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Fertilizer fate under golf course conditions in the midwestern region

by

Steven Kent Starrett

A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE

Department: Civil and Construction Engineering
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Signatures have been redacted for privacy

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Iowa State University
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GENERAL INTRODUCTION

The golf course industry has come under increased scrutiny in recent years due to heightened public awareness of environmental concerns. The public no longer views golf courses as just green areas of healthy and beautiful turf, but has made the realization that chemicals are being applied to maintain that turf. According to Walker et al. (1990, p.3), "Contamination of ground water is rapidly emerging as one of the major environmental issues of the next decade." Research is needed to verify the effects various fertilizers and pesticides have on the environment. The United States Golf Association (USGA) Green Section recognizes the importance of environmental quality and has provided funding for this project.

Besides providing a playing field for many different sports and general outdoor activities, there are benefits of turfgrass areas that are rarely mentioned. Some of these include: temperature modification, oxygen production, particulate entrapment, reduced runoff, and increased infiltration.

Nitrogen (N) and phosphorus (P) are of primary concern because they are commonly applied to turfgrasses, and can have detrimental effects on the environment. Nitrogen is an essential element for plant growth. According to Walker et al. (1990, p.43), "Nitrogen must be applied to maintain turfgrass shoot density, adequate recuperative potential, moderate shoot growth rate, and to lesser extent, color." A range of 90 - 180 kg N ha^{-1} yr^{-1} is commonly applied to Kentucky bluegrass (Walker et al., 1990).

Nitrate (NO_3^-) is believed to be the most mobile form of N that is found in the soil system. Kladivko et al. (1991) studied NO_3^- concentrations in subsurface drains under corn fields. They showed that the range for nitrate concentrations was 20 - 30 mg l^{-1}. Nitrate in the ground water around some urban areas has been viewed to have leached from surface applied fertilizers (Flipse et al., 1984). Possible health effects of excess concentrations of NO_3^- or nitrite (NO_2^-) in drinking water are: methemoglobinemia in infants (blue baby syndrome), and cancer (Keeney, 1982).

Phosphorus is also a critical element in plant growth. Low P concentrations can result in delayed plant maturity, reduced yields, and stunted leaf growth (Munson, 1982). Kladivko et al. (1991) showed that P concentrations in leachate were 0.005 - 1.000 mg l^{-1} in subsurface drains under corn fields. Phosphorus is applied during seeding to provide P to young plants. Phosphate availability decreases exponentially over time due to P immobility in the soil (Sample et al., 1980).

Eutrophication (i.e., algae blooms which decrease dissolved oxygen) of surface waters can occur if P and N are abundant. Availability of P is considered the limiting factor in eutrophication.

The motivation for this project comes from the fact that in previous studies by Joo et al. (1991), only 29% of the N applied to turf in a field test could be accounted for. The unaccounted N either volatilized in the form of ammonia (NH_3), denitrified, or leached below the testing depth of 17 cm in a period of five weeks. Macropores were evident in the soil, but their effect on N transport was unknown.

Jones et. al. (1977) studied the fate of N over three years when applied to soft chess (*Bromus Mollis* L.) and subclover (*Trifolium subterraneum* L.). This study showed that 3% of the applied N leached below 69 cm when applied to the soft chess and 9% leached for the subclover. Lysimeters with disturbed soil were used in this study. Since disturbed soil was used, a macropore system did not exist in the lysimeters.

According to Thomas and Phillips (1979, pp. 149,152), "In general, rapid flow down macropores and its effect on water and solute distribution have not been considered very important by the majority of researchers." They conclude by stating, " Because this type of flow occurs, soil water content, ground water, springs, streams, and the solutes in water are affected differently than what is often believed and taught."

Petrovic (1990, p.13) published a literature review of current articles pertaining to the fate of nitrogen fertilizers and summarized his article by stating: "The distribution of fertilizer N applied to turfgrass has generally been studied as a series of components rather than a complete system. Only Starr and DeRoo (1981) attempted to study the entire system of the fate of N applied to turfgrass....Thus, more information of this nature is needed on a wide range of conditions."

In this study, undisturbed soil columns were used: to keep macropores intact, to have a closed system, and to represent the field soil conditions. Nitrogen-15 was used as a tracer of the applied N. The different N fractions collected were: volatilized N in the form of NH_3, N taken up by the plant material, Kjeldahl N and ammonium (NH_4^+) in the soil material, and Kjeldahl N and NO_3^- in the leachate. Denitrification was not determined due to the complexity of its collection. Phosphorus concentrations were determined in the soil and in the leachate.

The effects that properly managed irrigation levels have on the fate of applied chemicals was also addressed. Two treatments of irrigation levels were used. A one time, heavy irrigation and a frequent light irrigation level were applied to compare the effects irrigation levels has on chemical fate.

The objectives of this study were: (i) to investigate the hydrology of an undisturbed soil column under a heavy and light irrigation scheme, (ii) to quantify the fate of N when it is applied to an undisturbed soil column covered with turf, using ^{15}N as a tracer, and (iii) to study the movement of P when applied to an undisturbed soil column.

Explanation of Thesis Format

I have used the alternate format for this thesis, and the paper included is suitable for publication. The following paper's format follows the Soil Science Society of America Journal format and will be submitted for publication. There is a General Summary following the paper, and the additional literature cited (in the General Introduction and the General Summary) follows the General Summary.

I designed the experimental setup, supervised and participated in all aspects of the project (with exception to analytical testing methods that were performed by Dr. Alfred Blackmer's laboratory and the Soil Testing Lab), and performed all calculations reported in this paper. Drs. Nick Christians, Al Austin, and Alfred Blackmer provided guidance continually during the project.

The soil columns were collected from the turf section of the Horticulture Farm north of Ames, Iowa. Work in the greenhouse was done in the research portion of the Horticulture Department greenhouses at Iowa State University.

PAPER: FATE OF PHOSPHORUS AND N-15 AMENDED UREA IN TURFGRASS AREAS.

Fate of phosphorus and N-15 amended urea in turfgrass areas.

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INTRODUCTION

Several types of chemicals are applied to golf courses, parks, school grounds, sports complexes, industrial parks, and other turf areas to improve the quality of grasses. Turf is used as a playing surface for many different sports, aesthetically pleasing areas around buildings, and a place for general outdoor activities. The variety of the chemicals used include: fertilizers, herbicides, insecticides, and fungicides.

With the current elevation of public concern for the environment, all industries are being questioned about their effect on the environment. The turfgrass industry is receiving criticism for applying chemicals to grasses that may be harmful to the environment. Proper management of these materials greatly reduces the risk of adverse environmental effects. An understanding of the fate of the various chemicals is needed to better manage turfgrass maintenance and to determine which chemicals pose a serious threat to the environment. A limited amount of research has been done concerning the environmental effects of chemicals applied to turfgrasses (Walker et al., 1990).

Nitrogen (N) and phosphorus (P) are of primary concern because they are commonly applied to turfgrass areas, and can have detrimental effects on the environment. Possible health effects of excess concentrations of nitrate (NO_3^-) or nitrite (NO_2^-) in drinking water are: methemoglobinemia in infants (blue baby syndrome), and cancer (Keeney, 1982). Eutrophication of surface waters can occur if P is sufficiently abundant.

Nitrogen and phosphorus are applied to improve the quality of the turf by supplying more for growth to the plant than naturally available. According to

Walker et al. (1990, p.43), "Nitrogen must be applied to maintain turfgrass shoot density, adequate recuperative potential, moderate shoot growth rate, and to lesser extent, color." Low P concentrations can result in delayed maturity, reduced yields, and stunted leaf growth (Munson, 1982).

Nitrate is believed to be the most mobile form of N that is found in the soil system. Nitrate in the ground water around some urban areas has been viewed to have leached from surface-applied fertilizers (Flipse et al., 1984). Brown et al. (1982) showed that NO_3^- leaching losses from ureaformaldehyde were negligible; however, he estimated NO_3^- leaching losses ranged from 9% to 22% when N was applied in the form of NH_4NO_3. A majority of the applied N is taken up by the plant under the right conditions. In a three year study using various forms of surface applied N at a level of 245 kg N ha^{-1} yr^{-1}, Hummel and Waddington (1981) found that N recovered in clippings ranged from 46 to 59%. Joo et al. (1991) studied the relative uptake of soil and fertilizer derived N by turf. They could account for less than 29% of the applied N in the plant material and the top 17 cm of the soil profile for a test period of five weeks. Starr and DeRoo (1981) showed that 15 to 21% of the applied N was stored in the top 30 cm of soil after a period of one year.

Different circumstances affect the amount of N needed to improve the quality of turf to a satisfactory condition. Areas that have been maintained as turf for an extended period of time needs less applied N than an area that has been maintained for less than 15 years (Porter et al., 1980).

Nitrogen volatilization depends greatly on the degree of irrigation after the application of fertilizer (Bowman et al., 1987, Joo et al., 1987). When no irrigation was used, Bowman et al. showed that 36% of the N volatilized. They also showed that an application of 1 cm water reduced the volatilization to 8%.

The fate of fertilizers and pesticides may include: volatilization to the atmosphere, transport by surface water, attachment to the soil particles, plant uptake, breakdown by microbial activity, and/or they may remain in a liquid solution and continue to leach through the soil.

