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Estimates of nitrogen (N) available from long-term application of organic amendments are required to balance N inputs with crop N requirements. Two studies were conducted to (1) determine N mineralized from organic amendments (manures and composts) during year 2 after application, and (2) compare plant-available N (PAN) determined via *in situ* microplot incubations with PAN determined via laboratory incubations under aerobic and anaerobic conditions.

In the first study, soil samples were collected from field plots with and without a history of screened dairy solids application at Oregon State University Vegetable Research Farm near Corvallis, OR. Amounts of N mineralized were estimated using a microplot technique. Microplots, open-ended cyclinders 5 cm i.d. x 15 cm long, were equipped with pillows that contained ion exchange resins at the base. The resins trapped nitrate ions leached from soil in the cylinders. Field microplot estimates of PAN were compared with estimations of PAN from aerobic and anaerobic laboratory incubations. Screened dairy solids immobilized PAN for approximately 700 degree days (0°C base temperature) after application, and then mineralized N after 700 degree days. In soil that had received screened dairy solids application for 2 to 3 previous years, the increase in net mineralization rate was approximately 0.01 mg N kg^{-1} dry soil degree day^{-1}. Field microplot and aerobic laboratory estimates of PAN were well correlated. Our study showed that a small

fraction of amendment total N was mineralized during years 2, 3 and 4 following amendment application. For example, dairy solids applied from 2001-2002 contained 1,728 kg N ha^{-1}. Only approximately 56 kg N ha^{-1}, or 3.2% of total cumulative manure-N applied was mineralized in 2003.

Other field studies were conducted at the North Willamette Research Extension Center near Aurora, OR and at the Washington State University Puyallup Research Center near Puyallup, WA. At these field sites a variety of organic amendment treatments were applied in 2003. In 2004, our study measured sweet corn crop response parameters including: N recovery from crop N uptake + post-harvest soil NO_3-N, ear yield, and leaf SPAD meter readings. In the laboratory, soil samples from the field sites were incubated under aerobic and anaerobic conditions to estimate PAN. Year 2 (2004) PAN averaged across all organic amendment treatments and both field locations was 6% of total N applied in year 1 (2003). PAN mineralized in the laboratory aerobic incubation was similar to PAN measured in field microplots and PAN determined by a fertilizer equivalence method at the field sites. This study found similar year 2 PAN for a variety of manure and compost treatments.

Nitrogen Mineralization from Organic Amendments During the Second Year Following Application

by
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NITROGEN MINERALIZATION FROM ORGANIC AMENDMENTS DURING THE SECOND YEAR FOLLOWING APPLICATION

GENERAL INTRODUCTION

Organic amendments manures and composts are widely used as nitrogen (N) sources for crop production. However, the quantity and timing of N supplied by these amendments is difficult to predict. The plant-available nitrogen (PAN) depends on N content of animal feed, manure handling and storage method, method and time of field application, and soil chemical, physical and biological properties. Long term mineralization of N from organic amendments is related to the stability of organic N compounds in the amendment; and the stability of decomposition products formed by biological activity in soil.

Our experiments were conducted to estimate PAN released from long-term application of organic amendments. The estimate of N availability from organic amendments in the following year of application is needed to obtain optimum yield and reduce accumulation of NO_3-N that can be a negative environmental consequence. Nitrogen mineralization, the conversion of organic N to mineral N, is an important biological process that controls available N in agricultural ecosystems. Several methods have been proposed to measure soil N mineralization including chemical and biological techniques in the laboratory and various field methods.

Estimates of N available from screened dairy solids during the first year following application in Western Oregon range from 0-20% of total N applied. There are no published local data for N mineralization in the second year after application. The field microplot method was used at the Oregon State University Vegetable Research Farm to estimate long-term effect of screened dairy solids on soil N mineralization (Chapter 2). For this method, a resin bag containing anion exchange was placed at the bottom of a cylinder to capture nitrate leached from soil by gravitational water. Laboratory incubations were also conducted under aerobic and anaerobic conditions to estimate N mineralization.

A field fertilizer N equivalence (FNE) method, field microplot and aerobic and anaerobic laboratory incubations were used to measure N availability at North Willamette Research Extension Center (NWREC), OR and Washington State University Puyallup Research Center (Puyallup), WA (Chapter 3). In the FNE method, crop response parameters were used to estimate plant-available nitrogen (PAN) in the second year after amendment application using the inverse prediction method.

The major objectives of this study were to (1) estimate PAN from a variety of organic amendments (manures and composts) in the second-year after application, (2) compare estimates of N mineralization using an *in situ* microplot incubation method and aerobic and anaerobic laboratory incubation methods.

LITERATURE REVIEW

INTRODUCTION

Of all mineral nutrients, nitrogen (N) is often deficient in agricultural cropping systems. Therefore, it is important to maintain the soil N level for optimum plant growth. Understanding the N supply of soil is essential for the efficient use of N, maximum economical crop production, and reduced N pollution. To determine a fertilizer recommendation, it is important to understand the processes and reactions that occur in the soil. Available N in soils is dependent on soil characteristics such as texture, structure, organic matter, and environmental factors such as soil temperature and moisture. Management practices such as winter cover crops and manure or compost application must be considered. In addition to NO_3-N mineralized from soils, NO_3-N also can be mineralized from crop residues or soil organic matter which is affected by application rate, method of application, timing and organic amendments or residue characteristics. Most soils contain 0.08 to 0.4% of N and 97 to 99% of organic N in soil organic matter (Dahnke and Johnson, 1990). Methods for determining the inorganic N fraction are already available (Keeney, 1982; Stanford, 1982). However, the amount of mineralized organic N is difficult to estimate, especially in soil receiving several annual organic amendment applications. Chemical and physical properties of soil organic matter (SOM) from past application make it stable and resistant to decompose.

The objectives of this literature review are to understand N dynamics in soils and also to include a variety of indices to estimate N mineralization. These indices include laboratory and field methods and computer simulation models. This review also provides evaluation, advantage, and limitation of these indices.

SOURCE OF NITROGEN IN ORGANIC-AMENED SOILS

Nitrogen, known as an essential plant macronutrient, is part of many important plant compounds. Soils receive N from added fertilizer, precipitated from atmosphere, decomposed from plant and animal residues or via biological fixation. As the same time, N can be lost by leaching or surface run-off, N cycle losses including nitrification and dinitrification processes, ammonia volatilization and also removed by harvested crops and immobilized or accumulated in soils. Mineralization process refers to the conversion of organic N to inorganic N, while the immobilization process is the uptake of inorganic N by microorganism activities. However, these processes are connected and dependent upon each other. To maximize N efficiency and reduce N losses, mineralization is the key process of N dynamics in soils (Jarvis et al., 1996).

In less favorable conditions for plant growth, NH_4-N is accumulated in soils. Conversely, NH_4-N is relatively low in well-drained soils because NH_4-N converts to NO_3-N very rapidly (Dahnke and Johnson, 1990). Soil environmental factors strongly affect the mineralization process which is initiated by microbial activity. Optimum soil moisture ranges between 50 and 70% water-holding capacity and soil temperature between 25 and 35°C (Havlin et al., 1999)

Nitrogen exists in many forms according to situation and soil environmental factors. Zaman et al. (1998) suggested that mineralized N from organic N sources applied to soil could be separated into five groups: 1) nitrate; 2) exchangeable ammonium ions and other readily mineralized N materials; 3) potential mineralizable N from organic N materials; 4) soil microbial biomass which controls decomposition rate, releases N from active and passive pools into labile forms; and 5) recalcitrant organic N materials. The exchangeable N pool is the main source of the rapidly mineralized NO_3-N during the first 4-6 weeks after incorporation into soils, and also loss as NH_3 by volatilization. Both pools 3 and 4 function as the source of mineralized N during the growing season.

Soil organic matter can be separated into active pools and passive pools. Readily mineralizable or active pools including fresh materials such as crop residue and manure application recently added into soils will be rapidly decomposed. On the other hand, passive pools contain exchangeable nutrients tightly locked into complex organic matters and finally became stable pools (Seiter and Horwath, 2004). This pool is relative larger than the active pools. However, the active fraction is released during the first week after application, while the stable fraction is mineralized in the later weeks (Bundy and Meisinger, 1994). Van Kessel et al. (2000) observed the rate of NH_4-N accumulation was most rapid at 2-7 days of aerobic incubation at 25°C indicating mineralization from readily mineralizable organic N components of dairy manure. Then NH_4-N was depleted after 14-28 days resulting from the N nitrification process.

Organic amendments, substrates for active pools of N, have been used to recycle waste, as soil amendments and to provide valuable nutrients, especially N, for plants. However, the various natures of organic sources such as uncertainty in decomposition rates, amount and available form of N make them difficult to manage or uniformly apply (Sims, 1995). Moisture and aeration are important factors that control N availability from organic manures. The decomposition rate of soil organic matter is most rapid at soil temperatures approximately 30 to 45°C (Wagner and Wolf, 1998), soil moisture 60% of water-holding capacity (Mahi and McGill, 1982), and neutral soil pH. In addition, decomposition also varies with management practices and characteristics of organic matter.

Depending on climate, soil depth, and annual organic amendment application, soil N content can range from 0.5% to more than 6% (Hassink, 1997). However, only 1 to 4% of NO_3-N in organic matter will be mineralized to inorganic forms and available to the plant during the growing season (Campbell et al., 1993; Havlin, et al., 1999). On the other hand, varying with organic amendment type, 30-60% of total N in the application rate is readily mineralized in the first-year application for organic

materials with C/N ratio less than 20. Then mineralization continues slowly in the next several years (Havlin, et al., 1999). Sommerfeldt et al. (1988) found that accumulated SOM is highest in the first 10 years after application and then progresses more slowly in the later year. In addition, the application method also affects plant-available N. If fresh manure is surface-applied, N can be readily lost via NH_3 volatilization (Thompson et al., 1987). Incorporated manures can increase the denitrification process (Comfort et al., 1988). In addition to environmental conditions and agricultural practices, characteristics of organic amendments also influence N mineralization. Van Kessel et al. (2000) concluded that N mineralization strongly occurred in composition of manure with more than 50 g kg^{-1} total N. Nitrogen immobilization was initiated in composition of manure with less than 24 g kg^{-1}.

MEASUREMENT AND PREDICTION OF NITROGEN MINERALIZATION

Nitrogen management in agricultural systems is usually based on yield and mineral N in soil. Rice and Havlin (1994) recommended the simple equation used to calculate N requirement:

$$N\ recommendation = a(yield\ goal) - b(soil\ test\ N) - c(N_{min}) \quad [1]$$

where yield goal is the expected yield by adding 5-10% of the average yield during the last 5-10 year, soil test N is the extractable inorganic N at sampling time such as PSNT and residual profile nitrate test, and N_{min} is the residue of NO_3- N in the soil or the potential mineralizable N. This potential mineralizable N is the result of previous crops, manure application, soil organic matter and other organic N sources varying with soil properties and weather (Pierzynski et al., 2000). In addition, crop N uptake efficiency or the ability of plants to use plant-available N should be considered before making a recommendation (Sullivan et al., 1997).

Efficient N use depends on the timely monitoring of soil N supply characteristics. However, estimated plant-available N is complicated by the complex and dynamic nature of the N cycle. Amounts of NO_3-N change from time to time, dependent on mineralization or immobilization of soil organic N. These processes are initiated by microbial activities and vary according to climate. In addition to mineralization/immobilization processes, NO_3-N can be lost from the available N pool by denitrification (Paul and Zebarth, 1997; Calderon et al., 2004), ammonia volatilization (Bussink and Oenema, 1998), and leaching processes (Mamo et al., 1999).

Many approaches attempt to provide indices of potentially available N or to predict N mineralization. Nitrogen mineralization indices can be divided into laboratory and field methods.

Laboratory Methods

Laboratory approaches are separated into chemical and biological methods. These methods are used to estimate the mineralized N pool or N released from labile soil organic matter which eventually becomes plant-available N during the growing season (Jarvis et al., 1996).

Chemical methods

Chemical methods are relatively rapid and inexpensive. However, many factors could affect the N mineralization rate. The disadvantage is that these methods are unlikely to imitate soil environment and microbial dynamics. These factors depend on each other and also interact with other factors such as soil management and soil properties.

Several chemical extraction methods are used for estimating potentially mineralizable N varying from strong acids or bases to neutral salts. These approaches also differ in concentration, time and temperature of extractants such as extraction with 0.025 M H_2SO_4 and 0.1 M $KMnO_4$ (Stanford and Smith, 1978), alkaline $KMnO_4$ (Stanford, 1978), heated 2 M KCl at 100°C for 4 hours (Gianello and Bremner, 1986; Campbell et al., 1997), 6 M HCl and heated at 95°C for 16 hours (Castellanos and Pratt, 1981), barium hydroxide [$Ba(OH)_2$] (Keeney and Bremner, 1966) and the Walkely-Black digest containing 0.5 M K_2CrO_7 with concentrated H_2SO_4 and concentrated H_3PO_4 and determined by ultraviolet spectrophotometer at 345, 465 and 665 nm (Douglas and Magdoff, 1991).

Nitrogen extracted from the soil could represent the plant-available N during the growing season or leaching during the winter if soil is extracted during the spring season (Jarvis et al., 1996). A soil N test is an instant measurement at the time of sampling (Zhang et al., 2002). To make the method more reliable, many studies have evaluated chemical indices with other biological and *in situ* indices. Douglas and Magdoff (1991) evaluated a variety of chemical indices to predict N availability. They found that the global Walkley-Black digestion method containing 0.5 M K_2CrO_7

concentrated H_2SO_4 and concentrated H_3PO_4 was the best index to predict N availability. The amount of NH_4-N released from the global Walkley-Black digestion significantly correlated with cumulative N mineralized during 67-d incubation at 25°C (r^2=0.88). Picone et al. (2002) found the $Ca(ClO_2)$ method was highly correlated with net N mineralized in a 24-d incubation at 25°C and 50% water-filled pore space (r^2 =0.77) and hot 2 M KCl (r^2=0.86), respectively. In addition, Smith et al. (2001) concluded that both the alkaline $KMnO_4$ and the 6 M HCl autoclaved at 95°C for 16 h methods were strongly correlated with the amount of N uptake by ryegrass after 168 d growth.

Biological methods

Biological methods refer to a known mass or volume of soil which is incubated under controlled optimal moisture, aeration and temperature conditions over a specific period of time. These conditions can promote N mineralization from organic sources. Biological methods may be short term (anaerobic incubation) or long term (aerobic incubation). The incubation time varies with the experimental objectives. However, Stanford et al. (1974) indicated that 8-10 weeks could be adequate time for estimating potentially mineralizable N.

Because microbial activities are used, biological approaches are more reliable than any other method (Dahnke and Johnson, 1990). The advantages of biological methods include no concern of water loss during incubation, simplicity and minimal reagent and apparatus requirements. However, the soil disturbance such as mixing, sieving, drying, or rewetting could influence mineralization potential. Cabrera and Kissel (1988) found that soil preperations caused the aerobic incubation method to over-predict approximately 67 to 343% when compared with N mineralized in the field.

Several studies propose aerobic incubation procedures varying with objectives. For example, Stanford and Smith (1972) proposed a method for predicting N mineralized from soil organic matter under laboratory aerobic conditions. Soils were

long-term incubated over 30 wk at 35°C. To evaluate the N fertilizer values of composts, Shi et al. (1999) conducted an 84-d laboratory incubation. Soils were mixed with composts and incubated at 20±2°C. The long-term incubation can be used to evaluate the effect of historical management practices, characterize components of the labile N pool and assess the potential long-term N-supplying capacities of soils (Stanford, 1982; Bundy and Meisinger, 1994).

Keeney (1982) proposed a short-term anaerobic incubation at 40°C for 7 days under waterlogged conditions to determine the N mineralization capacity of soil. Mineralizable N is measured by the accumulation of NH_4-N between initial and final incubation. Several studies have correlated anaerobic incubation to be a reliable *in situ* method. Christensen et al. (1999) found a strong relationship between an anaerobic incubation technique and crop N uptake for winter wheat in the Willamette Valley, OR under a moist xeric environment (r^2=0.78). However, Motavalli et al. (1989) found poor correlation between N released from anaerobic incubation and crop N uptake based on a fertilizer N equivalence method. In addition, Boone (1992) found no relationship between anaerobic incubation and a buried-bag *in situ* method. He concluded that anaerobic incubation probably was used to measure N in microbial biomass. In contrast with anaerobic incubation, chemical and *in situ* methods were used to measure plant-available N.

Other methods

In addition to measurements of mineralizable N, there are a variety of approaches to determine microbial biomass in soils. Soil microbial biomass regulates the transformation and storage of nutrients containing up to 5% of total soil N in the organic fraction (Smith and Paul, 1990). The fumigation method with chloroform has been used to estimate the amount of soil microbial biomass (Brookes et al., 1985; Collins et al., 1997; Sylvia et al., 1998). Carbon dioxide released from fumigated soil results from the decomposition of microbial components. Extractable NH_4^+ occurs as a

result of the mineralization of nitrogenous substrates from the lysed microorganisms (Horwath and Paul, 1994).

Several methods are proposed to estimate N components in soil such as the electro-ultra filtration method used to separate anions (NO_3^-), cations (NH_4^+) and soluble organic N in soil suspensions (Nemeth, 1982). Soil was extracted with $CaCl_2$ at 80°C for 2 hours and N_{org} was calculated by the difference between N_{total} and NO_3^- + NH_4^+ (Houba et al., 1986; Lin et al., 1997). In addition, Mulvaney et al. (2001) estimated hydrolyzable N and determined total hydrolyzable N, NH_4-N, (NH_4 + amino sugar)-N and amino acid. This method was done by heating soil and 6 M HCl at 110-120°C under reflux for 12 hours. These methods can measure all forms of N including NO_3^-, NH_4^+ and readily mineralized organic N (Jarvis et al., 1996). However, Lin et al. (1997) found that the organic N pool could be underestimated because some of the amino acid such as hydroxyl amino and glycine were detected as ammonium.

Field Methods

In situ methods can provide more accurate measurements of net N mineralization and the actual status of the field. Mineralized N evaluated in the field can be used as the standard method for calibration with other methods. Furthermore, accurate prediction of N mineralization under field conditions is required for optimizing N-use efficiency in many crop systems.

In situ methods include soil incubation such as buried bag, covered-cylinder, and ion exchange resins, and soil testing such as residual profile nitrate test, and the Presidedress Nitrate Test (PSNT). These studies measure inorganic N (NO_3^-) or the amount of plant-available N in soil before planting or at a specific time during the growing season. Another *in situ* method, plant analysis, includes chlorophyll content measurement and plant tissue test.

