To the Graduate Council:

I am submitting herewith a thesis written by Colleen Georgette Melhorn entitled "Soil Biological and Biochemical Properties Under Different Cover Crops and Fertilizer Levels in Long-Term, No-Till Corn". I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant and Soil Science.

Michael D.Mullen, Major Professor

We have read this thesis and
recommend its acceptance:

Accepted for the Council:

Associate Vice Chancellor
and Dean of the Graduate School

SOIL BIOLOGICAL AND BIOCHEMICAL PROPERTIES UNDER DIFFERENT COVER CROPS AND NITROGEN LEVELS IN LONG TERM, NO-TILL CORN

A Thesis

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ABSTRACT

This study was conducted to compare the effects of three types of cover situations, wheat, hairy vetch, and previous corn residue, and two rates of nitrogen fertilizer, 0 and 168 kg N ha^{-1}, on soil biological and biochemical properties in long term, no-till corn plots. The research plots were located in Milan,TN at the Milan Experiment Station on a Loring silt loam (fine-silty, mixed, thermic, Typic Fragiudalf), and were arranged in completely randomized split plot with four replicates. Plots were randomly sampled twelve times, four samples within the row and four times at 18.3 and 37.5 cm. from the row center. Samples were separated into three depths: 0-5, 5-10, and 10-20 cm. Four 37.7 by 37.7 cm. squares of mulch were randomly collected from each plot. Soils were analyzed for total carbon, total nitrogen, soil pH, total exchangeable bases, bacteria, fungi, *Aspergillus flavus*, fluorescent pseudomonads, cellulose degrader, and *Bacillus spp.* enumerations, microbial biomass carbon and nitrogen, acid phosphatase, alkaline phosphatase, β-glucosidase, arylsulfatase, L-asparaginase, and wet aggregate stability. Mulch samples were analyzed for total carbon and nitrogen content. Soil carbon and nitrogen values were significantly greater under vetch cover, due to the higher carbon and nitrogen concentration in the vetch mulch. Soils of the 168 N rate plots had significantly greater carbon and nitrogen than those of the low rate, due to increased crop mulch and available nitrogen associated with the fertilizer. Soil pH was significantly lower in vetch plots compared to wheat or previous corn residue plots, due to higher nitrogen mineralization and nitrification from fixed and/or fertilizer nitrogen. Fertilizer significantly decreased soil pH, because nitrification generates acidity. Exchangeable potassium and phosphorus concentrations were higher in previous corn residue soils due to increased corn yields in cover plots. Soil potassium and phosphorus concentrations were higher in 0 N rate plots due to decreasing availability with decreasing pH. Vetch mulch contained greater carbon and nitrogen due to the ability of symbiotic nitrogen fixation. Mulch from plots receiving the 168 N rate held greater carbon and nitrogen due to increased nutrient availability. Vetch plots yielded the greatest quantity of corn due to the nitrogen-rich vetch mulch. Plots receiving the 168 N rate yielded more corn due to greater nitrogen availability. Vetch plots with the 0 N rate and wheat plots with the

168 N rate yielded the greatest cover crop dry matter. The wheat yields in the 0N treatments were lowest due to lack of available nitrogen. The pH was significantly lower under vetch with 168 N treatments. Lower pH results in less vigorous legume growth. Vetch plots had greater numbers of bacteria, fungi, and *Bacillus spp.* due to the nitrogen-rich vetch mulch. Bacterial numbers were significantly greater in vetch plots with the 0 N rate, because fertilizer suppresses the high microbial activity of vetch plots. *Aspergillus flavus*, actinomycetes, and cellulose degrader counts were greater under wheat mulch based on their fungal nature to degrade cellulosic material. Fluorescent pseudomonad numbers were greater under vetch due to carbon and nitrogen concentrations in the mulch. Bacteria, actinomycetes, and *Bacillus* numbers were greater under plots receiving the 0 N rate due to soil acidification ensuing fertilizer amendment. Fungi, *Aspergillus flavus*, fluorescent pseudomonads, and cellulose degraders flourish in plots receiving the 168 N rate due to fungal and pseudomonad resistance to acidity. Microbial biomass nitrogen was greater in wheat plots with the 168 N rate and vetch plots with the 0 N rate, supporting enumeration data. All enzyme activities were significantly greater under vetch covers, due to the high carbon and nitrogen content of soils under vetch mulch. All enzyme activities except acid phosphatase and β-glucosidase were significantly greater in plots receiving the 0 N rate. Acid phosphatase and β-glucosidase are active at a lower pH range than the others. Soil aggregates were larger and more stable under vetch cover. A greater portion of total soil aggregates were retained on the 2 mm sieve in vetch plots. Overall, the greatest microbial numbers and activities came from soils of vetch plots receiving no nitrogen. Vetch efficiently fixes a sufficient amount of nitrogen. Any excessive nitrogen fertilizer on these plots causes reduced enzymatic activities and proliferation due to soil acidification.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

Popularized for increased organic matter availability and high degree of soil erosion control, no-tillage has become the preferred tillage procedure of the nineties. The use of no-tillage as a practice to reduce erosion, a great concern in Tennessee, is especially important in the western region near the Mississippi River. The erosiveness of soils in western Tennessee is primarily due to their silty composition. Carter and Berg (1991) report that conservation tillage with the fewest number of tillage operations over the entire cropping sequence (such as no-till) provides erosion reductions of forty seven to one hundred percent. Conservation tillage reduces erosion risk in both summer and winter crop seasons, having greater reduction in the summer than winter (Mills et al., 1991).

Although most of the nation's corn is produced in the Midwestern U.S., Tennessee is a large contributor to the nation's supply. Tennessee ranked eighteenth in the United States, producing 46,200,000 bushels of corn for grain in 1993 (USDA Tennessee Agriculture, 1994). In 1993, 290,000 acres of corn were planted in no-till, which amounted to about forty-four percent of corn planted under all tillage types (USDA Tennessee Agriculture, 1994). The counties comprising West Tennessee took top ranking for 1993 corn, wheat, cotton, soybeans, and sorghum production in the state (USDA Tennessee Agriculture, 1994). Erosion problems have plagued that area, making no-tillage a must in saving the nutrient-rich topsoil.

Another practice often employed with conservation tillage is the use of winter cover crops. Cover crops provide vegetation in the winter months and serve as an organic matter input for the system when the spring crop is planted (Tisdale et al., 1985). Cover crops help curb erosion by providing a canopy or raindrop shield over newly planted ground (Tisdale et al., 1985). A leguminous cover will also provide some of the nitrogen needed by the following crop (Ebelhar et al., 1982; Tisdale et al., 1985). Utomo and Frye (1983) found that no-till plots under hairy vetch resulted in significantly greater corn yields than did alfalfa or fertilizer amended, corn residue plots.

Different covers will reduce erosion based on their canopy coverage over the soil surface and their root system below ground. Covers will yield various nutrients depending on the rate of decomposition by soil organisms and the components of each plant species (Tisdale et al., 1985). For example, hairy vetch produces more dry matter with a higher percent nitrogen concentration than other legume crops (Ebelhar et al.,1984). Certain cover crops respond differently to varying levels of nitrogen. Hairy vetch can fix approximately ninety to one hundred kilograms of nitrogen per hectare, which decreases the amount of fertilizer needed by the spring crop (Ebelhar et al., 1984). Roberson et al. (1991) found that cover crop inputs of microbially available carbon stimulated rapid production of heavy fraction carbohydrates and improved soil structure, and cover crops significantly increase saturated hydraulic conductivity.

Little research concerning the effect of no-tillage practices on soil biological and biochemical properties of southeastern soils has been done. These properties include nature of the soil microbial population, which, in turn, governs nutrient cycling in the soil. The need for this research is important to the area, considering that the microbes degrade the ground covering residue and provide nutrients for the crop canopy. Coverage of bare ground is essential to erosion control. The benefits that soil microbiological research could provide are of special importance in erosion-stricken areas like those of western Tennessee.

LITERATURE REVIEW

Soil temperature in spring will be lower on soils with a cover crop than bare soil, but during the winter months, the soil temperature with cover will be greater than bare soil (Mitchell and Teel, 1977, Rodskjer and Tuvesson, 1976, Utomo and Frye, 1983). More solar radiation is received by the bare soil than soils under cover crops. However, the quantity of solar radiation reaching the soils under cover crops is retained by the cover mulch. The retention of warmth by overlying mulch causes the temperature difference (Utomo and Frye, 1983). In this way, cover acts as insulation from winter cold and spring/summer heat.

No-tillage is associated with greater total carbon and nitrogen concentrations in the surface layer when compared to conventional tillage (Doran, 1980; Ismail et al.,1994; Beare et al.,1994). Crop

residue carbon in no-tillage plots is retained at a higher concentration than in conventional tillage (Franzleubbers et al.,1994). Soil organic carbon content is directly related to the amount of crop canopy (Franzleubbers et al., 1994). Cover crops are an additional source of canopy and result in additional organic matter. When compared with conventional tillage, no-tillage plots were found to possess higher concentrations of labile phosphorus, exchangeable calcium, exchangeable magnesium, and exchangeable potassium (Ismail et al.,1994; Blevins et al.,1977).

The cultivation involved in conventional tillage causes decreased soil biological activity due to reduction of macro aggregates which provide a microbial habitat (Dick, 1992). Also, these macro aggregates provide an important mechanism for the protection of soil organic matter that may otherwise be mineralized under conventional tillage practices (Beare et al., 1994). Tillage disrupts aggregates and exposes organic aggregating agents to microbial attack (Adu and Oades, 1978; Reganold et al., 1987). No-tillage promotes both an increased concentration and stability of macro aggregates(Beare et al., 1994; Sutarman, 1991). Aggregate size in no till plots ranged from 0.41 to 1.08 mm. diameter (Drees et al., 1994). This may be compared with 0.25 to 0.39 mm. diameter aggregates in conventionally tilled plots (Drees et al., 1994). Cover crops significantly increase the concentration of heavy fraction carbohydrates and macro aggregate slaking resistance (Roberson et al., 1991). Heavy fraction carbohydrates are composed of microbial extracellular polysaccharides produced in response to cover crop carbon inputs. Heavy fraction carbohydrates are significantly correlated to aggregate stability and are shown to be important in the initial improvement of soil structure by cover crops (Roberson et al., 1991). Two year old cover crop treatments, on the average, had significantly less dispersible clay and significantly greater water stable aggregates than conventional and no-till corn treatments (Perfect et al., 1990). Surface horizons of conventionally tilled plots have limited structural development and less earthworm activity due to plowing. No-till plots are riddled with earthworm channels and their excrement in fillings, creating a more nutrient rich, aerated environment (Drees et al., 1994). No-till plots may have less total pore volume when compared with conventionally tilled plots, but the average pore size is much larger (Drees et al., 1994). Soil organic matter plays an important role in aggregate

stability because of its binding and cementing actions (Tisdale and Oades, 1982; Hayness et al., 1991; Oades, 1984). Hu et al. (1995) found a higher mannose to xylose ratio in micro aggregates than in macro aggregates. This suggests that organic matter in micro aggregates became strongly metabolized by soil microbes, but organic matter in macro aggregates were less processed. Fungi play a significant role in aggregate stability by increasing acid hydrolyzable carbohydrates (Hu et al., 1995). As well, the amount of calcium in the soil influences soil aggregation indirectly through its effects on organic matter or microbial activity (Martin et al., 1955; Sutarman, 1991).

Differences in crop management systems will significantly alter soil biomass and the associated mineralizable nitrogen level (Franzleubbers et al.,1994). Herbicides are used in the no-till practice to desiccate cover crops, which provide substrate for soil organisms. These herbicides have no negative effect on microbial life, and actually serve as a stimulant by creating available organic matter (Dick, 1984). Gianfreda et al. (1993) found that paraquat significantly activated invertase, but urease and acid phosphatase remained uninfluenced. The microbial biomass of soils under different cover crops in a no-till system has received limited study. Desiccated cover crops yield a carbonaceous substrate to soil organisms, encouraging the flourish of microbial populations. The effect a cover lends to flourishing biomass is a function of the cover's composition and whether relationships exist between microorganisms and the cover crop. Kirchner et al. (1993) found that no-till leguminous cover plots had greater microbial biomass than small grain and bare plots. Legume roots survive in symbiosis with beneficial microorganisms. Gauger (1987) found that hairy vetch cover plots contained a greater concentration of biomass carbon than crimson clover.

No-tillage soils tend to have larger microbial populations than conventionally tilled soils, because organic matter inputs are not quickly mineralized under no-till conditions (Franzleubbers et al., 1994). Biomass of no-till plots contained greater microbial biomass than conventionally tilled plots (Kirchner et al., 1993). The flourish or decline in soil microbial biomass is determined by the carbon pool availability in the soil (Buchanan and King, 1992; Kirchner et al., 1993). Carbon pool availability is dependent on organic matter inputs and the rate of mineralization by soil microorganisms. In conventionally tilled plots, plowing disrupts macro-aggregates allowing for

greater mineralization of organic matter, whereas no-tillage provides macro-aggregate protection of soil organic matter lengthening its availability in the soil (Beare et al., 1994).

There are seasonal fluctuations in soil microbial biomass in no-till plots with winter cover crops (Buchanan and King, 1992; Kirchner et al., 1993). In the winter when the cover crops are growing, the carbon pool decreases from microbial decomposition of organic matter. In the spring, the cover is desiccated and crop is drilled into cover residue. Here, the carbon pool is increased by the cover crop organic matter, leaving plenty of substrate for soil organisms. By summer, the carbon pool has decreased because the organic matter is mineralized. At this stage, microbial uptake has again decreased the carbon pool. By summers end, the unharvested crop residue will increase the carbon pool as the cover crop is planted (Buchanan and King, 1992). The carbon pool in the no-till cover crop system is constantly cycling with the microbial biomass.

A no-till system will have increased soil moisture content versus conventional tillage operations (Blevins et al., 1971). Given equal moisture contents, no-till plots have greater infiltration rate than conventionally tilled plots, demonstrating an advantage in reaping the benefit of a good rain (Dao, 1993). As well, cover crops effect soil moisture content. Utomo and Frye (1983) found that soils of rye cover plots and fertilizer amended, corn residue plots contain greater soil moisture than hairy vetch plots in the surface six inches.

Species populations within soils under the no-till, cover crop regime are more abundant than under conventional till system. No-tillage has a substantial effect on soil microbial populations which are dependant on water availability in the soil (Doran, 1980). Conventionally tilled plots have been shown to contain fewer *Bacillus spp.*, total bacteria, and actinomycetes than no-till plots (Kirchner et al., 1993). Water films serve as the mode of transportation for soil bacteria. This moisture maintenance can help bacteria reach an area of greater nutrition. Of course, the biggest influence on micro fauna remains the organic matter availability. The desiccation of cover crops provides nutrient rich organic matter at a time when carbon availability is limited.

Inorganic nitrogen fertilizer can influence the size of soil microbial populations. In no-till plots, the addition of nitrogen fertilizer increases soil fungal populations (Kirchner et al., 1993). Bardgett

and Leemans (1995) found that no application of fertilizer and lime to a grassland soil resulted in significant reductions in microbial biomass carbon and dehydrogenase activity by eighteen and twenty-one percent, respectively.

Soil depth also affects nutrient availability. In a no-till system, organic matter is not plowed under but remains on the surface. Surface decomposition dictates the level of nutrient availability in the whole profile. There were more aerobes, facultative anaerobes, and denitrifiers in the surface 7.5 cm of no-till soils than conventional till soils (Doran, 1980). In conventional tilled plots, organic matter is plowed under and readily mineralized. Due to increased aeration from plowing, conventional tilled soils from 7.5 to 15 cm deep contained more aerobes than no-till plots. However, at this depth the no-till soils displayed higher numbers of facultative anaerobes and denitrifiers (Doran, 1980).

Nitrogen availability is a necessity for protein production in all growing cells. In no-till systems with winter cover crops, the desiccated cover provides nitrogen according to its composition. Farmers add inorganic fertilizer to provide adequate nitrogen to get optimum crop yield. The recommended fertilizer rate in Tennessee for optimal corn yield is 100 to 225 pounds of nitrogen per acre (Savoy, 1996). However, excessive additions of fertilizer greater than necessary to maximize crop yields can cause losses in soil organic matter when compared to an adequately fertilized soil (Green et al., 1995). Additional fertilizer stimulates rapid mineralization of organic matter inputs while decreasing mineralization of stable organic matter. It has been suggested that repeated application of nitrogen through inorganic fertilizer reduces microbial activity in the soil by suppressing the production of certain soil enzymes involved in nutrient cycling (Dick, 1992). Increased inorganic fertilizer additions lowered the pH in the soil surface, especially in conservation tillage systems (Jacobsen and Westerman, 1991; Fauci and Dick, 1994). The reduction in pH will determine how active the microbes and therefore microbial enzymes will be. Dick et al. (1988) found that increased pH resulted in increased activities of arylsulfatase, urease, amidase, and alkaline phosphatase, while acid phosphatase activity decreased. Comparing no-till plots with and without nitrogen fertilizer, acid phosphatase and beta glucosidase activities were higher in plots with

nitrogen fertilizer (Kirchner et al., 1993). This suggests that while repeated fertilizer applications decrease activities of some soil enzymes, other enzymes become more active in the soil.

Enzymes are protein catalysts that speed the rate of a reaction by bringing reactants together in a stereochemical alignment suitable for reaction. Enzymatic reactions are the means by which microbial cells break down organic matter. Microbial cells produce endoenzymes and exoenzymes through protein production (Tabatabai, 1994). The extracellular enzymes are secreted into the soil to degrade near-by organic matter. Very small units of cellulose, glucose, and other small carbon substrates are brought back into the cell and digested by intracellular enzymes. In microbial ecology research, the extracellular enzymes are of greatest concern. Since they are excreted into the soil, they can be measured to yield an estimate of microbial activity.

Some of the more important enzymes include the phosphomonoesterases, sulfatases, amidases, and cellulase complex enzymes. Acid and alkaline phosphatase are important in phosphorus cycling, because they cleave orthophosphates from organic matter. Acid phosphatase has an optimum activity at pH 6.5 while alkaline phosphatase exhibit optimum activity around pH 11 (Tabatabai, 1994). The free soil phosphatase bonds to humic substances in the form of electron donor-acceptor complexes, the humics being the acceptor (Gosewinkel and Broadbent, 1986). Phosphatase activity in the soil is a function of plant available phosphorus and crop root intensity (Neilsen and Eiland, 1980) and is significantly correlated with organic carbon content (Speir, 1977). Phosphatase is inhibited by high concentrations of calcium, but enhanced by magnesium and manganese (Paw and Hughes, 1974). Arylsulfatase hydrolyses arylsulfate anions occurring in organic matter, cleaving ester sulfate to yield sulfate, making sulfur plant available (Tabatabai, 1994). There are many types of sulfatases, but arylsulfatase was the first sulfatase detected in nature (Tabatabai, 1994). So, arylsulfatase has received more attention than other groups of sulfatases. Arylsulfatase is believed to be partly responsible for sulfur cycling in the soil. Studies have shown that 40% to 70% of the total sulfur in surface soils of temperate regions is present in the ester sulfate form, the substrate of arylsulfatase (Tabatabai, 1994). L-asparaginase cleaves the ammonia group from the amino acid asparagine, yielding the amino acid aspartate and free

ammonia (Tabatabai, 1994). It is a type of amidase and serves as an indicator of nitrogen cycling. β-glucosidase hydrolyzes cellobiose into two glucose units, making glucose available for the organism (Tabatabai, 1994). After the cellulase complex breaks up the cellulose of organic matter into cellobiose units, β-glucosidase takes over. Monitoring the activity of this enzyme is a reflection of cellulose degradation.

Enzymes break down organic matter which supplies nutrients to plants and microbial cells. Tillage of the soil decreases enzyme activity (Dick, 1984; Klein and Koths, 1980). High soil moisture content increases enzyme activity (Dalal, 1975; Ramirez-Martinez and McLaren, 1966; Scott and Hagedorn, 1980). Enzyme activity is often highly correlated to organic matter content (Scott and Hagedorn, 1980; Dick, 1984). So, it follows that no-till soils with cover crops would have greater enzymatic activity than conventionally tilled soils (Dick, 1984; Doran, 1980).

Crop cover has a large impact on soil enzymes. Leguminous cover crops induced greater activities of alkaline phosphatase, arylsulfatase, and beta glucosidase when compared with small grain and no covers (Kirchner et al., 1993). Crimson clover stimulated the acid phosphatase, alkaline phosphatase, and arylsulfatase activities more so than nitrogen fertilization or rye cover (Gauger,1987).

OBJECTIVES

There is need for further research concerning soil biological and biochemical properties in no-till systems with winter cover crops (Dick, 1992; Buchanan and King, 1992). What effects do cover and nitrogen have on biological parameters in a no-till system? The work described in this thesis was directed to this question. The objectives of this study are to evaluate microbial populations and enzyme activities under three different cover crops and two levels of nitrogen fertilization on long-term, no-till corn plots. The null hypothesis states that there will be no effect of cover and nitrogen on biological parameters in a no-till system. The alternate hypothesis states that there will be an effect of cover and nitrogen on biological parameters in a no-till system.

CHAPTER II

MATERIALS AND METHODS

Hairy vetch (*Vicia villosa* Roth) and winter wheat (*Triticum aestivum* L.) were drilled into corn (*Zea mays* L.) residue each fall over ten years. The cover was desiccated by spraying with one quart of Round-Up herbicide per acre in April of each year. Zero kg ha^{-1} and 168 kg ha^{-1} rates of ammonium nitrate were applied at or around the time of planting corn. The 168 N rate was chosen because it is the amount of fertilizer recommended to produce optimal corn yields. Ninety kg ha^{-1} of P_2O_5 and K_2O were applied 4/23/93 and 3/16/95. Sixty-seven kg ha^{-1} of P_2O_5 and K_2O were applied 4/20/94. The plots were limed on 3/9/93 at a rate of 2.2 Mg ha^{-1}.

This project was part of a larger study of no-till corn with five different cover crops and five different rates of nitrogen. Besides hairy vetch, wheat, and previous corn residue, crimson clover and Austrian winter pea covers were grown. Also, three additional rates of nitrogen: 56, 112, and 224 kg N ha^{-1} were applied to the plots. For the sake of time and simplicity, only three cover crops and two rates of nitrogen were studied in this design.

EXPERIMENTAL DESIGN

The experiment was a completely randomized split plot design with four replicates. One of two nitrogen rates were randomly assigned to each of twenty-four plots, composing the main plots. One of three cover types were randomly assigned to each of twenty-four plots, composing the split plots.

SOIL AND MULCH SAMPLING

The soil at the site was a Loring silt loam (fine-silty, mixed, mesic Typic Fragiudalf). Each plot was sampled randomly four times within a row and four times at a distance of 18.3 cm and 37.5 cm from the row. Four 37.7cm x 37.7 cm squares of mulch were randomly collected from each plot, mixed, bagged, labeled, and packed on ice for transportation. Each core was divided into three depths for examination: 0-5, 5-10, and 10-20 cm. Depth increments were bagged, labeled, and mixed thoroughly, then packed on ice until they were transported to the lab. Soil samples were taken six times on the following dates: April 18, 1994, May 7, 1994, May 16, 1994, June 13, 1994,

August 4, 1994, and April 25, 1995. The cover was desiccated April 27, 1993; April 25, 1994; and April 19, 1995.

The soils were sieved to less than 2 mm, and stored at 4 degrees centigrade until used. Mulches were dried and ground for total carbon and nitrogen analysis. All soil depths were analyzed for total nitrogen, total carbon, pH, total calcium, copper, iron, potassium, magnesium, manganese, sodium, phosphorus, and zinc, total bacteria, total fungi, total cellulose degraders, total fluorescent pseudomonads, total *Aspergillus flavus*, total actinomycetes, and total *Bacillus spp.*, soil microbial biomass carbon and nitrogen, acid phosphatase activity, alkaline phosphatase activity, β–glucosidase activity, arylsulfatase activity, L-asparaginase activity, and aggregate stability. Total nitrogen and total carbon content were assessed for each mulch sample. Aggregate stability required unseived fresh soil samples. Enzymes, total carbon, total nitrogen, pH, and Melich I procedures used air dried soil samples. Enumerations as well as biomass carbon and nitrogen procedures required sieved, fresh soil samples.

SOIL AND MULCH PROPERTIES

Assessing total carbon was done by dry combustion on a Leco Carbon Determinator CR12 (Nelson and Sommers, 1982). A 1 g soil sample or 0.2 g ground mulch aliquot was burned in a boat inside the furnace where purified oxygen is present. The carbon dioxide evolved was measured by an infrared carbon dioxide detector after other evolved gases were removed by the magnesium perchlorate filters. Calcium carbonate was used to calibrate the instrument every ten samples, when running soil samples. Nicotinic acid was used to calibrate the instrument every ten samples when running mulch samples. Data was given as percent carbon.

The evaluation of total nitrogen was achieved via combustion in the Carlo Erba Instrumentazione NA1500 nitrogen analyzer (Bremner and Mulvaney, 1982). A sample aliquot of soil or mulch was placed in a tin boat which was heated to a high temperature (greater than 600 degrees C). The gases released were combusted in a stream of oxygen and passed through copper reduction columns, which reduced the nitrogen oxides to nitrogen gas and converted the carbon monoxide to carbon dioxide. Then the gases passed through a carbon dioxide trap column

to remove carbon dioxide. Gases passed through to a manganese anhydride column to remove water vapor. Nitrogen gas was collected in a nitrometer and the volume of gas measured. Determination of pH involved the use of a hydrogen electrode (McClean, 1982). Soil samples were mixed with water in a one to two ratio. The Melich I extraction method yielded concentrations of phosphorus, potassium, and exchangeable bases available in soil (Nelson et al., 1953). Twenty milliliters of extractant was added to five grams of soil. Samples were shaken for twenty minutes and allowed to settle. Supernatant of each sample was filtered through a Whatman No.2 filter paper. The filtrate was run through the Thermo Jarrel Ash Inductively Coupled Argon Plasma Atomic Emission Spectrophotometer model 61. This method provides data on many macro and micronutrients. In this study, I will be discussing only soil potassium and phosphorus concentrations. However, data for calcium, copper, iron, magnesium, manganese, sodium, and zinc concentrations are located in Appendix A.

MICROBIAL ENUMERATIONS

Total viable soil bacteria were grown on tryptic soy agar (Martin, 1975). Total viable soil fungi were cultured on Martin's Rose Bengal media (Wollum, 1994). Viable soil cellulose degraders were enumerated on cellulose media (Wollum, 1994). Viable fluorescent pseudomonads were cultivated on fluorescent pseudomonad agar (Wollum, 1994). Viable *Aspergillus flavus*, a simple fungi, were cultured on AFP agar (Atlas, 1993). Viable actinomycetes were grown on actinomycetes media (Atlas, 1993). For each soil sample a dry weight was derived from weighing ten grams of fresh, sieved soil and dried at 105 degrees C overnight. A series of soil dilutions were created for each soil sample. The dilution at which the cell growth was maximally countable was selected to plate. Two replications of each dilution were plated on a Spiral Biotech spiral plater. The plater logarithmically diluted the suspension across the plate, assuring proper distribution of cells across the media. Plates were stored inverted in the incubator at 30 degrees C until they were ready for counting. The logarithm of colony forming units per gram of soil was calculated by multiplying the number of cells counted on each plate by the dilution factor and dividing by the grams of soil used (Germida, 1993). The log CFU/g soil for the two replicates were averaged to

give the log CFU/g soil for the soil sample (Germida, 1993).

