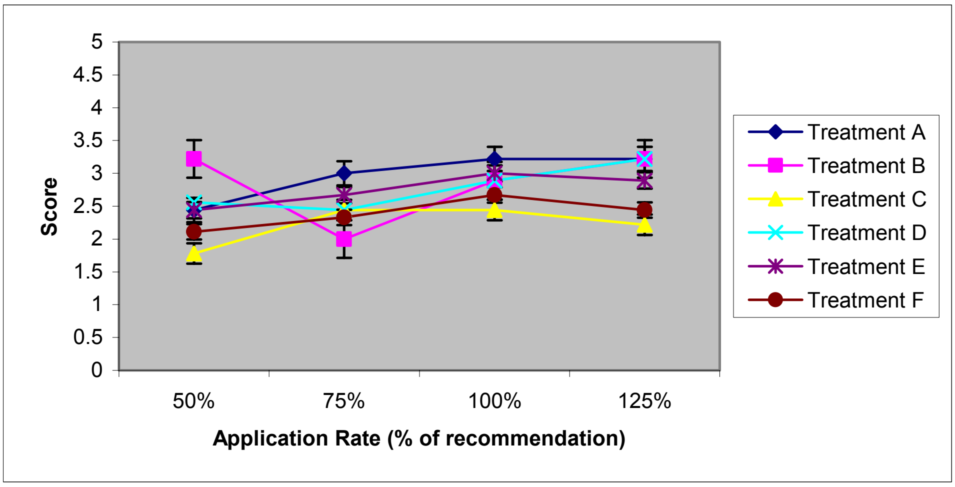

Figure 4.1b: Trial 1 broccoli hedonic score five weeks after transplant

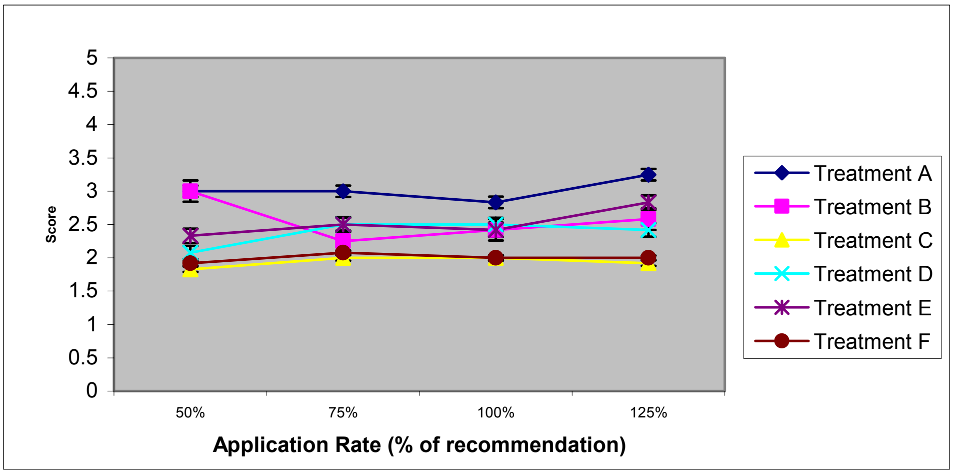

Figure 4.1c: Trial 1 cabbage hedonic score two weeks after transplant

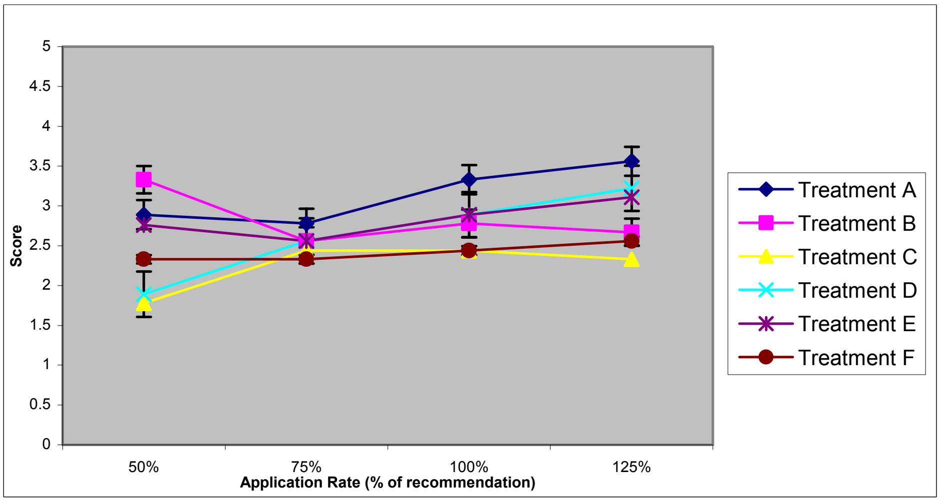

Figure 4.1d: Trial 1 cabbage hedonic score five weeks after transplant

Pre-plant chicken manure provided a similar transplant establishment to the use of mineral fertiliser. For cabbage, manure incorporated at pre-plant was slightly more effective than deep banding at higher application rates.

Plant Tissue Analysis
The nutritional status of both broccoli and cabbage crops at four, seven and nine weeks after transplant are outlined in Appendix A and B respectively. The figures show that the major yield limiting nutrients were nitrogen, magnesium and manganese. Nitrogen levels for broccoli dropped off for all treatments. For the cabbage crop however, levels only dropped off for those treatments not receiving routine top dressing with mineral fertiliser. Magnesium levels, which were good to start, also dropped off as the trial progressed. Manganese was low throughout the growing period for all plants not treated with chicken manure at pre-plant.

Fertiliser Treatment and Plant Weight
Figure 4.2a and 4.2b shows the average broccoli and cabbage head weights for the six fertiliser treatments. The results illustrate that certain fertiliser treatments on both broccoli and cabbage are more effective than others ($F(5,18) = 9.71$, $p<.05$).

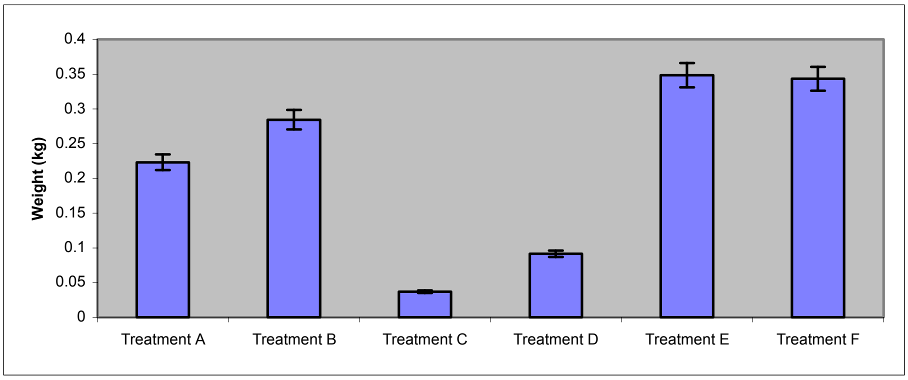

Figure 4.2a: Trial 1 average broccoli head weights for each treatment

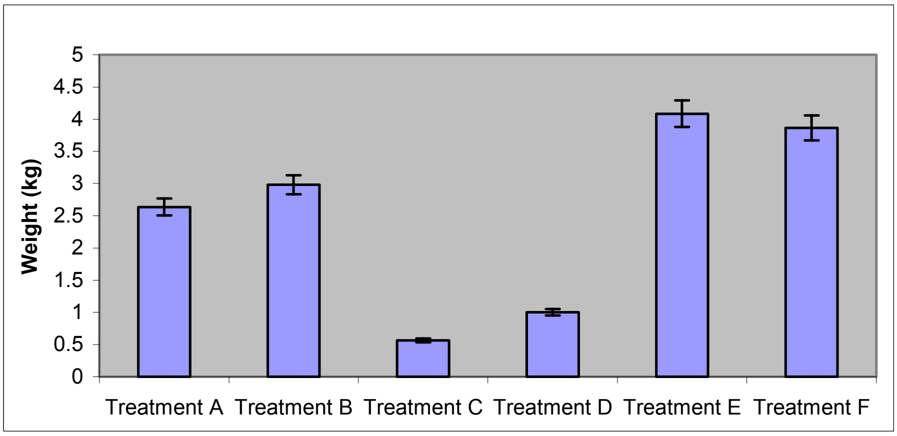

Figure 4.2b: Trial 1 average cabbage head weights for each treatment

Generally, the highest plant yields are obtained when using mineral fertiliser alone (at pre-plant and top-dressed every 10 days) or when in combination with surface banded manure at 2 weeks.
Manure and mineral fertiliser treatments are only effective when they include a mineral fertiliser top dressing every 10 days. In absence of routine mineral top dressing, plant performance is very poor.

Fertiliser Rate and Plant Weight

Figures 4.3 and 4.4 shows the average broccoli and cabbage head weights for the four application rates. The graphs illustrate that higher rates of fertiliser are more effective.

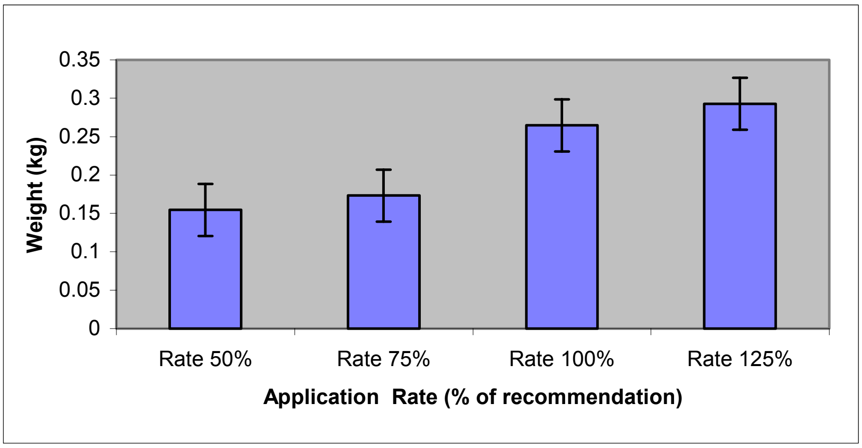

Figure 4.3: Trial 1 average broccoli head weights for each application rate

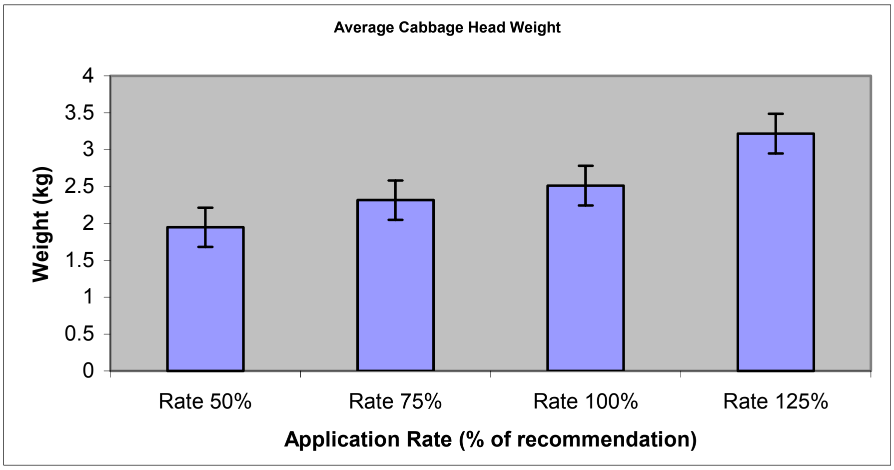

Figure 4.4: Trial 1 average cabbage head weight for each treatment

Generally, plant yield increases as more fertiliser is applied. For broccoli, the increase in yield tapers off at higher application rates ($F(3,23)=1.4, p>.05$) . However, there was a significant improvement in mean head weight for cabbages treated at 125% of the standard fertiliser recommendations set by Agriculture Western Australia ($F(3,23)=0.75, p>.05$).

Fertiliser Treatment/Fertiliser Rate Interaction

Figures 4.5a and 4.5b illustrate that certain fertiliser treatments are more effective than others when applied at different rates. In particular, treatments consisting only top dressing banded manure once did not grow well, even at high rates.

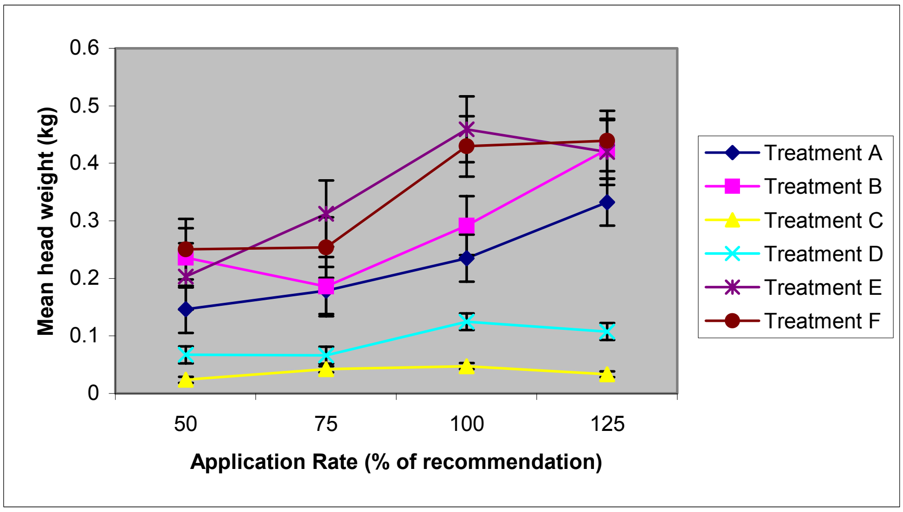

Figure 4.5a: Trial 1 average broccoli weight for each treatment and application rate

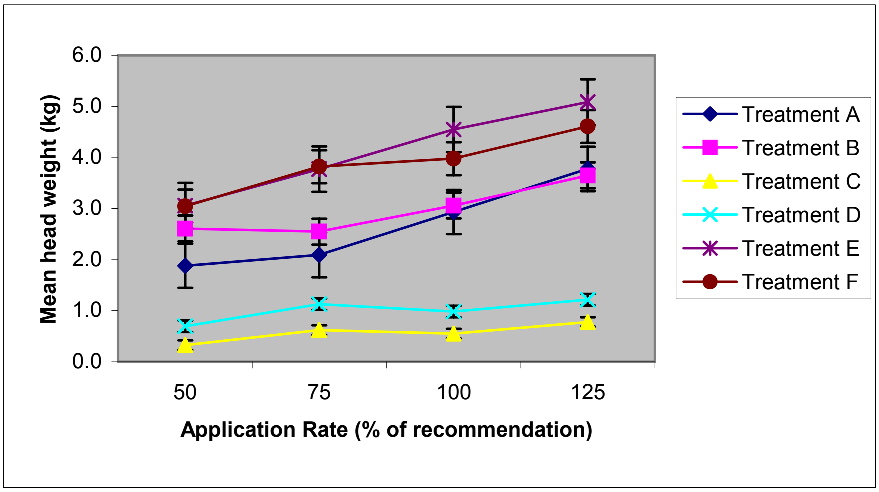

Figure 4.5b: Trial 1 average cabbage weight for each treatment and application rate

Overall, plants treated with pre-plant fertiliser and surface banded manure at two weeks with mineral top dressing every 10 days, performed as effectively as those treated with mineral only fertiliser (at pre-plant and top dressed every 10 days). Broccoli plants achieved the highest yield when treated with mineral fertiliser alone at 100% of the standard recommendation. Cabbage plants, receiving the same treatment, achieved their highest yield at 125% of the standard recommendation. For cabbages, deep banding proved as effective as incorporation at higher application rates. However, for broccoli, deep banding was more effective than incorporation for most application rates.

Generally, an increase in application rate had minimal effect on the yield of plants not receiving routine mineral top dressing, irrespective of the application rate.

Post Harvest Soil Analyses

At the completion of harvest, before trash was ploughed into soil, soil was sampled from each bed and analysed for nutrient ions, organic carbon, pH and EC. The detailed results are contained in Appendix A.

In general, most major and trace elements were available at only low levels. Levels of residual P and K were correlated to fertiliser application rate. Magnesium was generally at quite high levels. Paradoxically, the levels did not seem to reflect yield, as treatments C and D which produced poor yields were little different to other treatments. pH had declined slightly across all treatments and was not related to fertiliser treatment or application rate.

The soil organic matter analysis indicated that application of chicken manure had not promoted any accumulation of soil organic matter. Indeed the highest organic carbon levels were found in beds which received chemical fertiliser only, and in the treatments where banded manure was applied once (but as trash had not been ploughed in). These results suggested chicken manure had little medium term impact on carbon accumulation in soil.

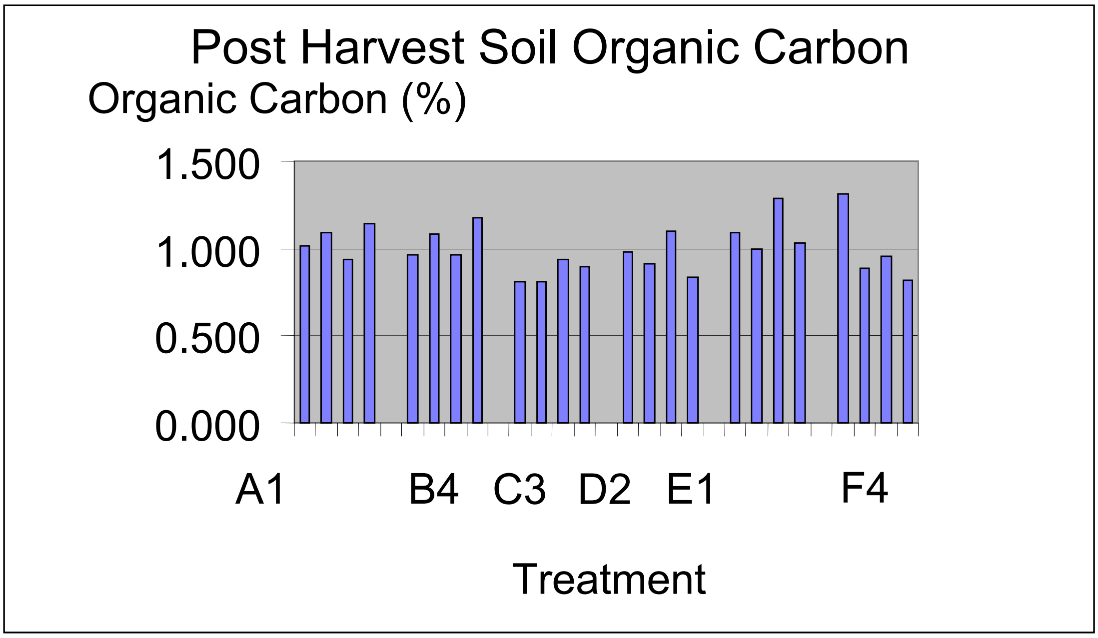

Figure 4.6 Soil organic carbon at the completion of trial 1.

Trial 2: Lettuce *Comparing different broiler litter applications and mineral fertiliser.*

The second field trial examined the effect of poultry manure on lettuce production over summer. The trial design was essentially the same as for the previous brassica trial except pre-plant deep banding of manure was not used. Six different fertiliser treatments were tested at 50%, 100%, 150% and 200% of the standard fertiliser recommendations set by Agriculture Western Australia for lettuce production. The fertiliser treatments employed for this trial were as follows:

TREATMENTS:

A: Manure incorporated pre-plant. Top dressing with NK every 7 days.
B: Manure incorporated pre-plant. Surface band Manure at 14 days
C: Manure incorporated pre-plant. Surface band Manure at 14 days, TD every 7 d.
D: Mineral PP. Top dressing NK every 7 days
E: Mineral PP. Surface band Manure at 14 days, TD every 7 d.
F: Mineral PP, Surface band Manure at 14 days, Surface band Manure at 42 days

Standard (100%) Fertiliser: 2.2 Tonnes Potato E per hectare pre-plant.

800 Kg Agran per hectare in 7 x 7 day doses (115 Kg/Ha)
1000 Kg Potassium Nitrate in 7 x 7day doses (140 Kg/Ha)
200 Kg Magnesium Sulphate in 8 x 7 day doses (25 Kg/Ha)
30 cubic meters of broiler litter taken as standard.

Hedonic Score

Comparison of the lettuce hedonic scores two weeks after transplant are illustrated in Figure 4.7 below:

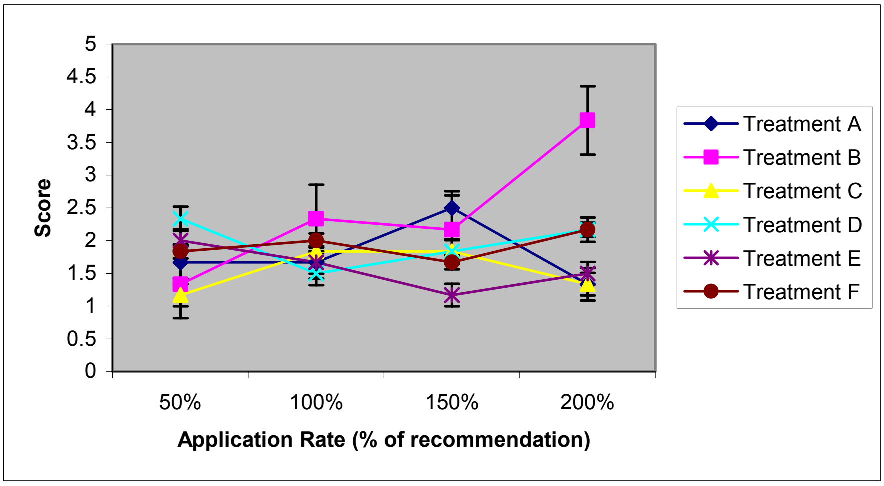

Figure4.7: Trial 2 summer lettuce hedonic score two weeks after transplant

Transplant establishment was similar for both pre-plant chicken manure and mineral fertiliser.

Plant Tissue Analysis

The nutritional status of the summer lettuce crop at three and six weeks after transplant are outlined in Appendix C. For most treatments and application rates, the concentration of major nutrients and trace elements were within the optimal range.

The only exception was for mineral fertiliser treatments at the lowest rare, where nitrogen and phosphorous were below optimum.

Fertiliser Treatment and Lettuce Weight

Figure 4.8 shows the average lettuce weights for the six treatments. The results illustrate that certain fertiliser treatments are more effective than others For lettuce, yield is greatest when manure is applied 14 days after transplant. ($F(5,18)=0.75, p>.05$)

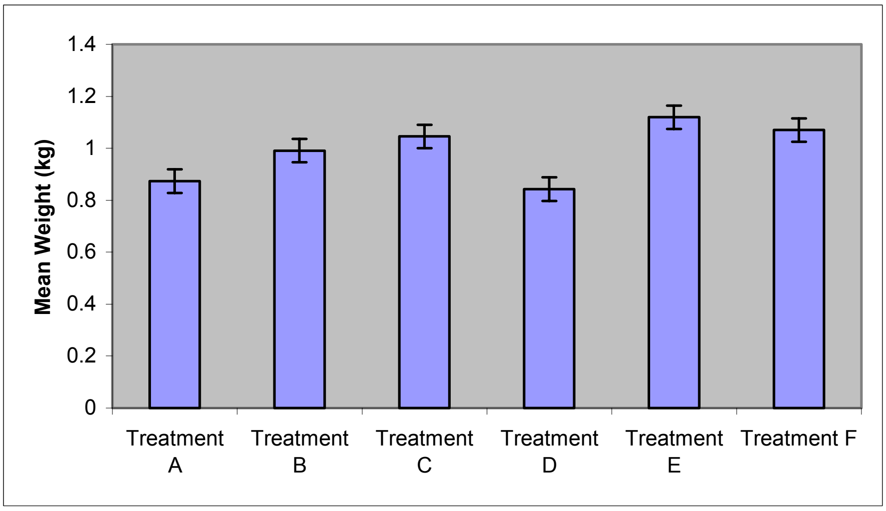

Figure4.8: Trial 2 average lettuce head weights for each treatment

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This time, Treatment D (mineral only) was the least effective of all treatments, having a mean weight of only 0.84 kg. Mineral pre-plant with manure surface banding at 14 days was the most effective of all treatments. However, in conjunction with manure incorporation at pre-plant, surface banding manure treatments (at 14 days) were similarly effective as mineral pre-plant/surface banding at 14 days.

Fertiliser Rates and Lettuce Weight

Figure 4.9 depicts the average lettuce weights for the four fertiliser rates. It shows the average weight of lettuce increases as more fertiliser is applied ($F(3,20)=13.83$, $p<0.5$). However, in excess of 150% of the standard fertiliser recommendations set by Agriculture Western Australia for lettuce production, yield decline slightly.

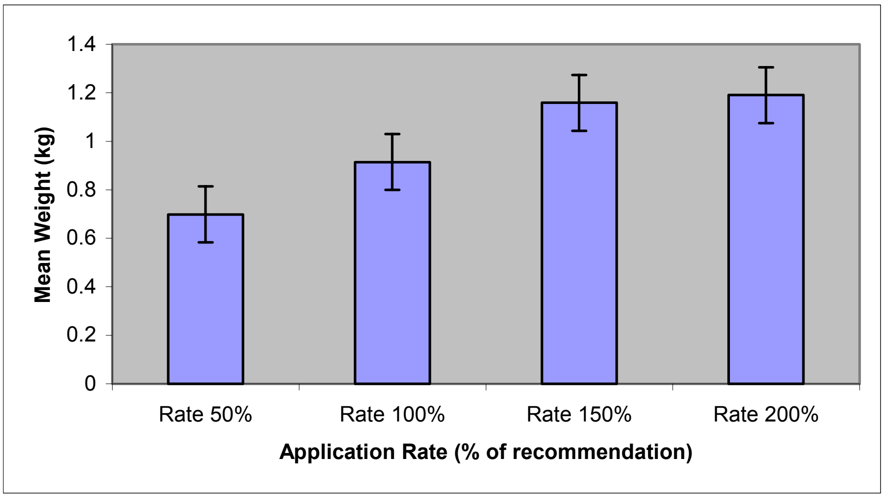

Figure 4.9: Trial 2 average lettuce head weights for each fertiliser application rate

Fertiliser Treatment/Fertiliser Rate Interaction

Figures 4.10 illustrates that certain fertiliser treatments are more effective than others when applied at different rates. Treatment E is most effective at low application rates; however, this tapers off above 100% of the standard recommended application rate. The performance of all other treatments plateau above 150% of the standard recommendation.

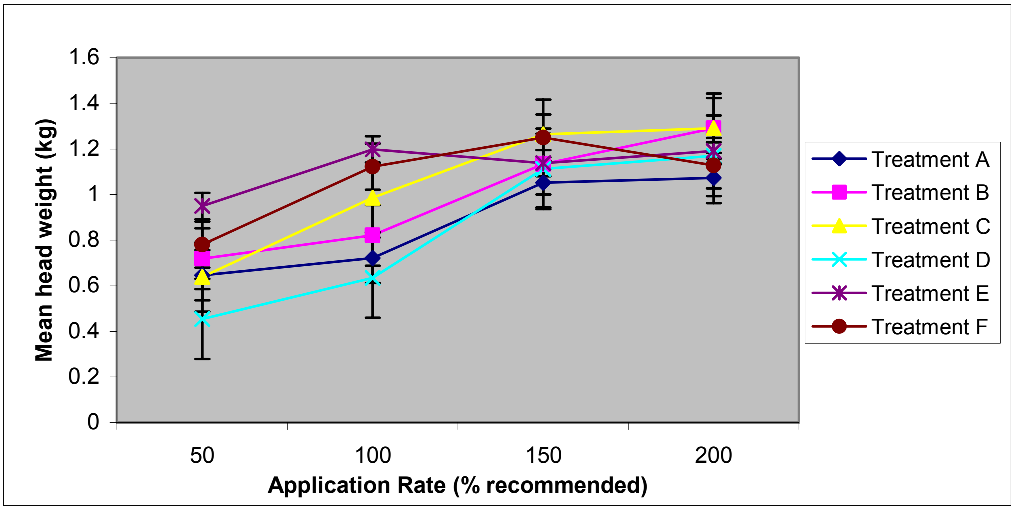

Figure4.10: Trial 2 average lettuce weights for each treatment and application rate

At standard rates or below, mineral fertiliser at pre-plant is more effective than manure incorporation, when used in conjunction with surface banding at 14 days after transplant. In most cases, the absence of surface banded manure at 14 days resulted in lower yields. Above standard rates, manure incorporated at pre-plant was more effective than mineral fertiliser alone, when used in conjunction with surface banded manure at 14 days after transplant.

In absence of surface banding at 14 days, manure incorporation was more effective than mineral pre-plant at lower rates. However, above standard rates, mineral fertiliser at pre-plant was slightly more superior to manure incorporation treatments.

Post Harvest Soil Analyses
At the completion of harvest, before trash was ploughed into soil, soil was sampled from each bed and analysed organic carbon, pH and EC. The detailed results are contained in Appendix C.

As with the previous trial, organic carbon (Figure 4.11) did not equate with chicken manure application, nor with fertiliser application rate, but rather with the yield produced, irrespective of fertiliser applied. After consecutive application of manures to beds, the total organic carbon levels remained at essentially the same level.

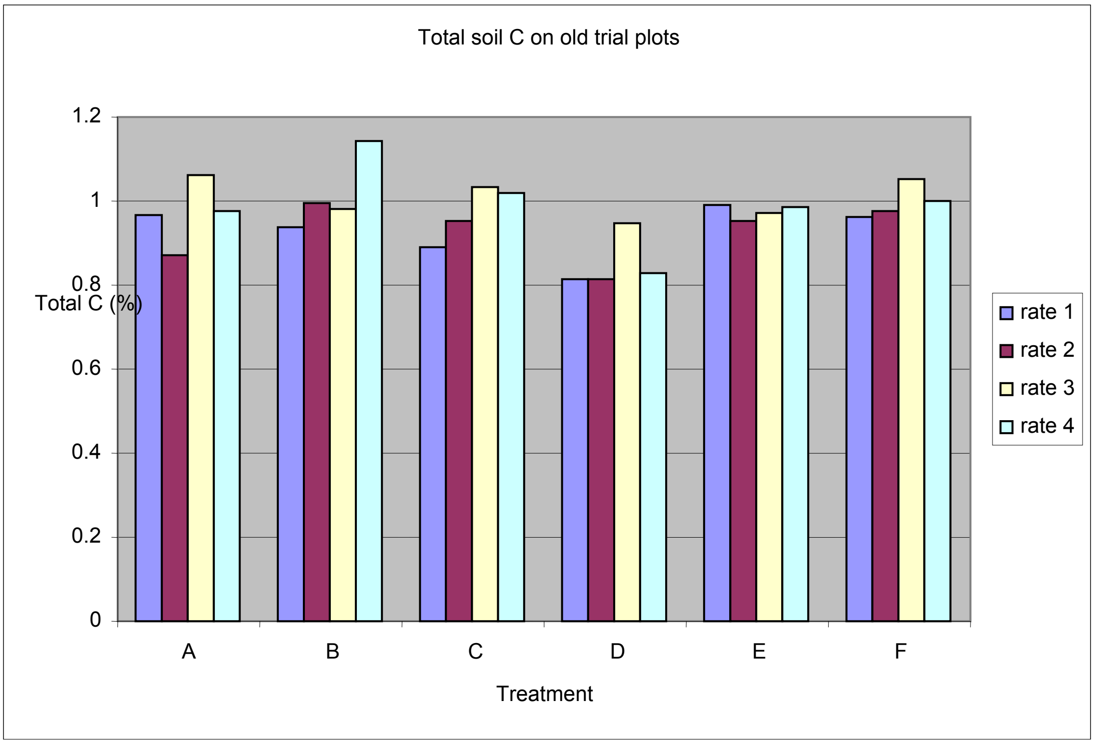

Figure 4.11. Soil organic carbon measured at the completion of trial 2.

Trial 3: Lettuce *Comparing different broiler litter applications and mineral fertiliser on new and old soils.*

The third trial examined the effect of poultry manure on lettuce production over winter. The trial design was essentially the same as the previous two trials; however, the entire trial was replicated in a newly prepared field that was had not been used for vegetable production. This enabled a 'real time' comparison between simulated market garden conditions and fallow ground. Six different fertiliser treatments were tested, but application rates were lowered to 50%, 100%, 125% and 150% of the standard fertiliser recommendations set by Agriculture Western Australia for lettuce production. The fertiliser treatments employed for this trial were as follows:

TREATMENTS:

A: Manure incorporated pre-plant. Top dress with NK every 7 days.
B: Manure incorporated pre-plant. Surface band Manure at 14 days.
C: Manure incorporated pre-plant. Surface band manure at 14 days, TD every 7 days.
D: Mineral PP. Top dressing NK every 7 days.
E: Mineral PP. Surface band manure at 14 days, TD every 7 days.
F: Mineral PP. Surface band manure at 14 days, surface band manure at 42 days.

Each treatment plan is the same for the 'new' and 'old' fields.

Hedonic Score

Comparison of the lettuce hedonic scores from the old and new fields, two weeks after transplant are illustrated in Figures 4.12a and 4.12b respectively.

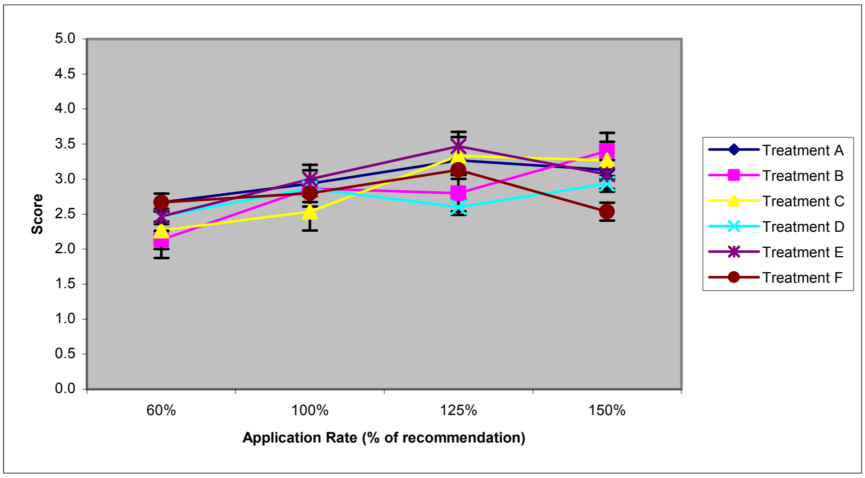

Figure 4.12a: Trial 3 lettuce hedonic score in old field two weeks after transplant

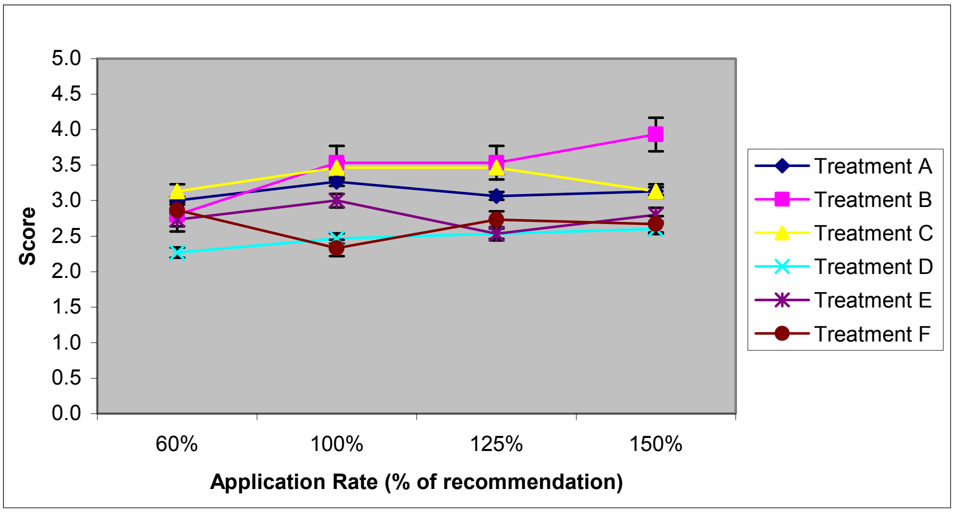

Figure 4.12b: Trial 3 lettuce hedonic scores in new field two weeks after transplant

Hedonic scores in the old field show that transplant establishment is similar for both pre-plant chicken manure and mineral fertiliser. Although there is an overall improvement in transplant establishment as fertiliser rates rise, this improvement ceases above 125% of the standard application rate.

Hedonic scores in the new field show that chicken manure incorporated at pre-plant provides better transplant establishment compared to mineral fertiliser.

Plant Tissue Analysis

The nutritional statuses of the winter lettuce crop at four and seven weeks after transplant are outlined in Appendix D (old field) and Appendix E (new field). For all treatments and application rates, the concentration of phosphorous was well above optimum range and the concentration of magnesium was below optimum, particularly for those receiving mineral only treatments. Potassium levels dropped off towards the end, and calcium levels, which were low to start, did pick up in the latter stages in the old field.

Frost Damage

Five weeks after transplanting the seedlings, the crop was hit with the first of four unusually heavy frosts. This had a significant impact on the growth of the lettuce. The severity of the damage caused by the frosts was determined using a five point hedonic scale, whereby a score of ‘1’ represented severe damage and a score of ‘5’ represented minimal damage. Scores given for each bed were averaged to give a mean score for each treatment. The results for the old and new fields are illustrated in Figures 4.13a and 4.13b respectively.

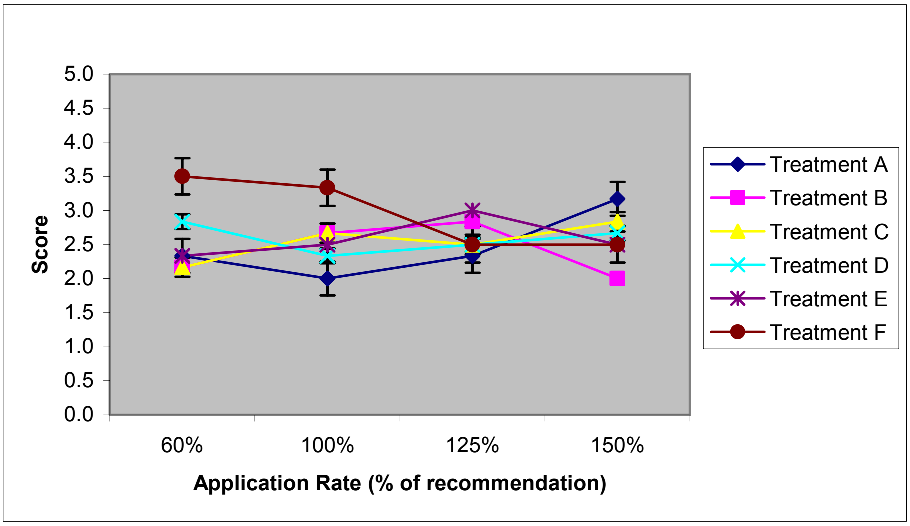

Figure 4.13a: Trial 3 frost damage in old field

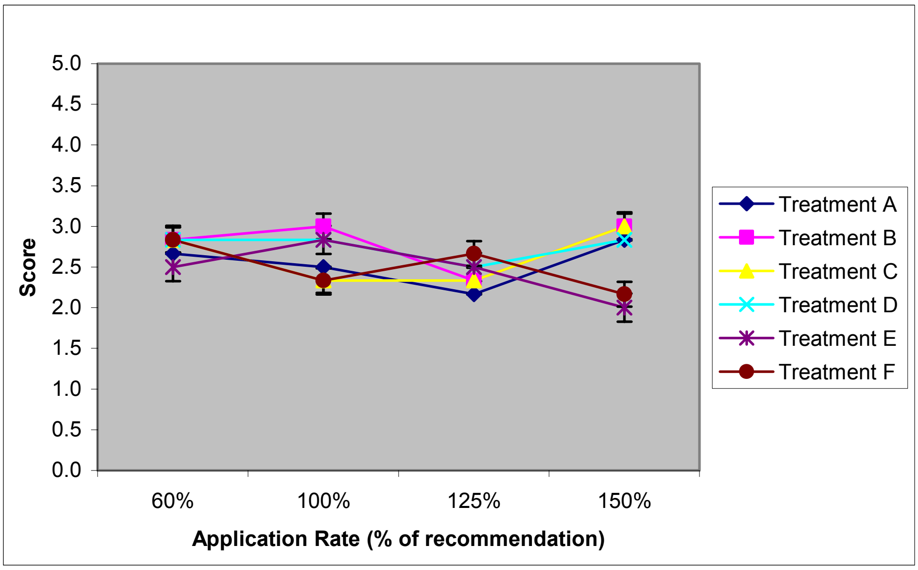

Figure 4.13b: Trial 3 frost damage in new field

Overall, the lettuces in the old and new fields were similarly affected by the severity of the heavy frosts, regardless of fertiliser treatment or application rate.

Fertiliser Treatment and Plant Weight

Figures 4.14a and 4.14b show the average winter lettuce weights for the six treatments in the old and new fields. The results illustrate that certain fertiliser treatments are more effective than others ($F(5,18)=2.32$, $p>.05$), and the effect of the treatments differ between fields ($F(5,18)=5.70$, $p<.05$).

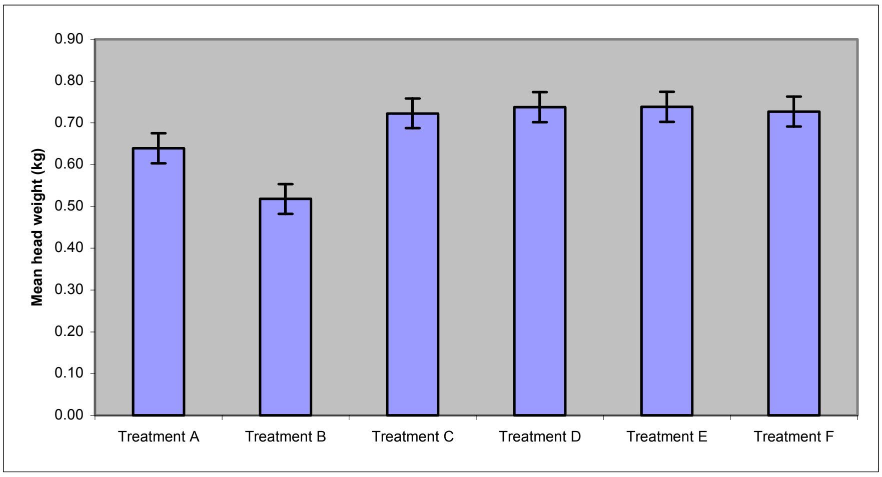

Figure 4.14a: Trial 3 average lettuce weights for each treatment in the old field

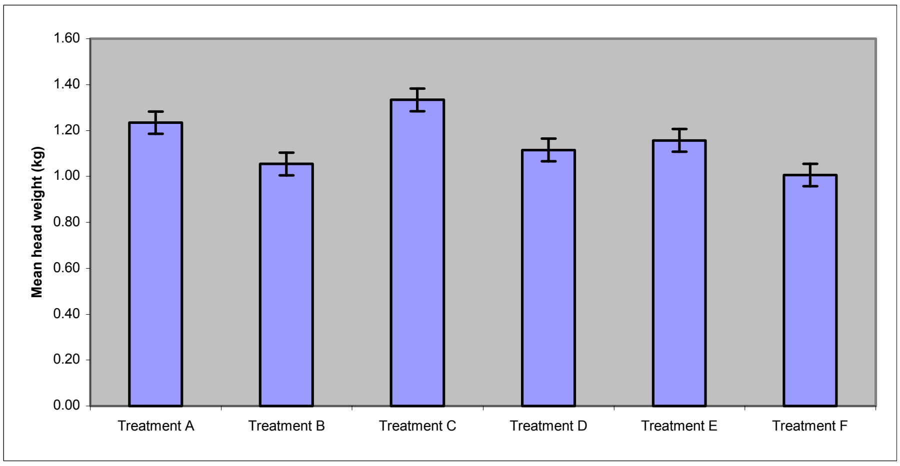

Figure 4.14b: Trial 3 average lettuce weights for each treatment in the new field

In the new field site, pre-plant manure incorporation, with manure surface banding at 14 days and mineral top dressing every 7 days was the most effective of all six treatments. The mineral pre-plant treatments were the least effective.
Results for the old field site show that the mineral pre-plant treatments were as effective as pre-plant manure incorporation, with manure surface banding at 14 days and mineral top dressing every 7 days.

Fertiliser Rate and Plant Weight

Figures 4.15a and 4.15b show the average winter lettuce weights for the four application rates in the old and new fields. The results show that there is a reducing improvement in yield as more fertiliser is applied in both old ($F(3,20)=1.3$, $p>.05$) and new fields ($F(3,20)=1.9$, $p>.05$).

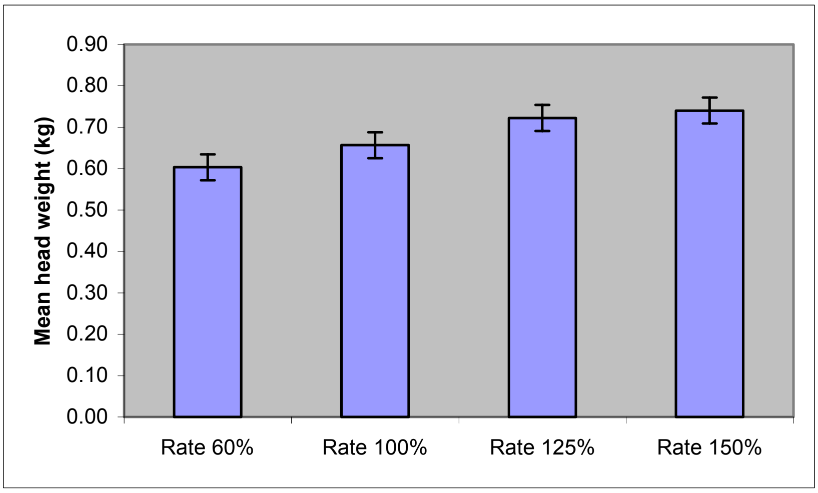

Figure 4.15a: Trial 3 average lettuce weights for each application rate in the old field

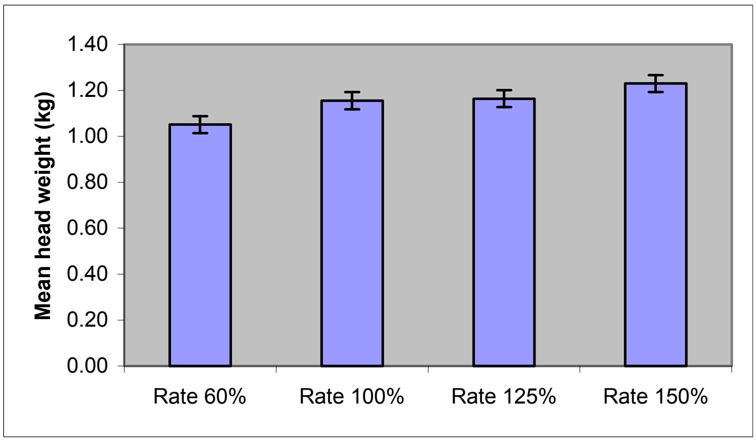

Figure 4.15b: Trial 3 average lettuce weights for each application rate in the new field

Fertiliser Treatment/Fertiliser Rate Interaction

Figures 4.16a and 4.16b illustrate that certain fertiliser treatments are more effective than others when applied at different rates, and the effect of these treatments differs between fields.

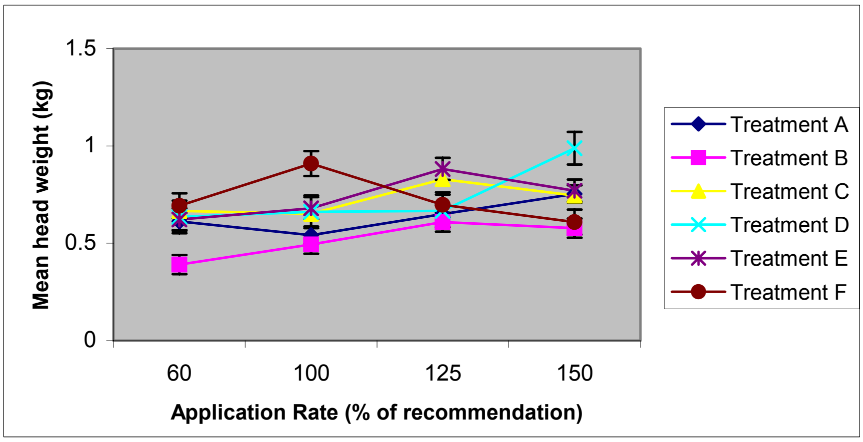

Figure 4.16a: Trial 3 average lettuce weights for each treatment and application rate in the old field

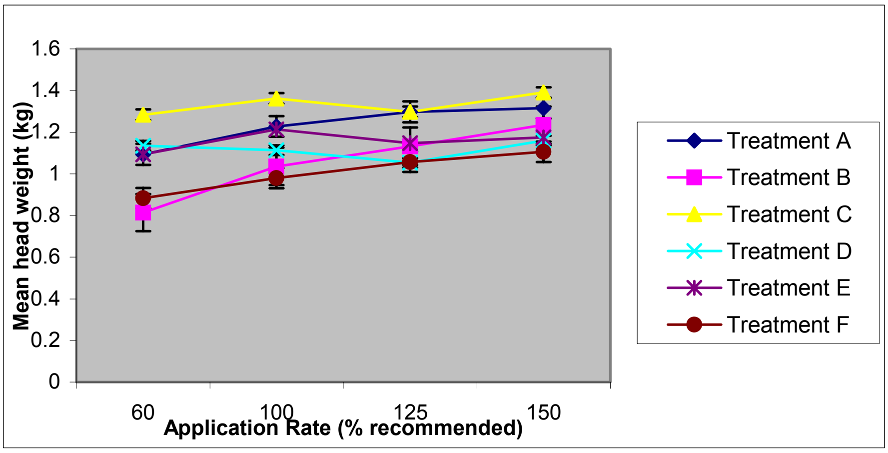

Figure 4.16b: Trial 3 average lettuce weights for each treatment and application rate in the new field

The productivity of the old field was not to expectations. Heavy frost damage had compromised growth, but this led to a subsequent heavy outbreak of Sclerotinea. Very minor sclerotinia had been present in the previous lettuce crop, however was well controlled by a single application of fungicide. This time the disease was difficult to control even with weekly fungicides, and disease severely effected crop performance throughout the latter stages of the growth trials.