Petrovic published a literature review of current articles pertaining to the fate of N fertilizers (1990, p.13) and summarized his article by stating: "The distribution of fertilizer N applied to turfgrass has generally been studied as a series of components rather than a complete system. Only Starr and DeRoo (1981) attempted to study the entire system of the fate of N applied to turfgrass [using lysimeters in the field]...Thus, more information of this nature is needed on a wide range of conditions."

Macropore flow may dominate transport of surface-applied irrigation under certain circumstances (Beven and Germann, 1982). Evert (1989) conducted a thorough review of macropore flow research. Evert's (1989) findings on macropore effects include: macropores increase water and solute flux through soils, and the influence of macropores is negated when experiments are done in a laboratory using dried, sieved, and repacked soil columns. Quisenberry and Phillips (1976) studied movement of irrigation in soils (undisturbed) in the field. They showed that 40% of an irrigation of 4.2 cm leached below 90 cm within one h after application.

The objectives of this study were: (i) to investigate the hydrology of an undisturbed soil column under a heavy and light irrigation scheme, (ii) to quantify the fate of N when it is applied to an undisturbed soil column covered with turf, using ^{15}N as a tracer, and (iii) to study the movement of P when applied to an undisturbed soil column.

MATERIALS AND METHODS

Fourteen undisturbed columns of mostly Nicollet (fine-loamy, mixed, mesic Aquic Hapludoll) soil, that had been graded in 1968, were taken from a 400 m^2 area at the Iowa State University Horticulture Research Station. The area had been established with Premium Sod Blend® (a blend of 'Parade', 'Adelphi', 'Rugby', 'Glade') Kentucky bluegrass (*Poa prantensis* L.) in 1979 and maintained at fairway mowing height (2.54 cm) since 1989. The columns measured 20 cm in diameter and were excavated to a 50 cm depth using the method described by Priebe and Blackmer (1989). A brief description of their method follows. A free standing column of soil was excavated by removing the surrounding material. Water was misted on the free-standing column to prevent drying of the soil. A 30 cm heating-duct pipe was placed around the column leaving 5 cm between the soil column and the pipe. Masonry concrete was poured between the pipe and soil column. The concrete was allowed to set for ten days in the field, and the columns were then moved to the greenhouse on 15 October 1990.

The soil columns were watered with approximately 1.3 cm of distilled water twice a week. Natural light was supplemented with high pressure sodium lights with an average intensity of 870 $\mu mol\ m^{-2}\ s^{-1}$ measured at 90 cm. A 14-h photoperiod was used for supplemental light in the winter months. The greenhouse was maintained between a nighttime temperature of 19 ± 2 °C and a daytime temperature of 27 ± 2 °C.

No pesticides were applied to the columns during this study. The annual application of sulfur coated urea to the turf during the growing season before excavation was 195 kg N ha^{-1} in four even applications. The last 49 kg N ha^{-1} application was in early October 1990.

To obtain a moisture content at water holding capacity, the columns were slowly lowered into distilled water over a six h period (8.33 cm h^{-1}) and left submerged for 24 h to obtain saturation. The columns were slowly raised out of the water and allowed to drain for 24 h (Priebe and Blackmer, 1989).

A collection system similar to that described by Joo et al. (1987) was used (Fig. 1) to collect volatilized ammonia (NH_3). The chamber was a glass hemisphere with a diameter of 21.5 cm. Two holes, 3.2 cm and 1.9 cm in diameter, were drilled in the glass to provide space for stoppers. Small glass tubes were placed in the stoppers to allow air intake and exhaust for the collection chamber. A hole was made directly on top of the column for the exhaust, and the intake hole was on the side. The intake air tube was connected to a 15 cm ring made from perforated copper tubing to disperse the incoming air. Mortite® rope caulk (Mortell Co., Kankakee, IL) was used to provide a tight and inert seal between the concrete and the glass chamber, and a rubber sealant was applied to the outside of the chamber for added protection against leakage. The sealant was not in contact with the air in the chamber.

Air was taken from the university compressed air system and filtered through DX (93% efficient for removal of 0.1 micron particles) and BX (99.99% efficient) Balston® (Balston Inc., Lexington, MA) paper filters to remove any solids or oil droplets that may have been in the air line. The air was then passed through a five gallon glass jar containing five liters of 0.25 normal sulfuric acid to remove NH_3 in the air supply. Next, the air was bubbled through a similar container of distilled water to humidify the air and to remove any acid from the air. Perforated stainless steel tubing was used to disperse the air in the sulfuric acid and in the distilled water. The air supply was branched to four different collection chambers connected in parallel. Air flow meters with flow valves were placed on both the intake and the exhaust of each collection chamber to insure proper flow levels. Tygon® tubing was used between the various devices.

The filtered, NH_3 free, and acid free air flowed (compressed air system) into the collection chamber, and was drawn through the collection chambers using a vacuum pump at 1.9 chamber volumes per min (5000 ml min^{-1}). The collected gas was bubbled through a trap solution of 0.25 normal H_2SO_4. The trap solution of acid was collected and replaced at 24 h, 48 h, and at the end of the seven d test period. The acid was tested to determine the amount of applied N volatilized in the form of NH_3.

Urea N (46%) labeled with a 5 atom % ^{15}N was applied to the surface of the Kentucky bluegrass turf at 49 kg N ha^{-1} using a spray-mist atomizer attached to an air pressure pump. Experimental treatments used two irrigation regimes. One treatment consisted of watering the column with 2.54 cm of distilled water immediately after the fertilizer was applied. The second treatment included a 0.64-cm application immediately after fertilizing, with three additional 0.64-cm applications at 42-h intervals. This gave a total of 2.54 cm of irrigation spread evenly over the seven-day test period. The two treatments were replicated seven times. The initial water applications were applied over a time period of two min with a Teejet® Conejet TXVS 4 nozzle before the volatilization chamber was placed on the column. For the three later applications of the light irrigation regime, the top stopper was removed and the spray nozzle inserted into the hole.

Monobasic calcium phosphate ($Ca(H_2PO_4)_2$), at 33 kg P ha^{-1}, was applied in the same manner as N and immediately after the application of N.

A plastic bag was placed around the bottom of the column and fastened to the sides to act as a leachate collection device and also prevented the bottom of the soil column from drying. Leachate was collected at various times and was immediately placed into a plastic bottle and frozen.

Clipping, verdure, and thatch mat samples were taken from each column, and the soil was excavated in 10 cm layers at the end of the seven day test period. The soil was spread into a thin layer and air dried for three days following the method of Priebe and Blackmer (1989). It was then placed in plastic bags, thoroughly mixed, and sampled for analysis.

The soil layers were tested for Kjeldahl N (Bremner and Mulvaney, 1982), ammonium (NH_4^+) and NO_3^- (steam distillation), and available P (Bray P-1 test). Leachate was tested for Kjeldahl N, NO_3^-, and available P. The plant materials and the trap solutions of sulfuric acid were tested for Kjeldahl N. Each fraction was tested for atom % ^{15}N present. All calculations were based on the atom % ^{15}N found in each sample according to the method of Sanchez and Blackmer (1988).

Immediately after water holding capacity was obtained, the total column was weighed to calculate moisture content at water holding capacity (beginning of test period).

At the end of the test period when all of the soil was removed from the column system, the hollow column shell was weighed. The volume of each column was determined by placing a large plastic bag inside the shell and adding known amounts of water to fill the core of the column. At the end of the seven-day test period soil samples were taken from each layer for each column to determine moisture content.

Specific surface was determined for each 10-cm soil layer according to Carter et al. (1986). Specific yield was determined by measuring the volume of leachate that drained from the soil column in going from saturation to water holding capacity and dividing by the volume of the soil column.

RESULTS AND DISCUSSION

Moisture content for the entire soil column at water holding capacity ranged from 0.13 kg kg^{-1} to 0.44 kg kg^{-1}. The mean moisture content at water holding capacity was 0.31 kg kg^{-1} (SD=0.07 kg kg^{-1}).

Bulk density for the 14 soil columns ranged from 1.32 Mg m^{-3} to 1.56 Mg m^{-3}. The mean bulk density value was 1.42 Mg m^{-3} (SD=0.061 Mg m^{-3}). Porosity averaged 0.46 m^3 m^{-3} (SD=0.023 m^3 m^{-3}) for the 14 soil columns. Specific surface for all soil layers ranged from 4.90 m^2 g^{-1} to 51.24 m^2 g^{-1}. The mean specific surface value was 21.23 m^2 g^{-1} (SD=0.099 m^2 g^{-1}). The specific yield for the 14 soil columns ranged from 0.029 m^3 m^{-3} to 0.099 m^3 m^{-3}. The mean specific yield value was 0.054 m^3 m^{-3} (SD=0.022 m^3 m^{-3}). Soil properties (water holding capacity, bulk density, porosity, specific surface, specific yield) were consistent between the two treatment groups.

A total of 808 ml of distilled water was applied to each column. Average seven-day total leachate volumes for treatments 1 and 2 were 806 ml (SD=152 ml) and 461 ml (SD=115 ml), respectively. There were significant differences between leachate quantities for the two treatments (P=0.004).