Bacillus spp., a gram negative bacteria, were cultured in a bacillus media (Wollum, 1982). The media was inoculated with a soil dilution heated in a water bath at 85 degrees C for ten minutes. The heat grills all microorganisms except those capable of survival as endospores. Colonies that remained after an incubation period were counted. Log CFU g $soil^{-1}$ and dry weights were calculated in the same manner as described above.

MICROBIAL BIOMASS CARBON AND NITROGEN

The chloroform fumigation-extraction methodology was chosen to determine the soil microbial biomass content (Voroney et al., 1993). The chloroform fumigation-extraction method was selected based on its' ability for use over a range of pH, on soils recently receiving organic matter input, and its' quick resolution of data (Kaiser et al., 1992). Three, 12 g subsamples of each soil sample were weighed out. One subsample was fumigated with chloroform in a desiccator for 24 hours. Another subsample was directly extracted with 0.5 M K_2SO_4. After shaking for one hour, the suspension was filtered. The third 12 g subsample was dried at 105 degrees C and weighed to yield the dry weight of the soil. After fumigation, the fumigated subsample was also extracted. Both filtrates were run on the dissolved organic carbon analyzer. The carbon analyzer oxidized the dissolved organic carbon forming carbon dioxide, which was collected and measured (Standard Methods for the Examination of Waste and Wastewater, 1992). The carbon between the fumigated and unfumigated samples was the carbon from solubilized biomass.

The alkaline persulfate method was utilized to determine soil microbial biomass nitrogen (Cabrera and Beare, 1993). The peroxydisulfate oxidized the nitrogen in the filtrate to nitrate at an elevated temperature in an alkaline environment. The peroxydisulfate autodecomposed with water in the autoclave to yield the oxygen (for oxidation of the nitrogen) and potassium sulfate. After autoclaving the samples, nitrate-nitrogen in the digests was determined on an Altech Inorganic Nitrogen Analyzer, which determined the concentrations of ammonium and nitrate nitrogen (Carlson et al., 1984).

SOIL ENZYME ACTIVITIES

Acid phosphatase activity was determined by the phosphomonoesterase assay (Tabatabai, 1994). One gram of soil sample was placed in a 50 milliliter flask to which toluene was added. Toluene would lyse cells limiting the concentration of enzymes in the sample to those that have been created prior to cell lysing. To the flask, buffer of pH 6.5 and para-nitrophenylphosphate (substrate) were added. The flask was swirled and incubated for one hour at 37 degrees C. After incubation, the enzyme activity was halted by the addition of calcium chloride and sodium hydroxide. The suspension was swirled and filtered. The yellow color intensity generated from the para-nitrophenol released was measured on the Milton Roy Spectrophotometer at 420 nm. Controls were performed in the same way, except the substrate was added after the salt and base. Controls were done on soil samples of three consecutive depths within each block, having the greatest activity. They were used in calibrating the other soil samples within each block.

Alkaline phosphatase activity was determined with the same phosphomonoesterases assay (Tabatabai, 1994). The only difference was that a buffer of pH 11 was used in place of the buffer of pH 6.5.

β-glucosidase activity was estimated by the β-glucosidase assay (Tabatabai, 1994). One gram of soil sample was placed in a 50 milliliter flask and toluene was added. Modified universal buffer pH 6 and para-nitrophenylglucose solution (substrate) were added. The flask was swirled to mix and incubated at 37 degrees C for one hour. Then, THAM buffer pH 12 and calcium chloride were added to raise the pH and salt out the enzymes. The suspension was swirled and filtered. The resulting para-nitrophenol yellow color was measured on a Milton Roy Spectrophotometer at 420 nm.

Arylsulfatase activity was determined through the arylsulfatase assay (Tabatabai, 1994). One gram of soil sample was inoculated with toluene in a 50 milliliter flask. Acetate buffer and para-nitrophenylsulfate (substrate) were added. The flask was swirled to mix and incubated for one hour at 37 degrees C. After incubation, sodium hydroxide and calcium chloride were added to stop the reactions. The flask was swirled and filtered. Filtrate was run through the spectrophotometer at

420 nm to determine the concentration of para-nitrophenol released. Controls were performed as described for other assay methods.

L-asparaginase activity was determined through an L-asparaginase assay (Tabatabai, 1994). Five grams of soil sample were placed in a 50 milliliter flask to which toluene was added to lyse the microbial cells. Buffer and 0.5 molar L-asparaginase solution (substrate) were added. The flask was swirled to mix and incubated for two hours at 37 degrees C. After two hours, potassium chloride-silver sulfate solution was added to the flask and swirled. The volume was brought to 50 milliliters with the potassium chloride-silver sulfate solution, stopping the enzymatic reactions. After mixing well, the ammonium nitrogen released by the enzymatic reactions, was resolved by the Altech Liquid Nitrogen Analyzer. Controls activities were performed for the soil samples of three consecutive depths within each block that had the highest activity. These control activity values calibrated the other soil samples within each block. Control assays followed the same method except the substrate was added after the potassium chloride-silver sulfate solution. This yielded the concentration of ammonium nitrogen in the soil not due to enzymatic activity caused by substrate addition.

AGGREGATE STABILITY

The procedure to determine the distribution of water-stable aggregates used forty grams of fresh soil aggregates, less than 8 mm diameter, from each plot. A sieving apparatus was composed of a column of sieves of decreasing mesh size (Kemper and Rosenau, 1986). The column was submerged in a water vat on top of a rocker arm (Kemper and Rosenau, 1986). The sieving apparatus served to separate aggregates into size classes based on sieve mesh size with the upstroke/downstroke of the column in water (Angers and Mehuys, 1993). Sieve sizes used were: 4.75, 2.0, 1.0, 0.5, and 0.25 mm. Forty grams of soil were placed on the top sieve below water level. The sieving machine ran twenty-nine times per minute for ten minutes with each sample. The contents of each sieve were washed into a labeled, tared flask and dried at 105 degrees C. The dried contents of each sieve were weighed. Fifty milliliters of 0.5 percent sodium hexametaphosphate, a dispersing agent, was added to each flask and shaken for 45 minutes. The

dispersed aggregates were washed onto their original sieves. Then, the remaining particles on each sieve were collected in their respective flasks. Each flask was dried at 105 degrees C and weighed. A fresh sample of each soil was weighed out, dried, and weighed again to determine gravimetric water content of each soil sample. Water stable aggregates for each soil sample were then calculated (Angers and Mehuys, 1993).

All data were analyzed using ANOVA procedures. Where appropriate, means were separated using the Least Significant Difference procedures (SAS Institute, 1985).

CHAPTER III

RESULTS AND DISCUSSION

SOIL AND MULCH PROPERTIES

Total Soil Carbon

Generally, total soil carbon was greater in soils under vetch cover and soils of wheat with 168 N plots for 4/18/94, 6/13/94, and 4/25/95 (Table 1). The trend can be observed for total carbon data of 5/16/94 and 8/4/94. Vetch soils were highly concentrated in carbon due to the increased mulch dry matter and high carbon content of the vetch mulch, which will be discussed later in this chapter. Vetch plots had increased biomass due to the nitrogen fixed by the vetch and the increased carbon. Wheat soils receiving 168 N had greater carbon due to the additional nitrogen in the system, which resulted in much higher wheat biomass production. The additional nitrogen provided through fertilizer stimulates mineralization of the wheat biomass and production of organic matter. Previous corn residue soils were generally lowest in soil carbon due to less plant biomass input. Previous corn residue plots receiving 168 N had higher carbon concentrations than the previous corn residue 0N treatments, due to the addition of nitrogen fertilizer to the soil system. Generally, in previous corn residue plots, the lack of nitrogen limits plant biomass. Carbon concentrations in soils are greater in the surface 5 cm followed by the 5 to 10 cm depth (Table 1).

Soils were higher in carbon in plots that had received fertilizer for all sampling dates (Table 1). A large nitrogen pool is of great importance for adequate organic matter mineralization. Additional nitrogen to the soil system stimulates mineralization, which is especially important in plots with a high C:N ratio's like wheat.

Total Soil Nitrogen

On 5/16/94, vetch plots with 168 N had significantly higher soil nitrogen than any other treatment combination (Table 2). On 4/25/95, wheat and vetch plots with 168 N had significantly higher soil nitrogen than any other treatment combination. The trend may be observed in data of 8/4/94. Vetch is a nitrogen fixing legume, providing nitrogen to the soil when the residue is mineralized. The addition of nitrogen fertilizer to vetch plots results in even higher soil nitrogen availability.

Table 1. Treatment Effect on % Total Soil Carbon in Each Depth.

Depth (cm)	Cover Crop	N rate (kg ha^{-1})	Total Soil Carbon at Each Sampling Date					
			4/18/94	5/7/94	5/16/94	6/13/94	8/4/94	4/25/95
0-5	None	0	1.02 c*	1.34 a	1.05 a	0.95 f	1.07 a	1.00 c
	None	168	1.39 b	1.48 a	1.20 a	1.24 d	1.35 a	1.25 b
	Vetch	0	1.69 a	1.60 a	1.37 a	1.47 b	1.42 a	1.47 ab
	Vetch	168	1.67 a	1.27 a	1.74 a	1.57 a	1.50 a	1.50 a
	Wheat	0	1.09 c	1.63 a	0.98 a	1.06 e	1.18 a	1.02 bc
	Wheat	168	1.49 ab	1.16 a	1.27 a	1.38 c	1.53 a	1.54 a
5-10	None	0	0.65 a	0.66 a	0.61 a	0.62 a	0.66 a	0.62 a
	None	168	0.66 a	0.69 a	0.62 a	0.66 a	0.69 a	0.63 a
	Vetch	0	0.80 a	0.71 a	0.68 a	0.70 a	0.72 a	0.72 a
	Vetch	168	0.67 a	0.67 a	0.74 a	0.67 a	0.68 a	0.71 a
	Wheat	0	0.70 a	0.67 a	0.68 a	0.68 a	0.76 a	0.83 a
	Wheat	168	0.68 a	0.64 a	0.64 a	0.64 a	0.71 a	0.69 a
10-20	None	0	0.58 a	0.55 a	0.56 a	0.53 a	0.57 a	0.55 a
	None	168	0.56 a	0.55 a	0.58 a	0.52 a	0.59 a	0.54 a
	Vetch	0	0.62 a	0.57 a	0.62 a	0.61 a	0.59 a	0.61 a
	Vetch	168	0.59 a	0.57 a	0.61 a	0.58 a	0.58 a	0.61 a
	Wheat	0	0.61 a	0.51 a	0.50 a	0.54 a	0.64 a	0.59 a
	Wheat	168	0.58 a	0.55 a	0.47 a	0.51 a	0.60 a	0.56 a

* Means within a column at a given depth followed by the same letter are not significantly different as determined at the 5% probability level.

Table 2. Treatment Effects on % Total Soil Nitrogen in Each Depth.

Depth (cm)	Cover Crop	N rate (kg ha^{-1})	Total Soil Nitrogen at Each Sampling Date					
			4/18/94	5/7/94	5/16/94	6/13/94	8/4/94	4/25/95
0-5	None	0	0.12 a*	0.58 a	0.12 c	0.11 a	0.09 a	0.11 c
	None	168	0.14 a	0.69 a	0.12 c	0.13 a	0.11 a	0.12 c
	Vetch	0	0.17 a	0.62 a	0.14 b	0.14 a	0.14 a	0.17 b
	Vetch	168	0.15 a	0.61 a	0.17 a	0.16 a	0.16 a	0.20 a
	Wheat	0	0.14 a	0.72 a	0.11 c	0.12 a	0.12 a	0.11 c
	Wheat	168	0.17 a	0.53 a	0.13 bc	0.13 a	0.14 a	0.18 ab
5-10	None	0	0.10 a	0.36 a	0.07 a	0.08 a	0.07 a	0.08 a
	None	168	0.10 a	0.38 a	0.08 a	0.08 a	0.07 a	0.08 a
	Vetch	0	0.11 a	0.40 a	0.09 a	0.09 a	0.05 a	0.09 a
	Vetch	168	0.10 a	0.38 a	0.08 a	0.09 a	0.08 a	0.09 a
	Wheat	0	0.12 a	0.38 a	0.08 a	0.09 a	0.07 a	0.10 a
	Wheat	168	0.11 a	0.36 a	0.08 a	0.09 a	0.07 a	0.09 a
10-20	None	0	0.09 a	0.31 a	0.07 a	0.08 a	0.05 a	0.07 a
	None	168	0.09 a	0.33 a	0.07 a	0.08 a	0.06 a	0.07 a
	Vetch	0	0.11 a	0.34 a	0.08 a	0.08 a	0.06 a	0.08 a
	Vetch	168	0.10 a	0.35 a	0.07 a	0.08 a	0.06 a	0.08 a
	Wheat	0	0.11 a	0.36 a	0.07 a	0.07 a	0.06 a	0.08 a
	Wheat	168	0.10 a	0.32 a	0.07 a	0.08 a	0.05 a	0.08 a

* Means within a column at a given depth followed by the same letter are not significantly different as determined at the 5% probability level.

Wheat plots with 168 N took up the residual nitrogen from the spring application. The increased plant biomass resulted in nitrogen input into the soil with organic matter mineralization. Generally, the lowest nitrogen concentrations were found in the previous corn residue treatments. Of the previous corn residue treatments, previous corn residue with 168 N had higher soil nitrogen due to fertilizer application on those plots. There were no significant differences in nitrogen concentration found below five centimeters.

Soils of plots receiving nitrogen fertilizer tended to contain greater total soil nitrogen than those that received the 0 N rate (Table 2). Beyond nitrogen concentrations in the soil from microbially decomposed surface organic matter, the addition of fertilizer resulted in even greater total soil nitrogen. Surface application of the fertilizer as well as surface concentrated mulch resulted in significantly greater total soil nitrogen in the top 5 cm. of soil (Table 2). It is interesting to note that soils under vetch with the 0 N rate were also very high and in many cases had higher soil nitrogen than other 0 N rate treatments. The ability of vetch to fix nitrogen is responsible for higher soil nitrogen concentrations.

Soil pH

Soil pH was significantly lower under vetch than wheat or previous corn residue on sampling dates 4/18/94, 5/7/94, and 5/16/94 (Table 3). The trend can be seen in pH data of the other sampling dates. *Rhizobium leguminosorum* bv.*viciae* forms a symbiotic relationship with vetch roots fixing atmospheric nitrogen into a form which is plant available. Mineralization of the organic nitrogen after dessication of the cover generates ammonium ions in the soil as well as ammonium nitrate fertilizer utilization. The pH effect resulted from nitrification of the ammonium ions by nitrifying bacteria. On 8/4/94, wheat plots with the 168 N rate had a higher pH than wheat plots receiving the 0 N rate. On 4/18/94 and 5/7/94, vetch plots with 168 N rate had a lower pH than vetch plots with the 0 N rate. Generally, soil pH was significantly lower in soils receiving the 168 N rate. The additional nitrogen added to the soil through fertilizer further decreased the pH through nitrification. In fact, soil pH was significantly lower in plots receiving the high rate of nitrogen for all six sampling dates (Table 3).

Table 3. Treatment Effects on Soil pH in Each Depth.

Depth (cm)	Cover Crop	N rate (kg ha^{-1})	Soil pH Values at Each Sampling Date					
			4/18/94	5/7/94	5/16/94	6/13/94	8/4/94	4/25/95
0-5	None	0	6.57 a*	6.35 a	6.36 a	6.53 a	6.68 a	6.58 a
	None	168	5.96 bc	5.86 b	5.68 b	5.04 b	5.88 b	5.61 b
	Vetch	0	6.30 ab	6.17 ab	6.15 a	6.33 a	6.44 ab	6.37 a
	Vetch	168	5.57 c	5.47 c	5.31 b	4.96 b	5.47 b	5.59 b
	Wheat	0	6.58 a	6.36 a	6.35 a	6.44 a	6.56 a	6.40 a
	Wheat	168	5.82 bc	5.93 b	5.72 b	4.93 b	5.96 b	5.52 b
5-10	None	0	5.87 ab	6.05 a	6.01 a	5.93 a	6.01 a	5.94 a
	None	168	5.70 ab	5.88 ab	5.58 b	5.28 b	5.71 ab	5.50 b
	Vetch	0	5.86 ab	5.93 ab	5.71 b	5.81 a	5.84 ab	5.99 a
	Vetch	168	5.39 b	5.53 b	5.29 c	4.97 b	5.49 b	5.53 b
	Wheat	0	5.99 a	6.01 ab	5.78 b	5.84 a	6.10 a	6.10 a
	Wheat	168	5.62 b	5.69 b	5.64 b	5.28 b	5.92 ab	5.46 b
10-20	None	0	5.71 ab	5.86 a	5.77 a	5.68 ab	5.81 a	5.78 a
	None	168	5.72 ab	5.90 a	5.73 ab	5.61 ab	5.76 a	5.83 a
	Vetch	0	5.67 ab	5.79 a	5.72 ab	5.70 ab	5.83 a	5.80 a
	Vetch	168	5.58 b	5.71 a	5.53 b	5.45 b	5.72 a	5.66 a
	Wheat	0	5.88 a	6.00 a	5.83 a	5.82 a	6.04 a	5.82 a
	Wheat	168	5.73 ab	5.88 a	5.70 ab	5.56 ab	5.89 a	5.80 a

* Means within a column at a given depth followed by the same letter are not significantly different as determined at the 5% probability level.

The soil pH's were generally higher in the surface 5 cm than 5 to 20 cm for all of the sampling dates (Table 3). Residual lime from liming one ton per acre on 3/9/1993, brought the higher pH in the surface 5 cm. However, root and microbial activities served to generate acidity at lower depths. Lime generally remains at the surface, because it was not incorporated into the soil.

Total Soil Potassium

Exchangeable potassium was significantly greater in the previous corn residue 0 N rate plots and the wheat 0 N rate plots on 8/4/94 (Table 4). Generally, there were few differences in potassium concentrations due to cover. The trend indicates that potassium levels were higher in plots that did not get seeded with a winter cover crop. Corn yields on cover plots were greater than on previous corn residue plots. Corn takes up potassium in large quantities as it is needed as a macronutrient. Potassium is absorbed by plants in larger amounts than any other mineral element except nitrogen (Tisdale et al., 1985). Unlike cover crops, corn is harvested and therefore represents a loss of nutrients from the soil system. Therefore, due to increased corn growth on cover plots, previous corn residue plots would have higher soil potassium concentrations. Due to the nutrient scavenging ability of the wheat cover, wheat plots retained high potassium levels (Zobel, 1991). Potassium is surface applied to all plots. Exchangeable potassium was largely surface concentrated due to surface application of potassium fertilizer (Table 4). Potassium is sequentially concentrated though the profile. Data from the 5-10 and 10-20 cm depths showed no significant differences.

Soils of plots receiving the 0 N rate contained significantly greater levels of potassium than soils of plots receiving the 168 N rate (Figures 1, 2). The trend may be observed in data of Table 4. Exchangeable potassium concentrations decrease as pH decreases (Nemeth and Grimme, 1972). Though this is true, soil potassium levels were lower in the 168 N rate plots due to increased uptake of potassium with increased plant growth on those plots. Corn yields were greater from 168 N plots.

Table 4. Treatment Effects on Soil Potassium Concentrations in the 0-5 cm Depth.

		Potassium Concentrations at Each Sampling Date (μg K^+g $soil^{-1}$)					
†C	N rate (kg ha^{-1})	4/18/94	5/7/94	5/16/94	6/13/94	8/4/94	4/25/95
N	0	239.71a*	176.42a	275.86a	257.41a	256.61a	296.85a
N	168	248.04a	250.78a	234.50a	213.61a	147.37c	211.93b
V	0	224.65a	132.86a	250.17a	216.46a	202.53b	224.73b
V	168	213.02a	200.82a	212.19a	185.41a	144.51c	215.36b
W	0	233.78a	453.39a	233.61a	237.43a	255.82a	216.47b
W	168	195.53a	302.93a	182.63a	180.18a	170.98bc	197.84b

* Means within a column at a given depth followed by the same letter are not significantly different as determined at the 5% probability level.

† Cover Crops legend: N=none; V=vetch; W=wheat.

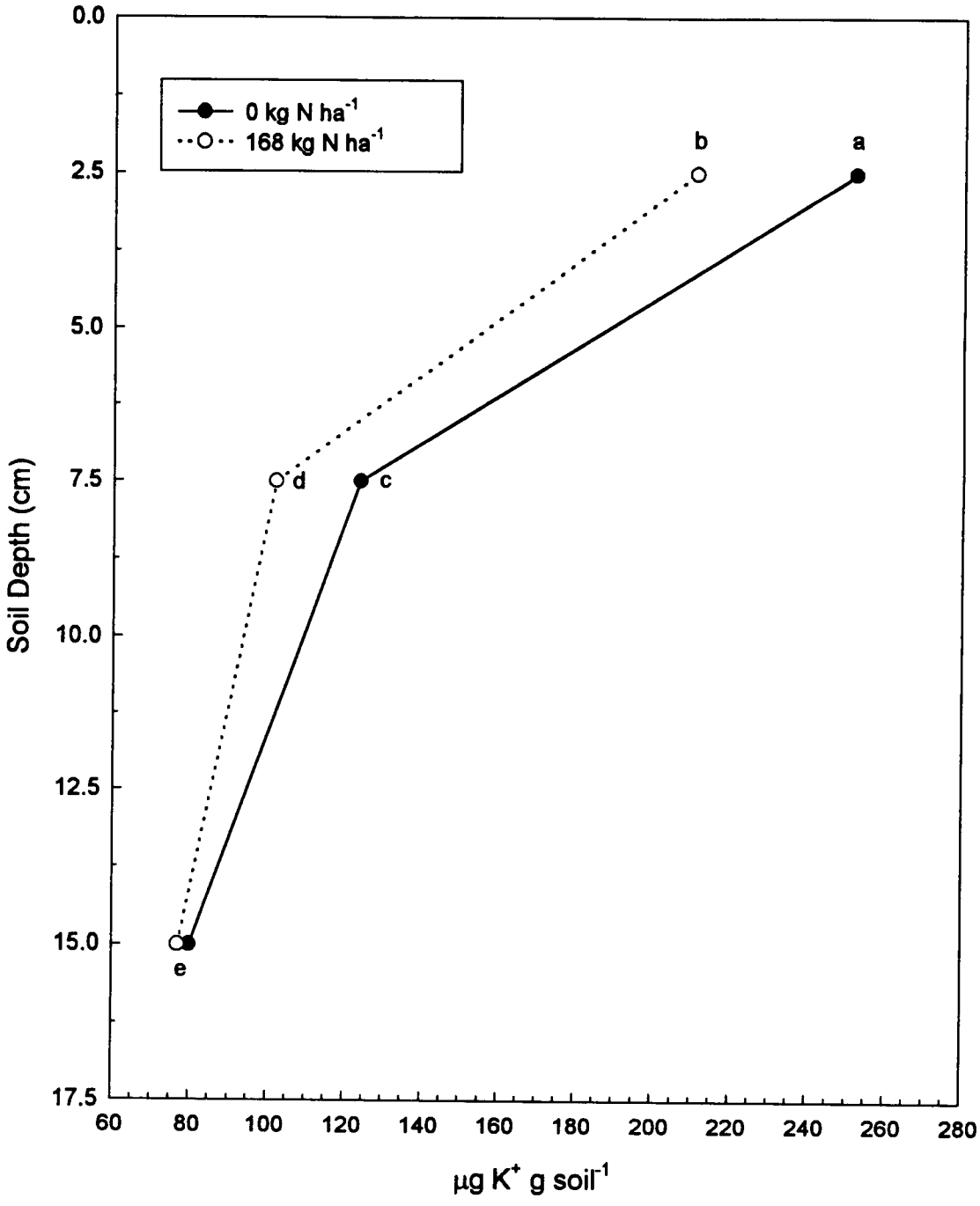


Figure 1. Effect of Nitrogen Rate on 5/16/94 Soil Potassium. Means followed by the same letter are not significantly different at the 5% probability level.

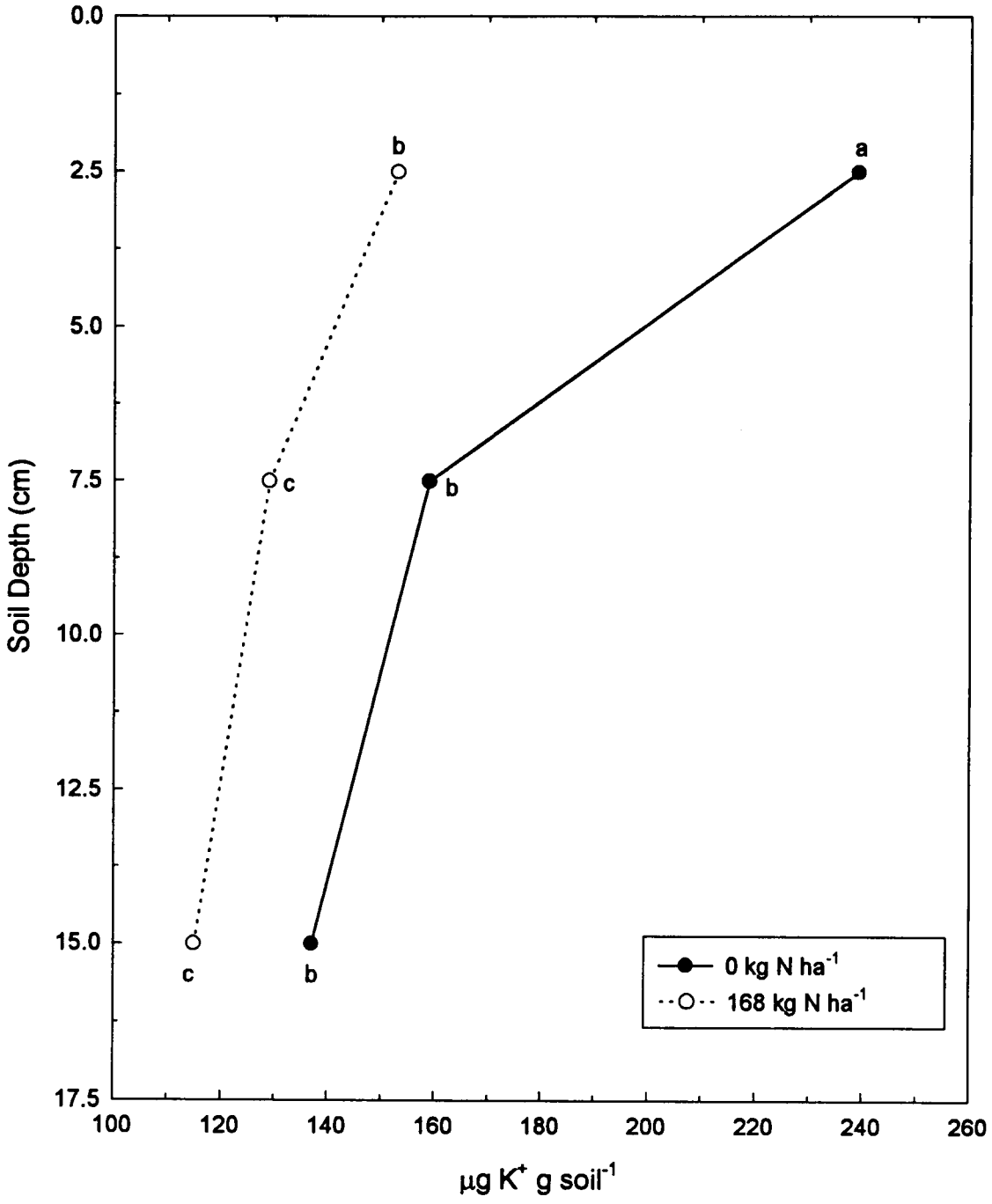


Figure 2. Effect of Nitrogen Rate on 8/4/94 Soil Potassium. Means followed by the same letter are not significantly different at the 5% probability level.