The new field, which was not affected by disease, and recovered remarkably well from the frost, produced satisfactory yields. This was attributed to a lower inoculum pressure in the soil, which had not previously been cultivated. Based on the harvest results from the new field, it is apparent that the most effective fertiliser treatment for winter lettuce is manure incorporated at pre-plant, with manure surface banding at 14 days after transplant and a mineral fertiliser top dress every 7 days, which consistently proved to be the most effective treatment for all application rates. At higher application rates, this treatment, in the absence of manure surface banding at 14 days after transplant, proved equally effective. Plants treated without a manure/mineral top dress combination performed poorly, regardless of application rate.

Trial 4: Corn *Comparing broiler litter and acid- treated broiler litter applications with mineral fertiliser.*

Following a meeting with the R&D committee, a decision was made to commence a study on the impact of treating manure with phosphoric acid as both a means of preventing flies breeding and increasing nutrient availability in manure. The fourth field trial tested the phosphoric acid amended manure ‘PAM’ against a “synthetic manure”, which for the convenience of our records was named “Nutraplex”.

Because the previous trial had experienced quite severe sclerotinia, which is a pathogen of both lettuce and brassicas, advice from growers suggested sweet corn would be a good break crop to reduce sclerote levels. The field was also treated with a commercial preparation of *Trichoderma harzianun* in order to attenduate disease pressure.

Trial 4 examined the effect of standard poultry manure, acid amended manure and synthetic manure on the productivity of corn grown through late spring to mid summer. Six different fertiliser treatments were tested at 60%, 100%, 125% and 150% of the standard fertiliser recommendations set by Agriculture Western Australia for corn production. The fertiliser treatments employed were as follows:

TREATMENTS

A:	Chicken manure (untreated control) pre plant, surface band chicken manure at week 2, mineral top dress every 7 days
B:	Amended chicken manure (3% H_3PO_4) pre plant; surface band amended chicken manure at week 2 and week 6.
C:	Amended chicken manure (3% H_3PO_4) pre plant; surface band amended chicken manure at week 2; mineral top dress every 7 days.
D:	Mineral pre plant; mineral top dress every 7 days.
E:	Amended chicken manure (1½% H_3PO_4) pre plant; surface band amended chicken manure at week 2; mineral top dress every 7 days
F:	Nutraplex pre plant; top dress Nutraplex at week 2 and week 6.

Standard (100%) Fertiliser: 1.2 Tonnes Potato E per hectare pre-plant.
650 Kg Agran per hectare in 10 x 7 day doses of 65Kg/Ha
700 Kg Potassium Nitrate in 10 x 7day doses of 70Kg/Ha
200 Kg Magnesium Sulphate in 10 x 7 day doses (20 Kg/Ha)
30 cubic meters/Ha of broiler litter taken as standard.
25 cubic meter/Ha of phosphate amended broiler litter.
30 cubic meters/Ha of Nutraplex

Plant Tissue Analysis
The nutritional status of the corn crop at four and six weeks after transplant is outlined in Appendix F. Generally, treatments A, B and C were limiting in nitrogen throughout. Potassium levels dropped to below ideal in all treatments towards the latter end of the trial

Fertiliser Treatment and Cob Weight
Figures 4.17a and 4.17b show the average cob weights for each of the six treatments.

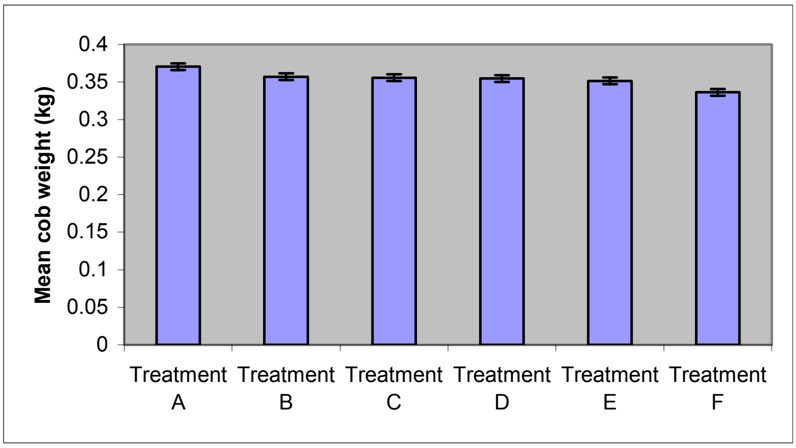

Figure 4.17a: Trial 4 first harvest average cob weights for each treatment

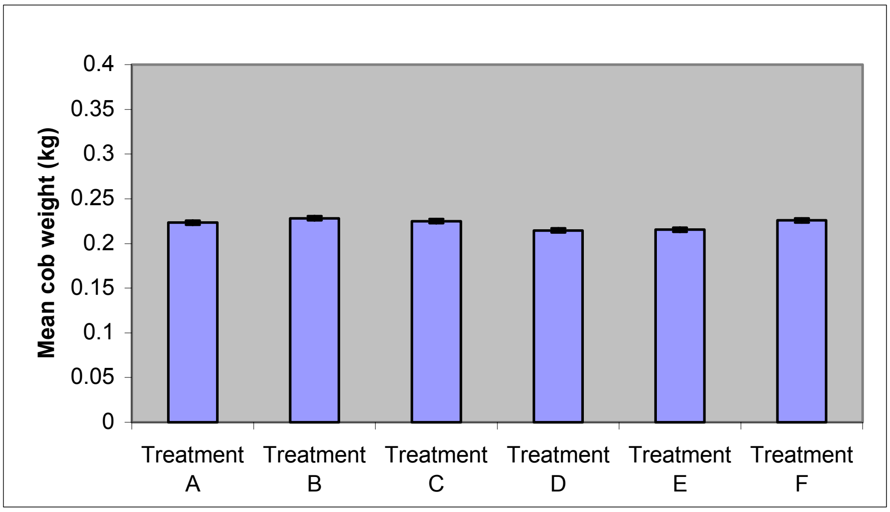

Figure 4.17b: Trial 4 second harvest average cob weights for each treatment

The results show meager differences between the mean cob weights for the six treatments, although cob weights are significantly lower for subsequent harvests. (First crop $F(5,18)=3.2, p<.05$, Second Crop $F(5,18)=0.17, p>.05$) The greatest difference, of only 34g, was recorded in the first harvest, between Treatment A (untreated chicken manure pre-plant, surface band manure at week 2 with mineral top dressing every 7 days) and Treatment F (Nutraplex pre-plant with Nutraplex top dress at week 2 and week 6).

Fertiliser Treatment and Cob Number

Figures 4.18a and 4.18b show the average number of cobs harvested for each of the six treatments. The results show that different fertiliser treatments have an effect on the average number of harvestable cobs.

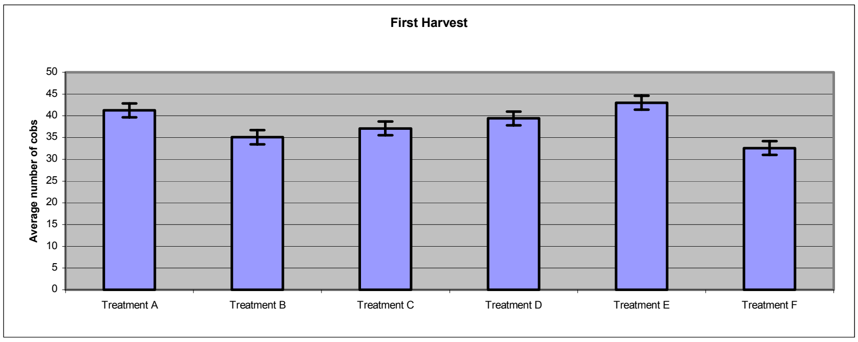

Figure 4.18a Sweet corn cob number, First Harvest

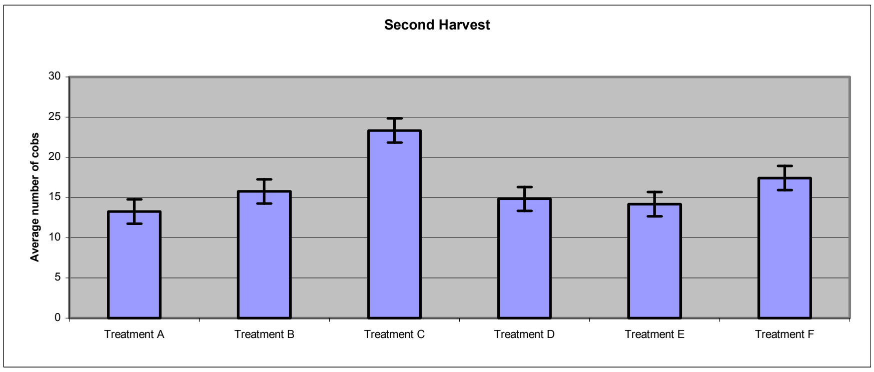

Figure 4.18b Sweet corn cob Number, Second Harvest

Combining the average number of cobs from both harvests, Treatment C (3% H_3PO_4 amended manure preplant, surface banded amended manure at week 2 with mineral top dress every 7 days) and Treatment A had the greatest yield with a total average of 60 and 57 cobs respectively. The Nutriplex treatment produced the lowest yield with a total average of around 50 cobs. (First Harvest $F(5,18)=1.4$, $p>.05$, Second Harvest $F(5,18)=2.37, p>.05$).

Treatment C produced a significantly greater number of cobs in the subsequent harvest.

Fertiliser Rate and Cob Weight

Figures 4.19a and 4.19b show the average cob weights for each of the four application rates. The results show that increasing fertiliser applications have a minimal effect on the average cob weight (First Harvest $F(3,20)=0.90,p>.05$, Second Harvest $F(3,20)=0.004,p>.05$).

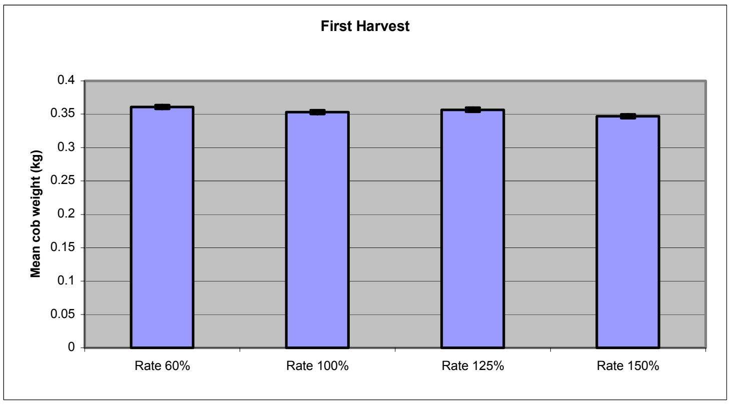

Figure 4.19a Mean Cob Weight at first harvest

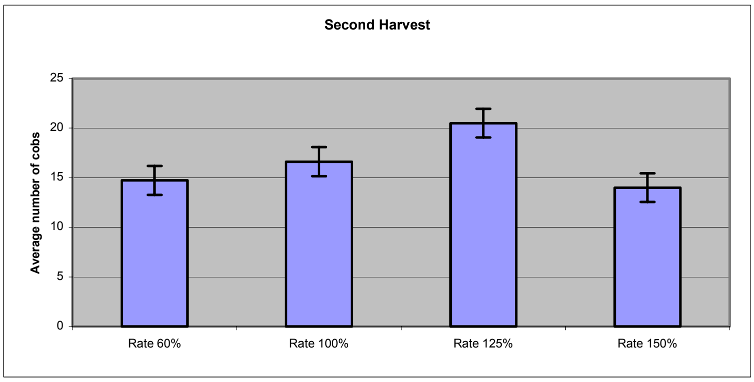

Figure 4.19b Mean Cob weight at second harvest

Fertiliser Rate and Cob Number

Figures 4.20a and 4.20b show the average number of cobs harvested for each of the four application rates. The results show that different fertiliser rates have an effect on the average number of harvestable cobs (First Harvest $F(3,20)=2.39$, $p>.05$, Second Harvest $F(3,20)=1.95$, $p>.05$).
Combining both harvests, the greatest average number of cobs is produced when fertiliser is applied at the standard recommendations for corn set by Agriculture

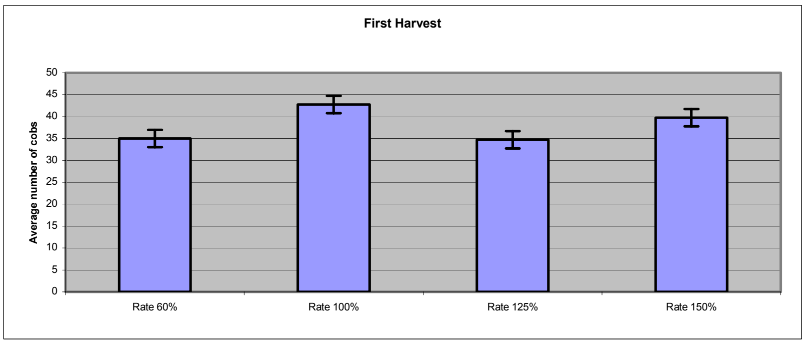

Figure 4.20a Cobs first harvested at fertiliser application rates

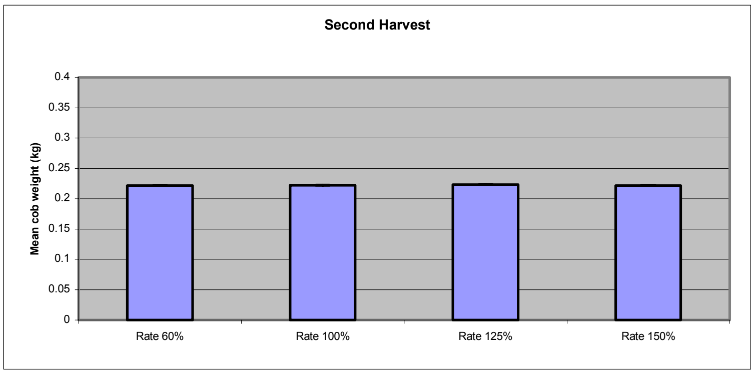

Figure 4.20 b Cobs second harvest at fertiliser application rates

Western Australia. This standard rate produces the greatest average number of corn cobs at first harvest. However fertiliser rates at 125% of standard recommendations yield the greatest average number of cobs in subsequent harvests.

Fertiliser Treatment/Fertiliser Rate Interaction

Figure 4.21 illustrates that for most treatments, the average cob weight is relatively unaffected by changes in fertiliser application rate. Treatments A and E shared the greatest average cob weight, when applied at 60% of the standard fertiliser recommendation set by Agriculture Western Australia. Although the differences between average cob weights at different rates were small, in general, Treatments B, C and D performed as effectively as each other.

Figure 4.21: Average Weight per cob - first harvest

Figure 4.22 shows the number of cobs harvested per half bed. A comparison of figures 4.21 and 4.22 show little correlation between cob weight and number. On average, the Nutriplex treatment performed the most poorly, having almost consistently lower cob weight and numbers. Slightly better yields are obtained when using chicken manure over mineral fertiliser alone. However, the most interesting finding is that growers can effectively reduce their overall fertiliser usage and costs, at the same time being more environmentally responsible, without the fear of a huge drop in yield.

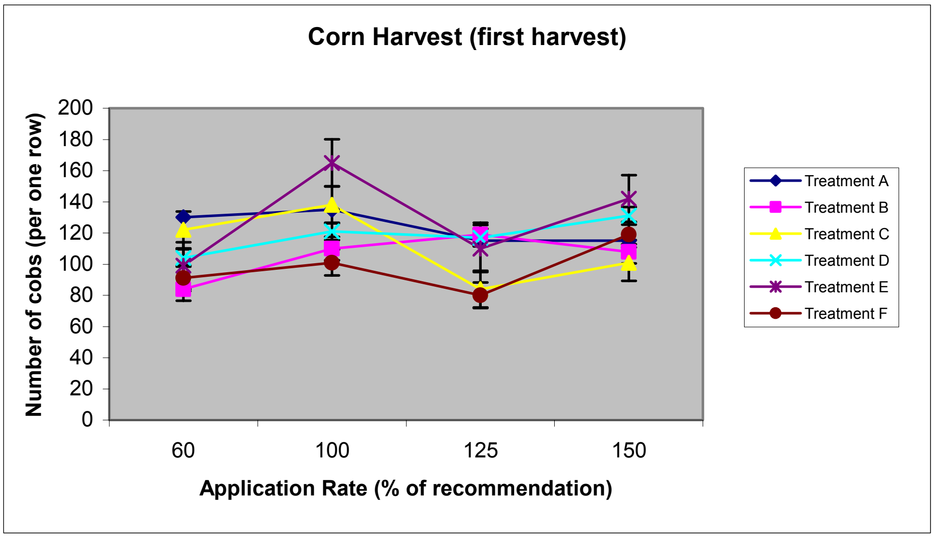

Figure 4.22: Number of cobs - first harvest

Unfortunately for this trial, many of the cobs were the target for caterpillars early on in the season, and rats and birds nearing harvest. This may have impacted somewhat on the results we obtained, particularly for Treatments A-150%, E-125%, F-60% and F-125%.

The trial did not produce the anticipated higher yield using phosphate-treated manure, however as the trial progressed it became apparent that phosphate was not well bound to the treated manure, thus may have leached earlier than anticipated, resulting in no reduction in manure pH.

Trial 5: Lettuce *Comparing different broiler litter applications with phosphate –treated litter and Nutraplex.*

The fifth trial was essentially the same as the previous trial, this time examining the effect of the standard manure, synthetic manure and amended manure on the productivity of lettuce grown during late summer to autumn. Six fertiliser treatments were tested at 30%, 60%, 90% and 120% of the standard recommendations set by Agriculture Western Australia for lettuce production (as stated in trial 3). Phosphate amended pre-plant applications were made the day before planting, whereas untreated manure was applied 7 days before planting. The fertiliser treatments employed were as follows:

TREATMENTS:

A: Chicken manure (untreated control) pre plant, surface band chicken manure at week 2, mineral top dress every 7 days
B: Amended chicken manure (3% H_3PO_4) pre plant; surface band amended chicken manure at week 2 and week 6
C: Amended chicken manure (3% H_3PO_4) pre plant; surface band amended chicken manure at week 2; mineral top dress every 7 days
D: Mineral pre plant; mineral top dress every 7 days
E: Nutraplex pre plant, surface band nutraplex at week 2; mineral top dress every 7 days
F: Nutraplex (chicken manure substitute) pre plant; top dress with Nutraplex at week 2 and week 6

Standard (100%) Fertiliser: 1.2 Tonnes Potato E per hectare pre-plant.
650 Kg Agran per hectare in 10 x 7 day doses of 65Kg/Ha
700 Kg Potassium Nitrate in 10 x 7day doses of 70Kg/Ha
200 Kg Magnesium Sulphate in 10 x 7 day doses (20 Kg/Ha)
30 cubic meters/Ha of broiler litter taken as standard.
25 cubic meter/Ha of phosphate amended broiler litter.
30 cubic meters/Ha of Nutraplex

Hedonic Score
Comparisons of the summer/autumn lettuce hedonic scores two weeks after transplant are illustrated in Figure 4.23.

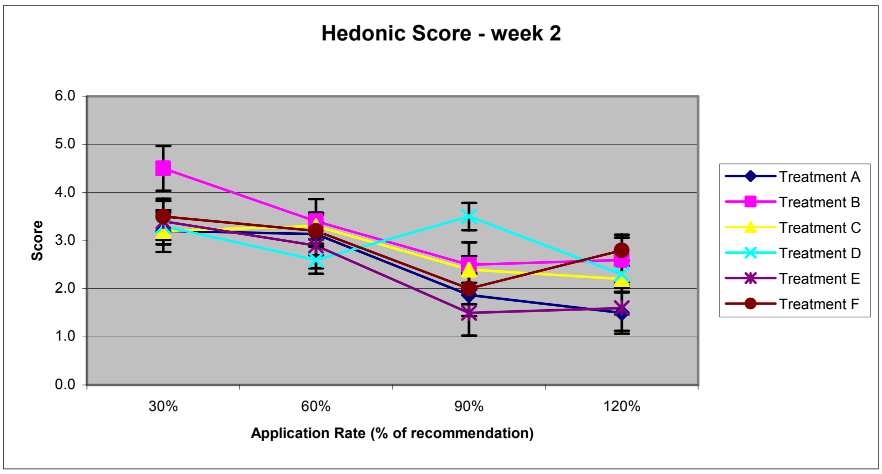

Figure 4. 23: Late summer/autumn lettuce hedonic scores - two weeks after transplant

Overall, transplant establishment was similar for standard manure, amended manure, synthetic manure and mineral fertiliser. Increasing fertiliser rates up to 90% of the recommended rate generally improved the rate of establishment. Beyond that, transplant establishment tapered off. There was no evidence that transplanting the day after acid-treated manure was applied caused any root burning.

Plant Tissue Analysis
The nutritional status of the late summer/autumn lettuce crop at four and six weeks after transplant is outlined in Appendix G. Although all mineral elements were at or above optimal levels at the start of the trial, towards the end, some treatments were lacking in particular major elements. Nitrogen levels dropped off for most treatments, with Treatment B most affected. Potassium levels too dropped off for Treatment B. Calcium levels fell below optimum for Treatments C, E and F, and so too magnesium for Treatment C.

Fertiliser Treatment and Plant Weight
Figure 4.24 shows the average lettuce weights for each of the six treatments. The graph shows that certain fertiliser treatments are more effective than others ($F=(5,18)=3.22$, $p<.05$).

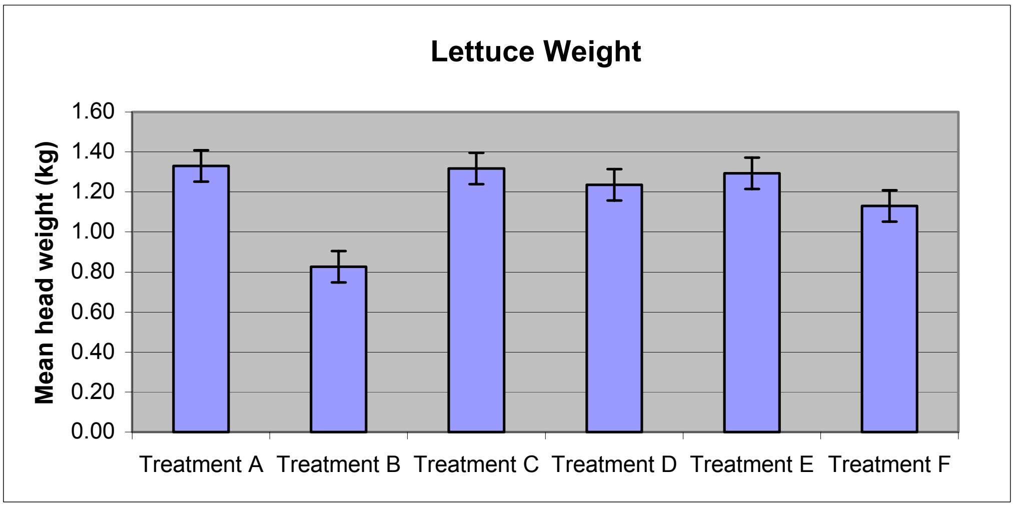

Figure 4.24: Average Lettuce Weight

Treating chicken manure with high doses of phosphoric acid has no significant effect on plant yield in comparison to untreated manure. Generally, the highest plant yields are obtained when chicken manure is applied at pre-plant, then again at week two and top dressed with mineral fertiliser every seven days – regardless of whether the manure has been treated with phosphoric acid or not.

Chicken manure treatments are only effective when they include a mineral fertiliser top dressing every seven days. In absence of a mineral fertiliser, Nutraplex (a chicken manure substitute) is more effective than chicken manure alone.

Fertiliser Rates and Plant Weights
Figure 4.25 shows the average lettuce weights for each of the four application rates. The graph illustrates that certain fertiliser rates are more effective than others ($F(3,20)=4.66$, $p<.05$) .

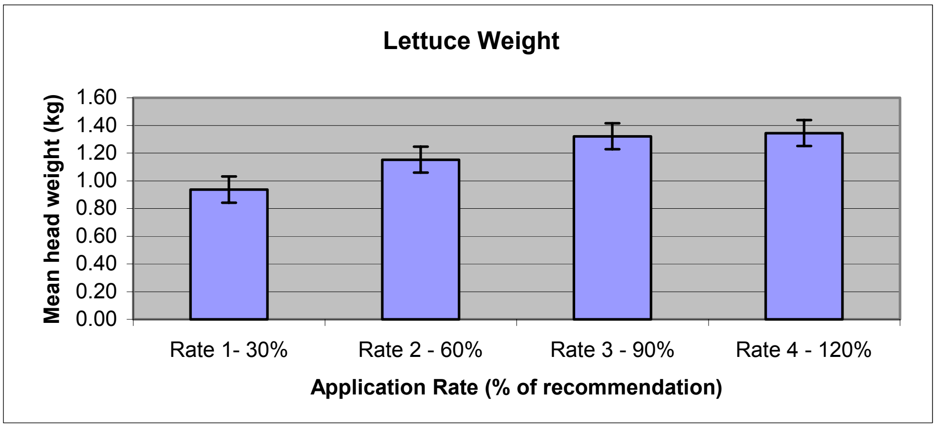

Figure 4.25: Average Lettuce Weight

Plant yield increases as more fertiliser is applied. However, there is no significant difference between the two highest application rates (90% and 120% of the standard fertiliser recommendations set by Agriculture Western Australia for lettuce production).

What this essentially means is that by reducing fertiliser use to 90% of the standard recommendation set by AgWA, growers can effectively reduce their overall fertiliser usage and costs, at the same time being more environmentally responsible, without the fear of a significant drop in yield.

Fertiliser Treatment/Fertiliser Rate Interaction

Figure 4.26 illustrates that certain fertiliser treatments are more effective than others when applied at certain rates ($F(3,15)=24.52$, $p<.05$).

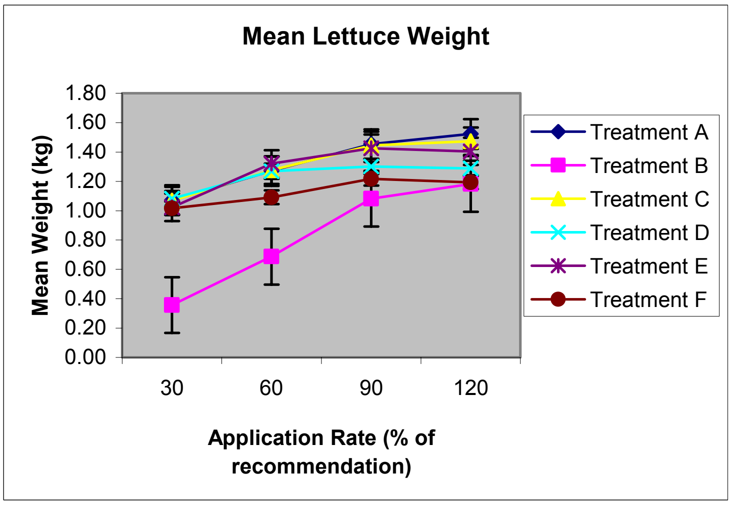

Figure 4.26: Average Lettuce Weight

Generally, plants receiving untreated chicken manure applied at preplant, then again at week two and top dressed every seven days at 120% of the standard recommendation, had the highest yield. The lowest yield was recorded for amended chicken manure, with no mineral top dress at 30% of the standard recommendation.

Irrespective of the acid treatment, chicken manure in combination with mineral fertiliser, performed as effectively as mineral fertiliser alone at lower application rates. At higher application rates, chicken manure in combination with mineral fertiliser, is more effective than mineral fertiliser alone. Generally, for most application rates, acid treated and untreated chicken manure perform as effectively as each other. However at 120% of the standard recommended rate, the 3% (phosphoric acid) amended manure is significantly more effective than the 1.5% (phosphoric acid) amended manure – which was unexpected given that A4 (untreated chicken manure applied at pre-plant, then again at week two and top dressed every seven days at 120% of the standard recommendation) is more effective than C4 (3% acid amended manure applied at pre-plant, then again at week two and top dressed every seven days at 120% of the standard recommendation).

One explanation for this is the prevalence of the fungal disease *Sclerotinia*, which posed somewhat of a problem, particularly during the latter stages of the trial. As Figure 4.27 illustrates, the disease was generally confined to two sections of the field, with beds 12, 22, 24, 59, 63, 67, and 68 considerably more affected than others. Assuming head weights had been compromised by disease, treatments A2, C2, D3, E1, E4, F2 and F4 may in effect have had lower than customary yields. This may account for treatments A4 and C4 having significantly higher head weights than E4.

1	4	7	10	13	16	19	22	25	28	31	34	37	40	43	46	48	52	55	58	61	64	67	70
2	5	8	11	14	17	20	23	26	29	32	35	38	41	44	47	50	53	56	59	62	65	68	71
3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72

Figure 4.27: Disease Prevalence

Trial 6:

The sixth trial was essentially the same as the previous trial, however this time, total fertiliser application rates were lowered, and Nutraplex was examined in combination with mineral fertiliser. Another inclusion to this trial was the effect that a "ferment based soil conditioner" had on plant productivity.

Bioscience manufactures "Bioprime" by fermenting molasses using bakers yeast under facultative anaerobic conditions, then stabilising the product using citric acid and urea. The result is a complex blend of organic acids and alcohols which promotes the rapid growth of soil heterotrophic bacteria. The object of the trial was to determine whether stimulation of soil heterotrophic bacteria would accelerate mineralization of treated and untreated poultry manure.

This trial tested six fertiliser treatments on summer lettuce at much lower application rates than the standard recommendations set by Agriculture Western Australia for lettuce production - 40%, 55%, 70% and 90%. The fertiliser treatments employed were as follows:

TREATMENTS:

A:	Chicken manure (untreated control) pre plant, surface band chicken manure at week 2, mineral top dress every 7 days
B:	Amended chicken manure (3% H3PO4) pre plant; surface band amended chicken manure at week 2 and week 6
C:	Amended chicken manure (3% H3PO4) pre plant; surface band amended chicken manure at week 2; mineral top dress every 7 days
D:	Mineral pre plant; mineral top dress every 7 days
E:	Nutraplex pre plant, surface band nutraplex at week 2; mineral top dress every 7 days
F:	Nutraplex (chicken manure substitute) pre plant; top dress with Nutraplex at week 2 and week 6

Hedonic Score

Comparisons of the summer lettuce hedonic scores five weeks after transplant are illustrated in Figure 4.28.

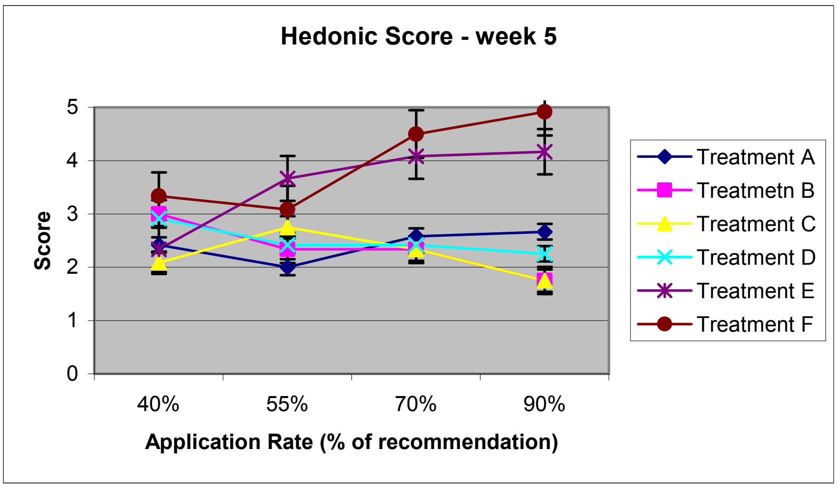

Figure 4.28: Summer lettuce hedonic scores - five weeks after transplant

For all application rates, transplant establishment was generally similar for unamended manure, amended manure and mineral fertiliser. However the rate of seedling establishment markedly deteriorated with increasing rates of synthetic manure.

Plant Tissue Analysis
The nutritional status of the summer lettuce crop at four and six weeks after transplant is outlined in Appendix H. Once again, nitrogen levels dropped towards the end of the trial for all treatments. Potassium levels were low throughout the growing period for Treatment B.

Fertiliser Treatment and Plant Weight
Figure 4.29 shows the average lettuce weights for each of the six treatments. The graph shows that certain fertiliser treatments are more effective than others.

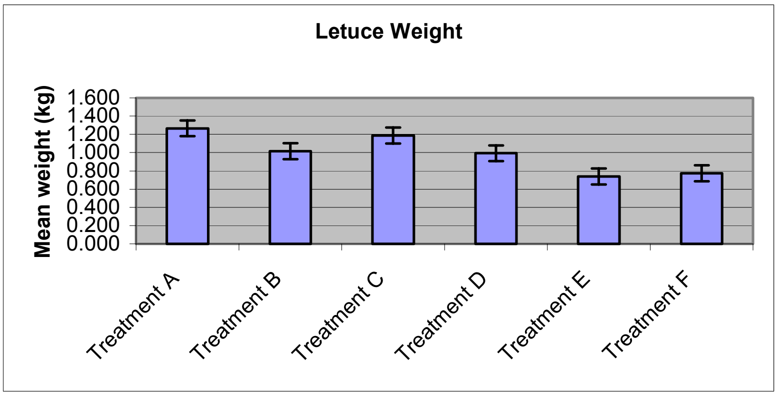

Figure 4.29: Average Lettuce Weight

Overall, chicken manure applied at pre-plant, then again two weeks after transplant with routine applications of mineral fertiliser, proved to be the most effective treatment. Marginally better yields were obtained with the untreated manure. Amended chicken manure applied at pre-plant, then again at two and six weeks after transplant, proved as effective as mineral treatments alone. Nutraplex was the least effective of all treatments, with little difference in yield when used in combination with mineral fertiliser.

Figure 4.30 shows the average lettuce weights for each of the six treatments, with and without the ferment application. For most treatments A,C and D, there was little or no improvement in yield when ferment was applied. However, a substantial improvement was seen for Treatments B and E following ferment application, whereas there was a deterioration in Treatment F. This suggested the ferment had a significant impact on surface banded treatments, but not on those incorporated.

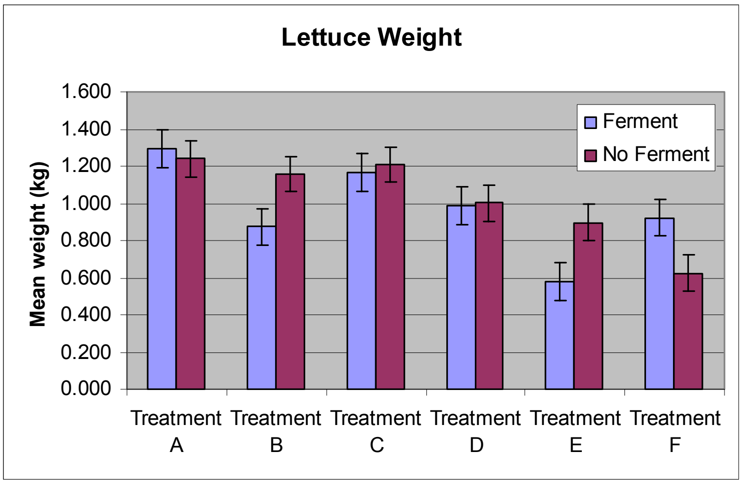

Figure 4.30: Average Lettuce Weight – with and without ferment application

Fertiliser Rates and Plant Weights

Figure 4.31 shows the average lettuce weights for each of the four rates. The graph illustrates that there was no significant improvement in yield once application rates exceed 55% of the standard recommendation.

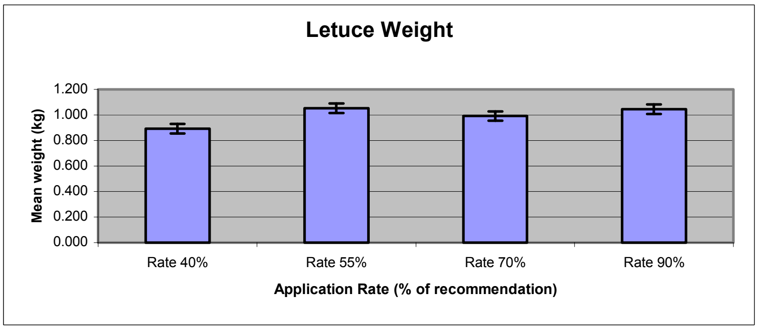

Figure 4.31: Average lettuce weights for each fertiliser rate

Figure 4.32 compares the average lettuce weights for each of the four rates, with and without ferment applications. The graph illustrates that there is little or no overall improvement in yield with ferment.

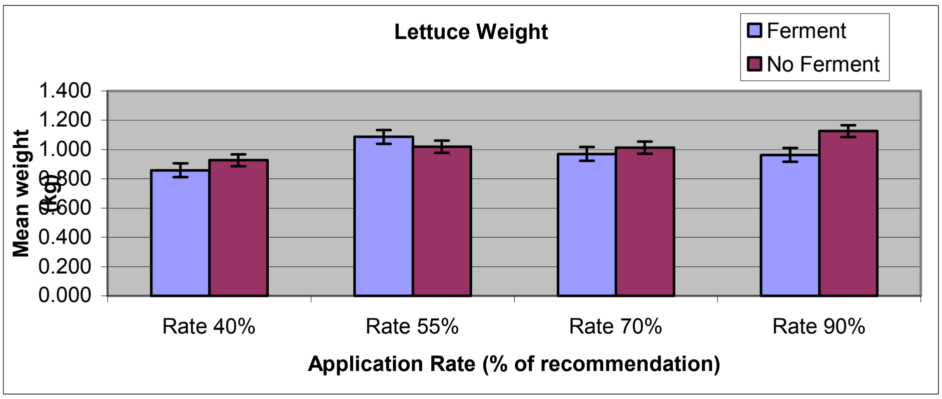

Figure 4.32: Average lettuce weights with and without ferment

Fertiliser Treatment/Fertiliser Rate Interaction

Figure 4.33 shows that certain fertiliser treatments are more effective when used at certain rates.

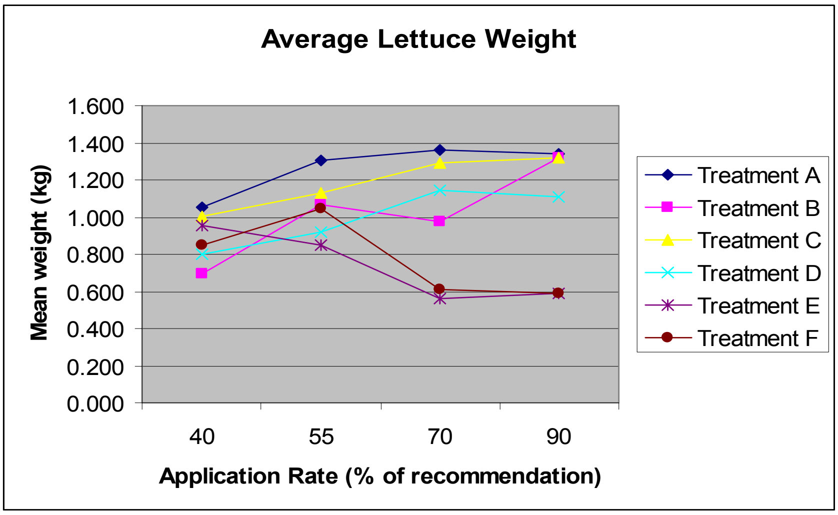

Figure 4.33 : Average lettuce weights

Untreated chicken manure applied at pre-plant, then again two weeks after transplant with weekly application of mineral fertiliser was the most effective treatment for all application rates. At 90% of the standard application rate, all manure treatments (amended and unamended) perform as effectively as each other.

In contrast to other treatments, Nutraplex was most effective at the lower application rates. The addition of routine mineral fertiliser applications to Nutraplex treatments had little effect on the resulting yield.

Trial 7: Broccoli *Comparing standard broiler litter applications with compost based broiler litter, phosphate amended, compost-based litter and mineral fertiliser.*

The closure of hardwood sawmills, as a result of the Regional Forest Agreement, led to a drop in sawdust production and a shortage of litter bedding for poultry producers. Bioscience's associated business, Oakford Organics commenced discussions with a number of broiler producers seeking an alternative to sawdust. Fine-ground, screened greenwaste was considered, however biosecurity risks prevented its use in commercial sheds. Compost was seen by them as a better alternative which would confer a number of benefits to poultry.

Trials undertaken in a broiler shed proved that compost was a superior material to sawdust for absorbing poultry fecal material. Laboratory analysis of this material after 35 and 50 days in the shed showed that it contained both higher N and higher P than conventional broiler litter.

The seventh trial examined the effect of this compost litter on broccoli production over winter. Six fertiliser treatments were tested at 40%, 55%, 70% and 90% of the standard recommendations set by Agriculture Western Australia for broccoli production. Acid treated manures and Nutraplex were again incorporated the day before planting. The treatments employed for this trial were as follows:

TREATMENTS:

A:	Chicken manure (untreated control) pre plant, surface band chicken manure at week 3, mineral top dress every 7 days from week 5 to end.
B:	Amended compost litter (3% H_3PO_4) pre plant; surface band amended chicken manure at week 3 and week 6.
C:	Amended compost litter (3% H_3PO_4) pre plant; surface band amended chicken manure at week 3; then mineral top dress every 7 days
D:	Mineral pre plant; mineral top dress every 7 days
E:	Compost litter (unamended), surface band at week 3; then mineral top dress every 7 days
F:	Amended compost litter (1.5% H_3PO_4) pre plant; top dress at week 3 and week 6

Standard (100%) Fertiliser: 1.2 Tonnes Potato E per hectare pre-plant.
650 Kg Agran per hectare in 10 x 7 day doses of 65Kg/Ha
700 Kg Potassium Nitrate in 10 x 7day doses of 70Kg/Ha
200 Kg Magnesium Sulphate in 10 x 7 day doses (20 Kg/Ha)
30 cubic meters/Ha of broiler litter taken as standard.
25 cubic meter/Ha of phosphate amended compost based broiler litter.
30 cubic meters/Ha of Nutraplex

Hedonic Score

Comparisons of the broccoli hedonic scores four and eight weeks after transplant are illustrated in Figure 4.34a and 4.34b respectively.

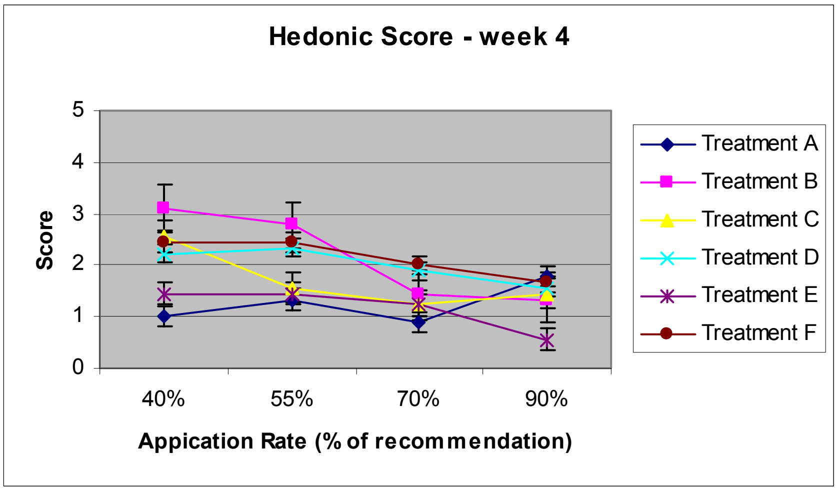

Figure 4.34a: Broccoli hedonic score four weeks after transplant

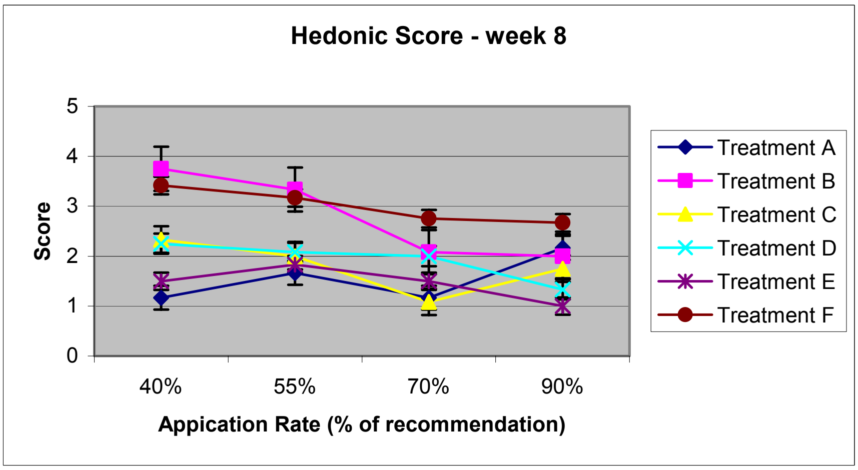

Figure 4.34b: Broccoli Hedonic score eight weeks after transplant

Generally, transplant establishment was similar for chicken manure, compost litter and mineral fertiliser, with increasing fertiliser rates enhancing establishment early on. The absence of routine top dressing with mineral fertiliser, particularly at lower application rates, reduced productivity midway through the growth trials. Phosphate amended manures promoted better establishment at all application rates.

Plant Tissue Analysis

The nutritional status of the broccoli crop at four and six weeks after transplant is contained in Appendix I. Generally, treatments A was limiting in limiting in nitrogen throughout whereas compost based manure provided better nitrogen supply. Potassium levels dropped to below ideal in all treatments towards the latter end of the trial

Fertiliser Treatment and Plant Weight

Figure 4.35 shows the average broccoli head weights for each of the six treatments. The graph illustrates that certain fertiliser treatments are more effective than others ($F(5,18)=0.738, p>.05$).

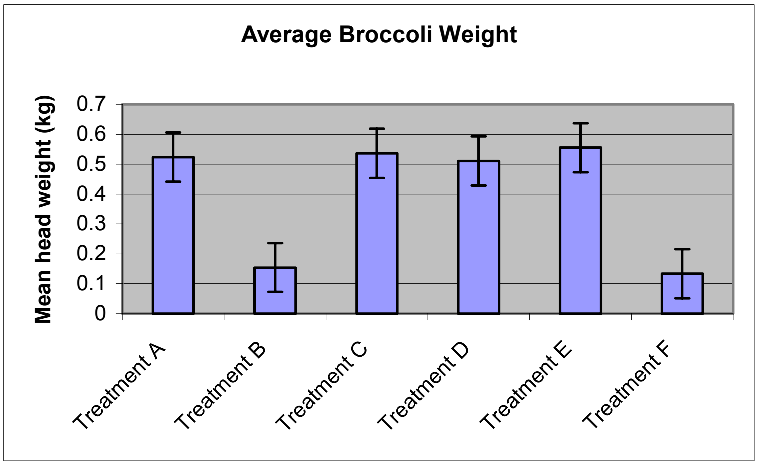

Figure 4.35: Average broccoli head weight

Treatments A, C, D and E perform as effectively as each other. In absence of routine mineral fertiliser top dressing in broccoli, plant productivity was very poor.

Fertiliser Rates and Plant Weights

Figure 4.36 shows the average broccoli weights for each of the four fertiliser rates ($F(3,20)=0.21, p>.05$). The graph illustrates that broccoli yield improves as more fertiliser is applied.

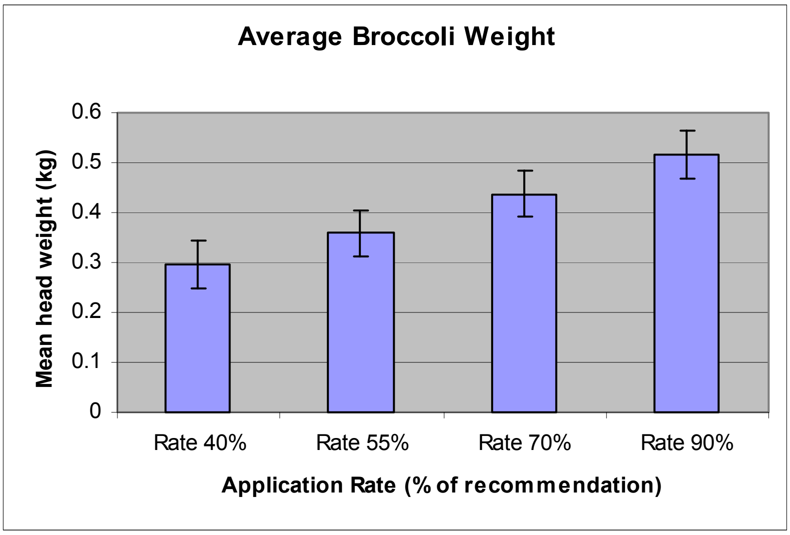

Figure 4.36: Average broccoli weight

Fertiliser Treatment/Fertiliser Rate Interaction

Figure 4.37 shows that certain fertiliser treatments are more effective than others at certain application rates.

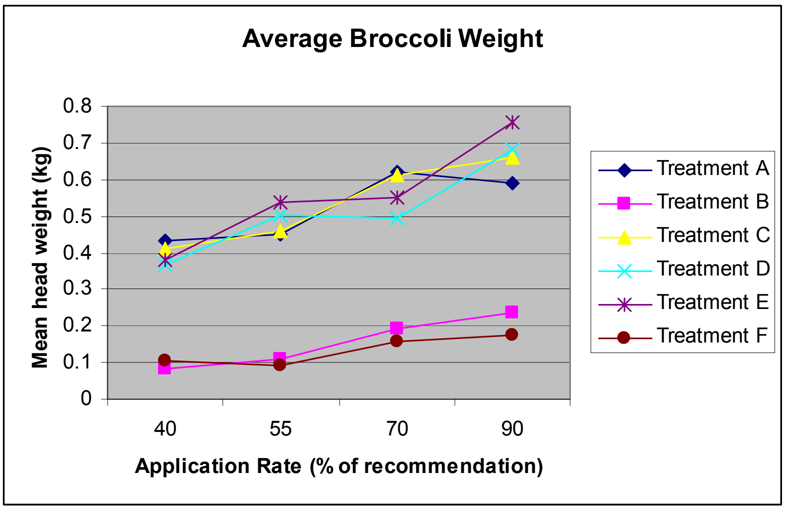

Figure 4.37: Average broccoli weight

The best yields are obtained with high applications of unamended compost litter applied at pre-plant, surface banded at week three, with routine mineral fertiliser top dress. Treatments A, C, D and E are equally effective as each other at low application rates. However compost litter outperforms regular chicken manure as application rates approach standard recommendations.

Soil analysis at the completion of trial 7 (Fig 4.38) indicated that using compost-based chicken manure at repeated applications (incorporated and top dressed) as in treatments B and C promoted a significant increase in residual soil organic carbon.