The mean thatch-mat-layer-moisture content at the end of the test period was 0.17 kg kg^{-1} (SD=0.06 kg kg^{-1}) for treatment 1 and 0.24 kg kg^{-1} (SD=0.05 kg kg^{-1}) for treatment 2. There was a difference between the two treatments for the moisture contents of the thatch mat layer (P=0.033).

An average of 75% of the total leachate for treatment 1 was collected in the first 2.2 hr. For treatment 2, an average of 10% was collected in the first 2.2 hr. The large amount of leachate accumulated in a short period of time shows the effect of the macropore system. When the soil columns were excavated, numerous earth worms were observed, and an abundance of worm holes were found in the soil columns. Many of the worm holes extended below a depth of 50 cm. It was obvious that macropore movement of surface applied irrigation would occur. Since 1.75 times the water leached below 50 cm for treatment 1, greater movement of surface applied chemicals would be expected.

The upper soil layers of columns with treatment 1 irrigation level were dryer at the end of the test period. Water that was lost to evapotranspiration was not being replaced as it was with the smaller, but more frequent, irrigation levels in treatment 2.

The columns were drained for 24 h but at least two of the columns did not reach water holding capacity before the beginning of the test. Total leachate from two soil columns considerably exceeded the amount of applied irrigation. Also, continued gravitational drainage was observed from two of the soil columns after 24 h. This shows that variation of hydraulic conductivity of soils occurs within a 400 m^2 area.

Total cumulative recovery of the applied N ranged from 59.3% to 96.8% and averaged 75.9% for the 14 soil columns. Nitrogen recovery averaged 74.5% and 77.3% for treatments 1 and 2, respectively (Table 1).

Soil layers, including the thatch mat and not including leachate, contained 59.1% of the total applied N for treatment 1 and 61.4% for treatment 2 (Table 2). For the soil below 30 cm (including N in leachate) treatment 1 contained more than 6.5 times the applied N found compared to treatment 2. Burt and Christians (1990) showed that an average of 79% of the root mass by weight was above 20 cm for improved Kentucky bluegrass cultivars.

Less than 1% of applied N was recovered in the form of NH_4^+ from the soil columns. Applied N recovered as NO_3^--N totaled 24.2% and 21.7% for treatment 1 and 2, respectively (Table 3).

Less than 1% of the applied N was lost to volatilization. Water was applied immediately after the liquid urea application preventing most of the urea from volatilizing into NH_3. Considerably less N volatilized from columns with treatment 1 versus treatment 2 ($P=0.071$). Since treatment 1 was a heavy irrigation scheme, more N was transported by the applied water into the soil columns. There was no difference in N recovery between treatment 1 and 2 for the clippings, verdure, thatch mat, 0-10 cm layer, 10-20 cm layer, and the 20-30 cm layer fractions. A difference does exist in N recovery values for the 30-40 cm layer ($P=0.055$), the 40-50 cm layer ($P= 0.075$), and the leachate fractions ($P=0.020$). There was no statistical difference in the sum of the fraction's of N recovered between the two treatments.

Denitrification was not quantified. Variation in the total amount of N recovered probably occurred due to variation in denitrification that occurred during the seven day test period.

Leachate for treatment 1 only constituted an average of 0.6% of the applied N. This is a small percentage considering the abundant macropore system (mostly worm holes) that was present throughout the soil columns. However, for one of the columns under treatment 1, 1.46 % of the applied N leached through in the first 1.3 h. Treatment 1 leachate averaged 2.16 atom % ^{15}N found for the first collection period compared to 0.43 for treatment 2 ($P=0.0001$). Eighty-five percent of the N found in the leachate was not in the form of NO_3^- and was assumed to be in the urea form since collection was within 5 h of application. Since urea-N transforms quickly into other forms of N, the N found in the leachate must have been transported quickly through the macropores in the soil column.

Nitrogen fractions were grouped into four categories: volatilized NH_3, clippings and verdure; thatch mat, 0-10 cm, 10-20 cm, and 20-30 cm layers; and 30-40 cm, 40-50 cm layers, and leachate. Important points of comparison include: (1) no differences were observed in plant uptake, (2) more N was observed above 30 cm for treatment 2 , and (3) a significant difference between treatment 1 and 2 for the 30-50 cm soil layer and leachate fractions (P=0.006) was found. One way to calculate the depth that N would be transported without preferential flow is by dividing applied irrigation (volume) by the area of the column and water holding capacity moisture content, mass basis, [depth = (volume of irrigation) / (area * (whc))]. Average depth of N calculated in this manner is 8.3 cm.

For the NO_3^--N analysis, the 30-40 cm, and 40-50 cm layers under treatment 1 contained more N compared to the same layers under treatment 2 (P=0.090 for 30-40 cm, P=0.005 for 40-50 cm). Nitrate-nitrogen recovery followed the same trends as the total N recovery.

Concentrations of elemental P were highest in the thatch mat layer (Table 4). There was a significant difference in P found between treatments for the thatch mat layer (P=0.073), 20-30 cm layer, and the leachate.

Phosphorus is considered highly immobile, but under treatment 1, P was found in some of the leachate samples. No P was detected in the leachate for 8 of the 14 soil columns. The P that leached through the soil column did so in the first five h of the test period showing evidence of preferential flow through macropores.

The results of this study showed that volatilization of N was negligible when irrigation was applied immediately after the application of N. One 2.54 cm application of irrigation significantly increased the transport of N below 30 cm, compared to four 0.64 cm applications over a seven-day period. Macropores played a major role in transport of surface applied chemicals through the soil profile. Eighty-five percent of the N found in the leachate was in the urea form. The N in the first collection of leachate was 2.16 atom % ^{15}N for treatment 1 showing preferential transport of N. Phosphorus was transported below 20 cm with a heavy irrigation after application. By applying a 0.64 cm irrigation instead of a heavy irrigation after an application of fertilizer, the possibility of N and P leaching was greatly reduced.

Nitrogen is used successfully to improve the quality of turfgrasses. Applicators need to understand the N cycle and apply only what is needed. By properly managing the time of application and irrigation levels that follow application, the risk of detrimental effects on the environment are greatly reduced.

Acknowledgments

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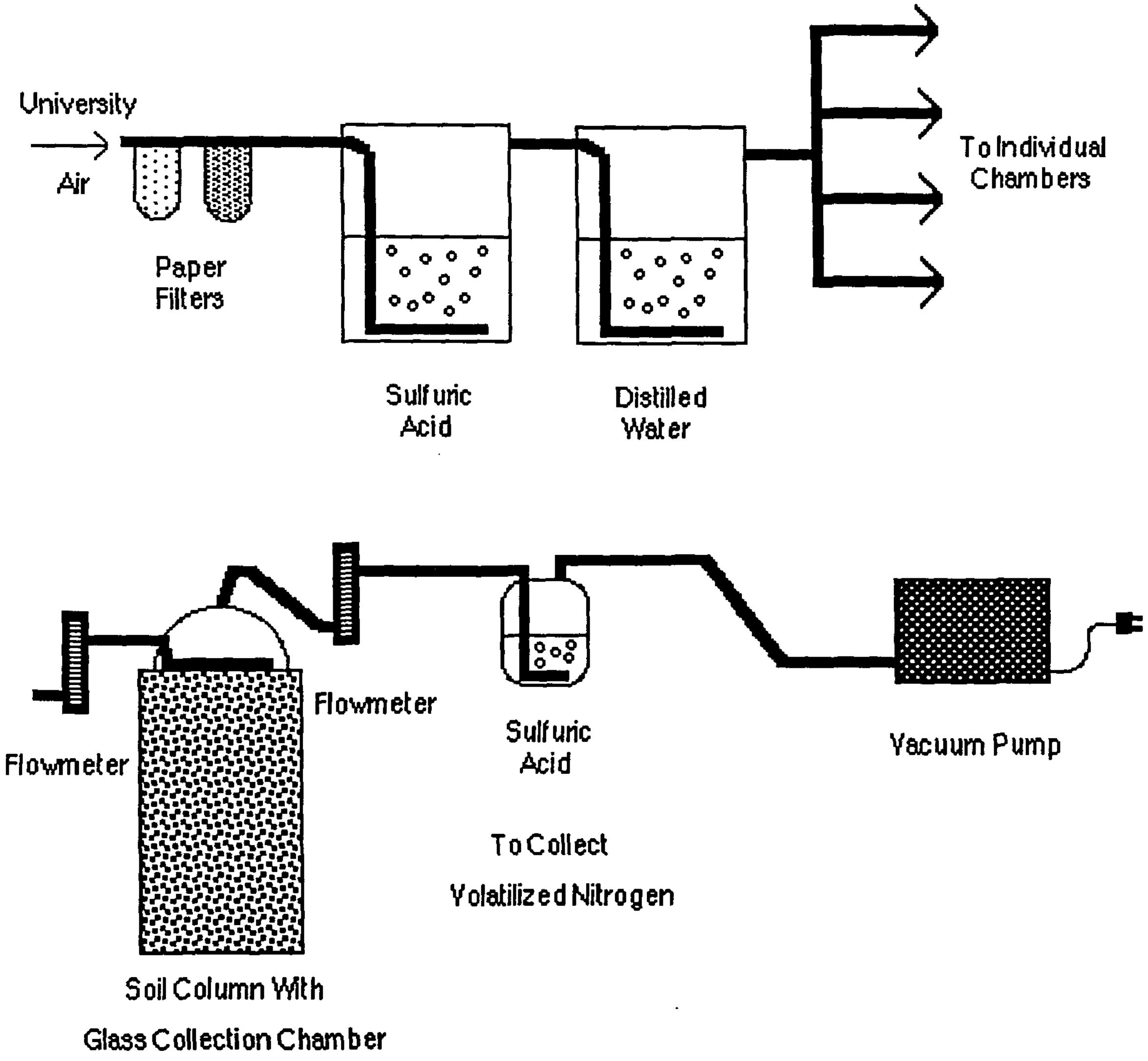

Figure 1. Schematic of Volatilizing Nitrogen Collection System

Table 1. Percentage of applied N recovered for treatments.