Total Soil Phosphorus

There were analytical problems in the data for 5/7/94. Therefore, the data will not be discussed. Though there were no significant differences among data for any sampling date, general trends show phosphorus concentrations to be higher in previous corn residue treatments (Table 5). Corn yields were greater in plots with a cover crop, therefore there was more removal of phosphorus from the system in those plots. For almost every sampling date, mean extractable phosphorus concentrations were lower in plots under vetch than wheat or previous corn residue. Vetch plots yielded more corn than wheat or previous corn residue, resulting in a larger loss of phosphorus from the system.

Distribution of phosphorus fertilizers is critical to phosphorus uptake (Terman et al., 1961). Phosphorus and potassium fertilizers were surface applied to all plots. Soil phosphorus concentrations were generally greater in the surface five cm of soil for all sampling dates due to fertilizer surface application and organic matter concentration. Because little of this element is lost by leaching, phosphorus added as fertilizer accumulates in the surface horizon of soils, particularly in the case of heavily fertilized crops (Cook et al., 1957).

The concentration of available phosphorus was dependent upon soil pH. At low pH values, the retention of phosphorus results largely from the reaction with iron, aluminum, and their hydrous oxides (Gilliam and Sample, 1968). Above pH 7, the ions of calcium and magnesium cause precipitation of the added phosphorus, and its' availability decreases (Gilliam and Sample, 1968). Phosphorus availability to crops is usually greatest within the pH range of 6 to 7 for most agricultural soils (Riley and Barber, 1971). Generally, soil phosphorus concentrations were higher in plots receiving the 0 N rate than in 168 N plots. The absence of acidification caused by nitrogen fertilizer resulted in greater solubilized phosphorus.

Mulch Total Carbon

The surface mulch for each sampling date except 4/25/95 was analyzed for total carbon and nitrogen content. Mulches were not collected for 4/25/95 due to field complications. One sampling

Table 5. Treatment Effects on Soil Phosphorus Concentrations in Each Depth.

Depth (cm)	Cover Crop	N rate (kg ha^{-1})	Phosphorus Concentrations at Each Sampling Date ($\mu g\ PO_4^- g\ soil^{-1}$)				
			4/18/94	5/16/94	6/13/94	8/4/94	4/25/95
0-5	None	0	97.22a*	132.92a	102.23a	103.24a	134.99a
	None	168	67.68a	70.93a	80.79a	75.45a	60.97a
	Vetch	0	67.32a	85.56a	54.11a	48.71a	62.30a
	Vetch	168	38.50a	57.82a	51.90a	35.19a	51.67a
	Wheat	0	81.02a	82.05a	90.43a	75.99a	78.82a
	Wheat	168	41.82a	35.81a	34.24a	36.29a	46.37a
5-10	None	0	13.12 a	14.95 a	15.40 a	17.19 a	12.18 a
	None	168	12.41 a	10.95 a	11.18 a	23.42 a	9.66 a
	Vetch	0	8.71 a	7.52 a	9.91 a	6.69 a	6.85 a
	Vetch	168	8.67 a	10.34 a	11.21 a	10.18 a	10.78 a
	Wheat	0	10.95 a	8.84 a	14.55 a	19.65 a	45.53 a
	Wheat	168	8.50 a	7.86 a	7.70 a	18.60 a	9.86 a
10-20	None	0	8.79 a	8.39 a	11.91 a	10.43 a	9.67 a
	None	168	8.25 a	10.30 a	8.78 a	10.35 a	1.51 a
	Vetch	0	5.06 a	7.03 a	7.36 a	4.86 a	1.50 a
	Vetch	168	6.88 a	7.74 a	8.62 a	7.35 a	4.58 a
	Wheat	0	7.00 a	6.35 a	8.00 a	13.55 a	2.86 a
	Wheat	168	6.30 a	7.70 a	7.41 a	8.54 a	3.83 a

* Means within a column at a given depth followed by the same letter are not significantly different as determined at the 5% probability level

date, 8/4/94, would indicate that hairy vetch contained significantly greater carbon than wheat or previous corn residue (Table 6). The trend may be observed in data of 4/18/94 and 5/16/94. Wheat rivals vetch for greatest previous corn residue (Table 6). This trend holds true carbon content on 5/7/94 and 6/13/94 (Table 6). Due to wheat's high carbon to nitrogen ratio and fertilizer amendment to the plots, wheat with 168 N rate had greater mean carbon. In fact on 4/18/94, plots receiving the high rate of nitrogen resulted in significantly greater carbon content (36.81%) in the mulch than plots receiving the 0 N rate (33.57%). Increased nitrogen made available to the germinating wheat seedlings results in increased plant biomass, thus increased carbon content. Vetch mulch is very nutrient rich, being especially concentrated in nitrogen more so than carbon (Table 6). Table 6 shows vetch plots to have significantly lower C:N ratio's than wheat for all sampling dates except 5/16/94 and 8/4/94.

Mulch Total Nitrogen

Vetch mulch had significantly greater nitrogen content than wheat or previous corn residue (Table 6). This holds true for four of the five sampling dates, but the trend can be seen for 6/13/94. The vetch plants' ability to fix nitrogen through the Rhizobium spp. symbiosis results in higher plant nitrogen content. Mulches on plots receiving the 168 N rate, generally, contained greater mean nitrogen than those of the 0 N rate (Table 6).

CROP YIELDS

Corn Yields

Two years of corn yield data from the Milan plots were provided for reference purposes by Dr. Bob Duck. In 1993, corn yields were significantly higher for all covers at the 168 N rate (Figure 3). Note that the corn yields at the 168 N rate were not affected by cover crop. Decker et al. (1994) found that vetch increased corn yields more so than previous corn residue or wheat. Wheat plots yielded less corn than previous corn residue or vetch (Decker et al., 1994). This was due to the high nitrogen concentrations in the vetch biomass. Overall yields were much lower in 1993 than in 1994 or 1995. Figure 4 shows the effect of cover crops on 1994 corn yields. In 1994, vetch plots

Table 6. Effect of Cover Crop on Mulch Layer % Total Carbon, % Total Nitrogen, and C:N ratio.

	% Total Carbon at Each Sampling Date				
Cover	4/18/94	5/7/94	5/16/94	6/13/94	8/4/94
	----------% Carbon----------				
None	33.33 a*	23.51 a	23.31a	22.91 a	19.10 b
Vetch	36.54 a	25.33 a	27.50 a	24.32 a	25.71 a
Wheat	35.89 a	29.45 a	23.11 a	27.78 a	18.63 b
Cover	% Total Nitrogen at Each Sampling Date				
	----------% Nitrogen----------				
None	0.89 b	0.79 b	0.63 b	0.99 a	0.71 b
Vetch	1.78 a	1.43 a	1.01 a	1.23 a	1.22 a
Wheat	0.91 b	0.82 b	0.64 b	0.83 a	0.73 b
Cover	Carbon:Nitrogen Ratio at Each Sampling Date				
	----------C:N----------				
None	35.78 a	31.30 a	40.61 a	24.99 b	26.54 a
Vetch	21.71 b	19.36 b	29.50 b	21.40 b	22.27 a
Wheat	40.42 a	36.09 a	37.90 ab	37.19 a	28.51 a

* Means within a column followed by the same letter are not significantly different as determined at the 5% probability level.

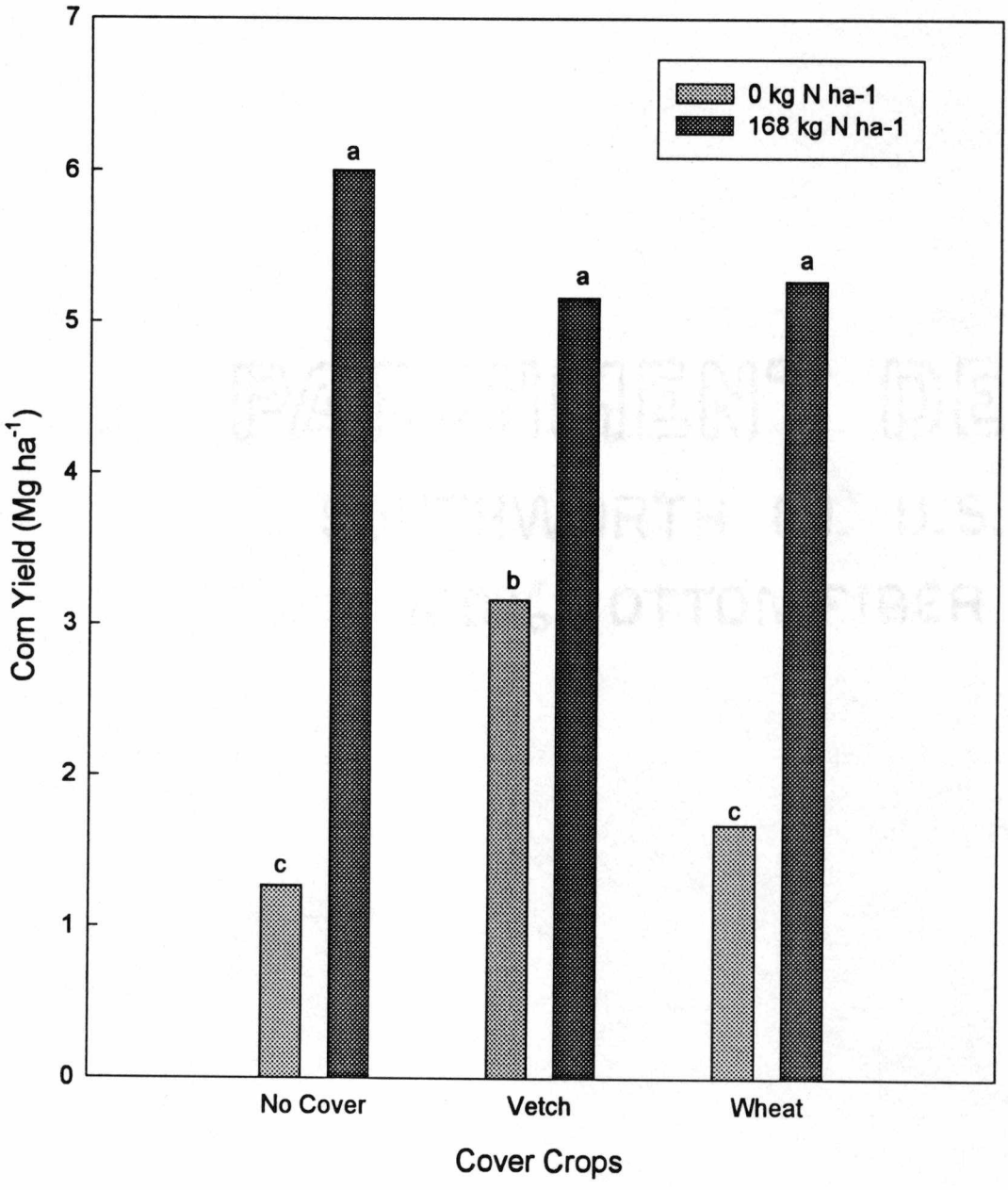


Figure 3. Effect of Cover Crop and Nitrogen Rate on 1993 Corn Yields. Means followed by the same letter are not significantly different at the 5% probability level.

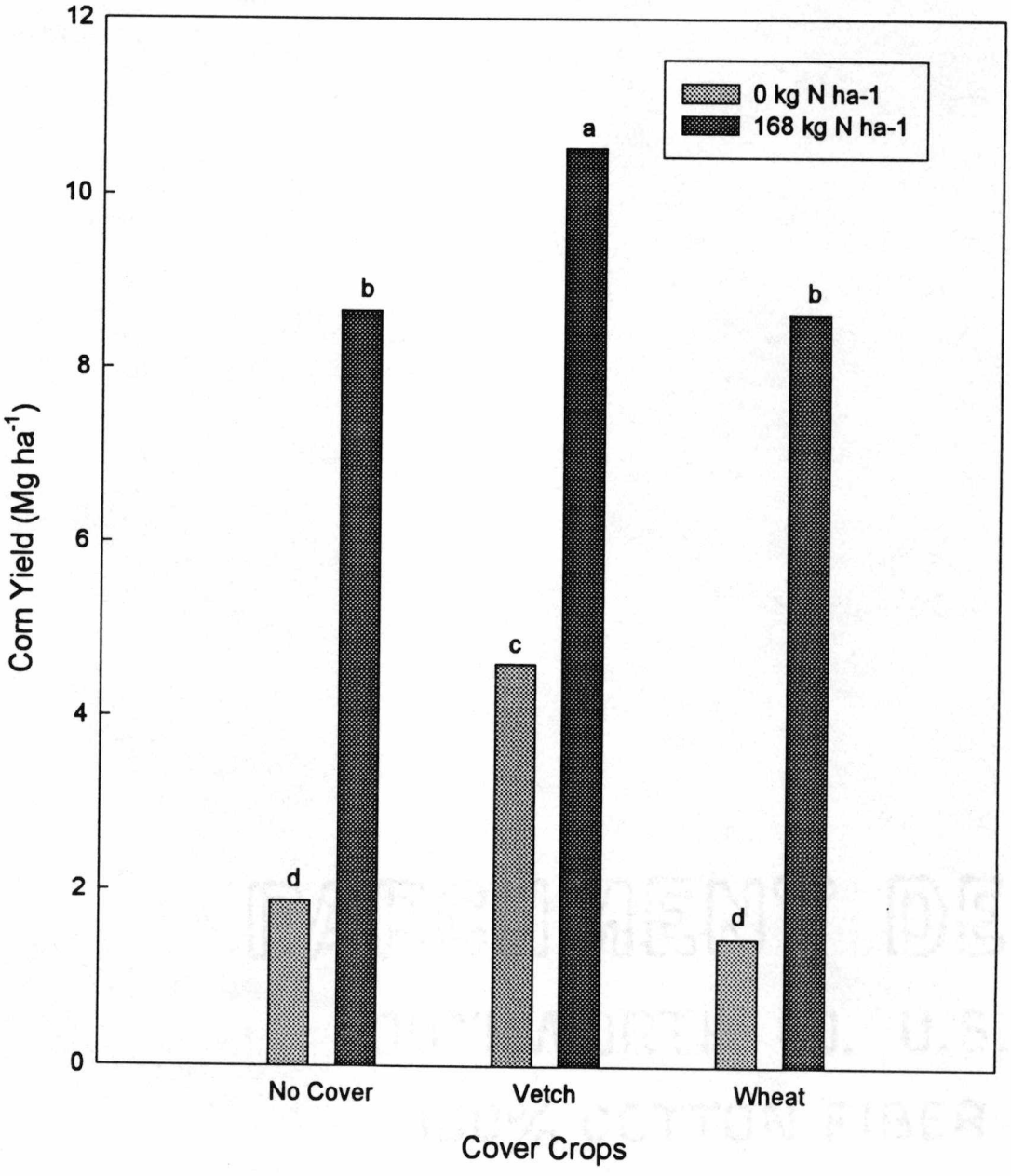


Figure 4. Effect of Cover Crop and Nitrogen Rate on 1994 Corn Yields. Means followed by the same letter are not significantly different at the 5% probability level.

with 168 N had significantly greater corn yields than any other treatment combination. Among the low nitrogen plots, vetch had significantly greater yields than wheat or previous corn residue. The nitrogen-fixing ability of vetch was obvious in relation to the higher corn yield data. In 1995, though there were no significant differences in yields across cover at the 168 N rate, the trend is the same as in 1994 yield data. However, when no nitrogen was applied, corn yields were significantly higher under vetch than under wheat or previous corn residue (Figure 5). Again, vetch provided nitrogen for corn growth during the season from mineralization. Of course, corn yields were significantly greater in plots receiving nitrogen than those without in 1994, due to the high nitrogen requirements of corn (Figure 4). The trend can be observed in corn yields of 1993 and 1995.

Cover Crop Dry Matter Yields

Three years of cover crop dry matter data were provided for reference purposes by Dr. Bob Duck from the Milan Experiment Station. Cover crop dry matter yields are important considering the amount of organic matter provided for microbial activities. The amount of available organic matter directly determines the amount of soil carbon. The effect of cover crop on cover crop dry matter yields are presented in Table 7. In 1993, vetch plots with both 0 and 168 N rates and wheat plots with the 168 N rate had higher cover crop yields than any other treatment combination. Vetch plots with the 0 N rate had the highest cover crop dry matter in 1993. Vetch plots receiving the 0 N rate yielded greater mean cover crop dry matter due to the high nutrient content of vetch and the pH effect of the 168 N rate on the soil microbes. Acidification resulted from nitrification of applied nitrogen fertilizer. The change in pH reduces microbial activities, decreasing vetch's ability to gather nutrients. Enzymes are optimally active at a certain pH, so lowering the pH changes enzymatic activity. In 1994, cover crop dry matter of wheat plots with the 168 N rate were significantly greater than all other treatment combinations. In fact, yield for wheat with the 168 N rate was approximately 0.4 Mg ha^{-1} greater than the yield for vetch with low nitrogen. However, this does not hold true for 1993 or 1995 cover crop dry matter yields. In 1995, like 1993, the highest yields were observed under vetch plots with the 0 N rate due to the pH effect of the 168 N rate on

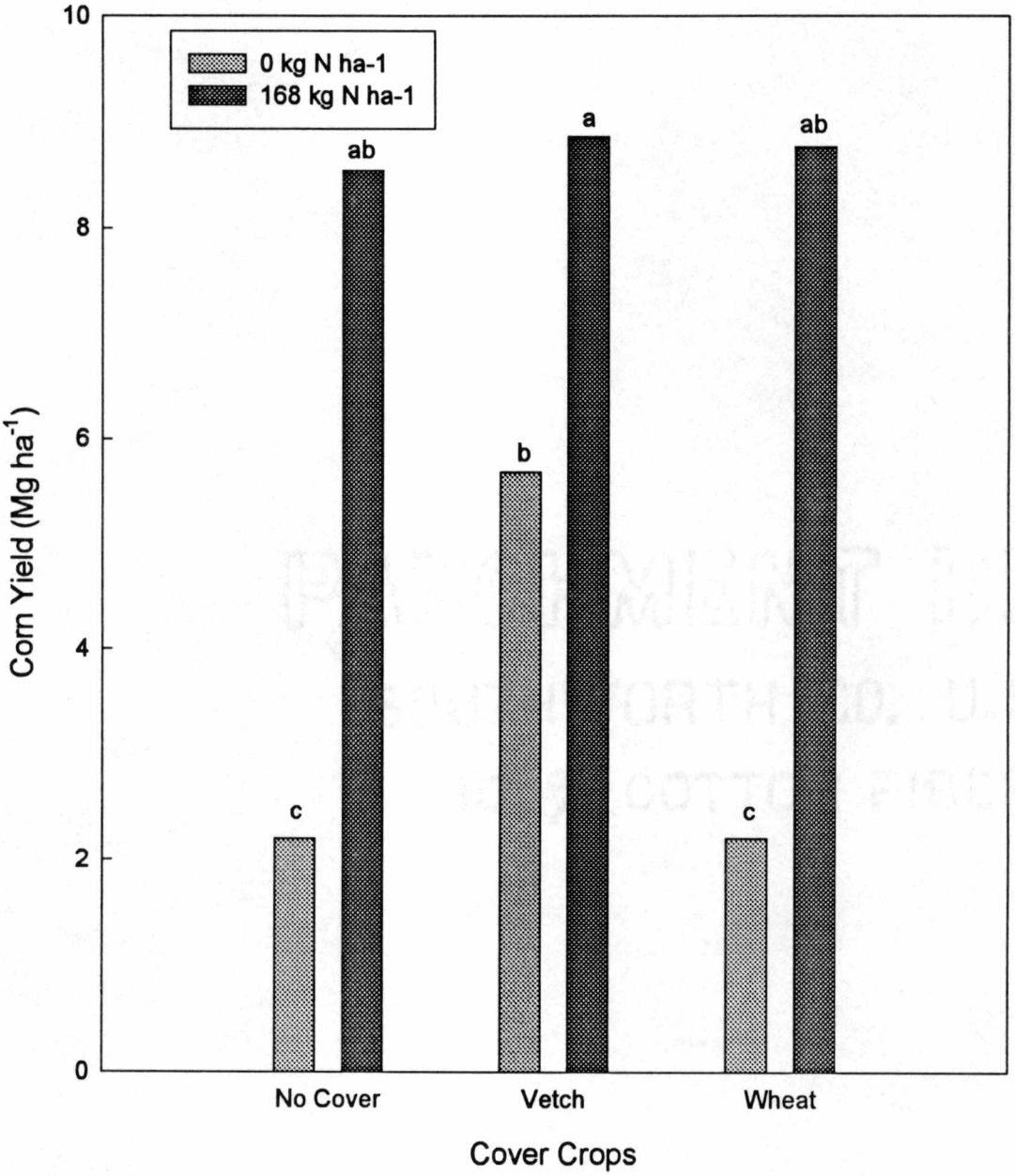


Figure 5. Effect of Cover Crop and Nitrogen Rate on 1995 Corn Yields. Means followed by the same letter are not significantly different at the 5% probability level.

Table 7. Effect of Cover Crop and Nitrogen Rate on Cover Crop Dry Matter Yields.

Cover	Nitrogen Rate	Cover Crop Dry Matter Yields of Each Year		
		1993	1994	1995
		Mg dry matter ha^{-1}		
None	Low	0.00 b	0.00 c	0.00 a
None	High	0.00 b	0.00 c	0.00 a
Vetch	Low	0.81 a	0.62 b	0.70 a
Vetch	High	0.52 a	0.54 b	0.61 a
Wheat	Low	0.33 b	0.31 b	0.33 a
Wheat	High	0.71 a	1.04 a	0.64 a

* Means within a column followed by the same letter are not significantly different as determined at the 5% probability level.

soil microbes.

MICROBIAL ENUMERATIONS

Bacteria Counts

Soil dilutions were plated on Tryptic Soy Agar to determine viable, aerobic, heterotrophic bacterial population estimates. All plating of the fresh soil samples within a shipment was done as soon as possible for accuracy and consistency. Plates were incubated approximately 16 hours before they were counted. Bacterial enumerations were completed for every sampling date.

Generally, higher bacterial numbers were observed in the vetch soils, versus the wheat and previous corn residue treatments (Table 8). Kirchner et al. (1993) also found higher bacterial counts in legume plots. Vetch contains a higher concentration of organic carbon and nitrogen than small grains, other legumes, or, of course, previous corn residue (Ebelhar et al., 1984, Utomo and Frye, 1983, Gauger, 1987). Vetch mulch, at 8/4/94, had a significantly greater concentration of carbon than wheat or previous corn residue mulch (Table 6). This trend holds true for most of the other sampling dates. Vetch mulch generally contained a higher concentration of nitrogen than wheat and previous corn residue mulch (Table 6). Most importantly, the C:N ratio is lower for vetch than for wheat (Table 6). Bacteria need both carbon and nitrogen in abundant quantities for cell building. Wheat is highly concentrated in carbon, but does not supply as much nitrogen as vetch for microbial mineralization. Kirchner et al. (1993) reported that microbial numbers were high in the spring and fall, dropping off near late summer. This was attributed to carbon cycling. The data of this project seems to agree with that. As the 1994 corn crop emerges, mean bacterial numbers were lower under wheat than vetch cover (Table 8). This was due to a higher carbon to nitrogen ratio than the other covers (Table 6). Mucoracious fungi are better equipped to decompose residues with low nitrogen contents (wheat) than bacteria (Roper and Gupta, 1995). Therefore, it was not expected to find higher bacteria numbers in wheat plots. On 4/18/94, previous corn residue plots with the 168 N rate had generally greater bacterial numbers than any other treatment combination. I speculate that this was due to higher soil temperatures in previous corn residue

Table 8. Treatment Effects on Bacterial Counts in Each Depth.

Depth (cm)	Cover Crop	N rate (kg ha^{-1})	Bacterial Counts at Each Sampling Date (log CFU g soil^{-1})					
			4/18/94	5/7/94	5/16/94	6/13/94	8/4/94	4/25/95
0-5	None	0	6.54 b*	6.75 a	7.64 a	7.97 a	7.29 a	7.13 b
	None	168	6.90 a	6.78 a	7.81 a	7.61 a	7.27 a	6.94 b
	Vetch	0	6.79 ab	7.19 a	7.98 a	8.05 a	7.21 a	7.41 a
	Vetch	168	6.56 b	7.09 a	7.75 a	7.87 a	7.16 a	7.26 ab
	Wheat	0	6.50 b	6.84 a	7.42 a	7.97 a	7.11 a	7.05 b
	Wheat	168	6.57 b	6.89 a	6.68 a	7.71 a	7.29 a	6.95 b
5-10	None	0	6.47 a	6.40 b	7.52 a	7.61 a	7.18 a	6.93 b
	None	168	6.37 a	6.40 b	7.31 a	7.50 a	7.06 a	6.85 b
	Vetch	0	6.54 a	6.70 a	7.51 a	7.68 a	7.04 a	7.16 a
	Vetch	168	6.27 a	6.52 b	7.00 a	7.45 a	6.86 a	7.07 a
	Wheat	0	6.44 a	6.72 a	7.33 a	7.61 a	7.05 a	7.06 a
	Wheat	168	6.52 a	6.57 ab	7.25 a	7.34 a	7.17 a	6.83 b
10-20	None	0	6.23 b	6.33 a	7.63 a	7.41 a	6.94 a	6.66 a
	None	168	6.29 ab	6.31 a	7.22 a	7.30 a	6.80 a	6.59 a
	Vetch	0	6.42 a	6.57 a	7.40 a	7.47 a	6.86 a	6.96 a
	Vetch	168	6.17 b	6.45 a	7.37 a	7.29 a	6.85 a	6.97 a
	Wheat	0	6.35 ab	6.44 a	7.13 a	7.37 a	6.98 a	6.79 a
	Wheat	168	6.43 a	6.38 a	7.16 a	7.15 a	6.85 a	6.68 a

* Means within a column at a given depth followed by the same letter are not significantly different as determined at the 5% probability level.

plots than in plots with an insulating cover crop. Bacterial counts were lower in 0 N previous corn residue soils than in soils of 168 N previous corn residue plots. Soil carbon concentrations were higher in 168 N treatments due to increased plant biomass. Therefore, the increased bacterial numbers in soils of 168 N previous corn residue plots were due to greater carbon availabilty as well. However, vetch with the 0 N rate had high bacterial counts as well. For almost every sampling date after 4/18/94, bacterial numbers were generally greater in vetch with 0 N plots than any other treatment combination. As previously mentioned, vetch cover has a low C:N ratio and high mulch carbon and nitrogen concentrations. In general, plots receiving no nitrogen had higher bacterial numbers than plots with the normal nitrogen rate. The vetch supplies 80 to 100 kg N ha^{-1} for corn, resulting in excessive NH_4^+ availability and subsequent acidification with the addition of 168 kg N ha^{-1} (Tisdale et al., 1985).