Soil testing

Soil incubation *in situ* methods including buried bag, covered-cylinder and ion exchange resins are widely accepted in many field researches. The buried bag method was originally developed by Eno (1960). He placed soils in polyethylene bags and buried them at a shallow depth in the field for a period of time. The plastic bag was permeable to gases but impermeable liquids (Gordon et al., 1987). Soil water content was adjusted at the beginning of incubation and represented field soil moisture for the entire incubation (Hart et al., 1994). The covered-cylinder method was developed to promote drainage with an open bottom of PVC tube or metal cylinder (Adams et al., 1989). In addition, holes were drilled on the side wall to promote air exchange with the field soils (Dou et al., 1997). The ion resin exchange method was developed to overcome limitations of other *in situ* methods (Hanselman et al., 2004). Soil temperature and aeration fluctuates in field soils. Ion exchange resins have been used to measure plant-available nutrient ions in soil, the dynamics of nutrient supply, cation exchange and slow release of nutrients from N mineralization process (Qian and Schoenau, 2002). In principle, an ion resin bag is placed at the bottom of a PVC or metal cylinder to capture ions leached from soil solutions by gravitational water (Krause and Ramlal, 1987).

In situ methods have advantages and disadvantages that should be recongnized before choosing an approach. Hanselman et al. (2004) evaluated three *in situ* methods including buried-bags, covered-cylinder and ion-exchange resins methods for measuring net N mineralization rates from organic amendments. They found that buried-bags were damaged by roots or insects and also filled with water. With the covered-cylinder method, soil moisture in the cylinder was drier when compared with field-reference soils. Some amount of NO_3-N could be lost by diffusion flow from the holes in the cylinder as well as from the bottom of the cylinder. In addition, plant roots could develop in the cylinder and absorb NO_3-N from incubated soils (Subler et al., 1995).

Although using the ion exchange resins method has many advantages compared with other *in situ* methods, some limitations could create significant variability and affect the precision and quality of *in situ* measurements. Considerations include the length of time the resins are kept in the soils, soil moisture effect and ability of resins to absorb nitrate and ammonium ions (Kjonaas, 1999). Hanselman et al. (2004) found that soil moisture of the ion resins method was higher when compared with field-reference soils. In addition, ion resins react with low molecular humic substances or organo-metal complexes which can result in reduced exchange capacity (Krause and Ramlal, 1987). The development of roots can severely influence the estimate of mineralized N, since roots and microbes will use resin as a nutrient source (Hart el al., 1994).

To assess NO_3-N availability, ion resins methods have been used in various studies such as grassland (Gibson et al., 1985; Hook and Burke, 1995), forests (Binkley and Matson, 1983; Binkley et al., 1986; Smeturst and Nambiar, 1989), deserts (Lajtha, 1988), dryland agroecosystems (Kolberg et al., 1997, 1999), moist, fertilized agricultural soil (Brye et al., 2002), land-applied manure, compost and organic soil amendment (Eghball, 2000; Hanselman et al., 2004) and arctic soils (Giblin et al., 1994)

Residual profile nitrate test is as an alternative for incubation methods. Direct soil measurements can be used to predict the N mineralization. Residual NO_3-N is the direct measurement by collecting soil samples before planting or after harvest. This test accounts for available N in the root zone regardless of the N source. Soil NO_3-N measurement does not assess available N contributions from specific organic N sources (Bundy and Meisinger, 1994). Roth and Fox (1990) and Liang et al. (1991) found that a fraction of soil NO_3-N could remain in the medium-to-fine-textured soils during winter and contribute to the subsequent crops. The soil profile nitrate-N test is a more reliable measurement in arid and semiarid agricultural areas where leaching or dinitrification processes occur less often than in humid climates (Dahnke and Johnson,

1990). In addition, the residual soil NO_3-N test also can indicate either plant-N use efficiency (Sullivan et al., 1998), excessive N application, or higher mineralization rate in that field (Neeteson, 1995). Marx et al. (1999) suggested that an amount of NO_3-N greater than 30 mg kg^{-1} in a 30 cm depth is considered excessive, leading to over-application of N fertilizer or leaching during the growing season.

The Pre-Sidedress Nitrate Test (PSNT) estimate for nitrogen sufficiency was first proposed by Magdoff et al. (1984). The PSNT is the measurement of NO_3^--N at the soil surface (0-1 ft) after corn is 12 inches tall or immediately before the highest uptake of N. While lowest in the late winter and early spring, the amount of NO_3^- increases in spring and early summer. This results from less leaching and denitrification loss, suitable temperature for microbial activities, mineralized N from annual manure application or crop residue and limited corn N uptake. In Western Oregon and Western Washington, Marx et al. (1997) suggested that if PSNT values are more than 25 mg kg^{-1} NO_3-N, it is not necessary for a supplemental fertilizer N application. The PSNT is found to be an effective method to provide the amount of additional N required by the crop and to reduce yield losses resulting from N deficiency (Pang and Letey, 2000).

However, this measurement is not applicable to all locations and cropping systems. It is used mainly with corn or other row crops and requirs an exact growth stage for sampling. Moreover, this method could not identify the source of NO_3^- in soil samples that could be either the excessive N application from the previous year or mineralized from early spring N fertilization (Magdoff, 1991).

Plant analysis

Chlorophyll meter measurement of leaf chlorophyll content is affected by the N status in plants. Leaf chlorophyll and the degree of green leaf color increase in response to the soil N supply up to a maximum level. Therefore, a chlorophyll meter or greenness measurement can be used as a tool to measure N mineralized during the growing season. The leaf chlorophyll value is best used for comparison with a standard plot in the same field receiving adequate N for maximum leaf greenness. This measurement has been used to determine crop N status following manure or compost application (Schepers and Meisinger, 1994). However, this method is sensitive to temperature and moisture, corn varieties and growth stages and plant disease or other nutrient deficiencies besides N. Peterson et al. (1993) suggested that a chlorophyll meter reading should be calibrated for each field that differs in management history. The corn leaf should be read on the newest fully expanded leaf having a leaf collar exposed, on the same location on each leaf, at the same time within a calibrated field. Different varieties of corn have unique greenness. Therefore, a chlorophyll reading cannot be used to compare among hybrids, locations and growth stages limiting its applicability to many situations (Schepers et al., 1992b). Furthermore, this value indicates N status in plants or soil only at the sample time but not for N-supplying capacity of soil. Therefore, the chlorophyll reading can not be used alone. Soil testing and other indices are required for making N recommendations (Schepers et al., 1992a).

Plant tissue tests can be done on fresh tissue in the field or in the laboratory. In the field, plant tissues are squeezed to obtain sap which is placed on a test strip. The sap mixes with reagents on the strip and a color develops. This color is compared with a standard chart that indicates quantitative values of nutrient content. This test determines concentration of specific nutrients in cell sap relative to the nutrient available in soil (Havlin et al., 1999). Sampling specific parts of a plant or whole plants can be used to estimate N status. Blackmer and Mallarino (1996) indicated that 0.25 to 2.0 g N kg^{-1} content in 20 cm segment of cornstalk at the end of the season is

an optimal range for N sufficient for corn growth. Plant tissue testing in the field is quick, easy and repeatable in a short time period. However, these sample tests indicate only the N status at the sampling time (Havlin et al., 1999). In addition, several factors affect N concentration in plant tissue, not only the plant efficiency to absorb N from soil but also the growth stage and biomass of the plant when sampled. Therefore, it is difficult to calibrate with standard tests (Neeteson, 1995).

Another plant tissue test, crop N uptake, can measure the amount of applied N that is actually taken up by plants (Bundy and Meisinger, 1994). This method is determined by planting crops under natural conditions without external input such as fertilizer, manure or other managements. Mineralization can be determined by combining the measurement of crop uptake, mineral N in the soil profile, or N in the soil organic pool (Vinten et al., 1992). Crop N uptake is widely used as an indirect method to estimate plant-available N from organic amendments in field research studies (Cogger et al, 2004; Munoz et al., 2004), and for correlation with other soil N availability indices (Velthof et al., 1998; Walley et al., 2002). However, N uptake or removal is mainly a research tool, as absolute values depend upon many other management practices and also plant variety and plant population. Although plant tissue testing is time consuming, laborious and site specific, this method is essential to validate chemical and biological indices for N measurement (Rice and Havlin, 1994).

Computer simulation models

As previously mentioned, soil tests indicate available N at only the sampling time. Therefore, they do not demonstrate the ability of soil N to mineralize during the growing season. Proposed by Stanford and Smith (1972), the first-order kinetics indicate the amount of mineralizable N that will decrease with time. This equation can also predict the plant-available N mineralized from soil organic matter (Campbell et al., 1991).

Some simple models are based on the first-order kinetics (Rice and Havlin, 1994).

$$N_m = N_0(1 - e^{kt}) \quad [2]$$

Where, N_m = N mineralized in time

N_0 = An active N pool or potentially mineralizable N

k = Mineralization rate constant

The k is dependent on temperature. Stanford et al. (1973) suggested the rate of N mineralization was doubled with a 10°C temperature increase. To predict N mineralized during the growing season, the first-order model should be adjusted for particular soil environmental conditions (Campbell et al., 1994). In addition, the N_0 and k vary with soil properties and cropping managements (Campbell et al., 1993). However, this single exponential model is suitable for undisturbed soil samples and controlled only by one substrate (Cabrera and Kissel, 1988).

Since soil organic matter is different in physical and chemical components, current models used in agricultural systems have been developed with varying objectives and degrees of complexity. Ma and Shaffer (2001) reviewed nine models simulating C and N dynamics used in the United States which range from a single pool model up to six pools. These models are also different in related component inputs and specific applications. Therefore, regional and local calibration is always required. For example, CERES-wheat model is developed to estimate fertilizer N requirements in Canadian conditions. Soil organic matter is separated into two pools: fresh organic matter pool and microbial biomass + humus pool (Campbell et al., 1997). To estimate plant-available N, the DECOMPOSITION model is composed of six pools based on rapid and slow release pools of fresh organic matter, microbial biomass and soil organic matter, respectively (Gilmour, 1998).

Other methods

Decay series have been used to estimate annual N mineralized from manure over several growing seasons. Soil that gradually received manure applications has an effect on the release of nutrient-available patterns and the pool for nutrient availability (Whalen et al., 2001). Stable organic manure N that is resistant to decomposition will be incorporated with SOM. The SOM is an important residual N source for the following seasons. Therefore, the stored soil N from previous years should be taken into account for fertilizer recommendations. Klausner et al. (1994) estimated a decay series of 0.21, 0.09, 0.03, 0.03 and 0.02 for organic N in dairy manure applied for corn in New York State based on N uptake using the fertilizer N equivalence method. The first number represents 21% of the organic N fraction mineralized in the first year. The second number refers to 9% of residual N mineralized after the first year that was mineralized in the second year. However, the decay series is site-specific so it has to be estimated for different climatic and soil properties. These values change with variations of soil microbial activities in the field and also require an accurate history of previous manure application.

The Fertilizer N Equivalence (FNE) method determines the amount of plant-available N from organic amendments by using crop response parameters. Based on assumption, efficiency of plants taking N mineralized from organic amendments is equaled to N efficiency for N fertilization (Motavalli et al., 1995; Sims, 1995). Crop response parameters are fit via different models such as a linear regression model (Sullivan et al., 2002; Cogger et al., 2004; and Munoz et al., 2004) a quadratic model for corn grain and silage yield (Jokela, 1992) and a quadratic model for grass yield (Sullivan et al., 2002). Another method, Apparent N Recovery (ANR), is calculated by the difference of crop N uptake from the treatment and control or non-amended treatment (Sullivan, et al., 1998). However, Munoz et al. (2004) argued that ANR estimates N mineralized from organic amendments actually taken up by plants, while FNE evaluates potentially utilizable N taken up by plants.

We know N mineralization is affected by soil environmental factors; many studies attempt to use soil temperature to predict plant-available N (Knoepp and Swank, 2002). Growing-degree-day is the accumulation of the mean daily soil temperatures. Honeycutt et al. (1988) first proposed the growing-degree-day concept to estimate net N mineralization from crop residues. Several researchers successfully use growth to predict cumulative N mineralization over the growing season from organic amendment (Honeycutt, 1999; Eghball, 2000; Griffin and Honeycutt, 2000). By using growing-degree-day, net N mineralization can be compared across soil temperature conditions (Sullivan et al., 1999).

CONCLUSION

Estimation of plant-available N is difficult because organic amendments are composed of a variety of N fractions. Chemical methods are simple and rapid approaches. However, these approaches are unlikely to be successful because they can not imitate soil microorganism activities and reflect the impacts of environmental conditions on the amount and rate of N mineralization (Bundy and Meisinger, 1994). Although biological methods can imitate environmental conditions, preparations for biological methods disturb the N dynamic in the soil resulting in uncertain estimations. In addition, field methods are time consuming and labor-intensive. However, these techniques give an accurate measurement under typical field conditions.

Fox and Piekieliek (1984) and Meisinger (1984) argue that no single soil index is acceptable to provide sufficiently accurate predictions for making N recommendations. The selection of these techniques is dependent on the objective of the work. The N recommendation should be validated under field conditions because of site-specificity and management. Especially in humid regions, NO_3^- has a high potential for leaching into groundwater. In addition, soil testing is not widely accepted in these regions (Bock et al., 1992). Increased research on computer simulation models by using laboratory and field data will provide information to better understand the N cycle and environmental factors. Developed models would make it possible to estimate crop N need, predict yield goal, and determine plant-available N from organic matter and residual soil N.

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EFFECT OF LONG-TERM APPLICATION OF SCREENED DAIRY SOLIDS ON SOIL NITROGEN MINERALIZATION

ABSTRACT

Screened dairy solids consist of coarse, fibrous material separated from dairy wastewater by a mechanical separator. Understanding the season-long mineralization of screened dairy solids is required to balance N inputs with the crop requirement for N. This study was conducted to (i) determine the cumulative effect of repeated annual application of screened dairy manure solids on soil N mineralization, (ii) compare microplots *in situ* technique with laboratory aerobic and anaerobic incubation methods. Screened dairy solids were applied at the Oregon State University Vegetable Research Farm on a Chehalis silt loam (fine-silty, mixed, mesic Cumulic Ultic Haploxerolls) annually beginning in 2001. Soil samples were collected (0-15 cm depth) from plots with and without a history of annual manure application. Open-ended cylindrical microplots (5 cm i.d.) were installed in June and harvested at 14-d intervals through September. A nylon mesh bag containing ion exchange resins was placed in the bottom of each microplot to capture NO_3-N. Screened dairy solids immobilized plant-available N (PAN) for approximately 700 degree day (0°C base temperature) following application, and then mineralized N thereafter. Soil receiving annual manure application for 3-4 yr had a net increase in mineralization rate of approximately 0.01 mg N kg^{-1} dry soil degree day^{-1}. Plant-available N measured via laboratory aerobic incubation and PAN measured via field microplot were highly correlated. This study showed that a small fraction of total N was mineralized to PAN during years 2 to 4 following a screened dairy solids application (less than 4% of total N applied). Some of the PAN from screened manure solids was mineralized during the fall season, suggesting that using winter cover cropping would improve nitrogen utilization.

INTRODUCTION

Plant-available N is supplied from a variety of sources, including pre-plant soil inorganic N, mineralized from soil organic matter during the growing season, and a fertilizer or organic N source (Schaffers, 2000). In soil that has received annual manure applications, residual NO_3- N in the soil profile or increased N mineralization from soil organic matter can supply much of the PAN needed by the crop. Therefore, it is important to have accurate estimates of N mineralized from soil organic matter in cropping systems that utilize manures or composts as an N source.

The pool of mineralizable soil N increases, with annual organic amendment applications (Whalen et al., 2001). Munoz et al. (2003) found that total N concentration in soil was increased after 3-yr of annual dairy manure application. By using a ^{15}N microplots technique, they found average approximately 46% of applied manure remained in the soil and only 18% was available to plant during the 3-yr study.

The decay series concept developed by Pratt et al. (1973) has been used to explain N mineralization patterns in manure-amended soils. In general, manure contains N that is readily available to plants as NH_4-N and N that is slowly released from organic N forms. The organic N pool is often much larger than the inorganic N pool. In addition, this pool is composed of various complex fractions with different mineralization kinetics (Van Kessel et al., 2000). Klausner et al. (1994) developed a decay series of dairy manure to describe organic N availability in New York State. Based on crop N uptake (fertilizer N equivalence method), organic N availability from dairy manure was 21% of the initial organic N in the first year. Nine percent of the residual organic N was mineralized in the second year, and 3%, 3% and 2% was mineralized in the third through fifth year, respectively. Cusick et al. (2002) used ^{15}N isotope methods to determine the annual decay series of N availability from dairy manure to be 0.14, 0.04 and 0.02 in years 1, 2, and 3 after application in a field experiment at Madison, WI.

Many studies have estimated N mineralization from dairy manure or compost under the field conditions (Eghball, 2000; Van Kessel and Reeves, 2002; Shi et al., 2004). Because manures vary widely in characteristics, they can mineralize or immobilize N (Serna and Pomares, 1991; Paul and Beauchamp, 1994; Sorensen, 1998; Shi et al., 2004). Van Kessel and Reeves (2002) collected 107 dairy manures which had C:N ratio ranging from approximately 10 to 75 from dairy production systems in Maryland, Virginia, Pennsylvania, New York and Connecticut. Since these dairy manures were highly variable in their qualities, amount of N mineralization ranged from -29.2 to 54.9% of the organic N. Shi et al. (2004) conducted aerobic incubation to measure N mineralization of composted dairy manure in Utah at 20°C and 23% soil moisture content for 70-d incubation. They found that only 6% of organic N in composted dairy manure was mineralized. Eghball (2000) determined N mineralization from a soil receiving beef cattle feedlot manure and compost in Nebraska using a microplot *in situ* incubation. For compost, approximately 12% of total N applied was mineralized in the first year, 12% in the second year and then 8% in the third year. For manure, approximately 19% of total manure N applied was mineralized in the first year, 28% in the second year and then 12% in the third year (Eghball, 2000).

Reported literature values for N mineralization from dairy manure depend on animal diet, bedding, manure handling, types of manure storage facility and method of manure application (Hart el al., 1997; Sorensen, 1998). In addition to organic amendment qualities, the microbially mediated N mineralization process is affected by soil temperature and moisture, soil properties and other agricultural practices (Antonopoulos, 1999). The optimum soil temperature for microbial acitivity in soil is 25 to 35°C (Havlin, et al., 1999). Griffin and Honeycutt (2000) compared the rate of net N mineralization of livestock manures at 10, 17 and 24°C. They found that NO_3-N accumulated faster with increasing temperature. A growing degree day approach using a 0°C base temperature was successfully used to predict N mineralization across

temperature regimes (Honeycutt et al., 1988; Honeycutt 1999; Griffin and Honeycutt, 2000). In addition to soil temperature, soil moisture also has impact on N dynamics. Linn and Doran (1984) reported that aerobic microbial activities such as mineralization, nitrification and decomposition processes were highest at 60% of soil water-holding capacity. These processes were decreased when soil moisture exceeded field capacity (> 80% of soil water-holding capacity). Water-holding capacity is defined by the ratio of volumetric water content to percent total soil porosity.