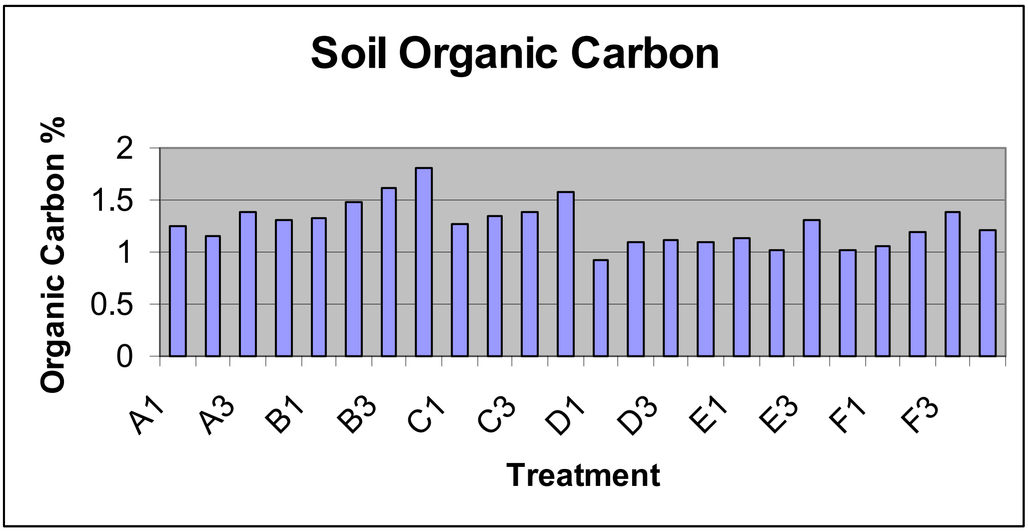

Fig 4.38 Soil organic carbon at the completion of trial 7.

Field Trial 8. Lettuce ***Comparing standard broiler litter applications with compost based broiler litter, phosphate amended, compost-based litter and mineral fertiliser.***

The eighth trial was to examine the effect of this compost litter on summer lettuce production. Six fertiliser treatments were tested at 40%, 55%, 70% and 90% of the standard recommendations set by Agriculture Western Australia for lettuce production. The treatments employed for this trial were the same as for trial 7 as follows:

TREATMENTS:

A:	Chicken manure (untreated control) pre plant, surface band chicken manure at week 3, mineral top dress every 7 days from week 5 to end.
B:	Amended compost litter (3% H_3PO_4) pre plant; surface band amended chicken manure at week 3 and week 6.
C:	Amended compost litter (3% H_3PO_4) pre plant; surface band amended chicken manure at week 3; then mineral top dress every 7 days
D:	Mineral pre plant; mineral top dress every 7 days
E:	Compost litter (unamended), surface band at week 3; then mineral top dress every 7 days
F:	Amended compost litter (1.5% H_3PO_4) pre plant; top dress at week 3 and week 6

Trial failure:
Some three weeks after planting lettuce in late February, the irrigation system suffered a catastrophic failure due to screens collapsing, sand entering the main lines and burning out the irrigation pump. This occurred on a Friday afternoon. By the time staff arrived on Monday the newly established crop had suffered significant damage due to heat stress and was severely wilted. The trial was abandoned while the irrigation system was repaired. The only useful information obtained from the trial related to fly breeding experiments and soil organic carbon. It took a further three weeks to repair the irrigation system. The field was then irrigated over a period of four days to return soil to normal moisture levels. Soil was collected for organic carbon analysis. The results at further to observations at the end of trial 7 that compost-based manures cause a greater accumulation of organic carbon compared to standard chicken manure.

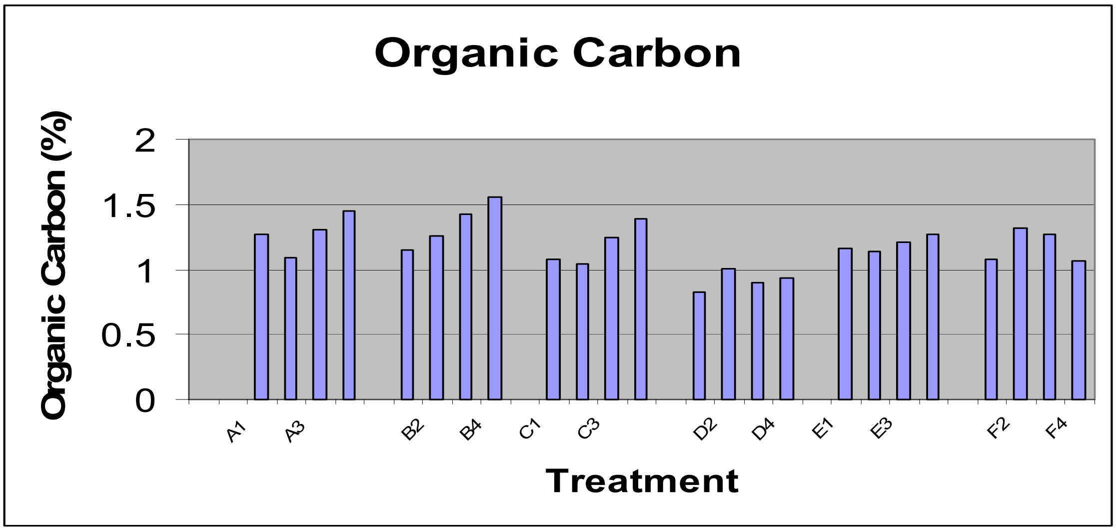

Figure 4.39: Organic carbon after (abandoned) Trial 8.

5. Leaching Column Trials

5.1 Introduction

Broiler litter is widely used in Western Australia by vegetable producers as a fertiliser and soil conditioner. As of September 1st 2001 the Department of Health has placed restrictions on the use of raw poultry manure in Western Australia. In order to better understand the properties chicken manure confers on soil, and perhaps develop a suitable alternative we need to understand the release and leaching of nutrients from broiler litter compared to other fertilisers and amendments. This is important in understanding how these fertilisers contribute to crops and to the potential for leaching of nutrients into water tables.

The objective of this study was to examine nutrient release from broiler litter compared with compost, mineral fertiliser and a broiler litter substitute, specifically by testing the following hypotheses which were derived from both literature review and from grower interviews:

1) In sandy soil, the rate of nutrient release from broiler litter is slow compared mineral fertiliser.
2) Leaching patterns change when fertilisers are added to the surface or incorporated into the soil.
3) An application of compost, incorporated into the soil affects the time course of nutrient release from broiler litter and fertilisers.

5.2 Materials and Methods

The Bassendean sand used in this study was collected from the property of Bioscience at Oakford in Western Australia. These soil samples had not been used for trials or received fertiliser or manure for at least ten years. Surface (top 30cm) sand was air-dried at 60° C and sieved through a 2mm screen. Broiler litter was collected from a local poultry house, and compost and broiler litter substitute ("Nutraplex" as described in 4.6) was made from compost supplied by Oakford Organics, which was also used without change in compost columns. 'NPK Blue Special was the mineral fertiliser used in the trial.

Soil, broiler litter, compost and BLS were analysed and the chemical properties are shown in Table 5.1. For nutrient analysis, materials were digested by peroxide and sulphuric acid at 360°C. Total NH_4 – N and PO_4 – P was then measured by colorimetry i.e. tartrate buffer, chlorine and sodium salicylate was added to 1ml of diluted digest, left for a period of 45 minutes for full colour development and read using the UV visible spectrophotometer (Varian DMS 100) set at 650nm. The phosphorus assay used 4% sulphuric acid, sodium molybdate and hydrazine sulphate reagents. These reagents are added to 1ml of diluted digest and heated in a water bath for 20 minutes at 85°C, then measured on the spectrophotometer at 820nm. Total K was determined using an atomic absorption spectrometer (Varian Spectra AA 110). Extractable K was extracted from materials using NH_4Cl with 1:20 material/solution ratio. NO_3 – N was extracted from soil and broiler litter using NH_4SO_4 + H_3BO_3 at a material/ solution ratio 1:2.5. Nitrate was measured using an ion specific electrode. pH was measured in H_2O and $CaCl_2$ at a material/water or $CaCl_2$ ratio of 1:5. EC was measured using a LC81 conductivity meter. Organic carbon and sulphur was measured using a LECO CS 200 auto-analyser. Water holding capacity, bulk density and moisture content was also measured using the standard methods outlined in Kassem *et al* 1995.

The columns used were constructed from 90mm PVC drainpipe 30 cm long. For incorporated treatments, fertilisers were mixed with soil in a large plastic bag before being added into the columns.

Bassendean sands were packed into leaching columns with broiler litter, mineral fertiliser, compost and BLS, on the surface and incorporated into the soil as described in Table 5.2. to give a calculated total nutrient addition as described in Table 5.3. Deionised water was added every 24 hours, and all leachate was collected and analysed. Laboratory analysis of leachate included NH_4 – N, NO_3, PO_4 – P, Ca, Mg, Na, K, SO_4, colour and pH.

On day one of the trial the soil in each column was saturated on day from the top of the column with DI water. The amount of water added to saturate soil was calculated as 100% water holding capacity. From day two 100mL of DI water was added every 24 hours. The volume of leachate was measured every 24 hours and the weight of the columns was recorded. All leachate was collected and stored (below 4°C) before analysis.

The total nitrogen and phosphorus in the leachate was measured by colorimetry, as described above. Potassium content was determined using an atomic absorption spectrometer. pH was measured using the glass electrode. EC is measured using a LC81 conductivity meter. Nitrate was measured with the Nitrate Ion Selective Electrode (ELIT 021). Sulphate was measured by turbidometry, using the Palintest system. Leachate colour is measured by a spectrophotometer at 610nm.

Table 5.1: Chemical composition of materials used in treatments

Treatment	Broiler litter	Compost	BLS	Mineral Fertiliser NKP Blue Special	Soil Bassendean Sand
Total NH4 -N %	3.55	1.02	4.51	12	*
Total PO4 - P %	0.95	0.41	0.305	5.2	*
Total K %	1.50	0.44	4.40	14.1	*
Ext NH_4 – N %	0.46	0.01	0.29	*	3.60 ppm
Ext PO_4 – P %	0.11	0.02	0.05	*	2.62 ppm
Ext K %	0.28	0.34	2.62	*	0.075 ppm
Nitrate NO_3 – N ppm	203	54.6	1422	*	*
Ec (mScm – 1)	6.88	1.73	27.70	*	0.024
pH H_20	7.00	8.08	7.05	*	5.64
pH $CaCl_2$	6.84	7.44	6.97	*	6.55
Moisture Content %	21.66	23.88	10.53	*	11.76
Organic Matter %	37.78	*	*	*	*
Sulfur %	0.260	*	*	*	*
Bulk Density g/L	393	*	*	*	*

Table 5.2: Treatments

1. C	Control	1.2 kg of sand packed into the column
2. BS	Broiler litter Surface	7.75g of broiler litter applied to the surface of 1.2kg of sand in the column
3. BI	Broiler litter Incorporated	7.75g of broiler litter mixed with 1.2kg of sand and packed into the column
4. BS/C	Broiler litter surface/ Compost blend	7.75g of compost mixed with 1.2kg of sand packed into column and 7.75g of broiler litter applied to the surface
5. CS	Compost Surface	15.5g of compost applied to the surface of 1.2 kg of sand in the column
6. CI	Compost Incorporated	15.5g of compost mixed with 1.2kg of sand and packed into the column.
7. MFS	Mineral Fertiliser Surface	1.5g of mineral fertiliser applied to the surface of 1.2kg of sand in the column.
8. MFI	Mineral Fertiliser Incorporated	1.5g of mineral fertiliser mixed with 1.2kg of sand and packed into the column.
9. MFS/C	Mineral Fertiliser Surface/ Compost blend	7.75g of compost mixed with 1.2kg of sand packed into the column and 1.5g of mineral fertiliser applied to the surface
10. SS	Broiler litter substitute Surface	6g of broiler litter substitute applied to surface of 1.2kg of sand in the column.
11. SI	Broiler litter substitute Incorporated	6g of broiler litter substitute mixed with 1.2kg of sand and packed into the column
12. SS/C	Broiler litter substitute Surface/ Compost blend	7.75g of compost mixed with 1.2 kg of sand packed into the column and 6g of broiler litter substitute applied to the surface.

Table 5.3: Amount of N, K, P added to each column in mg/kg

	Weight (g)	**N**	**P**	**K**
Broiler litter	7.75	280	74	116
Compost	15.5	158	64	68
BLS	6	270	63	264
Mineral fertiliser	1.5	180	78	210

5.3 Results

Overview

Broiler litter was found to mineralise and leach nutrients more rapidly than was expected from grower reports, however it had a slightly slower rate of nutrient release compared to mineral fertiliser and the broiler litter substitute. Compost had the slowest rate of nutrient release and mineral fertiliser had the fastest. There was a significant difference in mineralisation between the surface applied treatments and the incorporated applications. Overall more nutrients were recovered from the incorporated applications than the surface applications, and the nutrients leached out faster. The addition of compost to columns generally retarded nutrient leaching.

Ammonium Nitrogen

NH_4-N leaching from the broiler litter applications reached its maximum on day three but peaked again on day nine (Table 5.8). The BI application had leached 81% and the BS had leached 68% of the total NH_4 – N collected after two weeks. In Table 5.7 the percentage of nutrients recovered after two weeks is shown. The difference in recoverable nitrogen between the two treatments may be attributed to one of two things: 1) NH_3 volatilization from the surface treatment (Brinson, 1994), and 2) the position of the fertiliser within the soil column i.e. the incorporated fertiliser is further down the column, and leaches out first.

The leached NH_4-N from the CI reached its maximum at 10 days, and 18 days for CS (Table 5.7) CI had leached 74% of NH_4-N, compared with and 67% from CS by week two (Table 5.7). MFI application had leached 92 % of its NH_4-N by week two and the MFS application had leached 94%. The leaching patterns of MFI and MFS were similar. Eighty percent of the NH_4-N of the MFS/C application had leached by week two, which is a similar leaching pattern to broiler litter. The MFS/C reduced nitrogen leaching compared to the mineral fertiliser alone (Figure 1b).
The leaching pattern of the broiler litter substitute was similar to the broiler litter. NH_4-N leaching reached 81% after two weeks for SI.

The time delay between the leaching of organic and inorganic applied nitrogen is most likely due to the conversion of organic N into the mineral form of N (NH_4 – N), by the process called mineralisation (Peverill *et al*, 1999). The broiler litter, compost and SS applications had multiple peaks of NH_4-N release, compared with mineral fertiliser which had one distinct peak of N release in the first few days. This is consistent with the findings of He *et al*, 2000, who found that poultry manure had multiple phases of mineralisation and compost had two distinct phases of mineralisation, which may correspond to two fractions of organic components of different decomposition resistance.

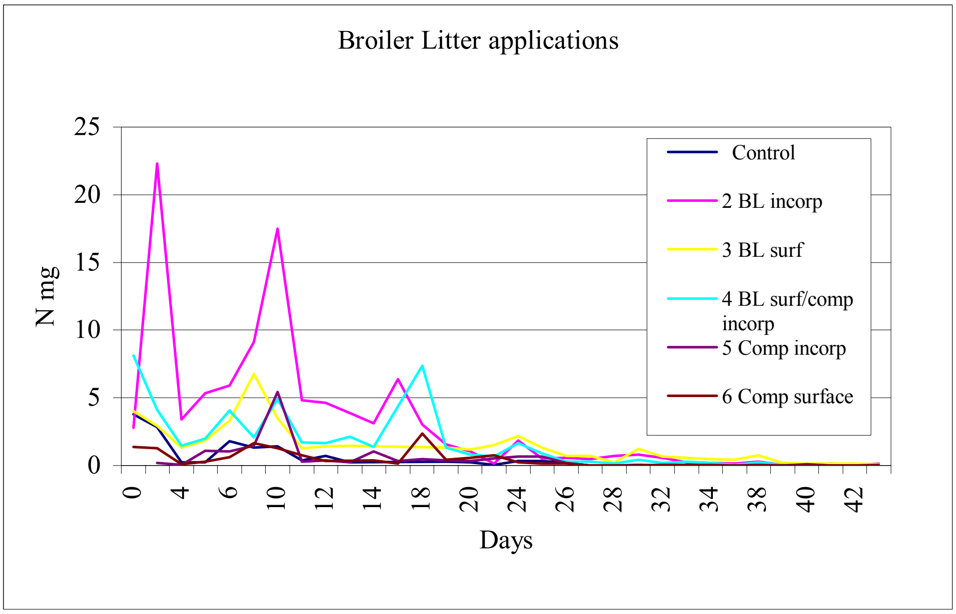

Figure 1a: NH_4–N leaching broiler litter and compost over time

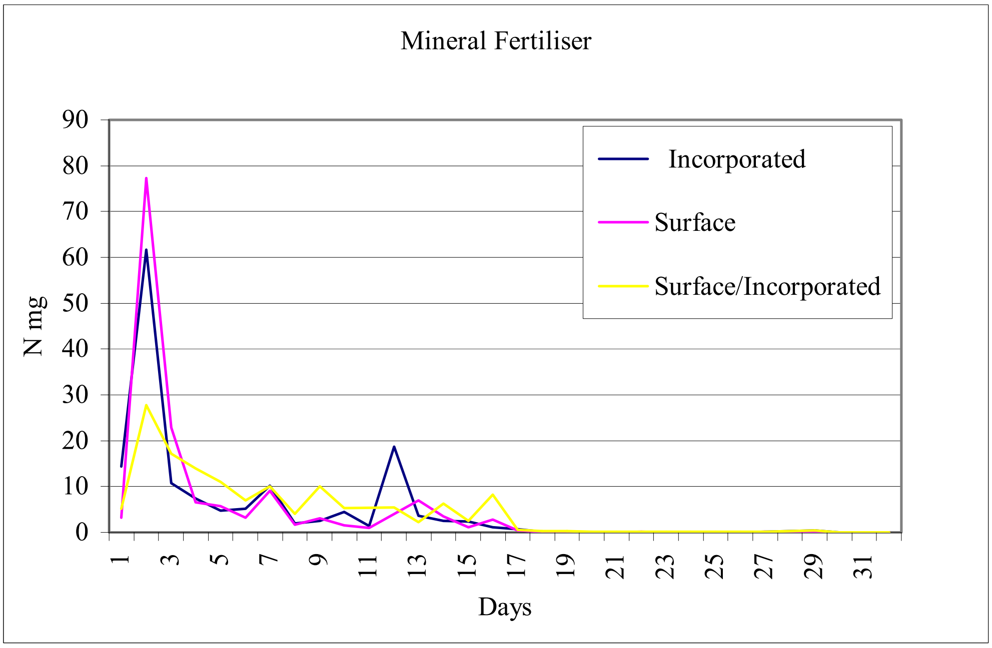

Figure 1b: NH_4–N leaching from mineral fertiliser over time

Nitrate Nitrogen

The leachate from the BS and BS/C reached their maximum nitrate level on day 18 of the trial. This increase in NO_3 – N in the broiler litter treatment is accompanied by a decrease in NH_4 – N which may indicate that the NH_4-N released from the broiler litter was nitrified into the NO_3 – N form. By the process called nitrification (Mason, 1998). The BS leachate reached its maximum at 6.87 mg/l and BS/C leachate reached its maximum at 9.83mg/L (Figure 2a). BS/C leachate had leached 44% of the NO_3- N by week two.

Seventy-seven percent of the NO_3 - N had leached from CI by week two, and 68% had leached from the CS. This difference in leaching patterns of nitrate between the incorporated and surface treatment may be due to nitrogen loss from the surface application by denitrification. Denitrification can be caused by water logging, and results in the production of gases such as gaseous nitrogen (N_2), nitrous oxide (N_2O), nitric oxide (NO) and nitrogen dioxide (NO_2), which are lost to the atmosphere (Mason, 1998). Nitrate levels in the compost applications decreased over time. Nitrate levels measured in the leachate of compost applications were much lower than other treatments.

Mineral fertiliser treatments and the broiler litter substitute treatments had very similar leaching patterns. The majority of the nitrate in these fertilisers leached very quickly in the first few days. Nitrate leaches very quickly through soil because it is a negatively charged ion and there is little to prevent its downward movement with water (Mason, 1998). By week two 94% of the nitrate recovered had leached out from MFS, 96% from MFI and 74% from MFS/C. The compost-incorporated application reduced the rate of nitrate leaching compared to MFS. The broiler litter substitute treatments had a slightly slower rate of leaching. By week two 72% of nitrate had leached from SS, 74% from SS and 73% from SS/C.

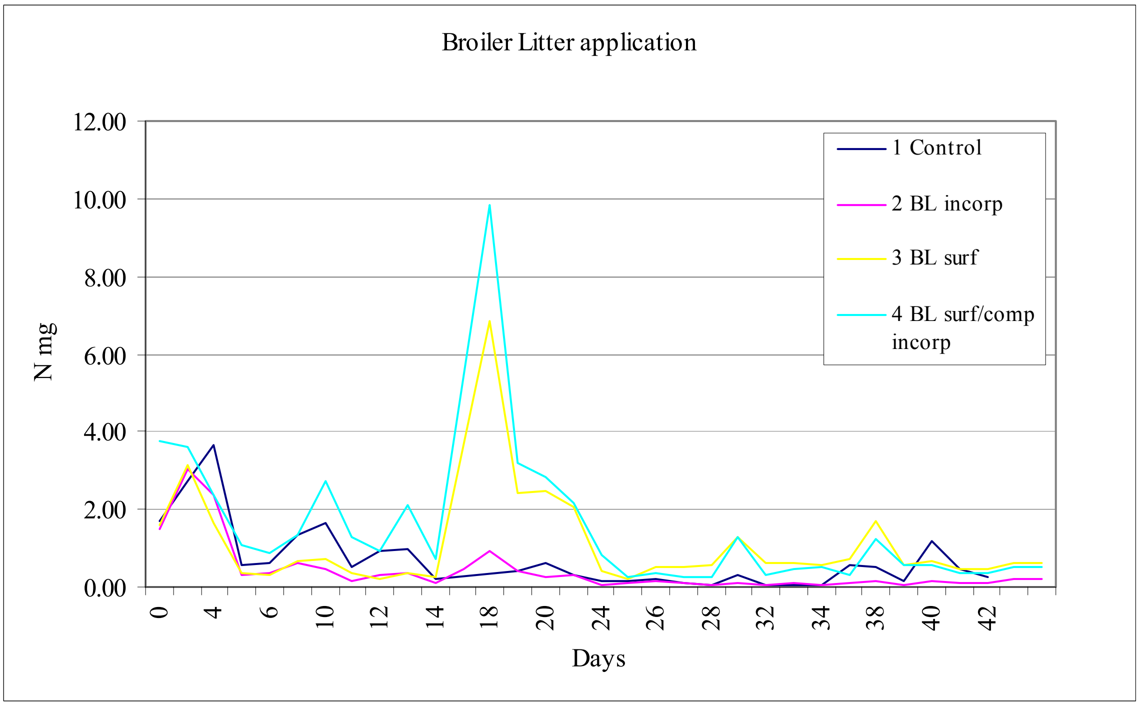

Figure 2a: Nitrate leaching from broiler litter applications over time

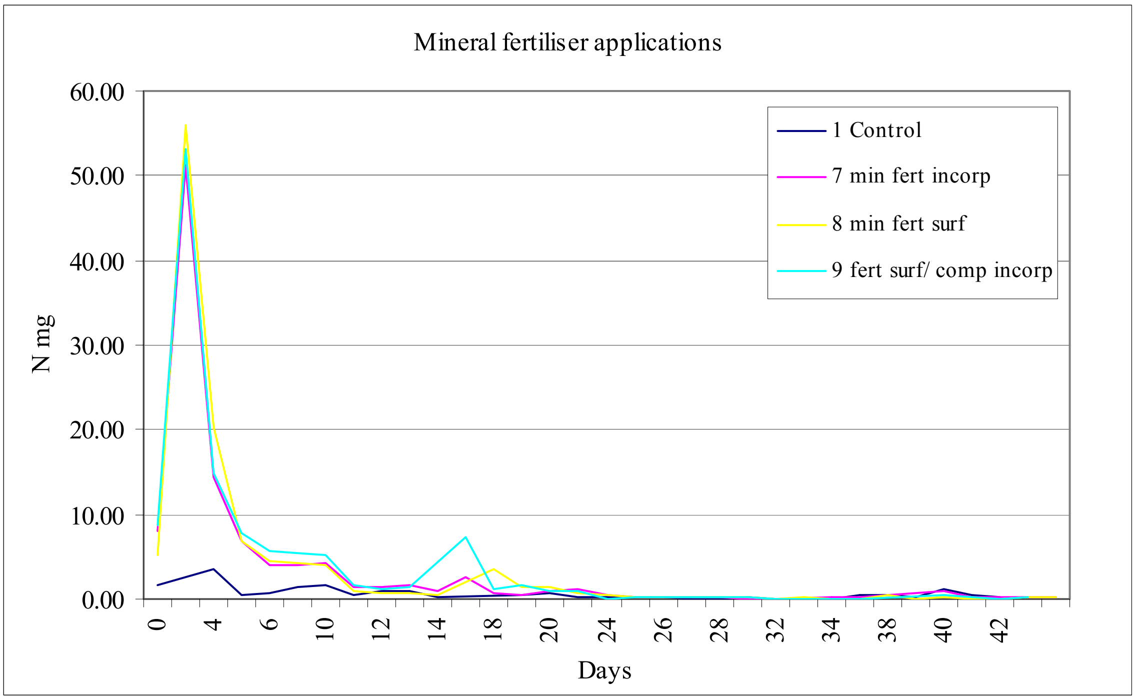

Figure 2 b Nitrate leaching from mineral fertiliser over time

Phosphorus

After two weeks the treatment with BI had leached 65% of the total leached P. The treatment with the BS had leached 32% and the BS/C had leached 44%. In the first two weeks BI leached more phosphorous, followed by BS/C. Overall the BI and BS leached the same concentration of phosphorous (Figure 3a).

CI leached P more rapidly than the CS. The CI had leached out 63% of the phosphorus by the end of two weeks, and CS had leached out 48% of P.
By week two 85% of phosphorus had leached out of the soil column from MFI. MFS had leached 80% by the end of week two (Table 5.7). MFS/C had a more gradual rate of leaching than the surface application alone.

In general the SS treatments had the slowest rate of phosphorus leaching followed by compost, broiler litter and mineral fertiliser. The SI had leached out 51% of the total phosphorus by week two. The SS leached 22%, and the SS/C leached 41% by week two.

The immediate flush of PO_4 – P is probably due to inorganic phosphate ions in solution. Following the rain the water soluble P in mineral fertiliser dissolves rapidly and moves into soil solution (Russel, 1973). This is consistent with the leaching patterns in our experiment for the mineral fertiliser. Phosphorus in manure is present in inorganic and organic forms, with most as inorganic P (60% to 90%). This ratio of inorganic to organic forms of P in manure varies as a function of manure type and animal diet (Barnett, 1994). Sharpley and Moyer, 2000, found that the potential for P to be leached from manure and compost is most closely related to water extractable inorganic P concentration of the respective materials. Organic phosphorus has little leaching potential due to it being bound to insoluble matter.

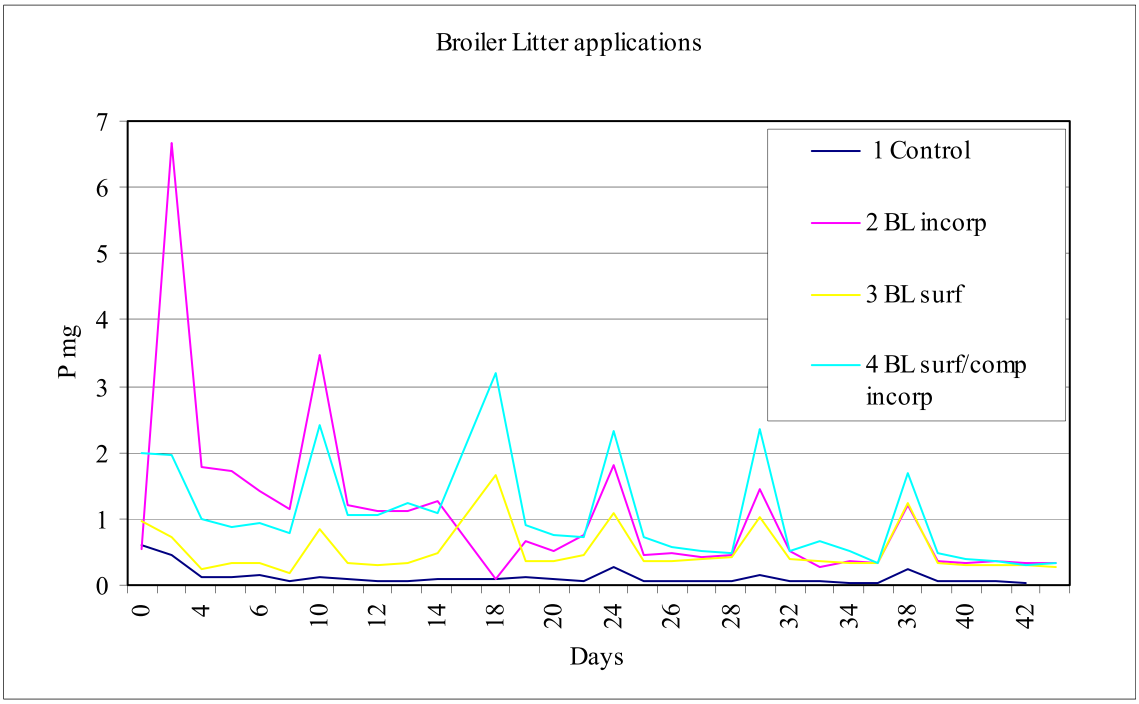

Figure 3a: Phosphorous leaching from broiler litter over time

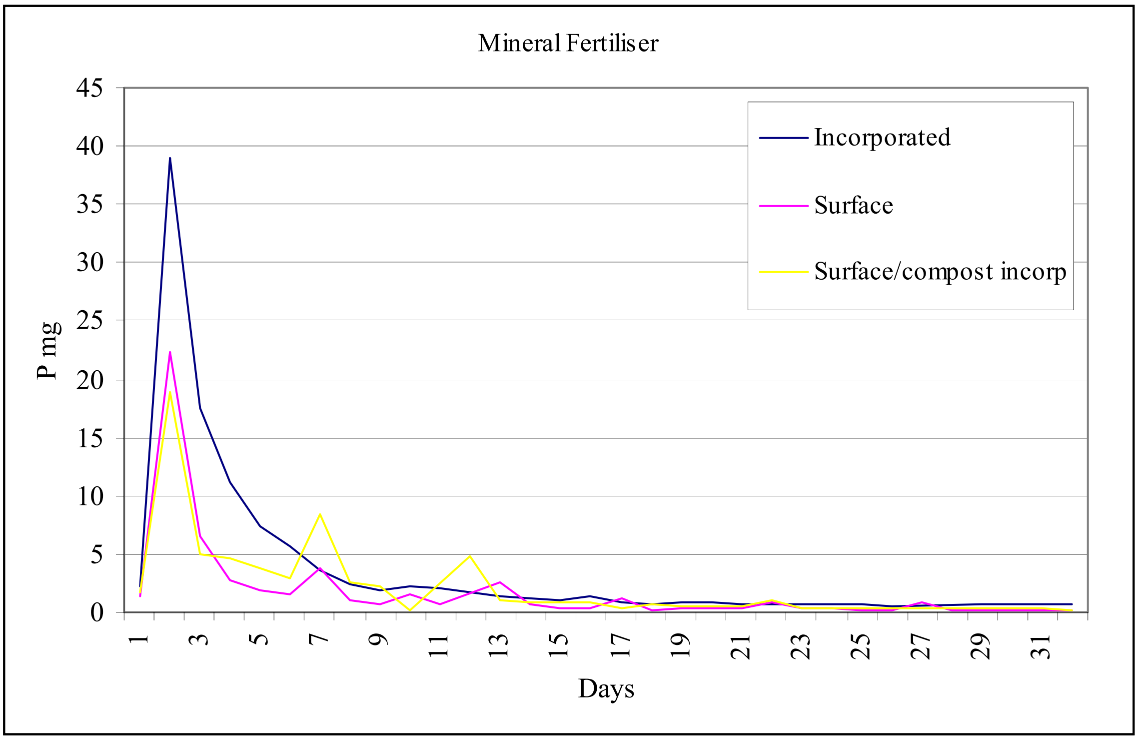

Figure 3b: Phosphorous leaching from mineral fertiliser over time

Potassium

BI had leached 59% of K by day 10. The BS had leached 56% on day 10. BS/C leached 59% by day 10.The K reached its maximum on day three then steadily decreased for all broiler litter treatments.

CI leached K more readily than CS. By day 10, 43% of the K from CI had leached out. CS had leached 40% of the total K by day 10.

MFI had leached 88% of K by day 10 and the MFS had leached 84%. MFS/ reduced the amount of K leaching compared with the MFS i.e. 75% of K had leached from this treatment by day 10.

The SI leached 78% of the K by day 10. SS leached 75% of the K by day 10. SS/C leached 76% by day 10. In general K remained in the soil for the longest duration of time in the compost applications. Mineral fertiliser leached K the fastest, followed by the broiler litter substitute then broiler litter. The MFS/C leached less K in the two week period i.e. the compost reduced the rate of K leaching.

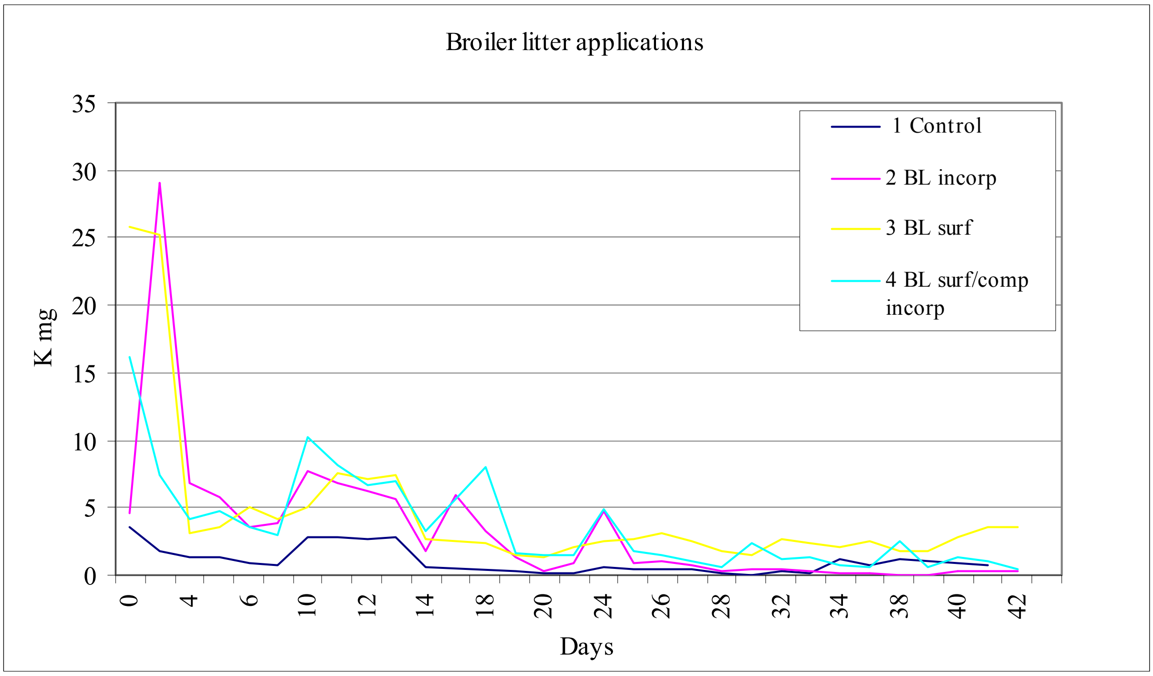

Figure 4a: Potassium leaching from broiler litter over time

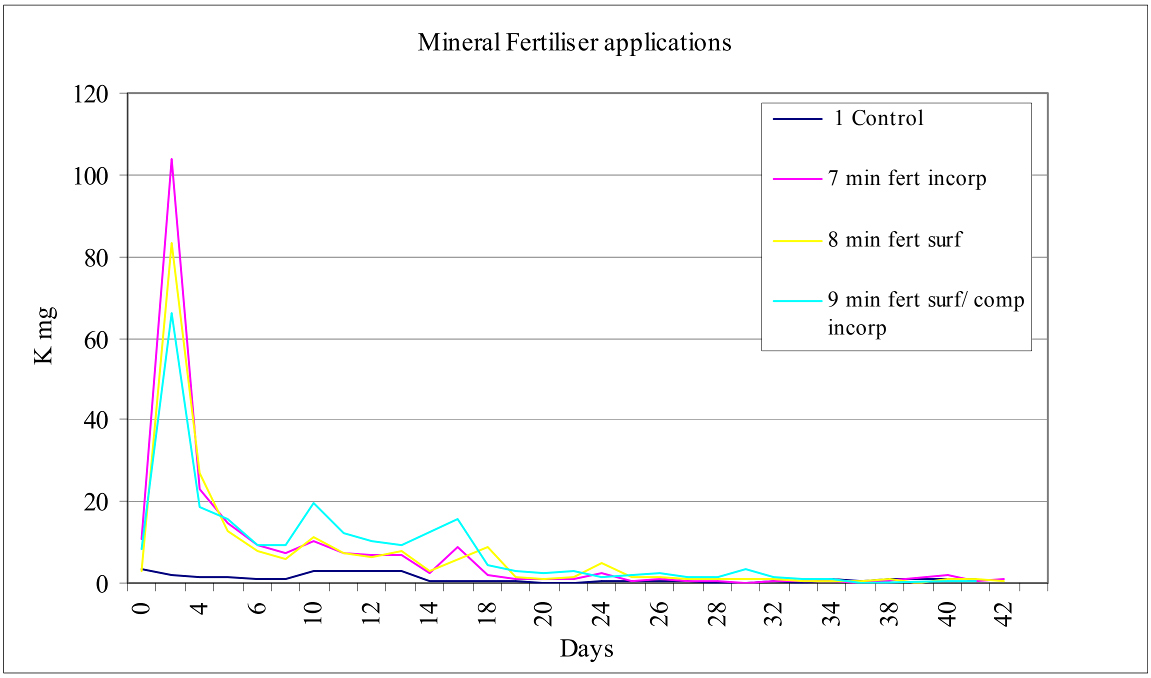

Figure 4b: Potassium leaching from mineral fertiliser over time

Calcium

After three weeks the incorporated broiler litter application had leached 51% of the calcium recovered, where as the surface treatment had leached 71%. This is an unusual trend compared with the other elements, where the incorporated applications usually leach nutrient faster than the surface applications. By week three 58% of calcium had leached from the compost incorporated and 48% from the surface application. The mineral fertiliser had leached 70 and 78% for the incorporated and surface treatments and 88% for the fertiliser surface, compost incorporated treatment. BLS incorporated had leached 75% by the end of week three and the surface treatment 78%. The BLS with compost incorporated leached 78%. In general, the compost had the slowest rate of calcium leaching followed by the broiler litter. The mineral fertiliser and broiler litter substitute had similar leaching patterns.

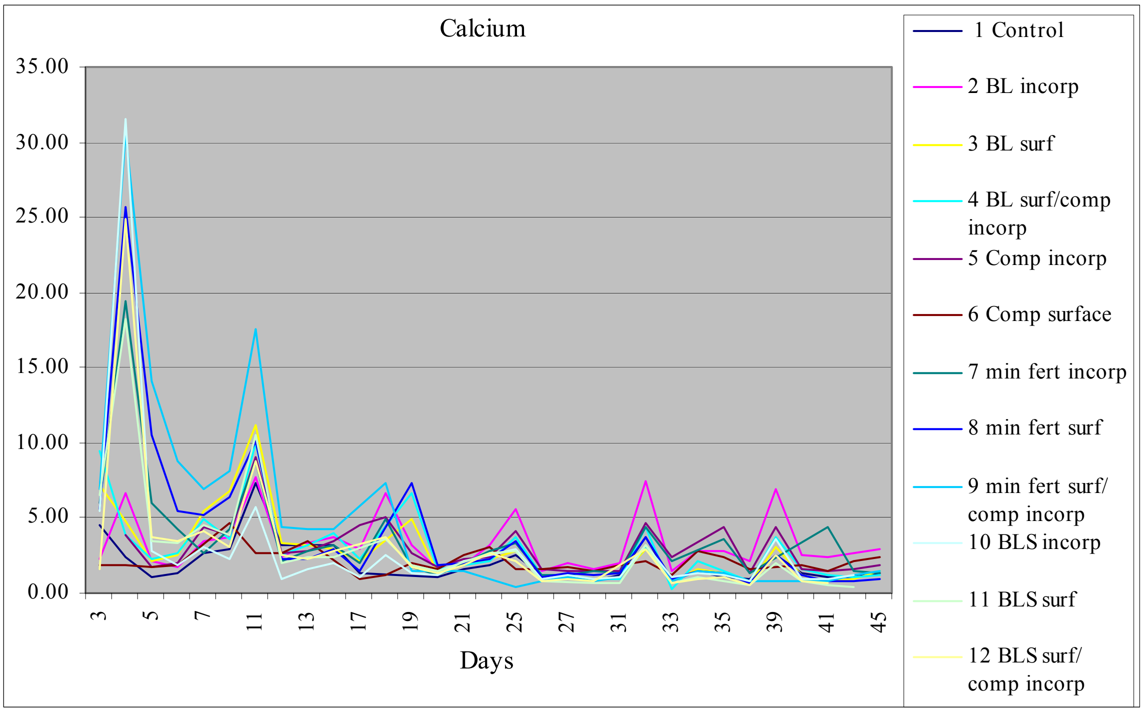

Figure 5: Calcium leaching from all treatments over time

Sodium

The broiler litter incorporated application had leached 82% of the sodium recovered by the end of week three. The surface application had leached 79% and the same for the compost incorporated application. The compost-incorporated application had leached 76% and the surface application had leached 78% by week three. Mineral fertiliser had leached 78% and the surface application had leached 81% by week three. The mineral fertiliser with compost incorporated into the soil leached 41% of its total sodium collected by week three, which again was a more gradual rate of leaching than the surface application alone. The BLS had leached the highest amount of sodium by week three. The broiler litter incorporated application had leached 88%, 83% and 86% for the surface, incorporated and compost incorporated applications respectively. Broiler litter, compost and mineral fertiliser have similar sodium leaching patterns, however broiler litter had a faster rate of leaching.

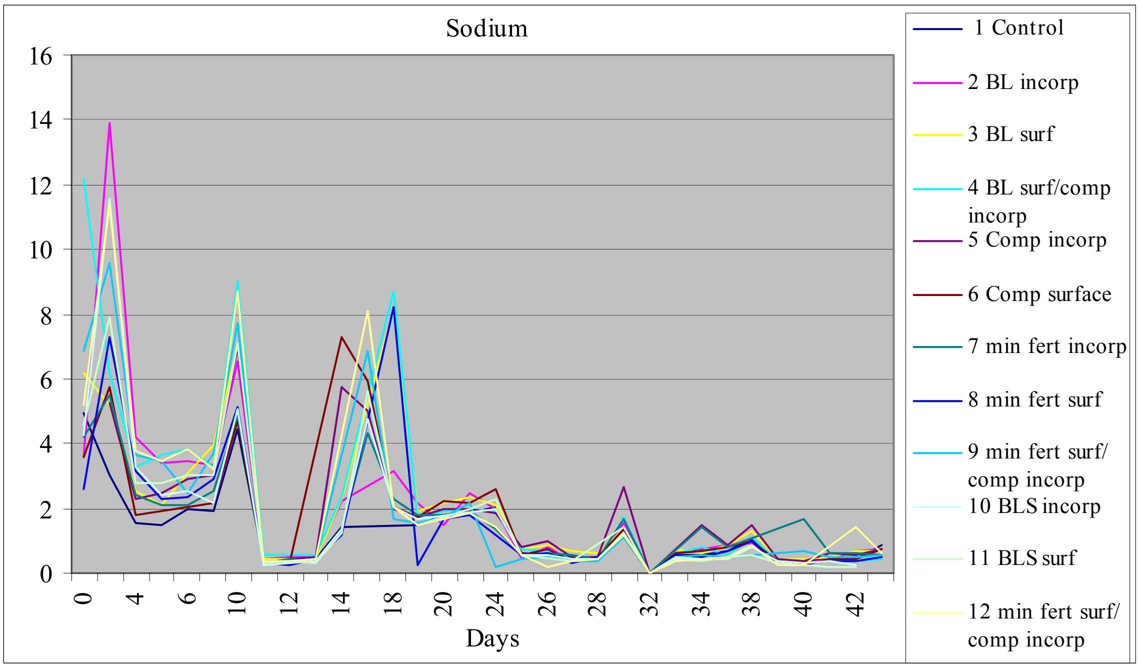

Figure 6: Sodium leaching from all treatments over time

Magnesium

The broiler litter incorporated had leached 57% of the magnesium by week three compared with 61% for the compost-incorporated application, 83% of the fertiliser incorporated and 78% for the BLS incorporated. In general, the surface applied treatments leached a higher rate of magnesium than the incorporated treatments, which is different from the leaching patterns of the majority of the elements. The treatments with compost incorporated into the soil reduced the rate of magnesium leaching.

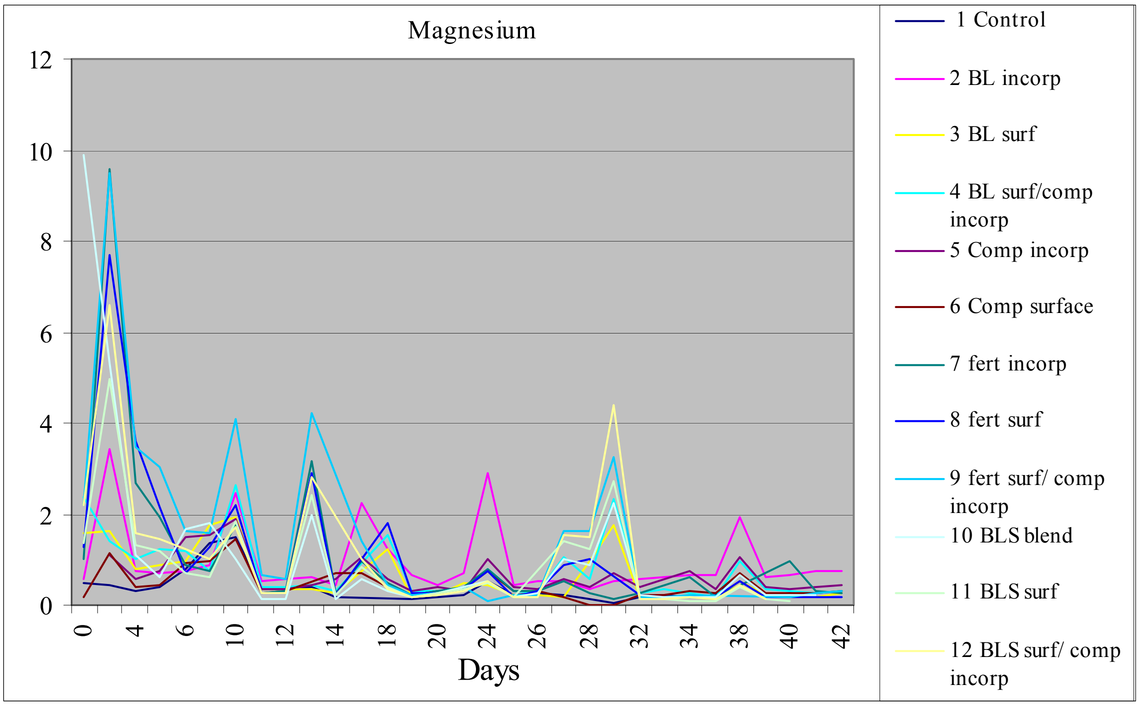

Figure 7: Magnesium leaching from columns over time

Sulfur

BI had leached 78% of sulfur by week two, compared with CI at 73%, MFI at 96% and SI at 74% (Figure8). There was little difference in the leaching patterns between the surface and incorporated treatments. The surface/compost-incorporated treatments had very similar leaching patterns to the surface treatments. Overall for sulfur compost had the slowest rate of leaching followed by the S, broiler litter and mineral fertiliser.

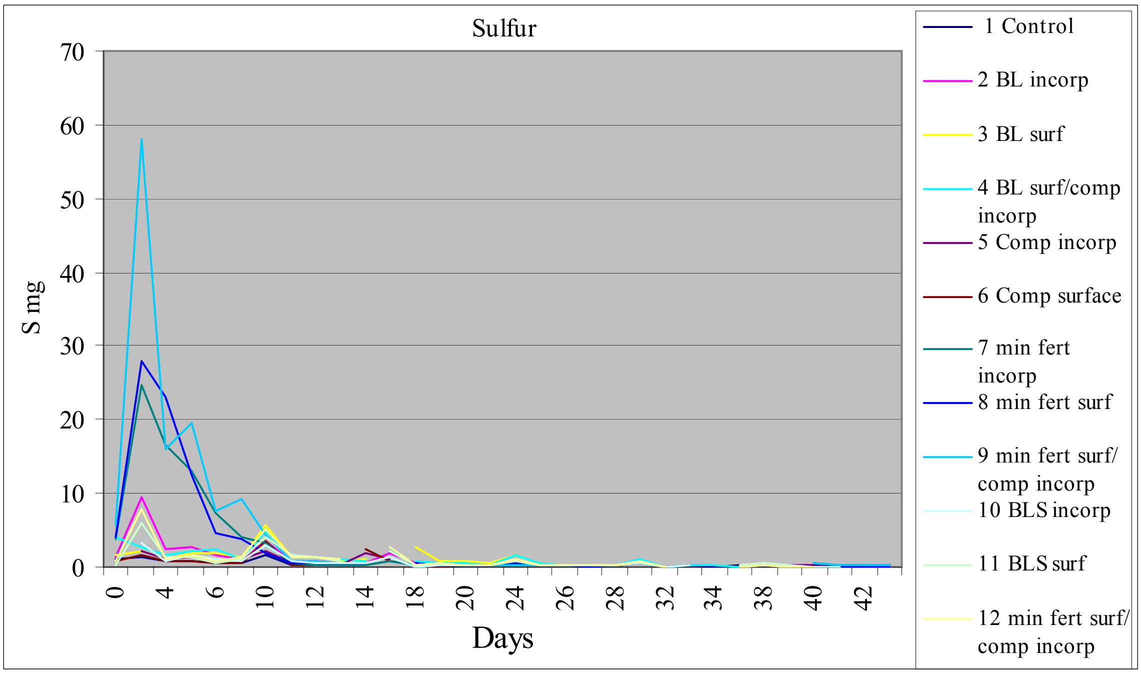

Figure 8: Sulfur leaching from broiler litter over time

Colour

Colour was measured as an indicator of soluble organic matter. The broiler litter leachate had the highest colour intensity, reaching 0.498 ABS for the incorporated application (Figure 9). Colour reached its maximum in week one and slowly decreased. Broiler litter substitute leachate had a higher colour intensity than compost and mineral fertiliser leachate but still much less than the broiler litter application. The broiler litter substitute leachate colour peaked on day 10 then decreased until the end of the trial. Compost leachate had a less steep colour decrease than leachate of SS. Mineral fertiliser leachate had very little colour.