Results generally show that bacterial numbers are increased by a winter cover crop. Bacterial numbers were highest at the surface 0-5 cm over all treatments. On 4/18/94, though bacterial numbers were lowest under wheat, wheat plots had greater mean bacterial numbers than the other covers in the 5-20 cm zone (Figure 6). There were no significant differences in the 5-10 cm depth, but there were differences in the 10-20 cm depth. All covers have matured by that time, which is seven days before each plot is desiccated. Vetch has a taproot root system (Zobel, 1991). There were fewer roots in the previous corn residue plots due to lack of winter cover. However, wheat has a fibrous, extensive root system (Zobel, 1991). Increased root mass means increased rhizosphere environment, which serves as an excellent microbial habitat (Zobel, 1991). As of 5/7/94, after desiccation and planting, soil under wheat is significantly lower in bacterial numbers than vetch soils at 0-5 cm. At the 5-10 cm depth, bacterial numbers in vetch plots do not significantly differ from wheat plots, yet both have significantly greater bacterial numbers than previous corn residue (Figure 7). In the 10-20 cm depth, vetch soils had higher mean bacterial counts than wheat, and both are greater than previous corn residue numbers (Figure 7). By this time, corn is growing and active rhizosphere zones have changed becoming surface oriented

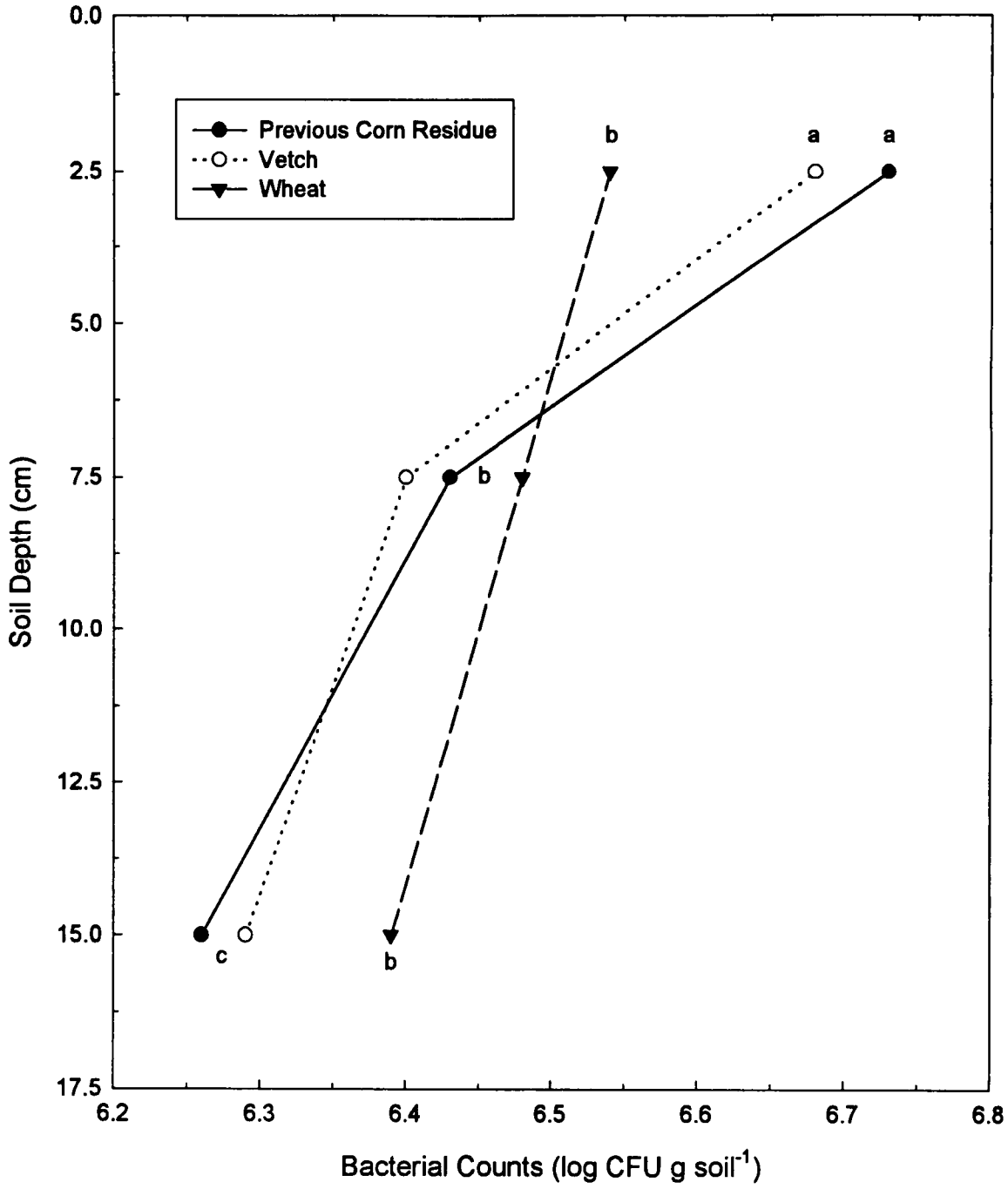


Figure 6. Effect of Cover Crop on 4/18/94 Bacterial Counts. Means followed by the same letter are not significantly different at the 5% probability level.

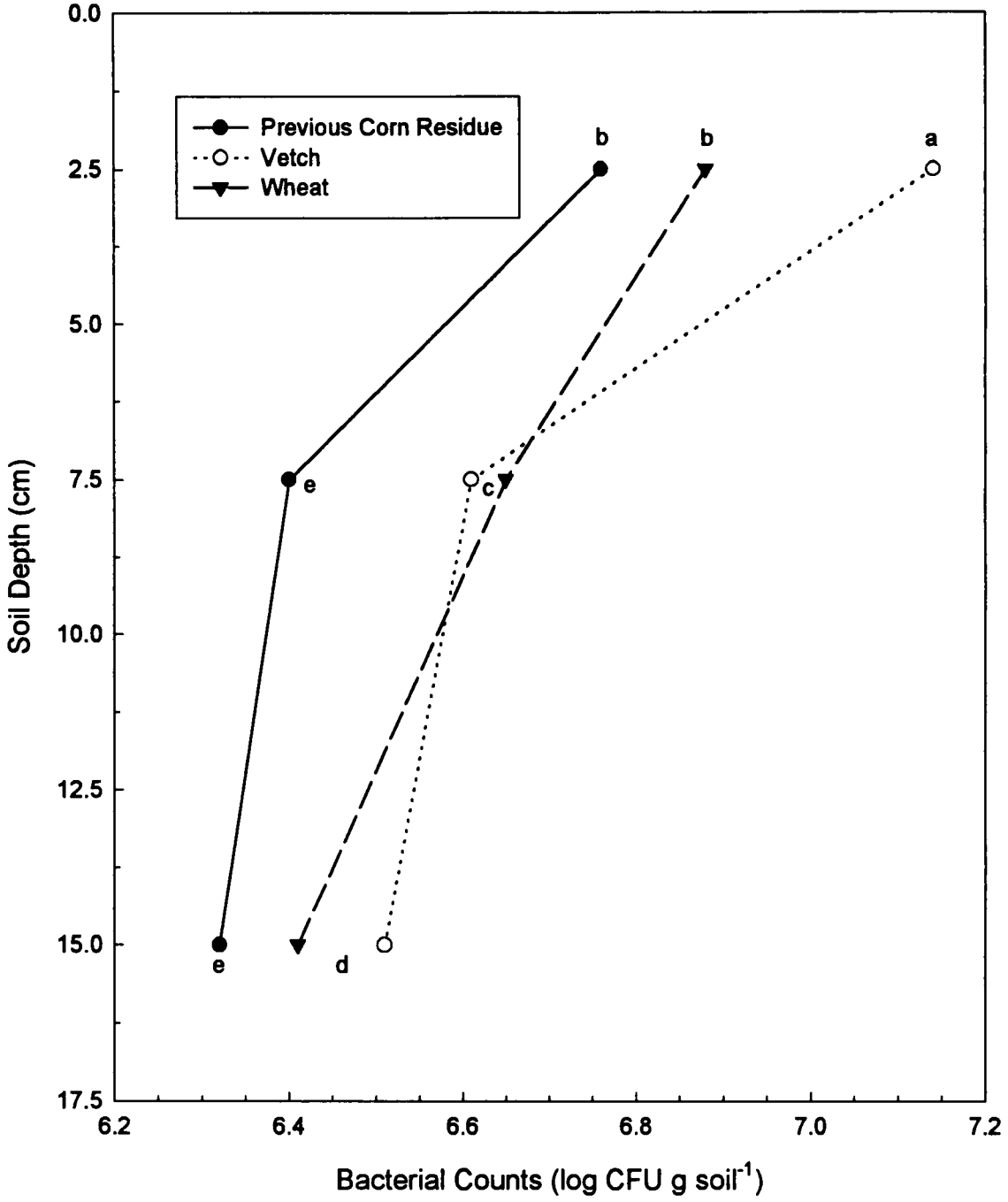


Figure 7. Effect of Cover Crop on 5/7/94 Bacterial Counts. Means followed by the same letter are not significantly different at the 5% probability level.

around the planted kernel. The bulkiest parts of the fibrous, decaying, wheat roots occur at shallow depths, while the vetch taproot runs deeper into the 10-20 cm depth (Zobel, 1991). These decaying roots provide a needed source of organic matter at depths in which organic matter is scarce in upland soils.

Fungal Counts

Total viable fungal colonies were counted after three to four days of incubation. Plating of all of the fresh soil samples within a shipment was done as soon as possible for accuracy and consistency. Fungal enumerations were completed for soils from 6/13/94, 8/4/94, and 4/25/95.

Estimates of fungi as affected by cover treatments are shown in Table 9. Numbers were significantly higher in the 0-5 cm depth than the 5-10 and 10-20 cm increments due to organic matter concentration. Fungi make up the largest portion of microbial biomass in reduced tillage systems (Hendrix et al., 1986; Dormaar and Lindwall, 1989). On 8/4/94, fungi were generally higher in the vetch 168 N plots due to the high nutrient concentrations in vetch mulch and acidity generated from fertilizer application to the soil. Wheat plots generally had the least quantity of fungi (Table 23). Wheat has a higher C:N ratio than vetch and previous corn residue, yielding a more limited nitrogen pool in wheat than in vetch or previous corn residue plots (Table 7).

The 168 N rate provided a favorable environment for fungi (Table 9). The effect nitrogen fertilizer application has on fungal numbers is obvious. In general, the 168 N rate plots had greater fungal numbers than the 0 N treatments. This can be attributed to fungal ability to withstand acidic soil conditions (Roper and Gupta, 1995). In low pH soils fungi have the advantage over bacteria. Vetch plot soils were significantly more acidic than wheat or previous corn residue soils, which may be another reason that fungal numbers were highest under vetch cover (Table 3). Kirchner et al. (1993) also found that a 168 N rate in a no-till soil yielded greater numbers of fungi than no-till soils without.

***Aspergillus flavus* Counts**

Aspergillus flavus is a common, soil, fungal species that secretes the toxin known as aflatoxin

Table 9. Treatment Effects on Fungal Colony Counts in Each Depth.

Depth (cm)	Cover Crop	N rate (kg ha^{-1})	Fungal Colony Counts at Each Sampling Date (log CFU g soil^{-1}) 6/13/94	8/4/94	4/25/95
0-5	None	0	5.02 a*	4.90 b	4.84 a
	None	168	5.21 a	5.13 a	4.89 a
	Vetch	0	5.08 a	5.00 ab	4.88 a
	Vetch	168	5.18 a	5.18 a	4.79 a
	Wheat	0	4.90 a	4.81 b	4.87 a
	Wheat	168	5.13 a	5.02 ab	4.73 a
5-10	None	0	4.73 a	4.59 a	4.43 a
	None	168	4.94 a	4.77 a	4.54 a
	Vetch	0	4.77 a	4.67 a	4.66 a
	Vetch	168	4.88 a	4.69 a	4.50 a
	Wheat	0	4.58 a	4.59 a	4.56 a
	Wheat	168	5.02 a	4.60 a	4.47 a
10-20	None	0	4.52 a	4.52 a	4.32 a
	None	168	4.82 a	4.65 a	4.44 a
	Vetch	0	4.78 a	4.65 a	4.68 a
	Vetch	168	4.79 a	4.71 a	4.58 a
	Wheat	0	4.82 a	4.57 a	4.38 a
	Wheat	168	4.57 a	4.57 a	4.46 a

* Means within a column at a given depth followed by the same letter are not significantly different as determined at the 5% probability level.

(Shank, 1978). This toxin is carcinogenic and can cause death in animals if consumed in a certain quantity. Though *A. flavus* is not the only species of the genus to secrete aflatoxin, this species does secrete a high level of aflatoxin (Shank, 1978; Kwon-Chung and Bennett, 1992). Also, *A. flavus* is relatively easy to isolate. The study of *A. flavus* numbers in soils in which crops grow give insight into possible levels of contamination and aflatoxin production on harvested crops. This information can be crucial for farmers with livestock. Corn grain produced in periods of drought from residue treated plots contained excessive levels of aflatoxin (>20 ppb) (Doran, 1980). No aflatoxin was detected in grain produced on the unmulched soils (Doran, 1980). Therefore, the *Aspergillus flavus* population was evaluated in this study. An interesting future study would be to evaluate aflatoxin production by *A. flavus* in no-till systems.

Total viable *Aspergillus flavus* colonies were counted after incubating plates 4-7 days. Colonies were very small and difficult to distinguish. A longer incubation period was required to distinguish true, red, *A. flavus* colonies. Soils from only two sampling dates were plated: 6/13/94 and 8/4/94. Enumeration of this species yielded low numbers. A more concentrated dilution might have given better colony counts. Had the last date been plated or those previous to 6/13/94, a better idea of this species population could exist.

For data of 6/13/94, numbers of this species were found to be significantly greater in wheat (2.92 log CFU g soil^{-1}) and vetch (2.74 log CFU g soil^{-1}) than previous corn residue soils (2.01 log CFU g soil^{-1}). The mean counts under wheat were slightly greater than those under vetch. Species numbers developed beneath wheat as opposed to vetch due to the C:N ratio differences of these covers. Wheat has a greater C:N ratio than vetch, as shown in Table 6. Numbers of other groups of organisms are greater under vetch cover. Fungi, generally have a greater ability to decompose residues with low nitrogen contents than do bacteria giving fungi the advantage in soils under high C:N ratio mulch. Fungi, like *A. flavus*, possess cellulose degrading enzymes giving fungi the advantage in a cellulose-rich environment. Previous corn residue plots tended to yield the least *A.flavus* colonies, due to the lack of cover organic matter available for mineralization. Soils from

8/4/94 contained had generally higher numbers under wheat (4.33 log CFU g soil^{-1}) and previous corn residue (4.31 log CFU g soil^{-1}) than vetch (4.22 log CFU g soil^{-1}), though not significantly different. Vetch soils were lower due to organism competition. Whereas, wheat may provide an advantageous environment for fungi, vetch plots may be dominated by bacteria, especially nitrifying bacteria.

Air serves as the most common vector for dispersal of *A. flavus* fungal spores and hyphal fragments (Marchisio et al., 1992). Approximately 73% of all air-borne propagules are Deuteromycetes, 23% of which are *Aspergillus* spp. and 63% are *Pennicillium* spp. (Marchisio et al., 1992). It would be interesting to look at the colonization differences between vetch and wheat biomass in relation to this fungal species.

On 6/13/94, numbers were found to be greater in plots receiving 168 kg ha^{-1} nitrogen (2.92 log CFU g soil^{-1}) than no nitrogen (2.10 log CFU g soil^{-1}). The effect nitrogen has on *A. flavus* counts is the same effect on all fungi. All fungi have the advantage in acidic soil conditions, as explained previously.

On 8/4/94, there was a significant difference by nitrogen effect in the first 0-5 cm. The 0 N rate plots (4.71 log CFU g soil^{-1}) had fewer *A. flavus* colonies than the normal rate plots (5.33 log CFU g soil^{-1}). This agrees with the fungal data in general.

Table 10 shows *A. flavus* colonization by depth. For 6/13/94, counts were greatest at the 5-10 cm. depth. Counts at 5-10 cm. were greater but not significantly different than the 10-20 cm. depth. By June, the corn is growing and roots are expanding. The rhizosphere becomes larger. This serves as a nurturing habitat for *A. flavus* colonies. Therefore, the 0-5 cm depth will have significantly greater *A. flavus* colonization than 10-20 cm, and greater mean counts than 5-10 cm.

Fluorescent Pseudomonad Counts

The genus and species name for this organism is *Pseudomonas fluorescens* or *P. putida*. Fluorescent pseudomonads are gram negative rods which can be plant and animal pathogens (Pelczar and Reid, 1965). They can fluoresce a spectrum of colors, dependant upon type of

Table 10. Effect of Depth on *Aspergillus flavus* Counts.

Depth	*Aspergillus flavus* Counts at Each Sampling Date	
	6/13/94	8/4/94
	log CFU g soil^{-1}	
0-5 cm.	1.83 b*	4.99 a
5-10 cm.	3.13 a	4.32 a
10-20 cm.	2.60 ab	3.44 b

* Means within a column followed by the same letter are not significantly different as determined at the 5% probability level.

plating media. On plates of this project, they fluoresced yellowish green. This species is capable of reducing nitrate to nitrite, ammonium, or free nitrogen (Pelczar and Reid, 1965). Pseudomonads are facultative aerobes. Some fluorescent pseudomonads are the cause of soft rots in plants (Atlas and Bartha, 1981).

Fluorescent pseudomonads were plated for sampling dates 6/13/94, 8/4/94, and 4/25/95. All plates were counted after a 2-3 day incubation period. The colonies appeared fluorescent in color on the media.

Cover and nitrogen treatments were significantly different on 4/25/95, only. Numbers of pseudomonads, like all bacteria, decreased during the summer months due to lack of moisture and increased soil temperatures (Table 11). In the spring of 1995, directly after desiccation, vetch cover provided for significantly more pseudomonads than wheat or previous corn residue (Table 11). Numbers under wheat and previous corn residue were significantly lower than vetch due to the high carbon and nitrogen concentrations in the vetch mulch. Generally, Pseudomonas numbers were higher in plots receiving nitrogen fertilizer than those that didn't (Table 11). Pseudomonads can denitrify nitrate as previously mentioned, which may explain the higher numbers in plots receiving ammonium nitrate.

Because pseudomonads are heterotrophs, it stands to reason that numbers were significantly greater from 0-5 cm than from 5-10 or 10-20 cm due to organic matter availability. On 6/13/94, cover by depth was significant (Figure 8). At 0-5 cm, covers were not significantly different in terms of pseudomonads. However, mean counts were greater under vetch than wheat or previous corn residue. From 5-10 cm, vetch soils had significantly more pseudomonad numbers than wheat, but counts were not significantly different from previous corn residue soils. Vetch and previous corn residue soils had lower pseudomonad numbers at 10-20 cm, though not significantly different. Decaying wheat roots at 10-20 cm provided a good carbon source.

Cellulose Degrader Counts

The *Cellulomonas* genus are cellulose degraders. They are pleomorphic rods that are gram

Table 11. Treatment Effects on Fluorescent Pseudomonad Counts in Each Depth.

Depth (cm)	Cover Crop	N rate (kg ha^{-1})	Fluorescent Pseudomonad Counts at Each Sampling Date (log CFU g soil^{-1})		
			6/13/94	8/4/94	4/25/95
0-5	None	0	4.70 a*	5.80 a	5.24 b
	None	168	4.86 a	5.27 a	5.27 b
	Vetch	0	5.64 a	5.45 a	6.06 a
	Vetch	168	4.87 a	5.42 a	6.16 a
	Wheat	0	4.73 a	5.12 a	4.67 c
	Wheat	168	2.93 a	5.41 a	5.47 b
5-10	None	0	4.94 a	5.23 a	4.57 a
	None	168	4.16 a	4.88 a	5.07 a
	Vetch	0	3.64 a	4.95 a	5.43 a
	Vetch	168	3.67 a	4.78 a	5.13 a
	Wheat	0	1.82 a	4.97 a	4.50 a
	Wheat	168	2.40 a	5.29 a	4.84 a
10-20	None	0	1.72 a	4.22 a	4.52 a
	None	168	2.86 a	4.91 a	4.53 a
	Vetch	0	2.48 a	4.80 a	5.03 a
	Vetch	168	2.50 a	4.36 a	4.90 a
	Wheat	0	2.89 a	4.99 a	4.38 a
	Wheat	168	4.03 a	4.74 a	4.62 a

* Means within a column at a given depth followed by the same letter are not significantly different as determined at the 5% probability level.

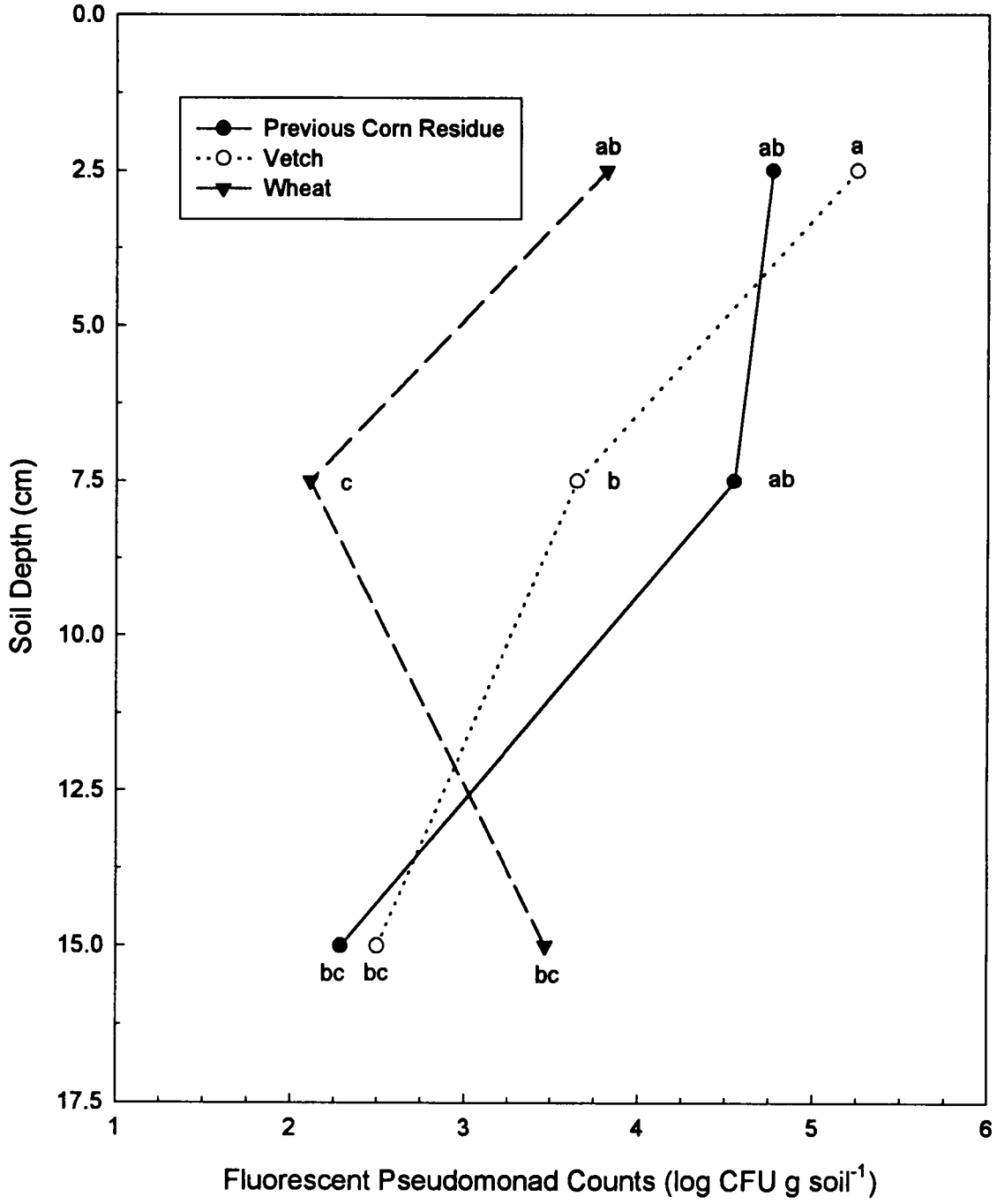


Figure 8. Effect of Cover Crop on 6/13/94 Fluorescent Pseudomonad Counts. Means followed by the same letter are not significantly different at the 5% probability level.

variable (Pelczar and Reid, 1965). As well, there are various other bacteria and fungi that degrade cellulose.

Cellulose degraders were plated for sampling dates: 6/13/94 and 8/4/94. The media recipe did not supply colonies that produced a well defined cleared zone. The soil samples contained cellulose degraders that were pinpoint size and they cleared a zone that was small and barely defined. Upon plating soils from 8/4/94, a longer incubation time was allotted, to grow larger colonies. 6/13/94 plates were incubated 16 days. 8/4/94 plates were incubated 21 days and were so overgrown with fungus that they could not be read. No statistical analysis were done for this sampling date. After 8/4/94, cellulose degraders were not plated. Only one sampling date of data was collected.

Cover did not significantly effect cellulose degrader counts. Mean numbers were generally greater under wheat (5.10 log CFU g $soil^{-1}$) than vetch (5.02 log CFU $gsoil^{-1}$) or previous corn residues (4.99 log CFU g $soil^{-1}$). This is due to the presence of large number of fungi able to degrade cellulose compared to bacteria. Fungi are able to decompose residues with lower nitrogen contents (Burns, 1982).

Plots with nitrogen (5.11 log CFU g $soil^{-1}$) yielded significantly more cellulose degrading microorganisms than those without (5.01 log CFU g $soil^{-1}$). Data from fungal counts for these soils are also significantly greater in plots with nitrogen than those without.