Screened dairy solids used in this study were obtained from a flush manure handling system at the Mallory dairy near Keizer, OR (Darby, 2003). At the dairy, an in-line mechanical stationary screen removed approximately 20 to 30% of the solids contained in the flushed dairy manure and bedding (Nordstedt et al., 1996). A survey of screened dairy solids at 51 dairies in Western Oregon reported average total N of 1.2%, and C:N ratio of 33 (Sullivan et al., 1997). Estimated N availability from screened dairy solids is low ranging from 0-20% of total N applied in the first year after application (Sullivan et al., 1997; Bary et al., 2000). No published local data is available for N mineralization for the second year following a screened dairy solids application. Previous research by our group found that in the first growing season PAN from screened dairy solids was approximately 6% of total N applied at a field site near Aurora, OR and approximately 12% of total N applied at a field site near Puyallup, WA (Gale, 2005).

In situ methods can accurately measure the actual amount of N mineralized and can also be used to calibrate laboratory predictions. Recently, ion exchange resin methods have been successfully used to measure soil nutrient availability in forests (Palik et al., 1997; Paschke et al., 2000; Hangs et al, 2004), agricultural studies (Subler, 1993; Giblin et al., 1994; Davis et al., 2003) and other environmental studies (Qian and Schoenau, 2002). First proposed by DiStefano and Gholz (1986), ion resins the method has the ability to capture mobilized nutrient forms especially NO_3-N which is a plant available nutrient.

Therefore, this method can be used to study the kinetics of nutrient release and transport under field conditions (Qian and Schoenau, 2002). Since the ion resin method reflects field soil temperature conditions, this *in situ* method is a most promising method for determining N mineralized after organic soil amendment application (Hanselman et al., 2004). However, the ability of resins to trap NO_3-N quantitatively is influenced by the type of resins, and soil conditions. Factors that can increase variability in experimental results with *in situ* ion exchange methods include resin extraction methods and competition among resin, plant roots and microbes for ion removal from soil solution (Kjonaas, 1999).

This study was conducted to: (i) determine the cumulative effect of repeated annual applications of screened dairy manure solids on soil N mineralization, and (ii) compare microplots *in situ* technique with laboratory aerobic and anaerobic incubation methods.

MATERIALS AND METHODS

Site description

This study was conducted within a field experiment established at the Oregon State University Vegetable Research Farm in the Willamette Valley of Oregon in 2001 (Darby, 2003). The soil is a Chehalis silt loam (fine-silty, mixed, mesic Cumulic Ultic Haploxerolls). This site was planted to sweet corn (*Zea mays*) in 2001, 2003, 2004 and snap bean (*Phaseolus vulgaris*) in 2000 and 2002. The field site was irrigated at approximately 7 d intervals by overhead solid-set sprinklers in summer until approximately August 15.

Soil Sampling

Screened dairy solids used in this study were the solid fibrous fraction obtained from liquid dairy manure and separated by using a screen separator, while composted dairy manure solids was made from raw dairy manure solids by composting in windrows for 2 months. In the first month, the windrow was turned twice a week and then once a week in the second month (Darby, 2003). Our experiment included 4 treatments chosen within the larger experiment (Darby, 2003). Each treatment was rates of screened dairy solids and replicated 4 times in a randomized complete block design. Each sub-plot in the field experiment was 6.1 x 9.2 m. Composted dairy manure solids and screened dairy solids were analyzed for chemical characteristics before application (Table 2.1). By using a push probe with a diameter of 5 cm, the soil used for our incubation experiments was collected at 15 cm depth on May 20, 2003 and on June 17, 2003, after the annual screened dairy solids application. In 2004, the field plots were separated into two sections. Only half of each field plot was re-amended with screened dairy solids at rate 33.6 dry Mg ha^{-1}, while another half was unamended. Therefore, each field plot size was 4.6 x 6.1 m. in 2004 (Fig 2.1).

Table 2.1. Chemical characteristics of composted dairy manure solids and screened dairy solids.

Year applied	Amendment	Total solids	Soluble Salts	Total P	Total K	Total N	NO_3-N	NH_4-N	Field application rate (dry weight)	Total N application rate
		%	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	Mg ha^{-1}	kg N ha^{-1}
2001	Composted, screened dairy solids	23.6	1.9	3.9	8.5	18.8	0.7	0.8	56.0	1053
2002	Composted, screened dairy solids	21.9	1.9	3.0	7.7	20.1	0.6	0.8	33.6	675
2003	Screened dairy solids	20.1	3.8	5.0	8.0	15.2	0.4	3.0	22.4	340
2004	Screened dairy solids	23.2	6.5	4.2	7.7	16.3	0.4	2.0	33.6	548

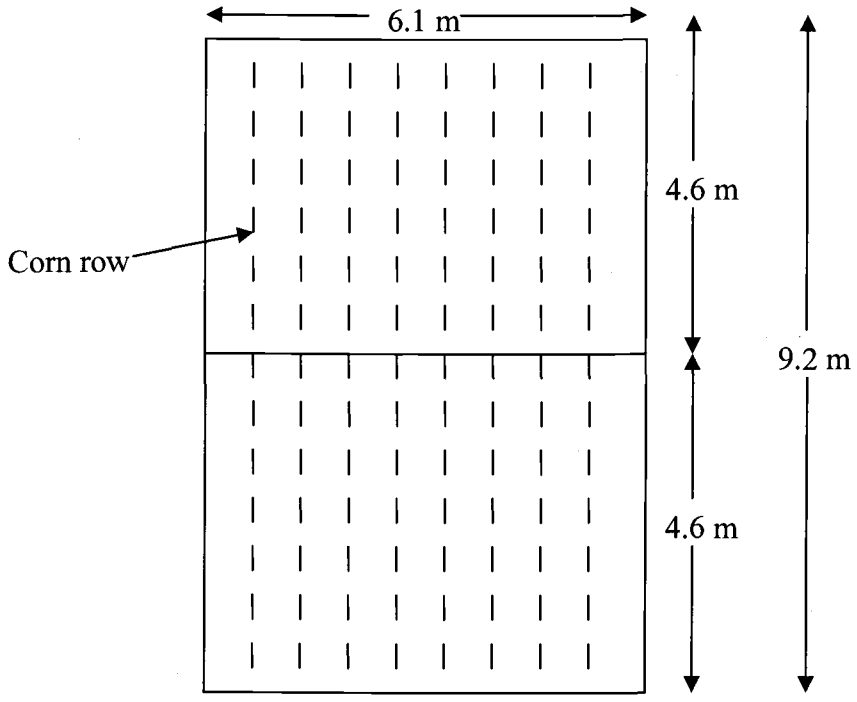

Fig. 2.1 Schematic of field subplot management in 2001 to 2004 at Oregon State University Vegetable Research Farm, OR. Subplots were 6.1 x 9.2 m in 2001, 2002 and 2003. In 2004, Stone and Hoffman (Department of Horticulture, Oregon State University) split their subplots in half. Soil samples for the incubation experiments came from 6.1 x 9.2 m subplots in 2003 and from 4.6 x 9.2 subplots in 2004. Soil samples were collected from center 4 corn rows to avoid uneven mixing of soil and dairy solids on plot edges.

Soil samples were collected on June 11, 2004. Treatment descriptions and timing of annual dairy solids application are shown in Table 2.2. Soils were also sampled on October, 6, 2004 for an additional aerobic incubation experiment (laboratory only). Soil samples taken in 2003 held at 25°C, while samples in 2004 were stored at 4°C until experiments were initiated.

Microplots incubation method

After collection, soils were thoroughly mixed; stones and weed residues were removed. Large aggregates were crushed to facilitate mixing. Aggregates larger than a diameter of 1cm were removed. To capture NO_3^- leaching, resin bags were prepared by weighing 25 g anion exchange resin (Purolite A400, Bala Cynwyd, PA.). Resin was placed in mesh bags made from a 5x6 cm piece of nylon stockings.

Before installation, resin bags were kept in sealable polyethylene bag and stored at 4^0C to avoid drying. Fig. 2.2 shows the placement of the microplot tube at the field sites. Soils were packed into a polyvinyl chloride (PVC) tube (15 cm length with a diameter of 5 cm) using a wooden dowel. The resin bag was placed at the bottom of the tube with firm contact between packed soil and resin. To prevent surface water runoff into the tubes, they were placed above ground level by 1-2 cm. The soil level inside and outside the microplots was approximately the same. After preparation, the soil-filled tubes were held at 4°C before placement into the field. Microplots were placed into a 5-cm diameter cylindrical hole within corn rows after seeding. The holes for field placement of tubes were made with a 5-cm diameter push probe. Then, soil was firmly packed around the PVC tube and ensured that the bottom of tube contact with the soil below to promote drainage.

Table 2.2. Treatment descriptions of microplots and aerobic incubation.

Treatment	Cumulative Application rate (dry weight)	Cumulative manure-N applied	Date manure applied	Date soil collected	Date microplots installed
	Mg ha^{-1}	kg N ha^{-1}			
2003†					
Applied manure from 2001 to 2002	89.6	1728	May 29	May 20	July 9
Applied manure from 2001 to 2003	112.0	2069	May 29	June 17	July 9
No amendment, before annual application	-	-	-	May 20	July 9
No amendment, after annual application	-	-	-	June 17	July 9
2004‡					
Applied manure from 2001 to 2003	112.0	2069	May 4	June 11	June 27
Applied manure from 2001 to 2004	145.6	2616	May 4	June 11	June 27
First year application in 2004	33.6	548	May 4	June 11	June 27
No amendment	-	-	-	June 11	June 27

† In 2003, microplots PVC tubes were harvested on July 23, August 6, August 20 and September 23, respectively.
‡ In 2004, microplots PVC tubes were harvested on July 11, July 27, August 10 and August 30, respectively.

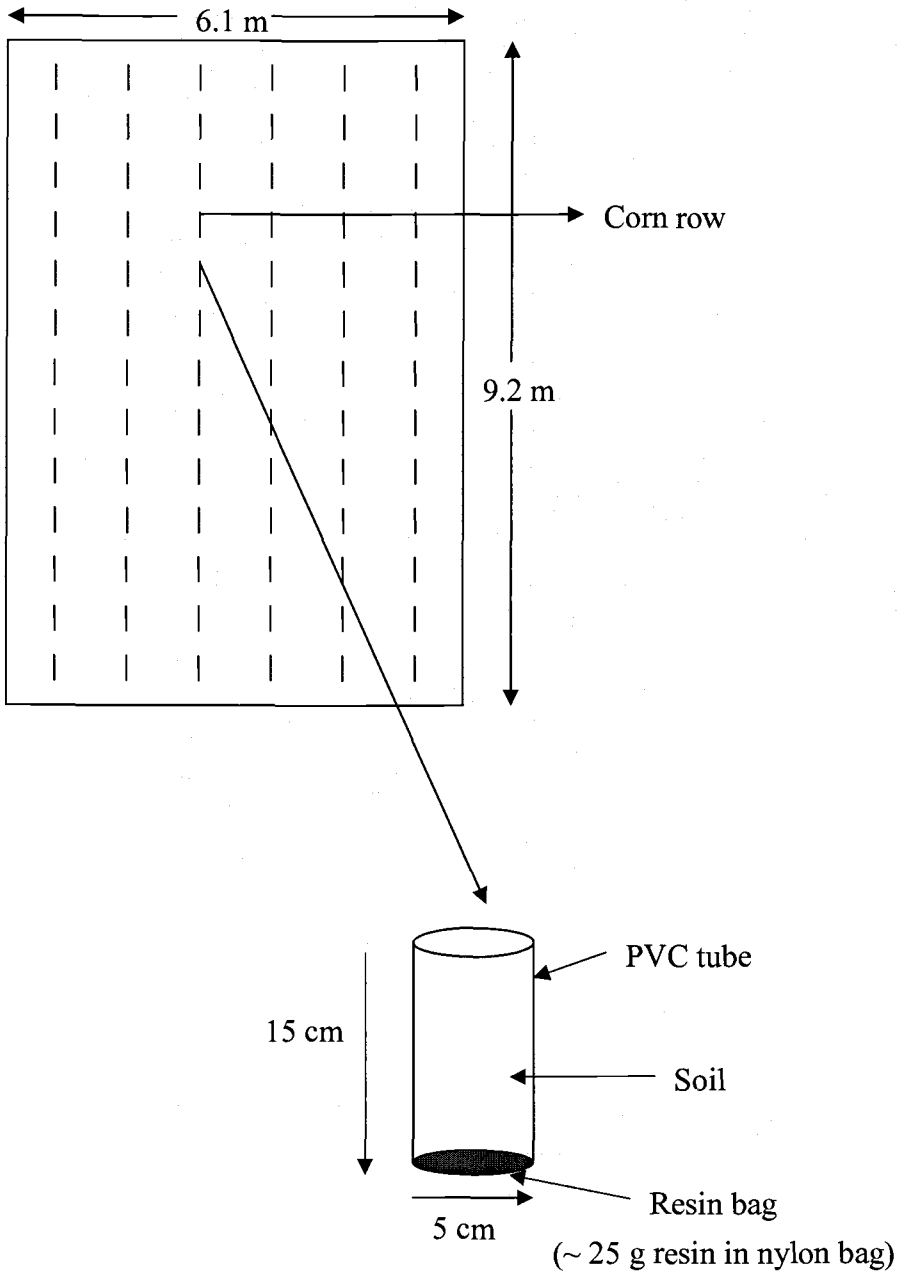

Fig. 2.2. Schematic diagrams and placement of field microplots incubation technique at Vegetable Research Farm in the Willamette Valley of Oregon.

Microplots were incubated in the field for 80 d in 2003 and 70 d in 2004. Soil samples were immediately analyzed after installation on Day 0 and were collected bi-weekly at Day 15, Day 30, Day 45, and Day 60 (Table 2.2). Microplot incubations were conducted during the period of greatest soil temperatures and the period of most frequent irrigation during the summer growing season. The PVC tubes were installed in row by using the sample date. Sixteen cylinders including 4 replications per treatment from the Vegetable Research farm were removed to laboratory analysis at each sample date.

Soil and resin analysis

Soil was removed from the cylinder and homogenously mixed. Inorganic N (NH_4-N and NO_3-N) was extracted from 10-15 g wet soil by shaking with 50 mL of 2 M KCl for 1 hour. The extract was filtered through Whatman no. 42 filter paper and analyzed inorganic N by using automated colorimetric analysis with the salicylate method for NH_4-N and cadmium reduction for NO_3-N (Keeney and Nelson, 1982). Ammonium and nitrate were determined for Day 0, and then only NO_3-N was analyzed after Day 0. Ammonium analysis was performed for several extractions after Day 0 in 2003, but this analysis was discontinued because analytical values were relatively low and did not differ among treatments (Table 2.4).

Gravimetric soil water content was determined for each sample by drying 20 g moist soil at 105°C for 24 hours. Gravimetric soil moisture was used to calculate soil N concentration on a dry soil basis.

For NO_3-N extraction, resin bags were cleaned with deionized water to remove soil particles and opened with scissors. The deionized water was used for only cleansing soil contamination (Giblin et al., 1994). Resin beads were extracted sequentially 5 times with 50 mL of 2 M KCl, for a total extraction volume of 250 mL. Kolberg et al. (1997) suggested that the amount of NO_3-N were recovered from ion

exchange resins was near 100% after 5 serial extractions. Extracts were used to determine NO_3-N by following the same procedure used for soil extracts.

Laboratory incubation method

Aerobic incubation

Moist soil (500 g), taken from the same bulk soil sample collected for the microplot experiment, was put into polyethylene storage bags (Ziploc®, SC Johnson & Son, Inc.). Soil moisture was adjusted to approximately 25-30% gravimetric moisture by adding distilled water with a spray bottle. These bags were thoroughly shaken to mix the soil after adding water. The incubation bags were placed into a 30 L plastic tub, and a moist foam pad was placed on the bottom of the incubation tub. It was re-moistened every 7 d to maintain moisture. The plastic bags holding the soil samples were left partially unzipped to allow air circulation. These soils were incubated at 22°C (Model CEL 38-15, Shearer Co., Asheville, NC). A 15-g composite sample from within each incubation bag was collected at Day 30, Day 60 and Day 90 for NO_3-N determination.

Anaerobic incubation

To measure mineralizable N, a dried soil sub-sample soil (20 g) taken from same bulk soil sample collected for the microplot experiment was weighed into 250 mL glass Mason jar with a screw-top lid. Twenty-five mL of distilled water and a stir rod were added to completely wet the soil. Another 25 mL of distilled water was added to thoroughly clean the stir rod and the side of the glass Mason jar. A new screw-top lid for the Mason jar was used for each sample to ensure an air-tight seal. These soils were incubated at 40°C ± 0.5 for 7 day. Then 50 mL of 2 M KCl was added to the soil and shaken for 1 hour to extract NH_4-N (Horneck et al., 1989).

Statistical analyses and calculations

Net available N ($N_{available}$) for manure-amended soil was calculated and expressed as percent of total N applied:

$$N_{\text{available}}\ (\%) = \frac{(NO_3 - N)_{treatment} - (NO_3 - N)_{control}}{Total\ \text{N}\ applied} x100 \quad [1]$$

where NO_3-$N_{treatment}$ is the amount of NO_3-N mineralized from a given screened dairy solids treatment (mg kg^{-1}), NO_3-$N_{control}$ is the amount of NO_3-N mineralized from control or no amendment (mg kg^{-1}), and total N applied is the cumulative of total N applied in each year (Table 2.2).

Amount of NO_3-N accumulated and sample date were fit to linear regression equation (Eq. [2]). This equation was used to estimate mineralization rate constants

$$N_{cum} = Y_0 + aDegreeDay \quad [2]$$

where N_{cum} is cumulative of N mineralization for amended soil which is measured by soil NO_3-N concentration as $N_{available}$ at growing degree day (mg kg^{-1}), Y_0 is the N_{cum} intercept or the NO_3-N cumulated at the growing degree day (mg kg^{-1}), a is mineralization rate (mg kg^{-1} degree day^{-1}), and degree day is thermal units determined by accumulating a daily heat unit index (DD total, 0°C base temperature) for each microplots sampling period (Integrated Plant Protection Center, 1996). Degree days were calculated based on daily average air temperature.