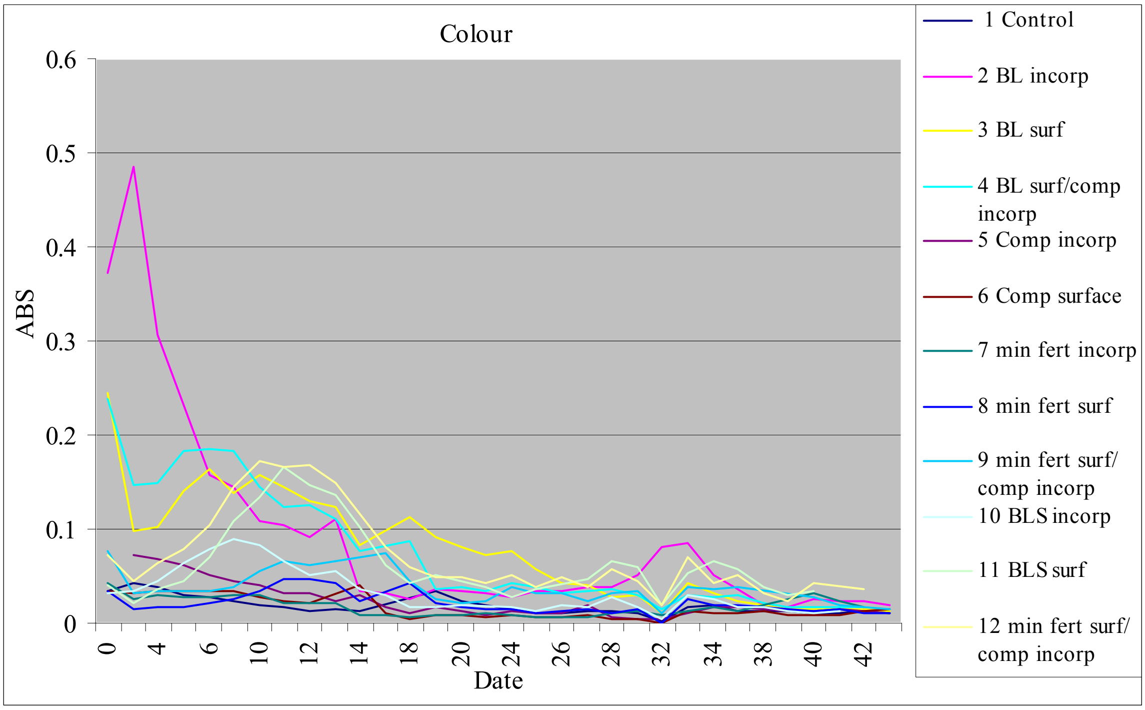

Figure 9: Colour of leachate over time

Conductivity

Conductivity was measured to indicate total salt release from fertilisers. The conductivity peaked for all treatments on day 3 and decreased to day 12 where it flattened out until the end of trial (See Figs 10 - 13). Broiler litter substitute had the highest dissolved salts from leachate followed by mineral fertiliser application, broiler litter then compost.

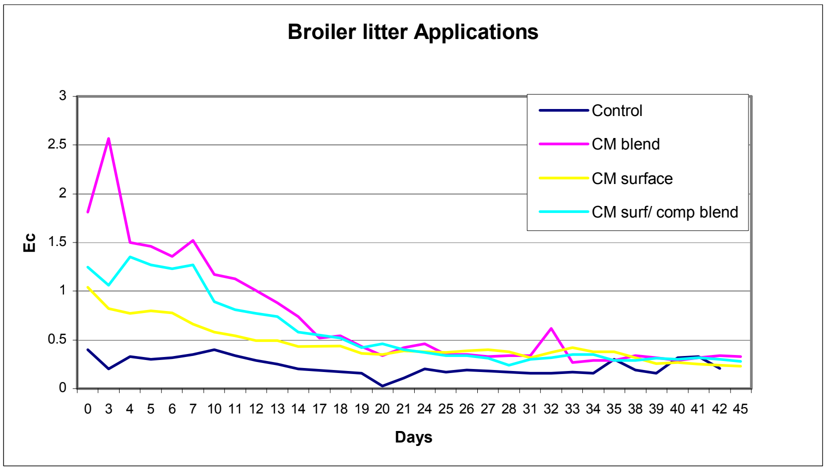

Figure 10: Conductivity of broiler litter leachate over time

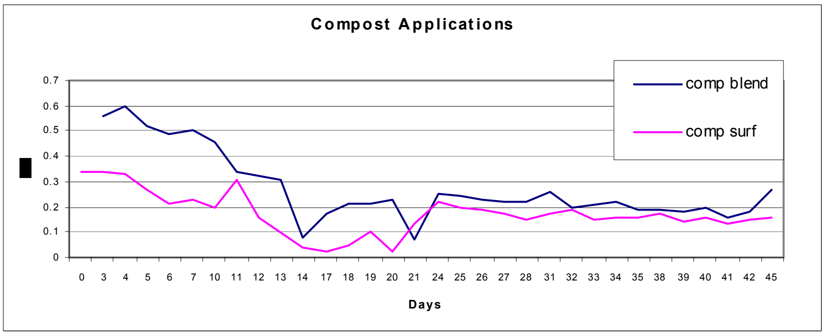

Figure 11: Conductivity of compost application leachate over time

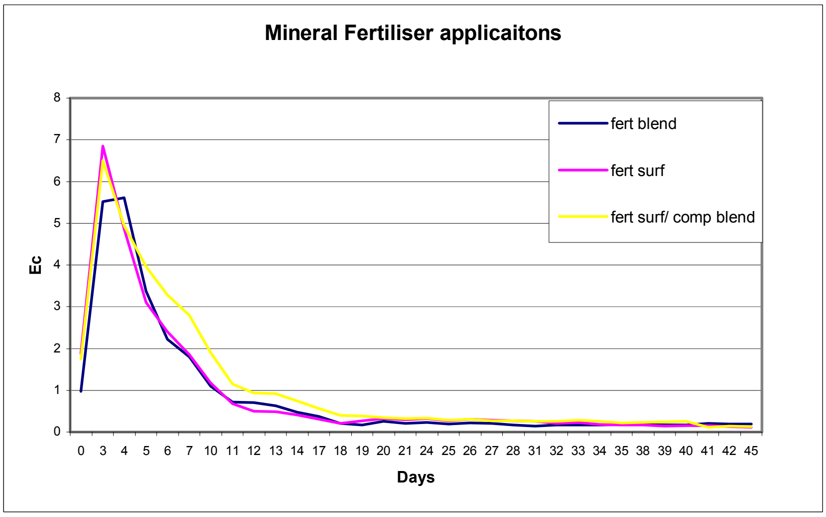

Figure 12: Conductivity of mineral fertiliser application leachate over time

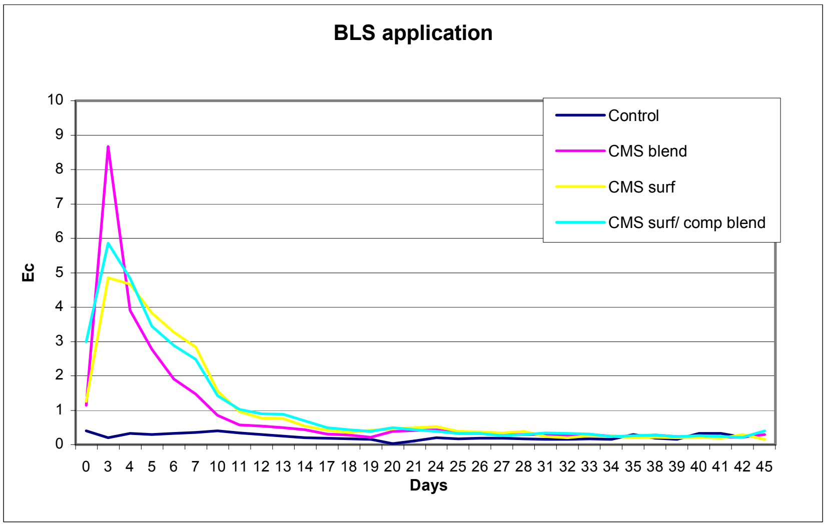

Figure 13: Conductivity of CMS application leachate over time

pH
Over the course of the trials pH of the leachate recovered from all treatments rose from 5.5 – 6.5 to 7 – 9. Blended treatments had a higher pH than the surface treatments. The change in pH may be due to changes in soil biology ie ammonium being oxidised into nitrate or organic matter decomposition (mineralisation). Overall there was no significant difference in pH between different treatments.

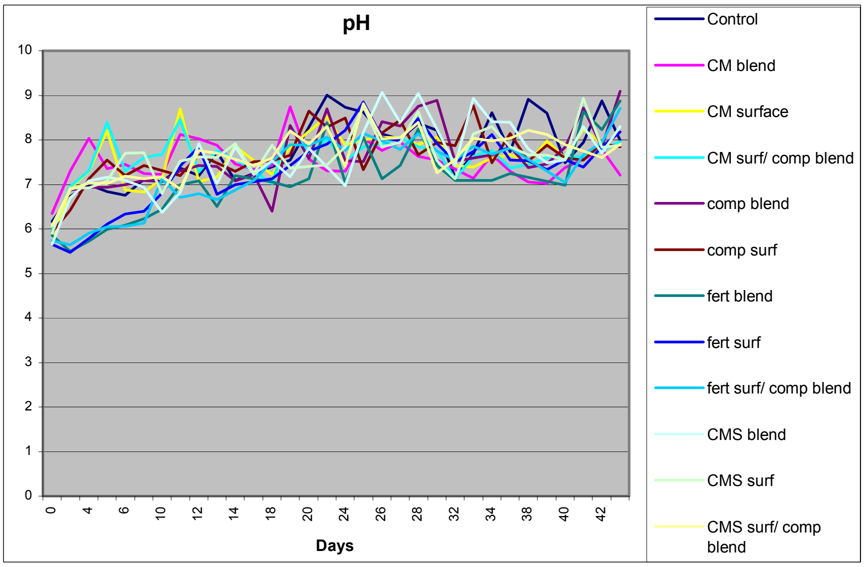

Figure 32: pH of leachate of all treatments over time

Post Trial Soil Analysis
When trial had completed after 45 days, soil was removed from columns, dried and analysed for remaining mineral nutrients using the methods described in Section 4.8. The results indicated than irrespective of treatment, there was very little remaining nitrate nitrogen or potassium in the soil. Some ammonium nitrogen was still present in soils treated with broiler litter, and phosphate was present at moderate levels in all treatments, however it was appreciably higher in soils treated with compost.

The organic carbon content of soils after 45 days suggested that very little carbon remains from broiler litter, whereas all soils treated with compost had appreciably higher organic carbon.

Treatment	pH (H20)	pH (CaCl2)	EC	Organic Carbon (%)	NO_3 (ppm)	Ext P (ppm)	Ext NH_4 (ppm)
Control	6.66	5.93	0.02	1.35	0.18	8.03	1.45
BS	6.60	5.94	0.02	1.36	0.16	9.27	3.63
BI	6.78	6.05	0.04	1.31	1.62	11.93	6.27
BS/C	6.91	6.16	0.04	1.50	1.64	21.62	9.62
CS	6.83	6.22	0.03	1.69	1.16	10.81	2.24
CI	6.65	5.98	0.04	1.56	1.05	7.11	2.54
MFS	6.72	6.02	0.03	1.37	1.12	11.12	1.35
MFI	6.81	5.89	0.03	1.23	1.23	10.51	4.02
MFS/C	6.91	6.12	0.03	1.57	1.89	16.06	3.13
SS	6.71	6.06	0.03	1.44	1.62	9.58	3.43
SI	6.85	6.08	0.03	1.49	1.57	7.72	1.45
SS/C	6.99	6.3	0.04	1.50	2.7	19.43	3.13

Table 5.6 Post trial soil analysis

Results Summary:
The differences between each treatment can be best appreciated by comparing the amount of nutrient recovered (expressed as a percent of the total applied) in leachate from each column after 14 days. Table 5.7 summarises this data and shows:

- Incorporation into soil promotes more rapid leaching than surface application except for mineral fertiliser where there is little difference.
- Mineral fertilisers leach much faster than nutrients applied in an organically bound form.
- Phosphorus is the slowest leaching nutrient and potassium is the fastest.
- Compost generally retard nutrient leaching.

Table 5.7: Percentage of nutrient recovered by week two, and colour, Ec and pH readings at week two

Treatment	**NH_4 - N**	**PO_4 - P**	**NO_3 - N**	**Sulfur**	**Colour (ABS)**	**Ec**	**pH**
BS	68	32	28	66	0.085	0.74	7.46
BI	81	65	70	78	0.035	0.43	7.09
BS/C	85	44	44	77	0.076	0.58	7.86
CS	67	48	68	68	0.04	0.08	7.08
CI	74	63	77	73	0.03	0.04	7.57
MFS	94	80	94	94	0.009	0.47	7.29
MFI	92	86	96	96	0.024	0.41	7.2
MFS/C	80	85	73	94	0.074	0.56	6.99
SS	86	22	72	72	0.102	0.44	7.84
SI	81	51	74	74	0.036	0.55	7.09
SS/C	82	41	73	73	0.08	0.5	7.92

Table 5.8 illustrates these observations further by considering the time when peak nutrient levels were attained in leachates.

Table 5.8: Day to peak recovery of nutrients

Treatments	NH_4 - N	PO_4 - P	K	NO_3 - N	Sulfur
BS	7	18	3	18	10
BI	3	3	3	3	10
BS/C	3	18	3	18	10
CS	18	5	3	3	10
CI	10	5	3	3	10
MFS	3	3	3	3	3
MFI	3	3	3	3	3
MFS/C	3	3	3	3	3
SS	3	13	3	3	3
SI	3	10	3	3	3
SS/C	3	17	3	3	3

Conclusions

In general broiler litter has slower nutrient leaching of ammonium N, Nitrate N and phosphate compared with mineral fertiliser and the broiler litter substitute. Compost had the slowest rate of nutrient leaching and mineral fertiliser had the fastest. Nutrient release from these fertilisers and their leaching capacity is related to mineralisation rate, whether they are located within or on the exterior of the soil aggregates, and soil properties such as cation exchange capacity, pH and fixation capacity (Stewart, 1998). Broiler litter and compost appear to improve these particular soil properties, as well as containing a large amount of organic nutrient, which is much slower to leach out. These factors may be the cause of the observed slower nutrient release rates.

Overall broiler litter substitute has very similar leaching patterns to broiler litter, and may prove to be a good substitute. However the high level of nitrate, and its rapid release may mean leaching losses could occur when added to the field, which may cause environmental concern.

There was a significant difference in leaching patterns between the surface applied treatments and the incorporated applications. Overall more nutrients were recovered from the incorporated applications than the surface applications, and the nutrients leached out faster. This may be a result of the position of the fertiliser within the soil column i.e. the fertiliser is further down the column, so the nutrients have less distance to travel before being collected as leachate. The surface treatments have more contact with air, which may explain the loss of some nutrients.

In general the mineral fertiliser application incorporated with compost limited nutrient leaching. The addition of organic matter to soil improves soil physical and biological properties such as bulk density, CEC and soil texture (Dayegamiyne, 1997). The Bassendean sand used in the soil columns has larger pores than those found in finer textured soils and this type of sand is typically drained rapidly and has a poor ability to hold water and nutrients (Peverill *et.al.*, 1999). Therefore this addition of the compost to the soil column with the mineral fertiliser application would have provided the soil with a better capacity to hold water and nutrients, which has limited the nutrient leaching.

We conclude from these studies that growers expressed belief that broiler litter acts as a slow release fertiliser is backed by experimental evidence, however the duration of release was found to be shorter than expected.

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6. Microbiology

6.1 Introduction:

There are two potential impacts chicken manure is expected to have related to microbiology. The first is the prospect of spreading pathogenic organisms onto growers or onto crops. The second is the impact on soil microbial activity.
The scientific literature contains very little information about human pathogens associated with broiler litter, and the vegetable production industry has a long history of using manure, yet there has not been an associate made between manure use and human disease, so prospects seemed remote. However, a series of investigations was undertaken to confirm safety.

Samples were collected by a commercial food testing laboratory, Microserve Pty Ltd, who took five samples times from freshly delivered manure, and took five leaf samples from lettuce one day after manure had been sided-banded next to crops. Samples were tested for the presence of *E coli*. All samples produced negative results using two test method. Further samples were tested for the potential pathogens *Bacillus cereus, Clostridium perfringens, Salmonella,* and *Listeria.* Only manure-treated soil was found (as expected) to contain *Bacillus cereus*. Other pathogens were not found in manure or soil. (Certificates of Analysis in Appendix I) The results confirmed poultry litter does not pose a significant contamination hazard.

6.2 Microbial Metabolism

Chicken manure contains a considerable amount of energy in the form of partially digested protein and because it has a high nitrogen content, it has a relatively low carbon to nitrogen ratio. This means it provides and ideal substrate for decay by bacteria. Evidence for this process occurring spontaneously is well known to growers. Particularly when manure is moist, it becomes quite hot and progressively loses mass. In a stockpile, moist manure also evolves ammonia gas and develops an alkaline pH, indicating that anaerobic bacteria are present.

It is not clear what microbial processes (aerobic or anaerobic) are involved when manure is blended into soil, and what consequences such decay has on plant health and growth.

In this project we attempted to make indirect measurements of microbial activity by measuring temperature increases associated with bacterial metabolism, by measuring the evolution of carbon dioxide from soil, and by measuring the hydrolysis of fluorescein diacetate (FDA).

6.3 Temperature

Trial 3 (winter lettuce) was used to examine the effect of poultry manure application on soil temperature, respiration and microbial activity.

Soil temperature was measured using a purpose-built ‘Monitemp’ probe system. This device consisted of a string of 18 solid state thyristor temperature sensors. Each one was encased in a water tight copper cylinder and connected to a personal computer for digital monitoring of soil temperature. Copper was used because of its high thermal conductivity. Cylinders were constructed from 19 mm diameter pipe, with each pipe 20 cm long, thereby exposing a large surface area for each sensor. The sensors were buried in 7 selected plots at a precise depth as described in Table 6.1. Before embedded in the plots, the temperature sensors were calibrated against the temperature registered by a mercury thermometer and proved to be accurate to 0.1^{o}C.

Table 6.1 . Soil temperature monitoring design using the Monitemp system.

Sensor No.	Plot No.	Treatment code	Depth	Calibration
1	43	F4	15	-0.1
2	43	F4	5	+0.4
3	49	E1	15	-0.3
4	49	E1	5	-0.4
5	55	A2	15	+0.3
6	55	A2	5	+0.3
7	58	B4	25	-0.2
8	58	B4	15	+0.3
9	58	B4	5	+0.4
10	56	A4	25	+0.1
11	56	A4	15	+0.3
12	56	A4	5	+0.3
13	50	D4	25	-0.1
14	50	D4	15	-0.3
15	50	D4	5	-0.2
16	51	C4	25	-0.1
17	51	C4	15	-0.3
18	51	C4	5	-0.1

Sensors were buried in the trial plots two days after soils were amended with manures. The temperatures of all probes was then automatically logged sequentially every 10 seconds and recorded on a database. Data was then corrected according to the calibration shown in Table 6.1. For graphical representation, each point represents the mean of 360 separate records over the hour.

Figures 6.1 to 6.4 illustrate the fluctuations in soil temperature for Trial 3 over winter. As expected, temperature fluctuations were greatest in the topsoil, and gradually lessened as depth increased, with the least daily change at 25 cm depth. The rate of temperature increase and decrease was also fastest in surface soil relative to deeper soil.

The addition of poultry manure to the soil reduced overall temperature fluctuations in the topsoil, with higher manure application rates providing a better shield against ambient temperature changes. Generally, surface banding manure alone proved as effective as when used in conjunction with pre-plant incorporation at keeping topsoil temperatures warmer during the warmest part of the day. However pre-plant incorporation of manure was more effective at keeping soil temperatures warmer during the coldest part of the day.

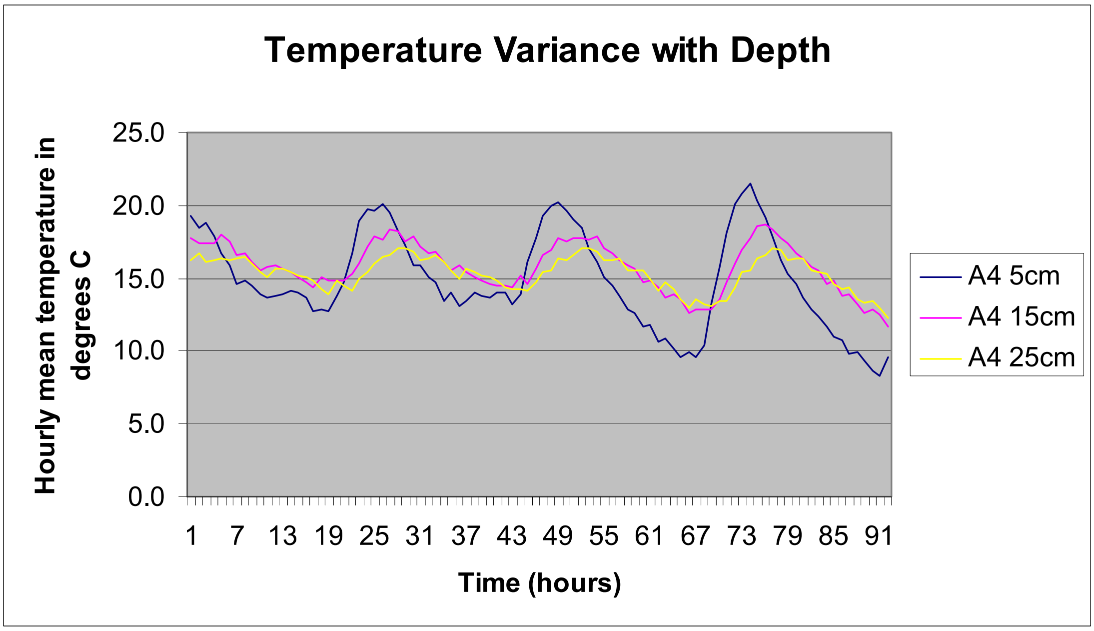
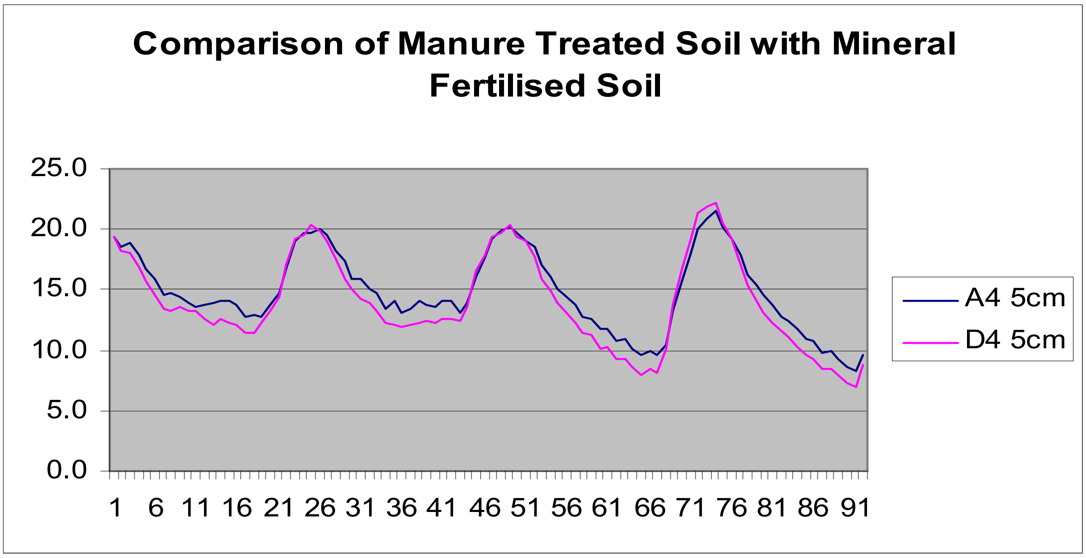
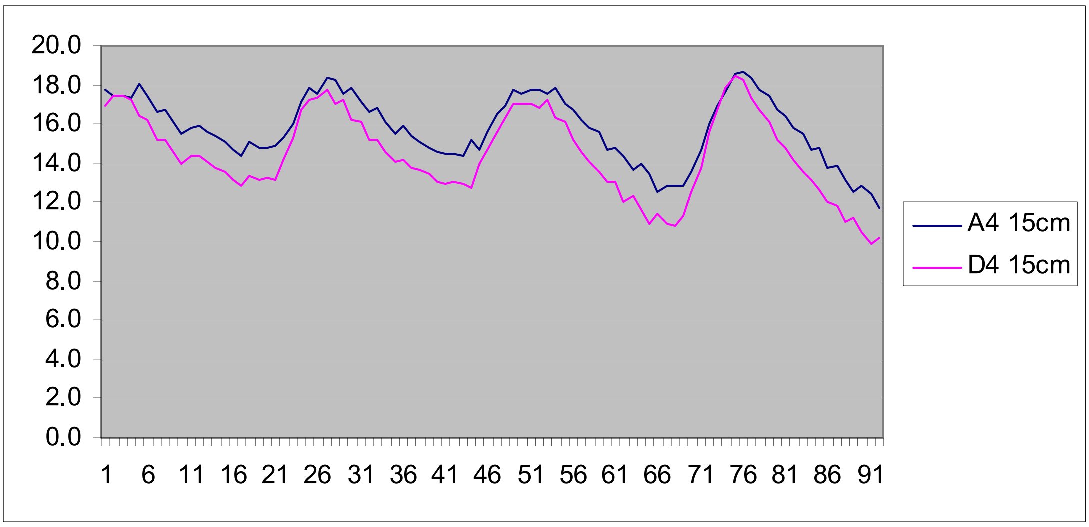


Figure 6.1 Temperature of soil over nearly 4 days in May. Both the extent and rate of change is greater near the surface compared to deeper layers.





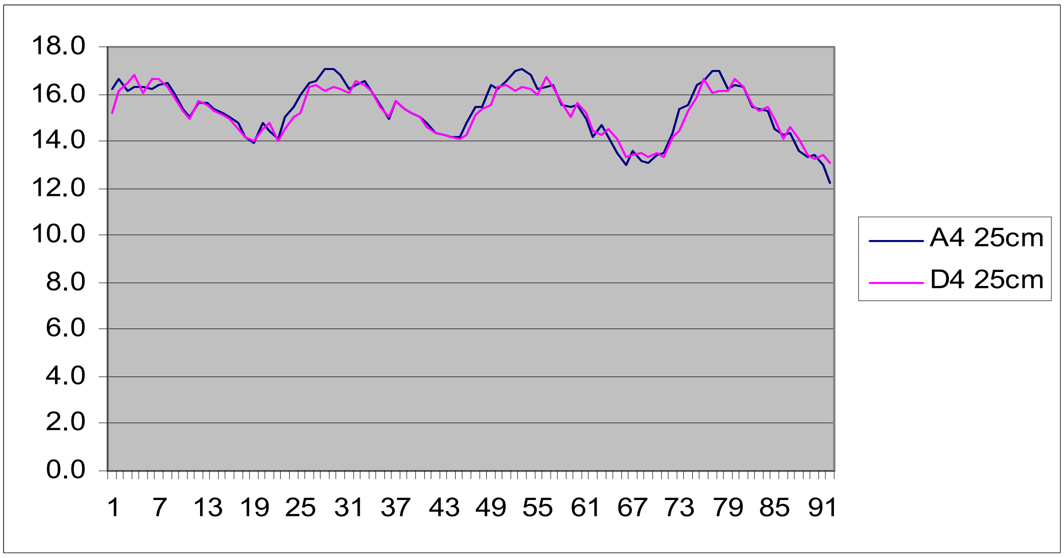


Figure 6.2 a(top), b(middle) and c(bottom). Difference in temperature of soil that had received either incorporated manure (A4) or mineral fertiliser (D4). At 5 cm depth, the maximum temperatures are identical whereas the minimum is about 2 degrees warmer with manure treatment, at 15 cm depth both maxima and minima are warmer with manure, but at 25 cm there is no appreciable difference.

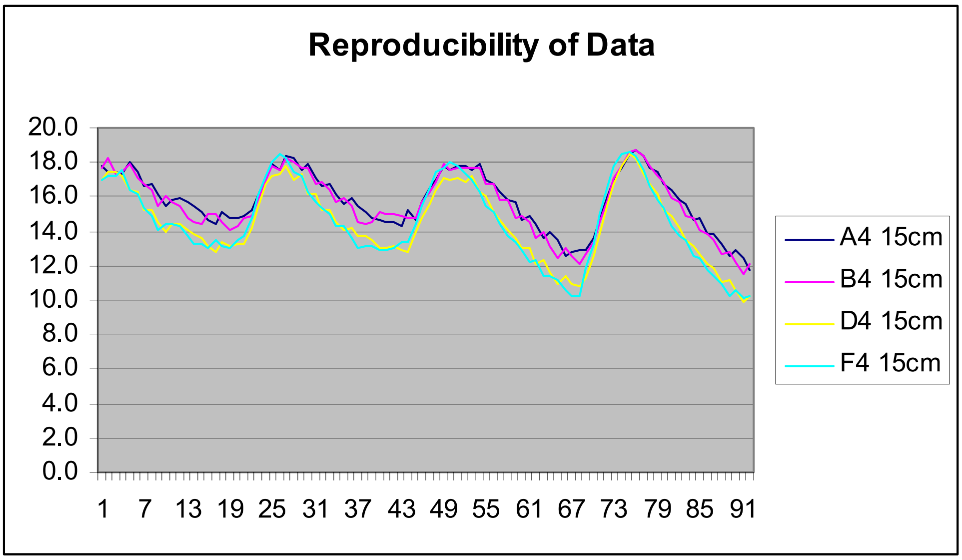


Figure 6.3. Treatment A4 and B4 had incorporated chicken manure, whereas D4 and F4 had mineral fertiliser. B4 and F4 were due to be top dressed with manure, but at this point in the trial, served to demonstrate that the temperature effect of manure was consistent between beds.

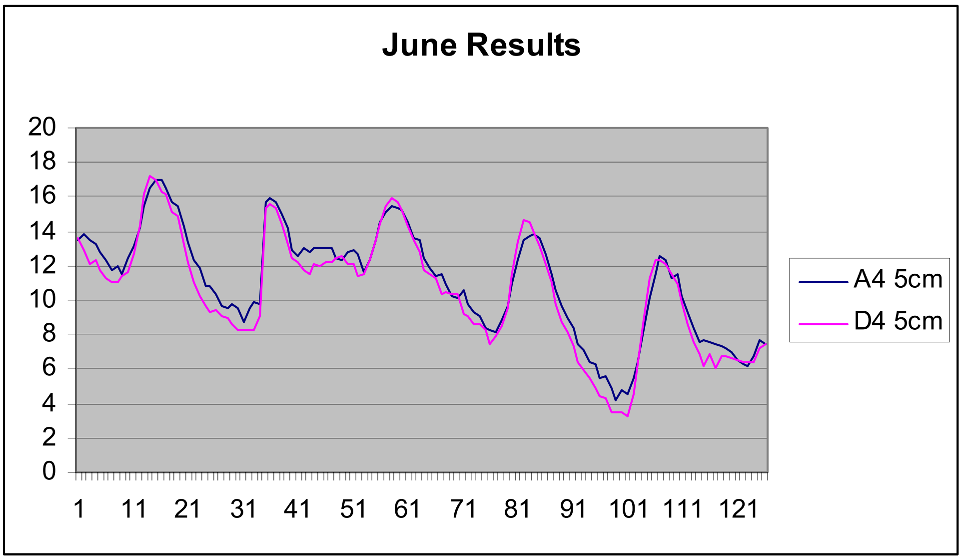


Figure 6.4 Temperature of soil over 5 days, 5 weeks after manure had been applied. The difference between treatments becomes reduced as manure degrades by processes of microbial decay.

Table 6.2 shows the mean soil temperature with maximum and minimum temperatures recorded during the trial 3 period for winter lettuce production shortly after beds were prepared. Compared to mineral fertiliser alone, manure treatments cause a slight but significant and persistent increase in soil temperature up to a depth of 15cm, with higher rates of manure application causing greater increases in the average temperature of the topsoil. The increase in temperature ranged from 0.7–1.1^{o}C at 5cm depth, to 0.1–1.3^{o}C at 15cm depth.

During the cooler months of June, July and August, the effect of pre-plant manure application had disappeared as manure decomposed. However surface banding side dressing alone resulted in higher average topsoil temperatures compared to incorporation at pre-plant or incorporation plus manure side banding. The improvement in temperature ranged between 0.1-0.4^{o}C. However manure incorporation together with surface banding, resulted in warmer average topsoil temperatures (between 0.2-0.3^{o}C) compared to manure incorporation alone.

At a depth of 15 cm, pre-plant incorporation of manure caused higher average soil temperatures compared to surface banding or incorporation plus surface banding. Through May and June, incorporation in conjunction with surface banding produced higher soil temperatures compared to surface banding alone. However, from July through to August, surface banding alone proved more effective at keeping up the average soil temperatures than when used in combination with incorporation at pre-plant.

Table 6.1. Temperature ranges experienced by the soil that had received various fertiliser treatments under during lettuce production in May – August 2001.

	May 24-30				June 1-8, 11-19, 25-30				July 1-23				August 6-10			
5cm	Max	Mean	Min	SD	Max	Mean	Min	SD	Max	Mean	Min	SD	Max	Mean	Min	SD
A2	23.0	14.3	8.4	3.60	21.8	12.5	3.4	4.11	17.7	9.7	3.2	3.54	20.6	12.7	8.3	3.00
A4	21.5	14.4	8.3	3.09	19.8	12.5	4.6	3.62	17.0	9.6	3.7	2.92	16.2	12.4	9.4	1.73
B4	22.1	14.6	8.6	3.19	20.3	13.0	5.6	3.33	16.9	10.1	4.5	2.75	15.5	12.8	10.2	1.37
C4	22.2	13.9	8.2	3.25	19.6	12.4	5.1	3.26	16.4	9.8	4.0	3.01	14.8	12.0	9.0	1.50
D4	22.2	13.6	7.0	3.57	20.4	11.9	3.1	4.07	17.2	9.4	3.0	3.42	17.2	11.8	8.2	2.35
E1	22.9	13.4	6.8	3.69	21.0	11.8	2.7	4.16	16.9	9.4	3.0	3.47	15.3	11.5	7.8	2.02
F4	23.3	14.1	7.7	3.72	21.8	12.8	3.5	4.09	19.0	10.1	3.8	3.29	17.6	12.8	9.5	2.02
15cm	Max	Mean	Min	SD	Max	Mean	Min	SD	Max	Mean	Min	SD	Max	Mean	Min	SD
A2	18.2	15.2	11.6	1.64	17.4	12.9	7.7	2.13	15.6	10.3	6.0	2.06	15.0	12.9	10.5	1.07
A4	18.7	15.4	11.7	1.67	17.7	13.1	7.4	2.15	15.8	10.4	6.1	1.98	14.6	12.9	11.4	0.81
B4	18.8	15.2	11.5	1.75	17.9	13.1	7.6	2.18	15.7	10.3	6.1	2.02	14.8	12.7	10.6	0.97
C4	18.5	14.2	9.8	2.11	17.3	12.3	5.8	2.40	15.4	10.0	5.4	2.22	14.1	11.9	9.7	1.03
D4	18.5	14.1	9.9	2.07	17.4	12.1	6.0	2.46	15.6	10.2	5.2	2.09	14.4	12.3	9.8	1.07
E1	18.4	14.2	10.0	2.04	17.4	12.2	6.1	2.46	15.3	10.2	5.0	2.17	15.0	12.1	9.8	1.20
F4	18.6	14.2	10.1	2.24	17.5	12.5	6.2	2.39	15.7	10.3	6.0	2.08	14.8	12.4	10.1	1.07
25cm	Max	Mean	Min	SD	Max	Mean	Min	SD	Max	Mean	Min	SD	Max	Mean	Min	SD
A2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A4	17.1	15.0	12.2	1.20	16.1	12.6	8.1	1.82	14.7	10.3	6.5	1.69	13.6	12.3	11.0	0.65
B4	16.9	15.1	12.8	1.11	15.8	12.7	9.1	1.62	14.5	10.5	7.4	1.56	13.6	12.3	10.8	0.63
C4	16.8	14.9	12.9	1.08	15.8	12.8	9.0	1.65	14.7	10.5	7.1	1.65	13.7	12.3	11.0	0.65
D4	16.8	14.9	12.9	1.06	15.9	12.7	8.9	1.67	14.8	10.6	7.1	1.58	13.6	12.4	11.0	0.66
E1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

6.4 Soil Respiration Methods

Soil respiration was measured using one of two methods: (1) *in situ* capped cylinder method described by Alef (1994) and the tight-sealed jar incubation method described by Anderson (1982). In both measurements, sodium hydroxide was used as alkali trap of CO_2 evolved from the soils. Sodium hydroxide containers were initially filled with a precisely measured volume of defined NaOH concentration. After trials, jars were sealed and returned to the laboratory. Titration against standard hydrochloric acid was the done, and the volume of acid required to reach pH 7 is in inverse proportion to the amount of carbon dioxide by the hydroxide solution.

Soil microbial activity was measured using a modification of the fluorescein diacetate hydrolysis (FDA) method. This modified method had previously been tested and refined by Bioscience to enable sensitive comparison of soils with different pH and organic matter content. The method involves mixing soil in a buffered solution containing fluoresein diacetate and incubating the mixture for exactly 15 minutes at 25^{o}C. The incubation is stopped by adding acetone, shaking, then placing the mixture in a centrifuge. The upper acetone layer is removed and absorbance is measured in a spectrophotometer at 480 nm.

The modification bioscience made to this method stemmed from the observation that in Bassendean sand, humic substances co-extract with fluorescein and interfere with absorbance. Absorption spectra of acetone extract of soil without fluorescein and fluorescein alone show that whereas fluorescein does not absorb any light at wavelengths below 450 nm, the humic extract has a strong absorbance at lower wavelength. By measuring the absorbance at 480 nm and 400 nm, a correction factor can be applied which accounts for absorbance at 480 nm which is due to humus rather than fluorescein. This enables a more sensitive and reproducible estimate of soil FDA activity in Bassendean sand.

6.5 Respiration Results

Soil respiration rate was measured on the soils from the plots used for the Monitemp monitoring. First, the respiration rate of the topsoil (0-10 cm depth) was measured at the field on June 5-6 and one month later on July 5-6. Topsoil respiration was overall higher in June than in July (Figures 6.7 & 6.8). The surface soil temperature was decreasing from May to July, particularly with the daily peak temperatures as illustrated in Figures 6.2 to 6.5.

The warmer soil temperatures experienced by the microbial community prior to the respiration measurement appeared to reflected in the higher respiration rate of soil, implying more vigorous microbial activity earlier in the trial. Microbial activity appeared to be higher, inferred from the higher soil respiration rates, in soils under A, B and C treatments than other treatments. The soil with A, B and C treatments had poultry manure incorporated between planting with lettuce seedlings.

Greater substrate availability with pre-plant with poultry manure incorporation promoted significantly higher microbial activity. The soil respiration rate in the topsoil that had received only mineral fertiliser (D) was the lowest in both June and July measurements. Lack of organic substrate and greater soil temperature fluctuation and generally cooler soil conditions would have negatively affected against microbial activity.

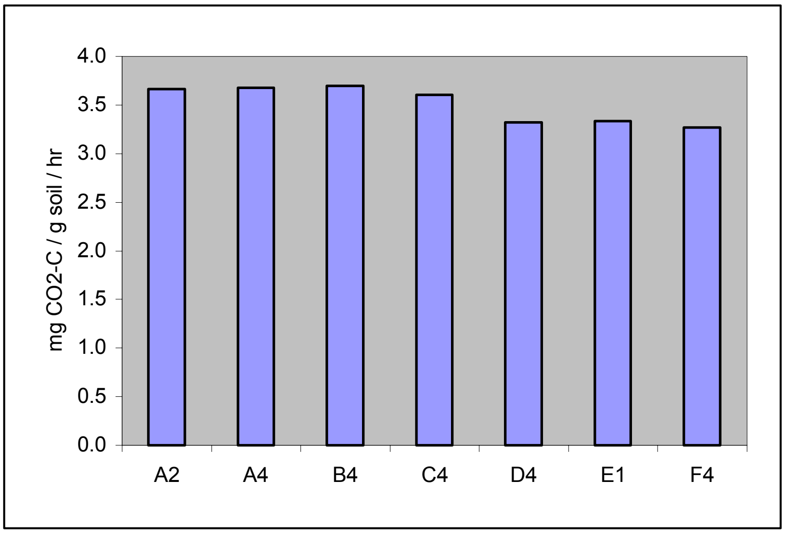


Figure 6.7 Surface respiration of soil on June 5 - 6 under various fertiliser treatments, measured *in situ* using capped cylinders embedded to 0-10 cm depth.

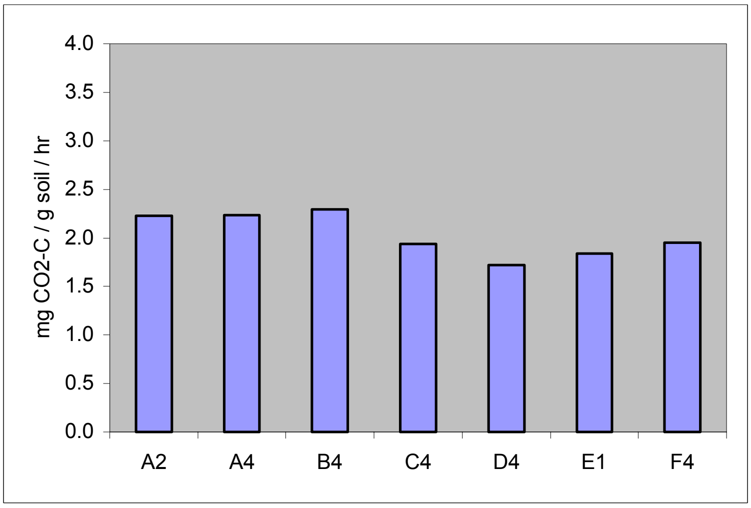


Figure 6.8 Surface respiration of soil on July 5 - 6 under various fertiliser treatments, measured *in situ* using capped cylinders embedded to 0-10 cm depth.

Using the soils collected from the field, the soil respiration could be measured along the depth as shown in Figure 6.9. The respiration rate of the topsoil (0-10 cm) was substantially lower than that of surface soil respiration measured in field. The soil for the laboratory analysis was collected excluding the manure layer and the 10cm-deep fractions were thoroughly mixed before incubation at more consistent room temperature. With the field respiration measurement, the capped cylinders were directly pushed into the selected soil bed with no disturbance to the surface soil conditions. Much of microbial activity occurred in the topsoil, again the lowest respiration rate in the soil that did not receive poultry manure.

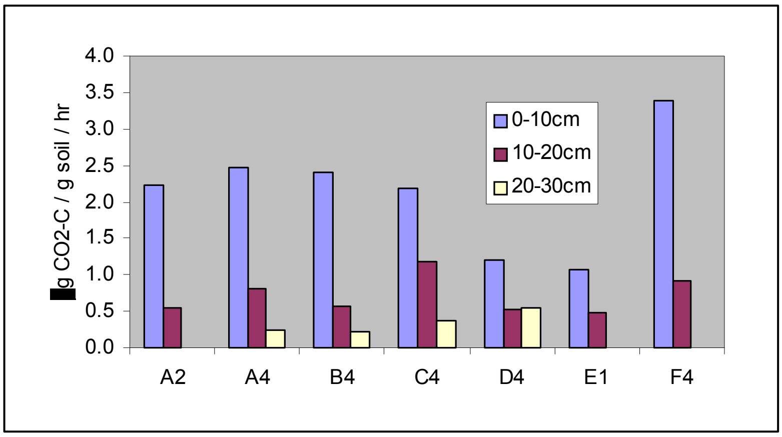


Figure 6.9 Respiration rate of soil with depth that had received various fertiliser treatments. Soil was collected in August before lettuce harvest.

6.6 FDA Metabolic Activity

Figure 6.10a and b illustrate the hydrolysis of FDA for soil samples taken 11 and 44 days after transplant at three soil depths. Microbial activity was highest in soils amended with manure. Most of the activity was found in the topsoil, with activity declining with increasing soil depth. In the early stages, the FDA hydrolytic activity of the topsoil was higher in those treated with higher rates of manure.

TREATMENTS:

A: Manure incorporated pre-plant. Top dress with NK every 7 days.
B: Manure incorporated pre-plant. Surface band Manure at 14 days.
C: Manure incorporated pre-plant. Surface band manure at 14 days, TD every 7 days.
D: Mineral PP. Top dressing NK every 7 days.
E: Mineral PP. Surface band manure at 14 days, TD every 7 days.
F: Mineral PP. Surface band manure at 14 days, surface band manure at 42 days

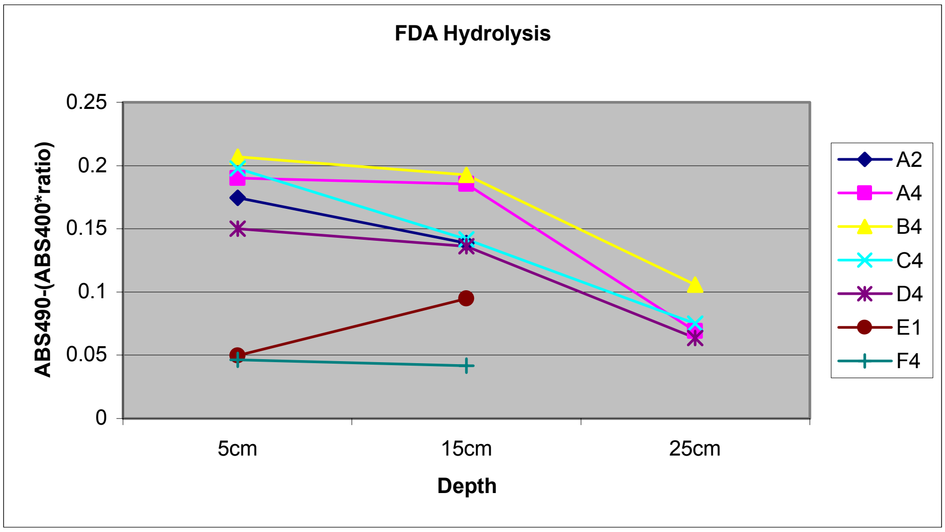


Figure6.10 a: FDA hydrolysis 11 days after transplant. Means of three replicate determinations are shown.

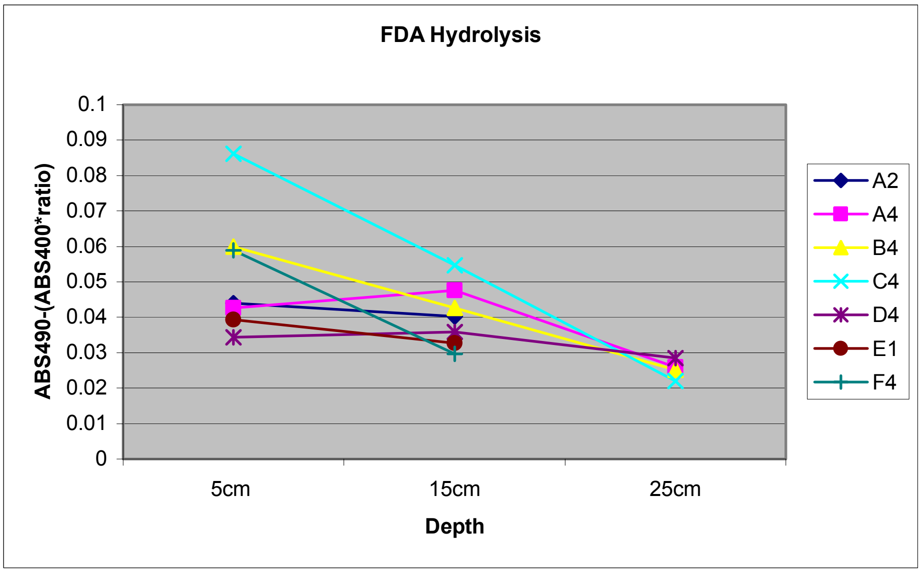


Figure 6.10 b: FDA hydrolysis 44 days after transplant. Means of three replicate determinations are shown.

Figure 6.11 illustrates FDA hydrolysis of the topsoil over the course of the trial. The level of activity was highest within the first couple of weeks following manure treatment. Within a month following manure treatments, microbial activity had dropped to untreated levels where they invariably stayed for the remainder of the trial.

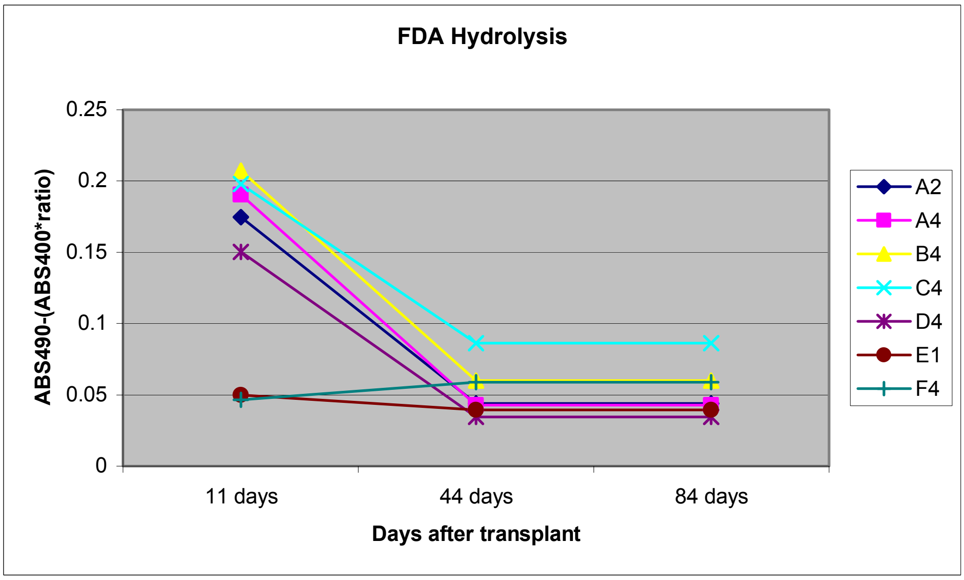


Figure 6.11: FDA hydrolysis of the topsoil over the course of the trial. Means of three replicate determinations are shown.