Numbers of cellulose degraders at the 10-20 cm depth (5.10 log CFU g $soil^{-1}$) were significantly greater than numbers at the surface 0-5 (4.90 log CFU g $soil^{-1}$) or 5-10 cm (5.02 log CFU g $soil^{-1}$). This may be due to the cover crop roots availability for decomposition.

Actinomycete Counts

Actinomycetes are aerobic, branching bacteria which produce mycelium and sporulate like fungi, but they also have traits of bacteria (Pelczar and Reid, 1965). Some actinomycetes produce antibiotics. Basically, actinomycetes share characteristics of both groups of organisms.

Actinomycetes were plated for the 4/25/95 date only. Actinomycetes were plated as opposed to

cellulose degraders. Plates were full and difficult to count after they were incubated 7-8 days.

Wheat and vetch with the 0 N rate, at the first depth contain a significantly greater population of actinomycetes than any of the other treatment combinations at any depth (Figure 9). At the surface, previous corn residue with 0 N had significantly more actinomycetes than any other cover with high nitrogen. This graph shows that actinomycetes are more numerous in plots receiving no nitrogen than those receiving nitrogen at the surface. Actinomycetes, as a bacterial genera, tend to prefer less acid soils (Waksman, 1950). The wheat cover has greater mean actinomycetes, because like the fungi, actinomycetes can degrade covers with low nitrogen content (Roper and Gupta, 1995). However, at 10-20 cm, vetch with low nitrogen yielded significantly greater numbers than the other combinations, due to dying vetch roots as available organic matter. Vetch roots would be higher in carbon and nitrogen than wheat roots, as previously discussed. Kirchner et al. (1993) found legume plots yielded greater actinomycetes. Of course, previous corn residue with the 168 N rate yielded some of the lowest counts regardless of depth. Wheat with 0 N went from yielding the greatest number of actinomycetes at the surface, to yielding some of the lowest numbers from 5-20 cm. This may be due to lower general bacterial numbers under wheat as opposed to the other covers.

***Bacillus* Counts**

Bacilli were plated for the 4/25/95 sampling date only. *Bacilli* plates were easily read after a one day incubation period. *Bacilli* are rod shaped cells, sometimes in chains, capable of producing endospores. They are a gram negative aerobic/facultatively anaerobic bacteria. A few species are animal and insect parasites and pathogens (Pelczar and Reid, 1965).

Bacillus numbers among covers were not significant. However, general means for vetch (5.32 log CFU g soil^{-1}) and previous corn residues (5.31 log CFU g soil^{-1}) were higher than wheat (5.21 log CFU g soil^{-1}). The trend would indicate that *Bacillus* numbers were higher under vetch cover than previous corn residue or wheat. *Bacillus,* like all bacteria, were higher under vetch and previous corn residue than wheat. Also, another bacterial trait, *Bacillus* numbers were significantly

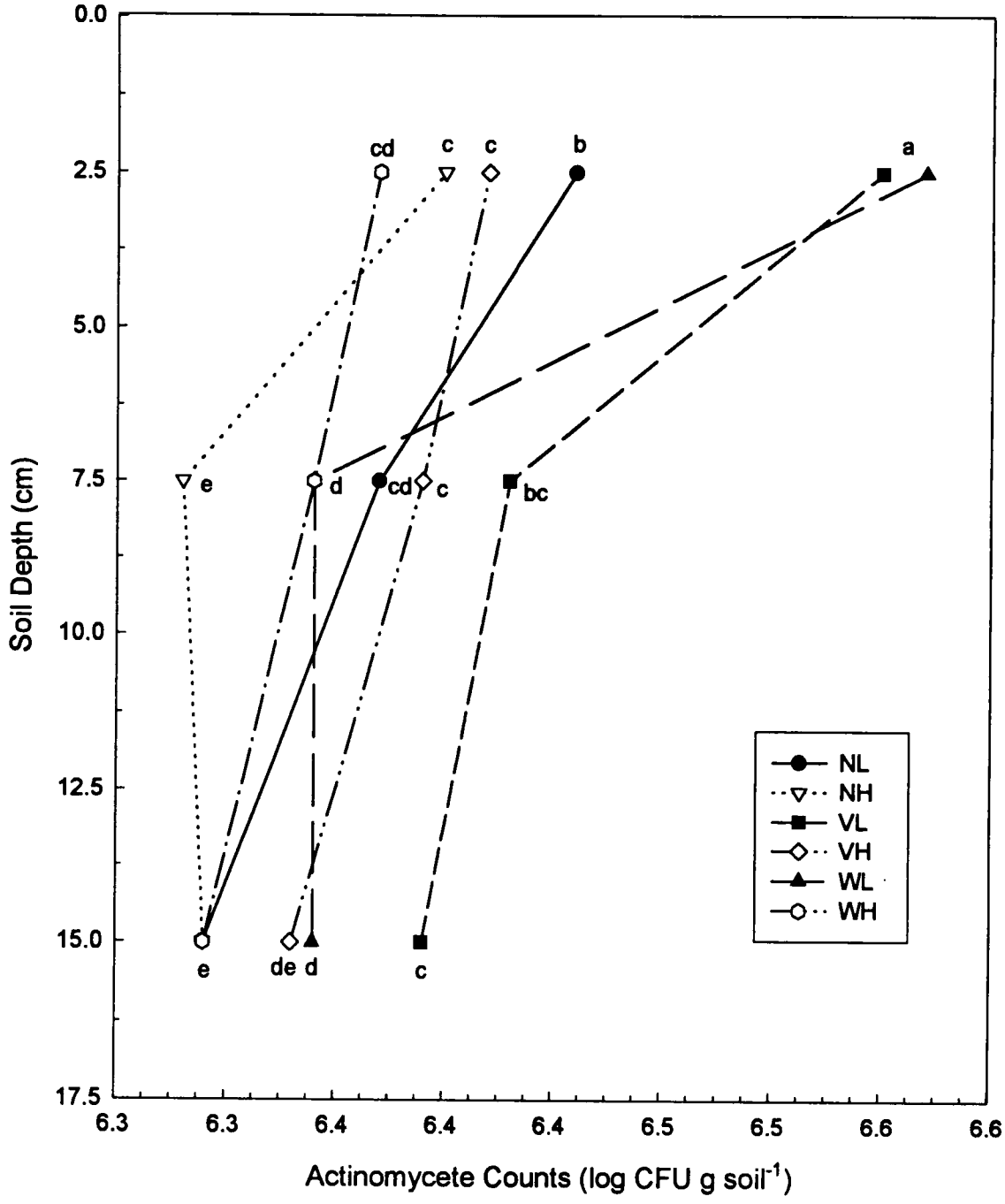


Figure 9. Effect of Cover Crop and Nitrogen Rate on 4/25/95 Actinomycete Counts. Means followed by the same letter are not significantly different at the 5% probability level.

lower under plots receiving nitrogen fertilizer (5.21 log CFU g soil^{-1}) than those that didn't (5.43 log CFU g soil^{-1}). *Bacillus* numbers were generally higher at 0-5 cm than at 5-20 cm as a function of available organic matter.

MICROBIAL BIOMASS CARBON AND NITROGEN DATA

Microbial Biomass Carbon

The only sampling dates for which soils were fumigated/extracted and analyzed for carbon content were 4/18/94, 5/7/94, and 5/16/94. Extracts of each sample were analyzed for total soluble carbon on a Dohrman total organic carbon analyzer. The data were not usable due to inconsistancies. Largely, the inconsistancies were due to technician error. Upon looking at the numbers, some of the samples had more carbon in the direct extracted solution than in either of the fumigated extracts. For many samples, one fumigated extract replicate was dramatically greater than the other. The carbon data for the three dates are in Appendix B.

In explaining the data fluctuations, there are several possibilities. Root exudation is a function of anoxia, mechanical force, water stress, nutrient status, temperature, pH, and day length (Barber and Gunn, 1974; Martin, 1977; Hale and Moore, 1979; Wiedenroth and Poskuta, 1981; Lee and Gaskins, 1982; Martin and Foster, 1985; Merckx et al., 1987; Smucker and Erickson, 1987; Meharg and Killham, 1990). A plausible explanation seems to be that during soil excavation and sieving of the fresh soils the plant roots are cut and mashed opening their cell contents into the soil. Badalucco et al. (1992) found that the release of some non-biomass sugar carbon seems to occur during fumigation. Joergensen et al. (1995) states that some fluctuations in biomass values have been observed during the early stages of storage in soils which haven't been pre-incubated, partly due to interference from freshly excised roots. The portion of biomass carbon attributed to root exudates come from sugars, amino acids, organic acids, hormones, vitamins, cell walls, sloughed-off cellular materials, and mucilage (Cheng et al., 1993). It has been suggested, however impractical and time consuming, that fresh soils should be sieved and stored at 4°C for at least one year before the procedure is performed, so that, the effects of organic matter mobilization by

sampling, excision of roots, and sieving have adequately subsided (Joergensen et al., 1995). The membranes of living roots are also under attack by chloroform in the process of fumigation (Mueller et al., 1992). This may serve to reinforce that a storage period is needed. This advice has been heeded by some (Badalucco et al., 1992). Some biomass studies involve sieving soils through small meshes (0.75mm.) and hand-picking the roots as needed (Jordan et al., 1995). Some prefer not to sieve soils at all, but to homogenize soils by hand and store in the cooler overnight and analyze the next morning (Joergensen et al., 1994). Ross (1992) examined biomass carbon and nitrogen values of soils under two mesh sizes: 2 and 5.6 mm. Levels of extractable carbon and nitrogen were greater in winter soil samples passed through a 2mm sieve as compared to the 5.6 mm sieve, because the <2mm soils were highest in root residues due to increased seiving (Ross, 1992). Sieving effects were significant, but less so than other variables of influence, like root residues and soil moisture content (Ross, 1992). In this study, soils were sieved through a 2 mm mesh and stored at 4°C until analysis for biomass carbon.

Though root excision may explain some problems with the biomass procedure, some others exist. One reason may be that chloroform does not lyse all microbial cells in the soil (Alef, 1993). Kaiser et al. (1992) compared chloroform fumigation-incubation, chloroform fumigation-extraction, and substrate induced respiration methodologies. The only one of the three methods that correlated to organic matter was the chloroform fumigation extraction method. This calls for caution in high organic matter field soils because problems arise when the ratio of extractable carbon from fumigated:non-fumigated soils gets closer and the error of the two measurements accumulates (Kaiser et al., 1992). Also, smearing and compacting of the soils must be avoided (Kaiser et al., 1992). In two or three shipments of soil samples, ice bags in the soil cooler broke, wetting some samples to mud. These samples were allowed to air dry until seiving was possible. Other samples in the same shipment were excessively moist. Joergensen et al. (1995) found that above a certain pH threshold (pH 5), microbial carbon:nitrogen values vary within a very small range over a wide range of pH values. Below this threshold, the range of carbon:nitrogen values

becomes very large. Individual soil sample pH in this study ranged from 4.5 to 6.5. Some of the soil samples have pH values above the threshold and some fell below the threshold. Another, very possible reason may lie in the processing of soil extracts. It is possible that the lab technician may have mislabelled, misplaced, or incorrectly collected the data.

Microbial Biomass Nitrogen

There were few significant differences among the data for microbial biomass nitrogen. Only the first depth was analyzed from air-dried soils for 4/18/94, 5/7/94, and 5/16/94. Soils from 6/13/94 and 8/4/94 were analyzed fresh as soon as possible. There were significant differences among cover and nitrogen rates for two out of the five dates analyzed (Table 12). It had been decided that the last date would not be analyzed for biomass nitrogen, because data was poor for the preceding dates. Table 12 relates that wheat with nitrogen and vetch without nitrogen yielded generally greater mean biomass nitrogen than others for three of the five sampling dates. Wheat with nitrogen and vetch without nitrogen had greater numbers of bacteria (Table 8). Cover crop yields in 1994 were significantly greater under wheat with168 N than for any other treatment combination (Table 7). This might be due to greater plant biomass available under wheat with high nitrogen that year. Of the two significant sampling dates, the first depth yielded significantly greater biomass nitrogen per gram soil than the other depths. On 6/13/94, the 0-5 cm depth yielded 22.62 μg biomass N g soil^{-1} as compared to the 5-10 (9.61 μg biomass N g soil^{-1}) and 10-20 cm depths (8.01 μg biomass N g soil^{-1}). On 8/4/94, the 0-5 cm depth yielded 21.51 μg biomass N g soil^{-1} as compared to the 5-10 (10.63 μg biomass N g soil^{-1}) and 10-20 cm depths (9.82 μg biomass N g soil^{-1}). Data for this analysis was shaky at best, and there are many theories for probable cause. Therefore, less attention should be paid to unreliable biomass results as opposed to plating and enzyme assay results.

Others attempting fumigation-extraction methodologies should examine the benefit of removal of roots by wet sieving (Mueller et al., 1992). This method is good for field soils. By decanting the root biomass in the supernatant, the data should at least make sense, whether analyzing for

Table 12. Effect of Cover Crop and Nitrogen Rate on Microbial Biomass Nitrogen.

Cover	Nitrogen Rate	Microbial Biomass Nitrogen at Each Sampling Date				
		4/18/94	5/7/94	5/16/94	6/13/94	8/4/94
		——————μg Biomass N g soil^{-1}——————				
None	Low	11.10 a*	4.54 b	53.31 a	11.00 a	13.10 a
None	High	1.83 c	18.12 b	54.00 a	15.72 a	12.42 a
Vetch	Low	9.91 a	164.60 a	26.42 a	16.81 a	15.04 a
Vetch	High	8.00 a	19.21 b	46.73 a	13.32 a	11.21 a
Wheat	Low	4.54 b	13.32 b	40.73 a	14.54 a	16.23 a
Wheat	High	10.31 a	252.83 a	78.71 a	8.92 a	15.92 a

* Means within a column followed by the same letter are not significantly different as determined at the 5% probability level.

biomass carbon or nitrogen. Due to time constraints and manual capability, it would be tedious to perform wet seiving on more than a few samples. One suggestion might be to analyze for biomass carbon or nitrogen after a lengthy storage period. This suggestion is also time consuming. The best possible recommendation would be to further investigate and improve the fumigation-extraction methodology.

SOIL ENZYMES

Acid Phosphatase

Soils from all sampling dates were assayed for acid phosphatase activity. The highest activities were noted in the vetch cover plots (Table 13). This is due to a higher population of microorganisms and organic carbon concentration found in vetch cover plots as opposed to the other covers. Carbon content is important, as it serves to provide the substrait for this enzyme in the form of organic phosphates. Phosphatase activity can be significantly correlated to organic carbon content (Speir, 1977; Neilsen and Eiland, 1980).

Surface acid phosphatase activities were significantly greater in plots receiving the 168 N rate (Figure 10). Since this enzyme is optimumly active at pH 6.5, it functions well in acidic environments (Tabatabai, 1994). Ammonium nitrate addition causes increased acidity. Greater acid phosphatase activity has been observed in fertilized soils as compared to unfertilized soils (Kirchner et al., 1993; Dick et al., 1988).

Acid phosphatase activities were concentrated in the surface five centimeters (Table 13). Activity, generally, decreased with increasing soil depth. Neilsen and Eiland (1980) found phosphatase activity to be correlated with available organic phosphorus in the system. In this study, the organic phosphorus is likely tied up in overlying cover mulch and in a no-till system is therefore concentrated at the surface.

Alkaline Phosphatase

Dates for alkaline phosphatase activity are shown in Table 14. On 5/16/94 and 6/13/94, alkaline phosphatase activities were significantly greater under vetch with 0 N than any other treatment

Table 13. Treatment Effects on Acid Phosphatase Activity in Each Depth.

Depth (cm)	C†	N	Acid Phosphatase Activity at Each Sampling Date (μg PNP g soil^{-1} h^{-1})					
			4/18/94	5/7/94	5/16/94	6/13/94	8/4/94	4/25/95
0-5	N	0	233.03b	185.50b	184.31c	187.50b	183.59b	229.21b
	N	168	304.90b	236.30b	241.77bc	230.60b	298.53a	328.34ab
	V	0	432.46a	346.49ab	404.99ab	342.09a	335.55a	404.14a
	V	168	415.43ab	385.74a	453.35a	321.61ab	295.41a	397.22a
	W	0	300.89b	273.26b	273.66bc	228.52b	265.90ab	263.83b
	W	168	380.26ab	279.83b	314.91b	286.83ab	317.65a	435.30a
5-10	N	0	120.78a	92.07a	78.36a	120.90a	118.93a	114.73a
	N	168	159.57a	124.34a	173.26a	135.75a	146.60a	140.67a
	V	0	217.91a	142.39a	168.11a	175.13a	167.05a	186.37a
	V	168	168.51a	133.78a	148.35a	142.23a	155.16a	166.04a
	W	0	181.71a	121.50a	161.24a	156.35a	167.65a	213.10a
	W	168	185.73a	127.13a	157.47a	153.59a	171.13a	157.86a
10-20	N	0	109.08a	80.50a	107.52a	100.35a	95.91a	103.45a
	N	168	98.09a	82.11a	119.64a	100.42a	108.29a	118.35a
	V	0	151.81a	105.39a	143.78a	137.16a	122.67a	157.32a
	V	168	135.11a	103.72a	119.55a	125.70a	113.69a	141.82a
	W	0	135.92a	104.59a	113.79a	116.23a	127.44a	132.05a
	W	168	131.65a	117.56a	106.88a	112.03a	137.14a	142.42a

* Means within a column at a given depth followed by the same letter are not significantly different as determined at the 5% probability level.

† Cover and N rate (kg ha^{-1}), N=none; V=vetch; W=wheat.

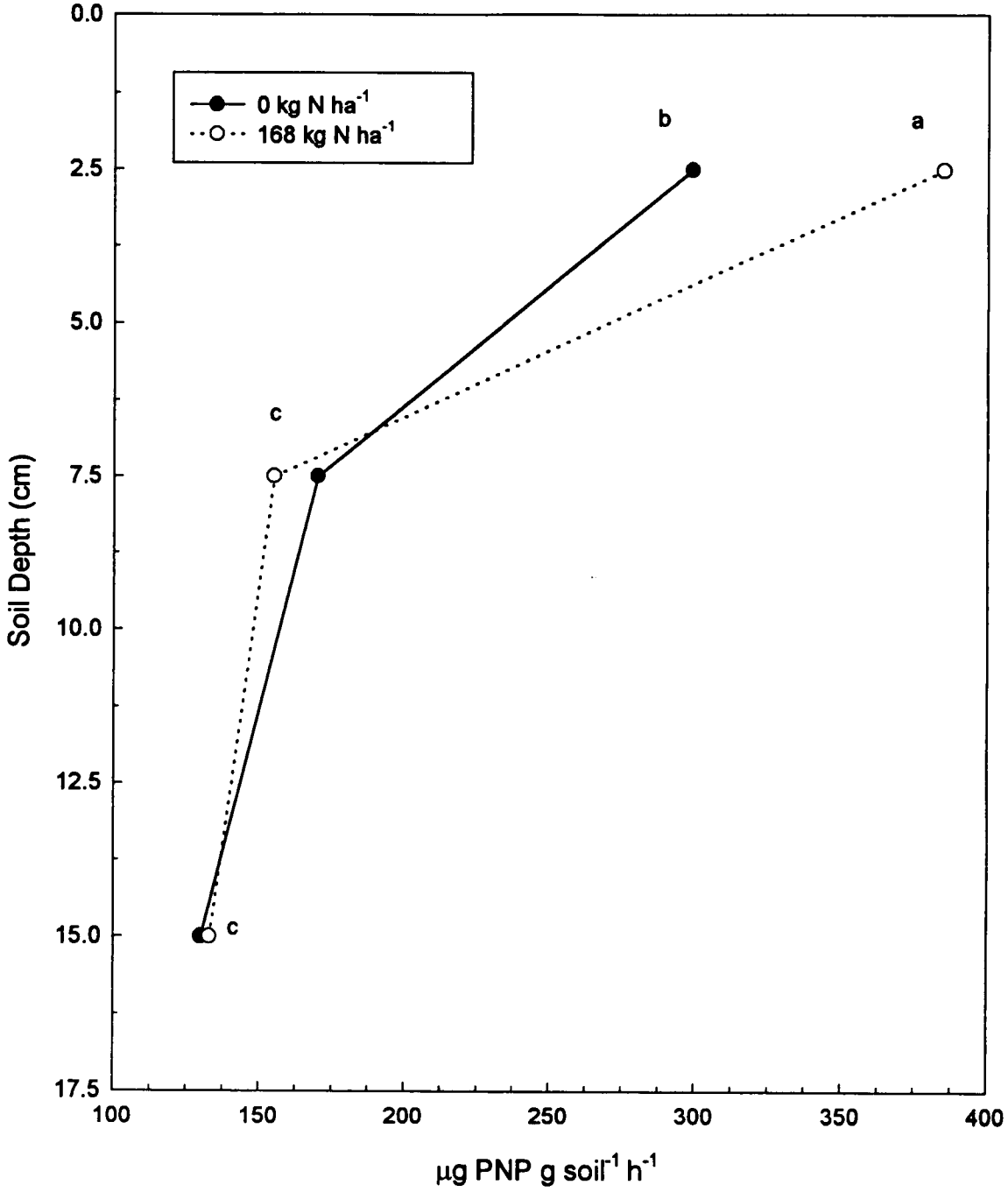


Figure 10. Effect of Nitrogen Rate on 4/25/95 Acid Phosphatase Activity. Means followed by the same letter are not significantly different at the 5% probability level.

Table 14. Treatment Effects on Alkaline Phosphatase Activity in Each Depth.

			Alkaline Phosphatase Activity at Each Sampling Date (μg PNP g soil^{-1} h^{-1})					
Depth (cm)	Cover Crop	N rate (kg ha^{-1})	4/18/94	5/7/94	5/16/94	6/13/94	8/4/94	4/25/95
0-5	None	0	87.32 a*	6.92 a	50.09 bc	55.51 b	6.92 a	6.92 a
	None	168	61.80 a	4.67 a	21.76 c	8.05 c	4.67 a	4.67 a
	Vetch	0	94.51 a	9.33 a	116.72 a	105.71 a	9.33 a	9.33 a
	Vetch	168	52.98 a	3.96 a	62.04 b	23.10 c	3.96 a	3.96 a
	Wheat	0	100.07 a	7.90 a	55.13 bc	71.23 b	7.90 a	7.90 a
	Wheat	168	61.98 a	5.76 a	31.28 c	10.27 c	5.76 a	5.76 a
5-10	None	0	8.91 a	1.74 a	6.35 a	8.28 a	1.74 a	1.74 a
	None	168	17.78 a	1.61 a	10.62 a	12.99 a	1.61 a	1.61 a
	Vetch	0	43.87 a	2.15 a	13.22 a	17.54 a	2.15 a	2.15 a
	Vetch	168	17.77 a	1.90 a	11.43 a	17.29 a	1.90 a	1.90 a
	Wheat	0	15.06 a	2.82 a	12.91 a	19.13 a	2.82 a	2.82 a
	Wheat	168	33.93 a	2.16 a	14.39 a	13.53 a	2.16 a	2.16 a
10-20	None	0	20.58 a	2.02 a	5.71 a	15.61 a	2.02 a	2.02 a
	None	168	45.24 a	1.87 a	6.75 a	16.77 a	1.87 a	1.87 a
	Vetch	0	13.93 a	2.30 a	14.84 a	22.15 a	2.30 a	2.30 a
	Vetch	168	38.30 a	1.29 a	12.97 a	26.08 a	1.29 a	1.29 a
	Wheat	0	6.84 a	2.58 a	9.63 a	16.55 a	2.58 a	2.58 a
	Wheat	168	21.54 a	2.32 a	10.78 a	20.24 a	2.32 a	2.32 a

* Means within a column at a given depth followed by the same letter are not significantly different as determined at the 5% probability level.

combination (Table 14). Vetch cover provides increased numbers of microorganisms and their activities. This is due to the increased organic matter availability and high carbon content in vetch plots. Phosphatase activity was significantly correlated with organic carbon content (Speir, 1977; Neilsen and Eiland, 1980). Alkaline phosphatase activities were generally lower on 5/7/94, 8/4/94, and 4/25/95 (Table 14). The decrease in activity is due to decrease in pH following nitrogen fertilizer application on 5/7/94 and 4/25/95. Because general soil pH values were closer to the optimal activity range of acid phosphatase at pH 6.5, alkaline phosphatase activities were far lower than acid phosphatase. Alkaline phosphatase is optimumly active at pH 11 (Tabatabai, 1994). Alkaline phosphatase activities were significantly higher without nitrogen fertilizer than with fertilizer due to the effect of fertilizer on soil pH (Table 15). Decreasing soil pH resulted in significantly lower alkaline phosphatase activity (Dick, 1988).

Alkaline phosphatase activities were significantly greater in the surface 5 cm than the other depths due to available substrate concentrated in overlying organic matter (Table 14). Neilsen and Eiland (1980) found phosphatase activity to be significantly correlated with organic phosphorus availability.

β-Glucosidase

Soils of all sampling dates were examined. Table 16 shows that for many sampling dates β-glucosidase activities are significantly greater under vetch. Figure 11 shows the effect of cover and nitrogen rate by depth for samples from 4/18/94. Vetch plots receiving the 0 N rate maintained the highest β-glucosidase activity regardless of depth. In fact, vetch with low nitrogen had significantly higher activities from 5-10 cm. At the 0-5 cm. depth, vetch plots receiving the 168 N rate were the next greatest in terms of activity. It can clearly be seen that the vetch cover had the greatest effect on β-glucosidase activities for this and other dates (Table 16; Figure 12). β-glucosidase activities were greater under vetch covers due to the increased numbers of fungal and bacterial populations (Table 8, 9). Fungi are of interest concerning this enzyme because fungi are the primary cellulose degraders (Tabatabai, 1994). Kirchner et al. (1993) found that legume plots yielded greater

Table 15. Effect of Nitrogen Rate on Alkaline Phosphatase Activity.

N Rate (kg ha^{-1})	Alkaline Phosphatase Activity at Each Sampling Date (μg PNP g $soil^{-1}$ h^{-1})					
	4/18/94	5/7/94	5/16/94	6/13/94	8/4/94	4/25/95
0	43.51 a*	4.21 a	31.62 a	36.90 a	4.21 a	4.21 a
168	38.95 a	2.84 b	20.20 b	16.51 b	2.84 b	2.84 b

* Means within a column followed by the same letter are not significantly different at the 5% probability level.

Table 16. Treatment Effects on β-Glucosidase Activity in Each Depth.