Net mineralizable ($N_{mineralizable}$) in the anaerobic incubation method was determined by:

$$N_{\text{min}\,eralizable} = (NH_4 - N_{treatment} - NH_4 - N_{initial(t)}) - (NH_4 - N_{control} - NH_4 - N_{initial(c)}) \quad [3]$$

where NH_4-$N_{treatment}$ is NH_4-N content measured from a given screened dairy solids treatment under 40°C at 7 d-anaerobic incubation (mg kg^{-1}), NH_4-$N_{initial(t)}$ is the amount of NH_4-N measured from a given screened dairy solids treatment before anaerobic incubation (mg kg^{-1}), NH_4-$N_{control}$ is the amount of NH_4-N measured from control or no amendment under 40°C at 7 d-anaerobic incubation (mg kg^{-1}), and NH_4-$N_{initial(c)}$ is

the amount of NH_4-N measured from the control or no amendment before anaerobic incubation (mg kg^{-1}).

All equations were fit via Sigmaplot (Sigmaplot 2002 for Windows 8.02, SPSS Inc.). Statistical analysis was performed with SAS (SAS system for Windows 8, SAS Institute Inc.). Nitrate accumulation was analyzed by using univariate ANOVA or split-plot in time ANOVA (Littell el at., 2002). Treatments were used as the main plot and installed days as the subplot.

RESULTS AND DISCUSSION

Rate and quantity of net N mineralization

The pattern of cumulative N mineralization by field microplots method during 76-d and 64-d incubation is shown in Fig 2.3 and Fig 2.4. Resins were placed at the bottom of PVC tubes to capture NO_3-N leaching from soil. In our study, the field microplot method was effective to measure N mineralization under the field conditions. The accumulation of NO_3-N followed the same patterns in both years. The amount of NO_3-N from resin was increased after 30-d after microplots installation coincident with the decline of NO_3-N from soil during the same period (Fig 2.3 and Fig 2.4).

It is apparent that the field microplot technique is likely reliable under this site condition. Lajtha (1988) suggested that percolated water makes the ion resin method more suitable for measurement of net N mineralization in moist soil. Soil moisture in the microplot cylinders ranged from 22 to 37% and average 30% for all treatment from 14 to 76 incubated d (Table 2.3). Resins showed sufficient capacity to capture NO_3-N leached from soil and then retained by the exchange resin. Nitrate content was transported from soil and accumulated in resin at rates of 42 to 87% of total NO_3-N mineralized. Eghball (2000) showed the capacity of resins for NO_3-N mineralization retained was approximately 89% of total inorganic N mineralized during 131-d incubation.

In addition, root development was not found in the resin bag or microplots tubes in this study. Therefore, the amount of NO_3-N measured from this experiment had no interference from vegetation.

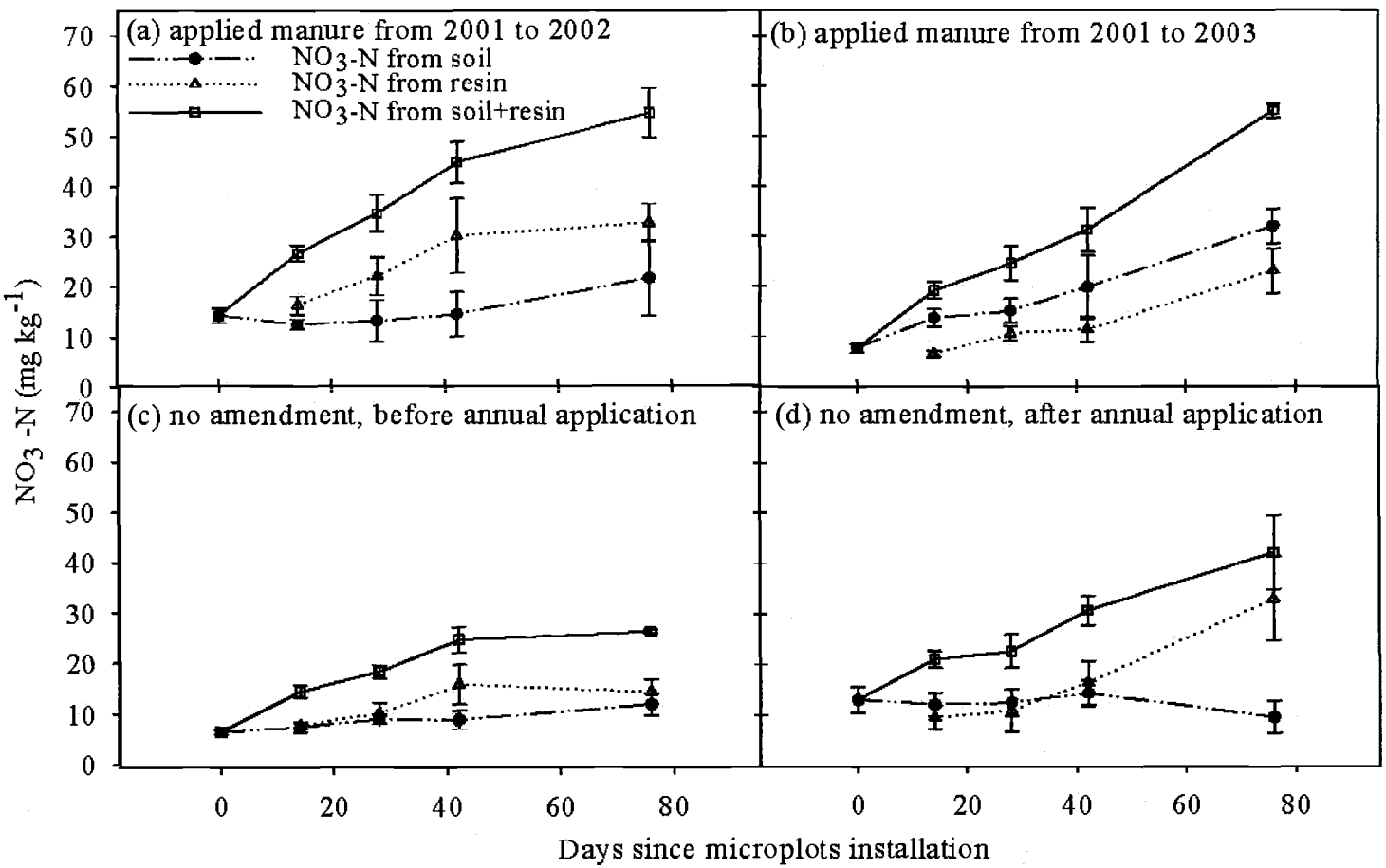

Fig. 2.3. Amount of N accumulated from applied dairy manure solids field microplots, Oregon State University Vegetable Research Farm, OR. Experiment started from July-August, 2003. Day 0 is July, 9, 2003. Applied manure from 2001 to 2002 (a), applied manure from 2001 to 2003 (b), no amendment plot, sampling before annual application (c), and no amendment plot, sampling after annual application (d). The vertical bars are standard errors (n=4).

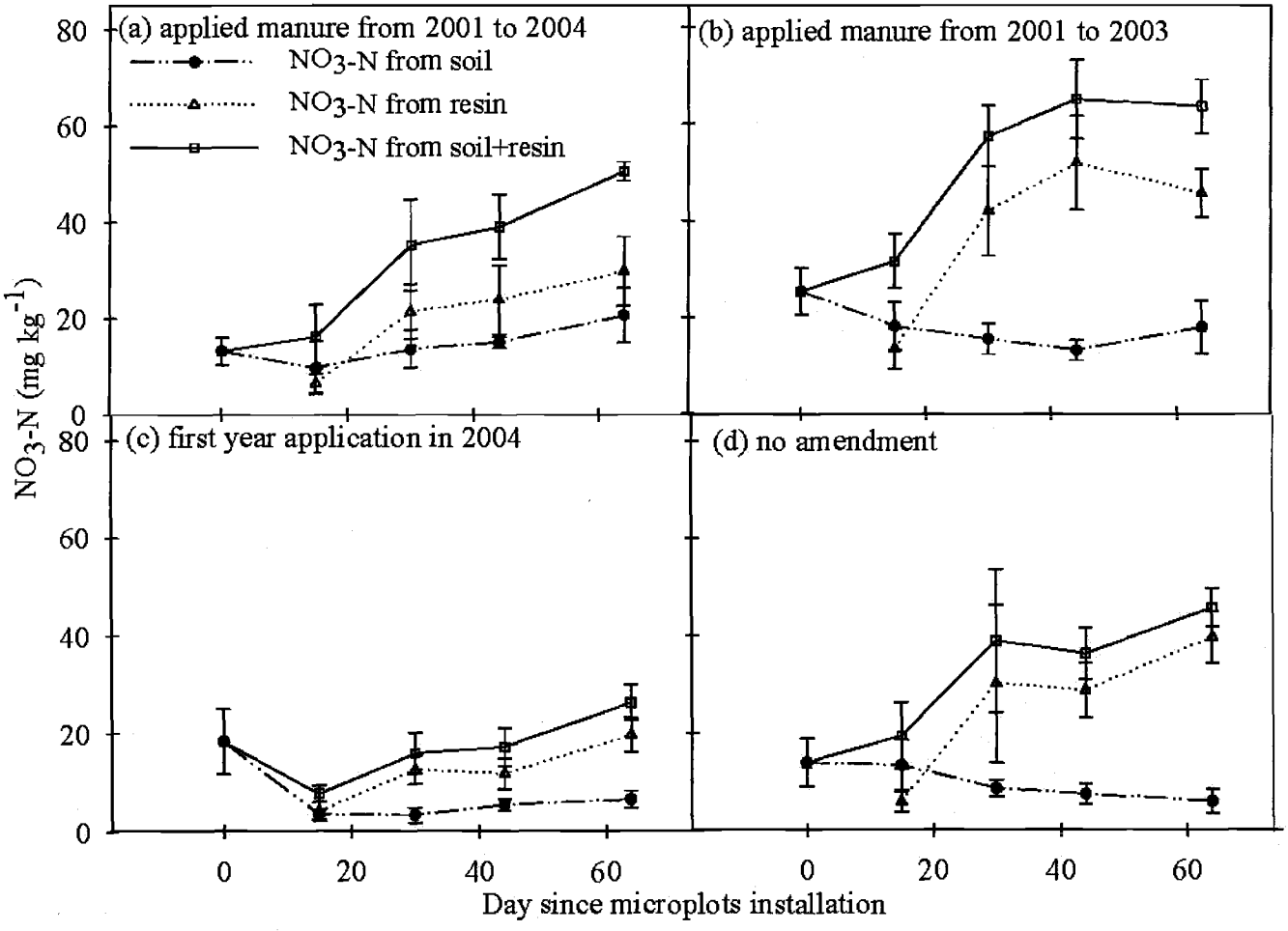

Fig. 2.4 Amount of N accumulated from applied dairy manure solids field microplots, Oregon State University Vegetable Research Farm, OR. Experiment was started from July - September 2004. Day 0 was June, 27, 2004. Applied manure from 2001 to 2004 (a), applied manure from 2001 to 2003 (b), first year application in 2004 (c), no amendment plot (d). The vertical bars are standard error (n=4).

Table 2.3. Measurement of soil moisture content from microplots and aerobic incubation (mean and SE). page 1/2.

Treatment	Sample date				
	0 d	14 d	38 d	42 d	76 d
	g g^{-1}	g g^{-1}	g g^{-1}	g g^{-1}	g g^{-1}
2003					
			Field microplots incubation		
Applied manure from 2001 to 2002	0.19 (0.008)	0.32 (0.011)	0.33 (0.022)	0.32 (0.021)	0.29 (0.012)
Applied manure from 2000 to 2003	0.14 (0.008)	0.34 (0.006)	0.37 (0.024)	0.36 (0.013)	0.30 (0.002)
No amendment, before annual application	0.16 (0.008)	0.30 (0.002)	0.33 (0.006)	0.29 (0.015)	0.22 (0.015)
No amendment, after annual application	0.10 (0.014)	0.29 (0.011)	0.27 (0.023)	0.29 (0.009)	0.25 (0.008)
			Laboratory aerobic incubation		
	0 d	32 d			
Applied manure from 2001 to 2002	0.20 (0.002)	0.22 (0.005)			
Applied manure from 2001 to 2003	0.20 (0.000)	0.17 (0.025)			
No amendment, before annual application	0.20 (0.000)	0.18 (0.035)			
No amendment, after annual application	0.20 (0.000)	0.22 (0.008)			

Table 2.3. Measurement of soil moisture content from microplots and aerobic incubation (mean and SE). page 2/2.

Treatment	Sample date				
	0 d	15 d	30 d	44 d	64 d
	g g^{-1}	g g^{-1}	g g^{-1}	g g^{-1}	g g^{-1}
2004					
			Field microplots incubation		
Applied manure from 2001 to 2003	0.29 (0.019)	0.31 (0.009)	0.33 (0.010)	0.29 (0.010)	0.25 (0.017)
Applied manure from 2001 to 2004	0.33 (0.023)	0.34 (0.021)	0.33 (0.013)	0.31 (0.018)	0.25 (0.043)
First year application in 2004	0.31 (0.007)	0.30 (0.017)	0.32 (0.014)	0.29 (0.011)	0.24 (0.018)
No amendment	0.27 (0.009)	0.27 (0.011)	0.25 (0.010)	0.24 (0.013)	0.20 (0.022)
			Laboratory aerobic incubation		
	0 d	34 d	62 d	91 d	
Applied manure from 2001 to 2003	0.29 (0.019)	0.31 (0.005)	0.26 (0.008)	0.26 (0.016)	
Applied manurefrom 2001 to 2004	0.33 (0.023)	0.33 (0.011)	0.28 (0.008)	0.28 (0.009)	
First year application in 2004	0.31 (0.007)	0.32 (0.010)	0.27 (0.007)	0.29 (0.011)	
No amendment	0.27 (0.009)	0.29 (0.006)	0.23 (0.009)	0.20 (0.030)	

The accumulation of NO_3-N was determined by adding total organic N in the soil and resin from amended treatment (Fig 2.3 and Fig 2.4). However, amount of NH_4-N and NO_3-N was determined for Day 0 and then only NO_3-N was analyzed after Day 0 to determine cumulative N mineralized. In 2003, we determined amounts of NH_4-N through 38 d of microplot incubation (Table 2.4). The concentrations of NH_4-N were found to be low and consistent across treatments ranging from 1 to 2 mg NH_4-N kg^{-1}. As found by Shi and Norton (2000), NH_4-N content was consistently low in soil amended with dairy-waste compost and control soil through 112 d-incubation. In addition, Calderon et al. (2004) found NH_4-N concentration was initially high but rapidly decreased in 14 d-incubation in soil amended with dairy manure and then consistently low over the remainder of the 42 d-incubation. Nitrate was the dominant form of inorganic N throughout the incubated experiment, because NH_4-N was rapidly oxidized to NO_3-N by nitrification process (Shi et al., 2004).

Table 2.4. Concentration of NH_4-N from microplots incubation in 2003 was contributed by the dairy solids manure over time (mean and SE).

Treatment	Sample date		
	0 d	14 d	38 d
	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
Applied manure from 2001 to 2002	1.5 (0.38)	2.2 (0.72)	0.8 (0.12)
Applied manure from 2001 to 2003	1.8 (0.34)	1.0 (0.01)	1.0 (0.04)
No amendment, before annual application	1.0 (0.10)	0.7 (0.03)	0.8 (0.04)
No amendment, after annual application	3.1 (1.42)	0.7 (0.06)	0.8 (0.05)

Table 2.5 shows significant differences between treatments, sample dates and interactions of treatment and sample date. Repeated application of screened dairy solids illustrated the impact of timing of application on available N. Nitrogen mineralization in soil with applied manure through current year (2003) in the 2003 experiment is equivalent to no the amendment treatment taken after the annual application (Fig 2.3b and Fig 2.3d). This finding also was shown in the 2004 experiment where manure applied to the soil through current year (2004) was not different than no amendment application treatment (Fig 2.4a and Fig 2.4d). Manure applied in the first year in 2004 was immediately immobilized following the application and then mineralized 30-d after microplot incubation (Fig 2.4c).

Net NO_3-N available was obtained by adding total inorganic N in the soil and resins from amended treatment. The amount of total inorganic N in the soil and resins was subtracted from the control or no amendment plot from amended treatment. Soil temperature had a major effect on the rate of N mineralization over time. Therefore, these values were represented as a function of degree day (Table 2.6 and Fig 2.5). In addition, regression analyses were performed to describe the effect of net NO_3-N available from soil receiving annual manure application on degree day (Table 2.7). In 2003, Fig 2.5a shows the amount of available NO_3-N was increased almost linearly throughout the 76-day incubation. The r^2 values were between 0.99 and 0.91 in soil applied manure from 2001 to 2002 and soil applied manure from 2001 to 2003, respectively (Table 2.7).

Table 2.5. Split plot in time ANOVA for the effect of treatment on N mineralization across sampling dates within years (2003 and 2004).

Source of variation†	df	*P*
Field microplots incubation		
2003		
Treatment		
None vs. Applied from 2001to 2002	1	<0.0001
None vs. Applied from 2001to 2003	1	0.5605
Date		
None vs. Applied from 2001to 2002	4	<0.0001
None vs. Applied from 2001to 2003	4	<0.0001
Treatment x date		
None vs. Applied from 2001to2002	4	<0.0001
None vs. Applied from 2001to2003	4	0.0845
Field microplots incubation		
2004		
Treatment	3	0.0061
None vs. Applied from 2001to2003	1	<0.0001
None vs. Applied from 2001to2004	1	0.9854
None vs. First year application in 2004	1	0.0001
Date	4	<0.0001
Treatment x date	12	0.0089
Laboratory aerobic incubation		
2004		
Treatment	3	0.0079
None vs. Applied from 2001to2003	1	<0.0001
None vs. Applied from 2001to2004	1	<0.0001
None vs. First year application in 2004	1	0.3352
Date	3	<0.0001
Treatment x date	9	<0.0001

† Two separate ANOVA were analyzed for field microplots incubation in 2003. The first experiment was for soil samples collected from field on May 20 (none vs. applied from 2001 to 2002); the second experiment in 2003 was for soil samples collected in June 17 (none vs. applied from 2001 to 2003). For field microplots and laboratory aerobic incubation in 2004, one ANOVA analyzed for soil samples collected on June 11.