6.7 Conclusions

The three testing methods used provided independent views of impacts of chicken manure on soil microbial activity, but each had its limitation. What was consistent was that measured changes only occurred for a relatively short period after chicken manure was applied to soil. This is consistent with observations of column leaching which demonstrated breakdown of chicken manure is rapid, has been essentially complete after three weeks.

The soil temperature measurements showed that the extent of metabolism is sufficient to raise soil temperature by up to 1.5 degrees at a depth of 15 cm. Whilst this may seem only a modest rise, under winter conditions this could make a significant difference to root metabolism and fertiliser uptake, particularly considering metabolic activity typically stops at about 4^{o}C. It must also be recognised that generally damp vegetable productions soils have high thermal conductivity, so the heat being generated by microbial metabolism is constantly being drawn away. A rise of 1.5 degrees thus signifies quite high metabolic rates.

Soil respiration jars suggested the difference in microbial metabolism between treatments was quite small, however *in situ* jars can only measure respiration at the soil surface. The temperature data suggests a greater influence is experienced deeper in the soil. A much greater difference between treatments was found when soil was removed from the field and respiration was measured at constant temperature in the laboratory. This data suggested microbial metabolism in the presence of manure is more than double that when mineral fertiliser is used (D4 compared to A2, A4 and F4 in Figure 6.9)

FDA activity showed the greatest difference between manure treated and mineral fertiliser treated beds, however the four fold activity difference found between manure and mineral fertiliser beds had completely disappeared by day 44.

7. Fly Breeding

7.1 Introduction

The perception that using chicken manure for vegetable production promotes fly breeding, particularly the problem stable fly, is what motivated banning the use of manure except in winter months in Western Australia.

Flies are attracted to the ammonia gas released from manures as they break down. The ammonia is indicative of the microbial breakdown of manure in high pH environments. It is ammonia in the environment which stimulates gravid female flies to lay eggs. The maggots hatch within 2 days of the eggs being laid. They feed on bacteria present in the manure. Maggots will feed for up to 2 weeks then dig down into the soil to pupate. Depending on the temperature of the soil the larvae will pupate from anywhere between 1 to 2 weeks. The young flies will then dig up to the surface. Colder temperatures will initiate an over-wintering response in the pupae. They will slow their metabolism to a standstill point until conditions become favorable again. House flies (*Musca domestica*) will tend to be the first populations to lay in the manure. Stable flies (*Stomoxys calcitrans*) will tend to move in a week later when the manure is further composted. House flies will be the first to emerge, followed by stable flies a week to 2 weeks later.

7.2 Project Aims

Grower interviews had identified broiler litter was used at different application rates and in a number of different ways, particularly pre-plant incorporation and side banding. We wanted to test whether there was any difference in fly breeding depending on application rate and method.

As pH of the medium influences ammonia volatilization, manure pH is important to egg laying. A second aim was to reduce broiler litter pH. In an attempt to deter fly egg laying, broiler litter was amended by adding 3% and $1^{1}/_{2}$ % phosphoric acid in odre to simultaneously lower the pH and increase plant-available phosphate. These treatments were then compared against untreated manure, mineral fertiliser and a broiler litter substitute Nutraplex in terms of their fly breeding capacity. Fly breeding trials were run concurrently with plant nutrition and growth trials.

7.3 Fly Counting

Two methods were used to enumerate flies emerging from vegetable production beds. The first method used fly traps kindly provide by Dr David Cook of Agriculture WA. These were a steel framed, square based pyramid clad with dense shade cloth. At the apex was a jar containing and inverted cone made from brass mesh. Flies which emerged from soil were attracted to light at the pyramid apex where they crawled through the small aperture formed by the brass mesh and became entrapped within the jar. Jars could be easily removed for fly recovery and counting. Each fly trap covered an area of exactly 1 m^2. A total of 12 traps were used.

The second method involved using much smaller traps formed from square plastic lunch boxes (20 x 20 cm) which had the bottom removed. A piece of thrip mesh gauze was placed over the top of the box and held in place using a large neoprene o-ring. These boxes were inserted into soil. Flies were removed firstly by spraying commercial fly spray through the mesh, then after some time, the mesh was removed and dead flies were collected from the soil surface using a small portable vacuum cleaner. Flies were taken from the vacuum cleaner dust bag and placed in a container for later counting in the laboratory. Because traps were small, three could be placed in each trial bed between plants.

7.4 Large Trap Trials

The first fly trapping trial was undertaken during Field Trial 4. Eight days after pre-plant manure applications and the day after corn was transplanted, traps were laid over the 150% application rate beds. Emergent flies were then collected weekly for the next three weeks. The results (Table 7.1) showed unexpected results wherein flies were trapped in beds which had not been treated with manure (Treatments D.E and F) and the anticipated reduction in fly breeding in phosphate amended manure was not found. However the significant variation in fly numbers found between replicate treatment meant the results were not statistically significant.

TREATMENTS:

A: Chicken manure (untreated control) pre plant, surface band chicken manure at week 2, mineral top dress every 7 days
B: Amended chicken manure (3% H3PO4) pre plant; surface band amended chicken manure at week 2 and week 6
C: Amended chicken manure (3% H3PO4) pre plant; surface band amended chicken manure at week 2; mineral top dress every 7 days
D: Mineral pre plant; mineral top dress every 7 days
E: Nutraplex pre plant, surface band nutraplex at week 2; mineral top dress every 7 days
F: Nutraplex (chicken manure substitute) pre plant; top dress with Nutraplex at week 2 and week 6

Treatment	A	B	C	D	E	F
Replicate 1	405 (18)	202 (41)	54 (0)	26 (9)	456 (38)	3 (0)
Replicate 2	22 (3)	18 (2)	388 (31)	121 (18)	31 (0)	84 (12)

Table 7.1 Total flies trapped in large traps during the first 20 days of Trial 4 (brackets are stable flies).

In order to investigate further the reasons why amendment had apparently not worked as anticipated, and the cause for such large replicate variance, further laboratory trials were undertaken with phosphate amendment and subsequently further beds were established without any plantings, and phosphate amendment.

It was determined that when broiler litter was amended with phosphoric acid, then added to fields and irrigated, the phosphate leached from the manure very rapidly and pH rose quickly. Further work determined that if the manure was allowed to dry in the sun after acid addition, the rate of phosphate leaching became less pronounced and this treatment was adopted thereafter. Details of the work done binding phosphate to various substrates, then examining phosphate leaching are contained in Appendix J.

A separate trial was undertaken in December when stable flies were likely to have reached higher numbers. Purpose made beds were prepared incorporating treated and untreated manure at a rate equivalent to 75 m^3 per hectare. It was believed that such high application rates should attract greater fly numbers. During the trial soil was collected from the treated area beside each trap to examined how treatments were influencing pH.

The results in Table 7.2 indicate this approach was successful as after four weeks traps contained very large numbers of house flies, but very few stable flies. This trial suggested that between replicate variance is much better at very high application rates, and treatment at lower phosphate rates rather than higher resulted in significantly less fly breeding.

Treatment	**Replicate**	**House Flies**	**Stable Flies**	**Total**
Mineral	R1	16	0	16
	R2	3	0	3
	R2	17	0	17
	Mean	12	0	12
1.5% PM	R1	301	0	301
	R2	189	0	189
	R3	93	5	98
	Mean	194	2	195
3.0 % PM	R1	1128	0	1128
	R2	1073	1	1074
	R3	909	2	911
	Mean	1036	1	1037
Raw M	R1	952	1	953
	R2	1450	1	1451
	R3	1077	0	1077
	Mean	1159	1	1160

Table 7.2 Fly trapping in special beds at very high manure application rates

Results of soil pH change after application of unamended or phosphate amended chicken manure (Table 7.3) provide some insight as to why anomalous results were found in flu traps.

The day after phosphate amended manures had been added, as expected the pH was lower, whereas it rose in unamended manured soil. However after 4 days the amended manured-treated soil actually had higher pH which peaked at day 7. The unamended manures reach higher pH, but took 10 days. The difference between surface soil (0 – 10 cm) and deeper soil (10 – 20 cm) was the rise occurred quicker in deeper soil, but the overall pattern was the same. This can be attributed to poorer oxygen availability in deeper soil promoting anaerobic conditions more quickly.

The difference in measurement of soil pH in Calcium Chloride compared to measuring in water it the former is thought to account for the natural buffering capacity of soil. It is thus unusual that the overall pattern of pH movement is the same, but the extent of change is about ½. This suggests that chicken manure confers a significant pH buffering effect on soil until it breaks down.

pH (Water)	Treatment	Day 0	Day 1	Day 4	Day 7	Day 10	Day 14
0 - 10 cm	Untreated CM	6.54	6.9	7.13	7.36	8.03	6.85
	3% Amended CM	6.54	6.18	7.32	7.98	7.27	6.71
	1.5% Amen. CM	6.54	6.65	7.42	8.51	7.31	7.29
	Mineral Fert.	6.54	6.32	6.72	6.11	6.48	5.4
10 -20 cm	Untreated CM	6.54	6.8	7.58	7.8	7.74	6.53
	3% Amended CM	6.54	6.46	7.38	7.54	6.62	5.88
	1.5% Amen. CM	6.54	6.6	7.26	7.87	6.6	6.66
	Mineral Fert.	6.54	6.52	6.69	6.5	6.22	6.18
pH CaCl2							
0 - 10 cm	Untreated CM	5.61	6.42	6.43	6.45	6.3	5.84
	3% Amended CM	5.61	5.65	6.15	6.67	6.21	5.56
	1.5% Amen. CM	5.61	6.06	6.11	6.51	6.13	5.96
	Mineral Fert.	5.61	5.47	5.54	5.8	5.61	5.11
10 -20 cm	Untreated CM	5.61	5.87	6.46	6.21	6.2	5.64
	3% Amended CM	5.61	5.8	5.95	6.05	5.95	5.2
	1.5% Amen. CM	5.61	6.01	6.61	7.43	5.58	5.4
	Mineral Fert.	5.61	5.59	5.68	5.96	5.17	5.2

Table 7.3 pH of soil adjacent to fly trap beds over 14 days.

Further field trials in specially prepared beds using low amounts of manure again suggested phosphate amended manures bred less flies, however between-replicate variance was still too high. A decision was made to use much smaller traps in greater numbers in order to reduce overall variance.

7.5 Small trap trials

Small traps were first used during Field trials 5 and 8.
Untreated chicken manure was incorporated into the soil 7 days before planting. This was to allow ammonia volatilization to take place and not burn the plants. Treated chicken manure, mineral and Nutraplex were incorporated 1 day prior to planting. Traps were laid out randomly along the bed rows two weeks after pre-plant incorporation. Flies were expected to emerge within 4 weeks of pre-plant incorporation. The traps were 20 cm by 20cm plastic frames with a cloth mesh cover. Three traps were randomly placed on each replicate bed with the results based on an average number of flies collected from three replicate beds (nine traps). Traps were left on the beds for a period of three weeks. Traps were emptied once a week for the duration of the trial. Flies were collected by spraying the top of the traps with insecticide (fly spray) and collecting the dead flies. Flies were counted and where possible identified.

Top Dress Fly Trial

A side band or top dress of chicken manure was applied to the crop in its second growing week. Two weeks after top dress was applied the fly traps were laid in random fashion as in the pre-plant collection. Due to the cold weather traps were left for a five-week period.

Results
No flies were collected from the mineral or Nutraplex treatments in either the preplant or top dress applications.

The pre-plant fly collections were higher than the top dress in all treatments except for 3% phosphoric acid amended.

There appeared to be correlation between application rates and fly collections. Application rates of 90% and 120% (rates 3 and 4), tended to have much higher fly counts than 30% and 60% (rates 1 and 2). In three of the four manure treatments application rates at 90% tended to have higher fly counts than 120%.

The highest incidence of flies came from the untreated broiler litter. 1 ½ % treated manure had to second highest fly counts while 3% amended manure without mineral top dressing had the lowest count.

Treatments A and C are directly comparable as the only difference being the amendment of the chicken manure.

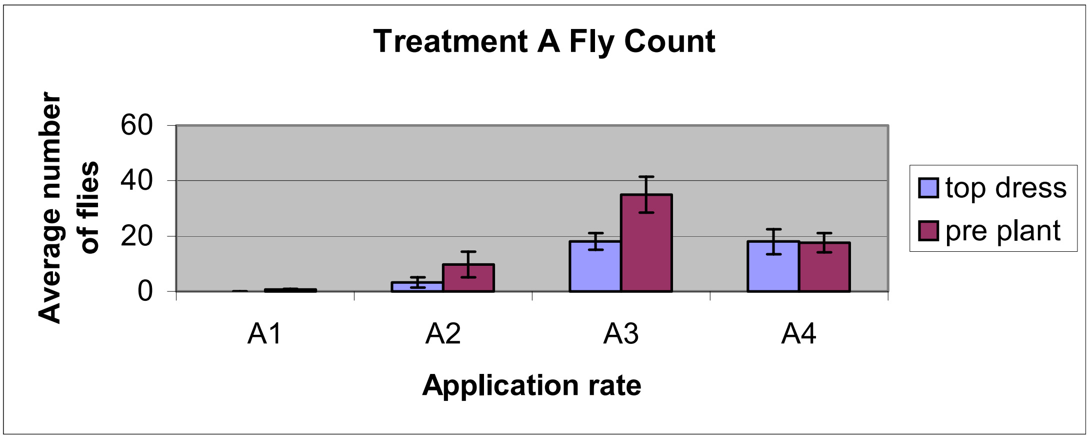


Figure 7.1: Treatment A (untreated broiler litter with mineral top dress) fly count with standard error of the mean

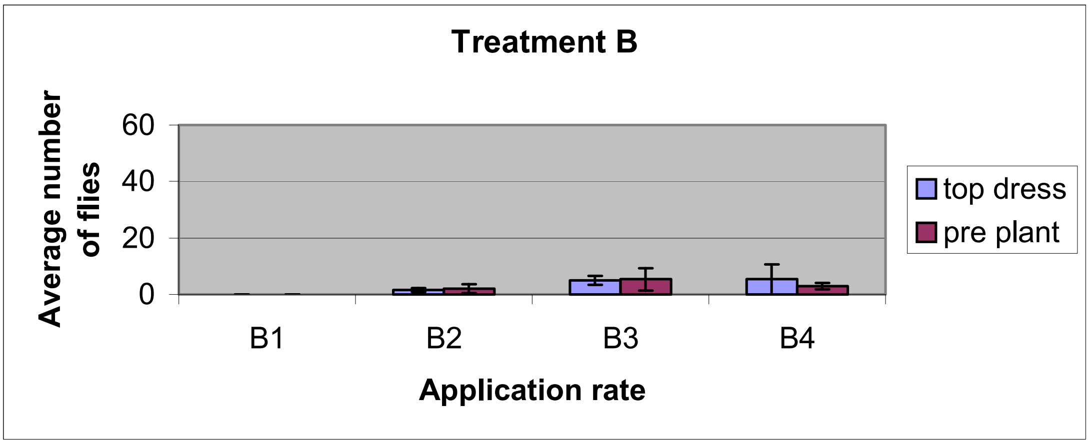


Figure 7.2: Treatment B (3% phosphoric acid treated chicken manure) fly count with standard error of the mean

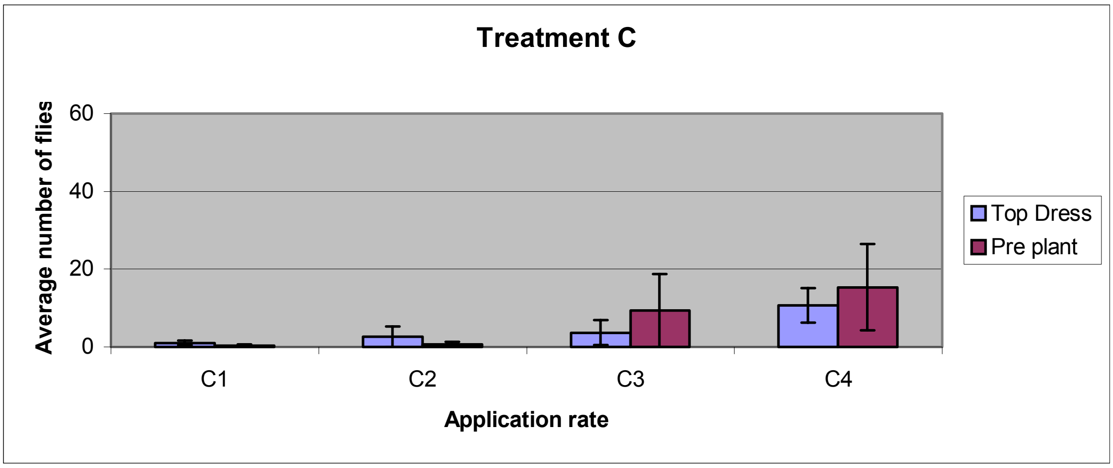


Figure 7.3: Treatment C (3% phosphoric acid treated chicken manure with mineral top dress) fly count with standard error of the mean

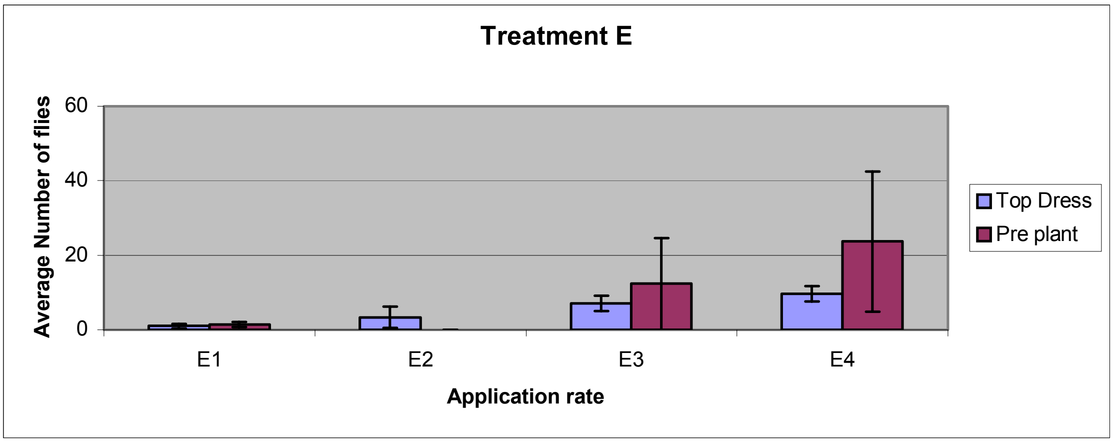


Figure 7.4: Treatment E (1 ½% phosphoric acid treated manure with mineral top dress) fly counts with standard error of the mean.

The wet, cooler weather resulted in many flies from the top dress collection decomposing quickly prior to identification. Although counts are relatively accurate for the period, actual number of stable flies positively identified was likely to be underestimated, so only total flies trapped are presented.

Stable flies were still present and alive at the five-week mark. Stable flies were mostly present in the treatment A traps. Although in small numbers (no more than 3 per trap) this is unusual as due to the colder weather we assumed the pupae would have over wintered rather than emerge. However, the cooler weather does explain the delay in which they emerged.

Another point to note is whether or not the tight canopy that the crop formed affected emergence. Some traps were completely void of light due to the plant canopy. Emerging flies are attracted to the light and may not have emerged from under the plants (where the traps were situated) as the light was blocked out. Spiders were also a problem, and it is hard to say what proportion of flies in each trap were taken or consumed by predators. The decomposing mites which were all over the dead flies in the pre-plant trials were again prevalent in this trial however they were not inhabiting as many beds.

The charts show that pre-plant had consistently higher numbers of flies than surface banded treatments. This could however be attributed for the change in weather over the season. Treatments A and B had a similar trend with number of flies collected increasing up until application rate 4. Fly numbers dropped off with the higher manure application. Treatments C and E had a similar trend in fly numbers, that is, the more manure applied the more flies were collected.

Flies other than housefly, false stable fly, stable fly, blowfly, face fly and false house fly are not considered nuisance flies. We had a few unusual flies such as flesh flies and other small shiny flies, which are not considered to be a pest.
At none of the application rates did we see fly numbers get to nuisance proportions.

The trial has shown that there is some suppression in fly breeding by using phosphoric acid, although it does not seem to affect the laying or larvae of the flies. Field inspection revealed that all manure treatments had larvae through them throughout the trial. The number of larvae observed did not correlate with trapped adults, so we conclude that phosphoric acid does not eliminate egg laying and hatching, but may hinder fly development at some other stage in their life cycle.

Field Trial 8.

Fertiliser application rates were reduced for this field trial. Because previous work had indicated more flies bred in incorporated chicken manure, this trial focused on laying traps on beds where untreated and phosphoric acid treated compost-based broiler litter had been pre-plant incorporated rather than side dressed. This enable still more traps to be laid per replicated bed.

The results (Figure 7.5) confirmed data from the previous trial:

- There was a significant reduction in fly breeding when manure was treated with phosphoric acid.
- At low manure application rates fly breeding activity was very low, even in unamended manures.
- Stable fly numbers were generally very low.
- Variance between replicates remained high.

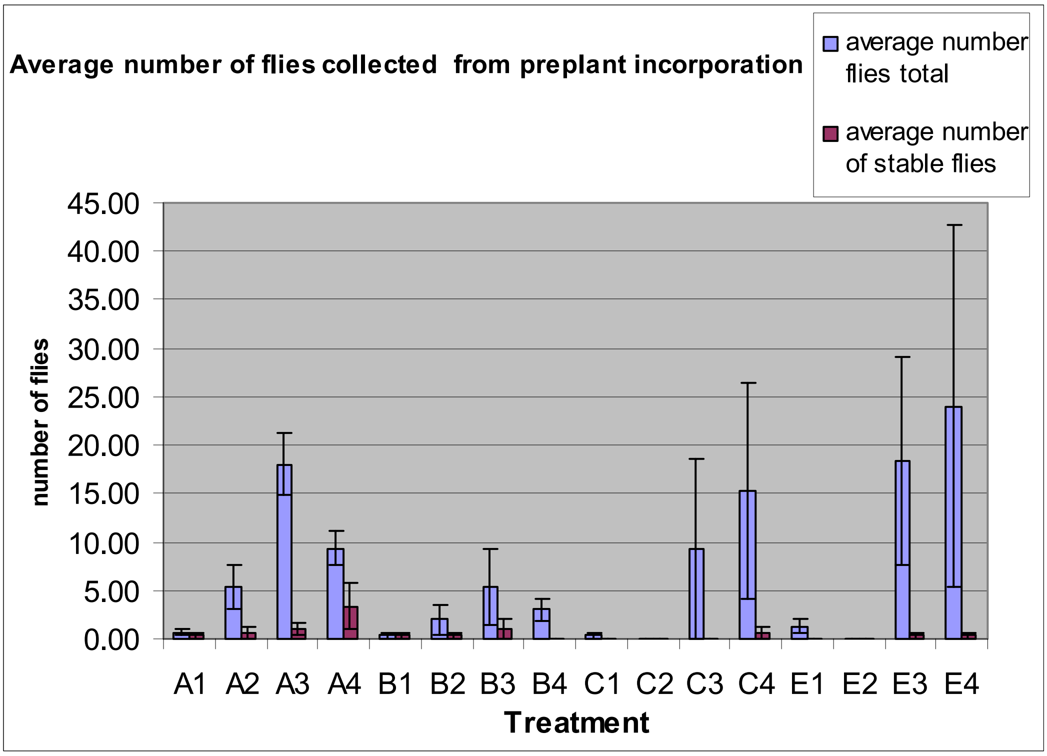


Figure 7.5. Fly emergence in pre-plant beds according to application rate.

Conclusions

Conducting fly breeding experiments during growth trials proved very challenging for a number of reasons. Firstly, stable flies, although the cause for banning the use of chicken manure in Western Australia, were quite uncommon for most of the trial period, and the common house fly was much more frequently trapped. Secondly, there was large variation between replicates during all work undertaken. This made drawing statistically valid conclusions impossible.

Notwithstanding these limitations, the work showed that flies grow to maturity much more when manure is buried within soil rather than surface banded, and breeding is very much reduced when manures are used at application rates below 15 m^3 per hectare. At high application rates in summer, very large numbers of flies can breed (1,000 flies per square meter or 10 million per hectare at 75 m^3 per hectare).

Adjusting the pH of manure by the addition of mineral acids further reduced fly breeding provided manure was thoroughly dried before application to fields. Further data is needed, but result obtained to date suggest that addition of phosphoric acid to 1.5% w/w is more effective at reducing fly breeding than addition to 3% w/w

8. Overall Conclusions and Recommendations from this Project.

As a result of this study the following conclusions have been drawn.

8.1
Chicken manure provides a very cost effective and reliable means of supplying vegetable crops with nutrients, particularly nitrogen, phosphorus and potassium, but also calcium, magnesium and sulphur.

8.2
When applied to soils, chicken manure breaks down quite rapidly by processes of microbial decay and leaves little residue. The majority of nutrients are mineralised within a week of application, and there is little further release after two weeks. Chicken manure does not by itself promote the accumulation of organic carbon in soil.

8.3
Driven by the perception that surface-banded chicken manure breeds flies, most growers now incorporate manure into soil a week before planting. Planting earlier after application promotes root burning due to high levels of ammonia in soil and this hinders crop establishment.

8.4
The current usage method is inefficient and counter-productive, for under normal irrigation regimes, most of the applied nitrogen and potassium is lost before roots can absorb these nutrients, and incorporation breeds more rather than less flies. The loss of mineral nutrients without plant uptake has potentially undesirable environmental consequences.

8.5
This study found that fly breeding potential of chicken manure use is related to application rate. Fly breeding was dramatically reduced when application rates are below 20 m^3 per hectare, and when manure is surface banded rather than incorporated.

8.6
Pre-treatment of manure with mineral acid to reduce pH and ammonia volatilisation further reduces fly breeding potential. Such pre-treatment means crops can be planted immediately after application, thus a greater proportion of applied nutrients can potentially be absorbed by plants, thereby making usage more efficient and environmentally friendly.

8.7
However fly breeding is highly seasonal, and the findings in this project needs to be studied in more detail and confirmed in areas and times when stable fly and house fly numbers are much higher than experienced during these trials.

8.8
This study found that the major contribution to increasing organic carbon in soils used for vegetable production is crop trash rather than chicken manure residue. The

healthier and more productive the crop, the greater the soil carbon accumulation, irrespective of fertiliser used.

8.9
Compost application was found to cause a more durable increase in soil organic carbon than chicken manure, but contains far less nutrient elements in readily available form.

8.10
“Synthetic” chicken manure made by blending compost with mineral nutrients produces a similar crop response to broiler litter, however the manufacturing cost means the price per tonne rises too high to be economically viable.

8.11
Broiler litter promotes very significant changes in soil microbial activity, including a slight rise in near surface soil temperature. This could be beneficial to plant growth during cool periods. The carbon dioxide evolved from decay of manure may also assist plant growth.

8.12
Potential human pathogenic bacteria were not found in chicken manure or on crops treated with chicken manure.

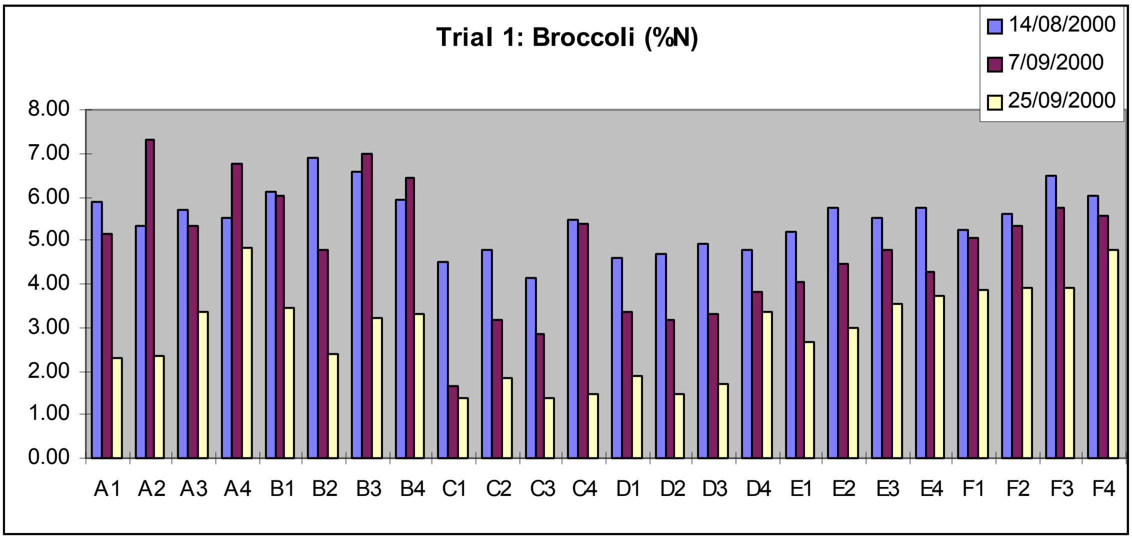
8.13
Cost effective and environmentally sustainable use of chicken manure to produce vegetable crops is a realistic possibility in Western Australia, but requires changes to current practice.

8.14
Broiler producers should be encouraged to use screened, dried compost as an alternative litter to sawdust, as this will promote better soil organic carbon accumulation for vegetable producers as well as provide improvements in chicken health.

8.15
Recovered broiler litter should be treated with phosphoric acid and dried to reduce pH and facilitate storage and used without breeding flies.

8.16
Vegetable growers should apply chicken manures at rates of 15 m^3 per hectare or less, with repeat application every two weeks.

8.17
The optimal usage which promotes high yield and quality vegetables and minimises environmental harm should involve incorporation of treated manure at 15 m^3 per hectare immediately before planting, then surface banded side dressing at 10 m^3 per hectare every two weeks until harvest.


Trial 1: Broccoli (%N)
14/08/2000
7/09/2000
25/09/2000
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
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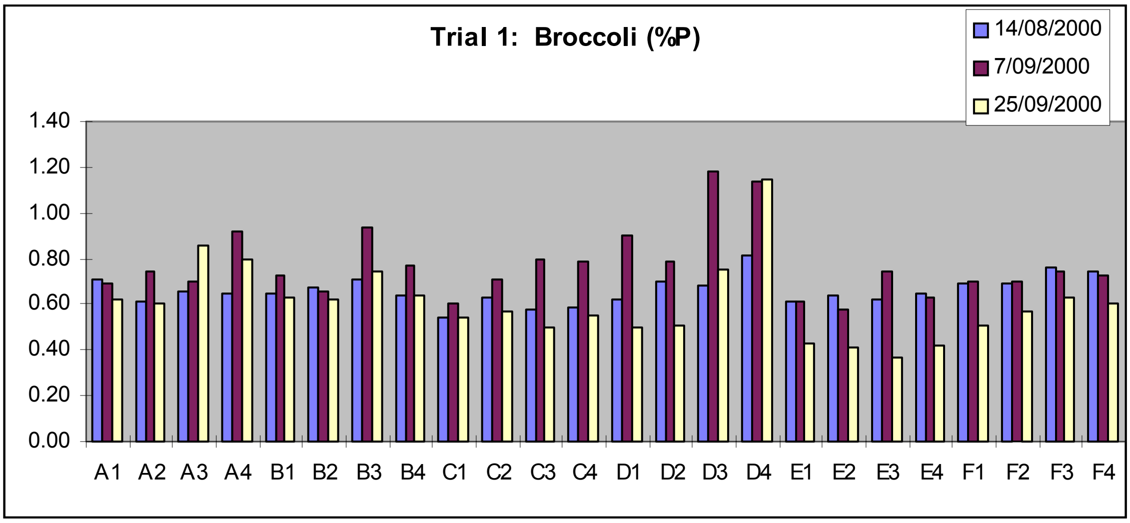
Trial 1: Broccoli (%P)
14/08/2000
7/09/2000
25/09/2000
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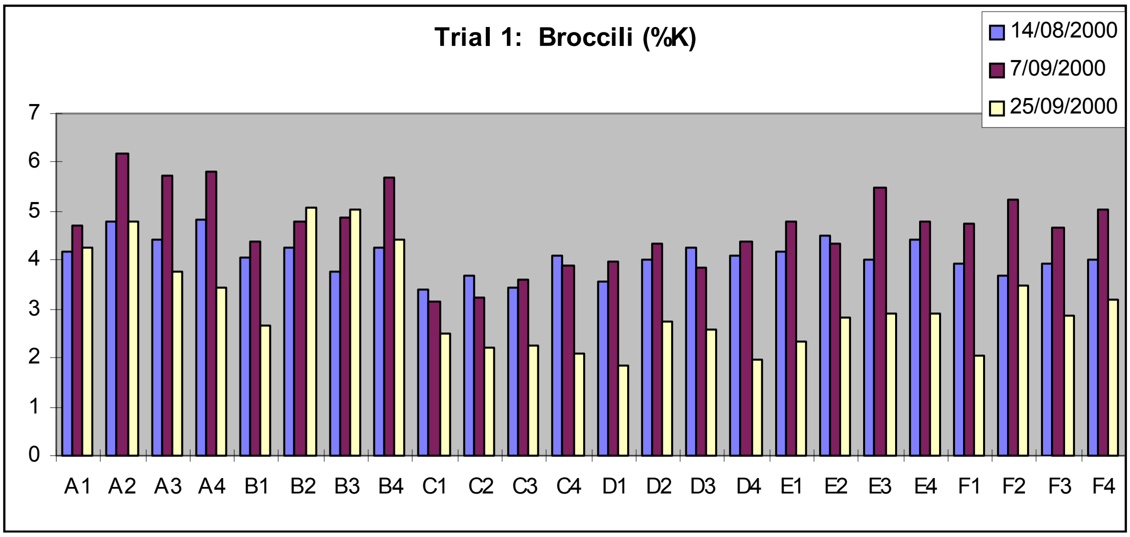
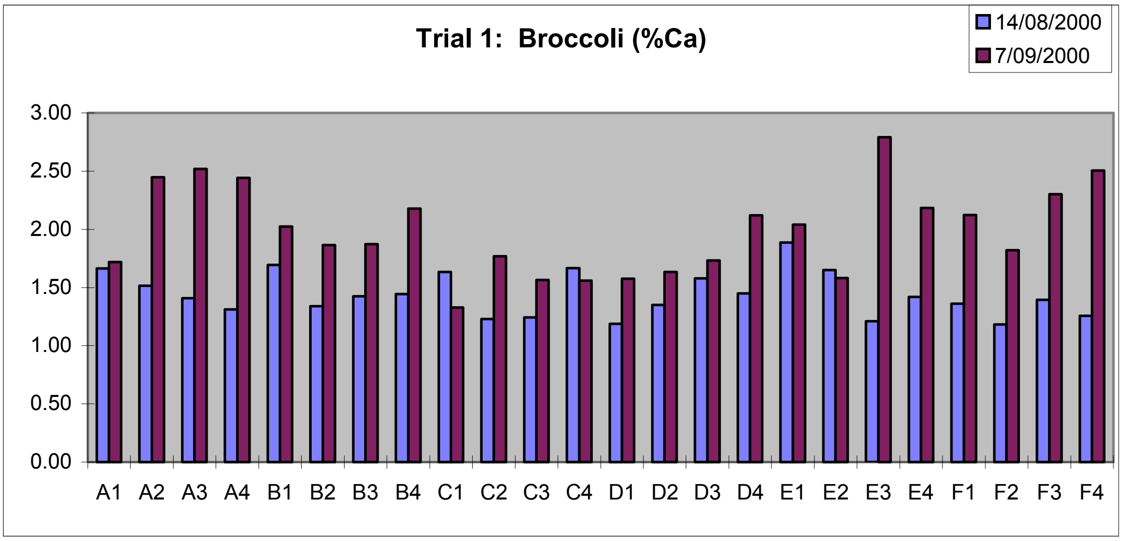
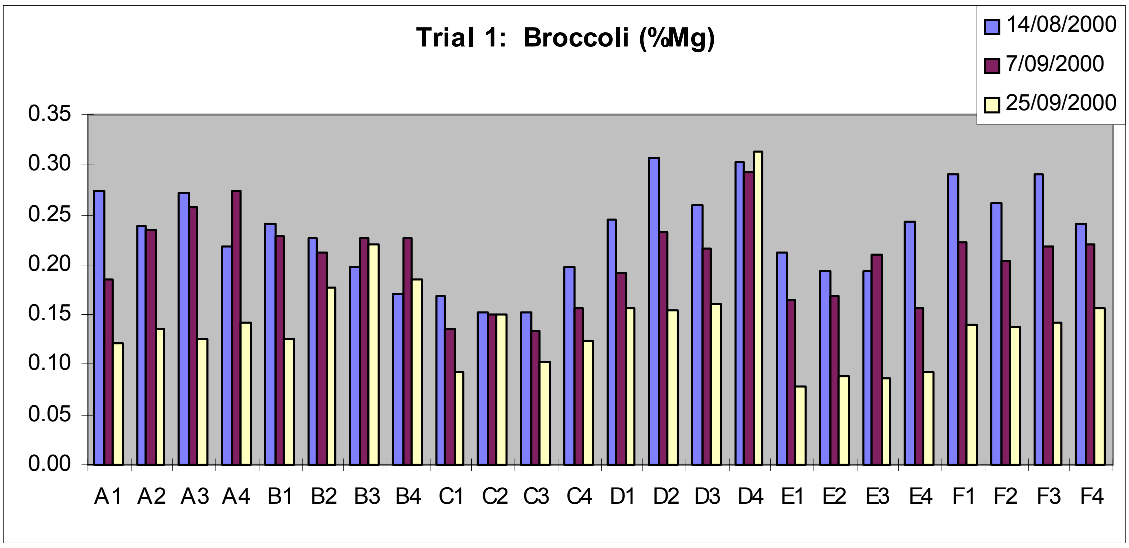
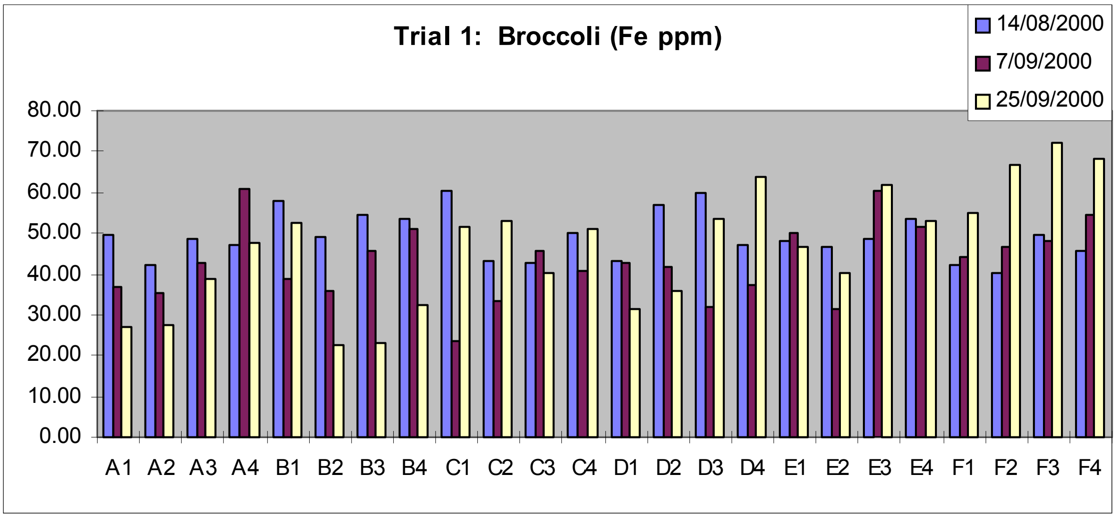
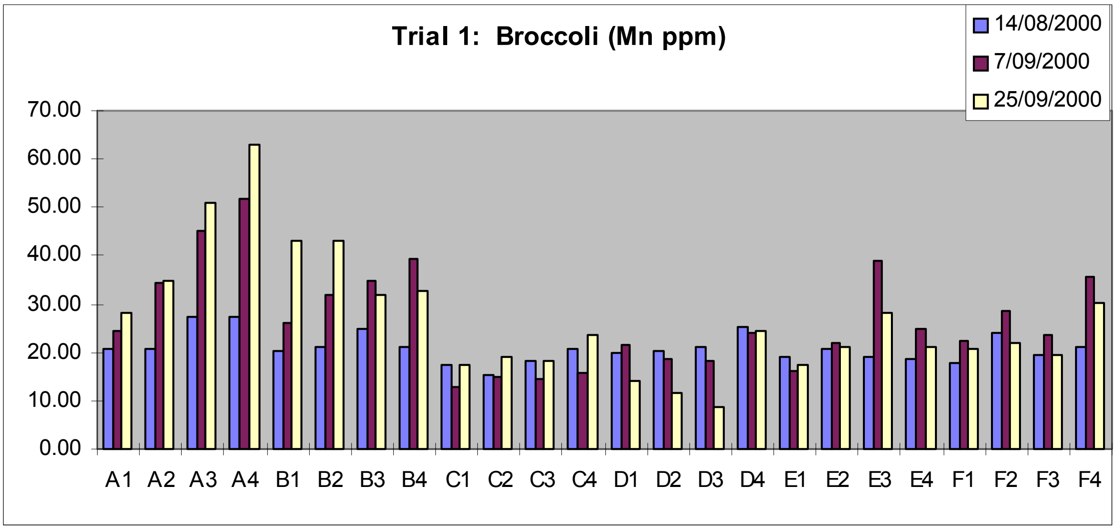
1.20
1.00
0.80
0.60
0.40
0.20
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4

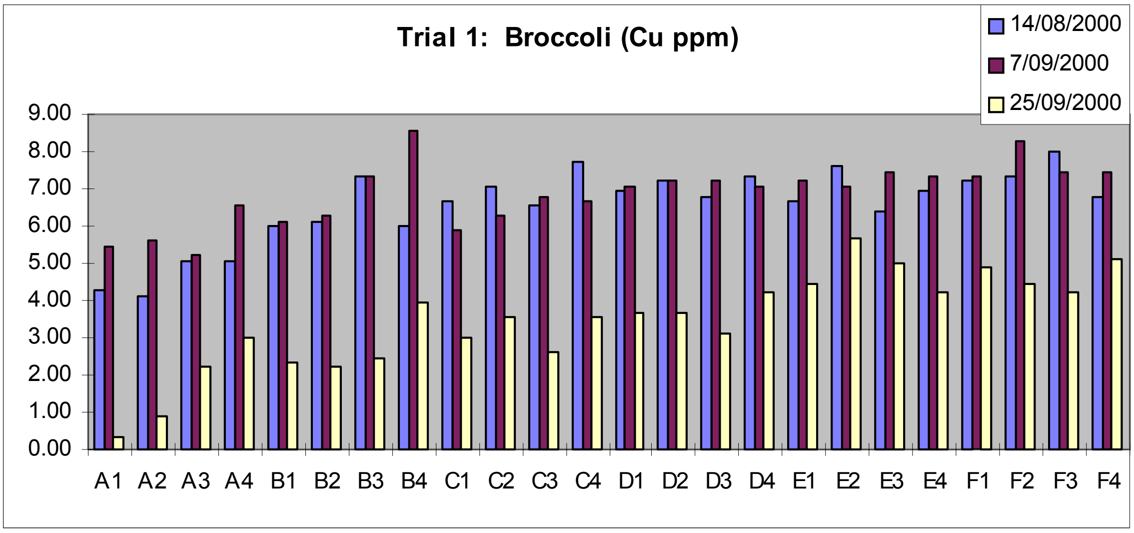

Trial 1: Broccili (%K)
14/08/2000
7/09/2000
25/09/2000
7
6
5
4
3
2
1
0
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4

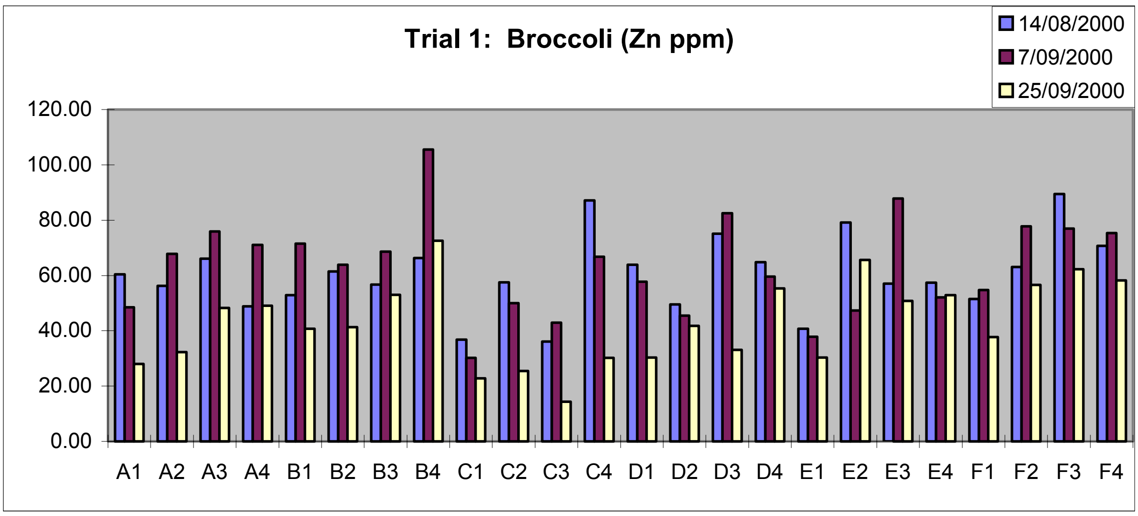

Trial 1: Broccoli (%Ca)
14/08/2000
7/09/2000
3.00
2.50
2.00
1.50
1.00
0.50
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4


Trial 1: Broccoli (%Mg)
14/08/2000
7/09/2000
25/09/2000
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4

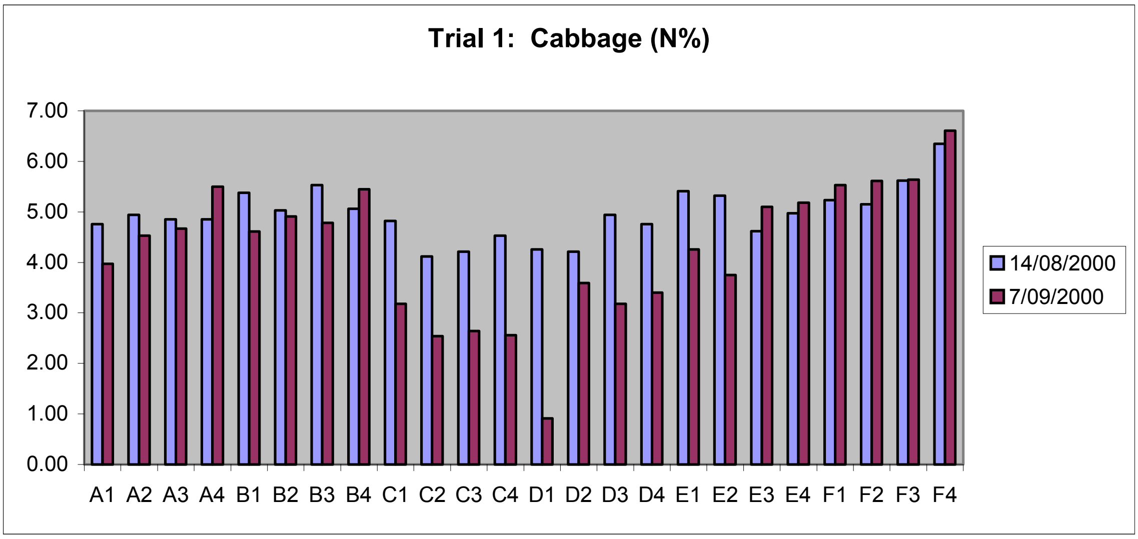

Trial 1: Broccoli (Fe ppm)
14/08/2000
7/09/2000
25/09/2000
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4

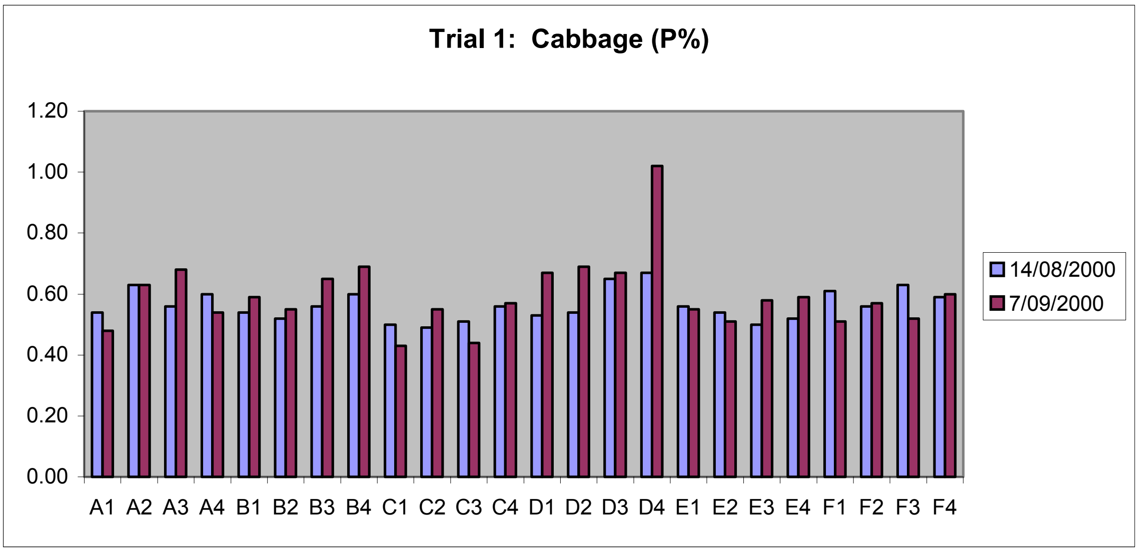

Trial 1: Broccoli (Mn ppm)
14/08/2000
7/09/2000
25/09/2000
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4

