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Application of Animal Manure/Compost in an Irrigated Alfalfa Production System

By

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Abstract. *The assessment of environmental degradation from farming practices has received recent attention due to the concern for sustainable agriculture. The United States Department of Agriculture and the Environmental Protection Agency have set forth the Unified National Animal Feeding Operation Strategy to protect the nation's water resources from contamination. The Unified Animal Feeding Operation Strategy requires that field application of manure, a common fertilization method and manure disposal practice, may not exceed crop nutrient needs. In this research, the effects of the application of manure, both fresh and composted, on a production alfalfa (Medicago sativa L.) field was examined. Manure and compost were applied to a production alfalfa field to determine the impact on alfalfa yield, soil nutrient content, and the potential for nitrate leaching. A conventional "no nitrogen added" treatment was also maintained as a control. Manure and compost were applied after each harvest in amounts such that the amount of nitrogen removed in the alfalfa harvest was replaced with the same amount of nitrogen in manure or compost. Soil analysis down to 150 cm depth showed an increase from the initial readings in the manure and compost plots but a relatively stable level in the no-nitrogen plots. Final PO_4-P soil analysis revealed that compost and manure plots again had significant increase from the initial readings while the no-nitrogen plot was lower. Alfalfa yield did not vary between treatments throughout the one and a half year study. Also, no detectable nitrate or phosphate was found in the leachate collected from each of the treatments.*

Keywords: Manure, irrigation, alfalfa, drainage lysimeters, nitrates, bacteria, phosphorus

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Introduction

Manure is a valuable and renewable resource that can be used as a fertilizer in crop production. However, in many cases it is applied to crops as a method of waste disposal. Application without regard to plant nutrient uptake can lead to nutrient loading of the soil and environmental contamination.

Manure application to alfalfa is rarely recommended because the plant does not need nitrogen. Alfalfa's symbiotic relationship with Rhizobium bacteria allows nitrogen fixation from the atmosphere. Meeting alfalfa's phosphorous and potassium needs with manure may provide nitrogen that is not needed and could be an environmental threat because the excess nitrogen can leach into groundwater. If surface waters are to be protected, nutrient loadings should be based on phosphorous. On the other hand, if groundwater is to be protected, nutrient loadings should be based on nitrogen (Kiely, 1997).

Arizona has little surface water. For most manure applications, nitrogen is the nutrient that limits application in southern Arizona. In many other states, the limiting nutrient is phosphorous.

In Arizona, CAFOs are often large. This presents a challenge when trying to keep the manure from contributing to nonpoint source pollution, even if the farmer intends to rid the farm of the manure by applying it to the land as fertilizer. In Arizona there are 7 registered feedlots. Three have at least 32,000 head of cattle. Another two have between 16,000 and 31,999 and the smaller two have less than 15,999 head of cattle (2001 Arizona Agricultural Statistics, 2002). In addition, there are 250 milk cow operations in Arizona. One hundred thirty have between 1 and 99 head of milk cows. Ten have between 100 and 199 and one hundred ten have 200 or more head of milk cows (2001 Arizona Agricultural Statistics, 2002).

A large CAFO is defined as having 700 head or more of mature dairy cows or 1,000 head or more of beef cattle or heifers (United States Environmental Protection Agency, 2002a). The numerous confined animals produce a large amount of manure. Therefore, it is important to find a useful and possibly economically beneficial way to dispose of the waste.

Within the past few years the United States Department of Agriculture and the Environmental Protection Agency set forth the Unified National Animal Feeding Operation Strategy. This is the foundation for the development of regulations that protect the nation's water resources from contamination from animal feeding operations. Within the document, a Comprehensive Nutrient Management Plan (CNMP) is defined that gives each operator guidelines on the management of their facility. The goal of the CNMPs is to receive an economic benefit from using manure while also minimizing the environmental risk.

A final ruling came out in December 2002 that plans to further the effective use of manure as a resource while reducing adverse effects. In addition to other implementations, the new rule requires all large CAFOs to apply for a permit, file an annual report, and build and abide by a plan for handling manure and wastewater (United States Environmental Protection Agency, 2002b).

The Unified Animal Feeding Operation Strategy requires that field application of manure may not exceed crop nutrient needs. This implies that manure should not be applied in excess of the nutrient uptake. But, one challenge is that the nutrient content of manure is not as consistent as fertilizer, where the nutrient content is designated, processed, and constant. Fertilizer has a statutory requirement to label or tag, where a detailed analysis of each ingredient is required (3 C.J.S., 1973). Manure is not regularly analyzed and its content can vary. Feedlot effluent characteristics are given in Miller et al. (2001). However, effluent characteristics can vary from feedlot to feedlot (Lehman, 1972; Sweeten, 1994).

Because of the variance of nutrients, following the guidelines is often done by making an educated guess because careful analysis to determine the amount to be applied is difficult, time consuming, and costly. It was found that fewer than fifty percent of farmers test soil regularly and even fewer test manure (DuBois, 1994). But it is understood that when making estimates and approximations, there is the potential risk for overloading the soil with nitrogen (Schmitt et al., 1994) and other nutrients, which may leach to groundwater.

This study is important because it may assist owners and operators of animal feeding operations abide by regulations of the Environmental Protection Agency, which will result in a minimization of the negative environmental impact of livestock operations. The results will assist in improving water quality by reducing the contribution of animal waste to the degradation of water quality. The data collected will also assist in the current development of requirements for CNMPs required for all CAFOs.

In this research, the effects of the application of manure, both fresh and composted, on a production alfalfa field were studied. The objectives of the research were to determine the impact on the following:
- alfalfa yield.
- alfalfa nitrogen content.
- soil total nitrogen.
- soil ammonium.
- soil nitrate.
- soil organic nitrogen.
- soil phosphate.
- soil electrical conductivity.
- leachate nitrate.
- leachate phosphate.

LITERATURE REVIEW

Reasons for Manure and Compost Application

Soils in the southwestern United States are low in organic matter and nutrients. To remedy this, nutrients in manure are recycled by applying manure to cropland (Davis et al., 1997). Many farmers also apply manure to crops as a method of recycling animal waste and relocating it off the farm, which can be an environmentally safe manner of disposal if it is done properly (Jokela, 1992; Miller and Donahue, 1995).

In some cases, field manuring is more for waste disposal than soil improvement (James et al., 1996). This may pose a threat to environmental quality if the soil is over-loaded with nutrients or if excess nitrogen reaches groundwater. In many cases, manure is applied to agricultural land to avoid manure storage (Withers et al., 2001). In these situations, the application of manure to alfalfa simply serves as a nitrogen sink (Daliparthy et al., 1994).

Risks and Benefits of Manure and Compost Application

Animal operations generate a great deal of manure and often apply it in large amounts to limited land in close proximity to the manure source (James et al., 1996). They are estimated to account for one-third of all agricultural nonpoint pollution (Eigenberg and Nienaber, 1998). The tendency is to apply manure close to its source because of the high cost of transporting manure from one location to another. That makes the nearby areas vulnerable to environmental damage due to nutrient loading (Chang and Janzen, 1996). One nutrient of concern, when applied in excess, is nitrogen because it can leach into groundwater (Chang and Janzen, 1996). Water quality can be negatively impacted not only by over-application of manure and compost but also by poor timing and bad management (Great Plains Agricultural Council, 1995). The resulting nitrate contamination in groundwater is a concern for consumers, scientists, farmers, and policy makers (Daliparthy et al., 1994).

On the other hand, the benefit of recycling manure is to supply nitrogen for plant production (Jokela, 1992). The appropriate use of this available commodity can reduce the need for mineral fertilizer (Van Kessel et al., 2000; Vellidis et al., 1996), thereby creating an economic incentive for use.

Also, using manure and compost as fertilizers provides financial savings through less use of commercial fertilizer (Thompson et al., 1997). Costs of using manure as a fertilizer include loading, hauling, spreading, and incurred pollution expenses (Freeze et al., 1993). These costs are normally less than the farmer's benefit from manure use. The environmental benefit includes saving fossil fuel reserves, which is used in the production of fertilizers (Peterson and Russelle, 1991).

Land application of animal wastes can be economical, practical, and have potentially low environmental risk, especially with the use of soil, plant, and manure test results to help determine the amount of manure to be applied (Safley, 1986). Yet farmers usually do not adequately test and credit the value of nutrients in manure (Thompson et al., 1997). But in order to avoid detrimental consequences on the environment, it is necessary to determine the correct rate, time, and methodology for each application (Kiely, 1997). Selection of an application rate should include considerations of the impact on water quality (Lanyon, 1994).

Besides the benefit of waste disposal, it is not certain if it is always possible to receive an economic benefit from an increase in crop yield because data reported regarding yield are variable. A sustainable system must provide farmers with enough profit otherwise farmers will not adopt it even if it benefits the environment (Lu et al., 1999).

Effects of Using Manure as a Fertilizer

Both positive and negative impacts of using manure as a fertilizer have been documented. The effects noted have a concentration on three areas. Spreading manure on crops can increase yield (Jokela, 1992; Daliparthy et al., 1995), weed infestation (Daliparthy et al., 1995), and pose a threat to water quality (Jokela, 1992; Lanyon, 1994; Sanderson and Jones, 1997; Vellidis et al., 1996; Daliparthy et al., 1994).

Any addition of nitrogen to a crop that can fix nitrogen from the atmosphere must be compensated by a reduced nitrogen fixation in order to avoid groundwater contamination (Borton et al., 1997). If applied in excess of crop needs, the surplus nitrogen may produce nitrate (NO3-) leaching (Jemison and Fox, 1994) from the field, which contributes to nonpoint source pollution (Lanyon, 1994; Daliparthy et al., 1995; Daliparthy et al., 1994).

A major risk involved in using manure as fertilizer is that nitrate is highly mobile in soils and migrates up to 3 mm per day (Marschner, 1995). It travels quickly because it is water soluble and is not held by negatively charged soil particles (Kimble et al., 1972). It migrates toward groundwater and wells, which are a major source of water for human consumption.

A national survey of drinking water from wells established that nitrate was the most commonly occurring contaminant that had concentrations above drinking water standards. Over fifty percent of rural wells had detectible concentrations and some exceeded the drinking water standard of 10 mg NO3--N L-1 (Jemison and Fox, 1994). One problem is that these consequences have no financial cost to the farmer (Withers et al., 2001).

With elevated levels of nitrate frequently observed in drinking water wells, it is likely that humans will ingest it. Consumption of nitrate is harmful to human health (Kiely, 1997). It can be toxic to any mammal that is pregnant, has cancer, or has a condition that alters stomach acidity. In healthy adults, the stomach acid rapidly absorbs and excretes nitrates, making poisoning unlikely (Miller and Donahue, 1995). But in babies, nitrate can cause "blue baby" syndrome, also known as Methemoglobinemia (Kiely, 1997; Miller and Donahue, 1995). This occurs when microorganisms in the digestive system reduce nitrate to nitrite, which is absorbed into the bloodstream. Here it oxidizes the oxygen carrier, oxyhemoglobin, to methemoglobin, which cannot carry oxygen. When oxygen cannot be carried throughout the body, the baby suffocates, giving rise to the name "blue baby" syndrome (Miller and Donahue, 1995).
Elevated nitrogen and phosphorous levels in estuaries pose additional environmental risks. The increase in concentration may trigger eutrophication, which refers to elevated nutrient concentrations that may lead to enhanced algal growth (Weil et al., 1990; Miller and Donahue, 1995). Enhanced algal growth has the potential to load the water with dead algae. When

decomposed by microorganisms, the water's dissolved oxygen is consumed, leading to anaerobic water (Miller and Donahue, 1995). In shallow water, the elevated nutrients may also boost mosquito breeding (Miller and Donahue, 1995).

METHODS AND MATERIALS

Alfalfa Plots

Alfalfa was planted on November 17, 2000, at the Maricopa Agricultural Center in Maricopa, Arizona. The variety was Mecca II seeded at a rate of 28 kg ha-1. The field, with Casa Grande fine-loam (mixed, hyperthermic Typic Natrargid) was split into 12 plots, which were each 6.1 m wide and 137.2 m long. Four plots were treated with manure, four were treated with compost, and the remaining four were no nitrogen added plots. See Figure 1.

Figure 1. Plot layout of alfalfa receiving manure, compost, and no nitrogen treatments where the top of the page represents north.

Replicate 4			Replicate 3			Replicate 2			Replicate 1		
Plot 12 M	Plot 11 N	Plot 10 C	Plot 9 C	Plot 8 M L	Plot 7 N	Plot 6 N	Plot 5 C L	Plot 4 M	Plot 3 M	Plot 2 N L	Plot 1 C
Irrigation Ditch											

M = Manure, N = No Nitrogen, C = Compost, L = Lysimeter

The field was divided into four replicate blocks with three plots per block, in a modified randomized complete block design. Three lysimeters previously existed in the field; one was located in each of the first three blocks. One no nitrogen, one compost, and one manure treatment plot was randomly assigned to each lysimeter. Other treatments were randomly assigned so that each block consisted of one replicate of each treatment.

Irrigation

The field had a zero slope and was surface irrigated with siphon tubes. Irrigations were scheduled using AZSCHED, the AriZona irrigation SCHEDuling computer program. AZSCHED is a computer model developed at the University of Arizona that integrates weather, soil factors, and crop factors to provide irrigation recommendations. Weather data, including rainfall, were obtained from an AZMET (AriZona METeorological Network) station approximately 805 m north of the field location. The program computes crop water usage with the Modified Penman equation to determine reference crop evapotranspiration combined with a heat unit based crop coefficient (Fox et al., 1992). For further technical details on the AZSCHED software, see Fox et al. (1992).