	Treatment 1†		Treatment 2‡		
Category	Mean	Std.Dev.	Mean	Std.Dev.	Probability§
Volatilization	0.3	0.3	0.7	0.3	0.071
Clippings	3.6	4.6	3.4	2.6	0.930
Verdure	11.1	8.1	11.9	5.0	0.825
Thatch Mat	12.9	2.8	16.3	4.8	0.128
0-10 cm	24.0	10.1	26.1	9.1	0.682
10-20 cm	12.2	4.3	12.4	5.6	0.928
20-30 cm	4.1	2.5	5.7	5.3	0.490
30-40 cm	4.2	4.2	1.0	1.2	0.055
40-50 cm	1.8	2.0	0.2	0.5	0.075
Leachate	0.6	0.6	0.0	0.0	0.020
Cum. Totals	74.8	9.7	77.7	11.0	0.630

† Treatment 1, one 2.54 cm irrigation application
‡ Treatment 2, four 0.64 cm irrigation applications
§ *t* - test.

Table 2. Percentage of applied N per vegetative material and depth.

	Treatment 1†		Treatment 2‡		
Category	Mean	Std.Dev.	Mean	Std.Dev.	Probability§
Ammonia	0.3	0.3	0.7	0.3	0.071
Clippings & Verdure	14.6	9.7	15.3	6.2	0.887
Thatch Mat & 0-30 cm	53.1	9.8	60.5	13.5	0.264
30-50 cm & Leachate	6.5	4.2	0.9	1.7	0.006

† Treatment 1, one 2.54 cm irrigation application
‡ Treatment 2, four 0.64 cm irrigation applications
§ *t* - test.

Table 3. Percentage of applied N recovered as NO_3^--N.

	Treatment 1†		Treatment 2‡		
Category	Mean	Std.Dev.	Mean	Std.Dev.	Probability§
Thatch Mat	0.8	1.1	0.8	0.8	0.959
0-10 cm	12.0	4.2	11.6	4.0	0.839
10-20 cm	4.6	0.9	5.3	3.0	0.574
20-30 cm	2.9	1.2	2.9	2.4	0.941
30-40 cm	2.0	1.1	1.0	1.0	0.090
40-50 cm	1.8	1.3	0.1	0.2	0.005
Leachate	0.1	0.1	0.0	0.0	0.206
Totals	24.2	4.0	21.7	7.1	0.429

† Treatment 1, one 2.54 cm irrigation application
‡ Treatment 2, four 0.64 cm irrigation applications
§ *t* - test.

Table 4. Available phosphorus concentrations (mg kg^{-1}).

	Treatment 1†		Treatment 2‡		
Category	Mean	Std.Dev.	Mean	Std.Dev.	Probability§
Thatch Mat	18.5	2.9	27.5	8.3	0.073
0-10 cm	6.7	1.5	6.4	1.6	0.735
10-20 cm	2.7	1.0	2.4	0.5	0.502
20-30 cm	2.3	0.8	1.4	0.5	0.031
30-40 cm	2.4	1.3	1.6	1.1	0.208
40-50 cm	3.0	1.6	2.0	1.7	0.288
Leachate††	1.0	1.0	0.0	0.0	0.024

† Treatment 1, one 2.54 cm irrigation application
‡ Treatment 2, four 0.64 cm irrigation applications
§ *t* - test.
†† mg of P found.

GENERAL SUMMARY

Development of methods

Collection of the soil columns were very labor intensive but proved well worth the effort. It is impossible to bring all of the field parameters into the greenhouse, but Priebe and Blackmer's (1989) method of collecting undisturbed soil columns is the best available method.

With the development of the methods used for this project, many obstacles were encountered. In preliminary studies the treated air, as described in the Materials and Methods section, was supplied under pressure to the intake of the chamber with the idea that connecting Tygon® tubing to the exhaust would cause the air to flow out of the chamber and bubble thru the trap solution. But, the resistance that a depth of 5 cm of trap solution exerts was enough to prevent air from flowing thru the solution. Thus, the air escaped thru the macropores of the soil column. Next, an attempt was made to draw the air supply through the acid solution with a vacuum, and this did not work due to the frictional losses of the Tygon® tubing. The air was being drawn through the macropores in the soil column instead of through the Tygon® tubing up stream from the collection chamber. This was discovered when a flow meter was placed between the water bath and the collection chamber and a reading of zero was given when the vacuum pump was running at 2000 ml / min. It was then determined that the air must be supplied at the same level as it was being drawn out of the chamber to maintain control of the air supply. Many weeks were spent in developing the air system for ammonia collection.

Summary of results

The results of this study showed that volatilization of N was negligible when irrigation was applied immediately after the application of N. Macropores played a major role in transport of surface applied chemicals through the soil profile. One 2.54 cm application of irrigation significantly increased the transport of N below 30 cm, compared to four 0.64 cm applications over a seven-day period. Eighty-five percent of the N found in the leachate was in the urea form. The N in the first collection of leachate was 2.16 atom % ^{15}N for treatment 1 showing preferential transport of N. Phosphorus was transported below 20 cm with a heavy irrigation after application. By applying a 0.64 cm irrigation instead of a heavy irrigation after an application of fertilizer and P, the possibility of N and P leaching is greatly reduced.

By properly managing the time of application and irrigation levels that follow application, the risk of detrimental effect on the environment are greatly reduced.

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APPENDIX 1: VOLATILIZED NITROGEN IN THE FORM OF AMMONIA

Table 1-A. Volatilized nitrogen in the form of ammonia.

col. #,	collection time	volume (ml)	atom % ^{15}N	ug N/ml	atom %-.366
1	24 hr	268.30	0.92	2	0.56
	48 hr	292.30	0.44	1	0.08
	168 hr	426.20	0.39	1	0.02
2	24 hr	254.30	1.64	4	1.27
	48 hr	258.80	0.60	6	0.23
	168 hr	349.50	0.43	2	0.07
4	24 hr	260.80	1.71	4	1.34
	48 hr	265.90	0.56	1	0.19
	168 hr	432.00	0.43	0	0.06
5	24 hr	272.30	2.55	11	2.18
	48 hr	277.20	1.30	3	0.93
	168 hr	237.90	1.01	7	0.65
6	24 hr	246.00	2.81	12	2.45
	48 hr	263.00	0.94	1	0.58
	168 hr	276.40	0.54	1	0.17
7	24 hr	252.30	2.03	5	1.67
	48 hr	269.90	0.64	1	0.28
	168 hr	273.10	0.68	1	0.32
8	24 hr	247.10	2.73	8	2.36
	48 hr	256.40	0.95	1	0.59
	168 hr	372.80	0.54	1	0.18
9	24 hr	247.60	0.90	3	0.53
	48 hr	270.70	0.46	0	0.09
	168 hr	252.00	0.42	1	0.05
10	24 hr	246.90	3.17	10	2.80
	48 hr	271.80	1.50	2	1.14
	168 hr	270.00	0.62	1	0.25
11	24 hr	265.30	1.33	4	0.97
	48 hr	264.10	0.70	2	0.33
	168 hr	168.20	0.84	6	0.40

Table 1-A. Continued.

12	24 hr	269.50	1.74	5	1.38
	48 hr	267.30	1.21	2	0.84
	168 hr	186.90	1.16	5	0.80
13	24 hr	252.50	1.03	2	0.66
	48 hr	264.40	0.52	1	0.15
	168 hr	312.50	0.45	2	0.09
14	24 hr	274.20	2.58	8	2.21
	48 hr	271.30	0.89	2	0.53
	168 hr	212.30	0.71	4	0.35
15	24 hr	252.60	1.69	7	1.32
	48 hr	257.80	0.83	1	0.46
	168 hr	331.40	0.94	5	0.57

Table 1-A. Continued.

ug ^{15}N/ml	ug N/ml	ug N/sample	mg N/column	% of applied
0.01	0.22	59.96	0.07	0.05
0.00	0.02	4.45		
0.00	0.00	2.05		
0.05	1.02	259.53	0.34	0.23
0.01	0.28	72.77		
0.00	0.03	9.38		
0.05	1.08	280.78	0.29	0.20
0.00	0.04	10.17		
0.00	0.00	0.00		
0.24	4.81	1310.08	1.68	1.14
0.03	0.56	155.55		
0.05	0.90	215.11		
0.29	5.88	1447.21	1.49	1.01
0.01	0.12	30.44		
0.00	0.03	9.41		
0.08	1.67	421.39	0.45	0.31
0.00	0.06	15.03		
0.00	0.06	17.28		
0.19	3.78	935.07	0.98	0.67
0.01	0.12	30.09		
0.00	0.04	13.29		
0.02	0.32	78.84	0.08	0.06
0.00	0.00	0.00		
0.00	0.01	2.47		
0.28	5.62	1386.45	1.52	1.04
0.02	0.46	123.89		
0.00	0.05	13.68		
0.04	0.77	205.08	0.34	0.23
0.01	0.13	34.91		
0.03	0.57	96.00		

Table 1-A. Continued.