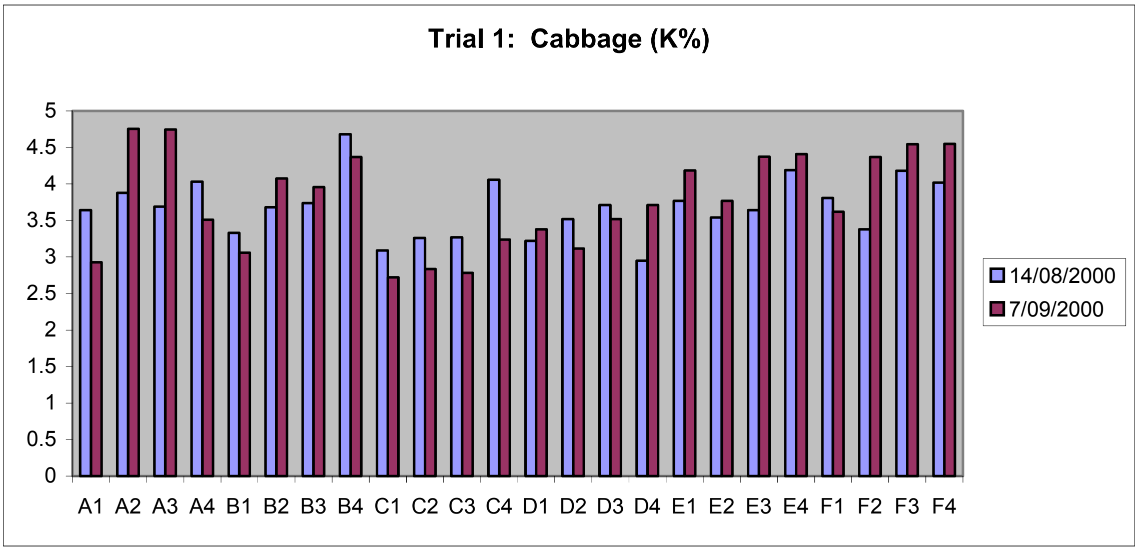

Trial 1: Broccoli (Cu ppm)
14/08/2000
7/09/2000
25/09/2000
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4

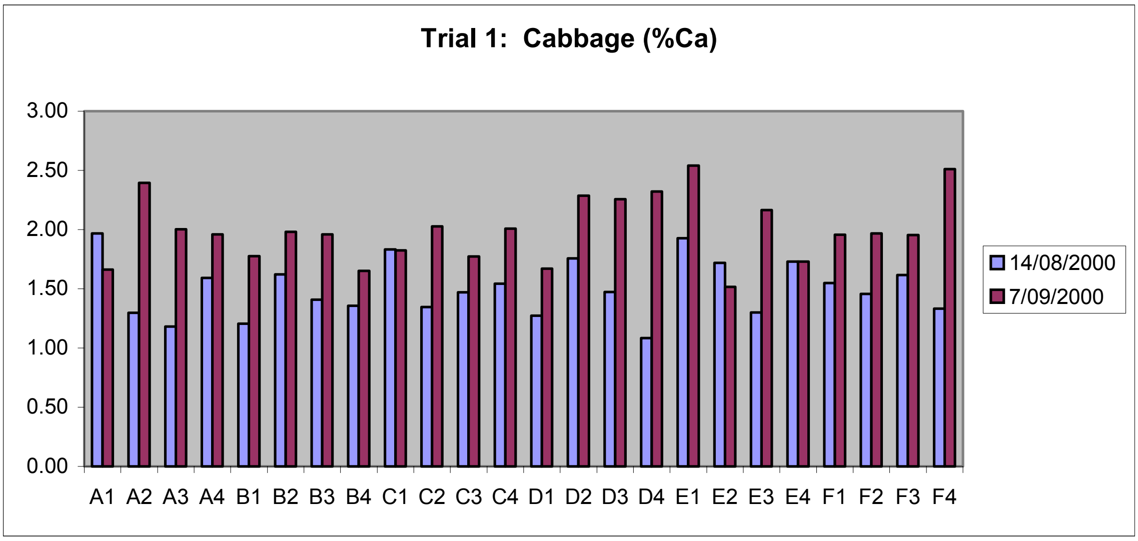

Trial 1: Broccoli (Zn ppm)
14/08/2000
7/09/2000
25/09/2000
120.00
100.00
80.00
60.00
40.00
20.00
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4

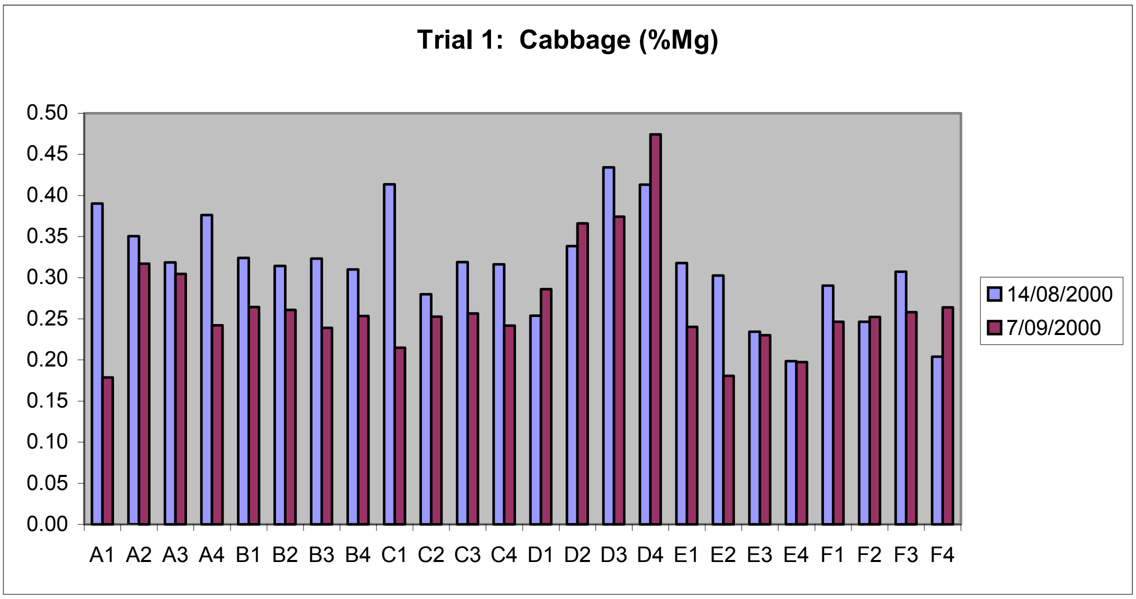
Appendix - B
Trial 1: Cabbage Leaf Tissue and Soil Analysis

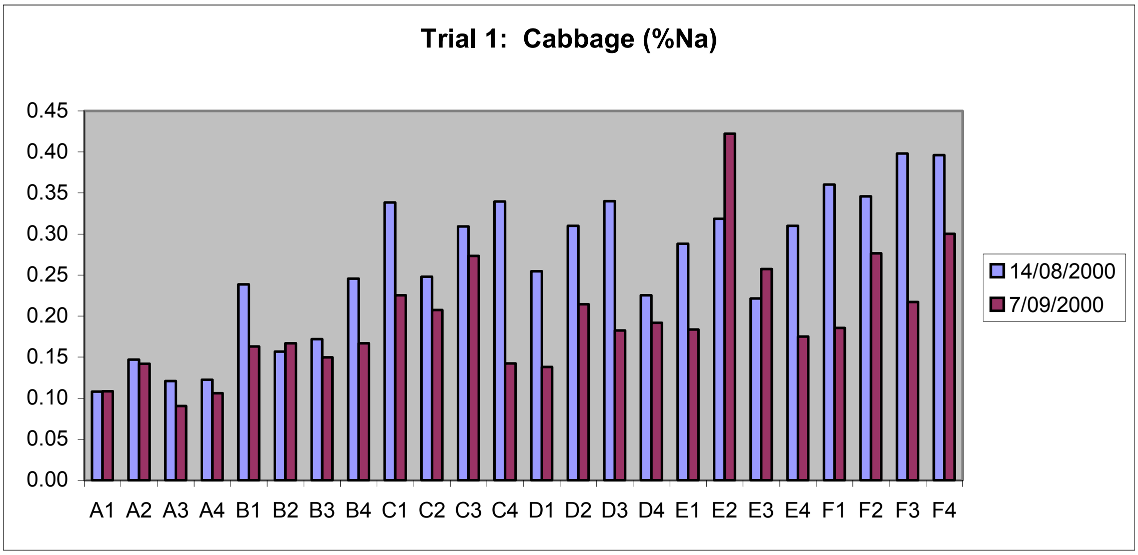


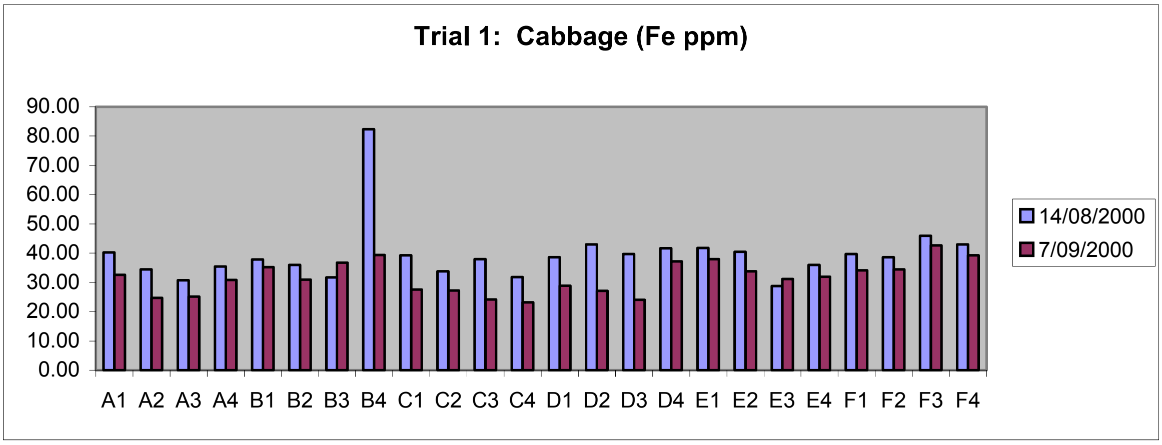


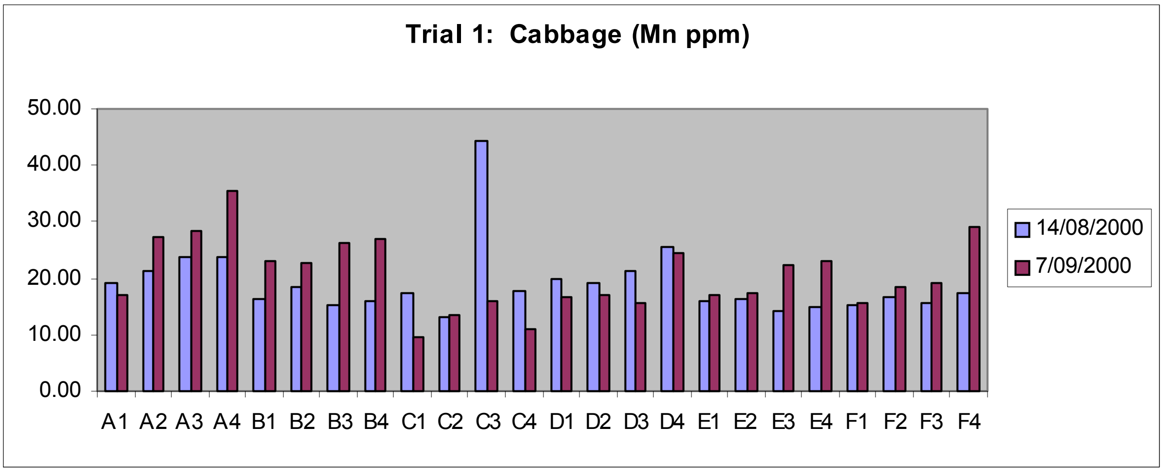

Trial 1: Cabbage (K%)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
14/08/2000
7/09/2000

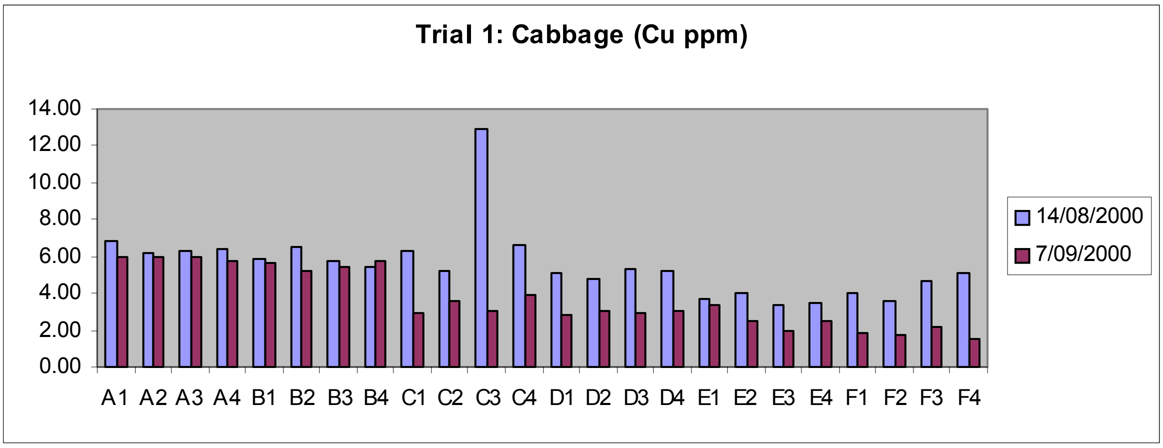

Trial 1: Cabbage (%Ca)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
14/08/2000
7/09/2000

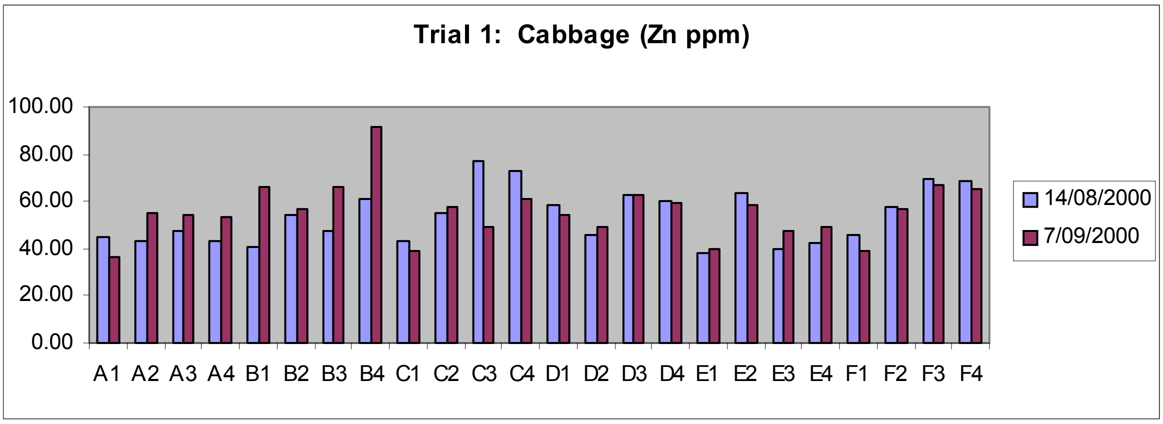

Trial 1: Cabbage (%Mg)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
14/08/2000
7/09/2000


Trial 1: Cabbage (%Na)
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
14/08/2000
7/09/2000


Trial 1: Cabbage (Fe ppm)
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
14/08/2000
7/09/2000


Trial 1: Cabbage (Mn ppm)
50.00
40.00
30.00
20.00
10.00
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
14/08/2000
7/09/2000





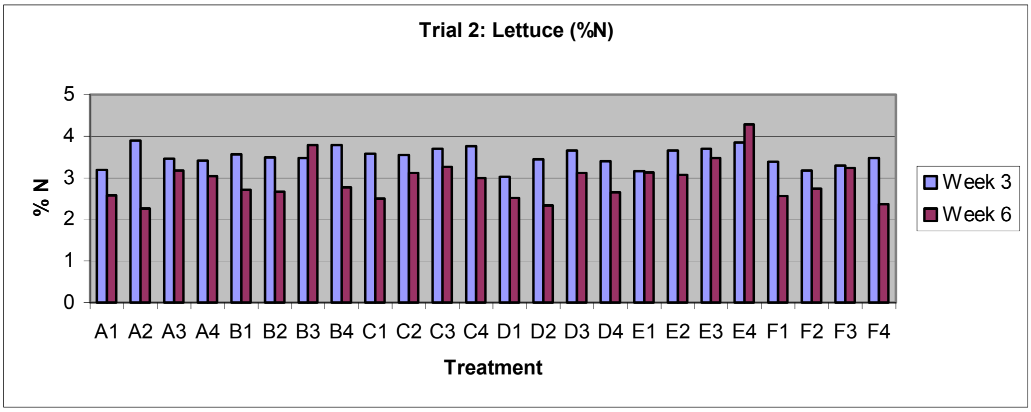
Trial 1 Soil After Harvest

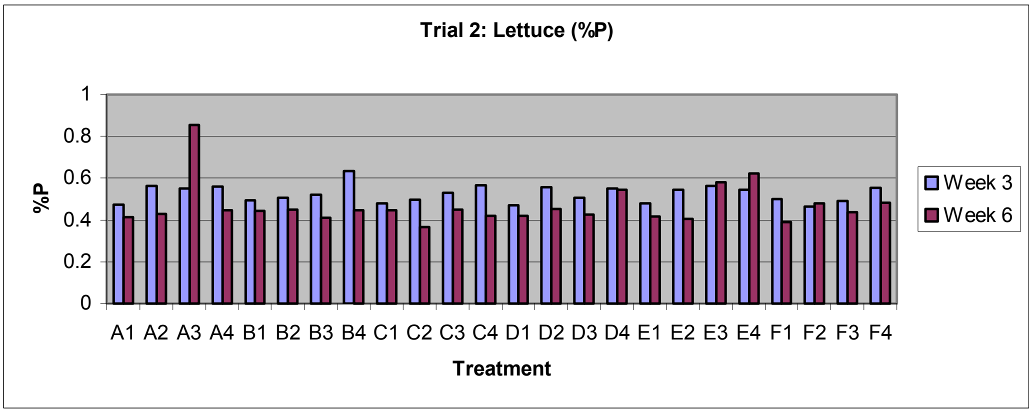
	K (meq)	Na (meq	Mg (meq)	Ca (meq	NH4-N (p	PO4-P(p	K (ppm)	pH[CaCl2	pH[H2O]	Ec(mScr	OC (%)
A1	**0.062**	**0.102**	**0.463**	**3.243**	**10.360**	**8.643**	**40.883**	**5.947**	**6.557**	**0.051**	**1.010**
A2	**0.051**	**0.134**	**0.388**	**2.327**	**9.093**	**7.957**	**45.017**	**6.053**	**6.503**	**0.038**	**1.093**
A3	**0.068**	**0.106**	**0.453**	**2.790**	**14.537**	**10.893**	**60.550**	**6.093**	**6.733**	**0.055**	**0.937**
A4	**0.079**	**0.129**	**0.451**	**2.923**	**16.917**	**10.460**	**66.147**	**6.000**	**6.747**	**0.050**	**1.143**
B1	**0.031**	**0.126**	**0.380**	**2.879**	**10.967**	**5.103**	**19.770**	**5.830**	**6.380**	**0.032**	**0.967**
B2	**0.028**	**0.091**	**0.347**	**2.830**	**6.803**	**6.917**	**21.637**	**6.103**	**6.613**	**0.036**	**1.080**
B3	**0.071**	**0.137**	**0.403**	**2.363**	**15.280**	**8.387**	**51.653**	**6.173**	**6.750**	**0.057**	**0.960**
B4	**0.045**	**0.112**	**0.334**	**2.750**	**9.773**	**8.037**	**41.883**	**6.133**	**6.650**	**0.057**	**1.177**
C1	**0.051**	**0.105**	**0.314**	**2.454**	**5.163**	**5.877**	**22.103**	**5.830**	**6.393**	**0.037**	**0.813**
C2	**0.034**	**0.097**	**0.266**	**2.103**	**6.157**	**7.347**	**31.260**	**6.087**	**6.430**	**0.040**	**0.807**
C3	**0.059**	**0.148**	**0.382**	**3.247**	**6.927**	**9.250**	**46.903**	**5.987**	**6.690**	**0.052**	**0.933**
C4	**0.067**	**0.116**	**0.358**	**3.543**	**7.017**	**11.583**	**45.297**	**6.043**	**6.520**	**0.051**	**0.893**
D1	**0.052**	**0.112**	**0.414**	**2.533**	**7.267**	**7.697**	**38.297**	**5.977**	**6.510**	**0.039**	**0.980**
D2	**0.067**	**0.078**	**0.355**	**2.596**	**12.740**	**8.383**	**48.363**	**5.977**	**6.527**	**0.044**	**0.910**
D3	**0.081**	**0.169**	**0.475**	**3.130**	**15.800**	**9.510**	**53.043**	**6.187**	**6.840**	**0.057**	**1.097**
D4	**0.064**	**0.042**	**0.403**	**2.180**	**14.920**	**10.287**	**65.377**	**5.997**	**6.640**	**0.043**	**0.837**
E1	**0.033**	**0.053**	**0.324**	**3.030**	**5.350**	**7.867**	**29.473**	**6.180**	**6.650**	**0.041**	**1.087**
E2	**0.033**	**0.088**	**0.307**	**2.660**	**5.847**	**7.867**	**29.527**	**6.003**	**6.487**	**0.037**	**0.997**
E3	**0.048**	**0.143**	**0.371**	**3.190**	**8.847**	**9.250**	**43.257**	**5.883**	**6.443**	**0.040**	**1.283**
E4	**0.054**	**0.252**	**0.341**	**2.880**	**5.657**	**6.917**	**33.883**	**5.987**	**6.430**	**0.041**	**1.030**
F1	**0.049**	**0.154**	**0.377**	**2.907**	**10.823**	**7.347**	**34.787**	**5.873**	**6.447**	**0.039**	**1.310**
F2	**0.047**	**0.105**	**0.373**	**2.640**	**6.927**	**7.780**	**37.437**	**5.817**	**6.303**	**0.039**	**0.887**
F3	**0.052**	**0.092**	**0.315**	**3.193**	**7.730**	**11.933**	**48.233**	**6.017**	**6.503**	**0.046**	**0.957**
F4	**0.047**	**0.147**	**0.309**	**2.867**	**5.753**	**10.893**	**34.973**	**6.140**	**6.590**	**0.034**	**0.817**

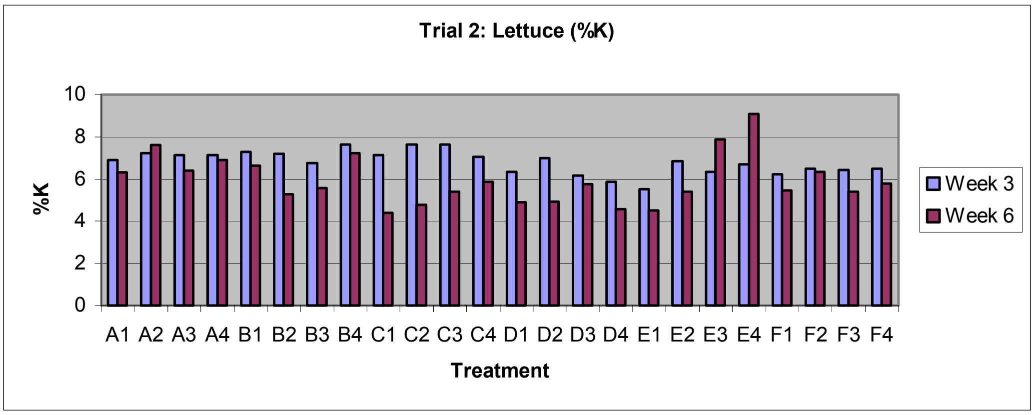
Appendix - C Trial 2: Lettuce Leaf Tissue Analysis

TREATMENTS
A: Manure incorporated pre-plant. Top dressing with NK every 7 days.
B: Manure incorporated pre-plant. Surface band Manure at 14 days
C: Manure incorporated pre-plant. Surface band Manure at 14 days, TD every 7 d.
D: Mineral PP. Top dressing NK every 7 days
E: Mineral PP. Surface band Manure at 14 days, TD every 7 d.
F: Mineral PP, Surface band Manure at 14 days, Surface band Manure at 42 days

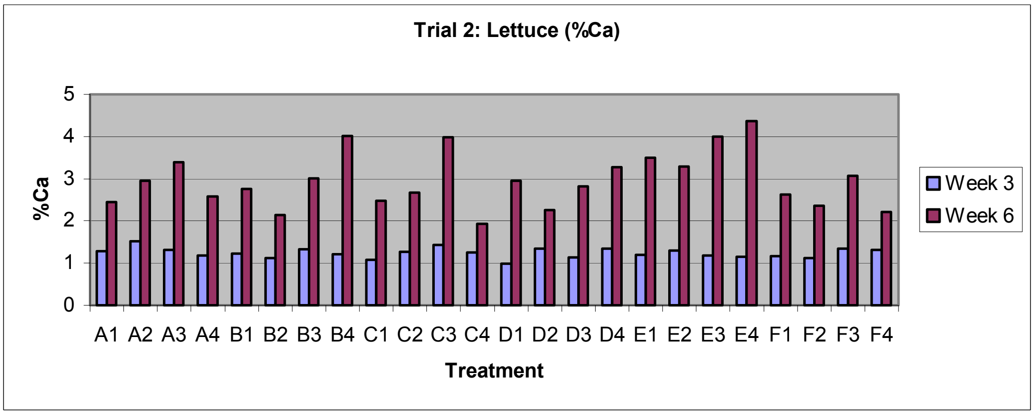
RATES
1: 50% of AgWA recommendations (from AgBul 4282, Feb94)*
2: 100% of AgWA recommendations (from AgBul 4282, Feb94)*
3: 150% of AgWA recommendations (from AgBul 4282, Feb94)*
4: 200% of AgWA recommendations (from AgBul 4282, Feb94)*
Note * modified upward from results of HRDC lettuce trials (D.Phillips) in 1998/99. The modification being changing Pot sulphate (AgBul 4282) to Pot Nitrate to supply extra N



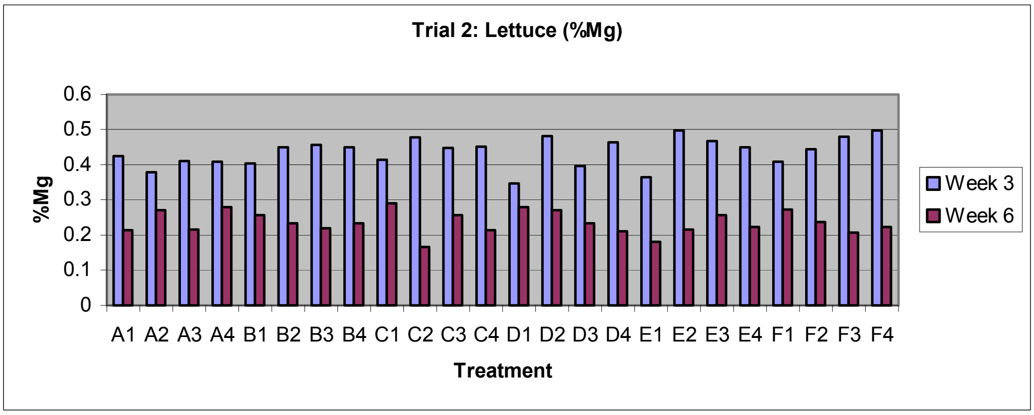




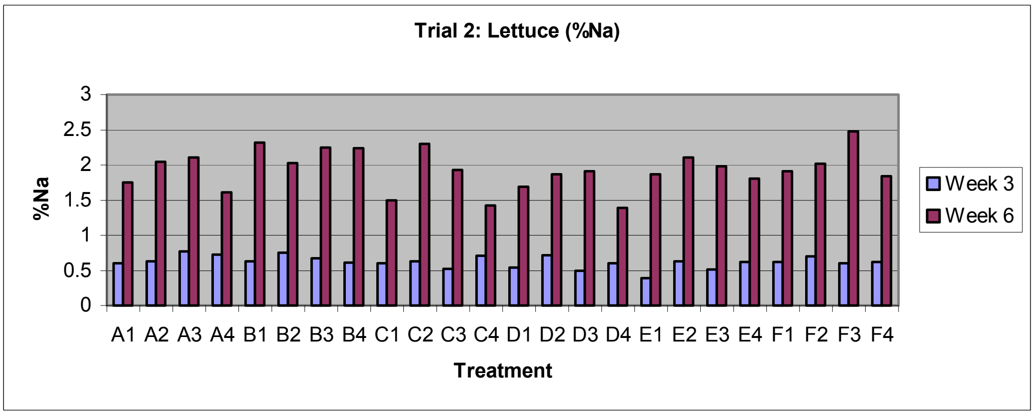
Trial 2: Lettuce (%K)
10
8
6
4
2
0
%K
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Treatment
Week 3
Week 6

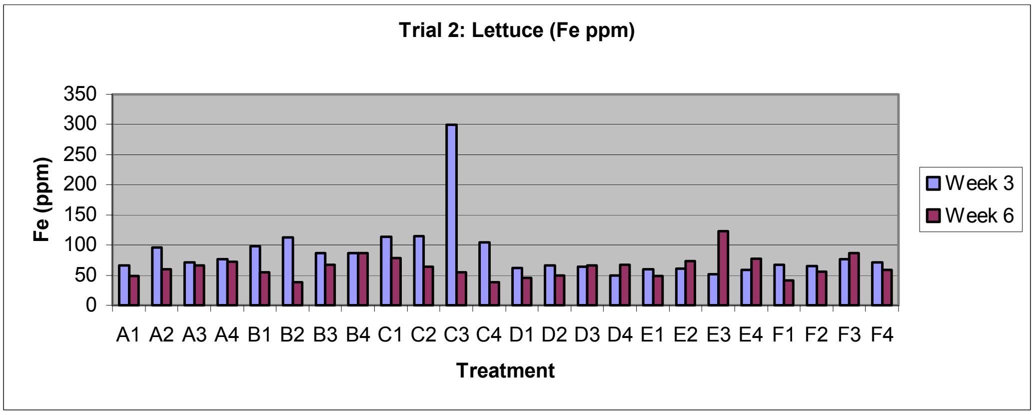


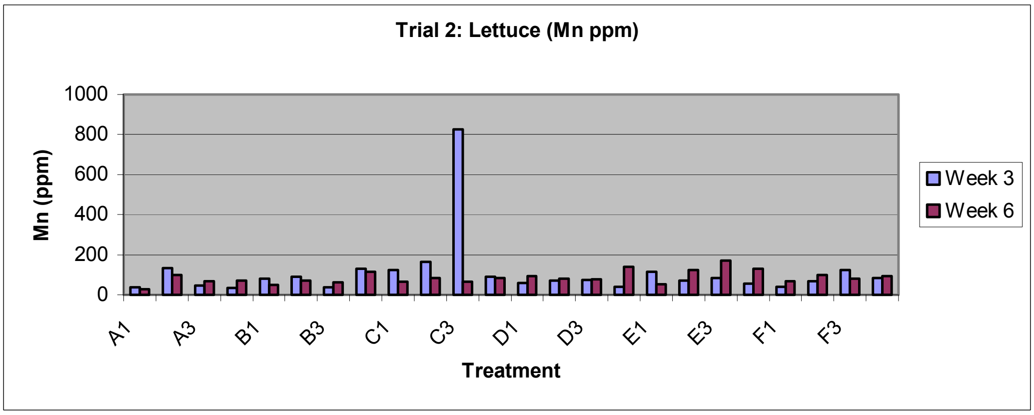
Trial 2: Lettuce (%Ca)
5
4
3
2
1
0
%Ca
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Treatment
Week 3
Week 6

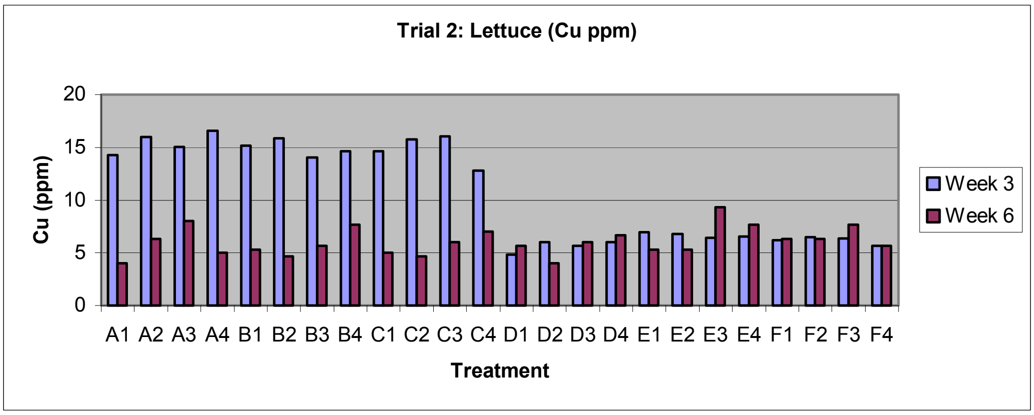


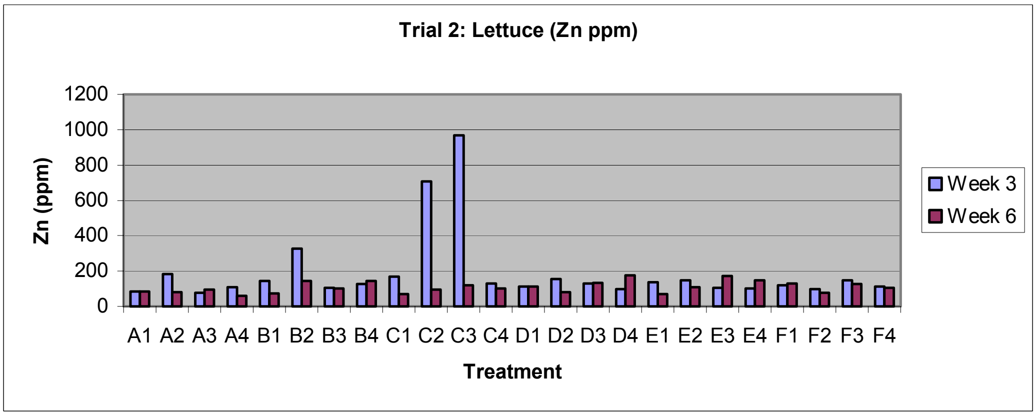
Trial 2: Lettuce (%Mg)
0.6
0.5
0.4
0.3
0.2
0.1
0
%Mg
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Treatment
Week 3
Week 6


Trial 2: Lettuce (%Na)
%Na
3
2.5
2
1.5
1
0.5
0
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Treatment
Week 3
Week 6


Trial 2: Lettuce (Fe ppm)
Fe (ppm)
350
300
250
200
150
100
50
0
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Treatment
Week 3
Week 6


Trial 2: Lettuce (Mn ppm)
Mn (ppm)
1000
800
600
400
200
0
A1 A3 B1 B3 C1 C3 D1 D3 E1 E3 F1 F3
Treatment
Week 3
Week 6

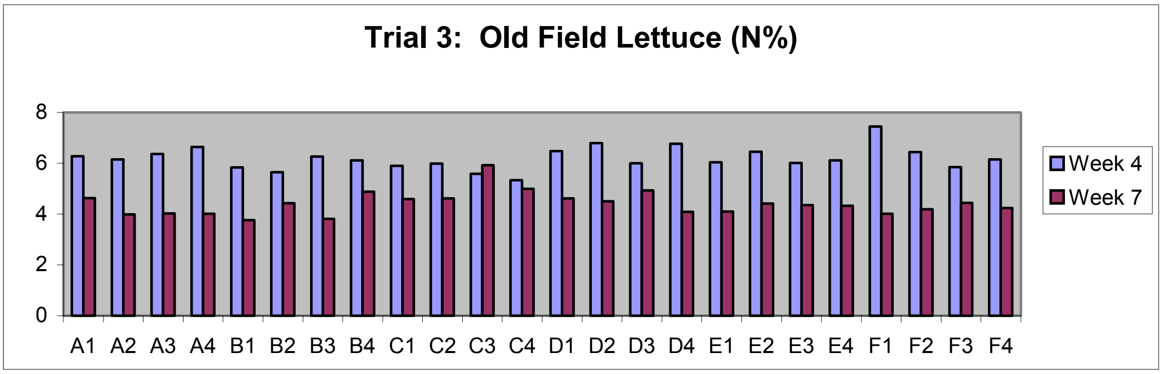

Trial 2: Lettuce (Cu ppm)
Cu (ppm)
0
5
10
15
20
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Treatment
Week 3
Week 6

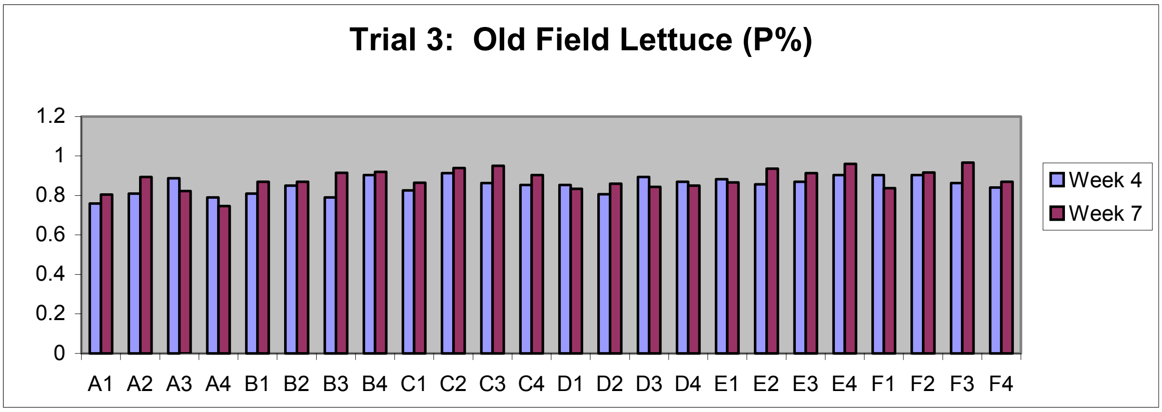

Trial 2: Lettuce (Zn ppm)
Zn (ppm)
0
200
400
600
800
1000
1200
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Treatment
Week 3
Week 6

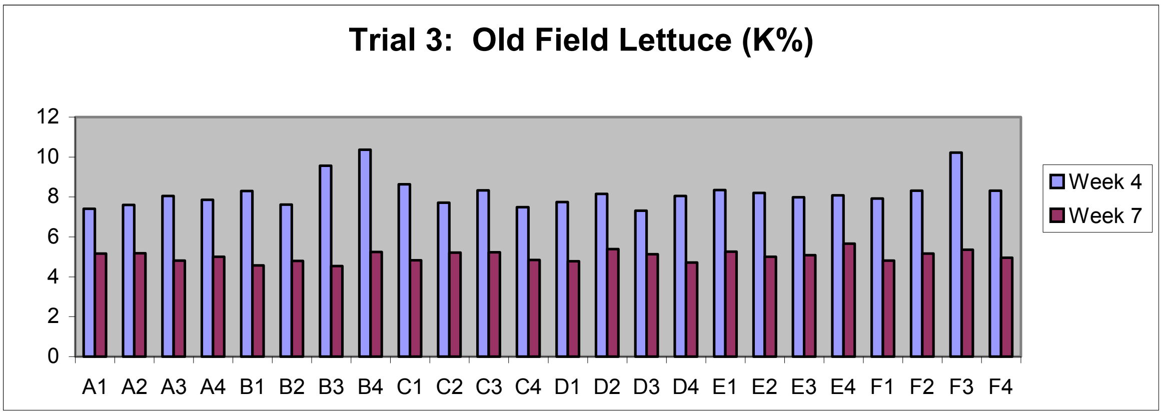
Appendix - D
Trial 3: Lettuce Leaf Tissue and Soil Analysis (Old Field)

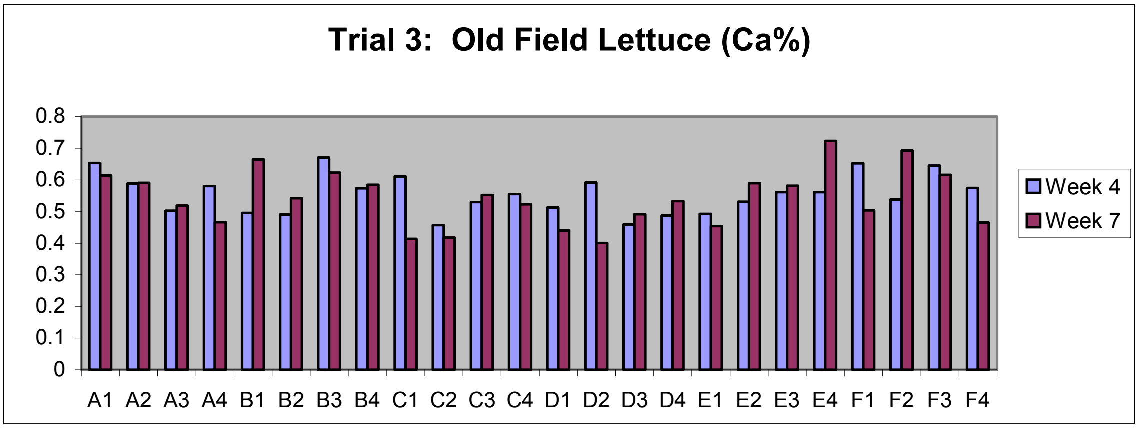
Treatments
A: Manure incorporated pre-plant. Top dress with NK every 7 days.
B: Manure incorporated pre-plant. Surface band Manure at 14 days.
C: Manure incorporated pre-plant. Surface band manure at 14 days, TD every 7 days.
D: Mineral PP. Top dressing NK every 7 days.
E: Mineral PP. Surface band manure at 14 days, TD every 7 days.
F: Mineral PP. Surface band manure at 14 days, surface band manure at 42 days.

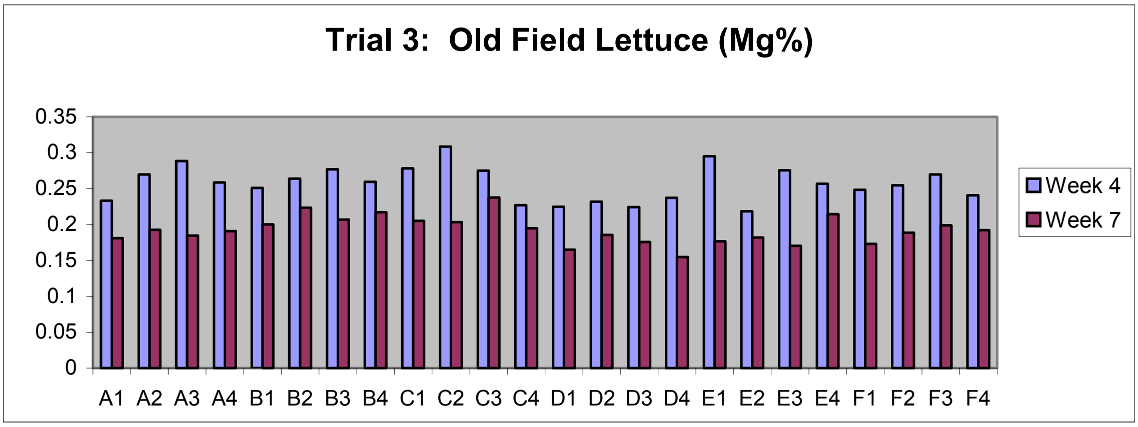
Rates
Rate 1: 60% of AgWA recommendations (from AgBulletin 4282, amended Oct 96)
Rate 2: 100% of AgWA recommendations (from AgBulletin 4282, amended Oct 96)
Rate 3: 125% of AgWA recommendations (from AgBulletin 4282, amended Oct 96)
Rate 4: 150% of AgWA recommendations (from AgBulletin 4282, amended Oct 96)

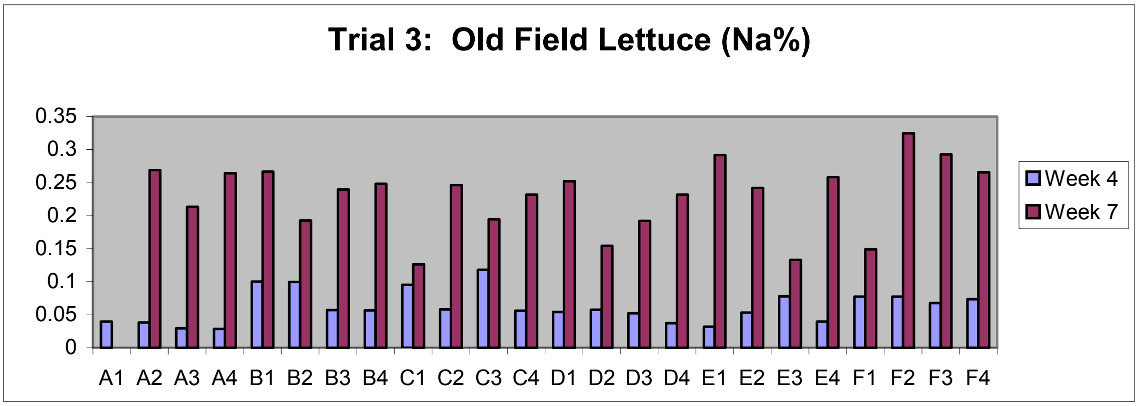


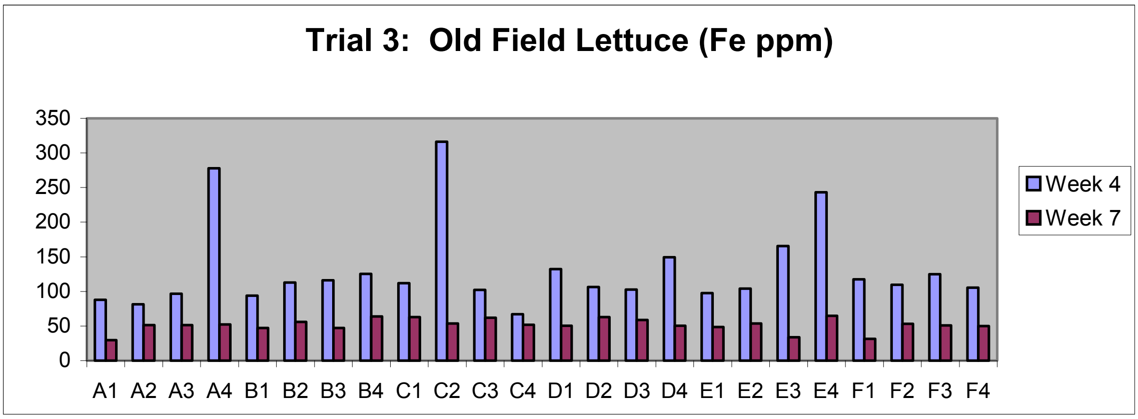



Trial 3: Old Field Lettuce (K%)
0
2
4
6
8
10
12
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 7

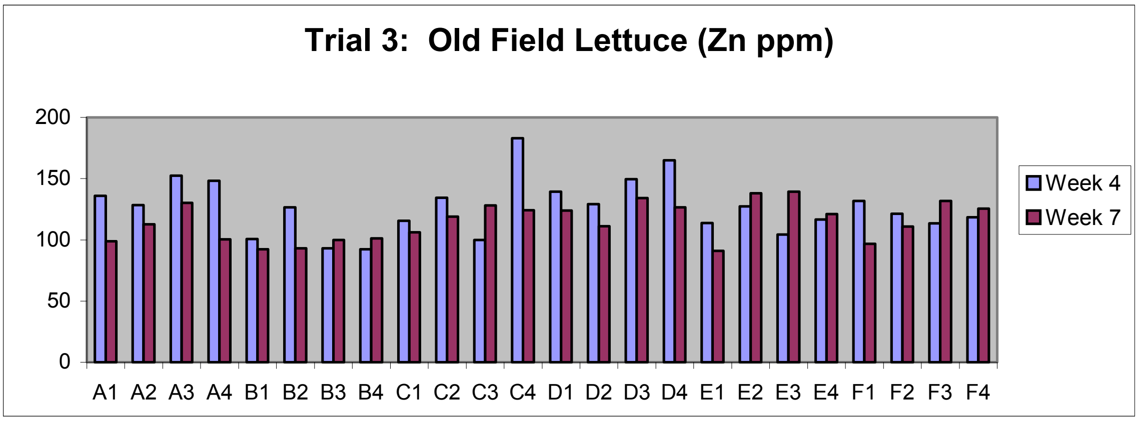

Trial 3: Old Field Lettuce (Ca%)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 7


Trial 3: Old Field Lettuce (Mg%)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 7

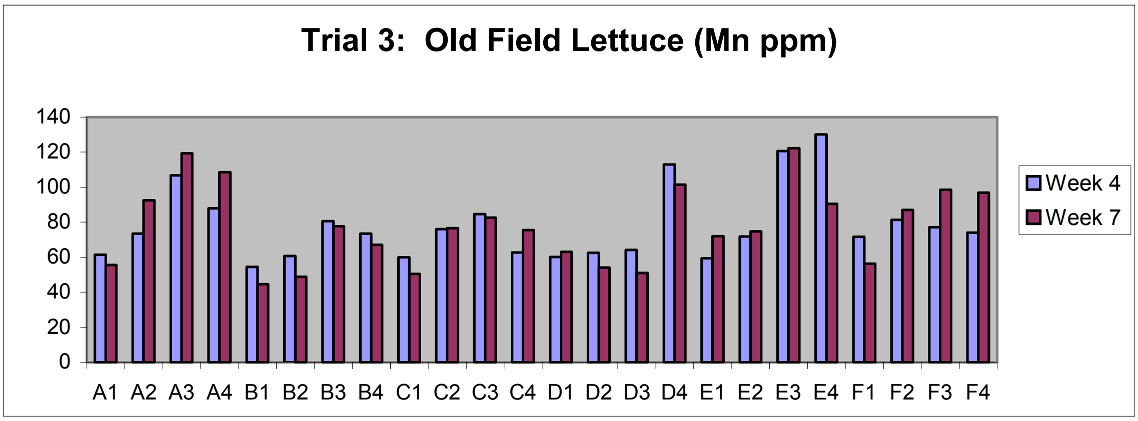

Trial 3: Old Field Lettuce (Na%)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 7



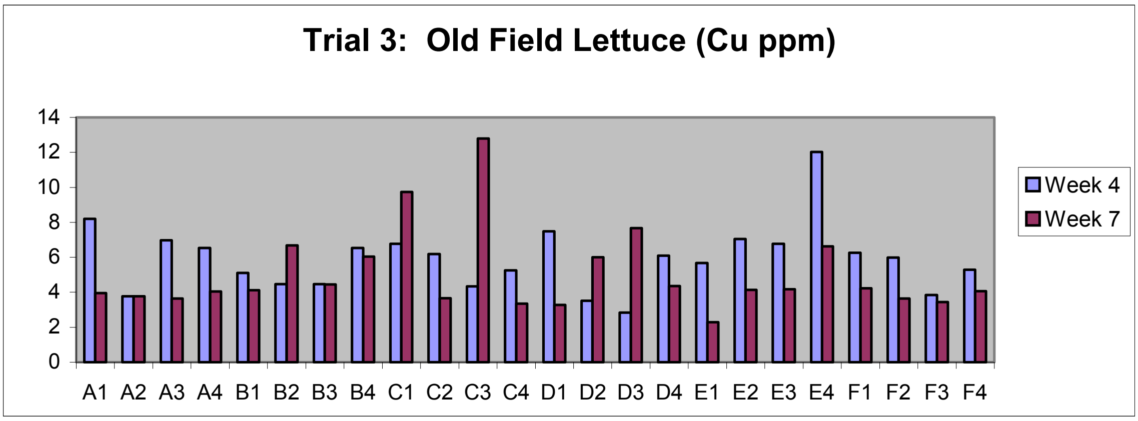
Trial 3: Old Field Lettuce (Fe ppm)
350
300
250
200
150
100
50
0
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 7