The initial settings on AZSCHED for soil moisture were as follows: 0 to 30 cm had 12.0 cm m-1 capacity, 30 to 60 cm had 12.0 cm m-1 capacity, 60 to 90 cm had 13.9 cm m-1 capacity, and 90 to 210 cm had 10.6 cm m-1 capacity (Martin et al., 1999). AZSCHED was programmed to start with full profile at the beginning of the experiment because the field was irrigated to full profile while the plant was not yet germinated.

Irrigation amounts and dates were calculated by AZSCHED using a maximum allowed depletion of fifty percent (Fox et al., 1992) and an irrigation efficiency of seventy five percent (Martin, 2000). The output from AZSCHED was the depth of water that needed to be applied over the field.

The flow rate from the irrigation ditch multiplied by the time for irrigation equaled the depth to be applied multiplied by the area of the field. Using the depth to be applied, the flow rate from the irrigation ditch, and the area of the field, the time for irrigation was found using the following equation:

$$t = (d * A)/(363\ Q) \qquad \text{Eq. (1)}$$

where:
t = time of irrigation (hr)
d = depth of water (cm)
A = area of the field (m^2)
Q = flow rate from irrigation ditch ($L\ s^{-1}$).

Alfalfa Harvest and Analysis

Harvest dates predicted by AZSCHED were used to determine the appropriate cutting dates. Predicted harvest dates were visually verified and the alfalfa was cut at approximately ten percent bloom. The alfalfa was then raked into windrows, one row per plot. A 2 m length of fresh cut alfalfa was then bagged from each plot. The sample was collected with a pitchfork and bagged for weighing.

The location of the collected sample was generated with a random integer generator. Two random numbers were generated for each plot. Beginning at the center of plot 1, the first number indicated whether to travel north or south within the plot. The second number indicated the number of paces required to reach the location of the sample that was collected.

After the samples were collected, the bags were weighed and a subsample was collected and weighed from each bag. Yield was determined from the samples collected. The subsamples were then dried at 65°C, reweighed to determine dry weight, and ground with a 0.5 mm sieve. The ground sample was used to determine nitrogen content in the alfalfa.

Nitrogen Analysis in the Alfalfa

The nitrogen content of the alfalfa was determined using the Kjeldahl digestion method in conjunction with an Alpkem Rapid Flow Analyzer 2. It was determined at the beginning of the experiment that alfalfa contained a concentration of less than 0.5 mg kg-1 nitrate or ammonium. Therefore, the major portion of nitrogen was in organic form. Thus, when Kjeldahl digestions converted the nitrogen to ammonium, it was assumed that the nitrogen removed from the tissue by the Kjeldahl digestions represented the total nitrogen content of the alfalfa.

The concentrations were used with the yield data to determine the total amount of nitrogen removed in the harvest. Manure and compost were also analyzed, as discussed in the following paragraphs. Using a spreader, the amount of nitrogen that was removed in the harvest was added in the form of manure and compost.

Manure and compost were spread by using a tractor pulling a Lakeside All Purpose Spreader, V-style, two-speed with rear discharge. It had a chain driven floor and was powered by a power take-off. In the rear of the spreader were two spinner plates to distribute the manure and compost.

Initially, a plot width of 4.3 m was used because this was the width of alfalfa cut at each harvest. However, it was found that this procedure did not account for the border effects. Alfalfa grew better on the edges of the rows and yields were higher in this part of the plots. Not accounting for the border effect caused the calculated yields to be too high. Therefore, the width of each plot was changed to 6.1 m to account for the border effect.

The change from 4.3 m width to 6.1 m width was made to the protocol in September 2001. Yields were previously calculated by extrapolating what was harvested from the 2.0 m x 4.3 m area. After changes were made, the same harvested area was considered to be 2.0 m x 6.1 m area. This caused a reduction in the calculated yields. As a result, the manure and compost applications prior to September 2001 were in excess of the nitrogen that was removed in the alfalfa. From September 2001 through the end of the project, the adjustment was included in the yield calculations in determining the manure and compost application amounts.

Soil Sample Analysis

Soil samples were taken from the field on three separate dates using a Giddings Probe and a 50.8 mm hollow core sampler. The samples were taken in October 2000, January 2002, and August 2002. Each time, three soil cores were taken from each plot. Thus, 36 soil cores were taken on each date. Each core consisted of a sample taken at a depth of 15, 30, 45, 60, 90, 120, and 150 cm.

All samples were analyzed for NH_4-N, total Kjeldahl nitrogen, NO_3-N, PO_4-P, and electrical conductivity. The total Kjeldahl nitrogen analysis was carried out as previously described. A 2 molar potassium chloride (KCl) extraction was carried out to test for the initial NH_4-N content. The sample was mixed with a 2 molar KCl solution on a stirring rack on high speed for one hour. It was then centrifuged for half an hour and the supernatant was analyzed in the Alpkem using the same procedure previously described to analyze for NH_4-N. This time the concentration represented the NH_4-N originally present in the sample prior to digestion. The concentration of the NH_4-N present in the sample was subtracted from the Kjeldahl nitrogen. The outcome was the organic nitrogen.

Nitrate-N analysis was completed using the same sample extract as prepared with the 2 molar KCl solution. This analysis was also done using the Alpkem. An additional coil containing granulated copper-cadmium was placed in the Alpkem. This coil reduced nitrate to nitrite. The nitrite (originally present plus the reduced nitrate) was measured colorimetrically with sulfanilamide and coupling with N-(1-naphthyl)-ethyledediamine dihydrochloride, which formed the azo dye (United States Environmental Protection Agency, 1983b).

As in the NH_4-N Alpkem analysis, EDTA was added to eliminate interference with other ions. The nitrite output readings then went to the computer where the concentrations were recorded. The dilution factor in the samples was then taken into account and the NO_3-N readings were added to the Kjeldahl nitrogen. The total of NO_3-N plus Kjeldahl nitrogen was the total nitrogen in the sample. The Kjeldahl nitrogen minus NH_4-N equaled the organic nitrogen.

Phosphate-P was extracted from the soil samples by using a buffered 0.5 molar sodium bicarbonate solution with a pH of 8.5. The addition of sodium bicarbonate decreased the chemical activity of calcium, which allowed the activity of the PO_4-P present in the soil sample to increase (Westerman, 1990). Sodium bicarbonate was added to a weighed portion, placed on a stirring rack on high for one hour and then centrifuged for half an hour. The supernatant was decanted and then the extraction solution was analyzed for PO_4-P with the Alpkem.

Electrical conductivity analysis was carried out by first adding deionized water to a weighed portion of the soil sample. It was then placed on the stirring rack at high speed for one hour followed by centrifuging for half an hour. The supernatant was then decanted and analyzed for electrical conductivity using an electrical conductivity electrode (Bremner and Mulvaney, 1982). Soil moisture analysis was done by drying a weighed portion of soil in either tins or paper bags. The samples were placed in an oven at 105°C for 24 hours. Then the samples were reweighed. The gravimetric soil moisture was determined by dividing the weight of water in the soil sample by the weight of the dry sample.

Manure and Compost Analysis

Dairy manure and compost were digested in the same manner as previously described for the alfalfa Kjeldahl digestion. The digested samples of manure and compost contained organic nitrogen that was converted to ammonium plus the ammonium contained in the sample prior to digestion. An analysis of NH_4-N was done on undigested samples as previously described and the readings were subtracted from the Kjeldahl analysis. The Kjeldahl NH_4-N minus the original NH_4-N in the sample yielded the organic nitrogen originally present in the manure and compost.

The NO_3-N content of the manure and compost was also determined by the 2 molar KCl extraction previously discussed. The total Kjeldahl nitrogen plus the NO_3-N equaled the total nitrogen.

Manure and compost were then added in an amount such that the nitrogen in the manure and compost equaled the nitrogen removed in the alfalfa harvest.

Lysimeters

The drainage lysimeters in the field were 2.0 m wide, 1.5 m long, and 1.8 m deep. They were constructed of stainless steel to prevent oxidation and chemical reactions. The lysimeters were installed by filling them with soil in a way that simulated the actual soil profile. They were located approximately 46 cm below the soil surface, which allowed leaching measurements to reach 2.3 m below the soil surface. For further details on installation, see Martin et al. (1999). The drainage water was collected in a stainless steel container. To remove the water from the collection system, the system was pressurized, which forced the leachate out of a drainage tube. Leachate from the lysimeters was analyzed for NO_3-N and PO_4-P content. The concentrations of these components were determined using the Alpkem. The amount of contamination in the leachate was an indicator of the concentration of nitrate and phosphate that was being leached below the root zone into the groundwater.

RESULTS

Alfalfa Analysis

Alfalfa was harvested and analyzed thirteen times throughout the study. Each harvest date is shown in Table 1.

Table 1. Alfalfa harvest number and dates for all plots.

Alfalfa Harvest Number	Alfalfa Harvest Date
#1	04-12-2001
#2	05-22-2001
#3	06-21-2001
#4	07-20-2001
#5	08-20-2001
#6	09-14-2001
#7	11-14-2001
#8	02-14-2002
#9	04-09-2002
#10	05-16-2002
#11	06-17-2002
#12	07-16-2002
#13	08-12-2002

Alfalfa yields for each treatment at each harvest are shown in Figure 2. It can be seen that yields were highest in May, June, and July.

Yields were highest in summer months because growth is optimum between 10°C and 35°C (Hanson et al., 1972). Air temperatures that reach above or below this range cause alfalfa yield reduction. Yet, variations in yield between treatments were minimal. This may have been due to the fact that alfalfa plots not receiving nitrogen through manure or compost treatments were still able to fix nitrogen from the atmosphere. Therefore, the plots not receiving manure or compost were not nitrogen deprived, making all yields similar.

The February 2002 harvest had a small yield. As temperatures began to rise in February, photosynthesis and growth started to increase. However, after the cold winter, the top stems and leaves were dead from freezing. The February cut took off the dead plant tissue and stimulated regrowth. The quality of that cut may have been sacrificed, but the following cuts contained good clean alfalfa.

It can be seen that Figure 6 also shows an unusually high yield for the no nitrogen plots in June 2002. The reason for this is unknown but may be due to human error in weighing or transcription of the data.

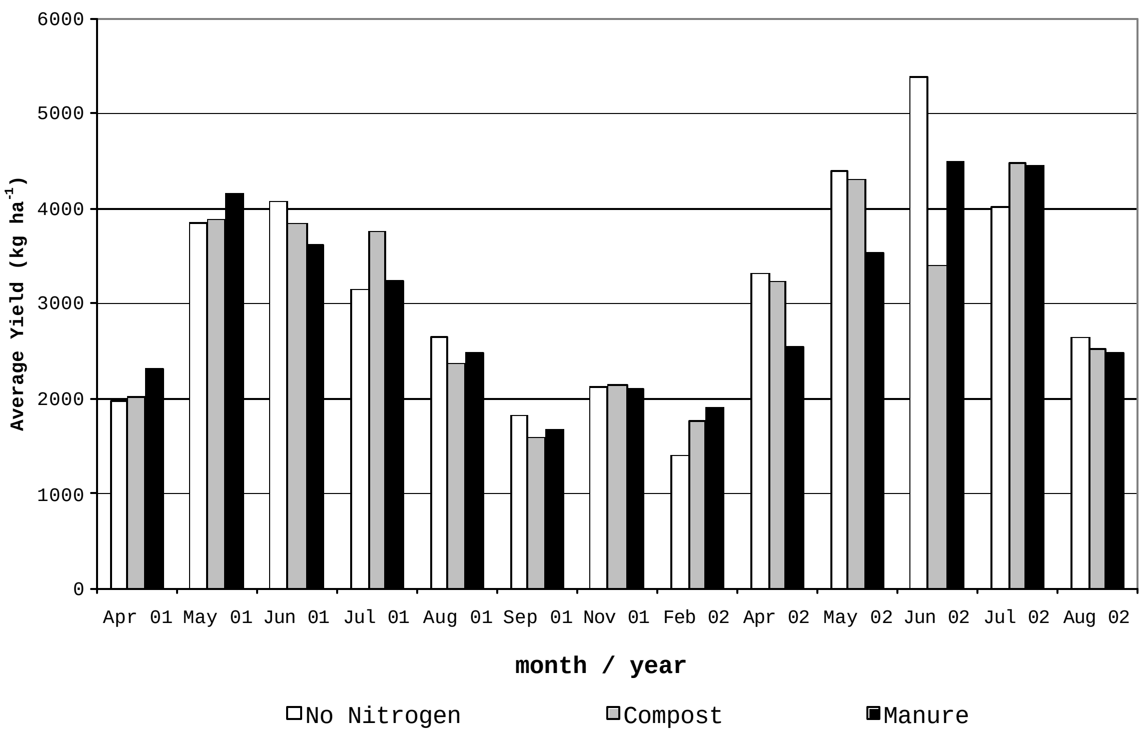

Figure 2. Alfalfa yield for no nitrogen, compost, and manure plots at each individual harvest.