			β-Glucosidase Activity at Each Sampling Date (μg PNG g soil^{-1} h^{-1})					
Depth (cm)	†C	N	4/18/94	5/7/94	5/16/94	6/13/94	8/4/94	4/25/95
0-5	N	0	91.49bc*	38.61a	65.05c	79.68c	64.56b	61.33c
	N	168	58.20c	55.89a	99.70b	86.93c	113.65ab	90.87c
	V	0	152.82a	116.89a	163.00a	167.43a	149.61a	172.12a
	V	168	116.75b	131.07a	159.87a	137.58b	102.37ab	147.38ab
	W	0	76.53c	84.07a	82.07bc	86.98c	90.12b	61.88c
	W	168	99.35bc	87.33a	106.12b	97.80c	134.46ab	136.54b
5-10	N	0	10.58a	6.04a	9.55b	17.78a	10.45a	7.85a
	N	168	15.61a	11.67a	18.58ab	23.80a	23.21a	9.60a
	V	0	37.29a	15.84a	23.25ab	37.54a	22.58a	23.85a
	V	168	19.29a	18.09a	25.88a	37.21a	22.60a	25.30a
	W	0	17.63a	15.41a	14.04b	29.62a	37.14a	39.73a
	W	168	21.53a	20.04a	22.15ab	26.92a	37.52a	17.31a
10-20	N	0	6.59a	4.16a	7.04a	12.45a	7.24a	5.36a
	N	168	8.61a	5.63a	9.86a	13.10a	8.91a	6.91a
	V	0	15.04a	8.28a	13.11a	21.80a	9.95a	12.44a
	V	168	14.21a	8.95a	10.67a	15.60a	9.12a	14.34a
	W	0	12.15a	6.73a	5.03a	14.00a	17.81a	8.66a
	W	168	12.86a	8.63a	4.03a	13.36a	13.86a	8.04a

* Means within a column at a given depth followed by the same letter are not significantly different as determined at the 5% probability level.

† Cover and N rate (kg ha^{-1}), N=none; V=vetch; W=wheat.

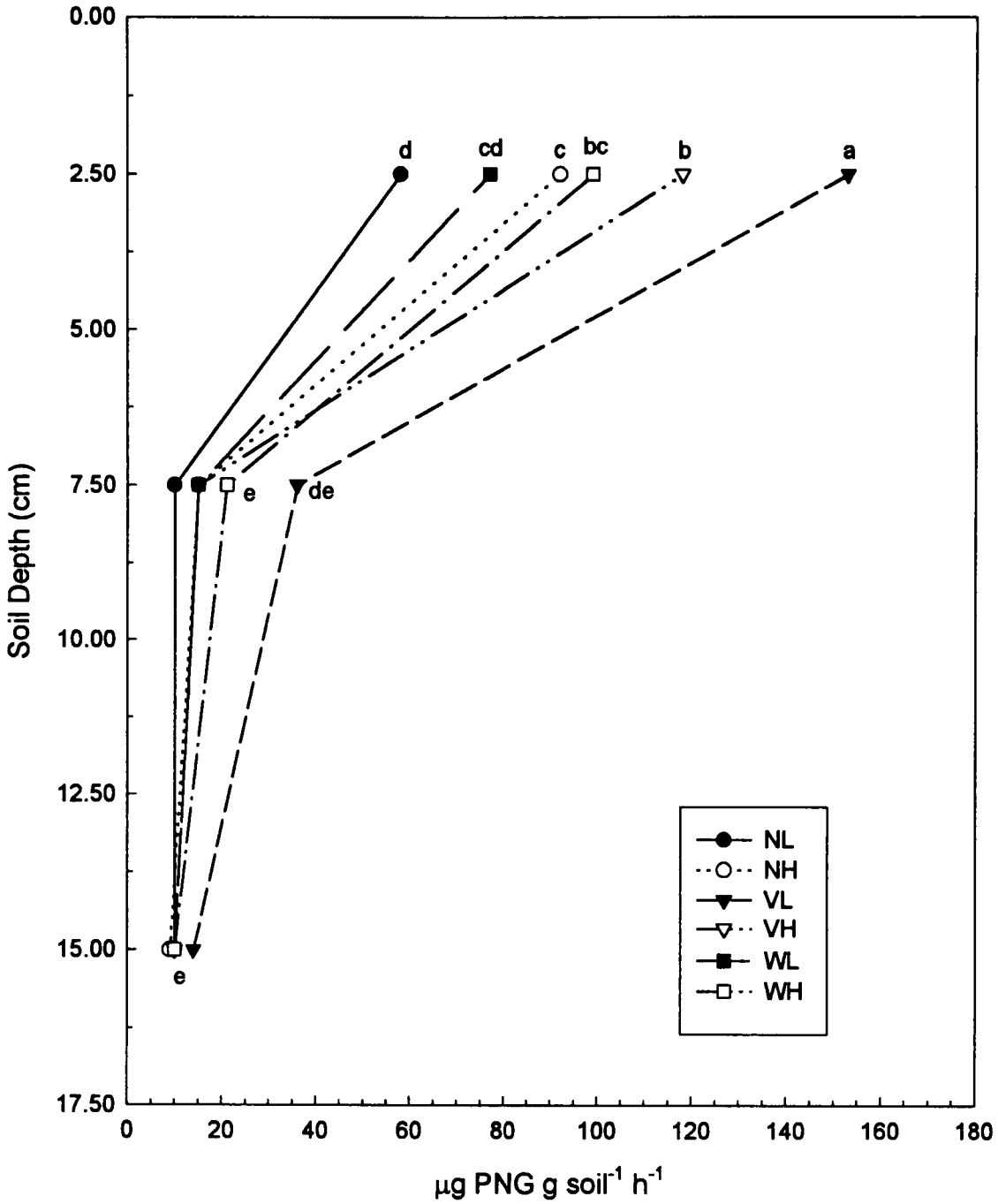


Figure 11. Effect of Cover Crop and Nitrogen Rate on 4/18/94 β-Glucosidase Activity. Means followed by the same letter are not significantly different at the 5% probability level.

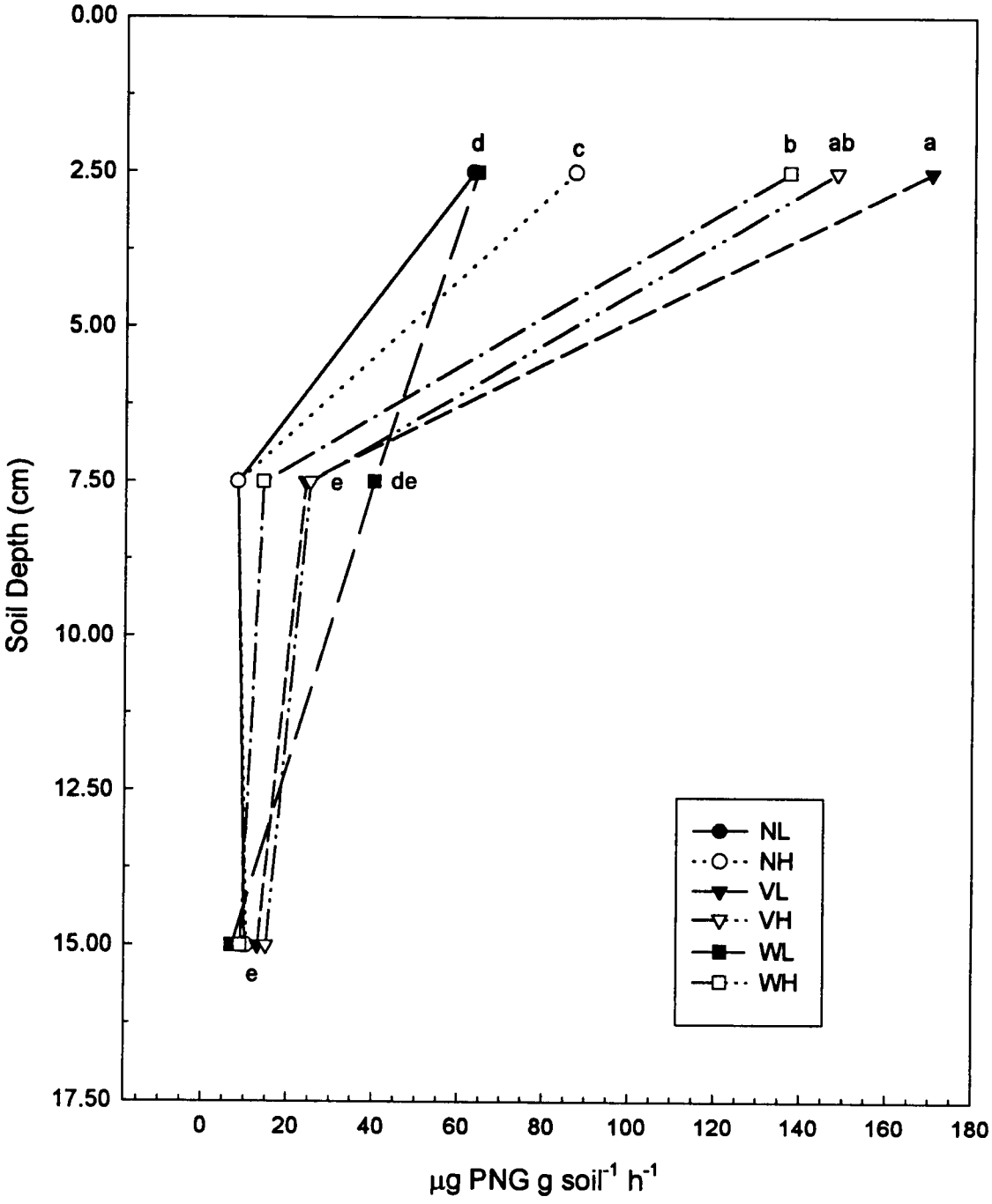


Figure 12. Effect of Cover Crop and Nitrogen Rate on 4/25/95 β-Glucosidase Activity. Means followed by the same letter are not significantly different at the 5% probability level.

β-glucosidase activity than previous corn residue treatments. For all dates, β-glucosidase activities were greatest in the surface 5 cm. than the 5-10, or 10-20 cm. depths due to the substrate availability at the surface (Table 16).

Plots receiving nitrogen had greater β-glucosidase activity than 0 N treatments (Table 16). β-glucosidase activity is optimal at pH 6, a neutral to acid pH (Tabatabai, 1994). Increased nitrogen content in the mulch or nitrogen added as fertilizer is required by microbial cells for cellular metabolism. As microbes break down cellulose releasing carbon, they also need nitrogen to build cellular amino acids, nuclei, organelles, etc. Kirchner et al. (1993) found greater β-glucosidase activity in plots receiving nitrogen than in plots without nitrogen. Greater fungal numbers in plots with the 168 N rate contributes to the higher activity in fertilized plots.

Arylsulfatase

At every sampling date, vetch with 0 N had significantly greater arylsulfatase activity than any other treatment combination (Figures 13-18;Table 17). Arylsulfatase activity has been found to be higher in legume plots than previous corn residue plots (Kirchner et al., 1993). The high enzymatic activity under vetch plots are associated with the high carbon and nitrogen concentrations in the vetch mulch as well as increasing microbial populations under vetch. On 8/4/94 and 4/18/94, arylsulfatase activity decreased due to limited substrate in the soil as available organic matter becomes less abundant. Arylsulfatase activity levels are significantly greater in the surface five centimeters than the other depths, for every sampling date (Table 17). With the exception of 4/18/94, previous corn residue plots receiving the 168 N rate yielded the lowest significance level of arylsulfatase activity in the surface five centimeters, regardless of sampling date (Figures 13-18). In general, treatment combinations with 168 kg N ha^{-1} had lower arylsulfatase activities than with 0 kg N ha^{-1}. Table 17 shows the effect of nitrogen rate on arylsulfatase activity. Arylsulfatase is optimumly active at pH 6 (Tabatabai, 1994). The pH effect caused by application of the 168 N rate is responsible for decreased arylsulfatase activity. Soil acidification provides an advantage for sulfur oxidizers (Tisdale et al., 1985). Sulfur oxidizers produce sulfate. Production of sulfate in high

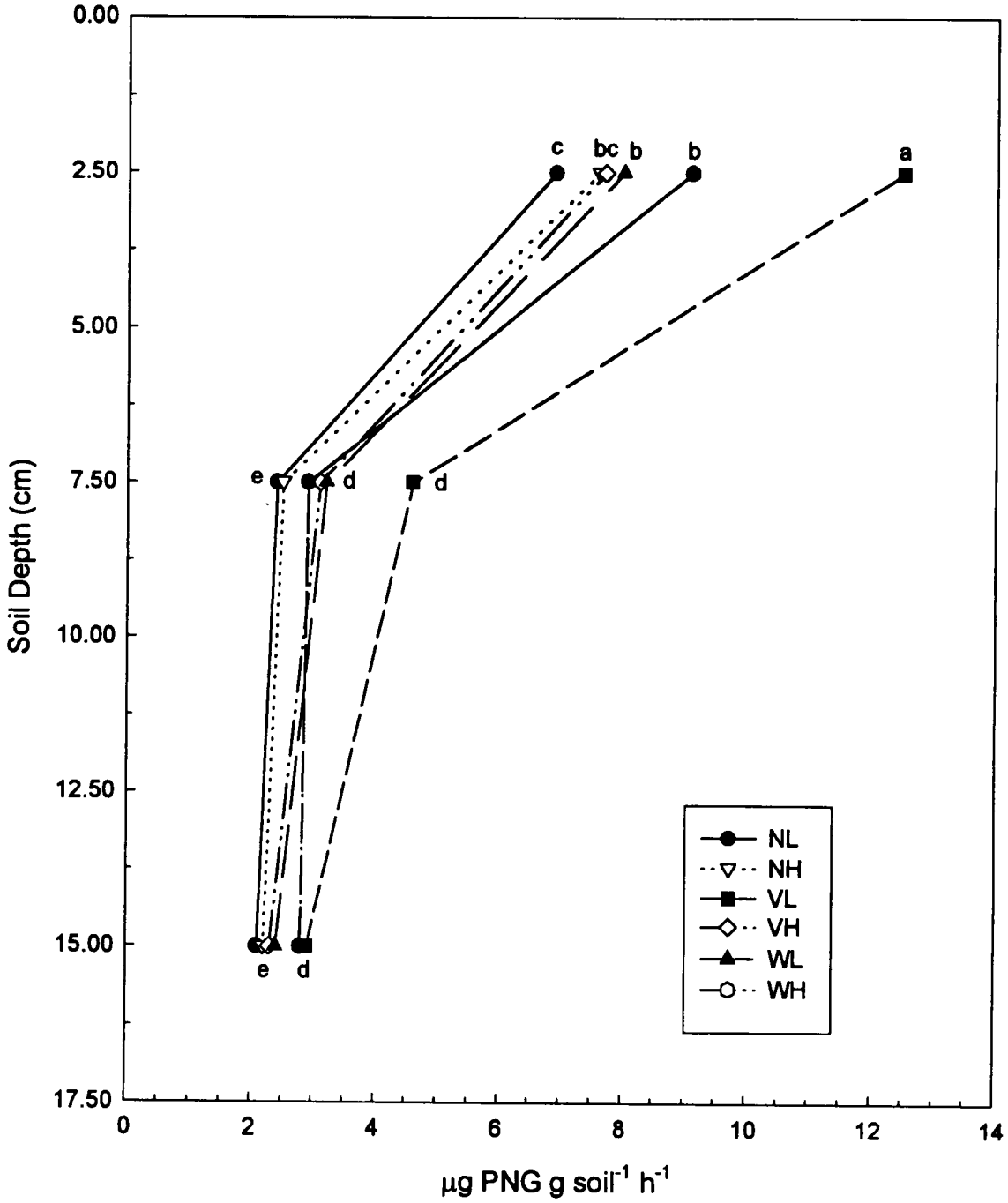


Figure 13. Effect of Cover and Nitrogen Rate on 4/18/94 Arylsulfatase Activity. Means followed by the same letter are not significantly different at the 5% probability level.

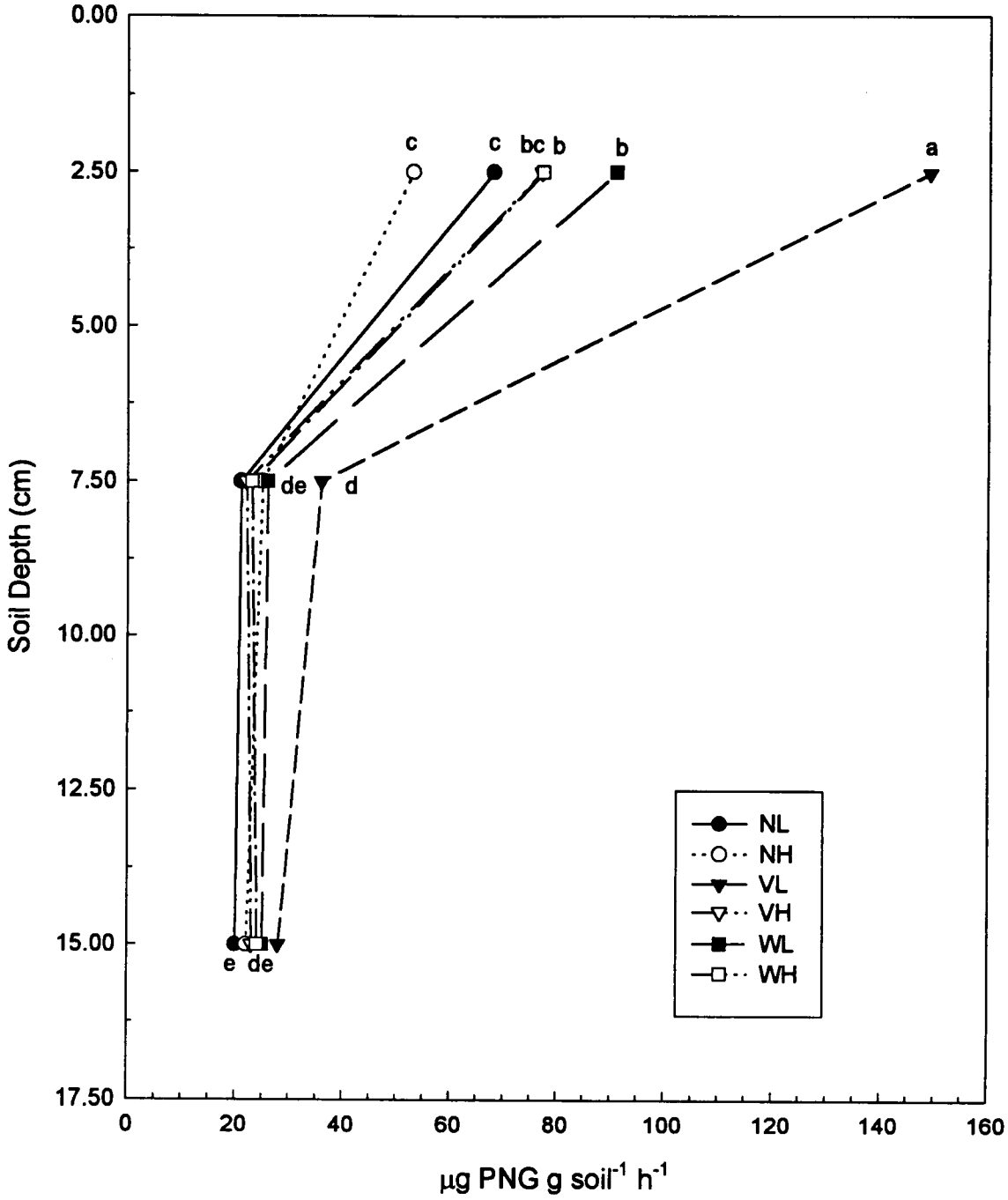


Figure 14. Effect of Cover Crop and Nitrogen Rate on 5/7/94 Arylsulfatase Activity. Means followed by the same letter are not significantly different at the 5% probability level.

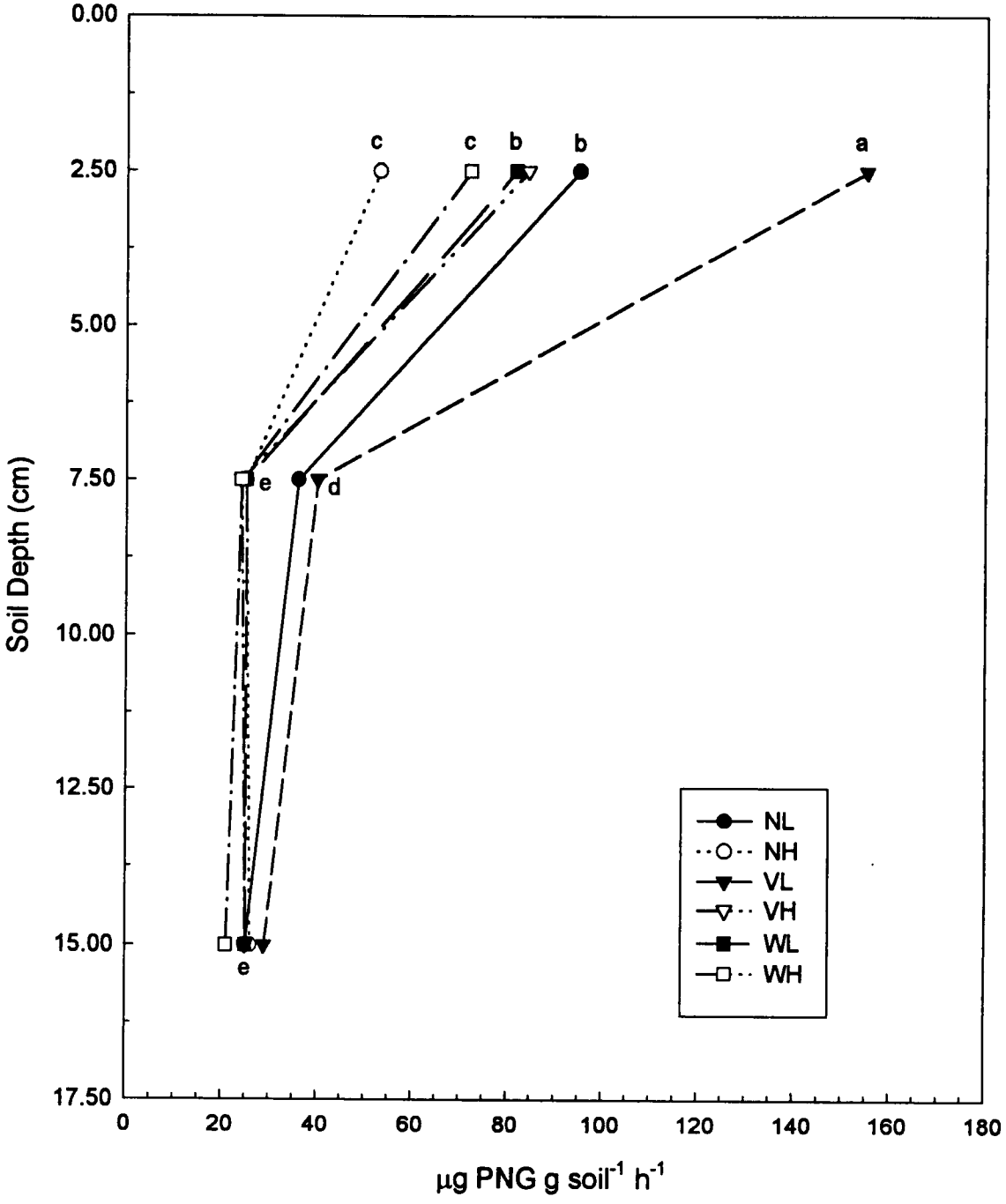


Figure 15. Effect of Cover Crop and Nitrogen Rate on 5/16/94 Arylsulfatase Activity. Means followed by the same letter are not significantly different at the 5% probability level.

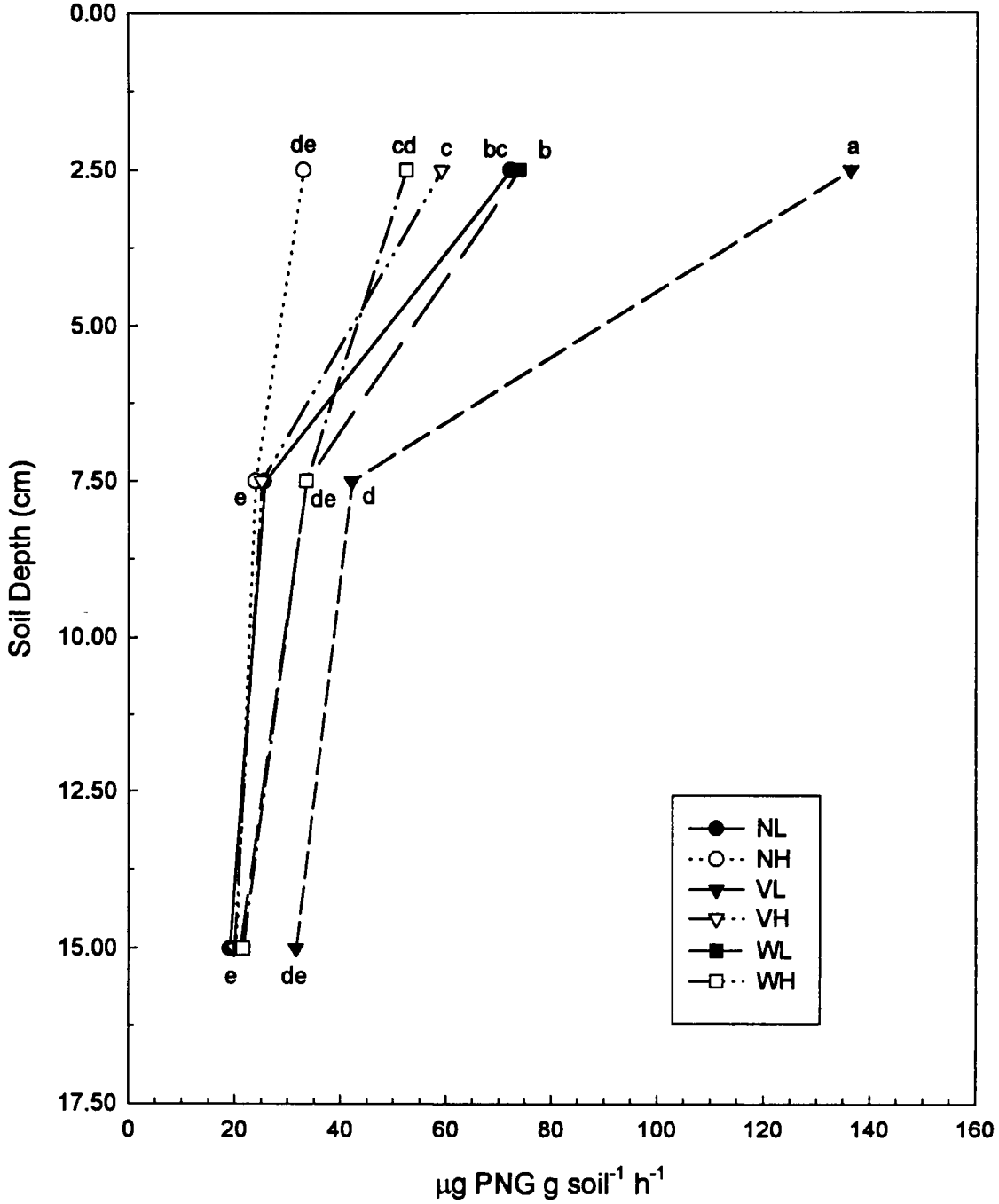


Figure 16. Effect of Cover Crop and Nitrogen Rate on 6/13/94 Arylsulfatase Activity. Means followed by the same letter are not significantly different at the 5% probability level.