0.07	1.38	371.05	0.61	0.41
0.02	0.34	89.93		
0.04	0.80	148.78		
0.01	0.27	67.15	0.09	0.06
0.00	0.03	8.05		
0.00	0.04	11.01		
0.18	3.55	972.17	1.09	0.74
0.01	0.21	57.27		
0.01	0.28	58.67		
0.09	1.85	467.07	0.68	0.46
0.00	0.09	23.85		
0.03	0.57	188.82		

APPENDIX 2: SOIL LAYERS AND PLANT MATERIAL KJELDAHL NITROGEN RECOVERY

Table 2-A. Soil layer and plant material Kjeldahl nitrogen recovery.

Col.#	layer	soil and veg. weight (g)	atom % N	atom %-.366	PPM N
1	0-10	3520.50	0.38	0.01	2351
	10-20	5484.50	0.38	0.01	1478
	20-30	4927.50	0.37	0.00	1186
	30-40	4711.50	0.36	0.00	851
	40-50	4313.50	0.37	0.01	854
	clippings	3.30	1.20	0.84	34164
	verdure	11.55	0.76	0.39	13287
	thatch mat	730.90	0.40	0.04	2868
2	0-10	3717.50	0.38	0.01	1976
	10-20	4297.50	0.39	0.03	1310
	20-30	4714.50	0.37	0.00	1233
	30-40	4384.50	0.36	0.00	860
	40-50	5182.50	0.36	0.00	669
	clippings	0.77	1.87	1.51	40051
	verdure	6.02	0.96	0.59	18281
	thatch mat	591.00	0.43	0.06	3067
4	0-10	3001.00	0.37	0.01	2449
	10-20	4151.00	0.38	0.02	1785
	20-30	3643.00	0.37	0.00	1471
	30-40	4158.00	0.37	0.01	1792
	40-50	5317.00	0.37	0.00	1249
	clippings	0.48	1.49	1.13	38008
	verdure	24.01	0.73	0.36	8388
	thatch mat	697.20	0.40	0.04	3456
5	0-10	2959.50	0.40	0.03	2506
	10-20	4399.00	0.38	0.02	1601
	20-30	4535.50	0.38	0.01	1596
	30-40	3933.50	0.36	0.00	1576
	40-50	5346.50	0.36	0.00	1221
	clippings	0.12	1.52	1.15	45257

Table 2-A. Continued.

	verdure	4.14	0.97	0.61	23456
	thatch mat	469.20	0.44	0.08	3503
6	0-10	4049.00	0.39	0.02	2086
	10-20	4183.00	0.38	0.02	1554
	20-30	4374.00	0.37	0.01	1412
	30-40	4312.50	0.36	0.00	1473
	40-50	4716.50	0.36	0.00	1113
	clippings	0.52	1.51	1.14	39908
	verdure	30.01	0.77	0.40	15840
	thatch mat	626.20	0.41	0.04	3144
7	0-10	3542.50	0.38	0.02	2189
	10-20	4434.00	0.37	0.01	1440
	20-30	4215.00	0.37	0.01	1186
	30-40	4110.00	0.37	0.01	1063
	40-50	4336.00	0.37	0.00	1038
	clippings	0.69	1.21	0.84	22603
	verdure	40.70	0.67	0.30	10234
	thatch mat	597.20	0.40	0.04	3357
8	0-10	3039.00	0.39	0.02	2163
	10-20	4281.00	0.38	0.02	1567
	20-30	4441.00	0.37	0.01	1324
	30-40	4483.00	0.37	0.00	1064
	40-50	4391.00	0.36	0.00	1075
	clippings	0.65	1.97	1.61	41466
	verdure	25.91	0.76	0.40	8633
	thatch mat	885.10	0.41	0.04	3080
9	0-10	3831.00	0.38	0.02	2522
	10-20	4188.00	0.38	0.01	1818
	20-30	4596.00	0.37	0.01	1677
	30-40	3509.50	0.37	0.01	1529
	40-50	4680.00	0.37	0.00	1350
	clippings	0.42	1.29	0.92	40834

Table 2-A. Continued.

	verdure	48.74	0.62	0.25	7629
	thatch mat	588.20	0.41	0.04	3578
10	0-10	4371.00	0.39	0.02	2122
	10-20	4161.00	0.38	0.01	1410
	20-30	5315.00	0.38	0.01	1155
	30-40	4284.75	0.37	0.00	781
	40-50	4893.00	0.36	0.00	715
	clippings	0.49	1.99	1.63	32395
	verdure	22.95	0.84	0.47	6578
	thatch mat	597.80	0.41	0.04	2781
11	0-10	3825.50	0.39	0.02	2367
	10-20	4803.00	0.37	0.01	1525
	20-30	4803.50	0.37	0.01	1222
	30-40	3941.50	0.37	0.01	1157
	40-50	4900.50	0.37	0.01	991
	clippings	0.11	1.20	0.84	48743
	verdure	4.34	0.72	0.36	25901
	thatch mat	287.20	0.43	0.06	3397
12	0-10	3570.50	0.39	0.02	2428
	10-20	4121.50	0.37	0.01	1583
	20-30	4458.50	0.37	0.00	1513
	30-40	4370.50	0.38	0.01	1476
	40-50	5087.50	0.36	0.00	1231
	clippings	0.27	1.48	1.11	42608
	verdure	3.62	0.96	0.59	23227
	thatch mat	349.70	0.44	0.07	3674
13	0-10	3914.50	0.40	0.03	2056
	10-20	4841.50	0.38	0.01	1231
	20-30	5069.50	0.37	0.00	1200
	30-40	4534.50	0.37	0.00	679
	40-50	4627.50	0.37	0.01	293
	clippings	0.00	0.00	0.00	0

Table 2-A. Continued.

	verdure	5.12	0.66	0.29	15410
	thatch mat	466.50	0.45	0.08	3199
14	0-10	3736.50	0.39	0.02	2054
	10-20	4581.50	0.38	0.01	1357
	20-30	3573.50	0.37	0.00	1223
	30-40	4463.50	0.37	0.00	816
	40-50	4145.00	0.36	0.00	302
	clippings	0.47	1.69	1.32	44020
	verdure	7.18	0.95	0.58	29997
	thatch mat	666.20	0.44	0.07	3523
15	0-10	4254.50	0.40	0.03	1884
	10-20	4711.50	0.37	0.01	1158
	20-30	4371.50	0.37	0.00	1380
	30-40	4100.50	0.36	0.00	614
	40-50	4249.50	0.36	0.00	883
	clippings	0.01	1.53	1.17	42026
	verdure	6.33	0.87	0.50	10881
	thatch mat	433.80	0.46	0.09	3032

Table 2-A. Continued.

ug ^{15}N/g	ug N/g	ug N /fraction	% N per fraction
0.33	7.06	24844.28	16.90
0.21	4.44	24332.18	16.55
0.05	1.02	5012.02	3.41
0.00	0.00	0.00	0.00
0.07	1.46	6318.57	4.30
285.27	6116.41	20184.16	13.73
52.09	1116.75	12898.42	8.77
1.06	22.75	16629.54	11.31
0.26	5.51	20474.94	13.93
0.33	7.02	30176.48	20.53
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
603.97	12949.59	9971.19	6.78
107.68	2308.64	13898.03	9.45
1.84	39.46	23318.14	15.86
0.15	3.15	9454.69	6.43
0.27	5.74	23829.98	16.21
0.03	0.63	2297.96	1.56
0.13	2.69	11183.09	7.61
0.01	0.27	1423.87	0.97
427.97	9176.03	4404.49	3.00
30.45	652.84	15674.68	10.66
1.21	25.93	18081.76	12.30
0.83	17.73	52475.29	35.70
0.29	6.18	27180.61	18.49
0.21	4.45	20176.36	13.73
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
520.00	11149.29	1337.91	0.91

Table 2-A. Continued.

142.38	3052.70	12638.18	8.60
2.66	57.08	26782.63	18.22
0.40	8.50	34407.82	23.41
0.26	5.66	23693.50	16.12
0.10	2.12	9269.43	6.31
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
456.15	9780.20	5085.70	3.46
63.36	1358.49	40768.30	27.73
1.35	28.99	18151.21	12.35
0.35	7.51	26602.17	18.10
0.12	2.47	10951.90	7.45
0.09	2.03	8574.60	5.83
0.05	1.14	4683.67	3.19
0.02	0.45	1930.00	1.31
190.54	4085.41	2818.93	1.92
31.11	667.05	27149.06	18.47
1.24	26.63	15904.29	10.82
0.48	10.20	31006.40	21.09
0.24	5.04	21574.81	14.68
0.11	2.27	10085.56	6.86
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
665.53	14269.50	9275.17	6.31
34.19	732.99	18991.79	12.92
1.36	29.06	25718.00	17.50
0.43	9.19	35216.62	23.96
0.16	3.51	14692.12	9.99
0.10	2.16	9915.30	6.75
0.12	2.62	9204.16	6.26
0.01	0.29	1354.63	0.92
375.67	8054.73	3382.99	2.30

Table 2-A. Continued.