Total alfalfa yield over the entire study is shown in Figure 3. It is interesting to note that the no nitrogen plots had a slightly higher total yield. The higher yield could be attributed to the alfalfa damage caused by the wheels of the tractor and spreader, which was visible during regrowth. Each time manure and compost was spread on the treatment plots, the wheels traveling over the plots damaged the alfalfa in those plots. On the other hand, the no-nitrogen plots did not have equipment traveling over them as often as the manure and compost plots did.

The total nitrogen removed for each treatment at each harvest is shown in Figure 4. It can be seen that no single treatment was consistently higher in nitrogen removed in each harvest. There is no statistical difference between treatments or blocks (a = 0.05). Total nitrogen removed was highest in May, June, and July because harvests were greatest during those months. Total nitrogen removed was found by multiplying the mg kg-1 nitrogen content of alfalfa by the kg ha-1 removed in the harvest.

Figure 5 shows the total amount of nitrogen removed over the entire study. It can be seen that there is no variation in nitrogen removed between the treatments and no statistical difference between treatments (a = 0.05). This, along with Figure 3, is an indication that the nitrogen and other nutrients supplied by the manure and compost did not significantly change the yield or nitrogen content in the alfalfa.

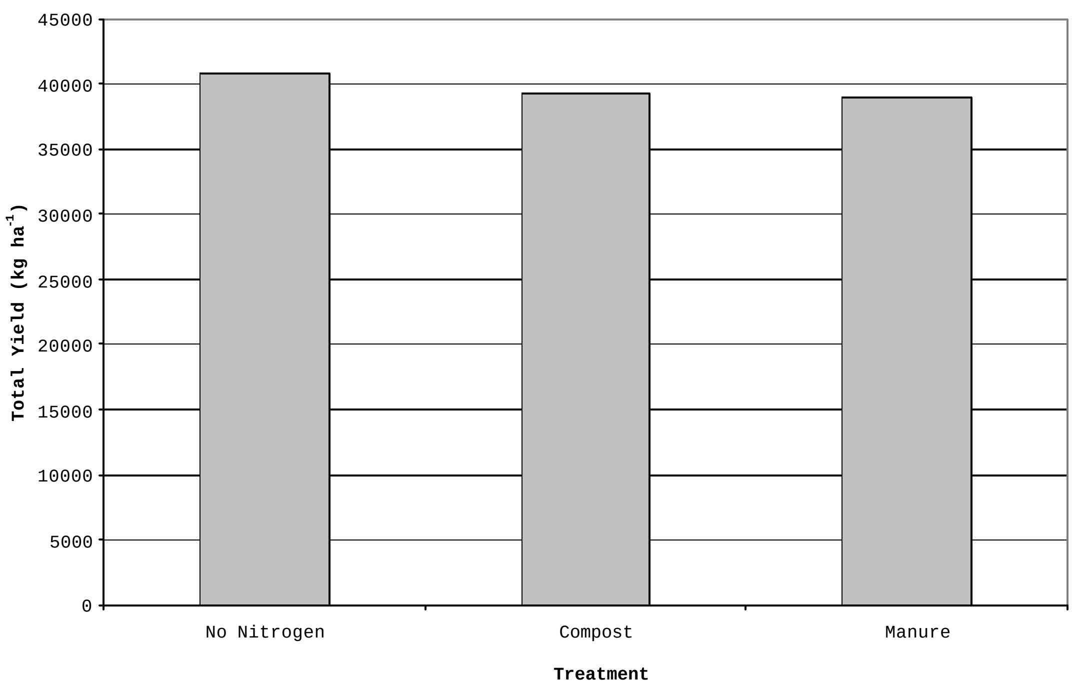

Figure 3. Total alfalfa yield for no nitrogen, compost, and manure plots over the entire study period.

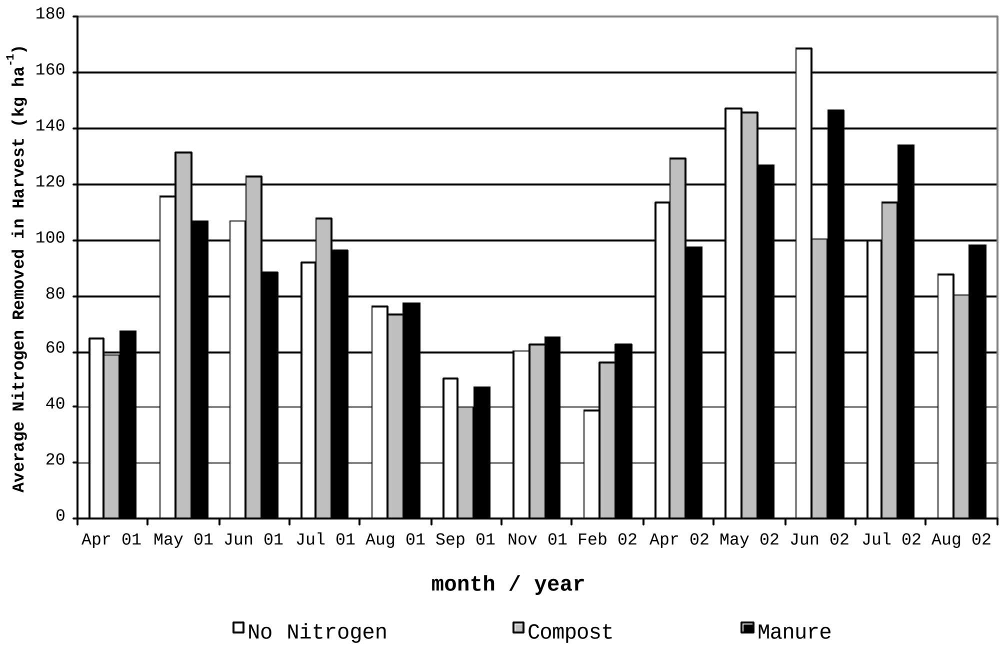

Figure 4. Average nitrogen removed in each alfalfa harvest for no nitrogen, compost, and manure plots at each individual harvest.

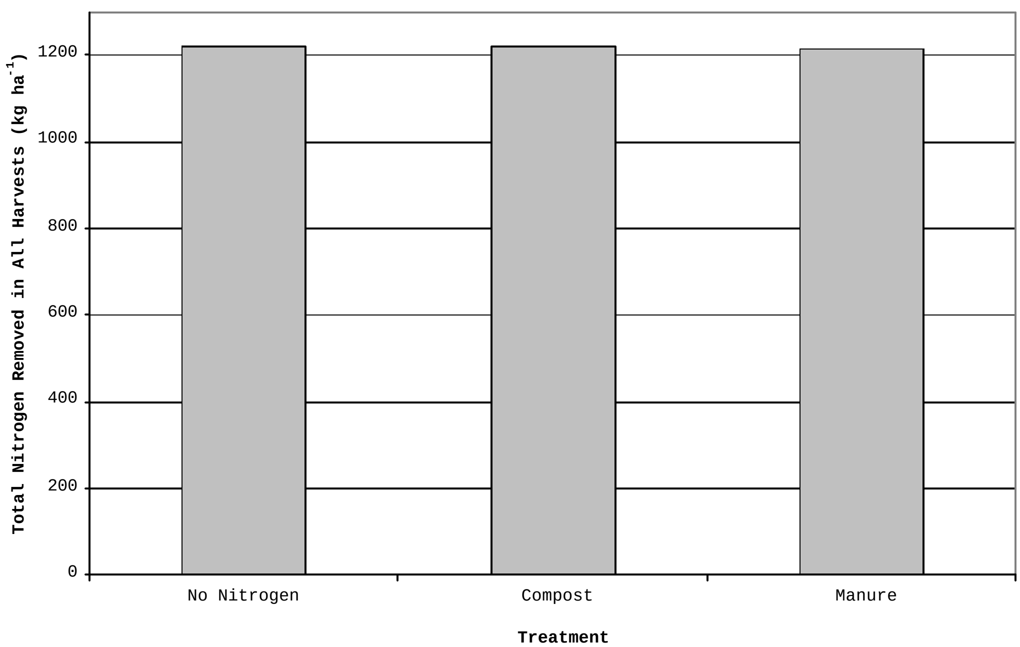

Figure 5. Total nitrogen removed in no nitrogen, compost, and manure plots over the entire study period.

Irrigation

Irrigations were scheduled approximately one week before harvest to allow the field to dry so that the harvest equipment could maneuver in the field. The total irrigation depth applied over the study period was 394.3 cm. The total rainfall over the study period was 21.0 cm.

Soil Sample Analysis

Soil samples were taken before, during, and after the study in October 2000, January 2002, and August 2002. A subsample was taken from each sample to determine gravimetric soil moisture. Additionally, textural analysis was performed on the August 2002 soil samples. Figures 6, 7 and 8 show the total nitrogen that was in the soil on these three dates.

Before the study began, there was more nitrogen in the no nitrogen plots. As the study proceeded, the nitrogen levels increased in the manure and compost plots and decreased in the no nitrogen plots, with most nitrogen in the shallow depths of the soil. Higher nitrogen in the shallow depths of the manure and compost plots was most likely due to the topdressing of the manure and compost.

In August 2002, the compost plots had a large increase in nitrogen with increases deep in the soil profile. Since the compost was finer than the manure, it is possible that compost worked down through the soil cracks into the depths, resulting in relatively higher nitrogen content throughout the soil profile.

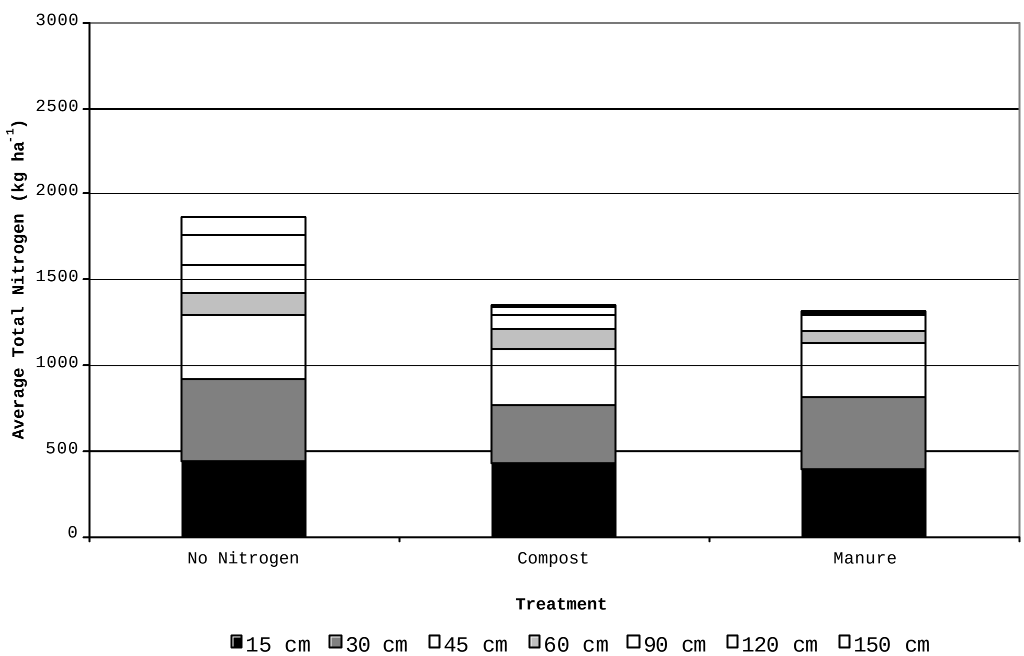

Figure 6. October 2000 total nitrogen in the soil by depth.

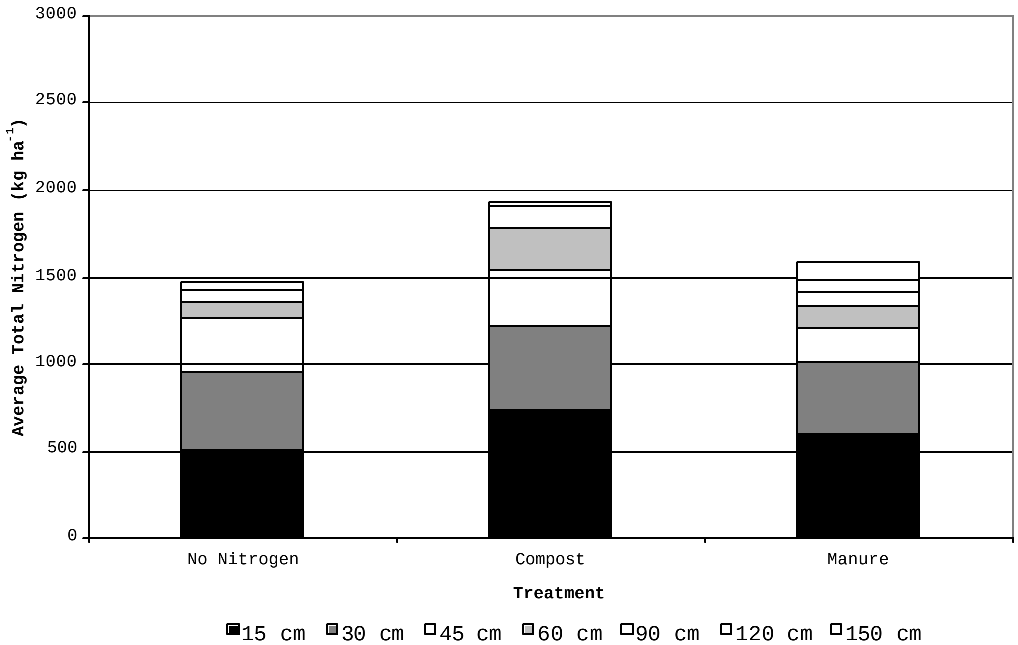

Figure 7. January 2002 total nitrogen in the soil by depth.