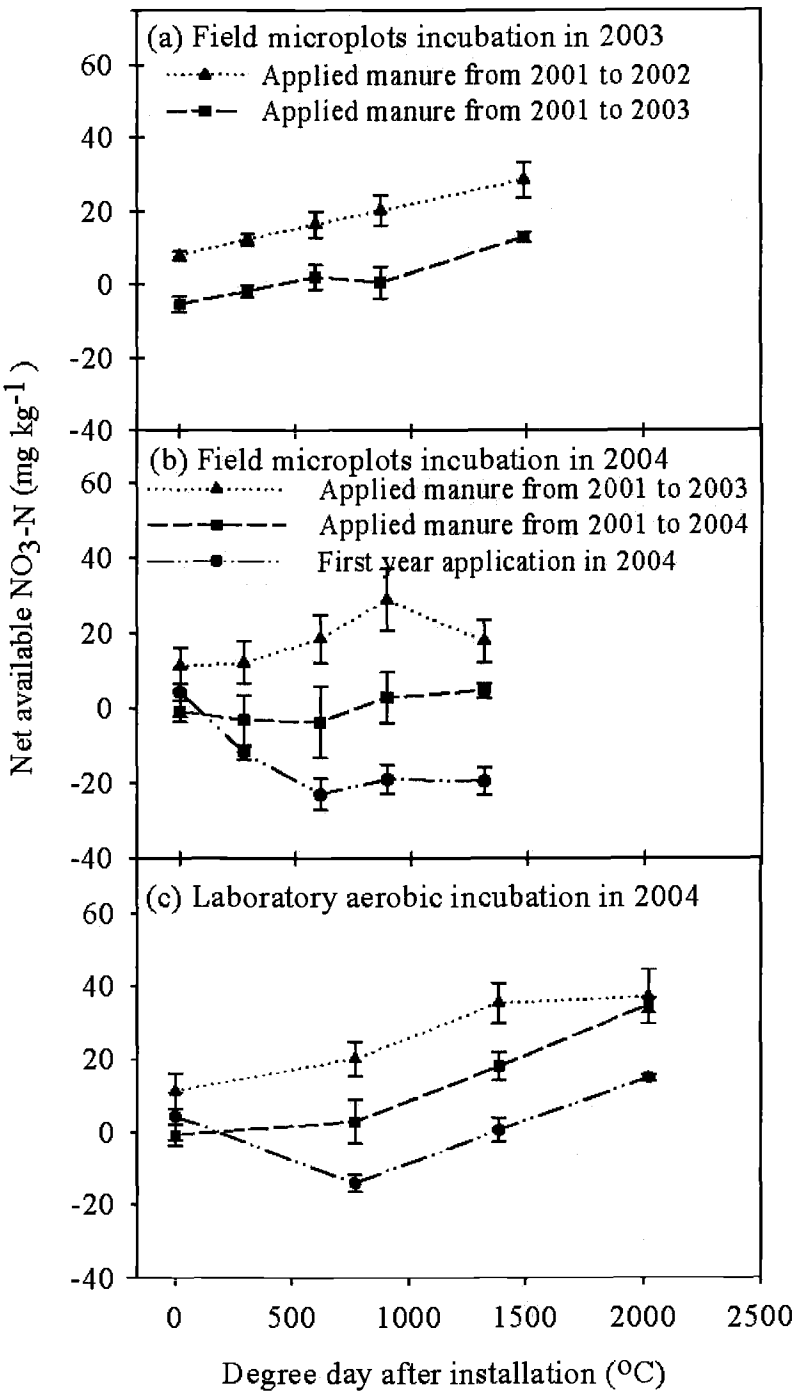

Fig. 2.5. Net available NO_3-N over growing degree day. Concentrations were determined by difference between amended and control soil.Microplots incubation in 2003 (a), microplots incubation in 2004 (b), and aerobic incubation in 2004 (c). The vertical bar are standard error (n=4).

Table 2.6. Degree day (DD total, 0°C base temperature) during microplots and aerobic incubation in 5 sampling dates.

Treatment	Degree day†			
	Date 2	Date 3	Date 4	Date 5
	°C	°C	°C	°C
2003				
Microplot	295	587	868	1486
Aerobic	704			
2004				
Microplot	276	605	894	1310
Aerobic	726	1342		

† Degree day is accumulated from day 0 (the beginning of incubation).

Table 2.7. Linear regressions relationships between net available N and degree days.

Treatment	Intercept	Slope	R^2	*P*
Field microplots incubation				
2003				
Applied manure from 2001 to 2002	8.09	0.014	0.99	<0.0001
Applied manure from 2001 to 2003	-5.77	0.012	0.91	0.0121
Field microplots incubation				
2004				
Applied manure from 2001 to 2003	12.46	0.009	0.39	0.2574
Applied manure from 2001 to 2004	-3.31	0.006	0.56	0.1436
First year application in 2004	-3.70	-0.016	0.59	0.1315
Laboratory aerobic incubation				
2004				
Applied manure from 2001 to 2003	11.57	0.014	0.93	0.0348
Applied manure from 2001 to 2004	-4.97	0.018	0.91	0.0440
First year application in 2004	-5.14	0.006	0.21	0.5441

Although regressions from all treatments in the microplots study in 2004 showed poor relationship (r^2 values ranging from 0.39 to 0.59), mineralization rate constants defined by using linear regression equation were similar in all treatments at 0.01 mg kg^{-1} degree day^{-1} (Fig 2.5 and Table 2.7).

However, soil receiving annual manure application in the first year in 2004 was initially immobilized and then mineralized after 30 d field microplot incubation. Gale (2005) measured NO_3-N accumulation of screened dairy solids using the apparent N recovery (ANR) method. He found that the screened dairy solids were initially immobilized during the first 14-d laboratory incubation and then mineralized after that approximately averaged 10% through 70-d laboratory incubation. Van Kessel et al. (2000) evaluated N mineralization characteristics of manure components. They concluded that N mineralization strongly occurred in organic amendments with more than 50 g kg^{-1} total N. On the other hand, N immobilization was initiated in organic amendment with less than 24 g kg^{-1}. In our study, screened dairy solids were composed of less than 20 g kg-^{1} total N in the every year of application.

From the typical increase in soil N mineralization rate (0.01 mg N kg^{-1} degree^{-1}), it is evident that there is a residual benefit associated with screened dairy solids application. Our findings suggested that an estimate of the residual effect of screened dairy solids during an incubation of 2000 degree days was approximately 20 mg kg^{-1} or 40 kg N ha^{-1} for a 15 cm soil depth having a bulk density of 1.3 g cm^{-3}.

Our observations indicated that the immobilization process from soil receiving annual manure application in the first year occurred during the early season and probably depleted the amount of net NO_3-N available. This amount balanced the N available in soil receiving annual manure application through past year. Therefore, soil receiving annual manure application through the current year was mineralized approximately 0 for first 1500 degree day after new manure applied (Fig. 2.5). This balance also is shown in Fig. 2.6. Soil samples were collected after corn was harvested in the fall season of 2004. Soils were incubated under aerobic conditions.

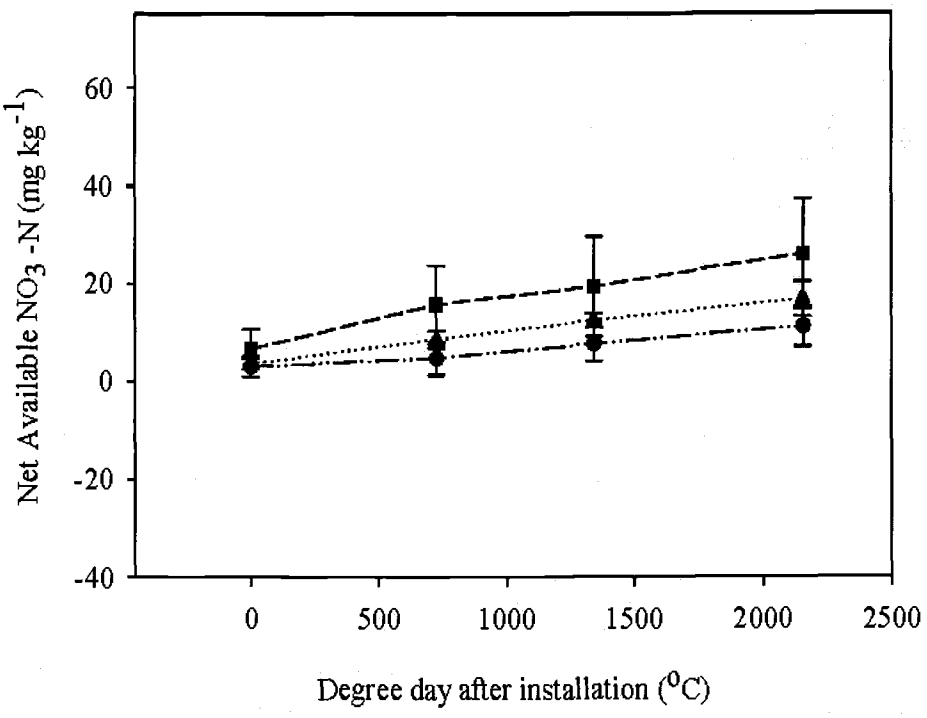

Fig. 2.6. Net available NO_3-N over degree day from aerobic incubation of soil sampled in the fall season.Concertrations were determined by difference between amended and control soil. The vertical bars are standard errors (n=4).

Soil receiving annual manure application in the first year, in 2004, was mineralized ranging from 3 to 11% during 2000 degree day. After the immobilization process from soil receiving annual manure application in the first year was completed, N mineralized from current season was additive to N mineralized from previous application.

Expressed as a percentage of total cumulative manure-N applied, screened dairy solids were mineralized at a relatively low amount during the growing season. The amount of PAN was represented by the percent of total accumulated N applied (Table 2.8 and Eq. [1]). In the second year after application, net N available from dairy solids ranged from 1.7% to 3.2% of total cumulative manure-N applied in previous years (Table 2.7).). The amount of NO_3-N mineralized from soil receiving annual manure application through the past year of treatment was higher than that of soil receiving annual manure application through current year in both years (Table 2.6). The amount of PAN was 3.2% for soil receiving annual manure application through the past year and 1.2% for soil receiving annual manure application through the current year in 2003. In 2004, 1.7% was available for soil receiving annual manure application through the past year and 0.4% was available for soil receiving annual manure application through the current year.

Low N mineralization from screened dairy solids probably is because of the compounds composed of easily convertible N passed through the screen separator. The remaining N fraction is in a more stable form with high C/N ratio (Shi et al., 2004).

Table 2.8. Amount of net available NO_3-N during 76-d and 64-d incubation in 2003 and 2004, respectively, expressed by percent of cumulative manure-N applied (mean and SE). Field microplot incubation experiment at Oregon State University Vegetable Research Farm, OR.

Treatment	Degree days†	Cumulative manure-N applied	Net available NO_3-N	
	°C	kg N ha^{-1}	mg kg^{-1}	% of manure-N applied‡
2003				
Applied manure from 2001 to 2002	1486	1728	28.5 (4.86)	3.2 (0.55)
Applied manure from 2001 to 2003	1486	2069	12.9 (1.43)	1.2 (0.14)
2004				
Applied manure from 2001 to 2003	1310	2069	17.9 (5.54)	1.7 (0.52)
Applied manure from 2001 to 2004	1310	2616	4.8 (1.97)	0.4 (0.15)
First year application in 2004	1310	548	-19.5 (3.65)	-7.0 (0.52)

†Degree days were calculated based on daily average air temperature by accumulating a daily heat unit index (0° base temperature).

‡Based on assumption, soil samples were collected at 15 cm depth and soil bulk density of 1.3 g cm^{-3}.

Relationship between field and laboratory indices of available N

Correlations between laboratory aerobic incubation and field microplot incubation were evaluated by plotting net NO_3-N available from both incubations with degree day. In the laboratory study in 2003, soils were drier with an average 18-21% gravimetric moisture content than in microplot which had an average of 10-37% gravimetric moisture content. Therefore, the amount of NO_3-N mineralized in the laboratory study was lower compared to the microplot study for same growing degree day (Table 2.3). Dry soil probably limits soil microbial activities and the N mineralization process (Schomberg et al., 1994). As found by Honeycutt (1999), N mineralization in drier soil under a field microplots method was underestimated when compared with constantly moist soil under laboratory incubation.

Since soil moisture is the major effect on soil N mineralization, soil moisture content was adjusted to be approximately 25-30% gravimetric moisture content and constantly maintained throughout the aerobic incubation period in 2004. Therefore, in 2004, soil moisture content was similar to that observed in the field study. In this study, the soil samples were incubated at 22°C for 90 d under aerobic incubation. These data were graphed by using thermal units since N mineralization as the time and temperature factor, facilitating comparisons with studies conducted under different temperature regimes (Honeycutt, 1999; Griffin and Honeycutt, 2000). In 2004, amount of N mineralized under the field conditions was generally comparable to that of aerobic incubation. This can be indicated by the overlapping of field and laboratory NO_3-N available in all treatments when fitted with degree day (Fig 2.7). However, the greater difference in net NO_3-N available was found in the last incubation time. Field soils dried to 23% gravimetric moisture at the last sampling date in the late season probably affected the N mineralization process.

The aerobic incubation study in 2004 showed a linear relationship in soil receiving annual manure application from 2001 to 2003 and soil receiving annual manure application from 2001 to 2004 (r^2 values at 0.93 and 0.91, respectively). Both field microplot and aerobic laboratory inucubation showed a linear relationship in soil in the absence of fresh manure application or in the second-year after application (Fig 2.7 and Table 2.7).

The amount of net mineralizable N (NH_4-N) from the 7-d anaerobic incubation was calculated by the difference in NH_4-N content between treatment and control soils (Materials and Methods, Eq. [3]). The amount of net mineralizable N from soil receiving annual manure application through the current year was highest in both years (Table 2.9). When compared to N mineralization measured in the aerobic laboratory incubation and in the field microplots, these values suggested that the anaerobic N mineralizable test best used when soil has not received recent organic matter (crop residue or manure inputs). Carlyle et al. (1998) argued that field measurements represented the net N mineralization under aerobic conditions, while the anaerobic incubation probably measured N released in part of the microbial biomass. Aerobic soil organisms were killed under anaerobic conditions. Boone (1992) suggested that the anaerobic incubation was used to measure N in soil biomass, while other methods under aerobic conditions measured plant-available N. Therefore, soil receiving annual manure application through the current year probably had a larger pool of soil biomass.

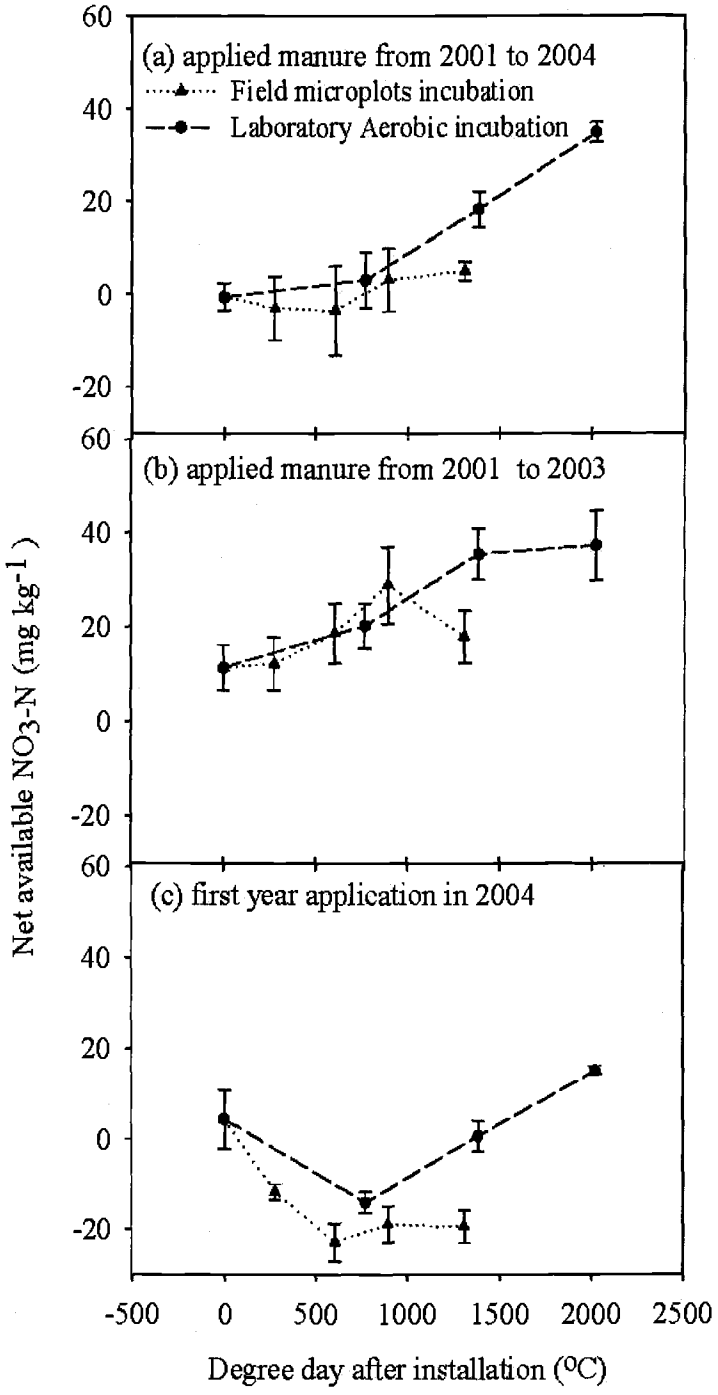

Fig. 2.7. Net available NO_3-N over growing degree day from microplots and aerobic incubation. Concentrations were determined by difference between amended and control soil. Applied manure from 2001 to 2004 (a), applied manure from 2001 to 2003 (b), and first year application in 2004 (c). The vertical bars are standard errors (n=4).

Table 2.9. Amount of net mineralizable N (NH_4-N) over 7 day of anaerobic incubation at 40°C ±0.5 (mean and SE).

Treatment	Net NH_4-N	
	2003	2004
	mg kg^{-1}	mg kg^{-1}
Applied manure through past year†	27.8 (2.00)	25.4 (7.65)
Applied manure through current year‡	89.2 (12.27)	36.5 (7.69)
First year application in 2004	-	26.0 (3.20)

†Applied manure through past year means applied manure from 2001 to 2002 treatment in 2003, and applied manure from 2001 to 2003 treatment in 2004.
‡Applied manure through current year means applied manure from 2001to 2003 treatment in 2003, applied manure from 2001 to 2004 treatment in 2004.

CONCLUSION

The soils receiving annual screened dairy solids application influence the patterns of N mineralization. Soil receiving annual manure application in the first year in 2004 was initially immobilized until 700 degree days, and then N mineralization was measured in the fall season. Soil receiving annual manure application through the current year and the past year had a mineralization constant rate approximately 0.01 mg kg^{-1} degree day^{-1}. The accumulation of net NO_3-N in soil receiving annual manure application through the current year made up the balance of the net NO_3-N available from soil receiving annual manure application through the past year and soil receiving annual manure application in the first year in 2004. In the second year after application, the amount of PAN from screened dairy solid approximately averaged 2.5% of total accumulated manure-N applied, and 0.8% in soil applied through the current year. Screened dairy solids which are most of the compounds composed with easily convertible N, passed through the screen separator and provided PAN in relatively low amounts of their total N applied.

Field microplot incubation can be used to estimate N mineralized in the field under the Willamette Valley conditions. The good relationship between *in situ* measurement and aerobic incubation was found. However, mineralized N measured from anaerobic incubation was poorly correlated with aerobic conditions in the laboratory and in the field. Our finding suggested that anaerobic laboratory incubation is best used when soil has not received recent organic matter. The major finding of this study is the timing of application had an impact on the accumulation and release N dynamics in soil. In addition, the soil moisture affected the N mineralization process and also made the field microplots technique more reliable in the Mediterranean climate in the Willamette Valley of Oregon.