19.38	415.47	20250.15	13.78
1.57	33.75	19854.52	13.51
0.47	10.01	43751.24	29.76
0.18	3.93	16353.16	11.12
0.14	2.97	15794.58	10.74
0.02	0.50	2152.48	1.46
0.00	0.00	0.00	0.00
526.74	11293.80	5533.96	3.76
30.92	662.88	15213.04	10.35
1.17	25.04	14970.89	10.18
0.57	12.18	46594.98	31.70
0.09	1.96	9422.70	6.41
0.10	2.10	10068.40	6.85
0.09	1.98	7822.15	5.32
0.07	1.49	7288.76	4.96
407.49	8736.95	961.06	0.65
92.21	1977.01	8580.21	5.84
2.17	46.61	13387.56	9.11
0.53	11.45	40892.33	27.82
0.13	2.72	11190.97	7.61
0.05	0.97	4339.01	2.95
0.16	3.48	15214.29	10.35
0.00	0.00	0.00	0.00
474.65	10176.95	2747.78	1.87
137.04	2938.24	10636.41	7.24
2.61	55.93	19558.46	13.31
0.66	14.11	55219.29	37.56
0.17	3.70	17889.88	12.17
0.01	0.26	1304.33	0.89
0.00	0.00	0.00	0.00
0.01	0.31	1453.54	0.99
0.00	0.00	0.00	0.00

Table 2-A. Continued.

45.00	964.78	4939.66	3.36
2.69	57.61	26877.36	18.28
0.47	10.13	37847.28	25.75
0.12	2.62	11996.97	8.16
0.05	1.05	3748.19	2.55
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
581.50	12467.93	5859.93	3.99
173.98	3730.33	26783.77	18.22
2.50	53.63	35728.69	24.31
0.62	13.33	56713.29	38.58
0.09	1.99	9358.35	6.37
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
490.02	10506.50	105.07	0.07
54.84	1175.82	7442.94	5.06
2.73	58.51	25380.65	17.27

APPENDIX 3: LEACHATE KJELDAHL NITROGEN RECOVERY

Table 3-A. Leachate Kjeldahl nitrogen recovery.

Col.#, # of irrigations	Time (hr)	Volume (ml)	atom % ^{15}N
1-1	1.00	480.92	1.468
	19.65	129.45	1.711
	41.78	11.43	1.691
	95.17	22.37	0.841
	168.00	38.03	0.568
2-4	1.00	40.99	0.358
	7.75	99.34	0.366
	19.55	83.46	0.367
	30.50	38.92	0.457
	71.17	55.70	0.000
	127.17	24.09	0.000
	168.00	27.40	0.362
4-1	1.00	531.99	2.300
	26.00	224.60	1.981
	91.50	35.60	2.276
	168.00	46.78	1.268
5-4	5.00	110.30	0.372
	24.33	35.53	0.368
	48.33	122.40	0.366
	93.00	93.27	0.366
	142.20	194.46	0.418
	168.00	17.08	0.374
6-1	1.30	677.74	3.337
	24.00	66.09	0.358
	94.30	260.58	0.359
	120.80	33.88	0.376
	140.30	143.66	0.470
	168.00	15.33	0.373
7-4	1.30	98.51	0.354
	24.00	98.92	0.362

Table 3-A. Continued.

	90.80	48.11	1.612
	120.80	12.46	0.908
	168.00	22.97	0.582
8-4	1.00	74.52	0.367
	44.25	86.18	0.375
	49.25	158.00	0.581
	91.50	26.17	0.410
	115.00	109.41	0.653
	141.00	148.24	0.450
	168.00	12.15	0.394
9-1	1.30	799.92	2.025
	24.00	84.32	0.958
	120.80	68.19	0.464
	168.00	21.28	0.397
10-4	1.30	84.75	0.784
	24.00	104.98	0.508
	47.80	121.43	0.389
	90.80	41.00	0.383
	94.30	70.90	0.477
	120.80	38.69	0.000
	140.30	118.33	0.485
	168.00	14.78	0.374
11-1	5.00	589.22	1.047
	48.33	47.40	1.213
	168.00	37.41	0.634
12-1	5.00	623.30	2.628
	48.42	32.02	1.956
	168.00	31.28	1.051
13-1	1.00	227.93	2.323
	19.70	290.22	0.709
	168.00	74.39	0.394
14-4	5.00	102.31	0.381

Table 3-A. Continued.

	24.33	18.91	0.000
	48.33	72.74	0.457
	93.00	61.40	0.431
	142.20	169.46	0.360
	168.00	29.75	0.357
15-4	1.00	31.36	0.355
	19.62	87.11	0.358
	29.33	20.83	0.353
	30.50	37.74	0.357
	37.00	105.04	0.362
	95.83	69.49	0.368
	127.00	21.81	0.355
	168.00	42.01	0.368

Table 3-A. Continued.

atom % ^{15}N-.366	mg N/liter (ppm)	mg ^{15}N/liter	mg ^{15}N/sample
1.10	3	0.03	0.02
1.35	3	0.04	0.01
1.33	4	0.05	0.00
0.48	1	0.00	0.00
0.20	2	0.00	0.00
0.00	2	0.00	0.00
0.00	1	0.00	0.00
0.00	1	0.00	0.00
0.09	1	0.00	0.00
0.00	1	0.00	0.00
0.00	0	0.00	0.00
0.00	3	0.00	0.00
1.93	1	0.02	0.01
1.62	3	0.05	0.01
1.91	2	0.04	0.00
0.90	1	0.01	0.00
0.01	2	0.00	0.00
0.00	2	0.00	0.00
0.00	2	0.00	0.00
0.00	2	0.00	0.00
0.05	2	0.00	0.00
0.01	3	0.00	0.00
2.97	5	0.15	0.10
0.00	1	0.00	0.00
0.00	2	0.00	0.00
0.01	2	0.00	0.00
0.10	2	0.00	0.00
0.01	2	0.00	0.00
0.00	2	0.00	0.00
0.00	1	0.00	0.00

Table 3-A. Continued.

1.25	1	0.01	0.00
0.54	1	0.01	0.00
0.22	0	0.00	0.00
0.00	1	0.00	0.00
0.01	0	0.00	0.00
0.22	1	0.00	0.00
0.04	2	0.00	0.00
0.29	1	0.00	0.00
0.08	2	0.00	0.00
0.03	2	0.00	0.00
1.66	2	0.03	0.03
0.59	2	0.01	0.00
0.10	1	0.00	0.00
0.03	2	0.00	0.00
0.42	2	0.01	0.00
0.14	2	0.00	0.00
0.02	2	0.00	0.00
0.02	1	0.00	0.00
0.11	2	0.00	0.00
0.00	2	0.00	0.00
0.12	2	0.00	0.00
0.01	3	0.00	0.00
0.68	2	0.01	0.01
0.85	2	0.02	0.00
0.27	1	0.00	0.00
2.26	6	0.14	0.08
1.59	4	0.06	0.00
0.69	1	0.01	0.00
1.96	1	0.02	0.00
0.34	1	0.00	0.00
0.03	1	0.00	0.00
0.02	2	0.00	0.00

Table 3-A. Continued.

0.00	0	0.00	0.00
0.09	2	0.00	0.00
0.07	2	0.00	0.00
0.00	2	0.00	0.00
0.00	1	0.00	0.00
0.00	1	0.00	0.00
0.00	2	0.00	0.00
0.00	2	0.00	0.00
0.00	2	0.00	0.00
0.00	2	0.00	0.00
0.00	8	0.00	0.00
0.00	1	0.00	0.00
0.00	2	0.00	0.00

Table 3-A. Continued.

mg N /sample	mg N /column	% of applied
0.34		
0.11		
0.01		
0.00		
0.00	0.47	0.32
0.00		
0.00		
0.00		
0.00		
0.00		
0.00		
0.00	0.00	0.00
0.22		
0.23		
0.03		
0.01	0.49	0.33
0.00		
0.00		
0.00		
0.00		
0.00		
0.00	0.00	0.00
2.16		
0.00		
0.00		
0.00		
0.01		
0.00	2.17	1.47
0.00		
0.00		

Table 3-A. Continued.

0.01		
0.00		
0.00	0.01	0.01
0.00		
0.00		
0.01		
0.00		
0.01		
0.01		
0.00	0.02	0.01
0.57		
0.02		
0.00		
0.00	0.59	0.40
0.02		
0.01		
0.00		
0.00		
0.00		
0.00		
0.01		
0.00	0.03	0.02
0.17		
0.02		
0.00	0.19	0.13
1.81		
0.04		
0.00	1.86	1.27
0.10		
0.02		
0.00	0.12	0.08

Table 3-A. Continued.