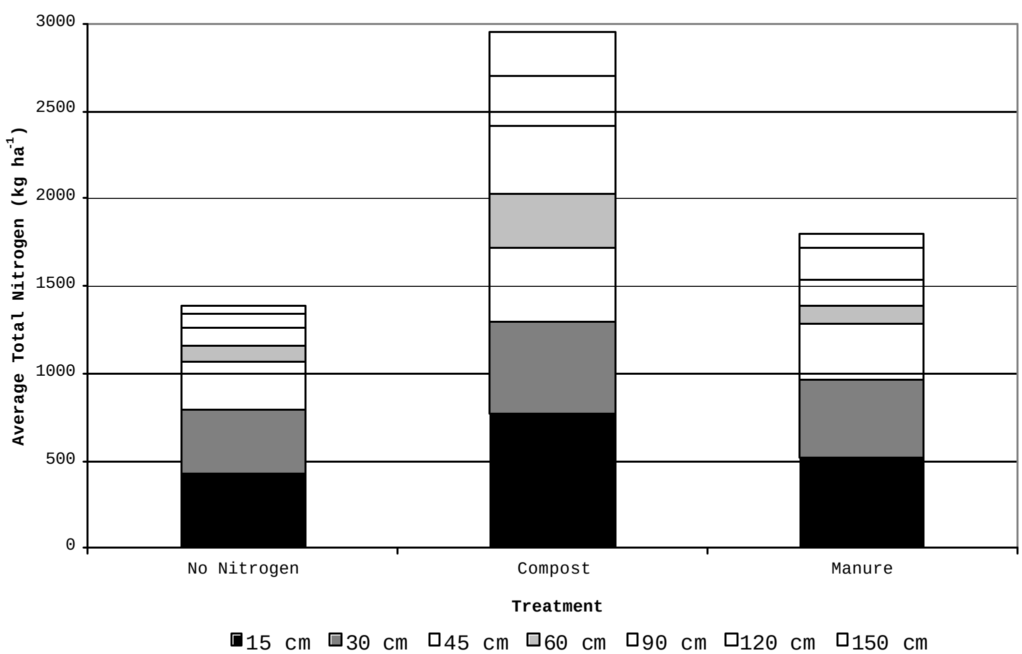

Figure 8. August 2002 total nitrogen in the soil by depth.

The lower nitrogen levels in the manure treatment plots and the higher levels in the compost treatment plots may be due to the application method of the treatments. The compost was finely ground and probably incorporated into the soil profile more readily. The manure was not finely ground and could be seen on the top of the soil throughout the study. Therefore, some portion of the manure may have been physically removed in harvest or dried and blew away. Also, much of the ammonium present in the manure may have volatilized. This would have removed a quantity of the nitrogen that was applied after each harvest. Hence, the better incorporation of the compost into the soil profile may have led to the higher nitrogen levels in the compost treated plots and a similar level between the manure and no nitrogen plots.

It is important to note that there were significant differences between the compost treatment and the no nitrogen and manure treatment for total soil nitrogen content but not between the no nitrogen and the manure treatment. This indicates no effect on soil nitrogen from the manure applications, reinforcing the notion that somehow the manure was lost.

Figures 9, 10, and 11 show the NH_4-N content in the soil throughout the study. It can be seen from the October 2000 graph that NH_4-N in the soil was low in the beginning with levels at or below 5 kg ha-1.

In January 2002, it had been since November 2001 that there had been a nitrogen application. The alfalfa was still growing but mineralization rates were low, slowly replacing nitrate taken up by the alfalfa. Thus, NH_4-N levels were slightly lower in the January 2002 samples.
The third soil sample showed an increase in NH_4-N in all treatments. This may be due to seasonal variations where warmer temperatures caused nitrogen to turnover.

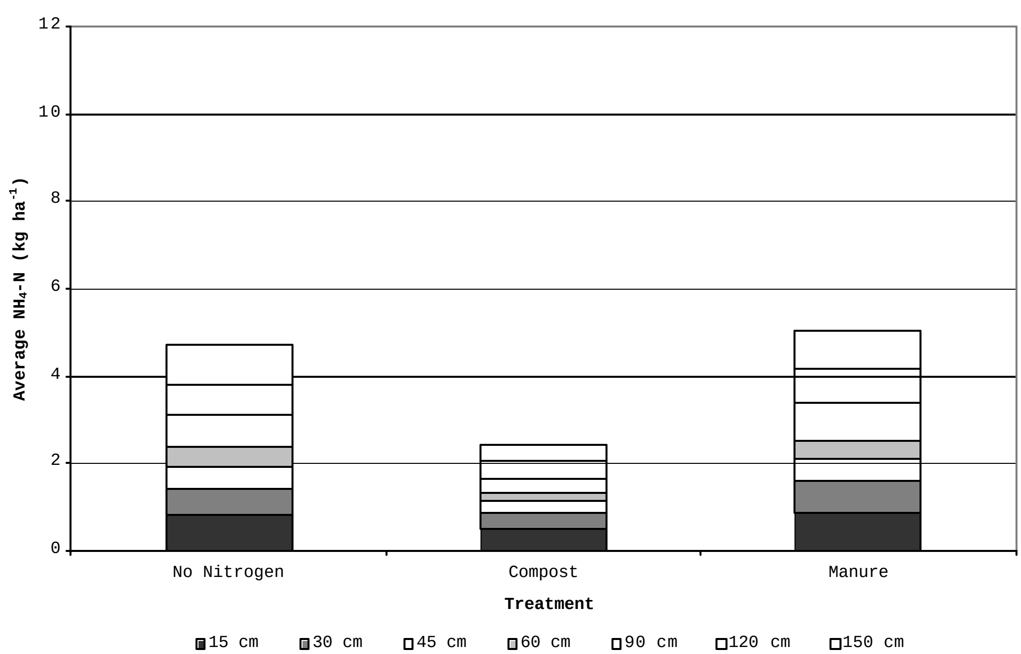

Figure 9. October 2000 NH_4-N in the soil by depth.

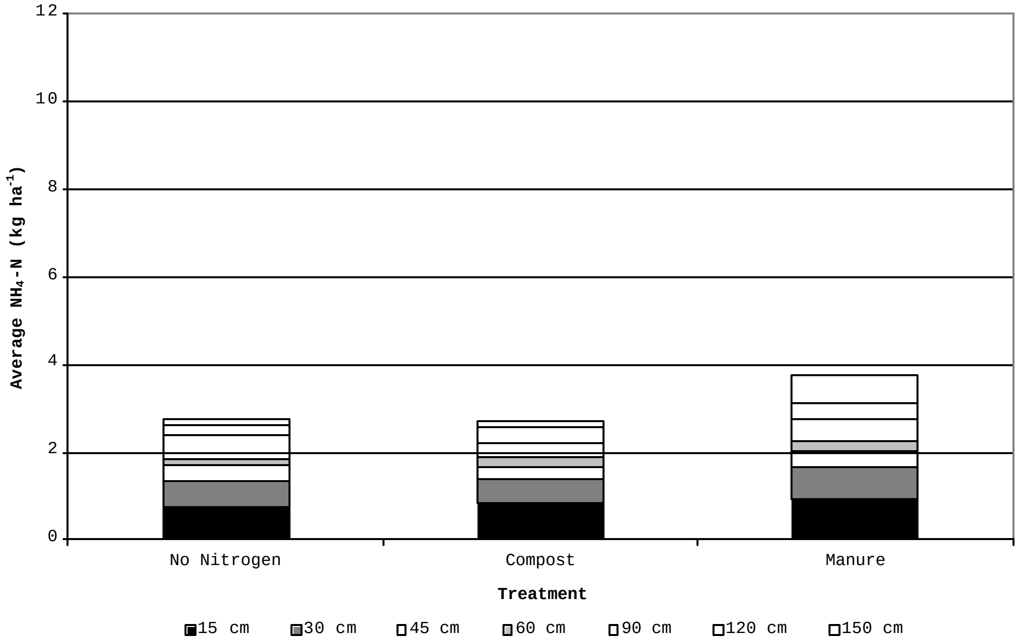

Figure 10. January 2002 NH_4-N in the soil by depth.

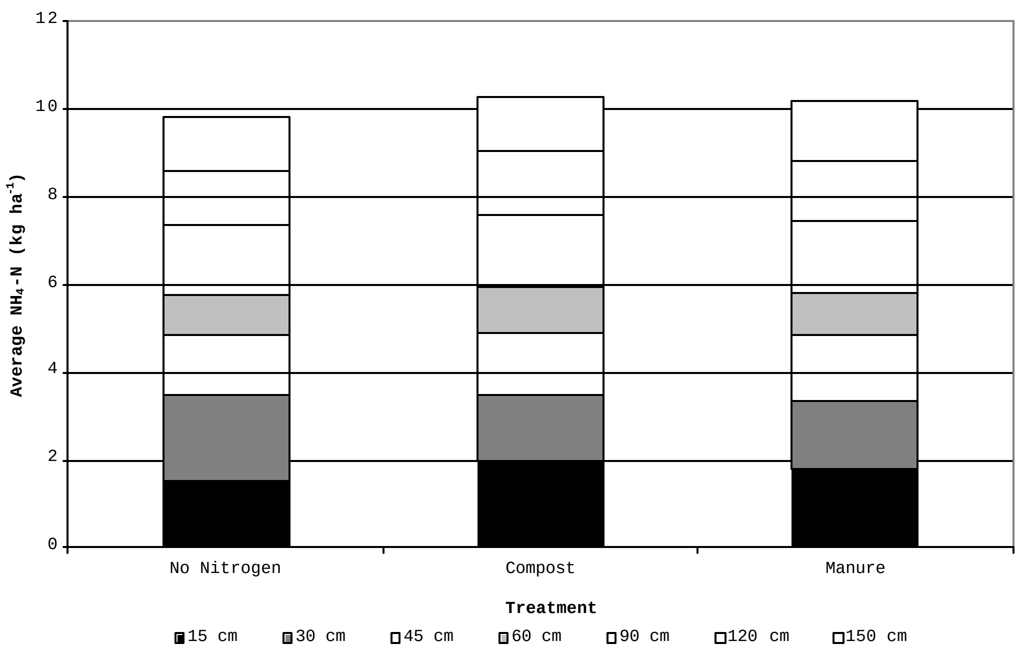

Figure 11. August 2002 NH_4-N in the soil by depth.

The NH_4-N levels in the soil were low in all samplings and the variations seen in the three collections may be due to cyclical variation of NH_4-N in soil throughout warmer and cooler times of the year. Also, there was no significant treatment effect on NH_4-N levels in the soil. Nitrate is the primary source of nitrogen for alfalfa usually because of its rapid mineralization from ammonium (Foth and Ellis, 1988). Nitrate-N levels are shown in Figures 12, 13, and 14.

Nitrate-N concentration in the soil during the first sampling was the highest of the three samples, although the differences were not significant between treatments. This may be due to the fact that the previous wheat crop was turned under and then the field was dormant for about six months. Prior to sampling, the field was irrigated to soften the soil to ease sampling. This could have activated mineralization of the wheat straw in the soil (Foth and Ellis, 1988). Therefore, soil NO_3-N levels increased.

In January 2002, temperatures were low and mineralization rates were also low. Yet the alfalfa was still growing and taking up nitrogen. Consequently, there was very little NO_3-N in the soil during the winter sampling. There was a treatment difference for the January nitrate content that occurred between the no nitrogen and the manure treatments.

In August 2002, the mineralization rates were higher due to the warmer temperatures. It can be seen that the plots receiving manure and compost had higher NO_3-N content than the no nitrogen plots. The differences between the no nitrogen and the compost and manure treatments were significant. However, between the compost and manure treatments there was no significance. In spite of the seemingly high levels, the total nitrate residual is far lower than many others have found in manure studies. Davis et al. (1997) had residual levels exceeding 300 kg ha^{-1}. Schmitt et al. (1994) reported similar results with over 300 kg ha-1 NO_3-N remaining in the soil.

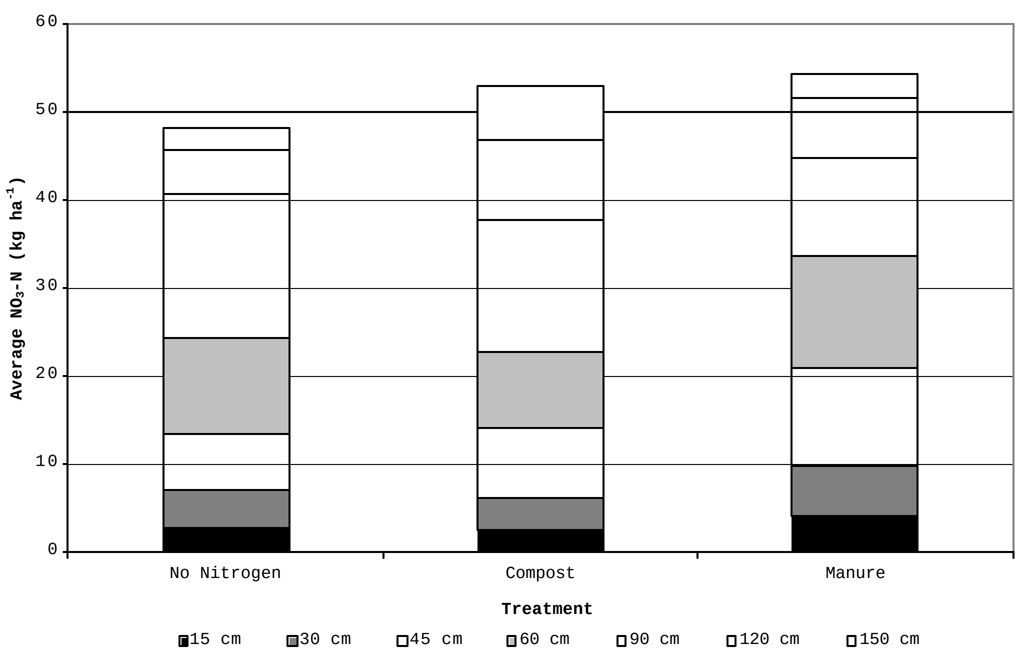

Figure 12. October 2000 NO_3-N in the soil by depth.