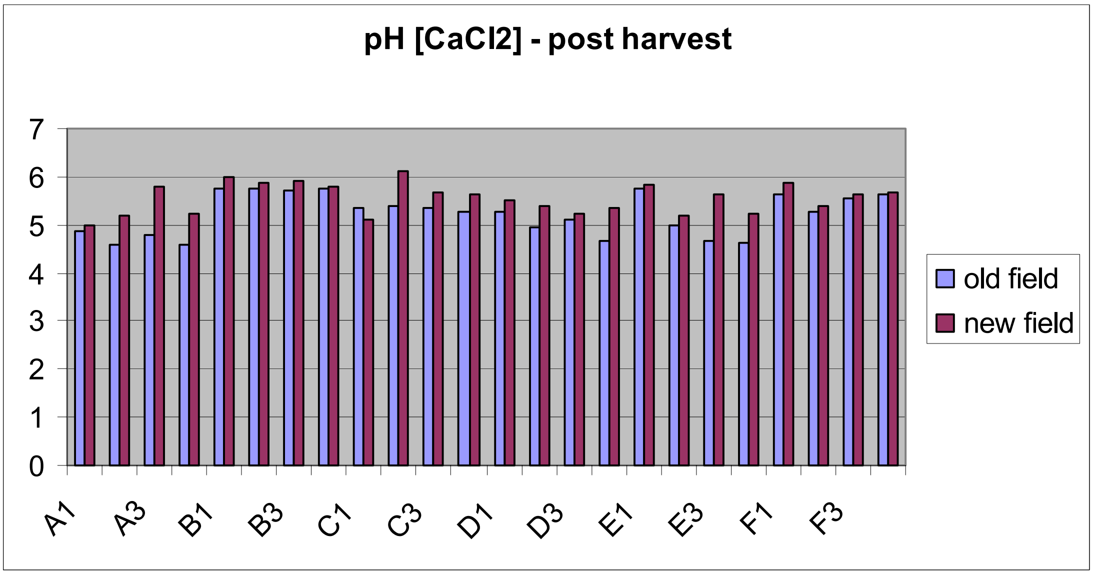


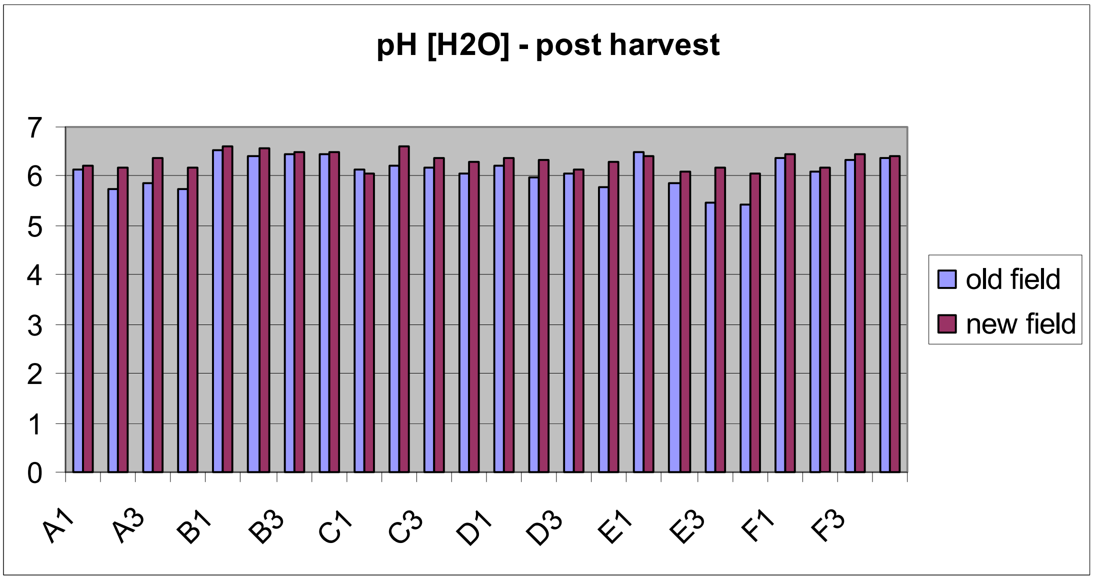
Trial 3: Old Field Lettuce (Zn ppm)
200
150
100
50
0
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 7

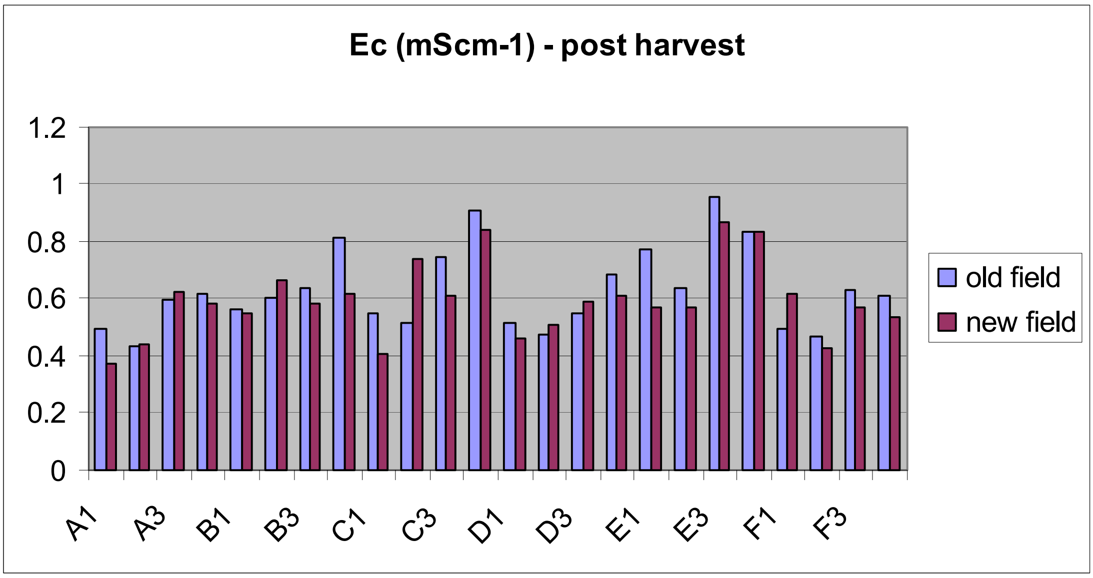


Trial 3: Old Field Lettuce (Mn ppm)
140
120
100
80
60
40
20
0
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 7


Trial 3: Old Field Lettuce (Cu ppm)
0
2
4
6
8
10
12
14
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 7


pH [CaCl2] - post harvest
0
1
2
3
4
5
6
7
A1 A3 B1 B3 C1 C3 D1 D3 E1 E3 F1 F3
old field
new field

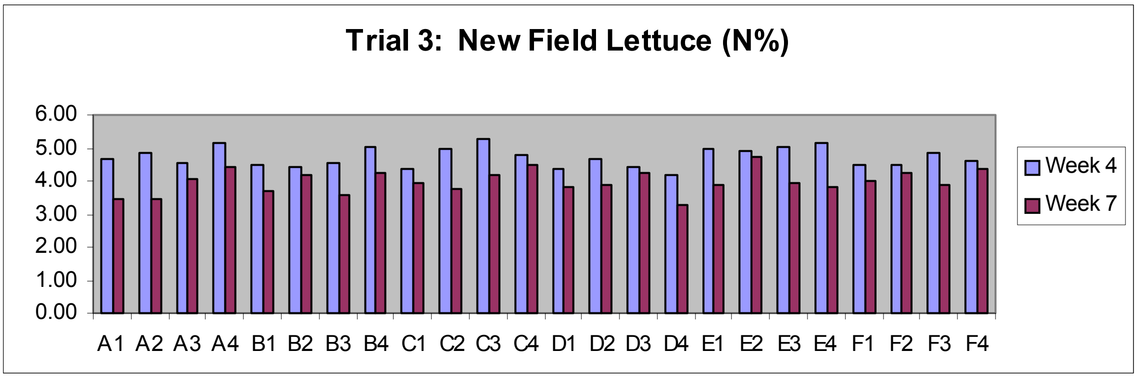

pH [H2O] - post harvest
0
1
2
3
4
5
6
7
A1 A3 B1 B3 C1 C3 D1 D3 E1 E3 F1 F3
old field
new field

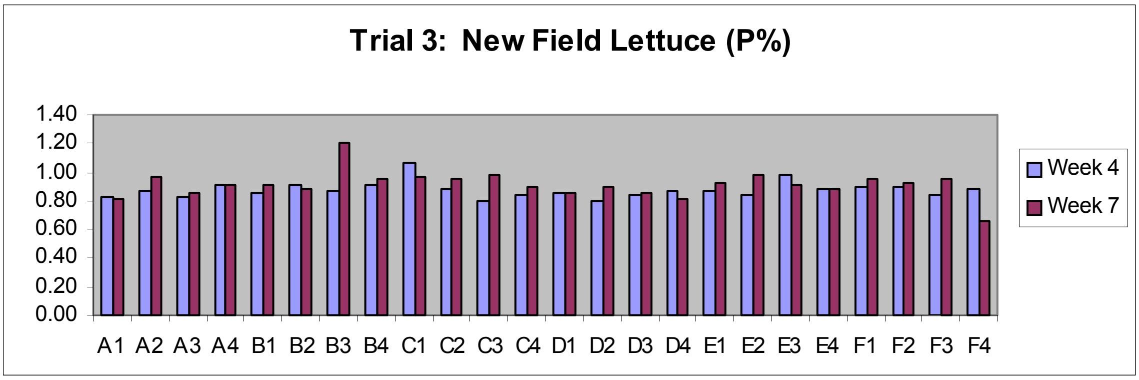

Ec (mScm-1) - post harvest
1.2
1
0.8
0.6
0.4
0.2
0
A1
A3
B1
B3
C1
C3
D1
D3
E1
E3
F1
F3
old field
new field

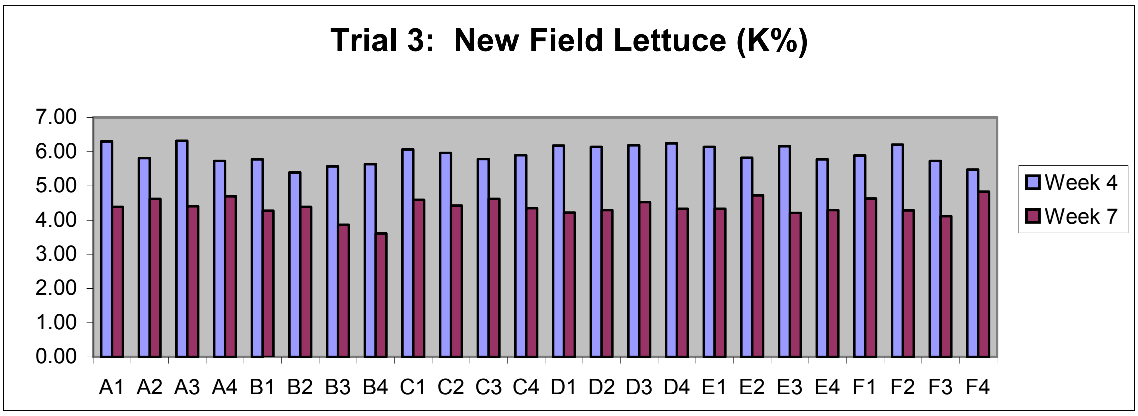
Appendix - E **Trial 3: Lettuce Leaf Tissue Analysis (New Field)**

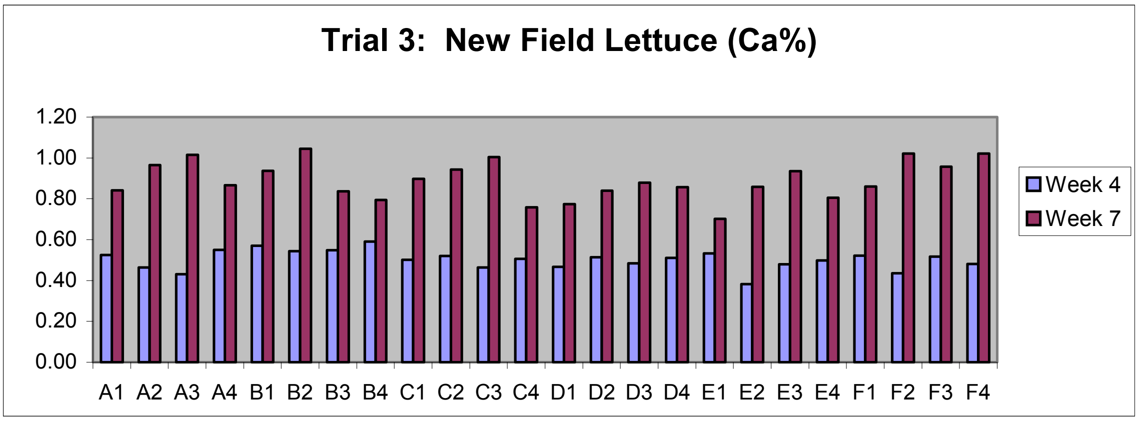
Treatments
A: Manure incorporated pre-plant. Top dress with NK every 7 days.
B: Manure incorporated pre-plant. Surface band Manure at 14 days.
C: Manure incorporated pre-plant. Surface band manure at 14 days, TD every 7 days.
D: Mineral PP. Top dressing NK every 7 days.
E: Mineral PP. Surface band manure at 14 days, TD every 7 days.
F: Mineral PP. Surface band manure at 14 days, surface band manure at 42 days.

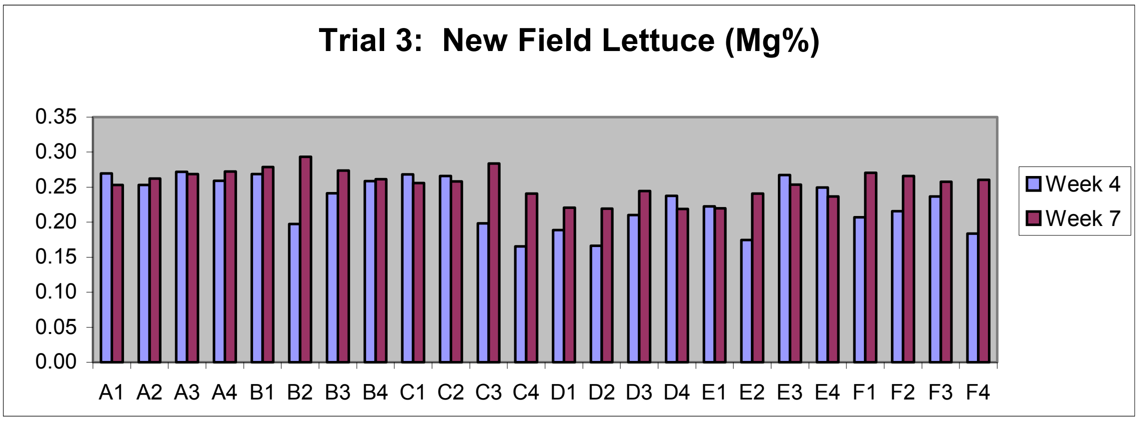
Rates
Rate 1: 60% of AgWA recommendations (from AgBulletin 4282, amended Oct 96)
Rate 2: 100% of AgWA recommendations (from AgBulletin 4282, amended Oct 96)
Rate 3: 125% of AgWA recommendations (from AgBulletin 4282, amended Oct 96)
Rate 4: 150% of AgWA recommendations (from AgBulletin 4282, amended Oct 96)

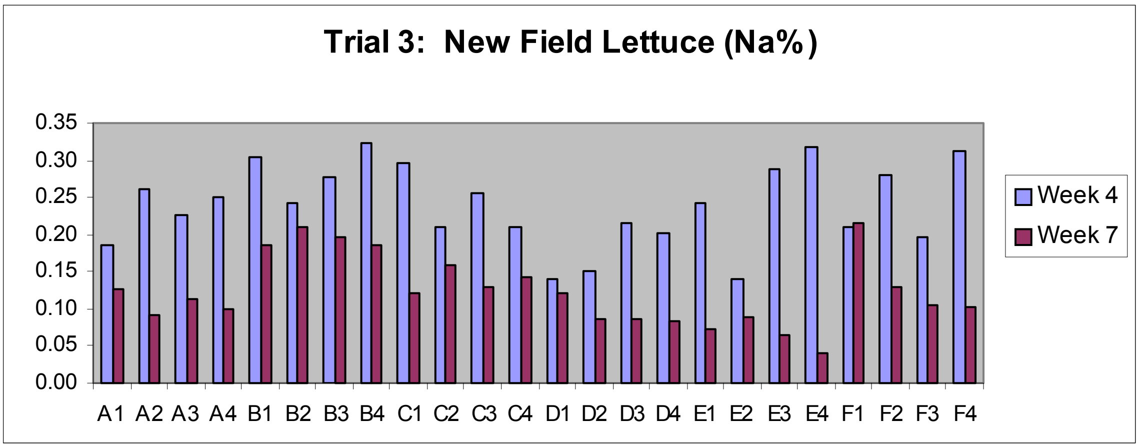


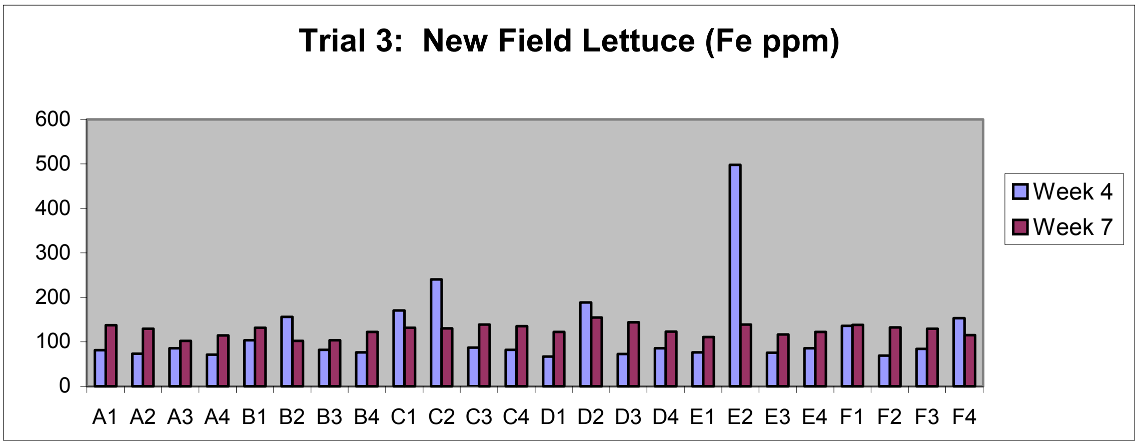


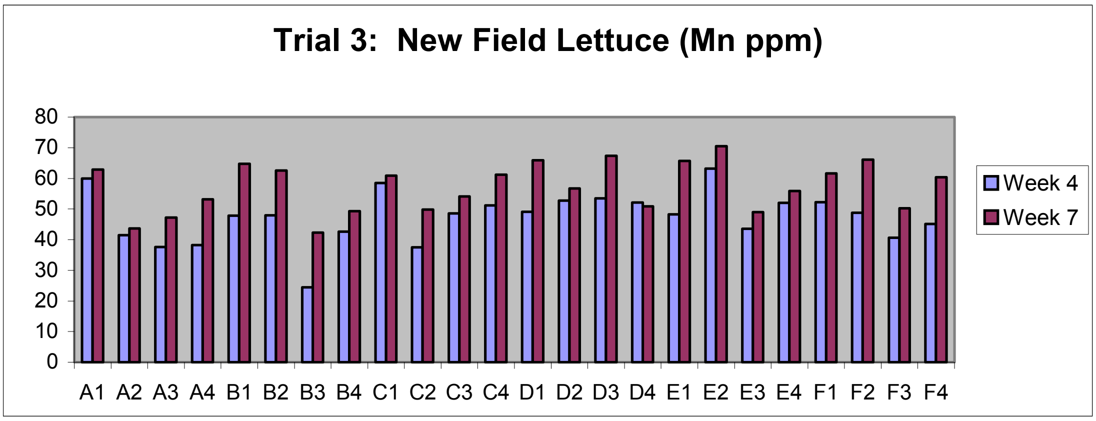



Trial 3: New Field Lettuce (Ca%)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 7

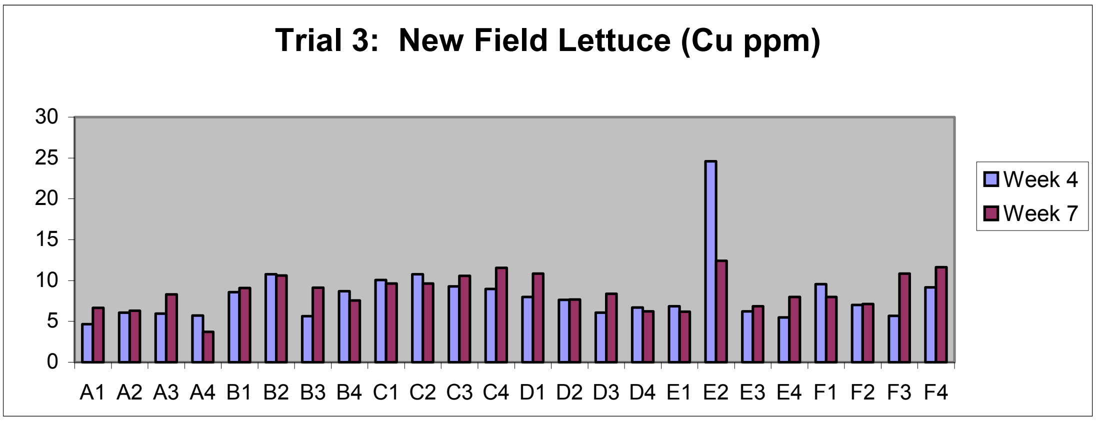

Trial 3: New Field Lettuce (Mg%)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 7


Trial 3: New Field Lettuce (Na%)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 7

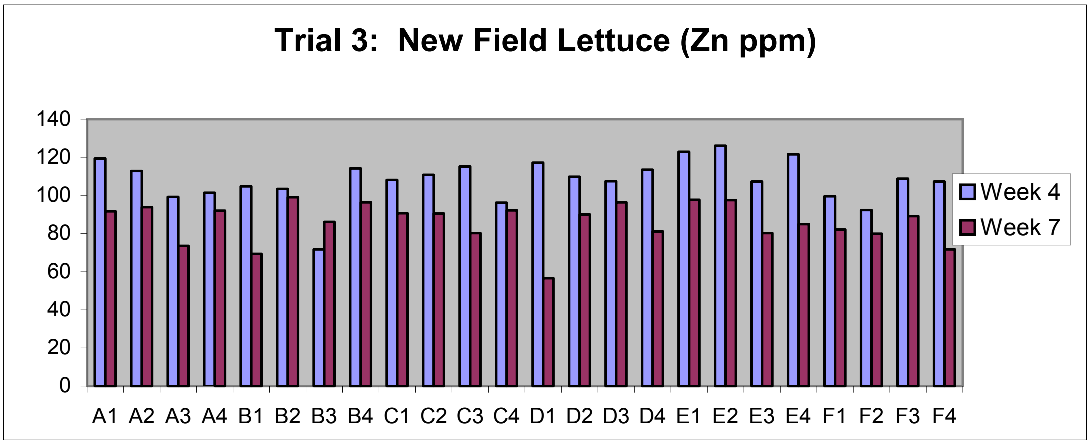

Trial 3: New Field Lettuce (Fe ppm)
600
500
400
300
200
100
0
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 7



Trial 3: New Field Lettuce (Mn ppm)
0
10
20
30
40
50
60
70
80
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 7



Trial 3: New Field Lettuce (Cu ppm)
0
5
10
15
20
25
30
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 7

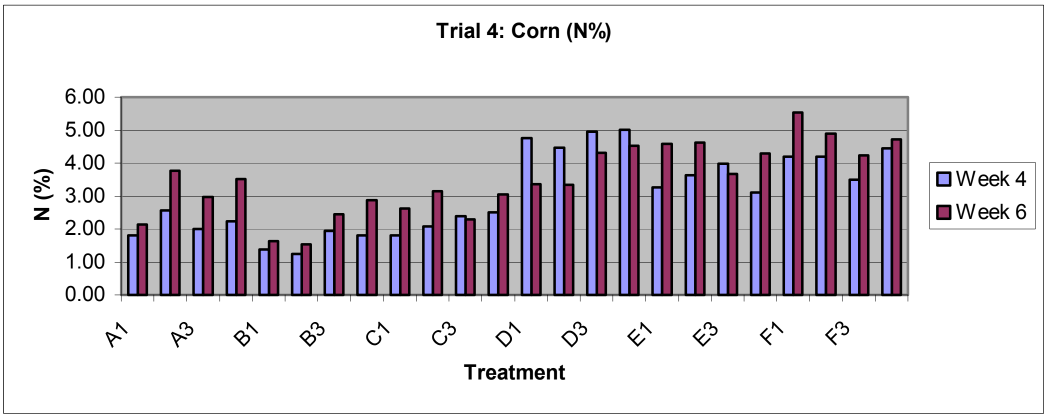


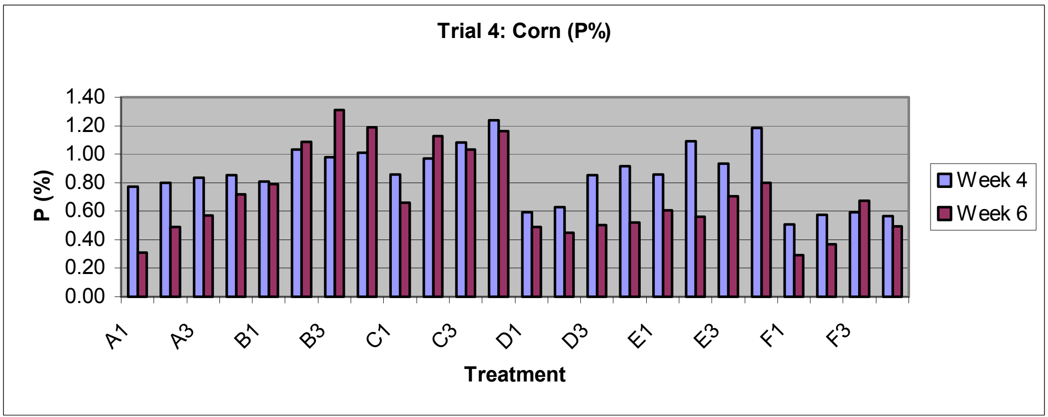
Trial 3: New Field Lettuce (Zn ppm)
0
20
40
60
80
100
120
140
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 7

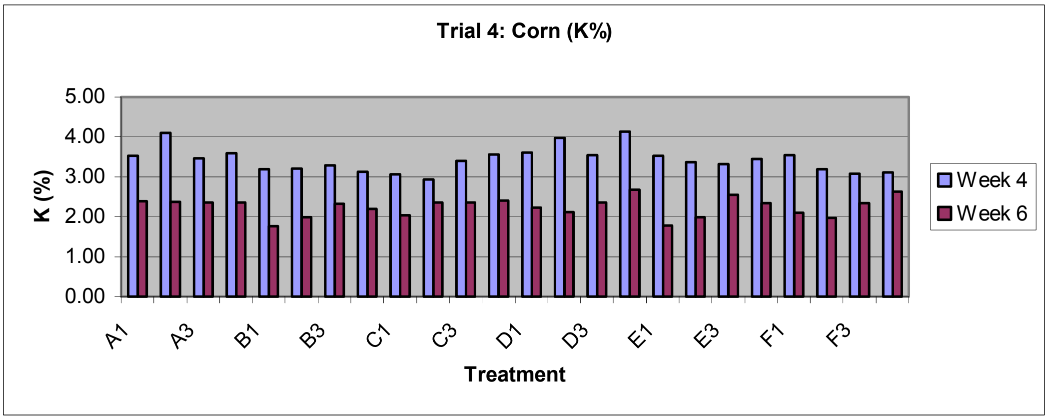
Appendix – F
Trial 4: Corn Leaf Tissue and Soil Analysis

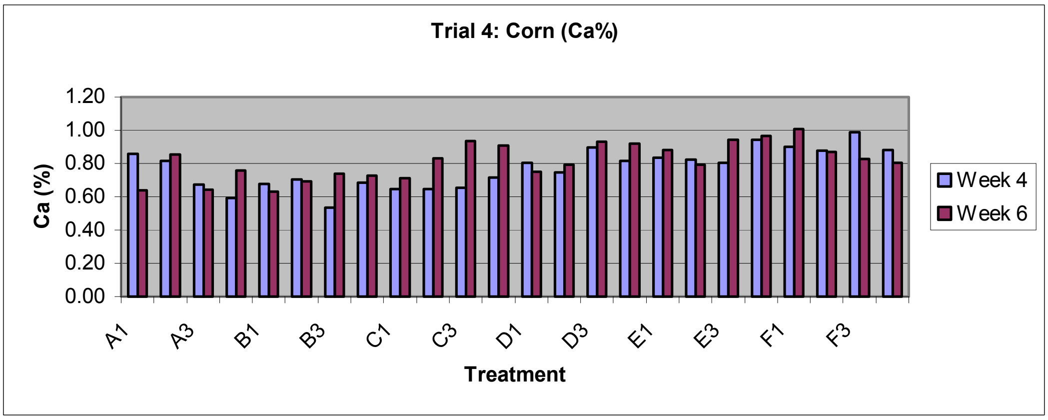
TREATMENTS:
A: Chicken manure (untreated control) pre plant, surface band chicken manure at week 2, mineral top dress every 7 days
B: Amended chicken manure (3% H_3PO_4) pre plant; surface band amended chicken manure at week 2 and week 6.
C: Amended chicken manure (3% H_3PO_4) pre plant; surface band amended chicken manure at week 2; mineral top dress every 7 days.
D: Mineral pre plant; mineral top dress every 7 days.
E: Amended chicken manure (1½% H_3PO_4) pre plant; surface band amended chicken manure at week 2; mineral top dress every 7 days
F: Nutraplex pre plant; top dress Nutraplex at week 2 and week 6.

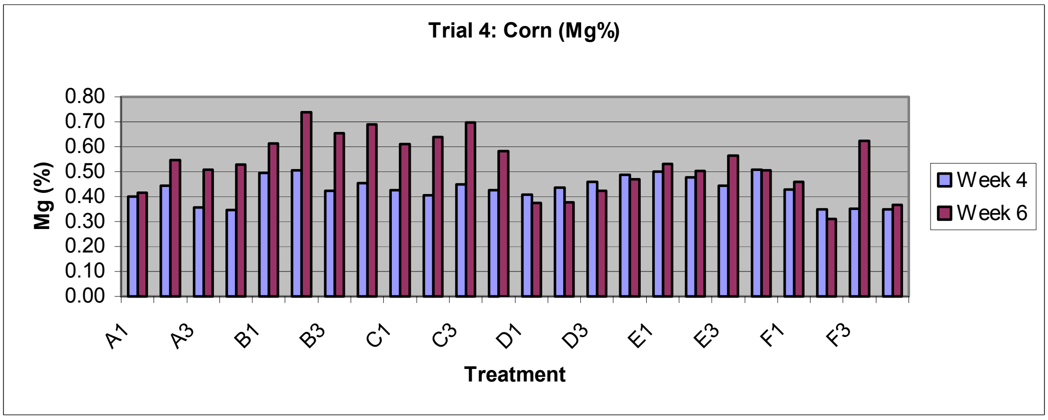
RATES: 60, 100, 125 and 150 % of modified AgWA recommendations.

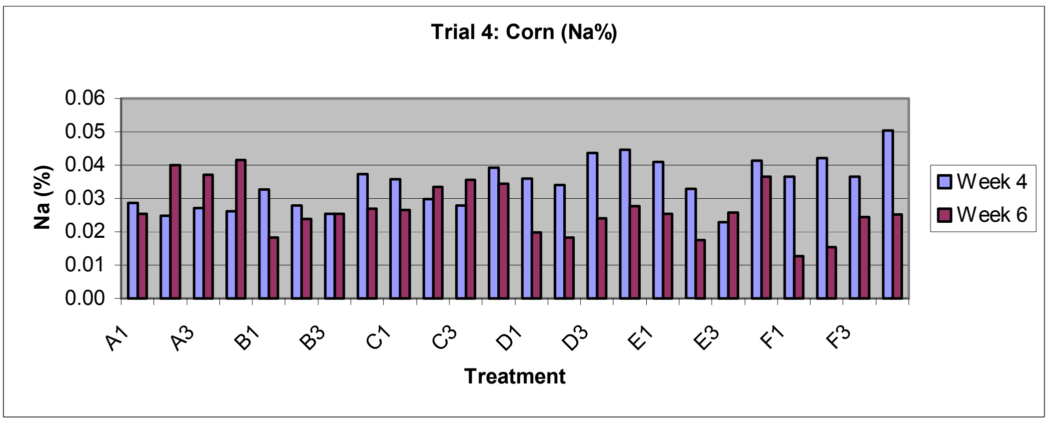


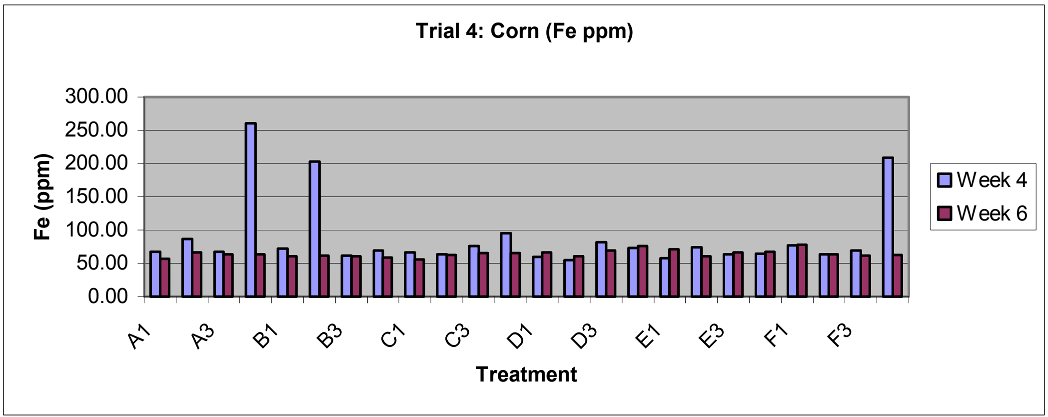


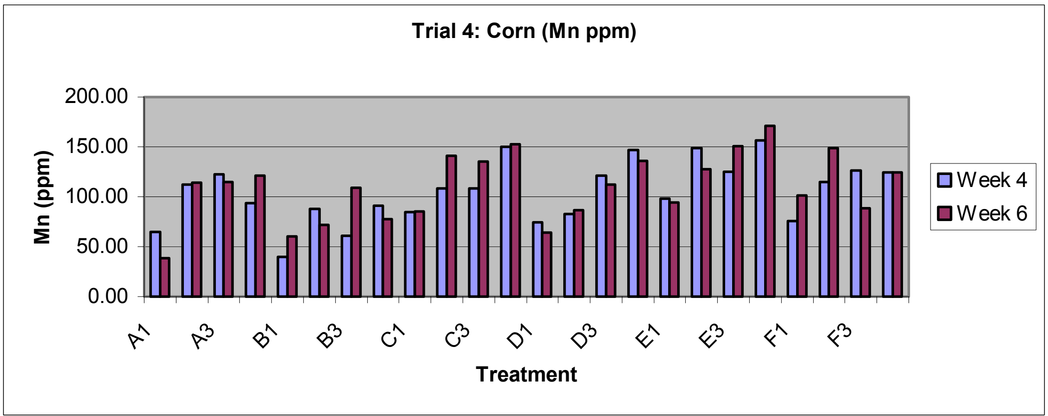

Trial 4: Corn (K%)
K (%)
5.00
4.00
3.00
2.00
1.00
0.00
A1
A3
B1
B3
C1
C3
D1
D3
E1
E3
F1
F3
Treatment
Week 4
Week 6

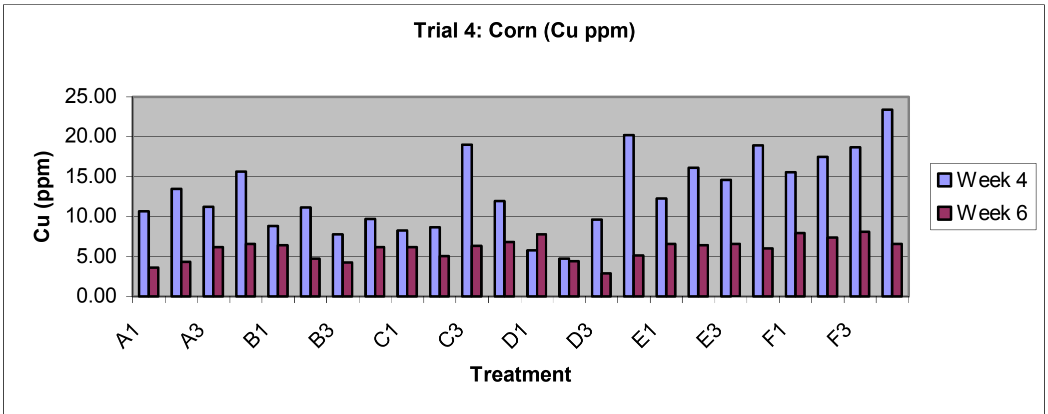

Trial 4: Corn (Ca%)
Ca (%)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
A1
A3
B1
B3
C1
C3
D1
D3
E1
E3
F1
F3
Treatment
Week 4
Week 6

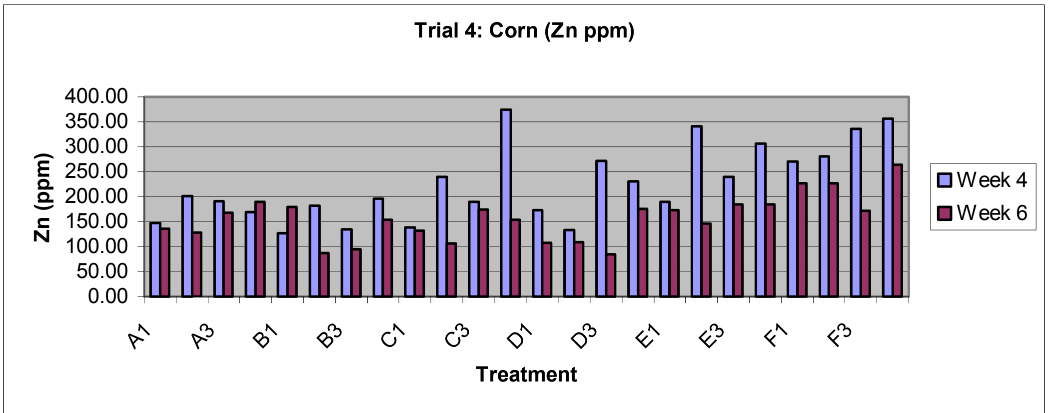

Trial 4: Corn (Mg%)
Mg (%)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
A1
A3
B1
B3
C1
C3
D1
D3
E1
E3
F1
F3
Treatment
Week 4
Week 6


Trial 4: Corn (Na%)
Na (%)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
A1
A3
B1
B3
C1
C3
D1
D3
E1
E3
F1
F3
Treatment
Week 4
Week 6


Trial 4: Corn (Fe ppm)
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Fe (ppm)
A1
A3
B1
B3
C1
C3
D1
D3
E1
E3
F1
F3
Treatment
Week 4
Week 6


Trial 4: Corn (Mn ppm)
200.00
150.00
100.00
50.00
0.00
Mn (ppm)
A1
A3
B1
B3
C1
C3
D1
D3
E1
E3
F1
F3
Treatment
Week 4
Week 6


Trial 4: Corn (Cu ppm)
25.00
20.00
15.00
10.00
5.00
0.00
Cu (ppm)
A1
A3
B1
B3
C1
C3
D1
D3
E1
E3
F1
F3
Treatment
Week 4
Week 6


Trial 4: Corn (Zn ppm)
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Zn (ppm)
A1
A3
B1
B3
C1
C3
D1
D3
E1
E3
F1
F3
Treatment
Week 4
Week 6

Treatment	pH [CaCl2]	pH [H2O]	Ec
A1	5.61	6.22	0.062
A1	5.08	5.9	0.053
A1	6.38	6.83	0.081
A2	5.12	5.67	0.088
A2	5.52	6.29	0.062
A2	5.11	5.61	0.068
A3	6.2	6.63	0.126
A3	6.24	6.66	0.06
A3	5.34	5.96	0.067
A4	6.24	6.67	0.084
A4	6.21	6.59	0.105
A4	6.18	6.56	0.084
B1	5.45	6.37	0.079
B1	5.47	5.98	0.111
B1	5.83	6.5	0.079
B2	5.99	6.47	0.066
B2	5.43	6	0.081
B2	6.12	6.49	0.059
B3	5.51	6.24	0.05
B3	5.85	6.43	0.057
B3	5.76	6.31	0.055
B4	4.97	5.8	0.081
B4	4.96	5.81	0.057
B4	4.75	5.78	0.038
C1	4.35	5.52	0.039
C1	5.46	6.35	0.059
C1	5.04	6.1	0.047
C2	4.75	6.02	0.064
C2	5.39	6.24	0.05
C2	5.4	6.3	0.056
C3	4.49	5.65	0.072
C3	4.16	5.08	0.078
C3	4.43	5.44	0.084
C4	5.07	6.03	0.053
C4	4.04	5.11	0.061
C4	4.59	5.9	0.043
D1	4.9	5.88	0.043
D1	5.01	5.97	0.037
D1	4.72	5.72	0.062
D2	5.02	6	0.05
D2	4.71	5.59	0.105
D2	5.49	6.45	0.044
D3	5.32	6.32	0.068
D3	5.4	6.21	0.048
D3	4.89	5.92	0.046
D4	5.88	6.7	0.091
D4	5	6.11	0.044
D4	5.01	5.94	0.063
E1	6.09	6.84	0.1
E1	4.56	5.91	0.053
E1	4.93	5.97	0.063
E2	5.72	6.47	0.066
E2	4.52	6.27	0.044
E2	5.26	6.45	0.055
E3	4.65	5.87	0.054
E3	4.29	5.75	0.045
E3	4.88	6.11	0.044
E4	5.6	6.45	0.063
E4	5.36	6.27	0.046
E4	5.64	6.33	0.05
F1	5.4	6.22	0.061
F1	5.11	6.17	0.041

Appendix - **Trial 5: Lettuce Leaf Tissue Analysis**

Treatments

A: Chicken manure (untreated control) pre plant, surface band chicken manure at week 2, mineral top dress every 7 days

B: Amended chicken manure (3% H3PO4) pre plant; surface band amended chicken manure at week 2 and week 6

C: Amended chicken manure (3% H3PO4) pre plant; surface band amended chicken manure at week 2; mineral top dress every 7 days

D: Mineral pre plant; mineral top dress every 7 days

E: Amended chicken manure (1 ½% H3PO4) pre plant; surface band amended chicken manure at week 2; mineral top dress every 7 days

F: Nutraplex (chicken manure substitute) pre plant; top dress with Nutrplex at week 2 and week 6

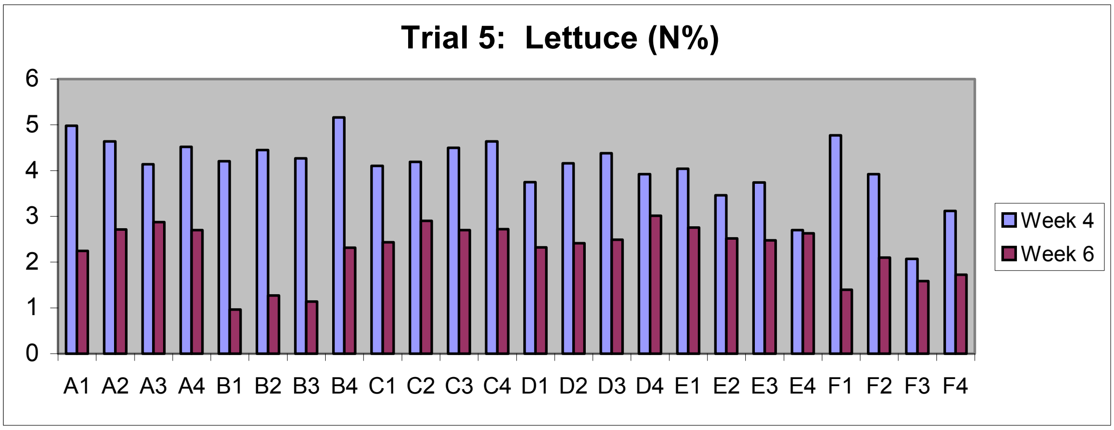
Rates

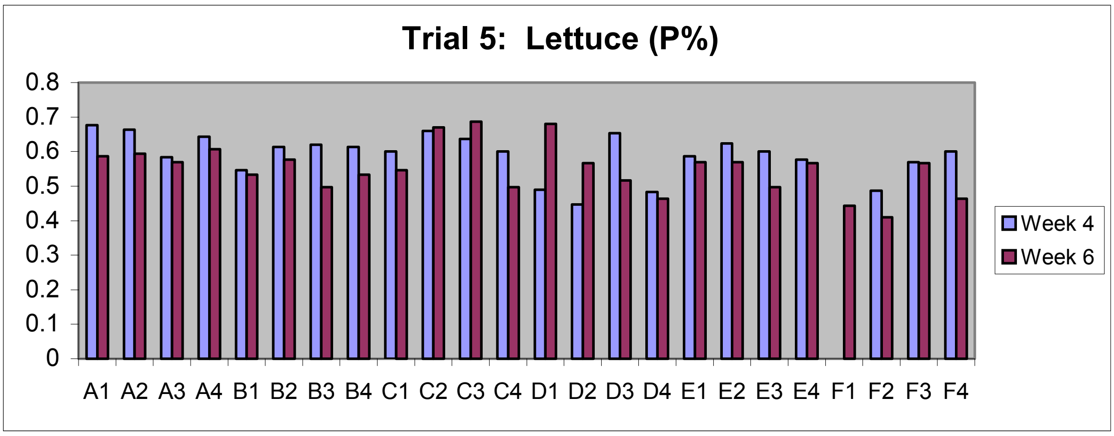
1: 30% of modified AgWA recommendations (AgBulletin 4282, amended Oct 96)

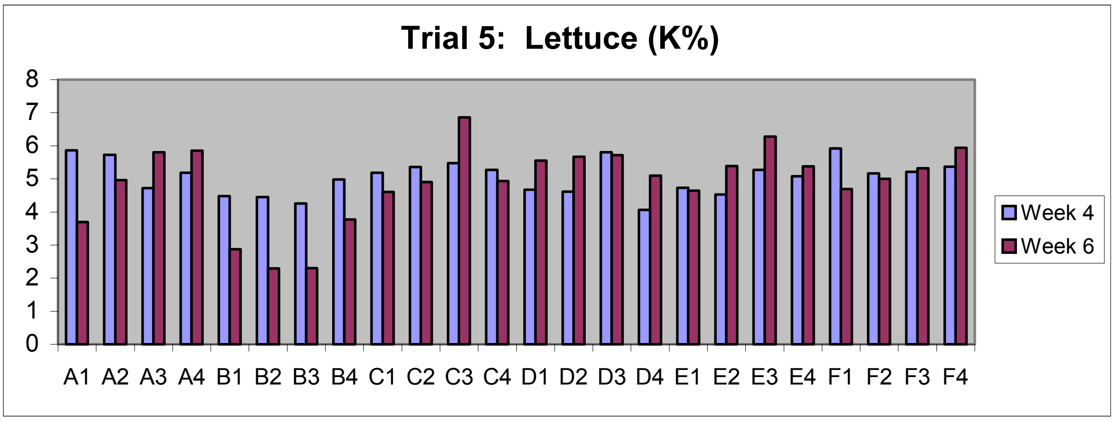
2: 60% of modified AgWA recommendations (AgBulletin 4282, amended Oct 96)

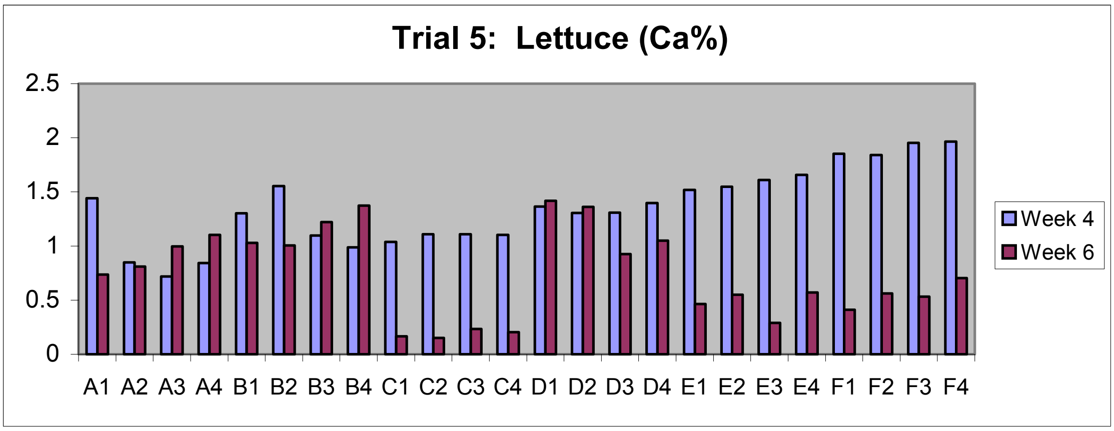
3: 90% of modified AgWA recommendations (AgBulletin 4282, amended Oct 96)