0.00		
0.00		
0.00		
0.00		
0.00		
0.00	0.01	0.00
0.00		
0.00		
0.00		
0.00		
0.00		
0.00		
0.00		
0.00	0.00	0.00

APPENDIX 4: SOIL LAYER NITRATE-NITROGEN RECOVERY

Table 4-A. Soil layer nitrate-nitrogen recovery.

Column #	layer	atom % NO_3^-	atom % - .366	PPM NO_3^-
1	0-10	1.18	0.82	17.83
	10-20	1.13	0.77	8.69
	20-30	1.21	0.84	6.11
	30-40	0.90	0.54	5.03
	40-50	1.15	0.78	5.36
	thatch mat	0.54	0.17	31.85
2	0-10	1.62	1.25	18.84
	10-20	1.29	0.92	9.33
	20-30	0.57	0.20	3.97
	30-40	0.34	0.00	2.75
	40-50	0.35	0.00	3.29
	thatch mat	0.69	0.32	22.40
4	0-10	1.44	1.07	19.21
	10-20	0.97	0.60	9.08
	20-30	0.63	0.26	7.52
	30-40	1.12	0.76	7.41
	40-50	0.90	0.53	7.92
	thatch mat	0.43	0.06	33.25
5	0-10	1.37	1.00	27.14
	10-20	1.20	0.83	15.40
	20-30	0.80	0.43	10.62
	30-40	0.53	0.17	8.80
	40-50	0.46	0.09	6.31
	thatch mat	0.54	0.17	68.25
6	0-10	1.78	1.41	17.76
	10-20	1.13	0.77	8.84
	20-30	1.02	0.66	8.67
	30-40	0.60	0.23	4.41
	40-50	0.60	0.24	3.63
	thatch mat	0.37	0.01	23.63

Table 4-A. Continued.

7	0-10	0.87	0.50	14.73
	10-20	0.34	0.00	8.20
	20-30	0.58	0.22	5.75
	30-40	1.27	0.91	4.13
	40-50	0.61	0.24	3.55
	thatch mat	0.40	0.04	29.93
8	0-10	1.97	1.60	15.01
	10-20	1.72	1.35	9.24
	20-30	1.48	1.12	7.61
	30-40	0.62	0.25	5.99
	40-50	0.38	0.02	4.16
	thatch mat	0.42	0.05	19.43
9	0-10	1.93	1.57	14.65
	10-20	1.78	1.41	5.75
	20-30	1.84	1.47	4.55
	30-40	1.88	1.52	3.57
	40-50	1.37	1.00	2.61
	thatch mat	0.64	0.27	24.50
10	0-10	1.60	1.23	16.91
	10-20	1.45	1.09	11.00
	20-30	1.34	0.98	8.73
	30-40	0.95	0.58	6.77
	40-50	0.46	0.10	4.28
	thatch mat	0.50	0.13	20.13
11	0-10	0.87	0.51	26.75
	10-20	1.14	0.77	8.77
	20-30	1.14	0.78	6.44
	30-40	1.24	0.87	5.69
	40-50	1.29	0.93	4.91
	thatch mat	0.68	0.31	36.40
12	0-10	1.52	1.16	23.50
	10-20	1.11	0.74	8.98

Table 4-A. Continued.

	20-30	0.84	0.47	7.15
	30-40	0.60	0.24	5.60
	40-50	0.63	0.27	3.62
	thatch mat	0.44	0.07	65.80
13	0-10	1.43	1.06	30.85
	10-20	1.19	0.82	9.95
	20-30	0.90	0.53	5.14
	30-40	1.03	0.66	3.66
	40-50	0.61	0.24	2.05
	thatch mat	0.78	0.41	114.10
14	0-10	1.44	1.07	20.57
	10-20	1.17	0.80	10.52
	20-30	1.05	0.69	6.67
	30-40	0.36	0.00	4.43
	40-50	0.44	0.08	2.95
	thatch mat	0.42	0.05	62.48
15	0-10	1.33	0.96	28.45
	10-20	0.65	0.29	13.39
	20-30	0.62	0.25	7.36
	30-40	0.44	0.07	5.71
	40-50	0.42	0.05	3.39
	thatch mat	0.83	0.47	86.10

Table 4-A. Continued.

ug ^{15}N/g soil	ug N/g soil	mg N /layer for NO_3^- N	% of applied
0.15	3.12	10.97	7.46
0.07	1.43	7.83	5.33
0.05	1.10	5.42	3.69
0.03	0.58	2.72	1.85
0.04	0.90	3.87	2.63
0.05	1.17	0.85	0.58
0.24	5.06	18.82	12.80
0.09	1.84	7.93	5.39
0.01	0.17	0.81	0.55
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
0.07	1.55	0.91	0.62
0.21	4.41	13.24	9.01
0.05	1.17	4.84	3.29
0.02	0.42	1.52	1.03
0.06	1.20	4.99	3.39
0.04	0.90	4.78	3.25
0.02	0.42	0.29	0.20
0.27	5.82	17.24	11.73
0.13	2.75	12.11	8.24
0.05	0.99	4.47	3.04
0.01	0.32	1.24	0.84
0.01	0.13	0.67	0.46
0.12	2.53	1.19	0.81
0.25	5.37	21.72	14.78
0.07	1.45	6.07	4.13
0.06	1.22	5.34	3.63
0.01	0.22	0.94	0.64
0.01	0.18	0.87	0.59
0.00	0.03	0.02	0.01

Table 4-A. Continued.

0.07	1.59	5.63	3.83
0.00	0.00	0.00	0.00
0.01	0.27	1.13	0.77
0.04	0.80	3.30	2.24
0.01	0.18	0.79	0.54
0.01	0.22	0.13	0.09
0.24	5.16	15.68	10.67
0.12	2.68	11.46	7.80
0.09	1.82	8.09	5.50
0.02	0.32	1.46	0.99
0.00	0.02	0.07	0.05
0.01	0.21	0.19	0.13
0.23	4.92	18.86	12.83
0.08	1.74	7.30	4.97
0.07	1.44	6.61	4.50
0.05	1.16	4.08	2.78
0.03	0.56	2.63	1.79
0.07	1.42	0.83	0.56
0.21	4.47	19.52	13.28
0.12	2.56	10.67	7.26
0.09	1.83	9.73	6.62
0.04	0.84	3.62	2.46
0.00	0.09	0.43	0.29
0.03	0.58	0.35	0.24
0.14	2.90	11.10	7.55
0.07	1.45	6.95	4.73
0.05	1.07	5.14	3.50
0.05	1.07	4.20	2.86
0.05	0.98	4.78	3.25
0.11	2.45	0.70	0.48
0.27	5.83	20.83	14.17
0.07	1.43	5.88	4.00

Table 4-A. Continued.

0.03	0.73	3.24	2.20
0.01	0.28	1.24	0.84
0.01	0.21	1.05	0.71
0.05	0.99	0.35	0.24
0.33	7.02	27.47	18.69
0.08	1.75	8.48	5.77
0.03	0.59	2.97	2.02
0.02	0.52	2.34	1.59
0.00	0.11	0.49	0.33
0.47	10.03	4.68	3.18
0.22	4.73	17.67	12.02
0.08	1.81	8.29	5.64
0.05	0.98	3.51	2.39
0.00	0.00	0.00	0.00
0.00	0.05	0.20	0.14
0.03	0.67	0.45	0.31
0.27	5.86	24.94	16.97
0.04	0.83	3.90	2.65
0.02	0.39	1.72	1.17
0.00	0.09	0.37	0.25
0.00	0.04	0.16	0.11
0.40	8.62	3.74	2.54

APPENDIX 5: LEACHATE NITRATE NITROGEN RECOVERY

Table 5-A. Leachate nitrate-nitrogen recovery.

Col. #, # of irrigation	Time (hr)	Volume (ml)
1-1	1.00	480.92
	19.65	129.45
	41.78	11.43
	95.17	22.37
	168.00	38.03
2-4	1.00	40.99
	7.75	99.34
	19.55	83.46
	30.50	38.92
	71.17	55.70
	127.17	24.09
	168.00	27.40
4-1	1.00	531.99
	26.00	224.60
	91.50	35.60
	168.00	46.78
5-4	5.00	110.30
	24.33	35.53
	48.33	122.40
	93.00	93.27
	142.20	194.46
	168.00	17.08
6-1	1.30	677.74
	24.00	66.09
	94.30	260.58
	120.80	33.88
	140.30	143.66
	168.00	15.33
7-4	1.30	98.51
	24.00	98.92

Table 5-A. Continued.

	90.80	48.11
	120.80	12.46
	168.00	22.97
8-4	1.00	74.52
	44.25	86.18
	49.25	158.00
	91.50	26.17
	115.00	109.41
	141.00	148.24
	168.00	12.15
9-1	1.30	799.92
	24.00	84.32
	120.80	68.19
	168.00	21.28
10-4	1.30	84.75
	24.00	104.98
	47.80	121.43
	90.80	41.00
	94.30	70.90
	120.80	38.69
	140.30	118.33
	168.00	14.78
11-1	5.00	589.22
	48.33	47.40
	168.00	37.41
12-1	5.00	623.30
	48.42	32.02
	168.00	31.28
13-1	1.00	227.93
	19.70	290.22
	168.00	74.39
14-4	5.00	102.31

Table 5-A. Continued.