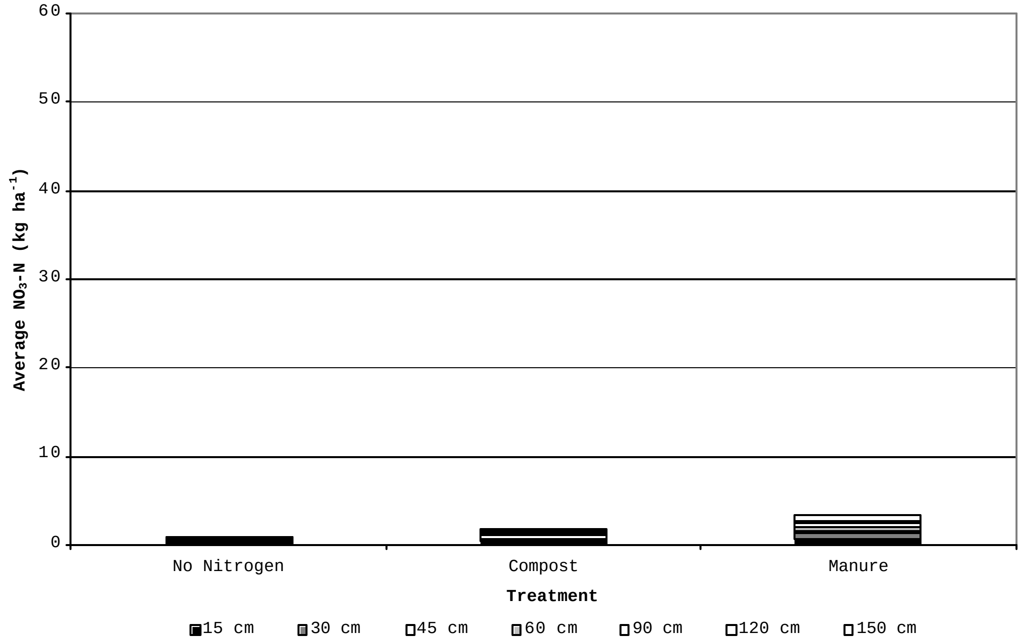

Figure 13. January 2002 NO_3-N in the soil by depth.

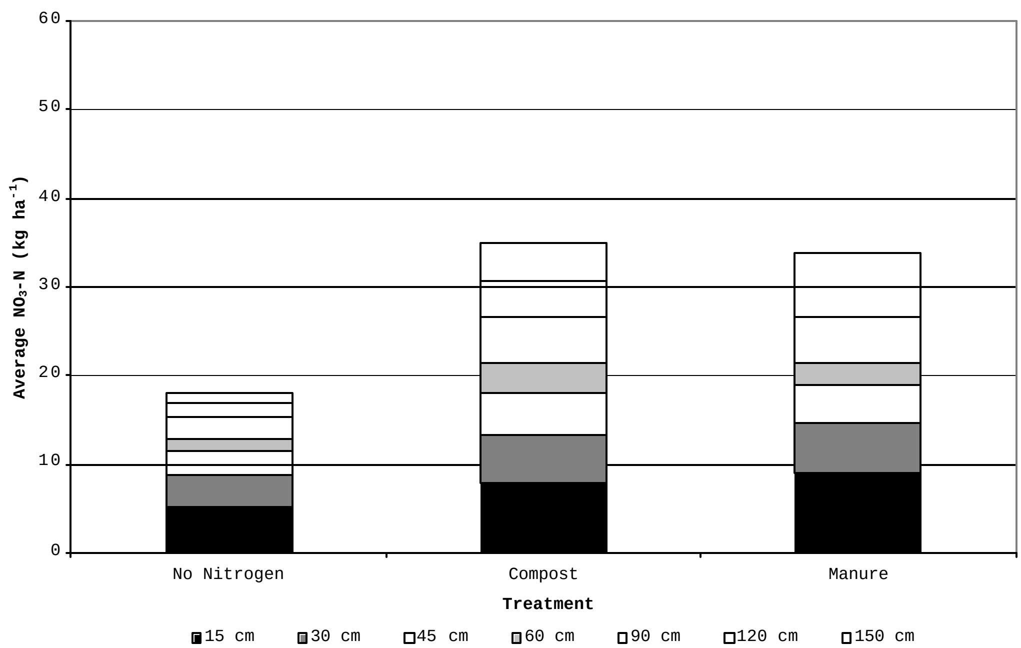

Figure 14. August 2002 NO_3-N in the soil by depth.

Total nitrogen minus NO_3-N minus NH_4-N equals organic nitrogen. Figures 15, 16, and 17 show the organic nitrogen content in the soil. Since NO_3-N and NH_4-N never exceeded 100 kg ha-1 and total nitrogen was at least one order of magnitude greater, the organic nitrogen and total nitrogen graphs resemble each other very closely. This means that nearly all the total nitrogen found in the soil was in organic form.

This can be seen in the January 2002 total nitrogen and organic nitrogen figures. At that time during the year, temperatures were low and bacteria converting organic nitrogen into ammonium and then nitrate metabolized nitrogen at a slower rate during this time. Both NO_3-N and NH_4-N were less than 4 kg ha-1 in January 2002 and total nitrogen was approximately 1500 to 2000 kg ha-1. Thus, the total nitrogen was almost entirely organic nitrogen as can be seen by comparing Figure 7 to Figure 16.

As in the total nitrogen figures, the manure treatment plots may have lost nitrogen through bailing, etc., causing a lower organic nitrogen level than in the compost plots.

The August 2002 sample data in the compost treated plots show results similar to James et al. (1996). In this study, a twofold increase in organic matter was reported in treated plots, which is similar to the difference in the no nitrogen and compost treated plots.

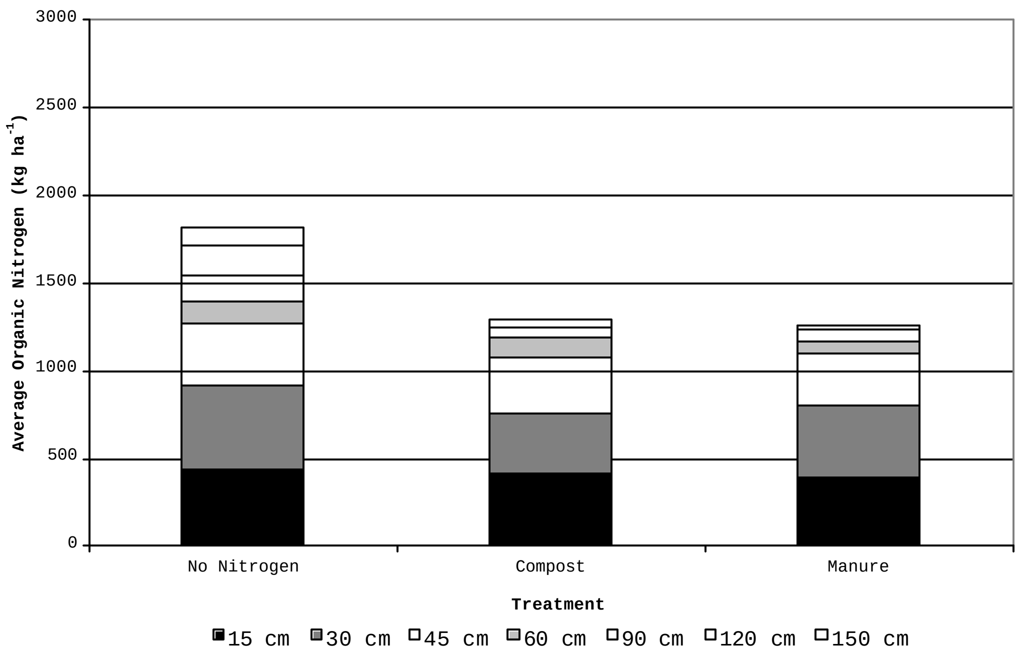

Figure 15. October 2000 organic nitrogen in the soil by depth.

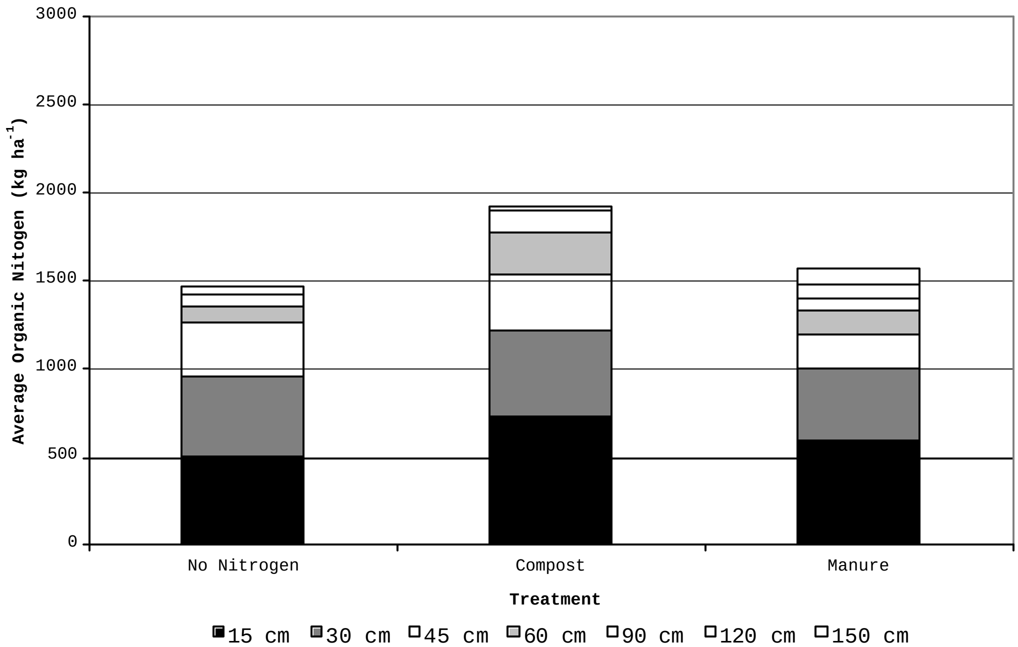

Figure 16. January 2002 organic nitrogen in the soil by depth.

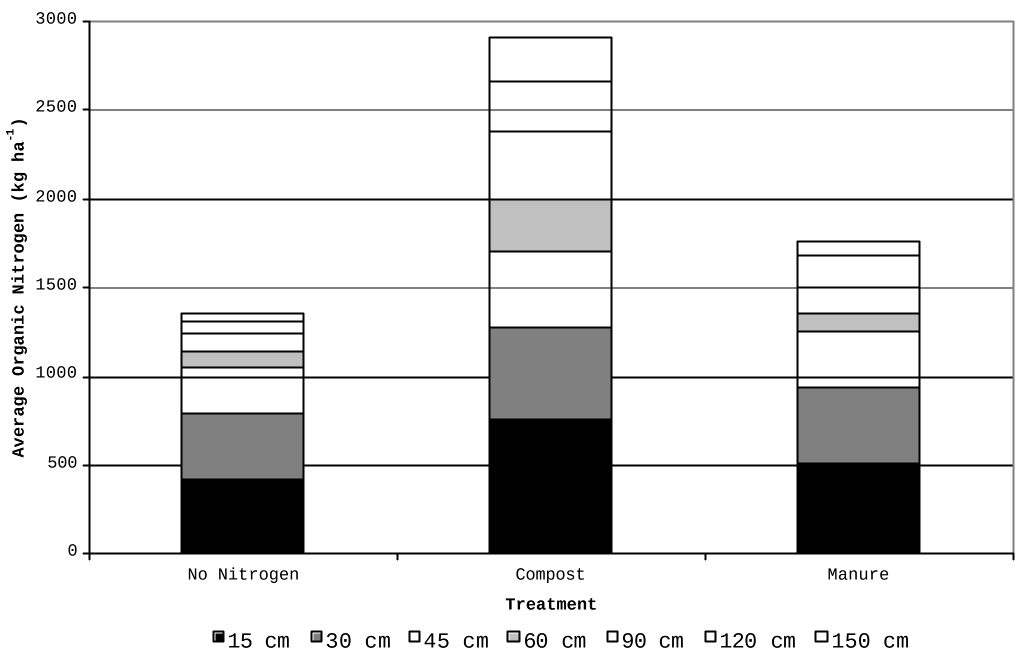

Figure 17. August 2002 organic nitrogen in the soil by depth.