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PREDICTING PLANT-AVAILABLE NITROGEN FROM ORGANIC AMENDMENTS IN THE SECOND YEAR AFTER APPLICATION

ABSTRACT

Organic amendments are widely used as nitrogen (N) sources. The amount of plant-available N (PAN) from organic amendments under actual field conditions needs to be determined, especially in the accumulative effects of amendments in the year following application. This study is conducted to estimate PAN from organic amendments applied in the previous year under field and laboratory approaches. A variety of organic amendments was applied in May, 2003 and the yield of sweet corn (*Zea mays L.*) and the N uptake were measured at harvest in the 2004 growing season. Plant-available N from organic amendments applied in 2003 was determined under fertilizer N equivalent methods. Crop response parameters including post-harvest N recovery from crop N uptake + soil NO_3-N, ear yield and SPAD meter readings were modeled with N fertilizer application rates. In addition, field microplots and laboratory aerobic and anaerobic incubation were also conducted. However, specific problems of each technique occurred. Laboratory aerobic incubation could be confirmed with the fertilizer N equivalence (FNE) method. Net N mineralization in the laboratory aerobic incubation was similar to that measured for the actual field soil. Nitrogen availability was much less affected by the type of organic amendments. Estimates of PAN averaged across all treatments and locations indicated approximately 6% of total N applied in the previous year was mineralized during the second year after application. Our study suggested that the amounts of PAN from organic amendments in the second-year after application were relatively low. Nitrogen availability was not affected by either sources of manure or locations.

INTRODUCTION

A nitrogen application rate model is recommended by Rice and Havlin, (1994). Contributions of the residues of NO_3- N in the soil or the potential mineralizable N resulting from organic amendments in the pervious year are important factors in the years after application. Therefore, understanding accumulative effects to soils from applied organic amendments after several years of applications is an important guide to obtain maximum yield and minimum environmental risk.

Several studies have evaluated available N from a variety of organic amendments in the year following applications (Beckwith et al., 1999; Eghball and Power, 1999; Eghball, 2000; Whalen et al., 2001; Cusick et al., 2002; Munoz et al., 2003). However, these experiments have been receiving annual organic amendments. Little information is available on the amount of PAN in the year following each application. Wen et al. (2003) evaluated hog and cattle manure in the second year following application using five N efficiency parameters. Based on crop N uptake parameters, they found that estimates of PAN were relatively low, approximately 6% of the total N applied in the previous year from hog manure and 4% total N applied from cattle manure across two locations. Based on N uptake using the fertilizer equivalence method, Klausner et al. (1994) estimated that organic N from dairy manure was mineralized 21% of the initial organic N in the first year, and then 9% of the residual organic N mineral from the previous year will be available in the second year. However, organic amendments are composed of various components (Van Kessel et al., 2000). Although these manures are the same amendment type, the quality of amendment also depends on the nutrient content of animal feed, manure handling and storage method, method and time of application and soil properties (Bitzer and Sims, 1988; Gordillo and Cabrera, 1997; Hart el al., 1997; Havlin et al., 1999). Predicting available N from organic amendments is difficult especially in uncontrollable conditions (Pierzynski et al., 2000).

Many indices have been developed to estimate PAN from organic amendments including field and laboratory methods (Bundy and Meisinger, 1994). The FNE method incorporates the amount of applied N which is actually taken by crops under field conditions (Munoz et al., 2004). This approach is an indirect calculation using crop response parameters such as the gain in N uptake, grain yield, whole-plant yield and crop N uptake by comparing the crop response between several rates of fertilizer application and amended plots (Motavalli et al, 1989; Cogger et al., 2004; Lynch et al., 2004; Munoz et al., 2004). Equivalent values determine the amount of N available from organic amendments needed to obtain yields equivalent to that obtained with applied fertilizer N (Sims, 1995). Crop N removal and soil test N are used not only to calibrate other soil tests but also to estimate N available to meet crop requirements, and to develop nutrient credit recommendations (Dahnke and Johnson, 1990).

In a previous study, Gale (2005) estimated PAN from several organic amendments in the first year using the FNE method based on N recovery from crop N uptake + soil NO_3-N after harvest. In the North Willamette Research Extension Center, OR site and the Puyallup, WA site, 13 different organic amendments were applied in 2003 at rates of total N applied ranging from 321 kg N ha^{-1} to 789 kg N ha^{-1} depending on estimates of PAN. Estimates of PAN in the first year varied with the source of organic amendments, and composition or characteristics of those amendments.

The specific objective of this current study was to estimate PAN from organic amendments in the second year following application by using field and laboratory methods.

MATERIALS AND METHODS

Site description

This experiment was conducted the second year after organic amendment application. First-year experiment results have been reported previously (Gale, 2005). The field experiment was conducted at two locations. The first site was on Willamette silt loam (fine-silty, mixed, superactive, mesic Pachic Ultic Argixerolls) at North Willamette Research Extension Center (NWREC), OR, located near Aurora, OR (approximately 40 km south of Portland, OR). The second field experiment was conducted on Puyallup fine sandy loam (coarse-loamy over sandy, isotic over mixed, mesic Vitrandic Haploxerolls) at Washington State University Puyallup Research Center in Puyallup, WA located 55 km south of Seattle. At NWREC, the previous crop history for the field site was fallow in 2002 and sweet corn in 2003. The Puyallup site had silage corn in 2002 and sweet corn in 2003.

Measurement of nitrogen mineralization

In this study, we chose a subset of organic amendment treatments for intensive N mineralization measurement using field microplots, aerobic laboratory incubation, and 7-d anaerobic incubation at 40°C. From both sites, treatments had substantial total N applied ranging from 321 kg N ha^{-1} to 789 kg N ha^{-1}, with an average of 571 kg N ha^{-1} depending on estimates of PAN in year 1. We hypothesized that the year 1 (2003) amendment would produce a measurable increase in N mineralized in year 2 (2004).

Microplots incubation method

At NWREC, 16 treatments were replicated 4 times in a randomized complete block design. Each plot was 4.6 x 9.1 m. By using a large diameter (5 cm) probe, the soil was collected from a depth of 0-15 cm on June 1, 2004. Soil samples were collected from 6 organic amendments: dairy solids, composted dairy solids, anaerobically digested dairy solids, composted yard trimmings, composted rabbit manure and peppermint hay. At the Puyallup site five organic amendment treatments were selected for N mineralization measurement: dairy solids, composted dairy solids and composted yard trimmings, on-farm compost and composted rabbit manure (Table 3.1).

Soil samples also were collected from year 1 (2003) treatments that received only inorganic N fertilization at rate of 56 urea-kg N ha^{-1} and 112 urea-kg N ha^{-1}. Organic amendments were analyzed for chemical characteristics before application (Table 3.2). These amendments and urea fertilizer were applied in 2003 only (Gale, 2005). The amendment application rates were based on estimates of PAN. The amendment application rate in year 1 were targeted to supply 50 to 100 kg PAN ha^{-1}. The amendment and fertilizer treatments were not re-applied to the same plots in 2004.

Soil samples for N mineralization studies were collected prior to application of N fertilizer in 2004 (year 2). In the field experiment, all treatments except the no-fertilizer check treatment received a broadcast application of 56 kg N ha^{-1} on June, 1, 2004 just prior to seeding. For field microplot and laboratory aerobic and anaerobic incubation, soil was collected prior to blanket N fertilizer (Table 3.3). At the six-leaf growth stage (June 30, 2004), additional urea was applied to supply the remainder of annual N application rate. Urea-nitrogen fertilizer was re-applied in year 2 (2004) to the same plots used in year 1 (2003), for annual application rate of 0, 56, 112, 168 and 224 kg N ha^{-1}.

Table 3.1. Organic amendment description.

Amendment Description†	Amendment Abbreviation	Site	Process
Anaerobically digested dairy solids	AD	OR	Solids removed from an anaerobic digester at CalGon Farms, Salem, OR. The anaerobic digester digests solids by flow system.
BioGro	BG	WA	Commercial fertilizer products.
Canola meal	CAN	WA	Ground canola seed.
Composted dry broiler litter	CC	OR, WA	Dry stacked more than 12 weeks.
Dry broiler litter	CM	OR, WA	Dry stacked within 2-8 weeks.
Composted dairy solids	DC	OR, WA	Separated dairy solids are composted in windrows; finished after 8-10 week.
Dairy solids	DS	OR, WA	Solid fibrous fraction obtained from liquid dairy manure using screen separator via flush system (Darby, 2003).
On-farm compost	OFC	WA	On-farm composted by WSU, Puyallup, WA.
Peppermint hay	PH	OR	Hay from peppermint crops, consisting of leaves and stems that have been heated to remove peppermint oil. During August to April, after distillation this hay was piled outdoors.
Composted rabbit manure	RC	OR, WA	Manure composted in turned windrows for 60 days and additionally stored under cover for 150 days (Gale, 2005).
Rabbit manure	RM	OR, WA	Fresh manure.
Yard trimmings	YT	OR, WA	Yard wastes including grass clippings, shredded, leaves and branches.
Composted yard trimmings	YTC	OR, WA	Separated yard trimmings are ground, turned to add air, and moistened. Composted are finished after 40 to 120 days (Brewer, 2001).

† At NWREC, OR, 6 organic amendments including DC, DS, YTC, AD, PH, and RC were used in microplots and laboratory incubations, while 5 treatments including DS, DS, YTC, OFC, and RC were conducted in Puyallup, WA.

Table 3.2. Chemical data analysis for organic amendments applied to field plots in year 1 (2003).

Location	Amendment Abbreviation	Total solids	C	N	C/N	NH_4-N	NO_3-N	Inorganic N	Application rate (dry weight)
		%	g kg^{-1}	g kg^{-1}	-	g kg^{-1}	mg kg^{-1}	% of total N	Mg ha^{-1}
NWREC, OR									
	AD	28	365	18.6	20	2.4	0	13	42
	CC	67	351	37.2	9	8.1	40	22	5
	CM	77	339	34.6	10	4.7	150	14	5
	DC	23	387	19.5	20	0.4	138	3	35
	DS	23	418	14.6	29	1.2	0	8	35
	PH	29	361	36.6	10	0.4	12	1	19
	RC	42	179	19.0	9	0.0	1978	11	18
	RM	25	338	31.3	11	9.3	0	30	13
	YT	35	235	17.9	13	3.1	7	17	15
	YTC	57	247	20.3	12	0.8	268	5	25
Puyallup, WA									
	BG	96	414	90.9	5	1.1	13	1	1
	CAN	97	452	56.6	8	0.1	18	0	3
	CC	63	337	41.2	8	9.3	45	23	4
	CM	78	356	35.1	10	4.9	223	15	5
	DC	21	396	19.4	20	0.8	15	4	32
	DS	18	425	15.5	27	2.4	6	16	28
	OFC	40	234	17.5	13	0.2	1126	8	44
	RC	44	178	16.9	11	0.0	1019	6	19
	RM	24	339	28.7	12	6.1	0	21	11
	YT	39	246	16.7	15	4.1	0	24	21
	YTC	56	241	19.9	12	1.7	3	8	30

Table 3.3. Details and schedule of data collections. Page 1/2.

Date	Event
NWREC, OR	
May 14 and 19, 2003	Organic amendments applied.
June 1, 2004	Collected soil samples for microplots and laboratory incubation; applied urea at rate 56 kg N ha^{-1} in all field except the control plot.
June 14, 2004	Microplots installed in the field and soil samples were analyzed for Day 0.
June 30, 2004	Collected Pre-sidedress nitrate test (PSNT) soil samples, thinned plants, applied urea at sidedress, and harvested microplots for monitoring soil moisture.
July 12, 2004	Harvested microplots; soil and resin bags were analyzed for Day 30.
July 27, 2004	Harvested microplots for monitoring soil moisture and measured leaf chlorophyll (SPAD chlorophyll reading).
August 10, 2004	Harvested microplots; soil and resin bags were analyzed for Day 60 and measured leaf chlorophyll (SPAD chlorophyll reading).
August 30, 2004	Harvested microplots for monitoring soil moisture and measured leaf chlorophyll (SPAD chlorophyll reading).
September 8, 2004	Harvested microplots; soil and resin bags were analyzed for Day 90. Harvested and measured qualities of ear yield.
September 9, 2004	Harvested and measured whole plant aboveground biomass.
September 16, 2004	Collected soil samples after harvested.

Table 3.3. Details and schedule of data collections. Page 2/2.

Date	Event
Puyallup, WA	
April 30, 2003	Organic amendments applied.
May 14, 2004	Collected soil samples for microplots and laboratory incubation.
May 25, 2004	Applied urea at rate 56 kg N ha^{-1} in all field except the control plot.
June 11, 2004	Microplots installed in the field and soil samples analyzed for Day 0.
June 25, 28, 2004	Collected PSNT soil samples, thinned plants, applied urea at sidedress time, and harvested microplots for monitoring soil moisture.
July 12, 2004	Harvested microplots; soil and resin bags were analyzed for Day 30.
August 11, 2004	Harvested microplots; soil and resin bags were analyzed for Day 60.
September 7, 2004	Harvested and measured qualities of ear yield.
September 8, 2004	Harvested and measured whole plant aboveground biomass.
September 10 2004	Harvested microplots; soil and resin bags were analyzed for Day 90.
October 6, 2004	Collected soil samples after harvested.

After soils were collected, they were thoroughly mixed; stones and weed residues were removed. Large aggregates were crushed to facilitate mixing. However, aggregates larger than a diameter of 1cm were removed. To capture NO_3^- leaching, resin bags were prepared by weighing 25 g anion exchange resin (Purolite A400, Bala Cynwyd, PA.). Resin was placed in mesh bags made from a 5x6 cm pieces of nylon stockings.

Before installation, resin bags were kept in a sealed polyethylene bag and stored at 4°C to avoid drying. Figure 3.1 shows diagrams and the placement of the tube in the field sites. Soils were packed into a polyvinyl chloride (PVC) tube (15 cm length with a diameter of 5 cm) using a wooden dowel. The resin bag was placed at the bottom of the tube with firm contact between packed soil and resin. To prevent surface water runoff into the tubes, they were placed above ground level by 1-2 cm. The soil level inside and outside the microplots was approximately the same. After preparation, soils in the filled tubes were kept at 4°C before placement into the field. Microplots were placed into a 5 cm diameter cylindrical hole within corn rows at the NWREC site and between corn rows in Puyallup site. The holes for field placement of the tubes were made with a 5 cm diameter push probe. Soil was firmly packed around the PVC tube to ensure that the bottom of tube contact with the soil below and to promote drainage.

Microplots were placed in the field with year 1 (2003) composted chicken litter plots (CCC) that was discontinued in year (2004). No measurements were collected from CCC treatment in year 2 (2004). Microplots were sampled destructively at 0, 30, 60, and 90 days after placement in the field plots. Table 3.3 shows details and the schedule of data collection. Microplot incubations were conducted during the period of greatest soil temperatures and the period of most frequent irrigation during the summer growing season. The PVC tubes were installed in a row by using sample date. At each sampling date, one microplot tube from each treatment was removed from each replication in the field. Soil moisture measurements were taken every 14 d.

Soil moisture also was measured when microplot N was determined at Day 30, Day 60, and Day 90. Additional microplot tubes were also installed for destructive measurement of soil water content at NWREC. These tubes were removed on Day 15, Day 45, and Day 75, respectively.

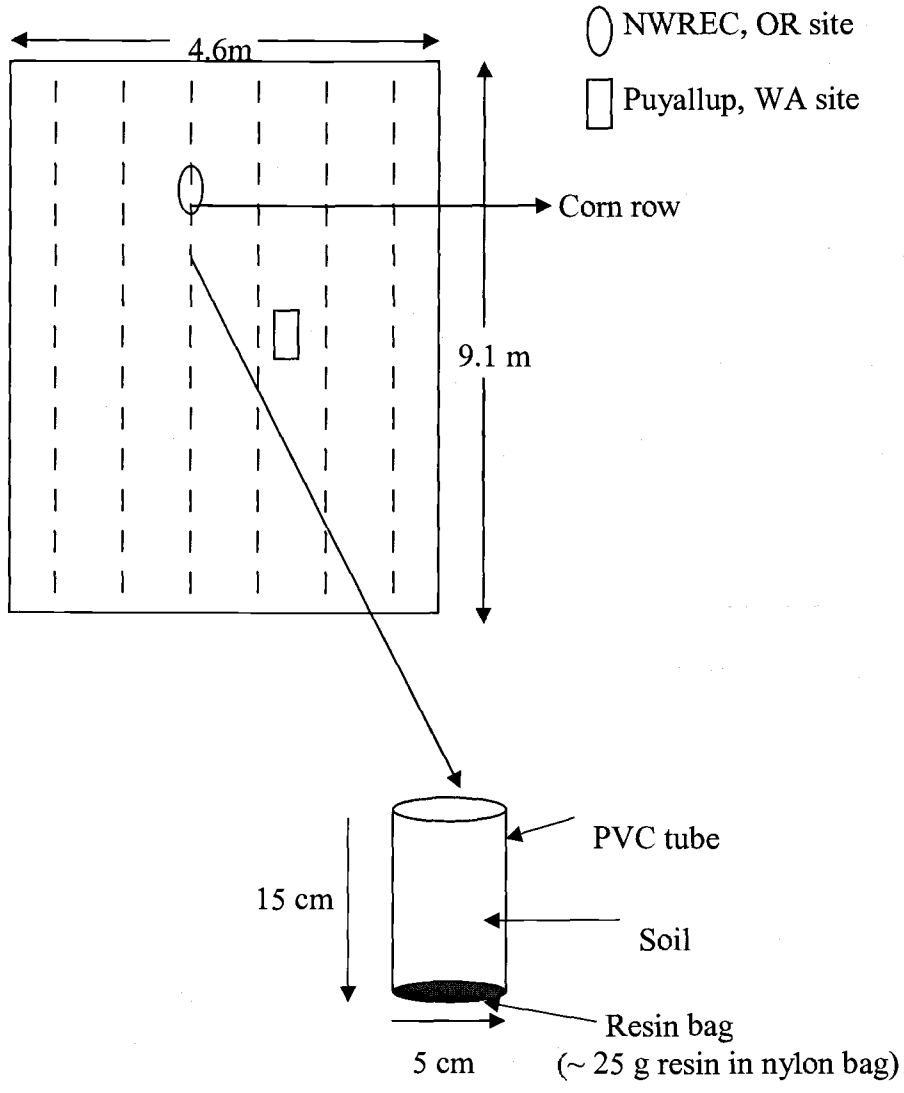


Fig. 3.1 Schematic diagrams and placement of microplots at NWREC, OR and Puyallup, WA site.