	24.33	18.91
	48.33	72.74
	93.00	61.40
	142.20	169.46
	168.00	29.75
15-4	1.00	31.36
	19.62	87.11
	29.33	20.83
	30.50	37.74
	37.00	105.04
	95.83	69.49
	127.00	21.81
	168.00	42.01

Table 5-A. Continued.

atom % ^{15}N	%^{15}N-.366%	mg N/liter	mg ^{15}N/liter
0.466	0.10	7.0	0.01
0.448	0.08	10.0	0.01
			0.00
			0.00
0.434	0.07	1.0	0.00
0.363	0.00	7.0	0.00
0.368	0.00	9.0	0.00
0.367	0.00	7.0	0.00
			0.00
			0.00
			0.00
			0.00
0.429	0.06	7.0	0.00
0.431	0.07	12.0	0.01
			0.00
			0.00
0.364	0.00	13.0	0.00
			0.00
0.368	0.00	20.0	0.00
0.371	0.01	20.0	0.00
0.395	0.03	19.0	0.01
			0.00
0.764	0.40	3.2	0.01
0.365	0.00	11.0	0.00
0.385	0.02	6.0	0.00
			0.00
0.459	0.09	19.0	0.02
			0.00
0.368	0.00	10.0	0.00
0.417	0.05	20.0	0.01

Table 5-A. Continued.

			0.00
			0.00
			0.00
0.364	0.00	8.0	0.00
0.367	0.00	7.0	0.00
0.742	0.38	3.0	0.01
			0.00
0.522	0.16	10.0	0.02
0.491	0.13	12.0	0.02
			0.00
0.423	0.06	9.2	0.01
0.425	0.06	10.0	0.01
0.460	0.09	3.0	0.00
			0.00
			0.00
0.372	0.01	11.0	0.00
0.527	0.16	16.0	0.03
			0.00
0.537	0.17	21.0	0.04
			0.00
0.456	0.09	16.0	0.01
			0.00
0.393	0.03	6.2	0.00
			0.00
			0.00
0.542	0.18	6.0	0.01
			0.00
			0.00
			0.00
0.376	0.01	19.0	0.00
0.377	0.01	5.0	0.00
0.365	0.00	20.0	0.00

Table 5-A. Continued.

			0.00
0.365	0.00	19.0	0.00
			0.00
0.376	0.01	17.0	0.00
			0.00
			0.00
			0.00
			0.00
			0.00
0.364	0.00	20.0	0.00
			0.00
			0.00
0.368	0.00	14.0	0.00

Table 5-A. Continued.

mg ^{15}N/sample	mg N / sample	mg N /column	% of applied
0.00	0.07		
0.00	0.02		
0.00	0.00		
0.00	0.00		
0.00	0.00	0.09	0.06
0.00	0.00		
0.00	0.00		
0.00	0.00		
0.00	0.00		
0.00	0.00		
0.00	0.00		
0.00	0.00	0.00	0.00
0.00	0.05		
0.00	0.04		
0.00	0.00		
0.00	0.00	0.09	0.06
0.00	0.00		
0.00	0.00		
0.00	0.00		
0.00	0.00		
0.00	0.02		
0.00	0.00	0.03	0.02
0.01	0.19		
0.00	0.00		
0.00	0.01		
0.00	0.00		
0.00	0.05		
0.00	0.00	0.25	0.17
0.00	0.00		
0.00	0.02		

Table 5-A. Continued.

0.00	0.00		
0.00	0.00		
0.00	0.00	0.02	0.02
0.00	0.00		
0.00	0.00		
0.00	0.04		
0.00	0.00		
0.00	0.04		
0.00	0.05		
0.00	0.00	0.12	0.08
0.00	0.09		
0.00	0.01		
0.00	0.00		
0.00	0.00	0.10	0.07
0.00	0.00		
0.00	0.00		
0.00	0.07		
0.00	0.00		
0.00	0.05		
0.00	0.00		
0.00	0.04		
0.00	0.00	0.16	0.11
0.00	0.02		
0.00	0.00		
0.00	0.00	0.02	0.01
0.01	0.14		
0.00	0.00		
0.00	0.00	0.14	0.10
0.00	0.00		
0.00	0.01		
0.00	0.00	0.01	0.01

Table 5-A. Continued.

0.00	0.00		
0.00	0.00		
0.00	0.00		
0.00	0.00		
0.00	0.01		
0.00	0.00	0.01	0.00
0.00	0.00		
0.00	0.00		
0.00	0.00		
0.00	0.00		
0.00	0.00		
0.00	0.00		
0.00	0.00		
0.00	0.00	0.00	0.00

APPENDIX 6: SOIL LAYER AVAILABLE PHOSPHORUS

Table 6-A. Soil layer available phosphorus.

Col. #	layer	P conc. (ppm)	Col.#	layer	P conc. (ppm)
1	Thatch	16	9	Thatch	21
	0-10 cm	8		0-10 cm	6
	10-20 cm	4		10-20 cm	3
	20-30 cm	3		20-30 cm	3
	30-40 cm	4		30-40 cm	3
	40-50 cm	5		40-50 cm	3
2	Thatch	31	10	Thatch	21
	0-10 cm	6		0-10 cm	9
	10-20 cm	3		10-20 cm	3
	20-30 cm	2		20-30 cm	2
	30-40 cm	3		30-40 cm	2
	40-50 cm	5		40-50 cm	2
4	Thatch	16	11	Thatch	0
	0-10 cm	7		0-10 cm	9
	10-20 cm	4		10-20 cm	2
	20-30 cm	3		20-30 cm	2
	30-40 cm	3		30-40 cm	3
	40-50 cm	4		40-50 cm	4
5	Thatch	39	12	Thatch	0
	0-10 cm	7		0-10 cm	7
	10-20 cm	3		10-20 cm	2
	20-30 cm	2		20-30 cm	2
	30-40 cm	2		30-40 cm	2
	40-50 cm	2		40-50 cm	3
6	Thatch	21	13	Thatch	0
	0-10 cm	5		0-10 cm	5
	10-20 cm	2		10-20 cm	2
	20-30 cm	2		20-30 cm	1
	30-40 cm	2		30-40 cm	0
	40-50 cm	2		40-50 cm	0

Table 6-A. Continued.

7	Thatch	16	14	Thatch	32
	0-10 cm	5		0-10 cm	5
	10-20 cm	2		10-20 cm	2
	20-30 cm	1		20-30 cm	1
	30-40 cm	2		30-40 cm	0
	40-50 cm	3		40-50 cm	0
8	Thatch	26	15	Thatch	0
	0-10 cm	5		0-10 cm	8
	10-20 cm	2		10-20 cm	2
	20-30 cm	1		20-30 cm	1
	30-40 cm	2		30-40 cm	0
	40-50 cm	2		40-50 cm	0

APPENDIX 7: LEACHATE PHOSPHORUS

Table 7-A. Leachate phosphorus.

Leachate (ml)	P (mg)	P (mg) per column	# of irrigations
483.42	1.47		
214.32	1.08	2.55	1
478.02	0.33		
284.01	0.30	0.63	1
98.92	0.08		
48.11	0.02	0.10	4
473.92	1.51		
149.38	0.46		
32.02	0.04	2.01	1
480.92	0.64		
129.45	0.05	0.69	1
227.93	0.85	0.85	1

APPENDIX 8: SOIL CHARACTERISTICS OF SOIL COLUMNS

Table 8-A. Soil characteristics of soil columns.

column #	volume (l)	empty (lb)	field cap. (lb)	soil (kg)	empty (kg)	field cap. (kg)	sat-f.c. (l)
1	17.07	106	173	23.69	48.12	78.54	0.55
2	16.17	104	170	22.89	47.22	77.18	0.54
4	15.88	103	163	20.97	46.76	74.00	1.37
5	15.50	106	171	21.64	48.12	77.63	1.11
6	16.00	101	167	22.26	45.85	75.82	0.71
7	15.00	105	169	21.23	47.67	76.73	1.49
8	14.57	108	171	21.52	49.03	77.63	1.00
9	15.25	103	171	21.39	46.76	77.63	0.83
10	16.28	110	169	23.62	49.94	76.73	1.13
11	15.39	105	171	22.56	47.67	77.63	0.77
12	15.47	105	171	21.96	47.67	77.63	0.45
13	15.07	111	174	23.45	50.39	79.00	0.54
14	14.40	113	174	21.18	51.30	79.00	0.78
15	16.45	110	173	22.12	49.94	78.54	0.54

Table 8-A. Continued.

storage yield	Bulk den. (kg/l)	m.c. (fc)	Porosity
0.032	1.39	0.28	0.48
0.033	1.42	0.31	0.47
0.086	1.32	0.30	0.50
0.071	1.40	0.36	0.47
0.044	1.39	0.35	0.48
0.099	1.42	0.37	0.47
0.069	1.48	0.33	0.44
0.054	1.40	0.44	0.47
0.069	1.45	0.13	0.45
0.050	1.47	0.33	0.45
0.029	1.42	0.36	0.46
0.036	1.56	0.22	0.41
0.054	1.47	0.31	0.44
0.033	1.34	0.29	0.49