Results of this study showed a much lower increase in organic nitrogen than results reported by Chang and Janzen (1996), where manure applications were done long-term. They found that the net increase in organic nitrogen (over control) in irrigated treatments were 5,900, 8,800 and 10,300 kg nitrogen ha-1 after about 20 years of manure applications.

Statistical analysis of the organic nitrogen levels showed a direct correlation to the total nitrogen content. Significant differences between dates and treatments were exactly the same as those found for the total nitrogen content.

Phosphate-P levels in the soil can be seen in Figures 18, 19, and 20. In October 2000, before the study began, the PO_4-P level in the soil was similar in all plots. However, the lower levels in the no-nitrogen treatment were significant when compared to the levels in the other two treatments.

By January 2002, the addition of PO_4-P in the compost and manure caused the soil PO_4-P levels to increase over the no nitrogen plots. This increase was significant between all treatments
.
In August 2002, it can clearly be seen that the addition of compost and manure had affected the soil PO_4-P level. More PO_4-P was applied to the manure treatment plots than to the compost treatment plots. However, the compost treatment plots had a higher PO_4-P level in the soil throughout the study.

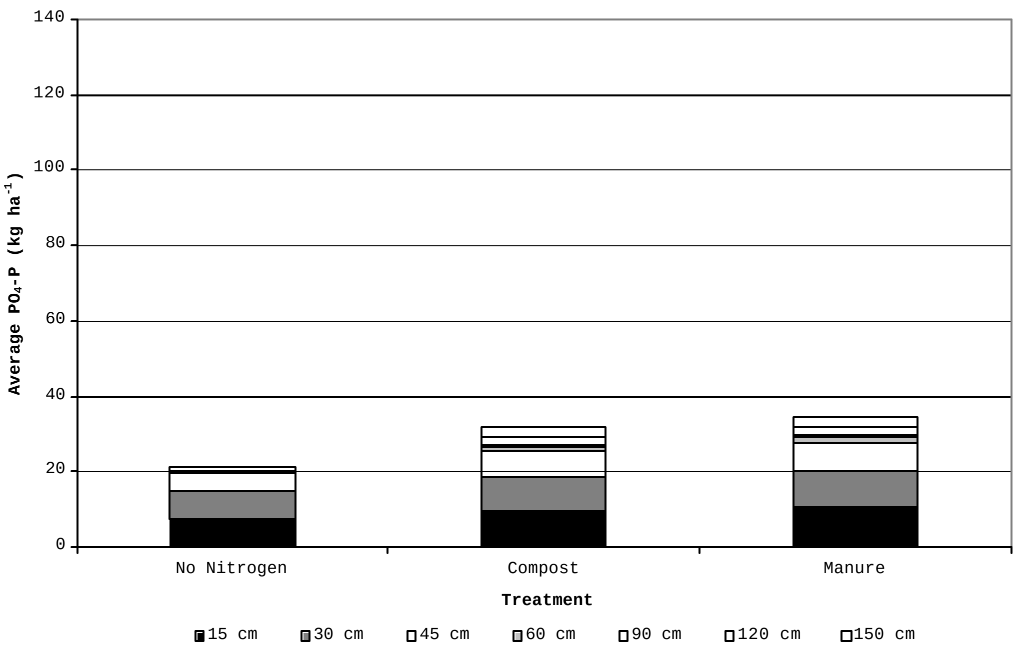

Figure 18. October 2000 PO_4-P in the soil by depth.

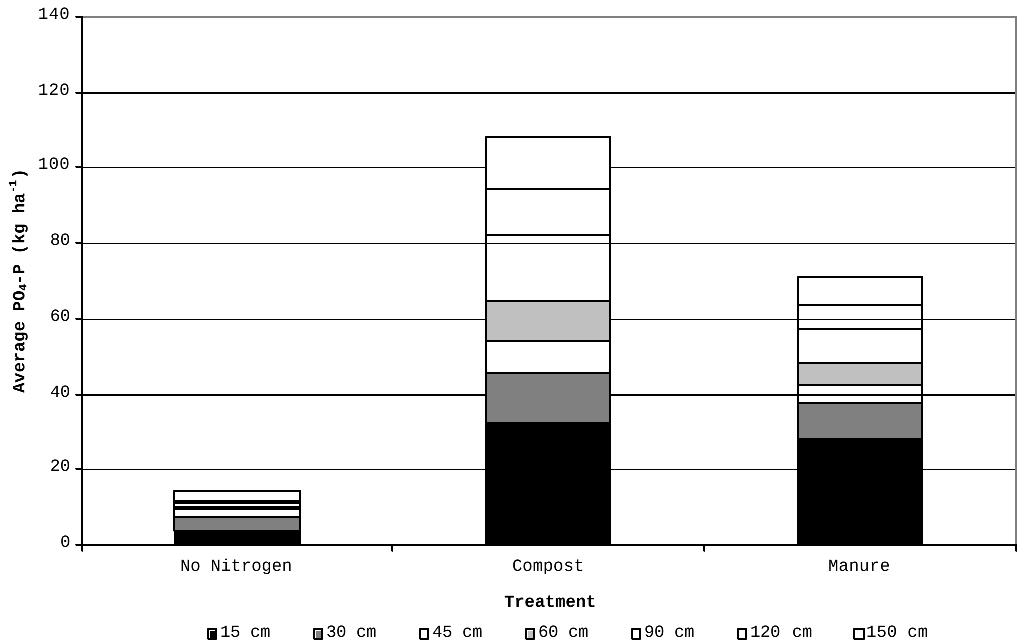

Figure 19. January 2002 PO_4-P in the soil by depth.

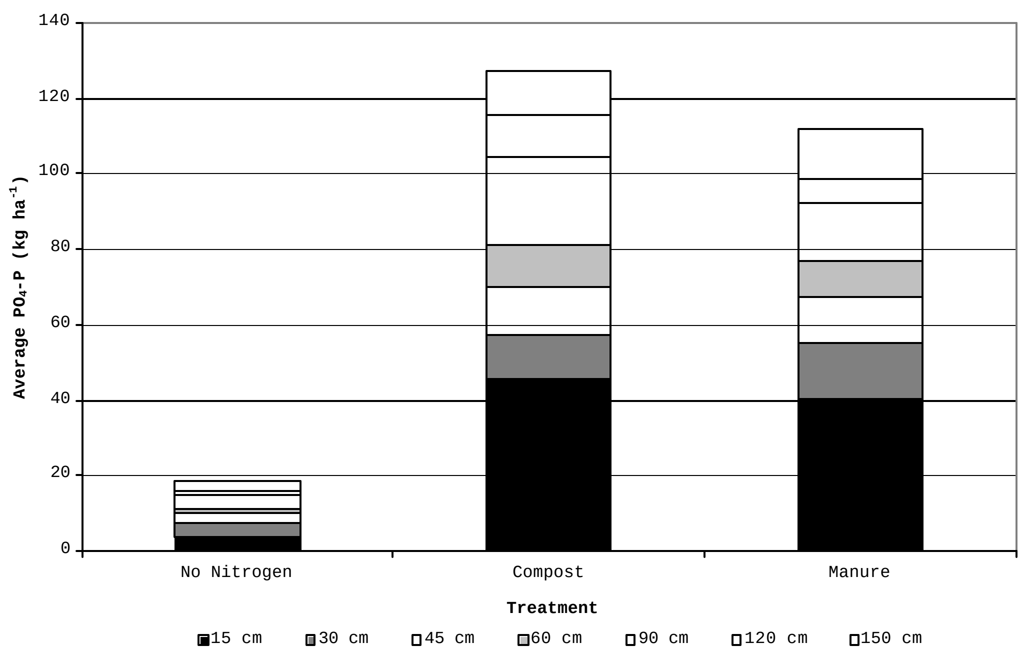

Figure 20. August 2002 PO_4-P in the soil by depth.

The lower PO_4-P levels in the manure treatment plots and the higher levels in the compost treatment plots may be due to the application method of the treatments. The compost was finely ground and may have incorporated itself into the soil profile with irrigation water. The manure was not finely ground and could be visually seen on the top of the soil. Therefore, the manure may have been physically removed in harvest. Hence, the better incorporation of the compost into the soil profile may have led to the higher PO_4-P levels in the compost treated plots. Although it should be noted that the difference between the PO_4-P levels in the compost and manure treatments was not significant in the August 2002 sampling.

Although the exact mechanism is not known, there was a considerable increase in PO_4-P levels at the 150 cm depth. This was quite significant because it indicated phosphorous movement in a calcareous phosphorous fixing soil.

Results of this study show less of an increase in soil phosphorous than a study by Sanderson and Jones (1997). They report that the extractable phosphorous in their study began around 30 kg ha-1 in the surface 15 cm of soil. After three years of manure application, the level had reached approximately 125 kg ha-1.

A longer-term study indicated that this increasing phosphorous trend would continue. Whalen and Chang (2001) reported that after a sixteen-year study, available phosphorous in irrigated manure treated plots showed a large increase over the control. Available phosphorous to 150 cm depth increased 1,200 to 2,900 kg ha-1 over control soils.

Electrical conductivity (EC) levels can be seen in Figures 21, 22, and 23. At the beginning of the experiment, EC levels were high, especially at the greater depths. This may be because the

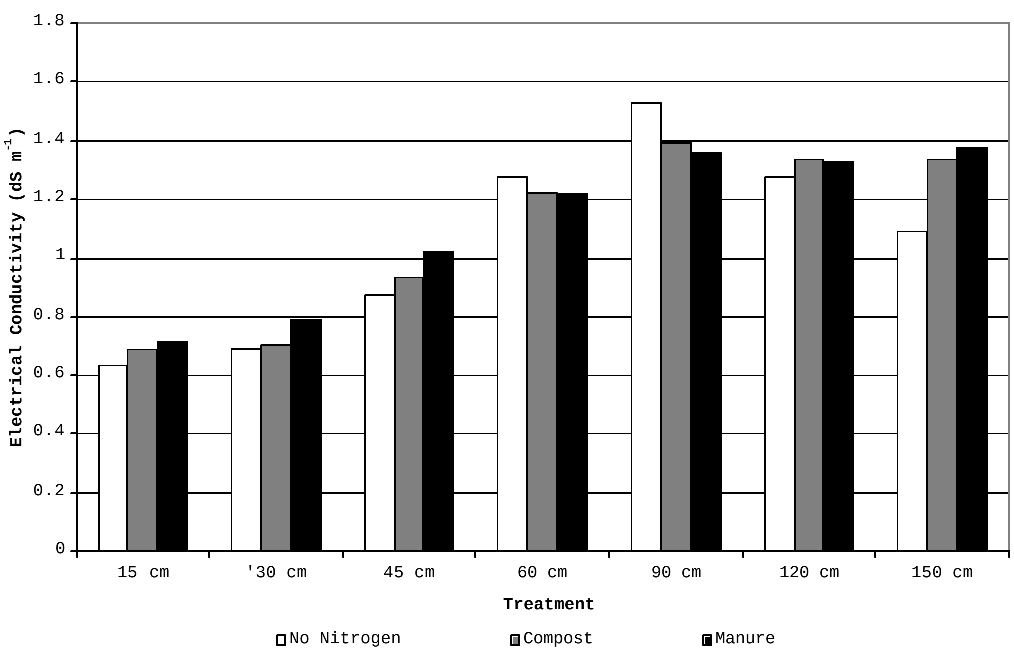

Figure 21. October 2000 electrical conductivity in the soil by depth.

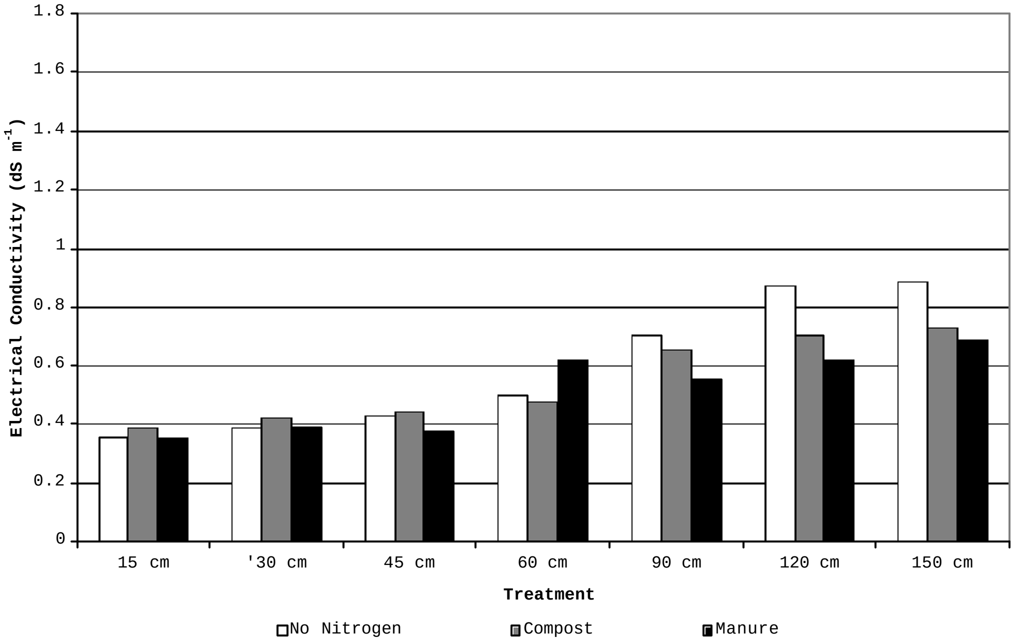

Figure 22. January 2002 electrical conductivity in the soil by depth.