Laboratory incubation method

Aerobic incubation: Moist soil (500 g) taken from the same bulk soil sample collected for the microplots experiment was put the polyethylene storage bags (Ziploc®, SC Johnson & Son, Inc.). Soil moisture was adjusted approximately to 25-30% gravimetric moisture content by adding distilled water with a spray bottle. These bags were thoroughly shaken after adding water to mix soils. A moist foam pad was placed on the bottom of the incubation tub. It was re-moistened every 7 d to maintain moisture. The plastic bags holding the soil samples were left partially unzipped to allow air circulation. These soils were incubated at 22°C (Model CEL 38-15, Shearer Co., Asheville, NC). A 15-g composite sample from within each incubation bag was collected at Day 30, Day 60 and Day 90 for NO_3-N determination.

Anaerobic incubation: To measure mineralizable N, a dried sub-sample of soil (20 g) taken from same bulk soil sample collected for the microplots experiment was weighed into 250 mL glass Mason jar with a screw-top lid. Distilled water (25 mL) and stir rod were added and soil was made completely wet. Then, another 25 mL of distilled water was added to thoroughly clean the stir rod and side of the glass Mason jar. A new screw-top lid for the Mason jar was used for each sample to ensure an air-tight seal. These soils were incubated at 40°C ± 0.5 for 7 d. Soil was then mixed with 50 mL of 2 M KCl and shaken for 1 hour to extract NH_4-N (Horneck et al., 1989).

Soil and resin analysis

Soil was removed from the cylinder and homogenously mixed by hand. Inorganic N (NH_4-N and NO_3-N) was extracted from 10-15 g of wet soil by shaking with 50 mL of 2 M KCl for 1 hour. The extract was filtered through Whatman no. 42 filter paper and inorganic N was analyzed by using automated colorimetric analysis with the salicylate method for NH_4-N and cadmium reduction for NO_3-N (Keeney and Nelson, 1982). Ammonium and NO_3-N were determined at Day 0; only NO_3-N was analyzed after Day 0.

Gravimetric soil water content was determined for each sample by drying 20 g moist soil at 105°C for 24 h. Gravimetric soil moisture was used to calculate soil N concentration on a dry soil basis.

Resin bags were cleaned with deionized water to remove soil particles and opened with scissors. Resin beads were extracted sequentially 5 times with 50 mL of 2 M KCl, for a total extraction volume of 250 mL. Extracted NO_3-N was determined by following the same procedure used for soil extracts.

Leaf chlorophyll meter

By using the SPAD 502 chlorophyll meter readings (Minolta Crop, Ramsey, NJ), 10 chlorophyll readings were randomly collected per plot by sampling the youngest fully expanded leaves. These readings were periodically conducted from V9 to R6 growth stages. Chlorophyll meter readings have no units; they are a relative measurement of leaf greenness. Values were generated from 0-80.

Plant sampling and analysis

Six rows of "Jubilee" sweet corn (*Zea mays L.*) were planted in each plot. Rows were 75 cm (30 inches) apart. Corn plants were maintained throughout the growing season. After corn emerged, the plants were thinned by hand in three harvest rows in the center of each plot. Numbers of plants ranged from 44 to 62 thousand whole plants harvested (average 56 thousand whole plants harvested) at the NWREC site and 70 to 80 thousand whole plants harvested (average 74 thousand whole plants harvested) in the Puyallup site. Ears were harvested from a 9.2 m row (30 ft) within each plot. Ears were weighed, and then 10 ears were selected randomly for ear length measurement. Whole aboveground biomass was harvested and weighed from a 4.6 m (15 ft) of row. After weighing, five selected plants were ground in a leaf-chipper, and then dried at 55°C. Dried plant samples were prepared for N analysis by grinding in a stainless steel Wiley Mill through a 2 mm screen.

Total N in plant tissue was determined via LECO combustion analyzer (LECO Total CNS, LECO Corp., St. Joseph, MI)(Sweeney, 1989).

Soil sampling and analysis

In June 2004, soil samples were collected at 0-30 cm depth at the six-leaf corn growth stage (Pre-sidedress Soil Nitrate Test: PSNT) prior to sidedress N fertilizer application. In addition to PSNT soil samples, soils also were taken after corn harvest using a 2 cm i.d. push probe. Nitrate was determined for both soil collections.

Statistical analyses and calculations

Plant-available N was determined by using a net fertilizer N equivalent method. Fertilizer N equivalence was obtained by using the inverse prediction method between urea-N application rate and N recovery (crop N uptake + soil NO_3-N post-harvest; kg N ha^{-1}) or fresh weight ear yield (Mg ha^{-1}). Nitrogen recovery (crop N uptake + soil NO_3-N post-harvest) was regressed against urea-N application rate using linear regression. Ear yield was fit using a quadratic-plateau regression model. The linear regression for N recovery (crop N uptake + soil NO_3-N post-harvest) was defined by Eq. [1].

$$y = Mx + B \qquad [1]$$

where y is the N recovery from crop N uptake + soil NO_3-N post-harvest at 0-30 cm depth (kg N ha^{-1}), M is the fraction of available N taken into the harvested portion, x is the urea N application rate (kg N ha^{-1}), and B is the N recovery from crop N uptake + soil NO_3-N with zero urea-N applied (kg N ha^{-1}).

The quadratic-plateau was defined by Eq. [2].

$$y = a + bx + cx^2 \qquad \text{if } x < C \qquad [2]$$

$$y = P \qquad \text{if } x \geq C \qquad [3]$$

where y is the fresh weight ear yield (Mg ha^{-1}), a is intercept, b is linear coefficient, c is quadratic coefficient, x is the urea N application rate (kg N ha^{-1}), C is the critical

rate of fertilization occurring at the intersection of the linear response and the plateau lines, and P in plateau yield. The a, b c, C, and P variables are the constants obtained by fitting the model to the data. To estimate net FNE values, these values were subtracted with amount of urea N applied before planting (56 kg N ha^{-1}).

Plant-available N in the second year after manure application was expressed by FNE as a percent of total N applied in year:

$$PAN\ (\%) = \frac{FNE}{Total\ \mathrm{N}\ applied} x100 \qquad [4]$$

where FNE is the estimate of fertilizer N equivalence (kg N ha^{-1}); Total N applied is the amount of organic amendment (kg N ha^{-1}) applied for a given treatment in year 1 (kg N ha^{-1}).

Net available N ($N_{available}$) for manure-amended soil was calculated by

$$N_{\text{available}}\ (\%) = (NO_3 - N)_{treatment} - (NO_3 - N)_{control} \qquad [5]$$

where NO_3-$N_{treatment}$ is the amount of NO_3-N mineralized from a given treatment (mg kg^{-1}), and NO_3-$N_{control}$ is the amount of NO_3-N mineralized from the control or no amendment (mg kg^{-1}).

The amounts of NO_3-N accumulated and sample date were fit to linear regression equation (Eq. [5]). This equation was used to estimate mineralization rate constants.

$$N_{cum} = Y_0 + aDegreeDay \qquad [5]$$

where N_{cum} is accumulation of N mineralization for amended soil which is measured by soil NO_3-N concentration as $N_{available}$ at degree day (mg kg^{-1}), Y_0 is the N_{cum} intercept or the NO_3-N cumulated at degree day (mg kg^{-1}), a is mineralization rate (mg kg^{-1} degree day^{-1}), and degree day is thermal units which were determined by accumulating a daily heat unit index (DD total, 0°C base temperature) for each microplots sampling period (Integrated Plant Protection Center, 1996). Degree days were calculated based on daily average air temperature at near by weather stations (Aurora, OR and Puyallup, WA).

Net mineralizable N ($N_{mineralizable}$) in the anaerobic incubation method was determined by

$$N_{mineralizable} = (NH_4 - N_{treatment} - NH_4 - N_{initial(t)}) - (NH_4 - N_{control} - NH_4 - N_{initial(c)}) \quad [6]$$

where NH_4-$N_{treatment}$ is NH_4-N content measured from a given treatment under 40°C at 7 d-anaerobic incubation (mg kg^{-1}), NH_4-$N_{initial(t)}$ is amount of NH_4-N measured from a given treatment before anaerobic incubation (mg kg^{-1}), NH_4-$N_{control}$ is amount of NH_4-N measured from control or no amendment under 40°C at 7 d-anaerobic incubation (mg kg^{-1}), and NH_4-$N_{initial(c)}$ is amount of NH_4-N measured from control or no amendment treatment before anaerobic incubation (mg kg^{-1}).

All equations were fit via Sigmaplot (Sigmaplot 2002 for Windows 8.02, SPSS Inc.) except for quadratic-plateau. The quadratic-plateau model was fit by using SAS (SAS, 1990)

Statistical analysis was performed by analysis of variance (ANOVA) using SAS (SAS, 1990). Organic amendments included in all experiments incubation (field microplots, laboratory aerobic and anaerobic incubation method) were compared to a no-amendment control treatment (urea at application rate 56 kg N ha^{-1}). Then, if F-test for ANOVA showed significance ($P<0.05$), least-significant differences (Tukey's Studentized Range Test) were calculated. Contrasts between selected organic amendment treatments (amendments vs. no-amendment) were also determined (Littell el at., 2002). However, other amendments not evaluated by direct measurement of soil N mineralization were limited to field FNE with standard error. These amendments were not included in statistical contrasts.

RESULTS AND DISCUSSION

Measurement of N mineralization

Fertilizer N equivalent (FNE) method

Crop response parameters: Based on assumption, N response per unit of available N in fertilized soils would produce the same yield as in amended soils (Sims, 1995). The FNE values were determined by using urea-N response curves and crop parameter including crop N uptake + soil NO_3-N after harvested (Table 3.4), ear yield (Table 3.5) and SPAD meter reading (Table 3.6).

Table 3.4 shows crop N uptake, whole plant harvest and residual soil NO_3-N and N recovery from crop and soil obtained from the different organic amendment treatments. The relationship between crop N uptake, soil NO_3-N and N recovery (crop + soil) and N fertilizer application rate are shown in Fig 3.2. Crop N uptake and residual soil NO_3-N responses to most organic amendments were equivalent to N fertilizer rates between those as applied fertilizer treatments at rates between 56 to 112 kg N ha^{-1} at both sites. Residual soil NO_3-N can be used to evaluate NO_3-N utilization efficiency (Neeteson, 1995). Marx et al. (1999) suggested that residual soil NO_3-N in 30 cm surface depth less than 39 kg ha^{-1}, assuming soil bulk density 1.3 g cm^{-3}, is considered to be a low concentration indicating efficient N utilization by plants. In this study, organic amendment treatments residual soil NO_3-N concentrations were low. Soil NO_3-N after-harvest concentration averaged across all organic amendment treatments was found to be 17 kg ha^{-1} in the NWREC site, and 32 kg ha^{-1} in the Puyallup site. Therefore, organic amendments could be considered as the effective N source. However, the amount of residual NO_3-N was significantly increased with a higher urea-N application rate. Crop N uptake and soil NO_3-N post-harvest had a quadratic relationship with the urea treatment resulting in r^2=0.9 in both sites. A linear model was fit between N recovery from crop and soil and fertilizer application rate.

Table 3.4(a). Measures of soil NO_3^-N from PSNT test, N uptake, residual NO_3^-N from soil, and N recovery from crop and soil at post-harvest at the North Willamette Research Extension Center, OR (mean and SE). Page 1/4.

Treatment†	PSNT	Whole plants harvested‡	Crop N concentration	Crop N uptake	Soil NO_3-N post-harvest§	N recovery from crop and soil¶
	mg kg^{-1}	ha^{-1} x 10^3	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}
NWREC, OR						
Urea & control treatments						
Control		59 (2.7)	6.4 (0.40)	44 (5.2)	3 (0.2)	47 (5.0)
Urea (56 kg N ha^{-1})	28.2 (1.68)	55 (0.7)	9.5 (0.55)	113 (17.2)	3 (0.5)	116 (17.2)
Urea (112 kg N ha^{-1})	31.3 (3.49)	62 (1.9)	12.0 (0.59)	147 (4.3)	5 (1.1)	152 (4.5)
Urea (168 kg N ha^{-1})		52 (5.4)	15.2 (0.39)	180 (9.0)	48 (11.0)	227 (14.8)
Urea (224 kg N ha^{-1})		59 (7.2)	14.8 (0.65)	201 (15.5)	138 (48.0)	339 (45.2)

† All urea and organic amendment treatments received pre-plant urea N application of 56 kg N ha^{-1}.

‡ Reported values equal actual values times the indicated factor.

§ Soil collected at 30 cm depth then transforms unit by mg kg^{-1} x3.5x1.12 = kg ha^{-1} and assumed that soil bulk density of 1.3 g cm^{-3}

¶ N Recovery obtained from crop N uptake + residual soil NO_3-N after harvested as calculated by Eq. [1].

Table 3.4(b). Measures of soil NO_3^-N from PSNT test, N uptake, residual NO_3^-N from soil, and N recovery from crop and soil at post-harvest at the North Willamette Research Extension Center, OR (mean and SE). Page 2/4.

Treatment†	PSNT	Whole plants harvested‡	Crop N concentration	Crop N uptake	Soil NO_3-N post-harvest§	N recovery from crop and soil¶
	mg kg^{-1}	ha^{-1} x 10^3	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}
NWREC, OR						
Organic amendments						
Anaerobically digested dairy solid (AD)	34.0 (3.08)	44 (6.3)	11.9 (0.90)	142 (11.6)	8 (1.6)	151 (12.0)
Composted dry broiler litter (CC)	32.5 (2.33)	59 (1.9)	10.5 (0.62)	122 (12.1)	3 (0.3)	125 (11.9)
Dry broiler litter (CM)	36.1 (3.26)	63 (1.7)	8.5 (0.69)	98 (13.3)	3 (0.9)	101 (13.3)
Composted dairy solids (DC)	37.9 (4.43)	53 (2.7)	12.5 (0.65)	166 (16.1)	6 (0.4)	173 (15.8)
Dairy solids (DS)	35.4 (2.33)	42 (5.4)	11.6 (0.99)	124 (15.6)	6 (1.3)	130 (16.6)
Peppermint hay (PH)	36.3 (5.49)	55 (4.4)	11.7 (0.19)	134 (7.1)	7 (1.5)	141 (7.8)
Composted rabbit manure (RC)	31.7 (1.20)	60 (2.4)	10.1 (0.68)	109 (9.3)	7 (3.6)	117 (7.5)
Rabbit manure (RM)	36.1 (4.26)	54 (2.3)	11.9 (0.99)	119 (9.5)	13 (4.8)	132 (9.0)
Yard-trimmings (YT)	31.5 (3.59)	60 (2.6)	9.4 (0.91)	119 (13.0)	3 (0.5)	121 (13.4)
Composted yard-trimmings (YTC)	31.8 (1.65)	58 (7.3)	10.0 (0.71)	127 (18.2)	5 (1.6)	132 (18.0)

† All urea and organic amendment treatments received pre-plant urea N application of 56 kg N ha^{-1}.

‡ Reported values equal actual values times the indicated factor.

§ Soil collected at 30 cm depth then transforms unit by mg kg^{-1} x3.5x1.12 = kg ha^{-1} and assumed that soil bulk density of 1.3 g cm^{-3}

¶ N Recovery obtained from crop N uptake + residual soil NO_3-N after harvested as calculated by Eq. [1].

Table 3.4(c). Measures of soil NO_3^-N from PSNT test, N uptake, residual NO_3^-N from soil, and N recovery from crop and soil at post- harvest at the Washington State University Puyallup Research Center, WA (mean and SE). Page 3/4

Treatment†	PSNT	Whole plants harvested‡	Crop N concentration	Crop N uptake	Soil NO_3-N post-harvest§	N recovery from crop and soil¶
	mg kg^{-1}	ha^{-1} x 10^3	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}
Puyallup, WA						
Urea & control treatments						
Control	11.9 (1.28)	71 (3.18)	8.7 (0.64)	47 (7.2)	22 (1.4)	69 (7.3)
Urea (56 kg N ha^{-1})	27.3 (3.46)	77 (2.71)	12.0 (0.14)	109 (3.2)	25 (6.2)	134 (3.7)
Urea (112 kg N ha^{-1})	29.5 (5.13)	77 (4.74)	14.2 (0.18)	142 (10.8)	35 (4.7)	177 (8.8)
Urea (168 kg N ha^{-1})	24.5 (2.38)	75 (2.96)	16.1 (0.42)	158 (3.0)	35 (9.0)	193 (6.6)
Urea (224 kg N ha^{-1})	25.6 (2.69)	77 (2.45)	16.1 (0.63)	158 (4.6)	64 (1.1)	222 (12.0)

† All urea and organic amendment treatments received pre-plant urea N application of 56 kg N ha^{-1}.

‡ Reported values equal actual values times the indicated factor.

§ Soil collected at 30 cm depth then transforms unit by mg kg^{-1} x3.5x1.12 = kg ha^{-1} and assumed that soil bulk density of 1.3 g cm^{-3}

¶ N Recovery obtained from crop N uptake + residual soil NO_3-N after harvested as calculated by Eq. [1].

Table 3.4(d). Measures of soil NO_3^-N from PSNT test, N uptake, residual NO_3^-N from soil, and N recovery from crop and soil at post- harvest at the Washington State University Puyallup Research Center, WA (mean and SE). Page 4/4.

Treatment†	PSNT	Whole plants harvested‡	Crop N concentration	Crop N uptake	Soil NO_3-N post-harvest§	N recovery from crop and soil¶
	mg kg^{-1}	ha^{-1} x 10^3	g kg^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}
Puyallup, WA						
BioGro (BG)	23.6 (3.29)	80 (2.03)	11.9 (0.19)	109 (4.4)	24 (2.5)	132 (2.3)
Canola meal (CAN)	24.9 (2.94)	70 (2.48)	13.3 (0.39)	110 (8.4)	23 (3.2)	132 (10.5)
Composted dry broiler litter (CC)	25.6 (2.55)	74 (3.39)	12.0 (0.42)	97 (5.8)	27 (1.5)	124 (5.2)
Dry broiler litter (CM)	22.4 (2.79)	72 (1.37)	12.1 (0.44)	102 (1.7)	29 (3.2)	131 (3.8)
Dairy solids (DS)	27.6 (0.60)	70 (4.74)	12.8 (0.19)	109 (2.2)	32 (2.4)	141 (3.2)
Composted dairy solids (DC)	23.7 (2.59)	70 (2.48)	12.2 (0.51)	112 (5.3)	29 (2.6)	140 (7.4)
On-farm compost (OFC)	31.5 (1.64)	72 (1.17)	12.6 (0.52)	112 (7.8)	37 (2.1)	149 (8.9)
Composted rabbit manure (RC)	26.0 (3.90)	74 (2.45)	12.2 (0.86)	117 (14.7)	30 (1.8)	147 (16.1)
Rabbit manure (RM)	30.7 (3.59)	72 (3.10)	10.7 (0.20)	88 (1.8)	28 (3.9)	115 (5.3)
Yard-trimmings (YT)	28.7 (0.84)	79 (3.41)	12.9 (0.14)	122 (6.9)	30 (2.2)	152 (6.3)
Composted yard-trimmings (YTC)	29.5 (1.67)	72 (3.31)	12.7 (0.77)	109 (9.0)	42 (1.5)	151 (8.5)

† All urea and organic amendment treatments received pre-plant urea N application of 56 kg N ha^{-1}.