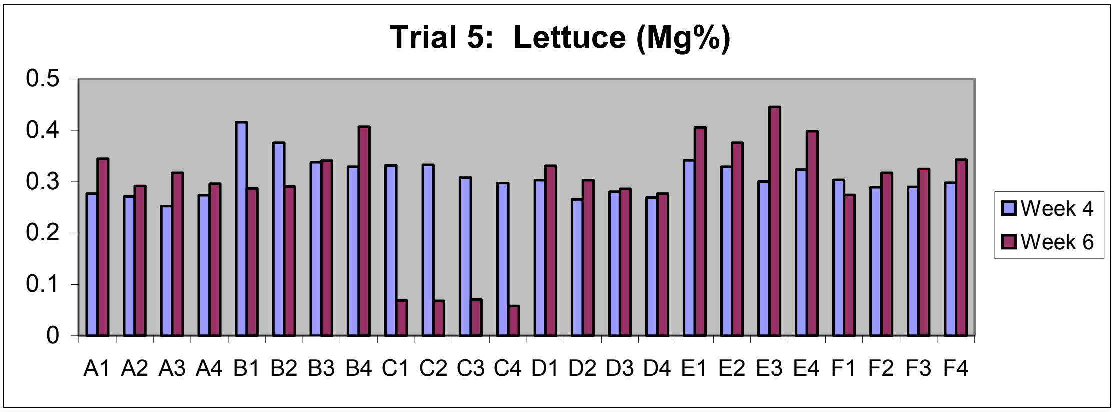
4: 120 % of modified AgWA recommendations (AgBulletin 4282, amended Oct 96)

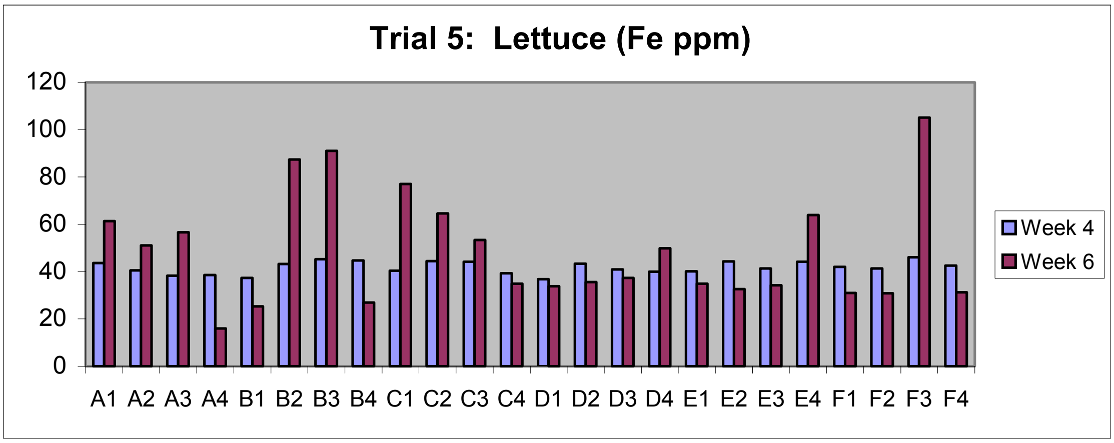


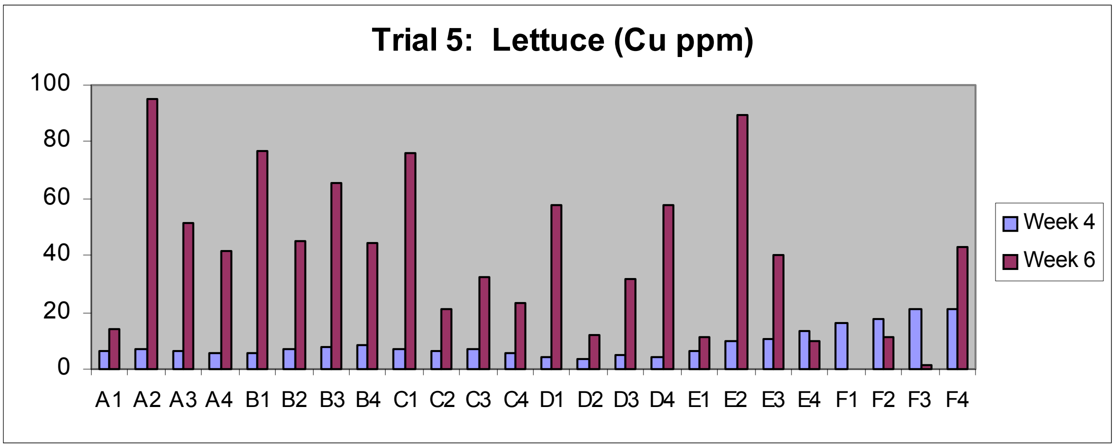



Trial 5: Lettuce (K%)
8
7
6
5
4
3
2
1
0
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 6

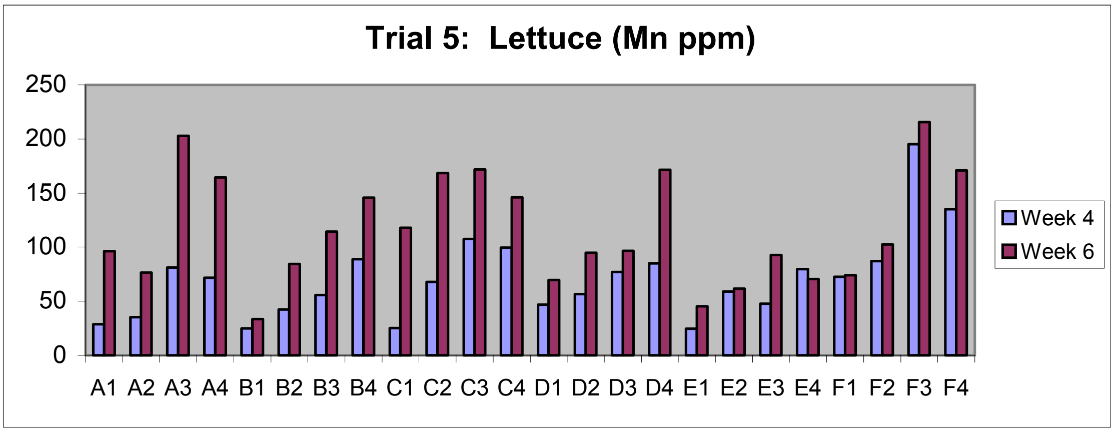

Trial 5: Lettuce (Ca%)
2.5
2
1.5
1
0.5
0
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 6


Trial 5: Lettuce (Mg%)
0.5
0.4
0.3
0.2
0.1
0
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 6

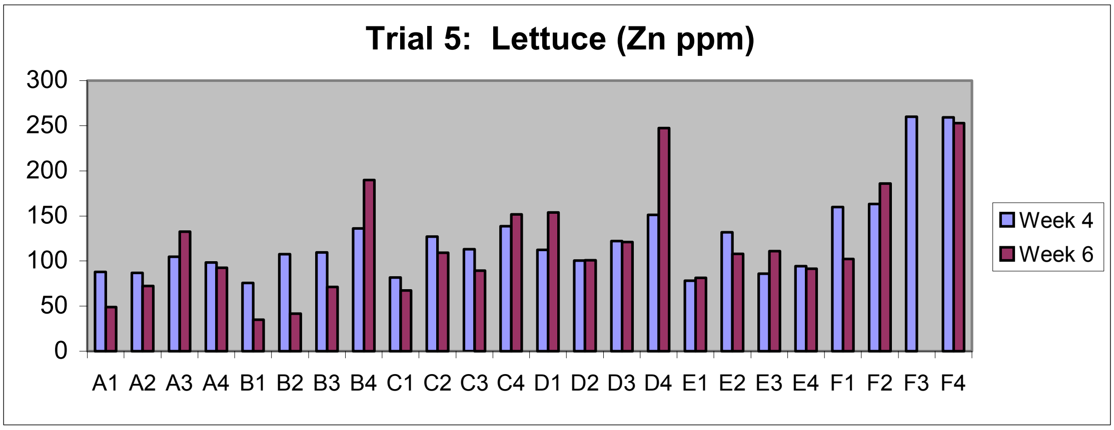

Trial 5: Lettuce (Fe ppm)
120
100
80
60
40
20
0
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 6



Trial 5: Lettuce (Cu ppm)
100
80
60
40
20
0
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 6



Trial 5: Lettuce (Mn ppm)
250
200
150
100
50
0
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 6



Trial 5: Lettuce (Zn ppm)
300
250
200
150
100
50
0
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 6

Appendix - Trial 6: Lettuce Leaf Tissue Analysis

Treatments

A: Chicken manure (untreated control) pre plant, surface band chicken manure at week 2, mineral top dress every 7 days

B: Amended chicken manure (3% H_3PO_4) pre plant; surface band amended chicken manure at week 2 and week 6

C: Amended chicken manure (3% H_3PO_4) pre plant; surface band amended chicken manure at week 2; mineral top dress every 7 days

D: Mineral pre plant; mineral top dress every 7 days

E: Nutraplex pre plant, surface band nutraplex at week 2; mineral top dress every 7 days

F: Nutraplex (chicken manure substitute) pre plant; top dress with Nutraplex at week 2 and week 6

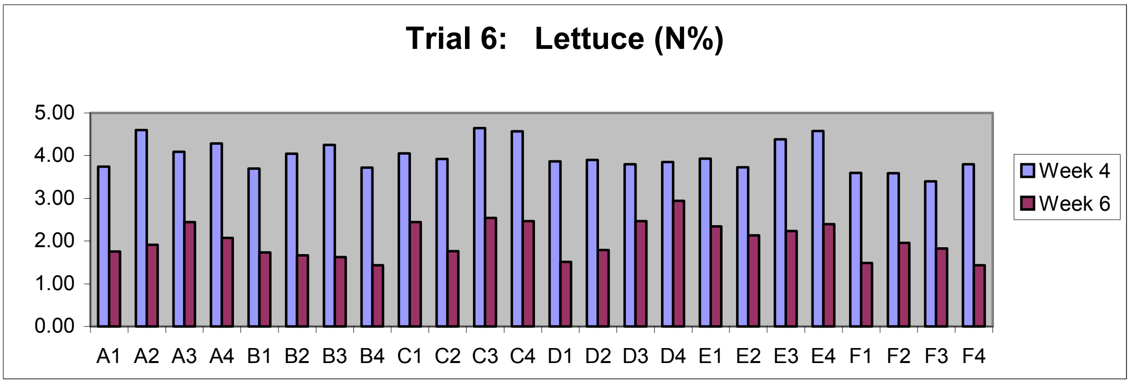
Rates

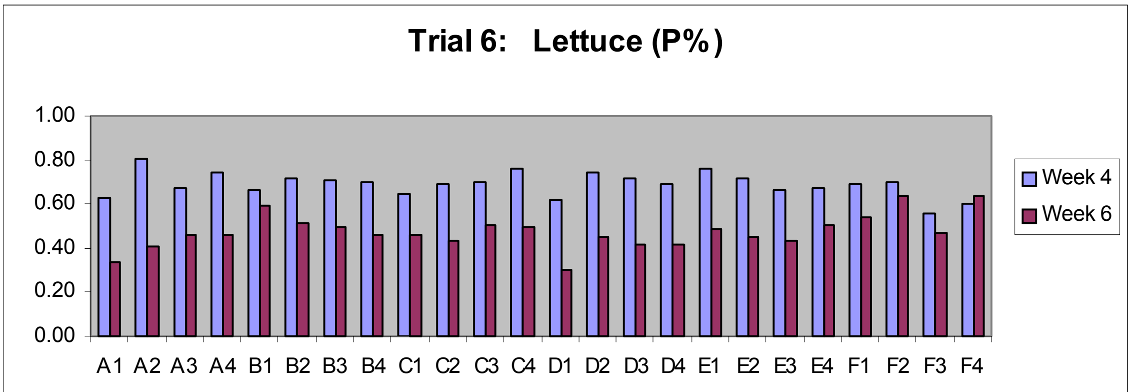
1: 40% of modified AgWA recommendations (from AgBulletin 4282, amended Oct 96)

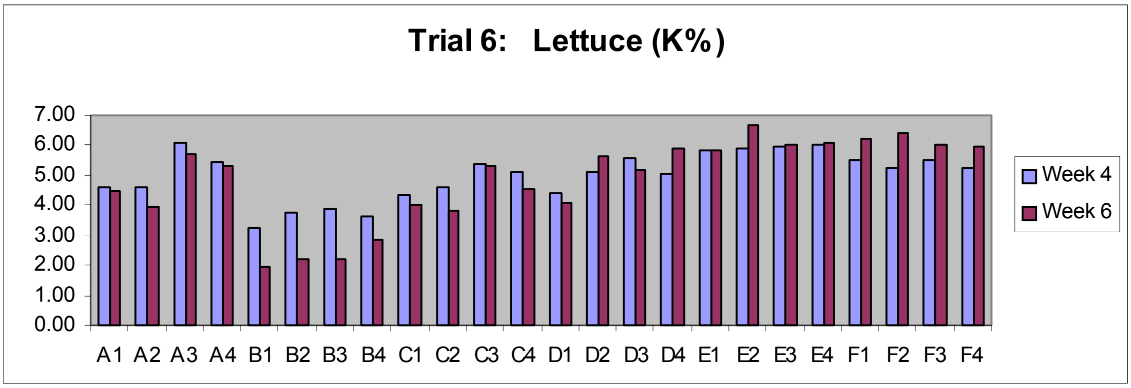
2: 55% of modified AgWA recommendations (from AgBulletin 4282, amended Oct 96)

3: 70% of modified AgWA recommendations (from AgBulletin 4282, amended Oct 96)

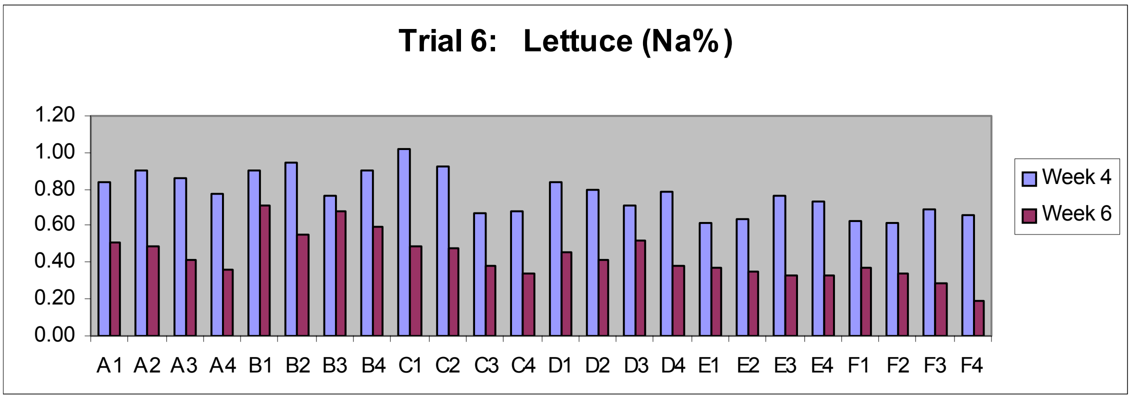
4: 90% of modified AgWA recommendations (from AgBulletin 4282, amended Oct 96)



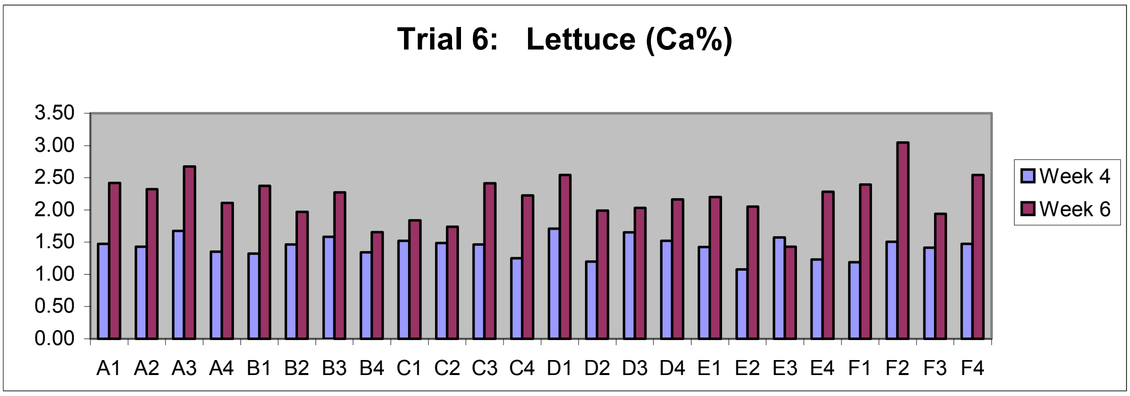




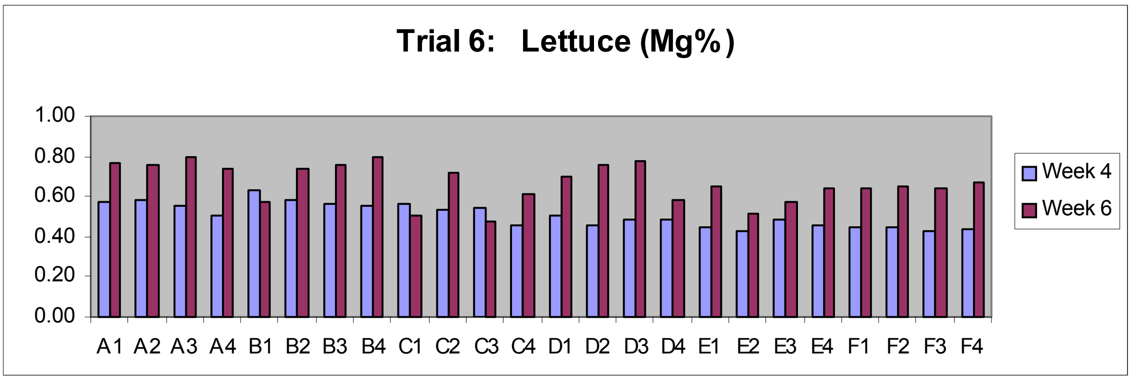
Trial 6: Lettuce (K%)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 6



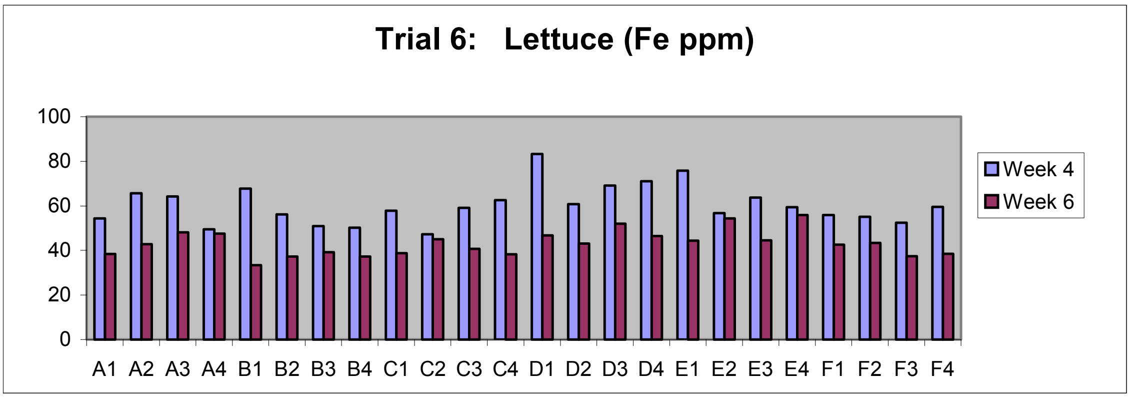
Trial 6: Lettuce (Na%)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 6

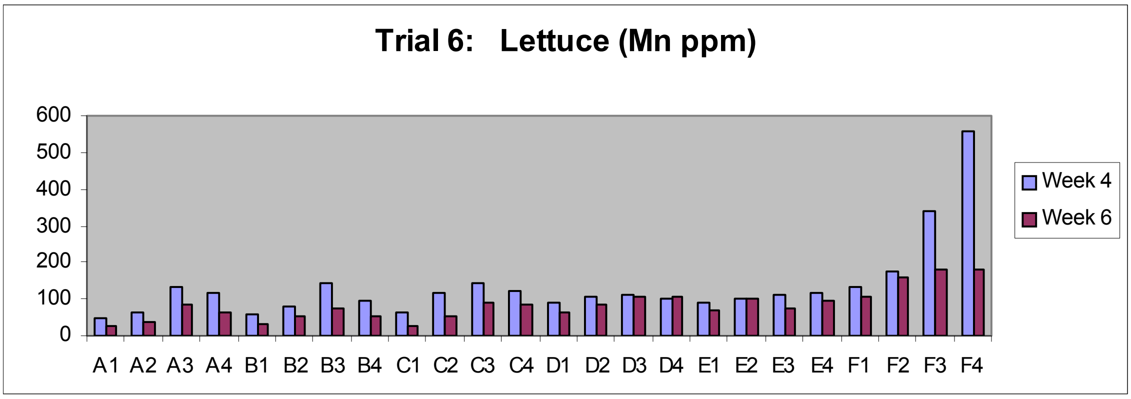


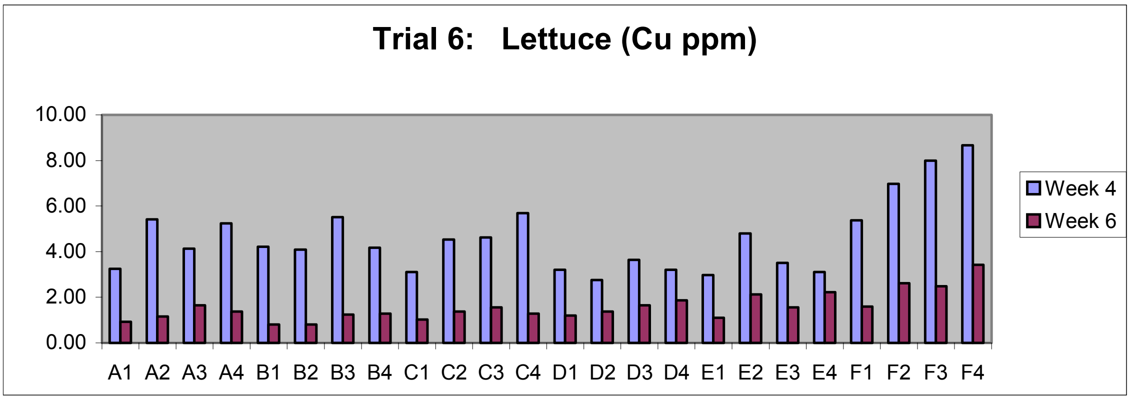
Trial 6: Lettuce (Ca%)
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 6

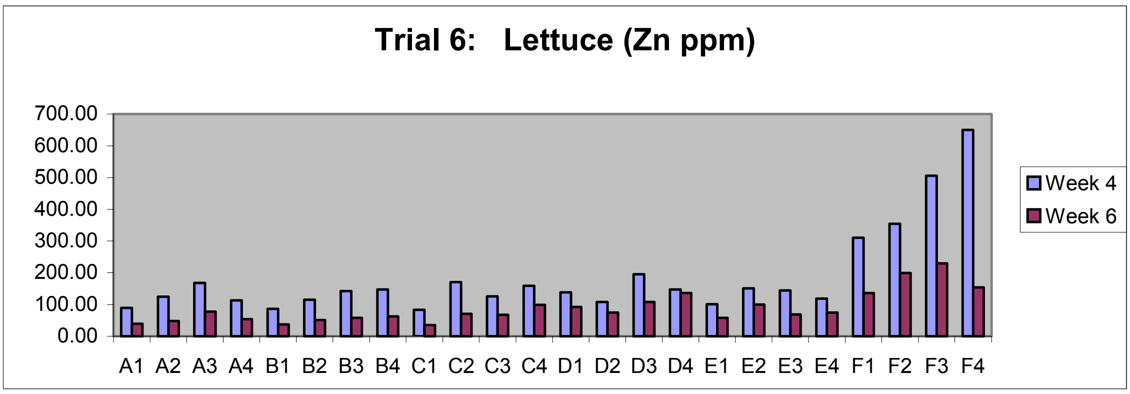


Trial 6: Lettuce (Mg%)
1.00
0.80
0.60
0.40
0.20
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 6


Trial 6: Lettuce (Fe ppm)
100
80
60
40
20
0
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 6


Trial 6: Lettuce (Mn ppm)
600
500
400
300
200
100
0
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 6


Trial 6: Lettuce (Cu ppm)
10.00
8.00
6.00
4.00
2.00
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 6


Trial 6: Lettuce (Zn ppm)
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
A1 A2 A3 A4 B1 B2 B3 B4 C1 C2 C3 C4 D1 D2 D3 D4 E1 E2 E3 E4 F1 F2 F3 F4
Week 4
Week 6

Appendix J

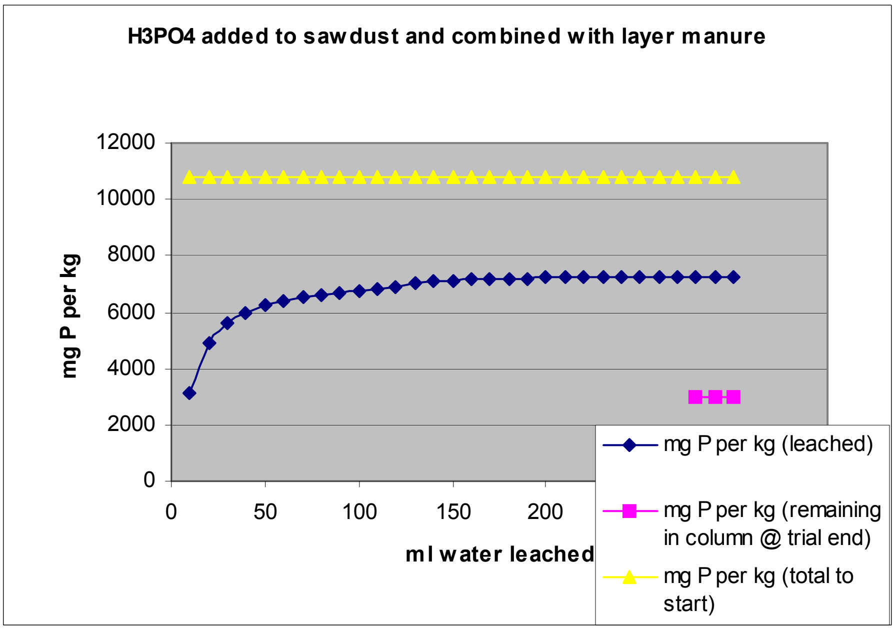
Phosphoric Acid Leaching Trials – Layer Vs Broiler Litter

In order to quantify phosphoric acid leaching from broiler litter, laboratory trials were undertaken to examine how rapidly and quantitatively phosphoric acid was leached from various materials and components found in Broiler litter, including fecal matter and sawdust.

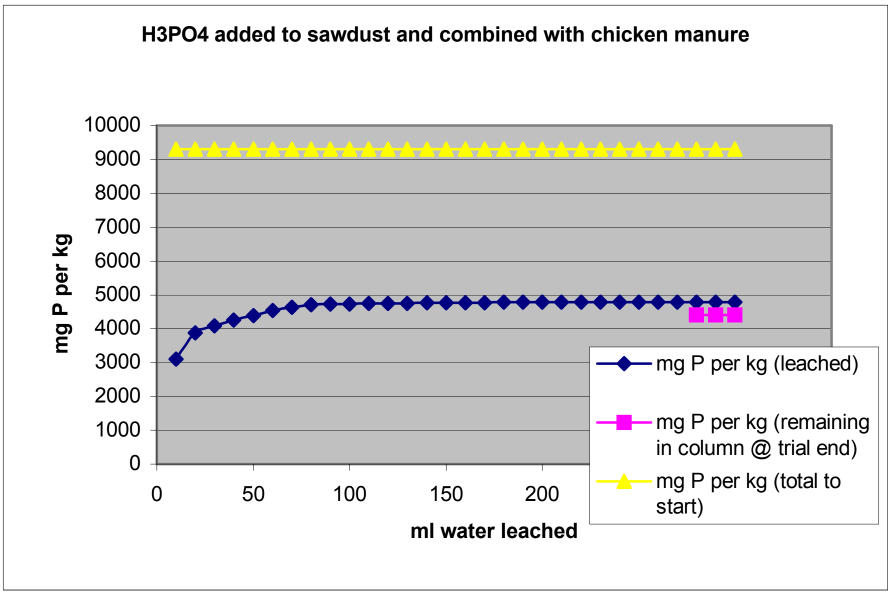
Dry materials were weighed, pure phosphoric acid (85% w/w, SG 1.66) was added, then after treatments mentioned, the material was packed loosely into a glass column. Water was percolated through the column and phosphate content of the leachate was measured.

Results:

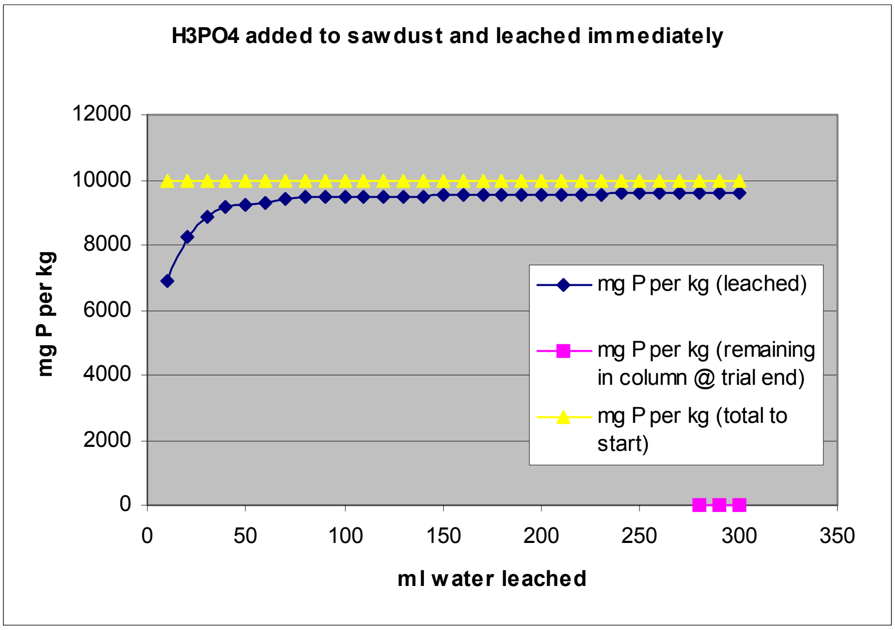
Test 1. 20ml sawdust containing H_3PO_4 was combined with 30ml layer manure.



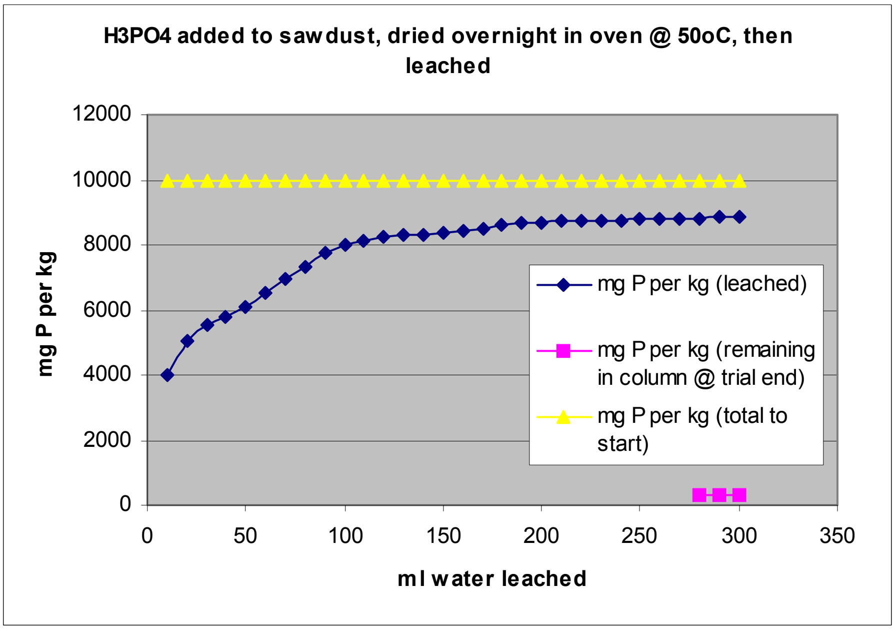
Test 2 – 20ml sawdust containing H_3PO_4 was combined with 30ml broiler litter.



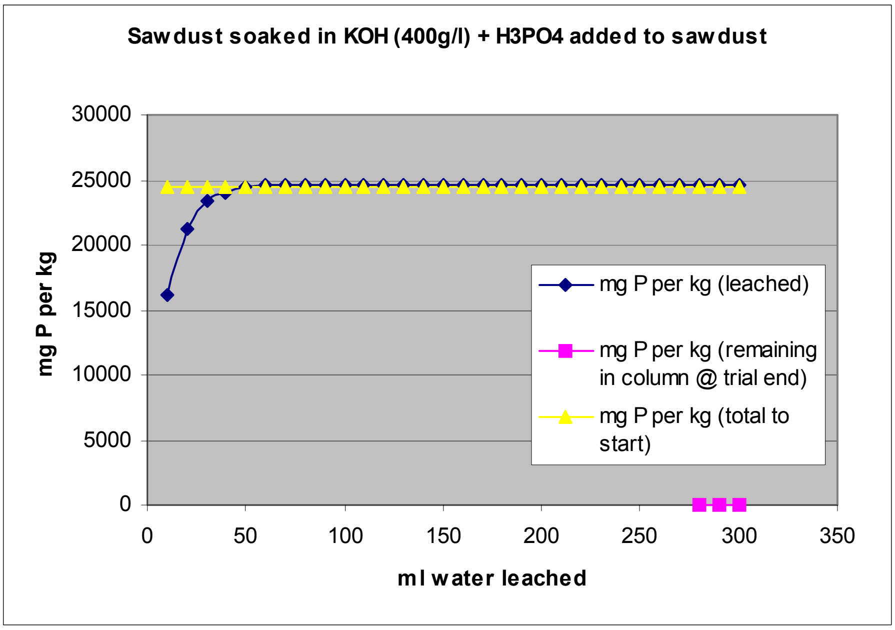
Test 3 - Phosphoric acid thoroughly mixed into dry sawdust and flushed soon after with with DI water.



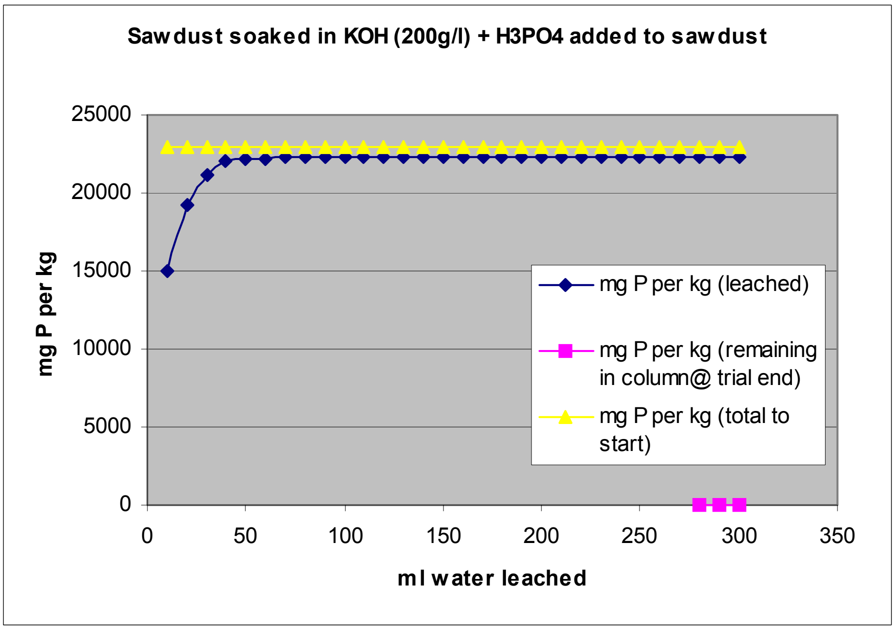
Test 4 - Phosphoric acid thoroughly mixed into dry sawdust and dried overnight at 50oC. Flushed with DI water the following day.



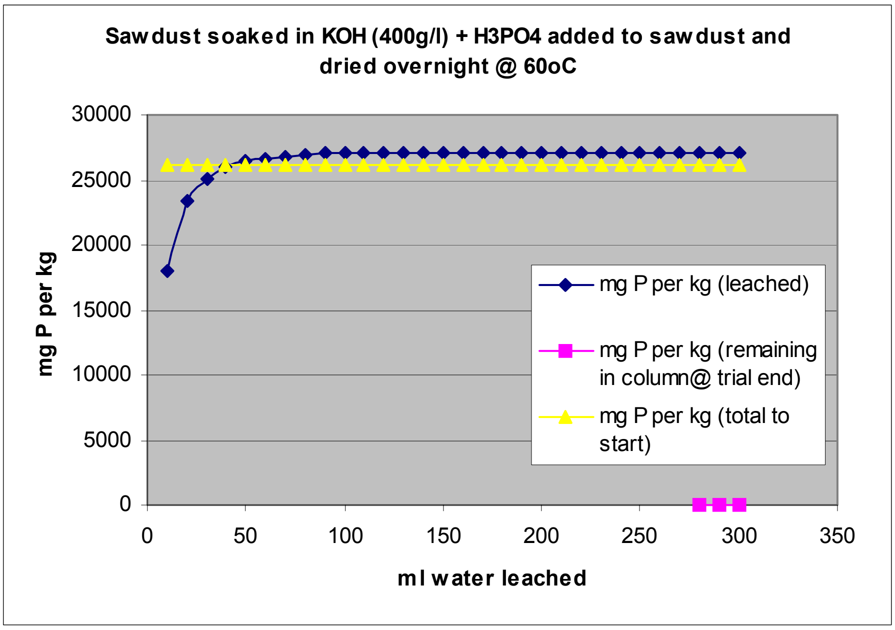
Test 5 – Dry sawdust soaked in KOH (400g/l) solution for 15 minutes. The sawdust was drained and rinsed three times with DI water. Phosphoric acid was thoroughly mixed into the rinsed media and flushed soon after with DI water.



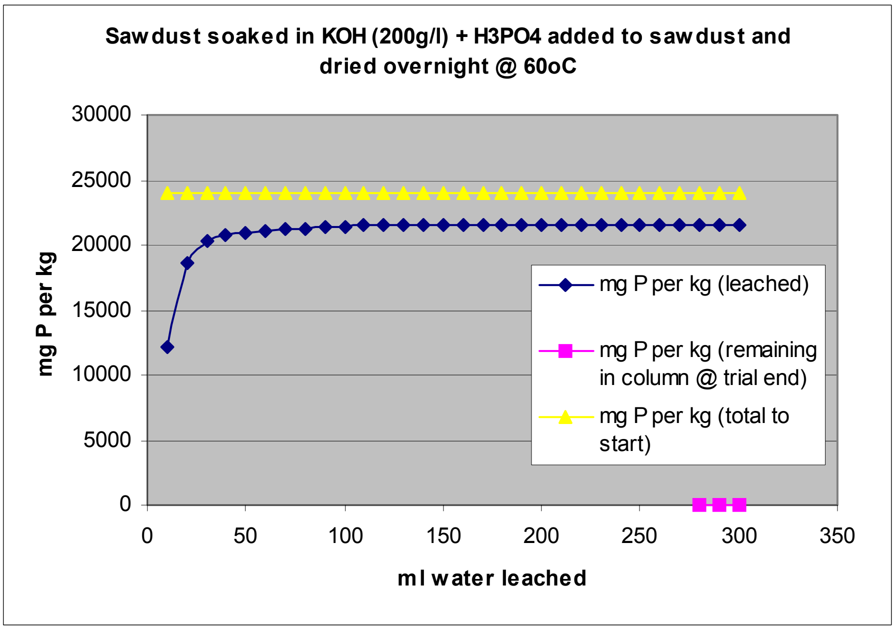
Test 6 – Dry sawdust soaked in KOH (200g/l) solution for 15 minutes. The sawdust was drained and rinsed three times with DI water. Phosphoric acid was thoroughly mixed into the rinsed media and flushed soon after with DI water.



Test 7 - Dry sawdust soaked in KOH (400g/l) solution for 15 minutes. The sawdust was drained and rinsed three times with DI water. Phosphoric acid was thoroughly mixed into the rinsed media, left to dry overnight at 60oC and flushed the following day with DI water.



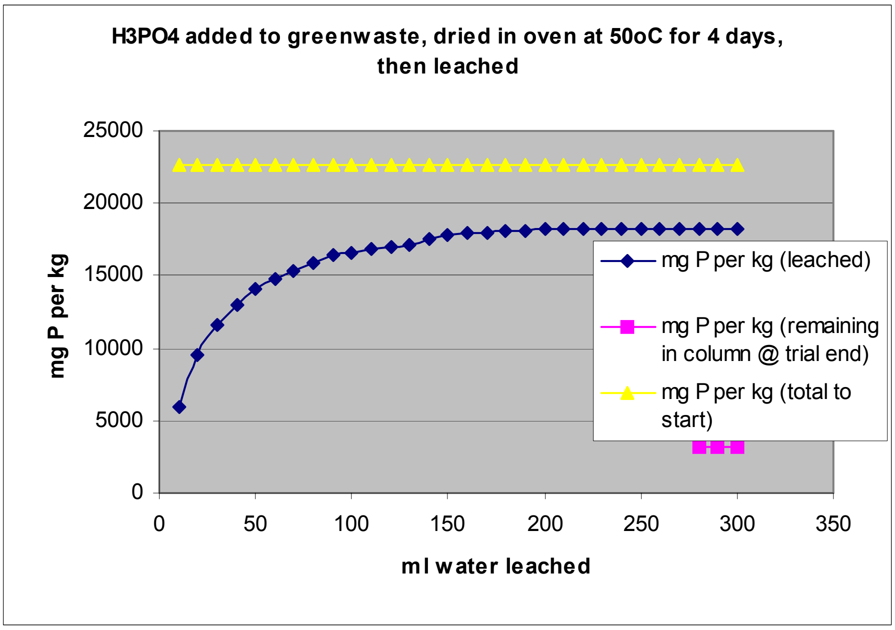
Test 8 - Dry sawdust soaked in KOH (200g/l) solution for 15 minutes. The sawdust was drained and rinsed three times with DI water. Phosphoric acid was thoroughly mixed into the rinsed media, left to dry overnight at 60oC and flushed the following day with DI water.

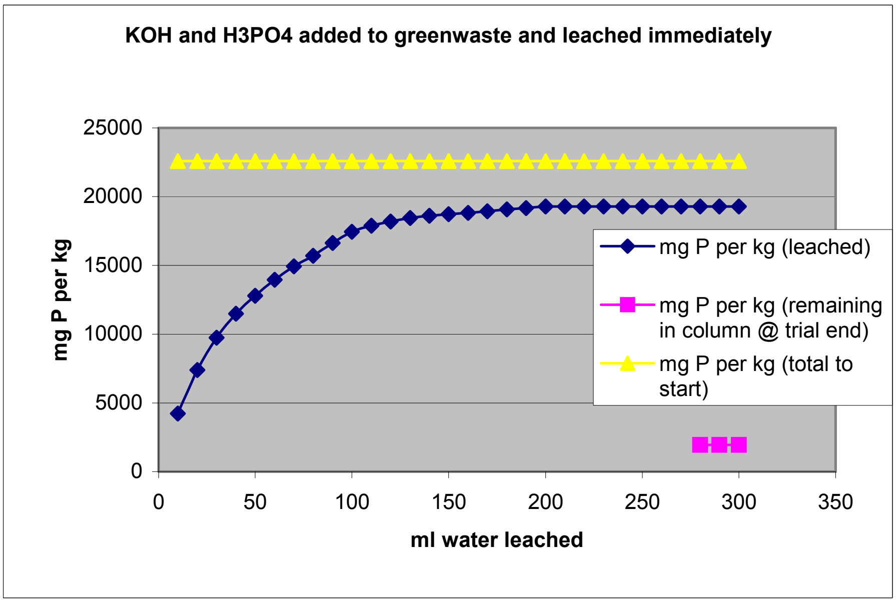


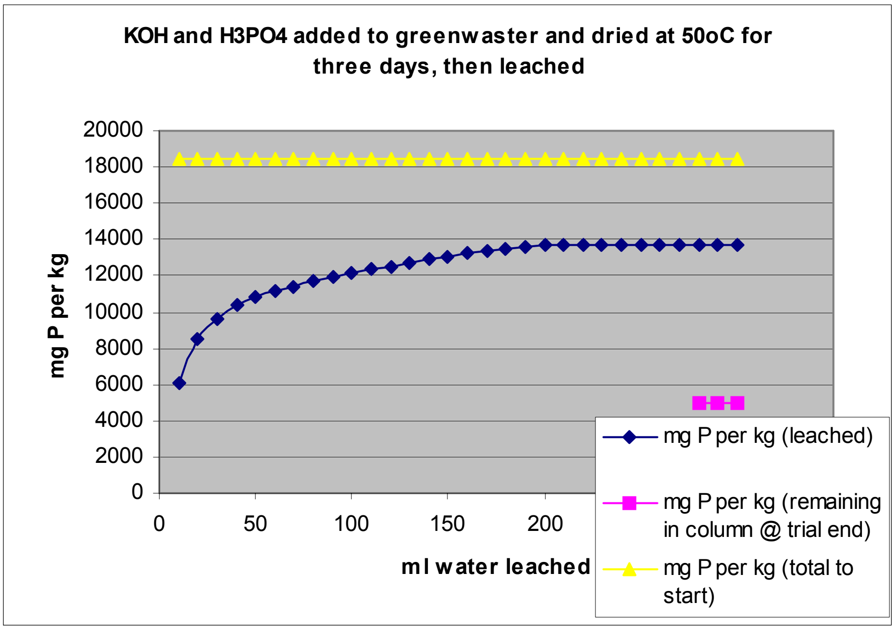
The graphs above indicate that phosphorous leaches fairly readily from sawdust amended with phosphoric acid. Phosphorous retention improves when the amended sawdust is dried for 12 hours at 50oC before flushing. Pre-treating the sawdust with potassium hydroxide does not improve the phosphorous binding capacity of the sawdust - even when dried overnight.

Looking at the graphs, it is obvious that for some trials (8-2-02-a in particular), the amount of phosphorous that was added to the sawdust did not equate to the amount of phosphorous that was leached and/or remained in the column. The reason being, the mass balance calculations are based on the weight of the media in the leaching column, and it was difficult to get accurate weights for media in the column. The small diameter of the leaching column made it difficult to pack and remove all media without either spilling or leaving some remaining in the column. The decision was made early on to weigh the contents of the column at the end of each leaching experiment, since more media was lost packing the column, than left behind trying to remove all its contents. As the volume of media used for each trial was relatively small to start, slight errors in the recorded weight made considerable differences when calculating the overall mass balance.

Tests 9, 10 and 11







Conclusions:

- **a)** The fecal component rather than sawdust is the major phosphate binding element in broiler litter.
- **b)** Drying manure after treatment reduces leaching.
- **c)** Pre-treating saw dust with caustic does not improve of phosphate binding to wood fractions.
- **d)** Phosphate binds to greenwaste better than sawdust, and such binding is improved by both pre-treatment with caustic, and by post treatment with drying.

Combined, these results indicate greenwaste and/or compost produced from greenwaste could provide a useful litter material for broiler shed, and the manure produced from such shed would be a useful fertiliser material with low fly-breeding potential.

Appendix K:

Chicken Manure Analysis before and after amendments.

Sample	pH (H_2O)	pH ($CaCl_2$)	EC	Total N (%)	Total P (%)	Total K (%)	Total Mg (%)
Treatment A Preplant (untreated CM)	7.81	7.34	8.1	2.65	0.80	0.77	0.29
Untreated CM (after drying)	7.25	7.02	6.2	2.28	0.87	0.66	0.31
Treatment B, C preplant (3%)	6.06	5.95	8.7	2.35	1.73	0.85	0.29
Treatment E preplant (1.5%)	6.53	6.27	7.2	2.15	1.22	0.83	0.28
Treatment F (nutraplex)	6.24	6.20	30.5	3.48	0.32	3.5	0.39

Sample	Total Ca (%)	Total Na (%)	Total Fe (ppm)	Total Cu (ppm)	Total Mn (ppm)	Total Zn (ppm)
Treatment A Preplant (untreated CM)	1.99	0.15	550	90.5	280	221
Untreated CM (after drying)	1.50	0.17	238	141	265	231
Treatment B, C preplant (3%)	1.35	0.18	286	131.5	258	227
Treatment E preplant (1.5%)	1.35	0.18	292	124.5	271	238
Treatment F (nutraplex)	1.76	0.32	232	2242	485	3948

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NATA Accreditation No. 10642

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Perth WA 6000

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Email admin@microservelab.com.au

MICROBIOLOGICAL REPORT

Client Details Bioscience Pty Ltd
21 Cumming Road
Oakford 6113

Sample Details Chicken Manure &
Lime amended Bassendean soil

Order No

Date Collected 8/6/01
Date Received 8/6/01

Attention Dr P Keating

Date Tested 11/6/01

Lab No	Sample	*E. coli* MPN per gram	*E. coli* - petrifilm CFU per gram
0109534M	Chicken Manure	< 3	<10
0109535M	Chicken Manure	< 3	< 10
0109536M	Chicken Manure	< 3	< 10
0109537M	Chicken Manure	< 3	< 10
0109538M	Chicken Manure	< 3	< 10
0109539M	Lime amended Bassendean soil	< 3	<10
0109540M	Lime amended Bassendean soil	< 3	10
0109541M	Lime amended Bassendean soil	< 3	15
0109542M	Lime amended Bassendean soil	< 3	< 10
0109543M	Lime amended Bassendean soil	< 3	< 10
	METHOD	**MMM 2.3F**	**MMM 2.18F**

Laboratory Comments:
The test results relate specifically to the sample/s as received in the laboratory.
< denotes less than > denotes greater than

E Frankish
Elizabeth Frankish
Managing Director
30/8/01

MFM 6/2

Consultants & Analysts in Microbiology

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Attention Dr P Keating

Lab No	**Sample**	***E. coli*** **MPN per gram**	***E. coli*** **- petrifilm CFU per gram**
0109534M	Chicken Manure	< 3	<10
0109535M	Chicken Manure	< 3	< 10
0109536M	Chicken Manure	< 3	< 10
0109537M	Chicken Manure	< 3	< 10
0109538M	Chicken Manure	< 3	< 10
0109539M	Lime amended Bassendean soil	< 3	<10
0109540M	Lime amended Bassendean soil	< 3	10
0109541M	Lime amended Bassendean soil	< 3	15
0109542M	Lime amended Bassendean soil	< 3	< 10
0109543M	Lime amended Bassendean soil	< 3	< 10
	METHOD	**MMM 2.3F**	**MMM 2.18F**

Laboratory Comments:
The test results relate specifically to the sample/s as received in the laboratory.
< denotes less than > denotes greater than

E Frankish
Elizabeth Frankish
Managing Director
30/8/01

MFM 6/2