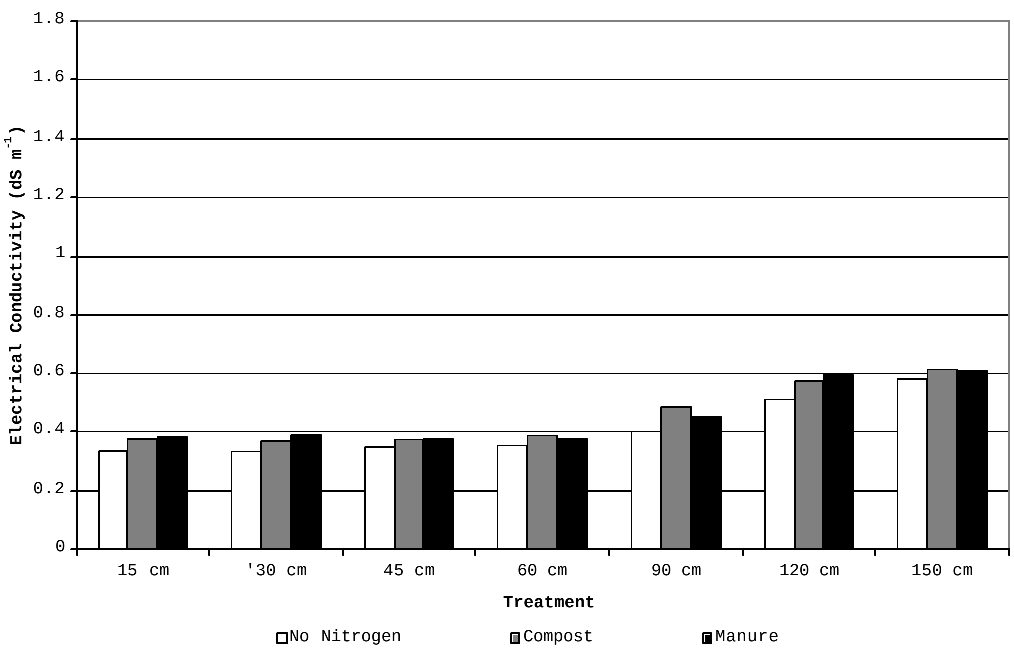

Figure 23. August 2002 electrical conductivity in the soil by depth.

previous crop of wheat had relatively shallow roots compared to alfalfa. Irrigation amounts were applied in such a way to irrigate just past this shallower root zone. This would have pushed salts in the soil just past the root zone. Therefore, salts would have accumulated starting around the

60 cm depth and deeper. Also, the lack of significant rainfall during the 2000 to 2001 period may have contributed to the immobility of the salt deposits.

By January 2002, the deeper alfalfa irrigations had pushed the dissolved solids past the 150 cm measurement zone. Therefore, EC levels greatly decreased throughout the soil profile.
By the end of the project, it can be seen that the manure and compost treated plots did not have a significant increase EC in the soil over the no nitrogen plots. Statistical analysis showed significant treatment differences only occurred in the January 2002 sample between the no nitrogen and the manure treatment plots. However, all differences were significant between dates for all treatments except the manure and compost for the last two sampling dates. Also, EC levels at the end of the experiment were below the threshold of 4 dS m-1 proposed by Kiely (1997).

Eghball et al. (2002) found an increase of 0.1 dS m-1 over the control in a forty-year study in the top 10 cm of soil. This increase was similar to the increase found in the August 2002 EC levels at the 15 cm depth, which was slightly less than 0.1 dS m-1.

Davis et al. (1997) reported that a field receiving manure for several years in sandy soil had EC levels of approximately 0.75 dS m-1 from 0 to 20 cm, 0.75 dS m-1 from 20 to 60 cm, 0.50 dS m-1 from 60 to 90 cm, and 0.40 dS m-1 from 90 to 120 cm. Except for the 90 to 120 cm depth, the results of Davis et al. (1997) were higher than the end results of this study.

Manure and Compost Analysis

Manure and compost were analyzed for total nitrogen content before each application date shown in Table 2. In addition to nitrogen analysis, five manure and five compost samples were analyzed for PO_4-P and total dissolved solids, shown in the following figures.

Table 2. Manure and compost application dates.

Manure/Compost Application Number	Application Date
#1	11-15-2000
#2	04-20-2001
#3	05-29-2001
#4	06-27-2001
#5	07-25-2001
#6	08-23-2001
#7	09-19-2001
#8	11-20-2001
#9	02-21-2002
#10	04-15-2002
#11	05-21-2002
#12	06-20-2002
#13	07-19-2002

Table 3 shows the total nitrogen content of manure and compost used for each individual application. It can be seen that the manure was typically higher in total nitrogen than the compost. This was probably due to the loss of nitrogen in composting from volatilization of ammonia into the atmosphere.

Table 3. Manure and compost total nitrogen content.

Manure/Compost Application Date	Manure mg kg-1	Compost mg kg-1
11-15-2000	15521	7244
04-20-2001	13820	7399
05-29-2001	13178	14263
06-27-2001	25832	15712
07-25-2001	20183	21220
08-23-2001	16120	13775
09-19-2001	9875	13377
11-20-2001	17857	16319
02-21-2002	12023	12517
04-15-2002	12732	8755
05-21-2002	14225	11979
06-20-2002	11418	7812
07-19-2002	15311	9690

Table 4 shows the amount of manure and compost applied to each plot for each individual treatment. The amount to be applied was determined by analyzing the total nitrogen contained in the alfalfa removed in harvest. The total nitrogen in manure or compost was determined and added in an amount so as to equal the nitrogen removed in the alfalfa harvest. Since the nitrogen removed in each treatment was similar and the compost had lower nitrogen content, compost applications were usually larger than manure applications. This can be seen in Table 4.

Table 4. Amount of manure and compost applied to each plot.

Application Date	Manure Applied (kg ha-1)	Compost Applied (kg ha-1)
11-15-2000	2279	5941
04-20-2001	11057	15044
05-29-2001	26475	26692
06-27-2001	4302	6510
07-25-2001	8615	8138
08-23-2001	27940	34558
09-19-2001	4639	3461
11-20-2001	7595	13997
02-21-2002	5197	4763
04-15-2002	5821	12516
05-21-2002	5658	7921
06-20-2002	7785	7297
07-19-2002	6310	9565
Total	123,673	156,403

Table 5 corresponds to Figure 24. It shows the total nitrogen applied to each plot on each application date. These amounts were found by multiplying the nitrogen content of manure and compost by the amount applied. After unit conversions, the total nitrogen applied to each plot on each application date was found.

Figure 24 shows that the amount of total nitrogen supplied by the manure and compost to the plots were similar for each harvest. This was due to the fact that the amount of nitrogen removed in harvest was similar for each treatment. Therefore, the nitrogen replaced in each harvest was similar.

Table 5. Total nitrogen applied to each plot on each individual application date.

Application Date	Manure Applied (kg ha-1)	Compost Applied (kg ha-1)
11-15-2000	35	43
04-20-2001	153	111
05-29-2001	349	381
06-27-2001	111	102
07-25-2001	174	173
08-23-2001	450	476
09-19-2001	46	46
11-20-2001	136	228
02-21-2002	62	60
04-15-2002	74	110
05-21-2002	80	95
06-20-2002	89	57
07-19-2002	97	93
Total	1856	1975

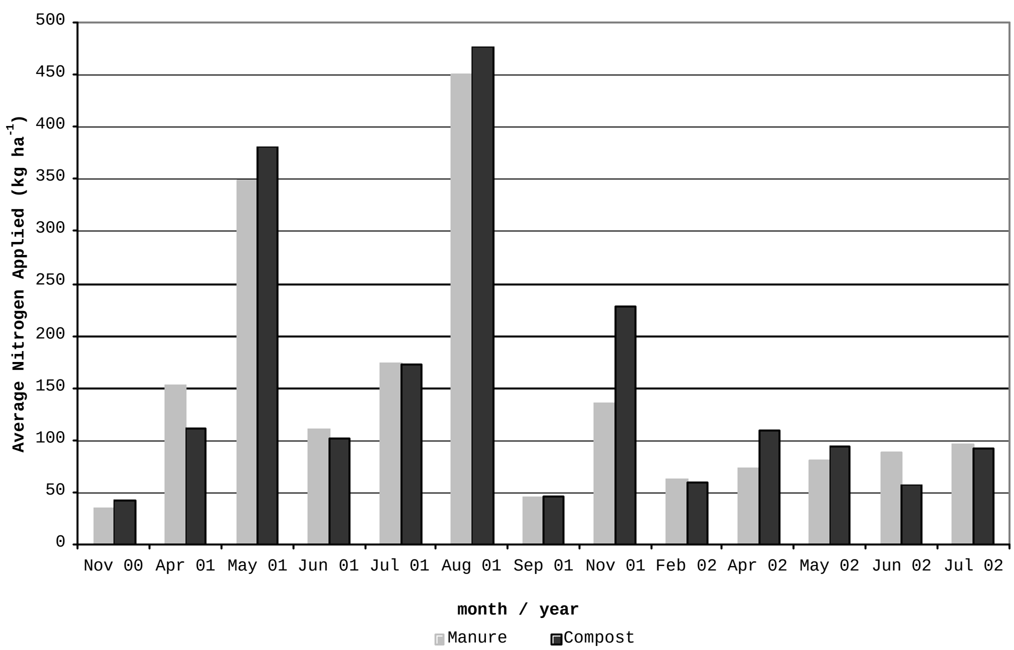

Figure 24. Total nitrogen applied during the application of manure and compost.

Figure 25 shows the NO_3-N applied during each application. Since compost had been mixed with plant material and had been allowed to sit over a period of time, the nitrogen had been mineralizing and converted to nitrate during that time. Manure was fresh and did not have time for mineralization and therefore had lower NO_3-N levels.

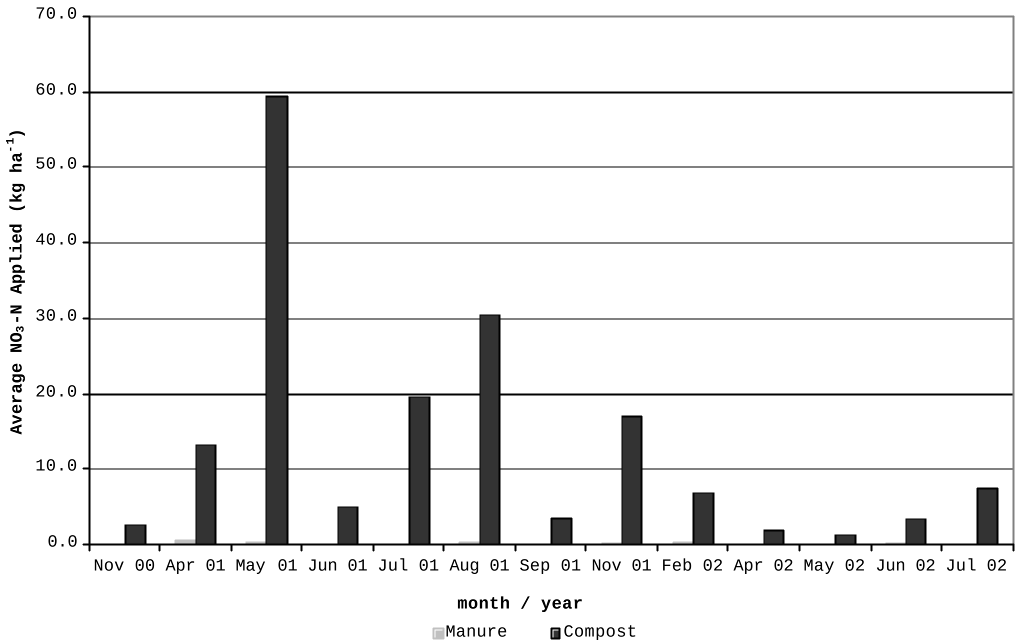

Figure 25. Nitrate-N applied during each application of manure and compost.

Figure 26 shows the NH_4-N applied in each application. Compost had lower levels of NH_4-N because volatilization of ammonia in composting decreased NH_4-N levels. The manure was fresh and had not volatilized as the compost did. Therefore, manure consistently had higher NH_4-N levels.

Figures 27 and 28 show manure and compost PO_4-P and electrical conductivity of the following five samples: November 2001, May 2001, August 2001, October 2001, and July 2002. Phosphate-P and electrical conductivity were higher in manure than in the compost samples. This is because compost essentially began as manure, with the same concentration of PO_4-P and electrical conductivity as manure. It was then diluted with other materials, usually plant materials, and was mixed for composting. The addition of plant materials lowered the levels of PO_4-P and electrical conductivity in the compost. Therefore, the manure applied contained a higher concentration of both of these components.