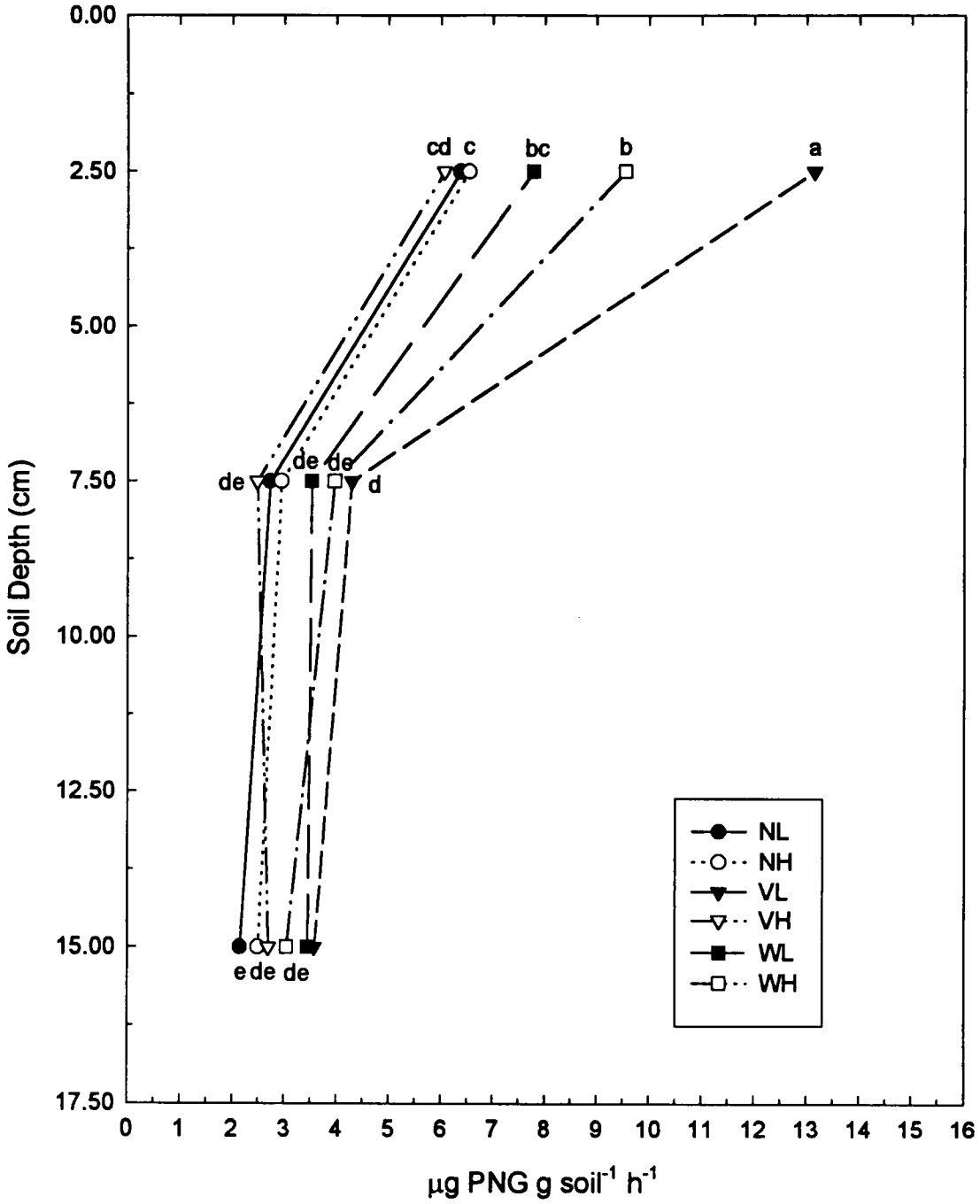


Figure 17. Effect of Cover Crop and Nitrogen Rate on 8/4/94 Arylsulfatase Activity. Means followed by the same letter are not significantly different at the 5% probability level.

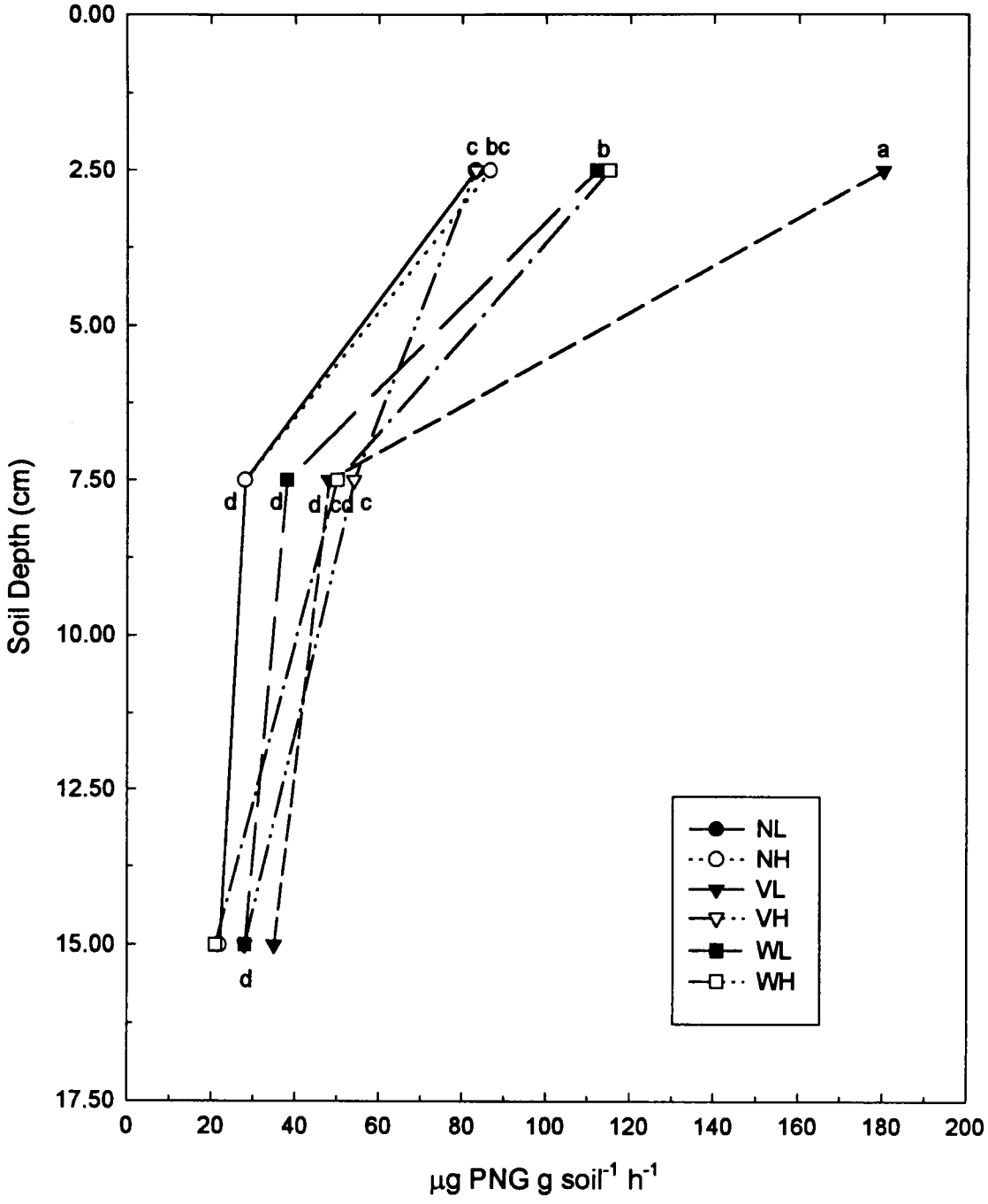


Figure 18. Effect of Cover Crop and Nitrogen Rate on 4/25/95 Arylsulfatase Activity. Means followed by the same letter are not significantly different at the 5% probability level.

Table 17. Treatment Effects on Arylsulfatase Activity in Each Depth.

Depth (cm)	Cover Crop	N rate (kg ha^{-1})	Arylsulfatase Activity at Each Sampling Date (μg PNG g soil^{-1} h^{-1})					
			4/18/94	5/7/94	5/16/94	6/13/94	8/4/94	4/25/95
0-5	None	0	6.82b*	67.82bc	72.37bc	72.16b	6.37bc	80.84b
	None	168	7.97b	53.78c	53.84c	33.00d	6.54bc	86.47b
	Vetch	0	12.45a	148.30a	155.61a	136.24a	13.14a	181.38a
	Vetch	168	7.58b	77.03bc	84.27b	59.06bc	6.06c	112.54b
	Wheat	0	7.66b	90.99b	81.66bc	73.90b	7.78bc	80.01b
	Wheat	168	9.11b	77.28bc	95.23b	52.45c	9.54b	115.64b
5-10	None	0	2.36b	21.31a	23.71a	25.63a	2.72c	28.32a
	None	168	2.66b	25.61a	25.76a	23.85a	2.94bc	27.47a
	Vetch	0	4.58a	35.92a	40.89a	42.14a	4.29a	46.44a
	Vetch	168	2.49b	25.52a	25.86a	25.06a	2.47c	36.28a
	Wheat	0	3.11b	33.15a	29.72a	33.48a	3.52b	54.30a
	Wheat	168	3.02b	30.90a	36.46a	30.86a	3.96ab	36.78a
10-20	None	0	2.00a	17.54a	19.22a	18.96a	2.15a	22.98a
	None	168	2.16a	19.44a	24.76a	20.22a	2.49a	24.59a
	Vetch	0	2.80a	26.46a	28.38a	31.58a	3.58a	34.42a
	Vetch	168	2.54a	22.63a	24.22a	19.85a	2.69a	28.31a
	Wheat	0	2.55a	23.97a	21.95a	21.00a	3.44a	27.94a
	Wheat	168	2.65a	27.08a	20.91a	21.53a	3.04a	28.52a

* Means within a column at a given depth followed by the same letter are not significantly different as determined at the 5% probability level.

concentrations inhibit arylsulfatase activity. Acidification of the soil by fertilizer decreases bacterial populations which effect enzyme activity levels. Decreased pH decreases arylsulfatase activity (Dick, 1984; Dick, 1988).

L-Asparaginase

Soils from all sampling dates were assayed for L-asparaginase activity. L-asparaginase cleaves off the ammonia group from the amino acid asparaginase, yielding the amino acid aspartate and free ammonia (Tabatabai, 1994). L-asparaginase is a type of amidase and indicative of nitrogen cycling in soils (Tabatabai, 1994). For five of the six sampling dates, vetch 0 N plots had significantly higher L-asparaginase activity than any other treatment combination (Table 18). The trend may be observed in data of 8/4/94. L-asparaginase activity of wheat plots did not significantly differ from that of the previous corn residue plots for five of the six sampling dates. The higher carbon and nitrogen concentrations in the vetch mulch and increased microbial populations under vetch with 0 N were (Tabatabai, 1994). L-asparaginase activity may be suppressed in plots receiving the 168 N rate by both product inhibition from the ammonium in the ammonium nitrate fertilizer and resulting associated decrease in pH (Dick, 1988). Acidification of the soil by fertilizer decreases bacterial populations, effecting soil enzymatic activity levels.

Figure 19 shows depth by treatment interaction for 4/18/94 L-asparaginase activity. L-asparaginase activity was significantly greater in vetch plots with no nitrogen than any other treatment combination. At the second depth, vetch covers with and without nitrogen fertilizer were significantly greater than any other treatment combination. Yet soils of 8/4/94 show that both vetch with 0 N and wheat with 168 N were significantly greater in L-asparaginase activity than any other treatment combination. By August, microbes have mineralized a large portion of the organic matter and released nutrients for the growing corn crop. The wheat crop has a high carbon to nitrogen ratio. In wheat plots with high nitrogen, L-asparaginase activity increases this date due to increased nutrient concentration and crop uptake of ammonium.

Table 18. Treatment Effects on L-Asparaginase Activity in Each Depth.

Depth (cm)	Cover Crop	N rate (kg ha^{-1})	L-Asparaginase Activity at Each Sampling Date ($\mu g\ NH_4^+\ g\ soil^{-1}\ h^{-1}$)					
			4/18/94	5/7/94	5/16/94	6/13/94	8/4/94	4/25/95
0-5	None	0	14.06b*	12.55 b	18.31b	15.25b	17.61b	20.58b
	None	168	18.35b	15.17 b	16.51b	15.28b	21.25b	24.88b
	Vetch	0	38.41a	30.38 a	30.13a	27.09a	33.76a	38.14a
	Vetch	168	17.79b	19.52 b	18.38b	10.38b	12.76b	24.58b
	Wheat	0	17.85b	17.35 b	15.81b	16.52b	21.41b	18.20b
	Wheat	168	17.22b	17.77 b	17.14b	12.47b	24.77a	23.63b
5-10	None	0	4.40b**	N/A	N/A	N/A	N/A	N/A
	None	168	4.50b**					
	Vetch	0	10.00a**					
	Vetch	168	4.42b**					
	Wheat	0	5.74b**					
	Wheat	168	5.21b**					
10-20	None	0	2.69a	N/A	N/A	N/A	N/A	N/A
	None	168	2.15a					
	Vetch	0	5.07a					
	Vetch	168	4.93a					
	Wheat	0	4.97a					
	Wheat	168	4.90a					

* Means within a column at a given depth followed by the same letter are not significantly different as determined at the 5% probability level.** Means within a column at a given depth followed by the same letter are not significantly different as determined at the 10% probability level.

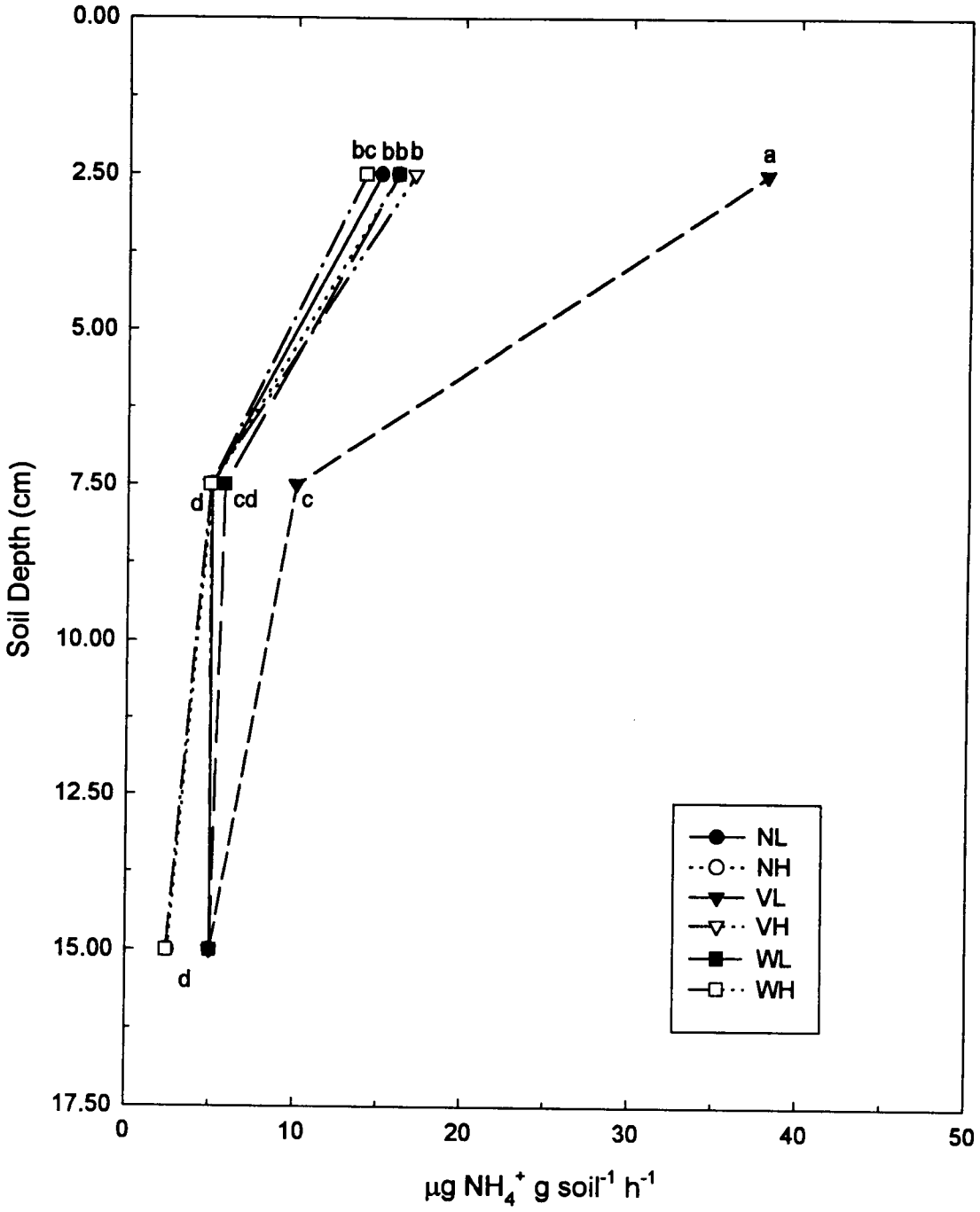


Figure 19. Effect of Cover Crop and Nitrogen Rate on 4/18/94 L-Asparaginase Activity. Means followed by the same letter are not significantly different at the 5% probability level.

WET AGGREGATE STABILITY

Vetch plots yielded significantly greater >2mm water stable aggregates than the previous corn residue plots (Figure 20). Though vetch soils had more mean aggregates of this size class, wheat plots were not significantly different. However, soils with wheat cover had significantly more aggregates larger than 0.5 mm diameter than vetch soils. Wheat plots had greater mean stable aggregates than previous corn residue plots, though not significantly greater. In the 1-2 mm size class, wheat soils had more mean water stable aggregates than vetch or previous corn residue soils. In the 1mm and 0.25 mm size classes, there were no differences observed. Increased organic matter increases soil aggregate stability through its' binding and cementing actions (Tisdale and Oades, 1982). Because organic carbon was plentiful in the vetch plots, microbial activities were significantly greater in vetch soils. The increased activity in vetch plots resulted in a greater quantity of aggregates of the largest size class. Soils under vetch had greater total soil aggregates collected on all seives (63%) than wheat (58%) or previous corn residue (48%). Microbial activities result in production of polysaccharides which act as a "glue-like" substance significantly increasing aggregate stability (Roberson et al., 1991; Hu et al., 1995). As well, aggregate stability increases with increased root length (Perfect et al., 1990). Vetch has a taproot system, penetrating deep into the soil (Zobel, 1991). The wheat root system is fibrous spreading out horizontally as well as vertically (Zobel, 1991). Wheat has greater small aggregates due to the fibrous network of roots. These fibrous roots expand through the soil disrupting larger aggregates, creating smaller aggregates in the process. The benefits of a cover crop are apparent concerning aggregate stability (Roberson et al., 1991). The mean weight diameter was significantly greater under vetch and wheat covers than previous corn residue (Figure 21). Mean weight diameter was greater under vetch than under wheat cover, though there were no significant differences. This was attributed to the taproot system, greater cover crop dry matter, high organic carbon in vetch mulch, and increased microbial activities. Organic carbon and root length is correlated with aggregate stability (Hu et al., 1995; Perfect et al., 1990; Roberson et al., 1991; Tisdale and Oades, 1982).

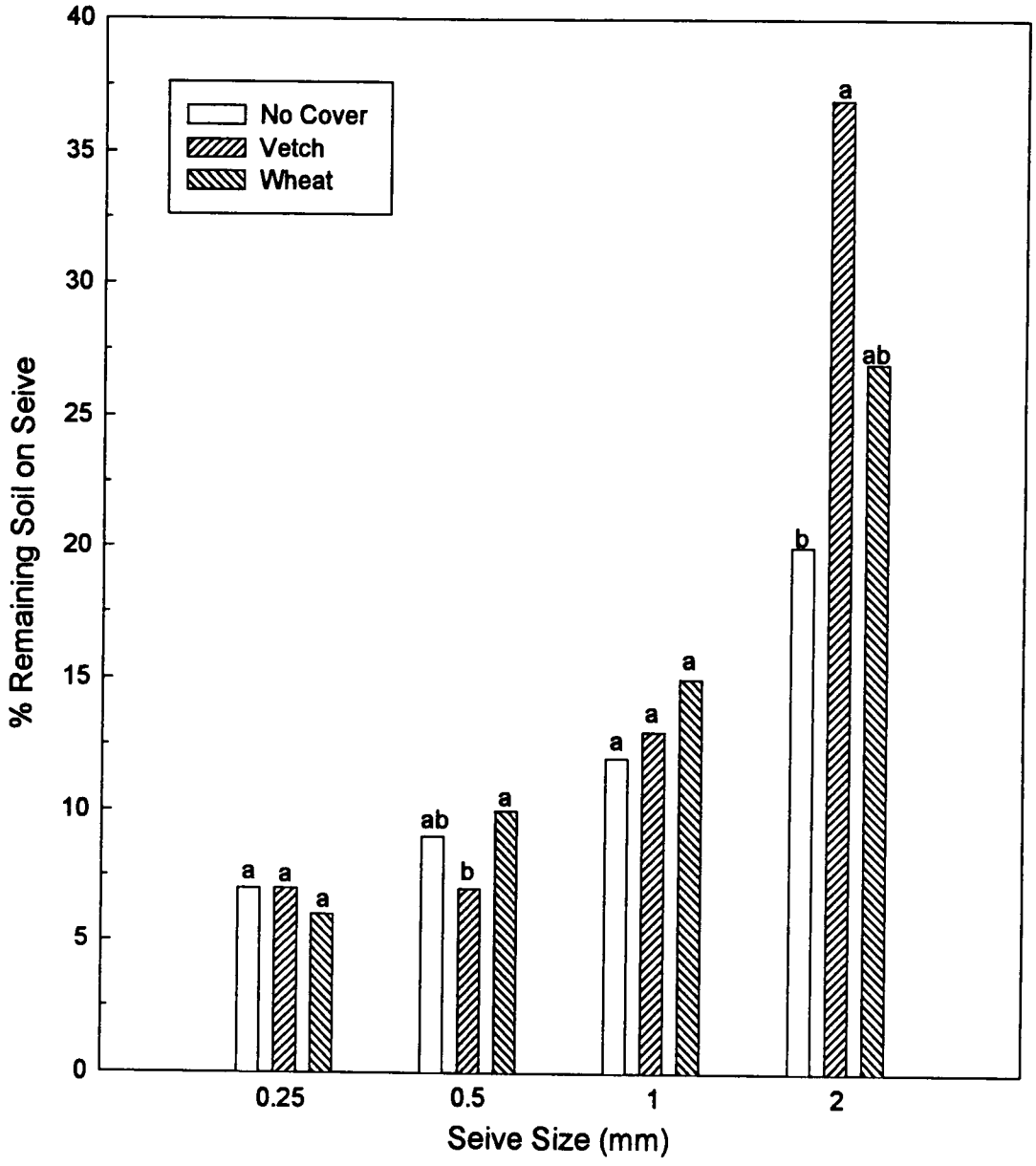


Figure 20. Effect of Cover Crop on % Remaining Soil for Each Seive Size. Means followed by the same letter within each sieve size are not significantly different at the 5% probability level.

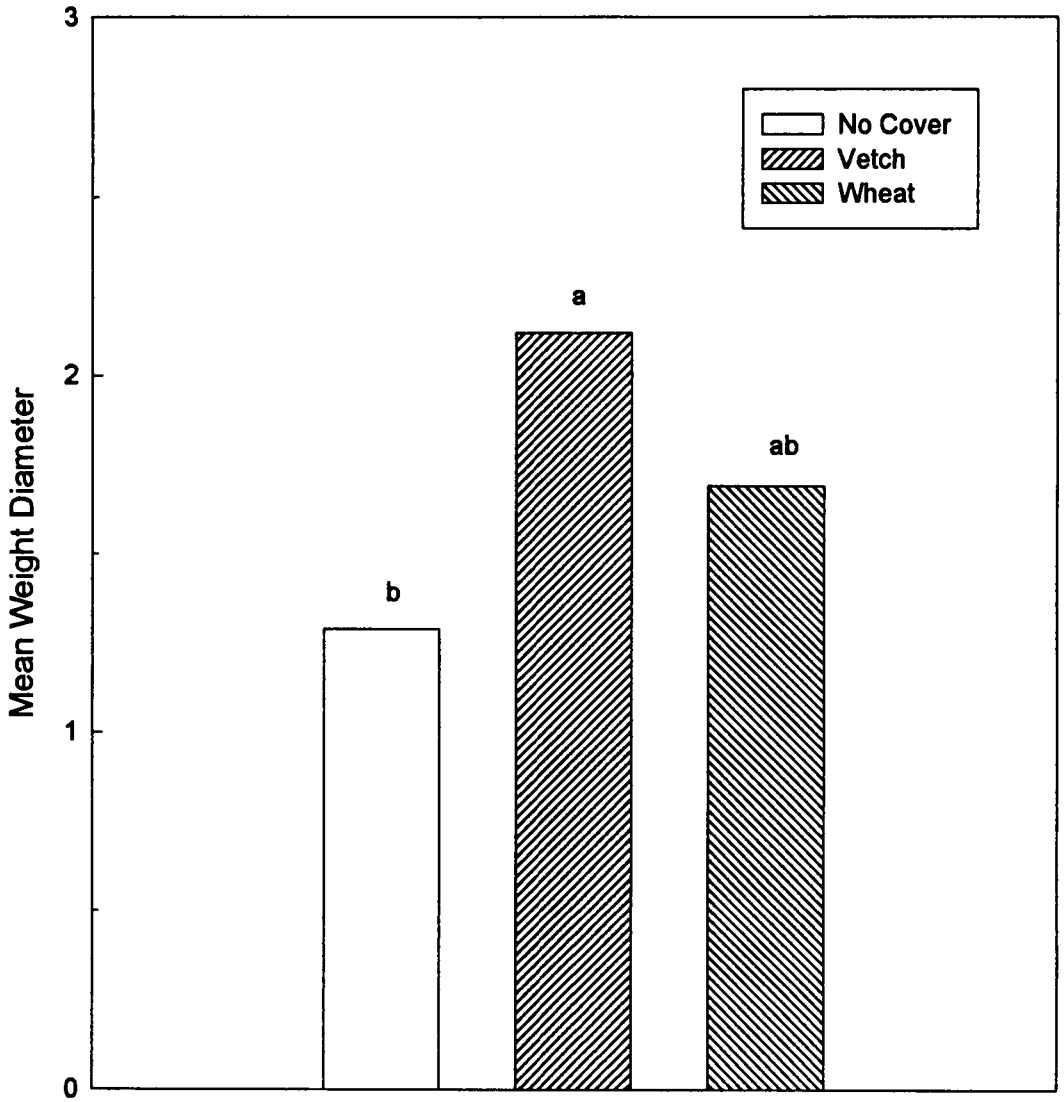


Figure 21. Effect of Cover Crop on Mean Weight Diameter of Soil Aggregates. Means followed by the same letter are not significantly different at the 5% probability level.

Aggregate stability increased with nitrogen fertilizer amendment. Plots receiving nitrogen (62% of original soil) had greater total aggregates on all seives collectively than the plots without nitrogen amendment (51%). Nitrogen fertilizer amendment causes soil acidification, creating a favorable habitat for fungi. Kirchner et al. (1993) found that fungal numbers increased with nitrogen fertilizer increases. Fungi produce polysaccharides which stabilize soil aggregates by their binding nature (Roberson et al., 1991; Hu et al., 1995). The increase in aggregation with nitrogen fertilizer can be attributed to fungal dominance.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Although this project had some complications, it illuminated several significant differences in relation to biological and biochemical changes in the soil. These significant differences were brought about by two factors, which were cover crop type and nitrogen level. Biological and biochemical changes in the soil revolve around the inhabiting microbial life, which was examined, in this study, through several different methodologies. The best methods for monitoring microbial activities were the various enzyme assays. The assays were simple to perform and more accurate in describing changes in the soil than enumerations or microbial biomass. The ease of the assay procedure may be improved through conversion to a microplate assay (Kremer, 1994). The conversion will decrease the amount of reagents, soil, filtrate aliquot, and time required. Of course, the microbial biomass method did not work out or the findings might have turned out differently. Jordan et al. (1995) found that, for long term plots, soil microbial biomass carbon and enzyme assays were chosen to best indicate cropping histories than other methods. Yet notice that in this study, the roots were hand picked from each sample before biomass analysis (Jordan et al., 1995).

Experiments on soils of this project yielded many findings. Soil carbon and nitrogen concentrations were significantly greater under vetch cover due to the carbon and nitrogen concentrations in the vetch mulch. Plots of the 168 N rate held significantly greater carbon and nitrogen due to increased crop mulch and available nitrogen associated with fertilizer. The C:N ratio was greater in wheat and lower in vetch, which was due to vetch's root symbiosis.

Soil pH was significantly lower under vetch cover than wheat or previous corn residue. The pH decrease was associated with mineralization, ammonification, and release of hydrogen ions from nitrification. Due to acidification by nitrogen fertilizer, the 0 N rate plots had a significantly greater soil pH.

Soil nutrient concentrations were effected by cover and nitrogen rate. Soil potassium and phosphorus were more available in previous corn residue soils due to increased corn yields off winter cover plots. Soil potassium and phosphorus were more available in the 0 N rate plots. Like

many other macronutrients, phosphorus availability decrease with decreasing pH.

Vetch mulch contained significantly greater carbon and nitrogen than wheat. The vetch plants' ability to fix nitrogen resulted in greater nutrient content in the mulch. Mulch off plots receiving the 168 N rate contained significantly greater carbon and nitrogen than mulch off 0 N rate plots. Fertilizer amendment increased carbon and nitrogen concentrations available to the mulches.

Nitrogen rate caused a great deal of difference in corn yields over the three years. All covers with the 168 N rate had greater yields due to increased nitrogen availability. However, among the 0 N rate plots, vetch cover resulted in greater corn yields than the other covers. Among the 168 N rate treatments, vetch soils had greater yields also. This was due to greater nitrogen availability in vetch soils and mulch.

Vetch plots with the 0 N rate and wheat plots with the 168 N rate yielded greater mean cover crop dry matter. Vetch mulch receiving the 0 N rate was greater due to vetchs' high carbon and nitrogen content and the pH effect of fertilizer on soil microbes. However, due to wheats' high carbon to nitrogen ratio, the residual nitrogen after corn harvest provided the necessary nitrogen to increase wheat yields.

Greater counts of bacteria, fungi, and *Bacillus spp.* were enumerated from soils of vetch plots. Bacteria numbers were significantly greater in vetch plots with the 0 N rate than any other treatment combination. Vetch cover had greater carbon and nitrogen concentration than wheat. Also, the absence of acidifying fertilizer increased microbial life and activities. Yet, *Aspergillus flavus* and cellulose degrader counts were greater under wheat mulch. Actinomycetes were greater in wheat plots receiving the 0 N rate because they have a competitive advantage over other soil organisms. They are capable of degrading materials with high cellulose content. *Aspergillus flavus* and cellulose degraders are types of fungi which are more adapted to degradation of low carbon to nitrogen materials like wheat. Fluorescent pseudomonads numbers were greater in vetch soils due to increased carbon and nitrogen availability. Bacteria, actinomycetes, and *Bacillus spp.* numbers were greater under plots receiving the 0 N rate due to the acidifying effect fertilizer had in the soil system. Fungi, *Aspergillus flavus*, fluorescent pseudomonads, and cellulose degraders flourish in

plots receiving the 168 N rate. This was due to fungal and pseudomonad resistance to acidity. Pseudomonads reduce nitrate to nitrite, ammonium, or free nitrogen, using hydrogen ions in the process.

Microbial biomass carbon methodology failed primarily due to lab errors. However poor the microbial biomass nitrogen data was, it did show that wheat plots with the high rate of nitrogen and vetch with the 0 N rate had greater biomass nitrogen than other treatment combinations. Wheat and vetch are highly concentrated in nutrients, but wheat has a much higher carbon to nitrogen ratio than vetch. Therefore, added fertilizer on wheat plots enhances degradation of organic matter, while it generates acidity on vetch plots, negatively affecting microbial activities.

Acid phosphatase, alkaline phosphatase, β-glucosidase, arylsulfatase, and L-asparaginase activities were greater under vetch cover due to the high carbon and nitrogen content of vetch mulch. Acid phosphatase and β-glucosidase activities were greater in plots receiving the 168 N rate due to their ability to function maximally in an acidic pH range. However, the other enzymes were more active in plots receiving the 0 N rate due to the acidification of soil by fertilizer decomposition.

The amount of soil aggregates were greater under vetch cover than wheat or previous corn residue due to increased carbon and nitrogen content in vetch mulch, increased microbial numbers under vetch, and resulting in higher total carbon content. Amounts of aggregates >2 mm diameter were greater under vetch, yet aggregates between 0.5 and 2 mm were greater under wheat. The fibrous root system of wheat may contribute to the smaller aggregates in this size class. Lastly, the amount of soil retained by the 0.25 mm sieve was greater under previous corn residue.

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APPENDICES

APPENDIX A

Table 19. Effect of Cover Crop, Nitrogen Rate, and Depth on Soil Calcium Concentrations.

	Calcium Concentrations at Each Sampling Date				
Cover	4/18/94	5/7/94	5/16/94	8/4/94	4/25/95
	μg Ca^{2+} g $soil^{-1}$				
None	1365.62 a*	1290.60 b	1227.03 a	1377.01 a	1109.74 a
Vetch	1397.70 a	1368.50 ab	1331.58 a	1438.49 a	1231.70 a
Wheat	1405.25 a	1640.10 a	1397.53 a	1556.53 a	1275.23 a
Nitrogen Rate					
Low	1457.07 a	1316.10 a	1394.36 a	1514.04 a	1345.85 a
High	1321.98 a	1549.90 a	1243.06 a	1400.64 a	1065.27 b
Depth					
0-5 cm	1818.35 a	1129.20 b	1750.91 a	1763.84 a	1667.66 a
5-10 cm	1179.50 b	1091.70 b	1116.46 b	1309.61 b	1037.87 b
10-20 cm	1170.71 b	2078.30 a	1088.76 b	1298.57 b	911.15 b

* Means within a column followed by the same letter are not significantly different as determined at the 5% probability level.

Table 20. Effect of Cover Crop, Nitrogen Rate, and Depth on Soil Copper Concentrations.

	Copper Concentrations at Each Sampling Date					
Cover	4/18/94	5/7/94	5/16/94	6/13/94	8/4/94	4/25/95
	——————————μg Cu^{2+} $g\ soil^{-1}$——————————					
None	1.45 a*	1.44 a	2.59 a**	1.11 b	1.26 a	1.30 a
Vetch	1.42 a	1.40 a	1.34 b**	1.13 b	1.26 a	1.43 a
Wheat	1.60 a	1.36 a	2.49 ab**	1.31 a	1.37 a	1.50 a
Nitrogen Rate						
Low	1.60 a	1.46 a	2.20 a	1.19 a	1.34 a	1.50 a
High	1.40 b	1.34 b	2.10 a	1.17 a	1.25 a	1.40 a
Depth						
0-5 cm	1.14 b	1.35 b	2.20 a	1.10 b	1.20 a	1.46 a
5-10 cm	1.60 a	1.35 b	2.00 a	1.20 ab	1.40 a	1.47 a
10-20 cm	1.50 a	1.50 a	2.30 a	1.30 a	1.30 a	1.32 a

* Means within a column followed by the same letter are not significantly different at the 5% probability level.** Means within a column followed by the same letter are not significantly different at the 10% probability level.

Table 21. Effect of Cover Crop, Nitrogen Rate, and Depth on Soil Iron Concentrations.

	Iron Concentrations at Each Sampling Date					
Cover	4/18/94	5/7/94	5/16/94	6/13/94	8/4/94	4/25/95
	μg Fe^{2+} g $soil^{-1}$					
None	75.42 a*	74.21 a	59.11 a	66.22 c	68.71 a	48.63 a
Vetch	76.41 a	86.00 a	63.52 a	78.40 b	70.10 a	55.39 a
Wheat	76.33 a	88.01 a	67.44 a	90.33 a	75.02 a	71.21 a
Nitrogen Rate						
Low	73.90 a	76.00 b	59.90 a	77.10 a	69.50 a	57.30 a
High	78.20 a	89.71 a	66.70 a	79.50 a	73.10 a	59.50 a
Depth						
0-5 cm	72.31 a	85.52 a	71.44 a	77.41 a	72.57 a	67.56 a
5-10 cm	77.70 a	78.59 a	53.69 b	76.20 a	69.64 a	59.01 a
10-20 cm	78.10 a	84.33 a	64.88 ab	81.21 a	71.67 a	48.52 a

* Means within a column followed by the same letter are not significantly different at the 5% probability level.

Table 22. Effect of Nitrogen Rate on 4/18/94 5-10 cm Depth, Soil Iron Concentrations.

Nitrogen Rate	μg Fe^{2+} g $soil^{-1}$
Low	64.10 b*
High	80.60 a

* Means within a column followed by the same letter are not significantly different at the 5% probability level.

Table 23. Effect of Cover Crop, Nitrogen Rate and Depth on Magnesium Concentrations.

	Magnesium Concentrations at Each Sampling Date					
Cover	4/18/94	5/7/94	5/16/94	6/13/94	8/4/94	4/25/95
	——————————μg Mg^{2+} $g\ soil^{-1}$——————————					
None	139.33 a*	139.31 ab**	125.54 a	139.81 a	139.78 a	113.10 a
Vetch	154.00 a	154.00 b**	139.56 a	157.89 a	154.22 a	127.21 a
Wheat	167.11 a	166.46 a**	156.78 a	167.03 a	165.43 a	135.72 a
Nitrogen Rate						
Low	133.88 b	131.01 b	157.36a	178.11a	167.71a	147.10 a
High	173.03 a	175.69 a	123.77b	131.73b	138.52b	103.51 b
Depth (cm)						
0-5	160.10 a	143.61 ab**	153.71 a	157.11 a	160.70 a	143.10 a
5-10	133.42 a	159.35 b**	120.69 a	139.88 a	139.22 a	116.21 a
10-20	166.89 a	157.10 a**	147.48 a	167.58 a	159.45 a	116.63 a

* Means within a column followed by the same letter are not significantly different at the 5% probability level.** Means within a column followed by the same letter are not significantly different at the 10% probability level.

Table 24. Effect of Cover Crop, Nitrogen Rate, and Depth on Manganese Concentrations.

	Manganese Concentrations at Each Sampling Date			
Cover	4/18/94	5/7/94	6/13/94	4/25/95
	——————————μg Mn^{2+} g $soil^{-1}$——————————			
None	181.01 a*	94.31 c	149.88 a	115.62 a
Vetch	173.46 a	132.06 b	158.67 a	121.81 a
Wheat	174.22 a	168.85 a	159.71 a	136.78 a
Nitrogen Rate				
Low	160.88 b	138.71 a	140.12 b	120.38 a
High	191.48 a	160.62 a	164.32 a	129.02 a
Depth				
0-5 cm	228.59 a	196.31 a	189.03 a	164.14 a
5-10 cm	164.03 b	138.44 b	146.33 b	121.11 b
10-20 cm	136.11 c	114.10 b	121.41 b	89.01 b

* Means within a column followed by the same letter are not significantly different at the 5% probability level.

Table 25. Effect of Cover Crop, Nitrogen Rate, and Depth on Sodium Concentrations.

	Sodium Concentrations at Each Sampling Date					
Cover	4/18/94	5/7/94	5/16/94	6/13/94	8/4/94	4/25/95
	μg Na^+ g $soil^{-1}$					
None	15.03 a*	13.25 ab	16.11 b**	15.13 a	14.89 a	17.68 a
Vetch	14.04 a	12.37 b	16.68 b**	15.47 a	18.38 a	18.46 a
Wheat	15.28 a	14.10 a	18.31 a**	15.88 a	16.21 a	18.02 a
Nitrogen Rate						
Low	15.03 a	15.62 a	17.10 a	16.33 a	17.29 a	18.78 a
High	14.46 a	14.59 a	17.01 a	14.68 b	15.68 a	17.42 b
Depth						
0-5 cm.	14.29 a	12.99 b	14.38 a	15.29 a	15.93 a	15.33 a
5-10 cm.	14.68 a	12.26 b	14.75 a	15.18 a	16.02 a	15.68 a
10-20 cm.	15.21 a	14.47 a	15.31 a	16.02 a	17.54 a	15.98 a

* Means within a column followed by the same letter are not significantly different at the 5% probability level.** Means within a column followed by the same letter are not significantly different at the 10% probability level.

Table 26. Effect of Cover Crop on 8/4/94 5-10 cm Depth, Soil Sodium Concentrations.

Cover	μg Na^+ g $soil^{-1}$
None	14.02 b*
Vetch	17.53 a
Wheat	16.57 a

* Means within a column followed by the same letter are not significantly different at the 5% probability level.

Table 27. Effect of Nitrogen Rate on 4/18/94 10-20 cm Depth, Soil Sodium Concentrations.

Nitrogen Rate	μg Na^+ g $soil^{-1}$
Low	16.52 a*
High	13.88 b

* Means within a column followed by the same letter are not significantly different at the 5% probability level.

Table 28. Effect of Cover Crop, Nitrogen Rate, and Depth on Zinc Concentrations.

	Zinc Concentrations at Each Sampling Date					
Cover	4/18/94	5/7/94	5/16/94	6/13/94	8/4/94	4/25/95
	μg Zn^{2+} g $soil^{-1}$					
None	3.56 a*	4.10 a	2.63 a	3.43 a	3.11 a	3.22 b
Vetch	2.01 b	5.32 a	5.44 a	5.10 a	3.10 a	4.88 a
Wheat	2.21 b	5.11 a	2.91 a	3.41 a	2.82 a	3.51 b
Nitrogen Rate						
Low	3.11 a	5.63 a	4.46 a	4.47 a	3.10 a	4.10 a
High	2.10 a	4.06 b	2.88 a	3.41 a	2.90 a	3.72 a
Depth						
0-5 cm	3.00 a	4.68 a	5.56 a	4.22 a	3.89 a	5.52 a
5-10 cm	1.91 a	3.12 a	3.10 ab	4.54 a	2.54 b	3.10 b
10-20 cm	2.92 a	3.06 a	2.30 b	3.32 a	2.53 b	3.02 b

* Means within a column followed by the same letter are not significantly different at the 5% probability level.

APPENDIX B

General Linear Models Procedure

Dependent Variable: BU_AC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	22164.712	2014.974	5.49	.00330
Error	12	4403.908	366.992		
Corrected Total	23	26568.620			

R-Square	C.V.	Root MSE	BU_AC Mean
0.834244	32.01422	19.157	59.839

Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	633.826	211.275	0.58	.64188
NRATE	1	18334.165	18334.165	49.96	1.E-05
BLOCK*NRATE	3	720.132	240.044	0.65	.59562
COVER	2	559.851	279.925	0.76	.48771
NRATE*COVER	2	1916.738	958.369	2.61	.11441

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	633.826	211.275	0.58	.64188
NRATE	1	18334.165	18334.165	49.96	1.E-05
BLOCK*NRATE	3	720.132	240.044	0.65	.59562
COVER	2	559.851	279.925	0.76	.48771
NRATE*COVER	2	1916.738	958.369	2.61	.11441

TOTAL BIOMASS CARBON DATA FOR 4/18/94

TRT	DEPTH	[C] in ug/ml [F1]	[F2]	[DE]
NL	1	77.45	66.85	39.70
NL	2	54.35	61.40	35.00
NL	3	52.20		56.75
NH	1	38.65	73.35	54.85
NH	2		32.30	43.70
NH	3	57.45		43.80
VL	1	112.85	120.15	35.45
VL	2	71.65	101.45	86.60
VL	3	91.40	73.20	82.15
VH	1	107.15	53.90	56.30
VH	2	93.90	79.75	46.00
VH	3	60.90	60.05	47.30
WL	1	78.75	70.65	14.40
WL	2	65.20	68.95	42.00
WL	3	57.20	54.75	25.70
WH	1	93.55	78.80	68.35
WH	2	66.35	50.55	58.30
WH	3	78.80	44.10	80.30
NL	1	54.25	66.30	31.55
NL	2	37.95	62.80	
NL	3	69.85	57.20	24.55
NH	1	57.50	36.00	38.90
NH	2	43.60	47.05	
NH	3	58.75	38.30	77.00
VL	1	93.75	63.75	76.05
VL	2	50.25	44.15	27.35
VL	3	80.15	60.80	39.25
VH	1	102.25	60.00	46.95
VH	2	89.00	43.75	80.55
VH	3	66.20	60.00	32.90
WL	1	67.35	38.40	38.65
WL	2		43.10	37.30
WL	3	43.45	70.30	39.40
WH	1	89.55	72.85	66.85
WH	2	56.00	40.00	37.75
WH	3	42.30	73.60	43.35
NL	1	64.95	71.65	112.20
NL	2	59.55	53.70	31.75
NL	3	43.40	75.60	41.40
NH	1	60.85	59.30	65.05
NH	2	70.00	44.75	36.35
NH	3	49.00	83.80	44.85
VL	1	99.80	75.90	65.25
VL	2	78.95	98.65	48.60
VL	3	63.10	54.45	
VH	1	49.30	54.45	58.50
VH	2	47.85	73.10	44.30
VH	3	47.25	53.95	38.35
WL	1	81.90	58.40	115.55
WL	2	75.10	45.35	39.75
WL	3	49.95	53.75	37.40

TRT	DEPTH	[C] in ug/ml [F1]	[F2]	[DE]
WH	1	71.55	75.10	23.35
WH	2	70.80	54.05	39.90
WH	3	64.00	60.95	
NL	1	63.55	3.93	48.15
NL	2	60.40	46.35	
NL	3	50.45		44.95
NH	1	81.00	47.90	50.45
NH	2	50.55	78.55	36.20
NH	3	53.20	68.40	38.10
VL	1	100.00	94.25	40.00
VL	2	67.35		40.80
VL	3	54.20	61.05	37.35
VH	1	75.65	82.50	59.50
VH	2	51.50	96.75	38.75
VH	3	56.55	56.00	37.90
WL	1	84.35	75.50	37.60
WL	2	61.55	72.50	43.20
WL	3	57.25	93.45	36.95
WH	1	81.30	84.10	35.75
WH	2	62.05	63.10	58.70
WH	3	56.15	54.15	44.10

LEGEND

NL is no cover, low nitrogen
NH is no cover, high nitrogen
VL is vetch cover, low nitrogen
VH is vetch cover, high nitrogen
WL is wheat cover, low nitrogen
WH is wheat cover, high nitrogen
[F1] is the first fumigated replicate
[F2] is the second fumigated replicate
[DE] is the direct extracted sample

TOTAL BIOMASS CARBON DATA FOR 5/7/94

TRT	DEPTH	[C] in ug/ml [F1]	[F2]	[DE]
NL	1			
NL	2			
NL	3			
NH	1			
NH	2			
NH	3			
VL	1			
VL	2			
VL	3			
VH	1			
VH	2			
VH	3			
WL	1			
WL	2			
WL	3			
WH	1			
WH	2			
WH	3			
NL	1	12.74	16.39	6.74
NL	2	9.85	11.68	7.53
NL	3	13.13	16.15	6.83
NH	1	9.84	11.55	4.92
NH	2	8.89	0.09	4.17
NH	3	14.31	7.43	3.64
VL	1	13.95	11.26	6.16
VL	2	13.97	13.68	6.43
VL	3	21.90	11.24	4.92
VH	1	0.91	17.53	6.96
VH	2	13.71	18.99	6.90
VH	3	11.08	12.69	5.54
WL	1	9.19	11.24	12.81
WL	2	10.27	10.79	5.48
WL	3	10.14	20.11	6.07
WH	1	11.15	13.99	6.30
WH	2	7.84	14.18	9.76
WH	3	13.33	10.37	4.75
NL	1	49.44	41.88	15.66
NL	2	57.18	40.13	17.38
NL	3	3.57	55.41	20.33
NH	1	2.76	91.61	1.16
NH	2	3.14	2.51	29.41
NH	3	3.27	1.77	1.09
VL	1	3.02	2.85	1.31
VL	2	53.08	49.88	1.81
VL	3	1.92	1.81	19.71
VH	1	4.73	89.18	1.43
VH	2	71.25	2.08	1.29
VH	3	2.00	2.31	0.96
WL	1	4.74	54.44	19.81
WL	2	74.46	73.86	27.90
WL	3		2.15	1.24

TRT	DEPTH	[C] in ug/ml [F1]	[F2]	[DE]
WH	1	2.30	67.14	31.32
WH	2	26.52	65.25	26.86
WH	3	1.60	1.89	1.14
NL	1	7.96	6.52	1.59
NL	2	9.42	8.72	28.27
NL	3	8.16	8.60	2.10
NH	1	10.01	11.66	38.65
NH	2	12.60	65.98	2.33
NH	3	10.33	5.38	26.88
VL	1	13.70	10.44	32.01
VL	2	10.78	901.00	32.63
VL	3	7.75	2.56	27.54
VH	1	9.24	9.29	2.32
VH	2	9.54	66.94	2.08
VH	3	9.76	2.80	2.15
WL	1	10.89	8.96	1.65
WL	2	10.56	11.11	30.95
WL	3	9.37	9.24	1.74
WH	1	8.41	4.07	31.18
WH	2	13.66	70.46	31.65
WH	3	10.12	54.63	1.74

LEGEND

NL is no cover, low nitrogen
NH is no cover, high nitrogen
VL is vetch cover, low nitrogen
VH is vetch cover, high nitrogen
WL is wheat cover, low nitrogen
WH is wheat cover, high nitrogen
[F1] is the first fumigated replicate
[F2] is the second fumigated replicate
[DE] is the direct extracted sample

TOTAL BIOMASS CARBON DATA FOR 5/16/94

TRT	DEPTH	[C] in ug/ml [F1]	[F2]	[DE]
NL	1	42.97	43.73	1.36
NL	2	26.71	29.47	0.89
NL	3	1.71	31.29	12.98
NH	1	41.64	1.85	20.11
NH	2	2.21	44.00	19.11
NH	3	2.33	1.87	22.39
VL	1	53.27	2.25	21.43
VL	2	32.72	37.09	0.80
VL	3	35.45	34.51	22.56
VH	1	14.86	71.90	1.33
VH	2	1.81	49.05	1.36
VH	3	47.73	45.90	1.19
WL	1	1.60	44.61	0.73
WL	2	30.39	1.60	11.29
WL	3	2.11	36.65	11.92
WH	1	52.33	54.20	18.13
WH	2	41.87	1.95	20.98
WH	3	3.35	37.35	19.58
NL	1	39.26	1.54	20.53
NL	2	51.22	40.61	27.39
NL	3	41.38	40.77	22.26
NH	1	35.04	31.48	17.20
NH	2	1.13	1.43	13.83
NH	3	24.62	20.35	3.08
VL	1	55.50		21.88
VL	2		56.61	26.94
VL	3	42.60	40.66	13.84
VH	1	59.62		25.87
VH	2	46.33	35.22	23.31
VH	3	41.20	37.88	1.32
WL	1	1.16	57.50	16.63
WL	2	32.69	33.07	20.44
WL	3	36.36	33.17	18.71
WH	1	1.52	1.74	1.13
WH	2	32.69	30.12	1.20
WH	3	30.47	41.79	16.31
NL	1	30.93	31.59	15.21
NL	2	2.08	1.75	14.71
NL	3	41.88	44.23	17.05
NH	1	60.04	47.09	25.02
NH	2	2.42	47.41	25.14
NH	3	1.84	33.89	20.47
VL	1	52.32	60.33	17.86
VL	2	51.39	42.53	19.04
VL	3	1.79	39.18	16.81
VH	1	59.20	54.99	29.18
VH	2	54.69	44.31	28.04
VH	3	37.52	1.70	22.17
WL	1	2.32	2.36	18.80
WL	2	45.35	41.75	22.96
WL	3	48.61	2.36	20.43

TRT	DEPTH	[C] in ug/ml [F1]	[F2]	[DE]
WH	1	16.37	2.46	22.70
WH	2	1.49	37.56	22.15
WH	3	36.32	1.46	17.42
NL	1	1.45	24.48	18.41
NL	2	20.34	22.05	18.59
NL	3	20.54	1.11	18.83
NH	1	37.78	38.48	22.96
NH	2	1.16	34.55	23.38
NH	3	44.44	25.78	20.10
VL	1	1.75	37.97	19.90
VL	2	1.14	1.50	25.13
VL	3	25.85	1.76	20.58
VH	1	41.16	39.35	21.81
VH	2	24.99	24.51	21.09
VH	3	1.21	23.39	19.94
WL	1	31.56	26.72	18.45
WL	2	25.88	1.47	20.95
WL	3	1.31	1.24	19.11
WH	1	1.98	1.54	19.25
WH	2	25.02	24.05	20.02
WH	3	23.60	26.99	17.38

LEGEND

NL is no cover, low nitrogen
NH is no cover, high nitrogen
VL is vetch cover, low nitrogen
VH is vetch cover, high nitrogen
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[F1] is the first fumigated replicate
[F2] is the second fumigated replicate
[DE] is the direct extracted sample

VITA

Colleen Georgette Melhorn is a native of Oliver Springs, TN. She was born June 13, 1971. After graduating from high school Colleen entered classes at Tennessee Technological University, where she studied soil science.

During her four years at Tennessee Technological University, she interned for three summers with the Soil Conservation Service. In her senior year of college, she enrolled in a clinical microbiology course, which focussed her career interests. She received her Bachelor's degree in agronomy from Tennessee Technological University in May of 1993. With the encouragement of family and friends, Colleen entered the University of Tennessee, Knoxville as a graduate student in soil microbiology. She graduated with her Master's in soil microbiology from the University of Tennessee, Knoxville in August of 1996.