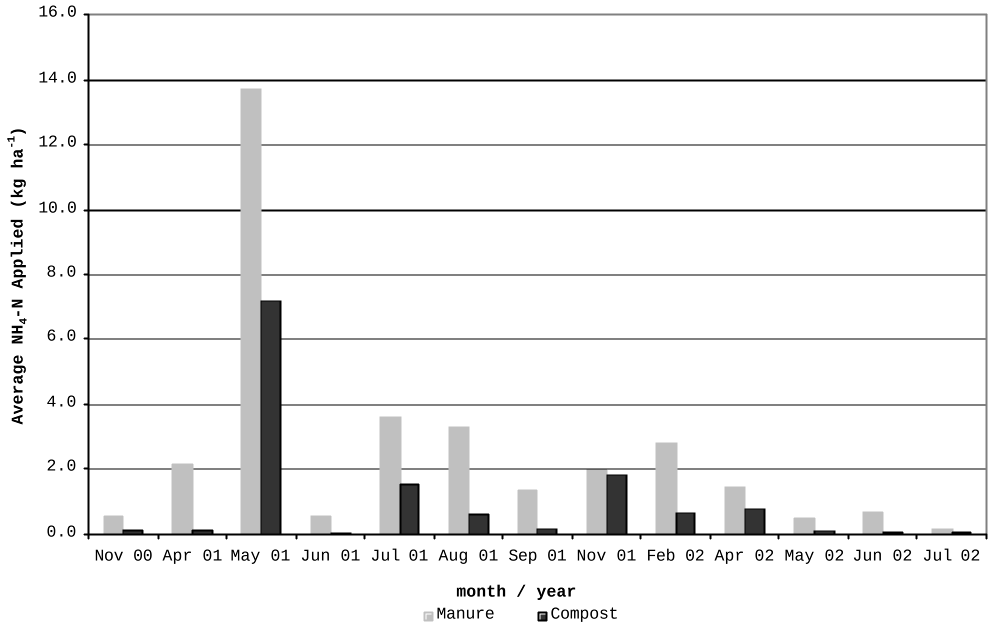

Figure 26. Ammonium-N applied during each application of manure and compost.

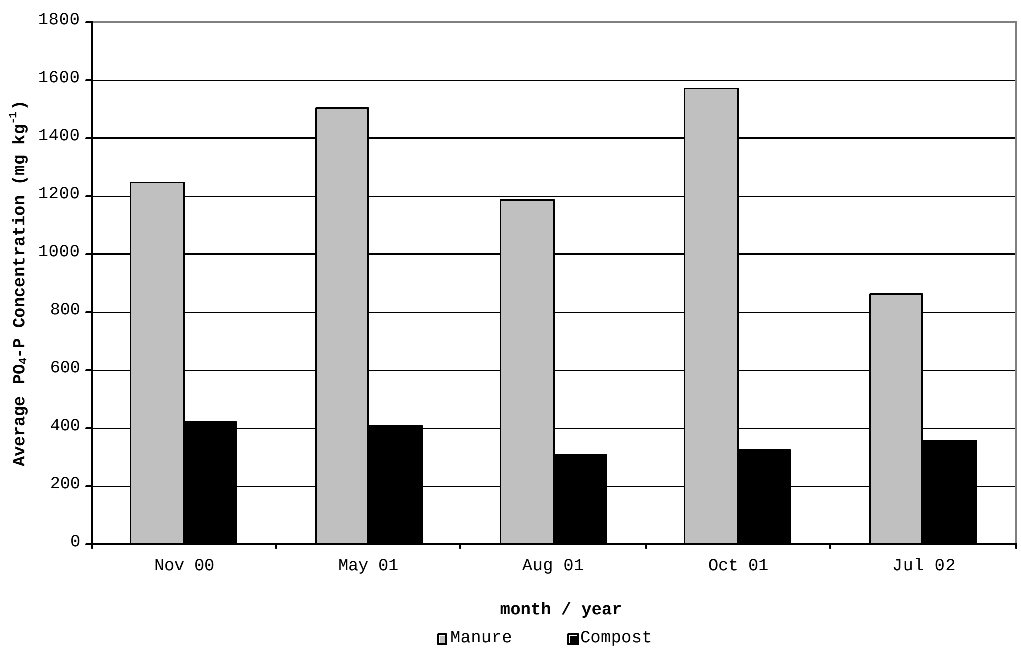

Figure 27. Manure and compost PO_4-P concentration contained in five samples.

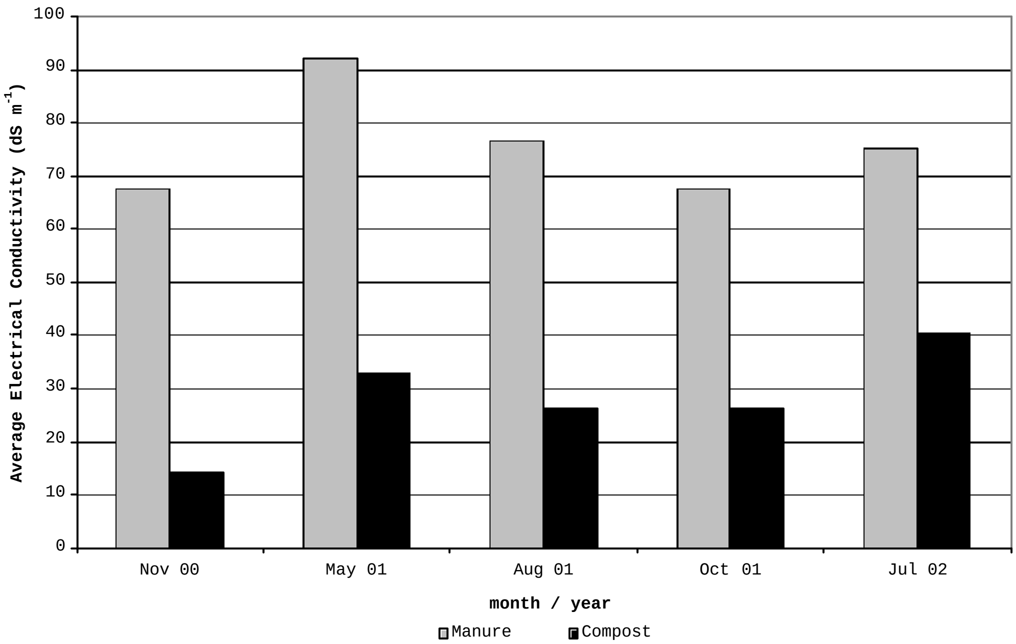

Figure 28. Manure and compost electrical conductivity of five samples.

Lysimeters

Leachate was collected from the three lysimeters. One lysimeter was located in a no nitrogen plot, one was in a compost treatment plot, and one was positioned in a manure treatment plot. Each lysimeter covered a 3 m2 surface area in the field. AZSCHED indicated that the total leaching in the field was approximately 2.5 cm over the study period. Multiplying 3 m2 by 2.5 cm yields a total leachate volume of 0.075 m3 (75 liters) collected in each lysimeter.

There was no significant leaching during the entire study. This was probably due to proper irrigation and a lack of significant rainfall. At the end of the study, the field was heavily irrigated to induce leaching. It was assumed that any contribution to leaching would have occurred within that volume of leachate. The level of NO_3-N in the leachate was below the detection limit (0.5 mg kg-1). Therefore, essentially no nitrate was leached through the soil profile under the management practices of this study.

The PO_4-P concentration of the drainage was also analyzed. It was found that no PO_4-P was leached through the soil profile at a 0.25 mg kg-1 detection limit.

Because of the management strategies applied, a relatively small volume of water was obtained for analysis from the lysimeters. Thus, following the study, the field was flushed with repeated irrigations to force leachate through the lysimeters.

CONCLUSION

Nitrogen Mass Balance

A nitrogen mass balance calculation was performed in order to gain knowledge on nitrogen fixation from the atmosphere and losses, such as volatilization. Tables 6 to 8 correspond to Figures 6 to 8. The kg ha-1 total nitrogen in the tables corresponds to the total kg ha-1 in the figures.

Table 6. October 2000 measured total nitrogen in the soil for each treatment.

October 2000 total nitrogen	
	(kg ha^{-1})
No Nitrogen	1865.92
Compost	1347.14
Manure	1319.22

Table 7. January 2002 measured total nitrogen in the soil for each treatment.

January 2002 total nitrogen	
	(kg ha^{-1})
No Nitrogen	1468.18
Compost	1925.50
Manure	1579.77

Table 8. August 2002 measured total nitrogen in the soil for each treatment.

August 2002 total nitrogen	
	(kg ha^{-1})
No Nitrogen	1383.23
Compost	2950.41
Manure	1799.07

Table 9 shows the total nitrogen mass balance calculations for each treatment. The "start with in soil" values were obtained from Tables 6 to 8. The mass of nitrogen applied in each application of manure or compost was added to the initial value in the soil. Then the mass of nitrogen removed in harvest was subtracted for each treatment. The "total nitrogen at the end of the period" represented the calculated nitrogen at the end of the October 2000 to January 2002 or January 2002 to August 2002 period.

Table 9. Total nitrogen mass balance for each treatment.

	No Nitrogen Plots		Compost Plots		Manure Plots	
Total nitrogen	October 2000 through January 2002 kg ha^{-1}	January 2002 through August 2002 kg ha^{-1}	October 2000 through January 2002 kg ha^{-1}	January 2002 through August 2002 kg ha^{-1}	October 2000 through January 2002 kg ha^{-1}	January 2002 through August 2002 kg ha^{-1}
Start with in soil	1866	1300	1347	2311	1319	2212
Add manure					35	62
					153	74
					349	80
					111	89
					174	97
					450	
					46	
					136	
Add compost			43	60		
			111	110		
			381	95		
			102	57		
			173	93		
			476			
			46			
			228			
Take off in harvest	65	39	59	56	68	63
	116	114	131	129	119	97
	107	147	123	146	88	127
	92	169	108	100	96	146
	76	100	74	113	77	134
	51	88	40	80	48	98
	60		62		65	
Total nitrogen at the end of the period	1300	645	2311	2100	2212	1950

Tables 10 to 12 compare the measured values of the mass of total nitrogen in the soil for each treatment, taken from Tables 6 to 8, to the calculated values, obtained from Table 9.

Table 10. Comparison of measured and calculated total nitrogen in the soil in the no nitrogen plots.

No Nitrogen Plots		
	Measured kg ha^{-1}	Calculated kg ha^{-1}
October 2000	1866	-
January 2002	1468	1300
August 2002	1383	645

Table 11. Comparison of measured and calculated total nitrogen in the soil in the compost treated plots.

Compost Plots		
	Measured kg ha^{-1}	Calculated kg ha^{-1}
October 2000	1347	-
January 2002	1926	2311
August 2002	2950	2100

Table 12. Comparison of measured and calculated total nitrogen in the soil in the manure treated plots.

Manure Plots		
	Measured kg ha^{-1}	Calculated kg ha^{-1}
October 2000	1319	-
January 2002	1580	2212
August 2002	1799	1950

In the no nitrogen plots, the measured total nitrogen values were higher than the calculated values. This was most likely due to the fact that the alfalfa in these plots had to fix nitrogen from the atmosphere since no nitrogen was applied. This addition of nitrogen was not accounted for in the calculated value. Hence, the calculated value was lower. The difference between the measured and calculated values in August 2002 may be considered to be the amount of nitrogen fixed. This value was 738 kg ha-1 over the one and a half year study period.

In the compost treated plots, the measured total nitrogen values were also higher than the calculated values. The difference between the measured and calculated values in August 2002 was 850 kg ha-1. This may indicate that even though nitrogen was added, the alfalfa in these plots did not use much of the nitrogen applied. In other words, there was still nitrogen fixation taking place in these plots. It is possible that the organic nitrogen applied did not turn over rapidly enough for plant uptake or supply all of the plant's nitrogen needs.

In order to achieve no biological nitrogen fixation from the atmosphere, it is likely that much higher rates of compost would have to be spread over the plots. The levels of application used in this study assumed that all of the nitrogen applied could be taken up by the plant. However, with losses and nitrogen conversion time, this may not have occurred. Therefore, biological fixation was nearly inevitable at the relatively low rates of application used in this study.

The no nitrogen plots and compost treated plots had similar values representing the amount of nitrogen fixation taking place in these plots. On the other hand, in the manure treated plots, the measured values were lower than the calculated values. The difference between the measured and calculated values in August 2002 was -151 kg ha-1. This indicated that nitrogen was being removed from the field in ways that were not accounted for in this study.

When manure was applied to the plots, it was not finely ground as the compost was. The spreading method allowed much of the manure applied to be in large chunks. This form of application may not have allowed the manure to be incorporated into the soil profile. Therefore, nitrogen could have been lost in ammonia volatilization, manure may have dried up and blown away, or chunks could have been physically carried away in the hay bailing process.

If it is assumed that the manure treatment plots fixed a similar amount of nitrogen as the no nitrogen plots, which was 738 kg ha-1, the difference between 738 kg ha-1 and -151 kg ha-1 is approximately 890 kg ha-1. The 890 kg ha-1 may be assumed to represent the amount of nitrogen that was lost in volatilization, blew away, or bailed in harvest.

January 2002 and August 2002, compost treated plots had more total nitrogen than the manure treated plots, even though nitrogen additions were similar.

Manure and compost were applied to a production alfalfa field. The following impacts were observed:

- Alfalfa yield did not vary between treatments.
- Alfalfa nitrogen content did not vary between treatments.
- Soil total nitrogen increased in the compost treatment plots.
- Soil ammonium increased in all plots.
- Soil nitrate in the manure and compost treatment plots were higher than the control at the end of the study.
- Soil organic nitrogen increased in the compost treatment plots.
- Soil phosphate increased in the manure and compost treatment plots.
- Soil electrical conductivity in all plots was the same at the end of the study.
- Leachate nitrate remained below detectable limits.
- Leachate phosphate remained below detectable limits.

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