‡ Reported values equal actual values times the indicated factor.

§ Soil collected at 30 cm depth then transforms unit by mg kg^{-1} x3.5x1.12 = kg ha^{-1} and assumed that soil bulk density of 1.3 g cm^{-3}

¶ N Recovery obtained from crop N uptake + residual soil NO_3-N after harvested as calculated by Eq. [1].

Table 3.5(a). Measures of ear quality taken at harvest at the North Willamette Research Extension Center, OR (mean and SE). Page 1/2.

Treatment	Ear harvested†	Ear yield	Mean ear length‡
	$ha^{-1} \times 10^3$	Mg ha^{-1}	cm
NWREC,OR			
Urea & control treatments			
Control	32 (2.6)	8 (0.7)	25 (0.8)
Urea (56 kg N ha^{-1})	52 (0.9)	18 (0.6)	28 (0.4)
Urea (112 kg N ha^{-1})	56 (2.3)	22 (1.2)	28 (0.3)
Urea (168 kg N ha^{-1})	62 (3.7)	22 (1.4)	28 (0.6)
Urea (224 kg N ha^{-1})	65 (5.8)	23 (2.5)	26 (0.9)
Organic amendments			
Anaerobically digested dairy solid (AD)	56 (4.3)	21 (1.5)	28 (0.4)
Composted dry broiler litter (CC)	53 (3.7)	18 (1.1)	27 (1.0)
Dry broiler litter (CM)	54 (3.2)	18 (0.8)	26 (0.4)
Composted dairy solids (DC)	56 (2.3)	21 (1.0)	28 (1.3)
Dairy solids (DS)	63 (2.9)	23 (0.9)	27 (0.4)
Peppermint hay (PH)	54 (5.2)	20 (2.2)	29 (0.5)
Composted rabbit manure (RC)	54 (2.9)	18 (1.0)	27 (0.6)
Rabbit manure (RM)	54 (1.8)	18 (1.0)	25 (1.0)
Yard-trimmings (YT)	60 (3.9)	21 (2.0)	27 (0.6)
Composted yard-trimmings (YTC)	54 (0.8)	20 (0.5)	27 (1.0)

† Reported values equal actual values times the indicated factor.
‡Determined from a sub-sample of 10 ears per plots.

Table 3.5(b). Measures of ear quality taken at harvest at Washington State University Puyallup Research Center, WA (mean and SE). Page 2/2.

Treatment	Ear harvested†	Ear yield	Mean ear length‡
	$ha^{-1} \times 10^3$	$Mg\ ha^{-1}$	cm
Puyallup, WA			
Urea & control treatments			
Control	14 (3.0)	2 (0.4)	17 (0.2)
Urea (56 kg N ha^{-1})	67 (3.7)	16 (0.8)	22 (0.3)
Urea (112 kg N ha^{-1})	65 (3.6)	16 (1.9)	22 (0.6)
Urea (168 kg N ha^{-1})	70 (4.3)	17 (1.3)	22 (0.4)
Urea (224 kg N ha^{-1})	71 (1.2)	19 (0.8)	22 (0.5)
Organic amendments			
BioGro (BG)	62 (3.4)	14 (0.9)	22 (0.5)
Canola meal (CAN)	62 (3.7)	14 (0.5)	21 (0.6)
Composted dry broiler litter (CC)	58 (4.5)	13 (1.6)	20 (0.2)
Dry broiler litter (CM)	54 (5.7)	12 (1.7)	21 (0.4)
Dairy solids (DS)	50 (7.3)	11 (1.8)	21 (0.3)
Composted dairy solids (DC)	60 (2.6)	15 (1.0)	21 (0.4)
On-farm compost (OFC)	50 (8.3)	12 (2.9)	21 (0.3)
Composted rabbit manure (RC)	57 (3.4)	14 (0.8)	20 (0.8)
Rabbit manure (RM)	51 (8.6)	12 (2.1)	22 (0.6)
Yard-trimmings (YT)	56 (8.1)	14 (2.4)	21 (0.6)
Composted yard-trimmings (YTC)	55 (7.6)	13 (1.9)	21 (0.5)

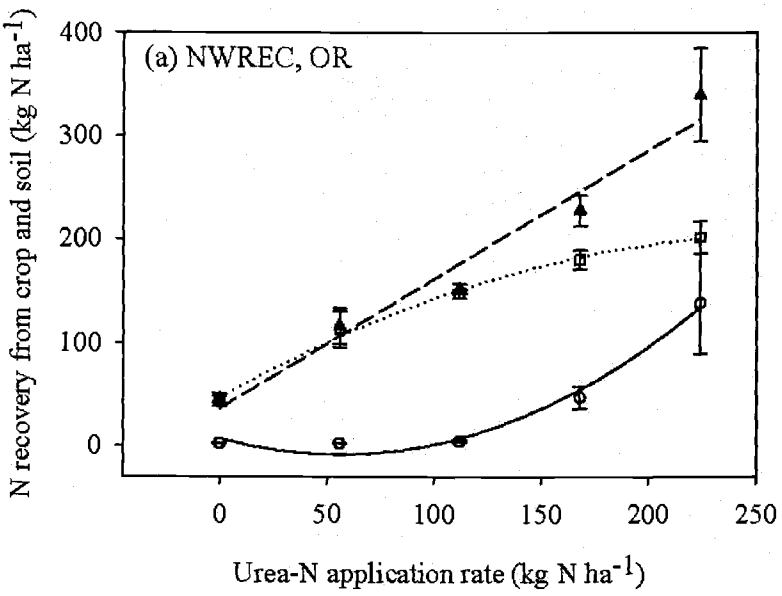
† Reported values equal actual values times the indicated factor.
‡Determined from a sub-sample of 10 ears per plots.

Table 3.6. SPAD meter readings expressed as columns are day-reading and approximate growth stage at the North Willamette Research Extension Center, OR (mean and SE)†.

Treatment	SPAD readings		
	27-July (VT)	10-August (R1-2)	30-August (R3)
Urea & control treatments			
Control	38.0 (0.74)	31.3 (1.01)	28.3 (1.89)
Urea (56 kg N ha^{-1})	44.9 (1.28)	43.0 (1.30)	41.1 (1.73)
Urea (112 kg N ha^{-1})	48.1 (0.55)	48.8 (0.86)	48.7 (0.76)
Urea (168 kg N ha^{-1})	46.4 (1.29)	47.6 (0.70)	47.2 (1.64)
Urea (224 kg N ha^{-1})	45.8 (1.19)	50.1 (1.48)	48.2 (1.19)
Organic amendments			
Anaerobically digested dairy solid (AD)	47.4 (0.69)	49.0 (0.73)	48.1 (1.51)
Composted dry broiler litter (CC)	47.1 (1.11)	44.6 (1.15)	40.7 (3.29)
Dry broiler litter (CM)	43.5 (1.43)	42.9 (1.25)	41.0 (1.66)
Composted dairy solids (DC)	46.9 (0.51)	48.3 (0.80)	45.5 (0.97)
Dairy solids (DS)	46.5 (0.29)	50.1 (0.92)	47.5 (0.94)
Peppermint hay (PH)	47.3 (0.68)	48.0 (0.78)	46.2 (2.02)
Composted rabbit manure (RC)	42.7 (0.28)	44.4 (0.20)	40.6 (0.53)
Rabbit manure (RM)	44.3 (1.59)	45.7 (1.25)	42.2 (1.28)
Yard-trimmings (YT)	46.8 (0.92)	46.6 (1.23)	41.8 (2.36)
Composted yard-trimmings (YTC)	45.7 (0.58)	47.7 (1.79)	44.0 (1.72)
	Fertilizer N Equivalency‡		
	kg N ha^{-1}	kg N ha^{-1}	kg N ha^{-1}
Anaerobically digested dairy solid (AD)	47.8 (5.05)	53.8 (1.78)	45.8 (7.23)
Composted dry broiler litter (CC)	38.2 (11.96)	21.7 (9.73)	5.3 (19.70)
Dry broiler litter (CM)	-0.2 (20.39)	7.5 (9.66)	3.6 (10.71)
Composted dairy solids (DC)	45.3 (6.72)	49.2 (3.95)	34.2 (7.93)
Dairy solids (DS)	44.5 (6.92)	56.0 (0.00)	46.3 (4.82)
Peppermint hay (PH)	48.0 (8.00)	47.7 (10.69)	36.1 (12.92)
Composted rabbit manure (RC)	-16.7 (3.09)	18.4 (1.63)	-0.1 (3.06)
Rabbit manure (RM)	12.7 (21.95)	28.4 (9.79)	10.4 (8.67)
Yard-trimmings (YT)	43.0 (13.00)	38.8 (10.87)	10.6 (15.81)
Composted yard-trimmings (YTC)	28.4 (11.88)	41.7 (10.99)	23.5 (11.43)

†The growth stage obtained by sweet corn [Jubilee]; crop model of Coop et al. (1993) and compared with "How a Corn plant develops" by Ritchie et al. (1993). VT stage means vegetative stages at tasseling, R1-2 means reproductive stage between blister and milk, and R3 means reproductive stage at milk. The late SPAD reading collected before harvesting.

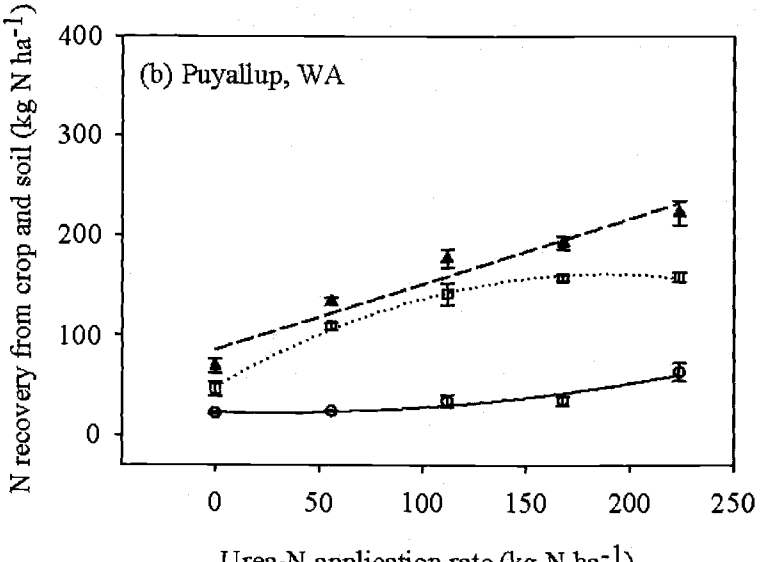
‡Fertilizer N Equivalency calculation limited to regression line between 0 and 112 kg urea-N ha^{-1} maximum FNE = 56 kg N ha^{-1}.



□ Crop N uptake: $y = 46.88+1.17x-0.0022x^2$ ($R^2=0.99$; $P=0.0057$)

○ Soil NO_3-N post-harvest; $y = 7.71-0.56x+0.005x^2$ ($R^2=0.98$; $P=0.0161$)

▲ N recovery from crop and soil: $y = 42.69+1.048x$ ($R^2=0.90$; $P=0.0026$)



□ Crop N uptake: $y = 48.45+1.2x-0.0032x^2$ ($R^2= 0.99$; $P=0.0028$)

○ Soil NO_3-N post-harvest: $y = 23.60-0.0517+0.0010x^2$ ($R^2=0.92$; $P=0.0764$)

▲ N recovery from crop and soil: $y = 85.94+0.6520x$ ($R^2=0.94$; $P=0.0061$)

Fig. 3.2. Amount of crop N uptake, soil NO_3-N post-harvest and N recovery from crop and soil as affected by urea-N application rate at NWREC, OR (a), and Puyallup, WA (b). The quadratic and linear models were fit to average values (n=4).

As shown in Fig 3.2, N recovery (crop + soil) was related mostly to crop N uptake at rate between 0 to 112 kg N ha^{-1} of N fertilizer applied. After that, N recovery (crop + soil) was mainly a function of soil NO_3-N accumulation indicated by the flat part of the response curve of crop N uptake at rate between 112 to 224 kg N ha^{-1} of N fertilizer applied. The model of N recovery that was used incorporated both crop N uptake and soil NO_3-N after harvest.

Ear yield quality and quantity are shown in Table 3.5; Fig 3.3 represents a quadratic-plateau relationship between ear yield and N fertilizer application rate. As shown by aboveground biomass harvest, ear yield responses to organic amendments were equivalent to N fertilizer rates as applied fertilizer treatments at rates between 56 to 112 kg N ha^{-1} at both sites. For ear yield response, a quadratic-plateau model was fit. Cerrato and Blackmer (1990) evaluated five models including linear-plateau, quadratic-plateau, quadratic, exponential and square root to describe crop yield response to several applied fertilizer rates. They concluded that a quadratic-plateau was the best for prediction of optimal fertilizer rate and maximum ear yield. In addition, grain yield reached a plateau at approximately 100 and 150 kg N ha^{-1} (Cerrato and Blackmer, 1990). In our study, ear yield at the NWREC site did not respond to increasing N fertilizer inputs above 125 kg N ha^{-1}(Fig. 3.3). Similarly, Gale (2005) found plateaus for ear yield at average approximately 120 kg N ha^{-1} in 2002 and 220 kg N ha^{-1} in 2003 in both the NWREC site and the Puyallup site. The quadratic-plateau model of the Puyallup site was less responsive than that of NWREC, OR site. Ear yield at the Puyallup site in this study reached the maximum yield plateau at 80 kg N ha^{-1} (Fig 3.3). Therefore, the Puyallup ear yield model did not detect response to N fertilizer inputs greater than 80 kg N ha^{-1}. At the Puyallup site, we present only N recovery from crop + soil (full season PAN).

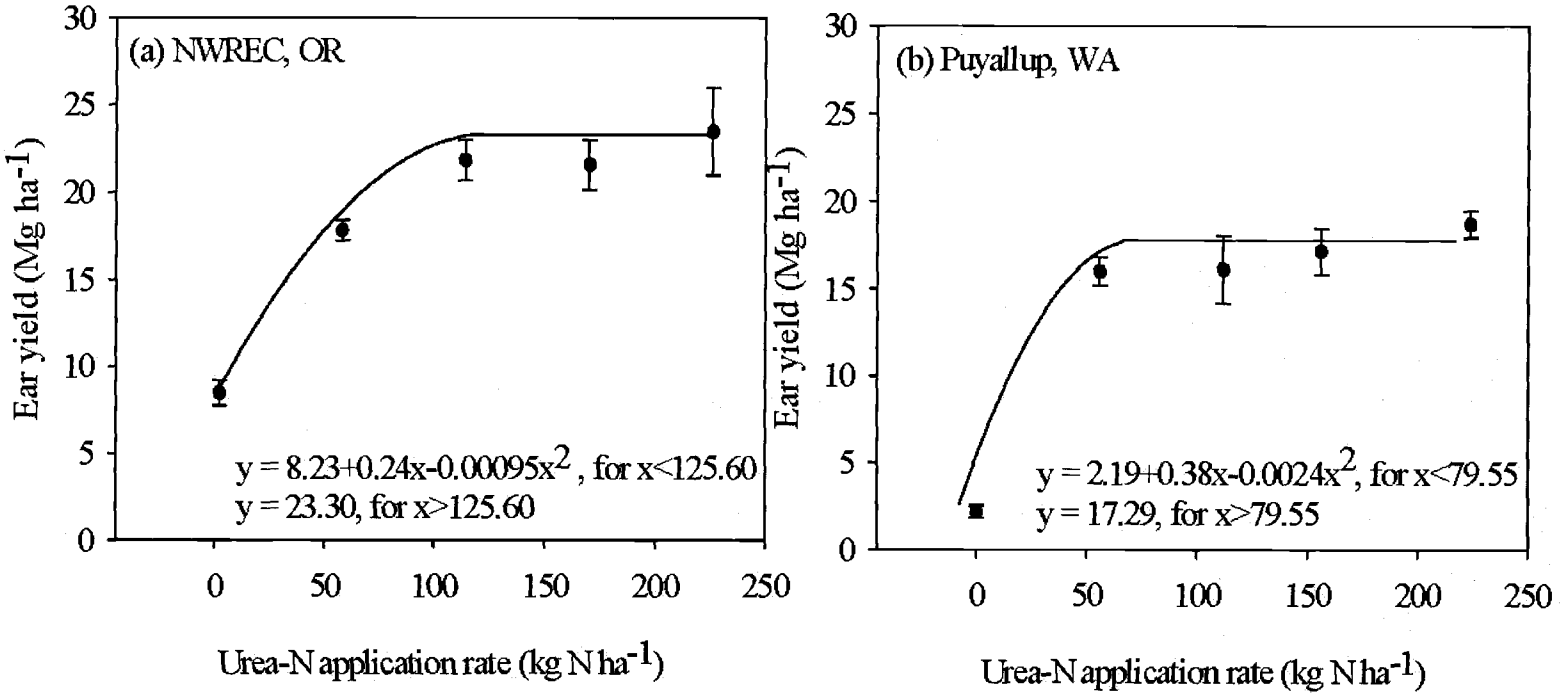


Fig. 3.3. Ear yield as a function of urea N application rate North Willamette Research Center Extension, OR (a), and Washington State University Puyallup Research Center, WA (b). A quadratic plateau model was fit to average values (n=4).

SPAD data were collected at three growing stages: 1) vegetative stage at tasseling (VT); 2) reproductive stage between blister and milk (R1-2); and 3) reproductive stage at milk (R3) as shown in Table 3.6. Wood et al. (1992) suggested that SPAD readings of 56.4 at the V10 growing stage was a critical value for corn (*Zea mays* L.) in Norfolk sandy loam soil in AL. However, this critical value depends on several factors such as plant variety, environmental factors and crop growing stage (Peterson et al., 1993). In this study, SPAD readings from organic amendment treatments were approximately between 30 and 50 at three growth stages. These values are comparable with SPAD readings from organic amendment treatments in 2003 at the same field site at NWREC (Gale, 2005). A quadratic model was fit between SPAD meter reading parameters and fertilizer application rates (Fig 3.4). The SPAD reading models were highly correlated (r^2=0.9) with urea-N application rate in all growing stages. Because of variability of SPAD data across dates, all three growth stages results were used to calculate PAN. Average values across all three SPAD determinations are presented in Table 3.7.

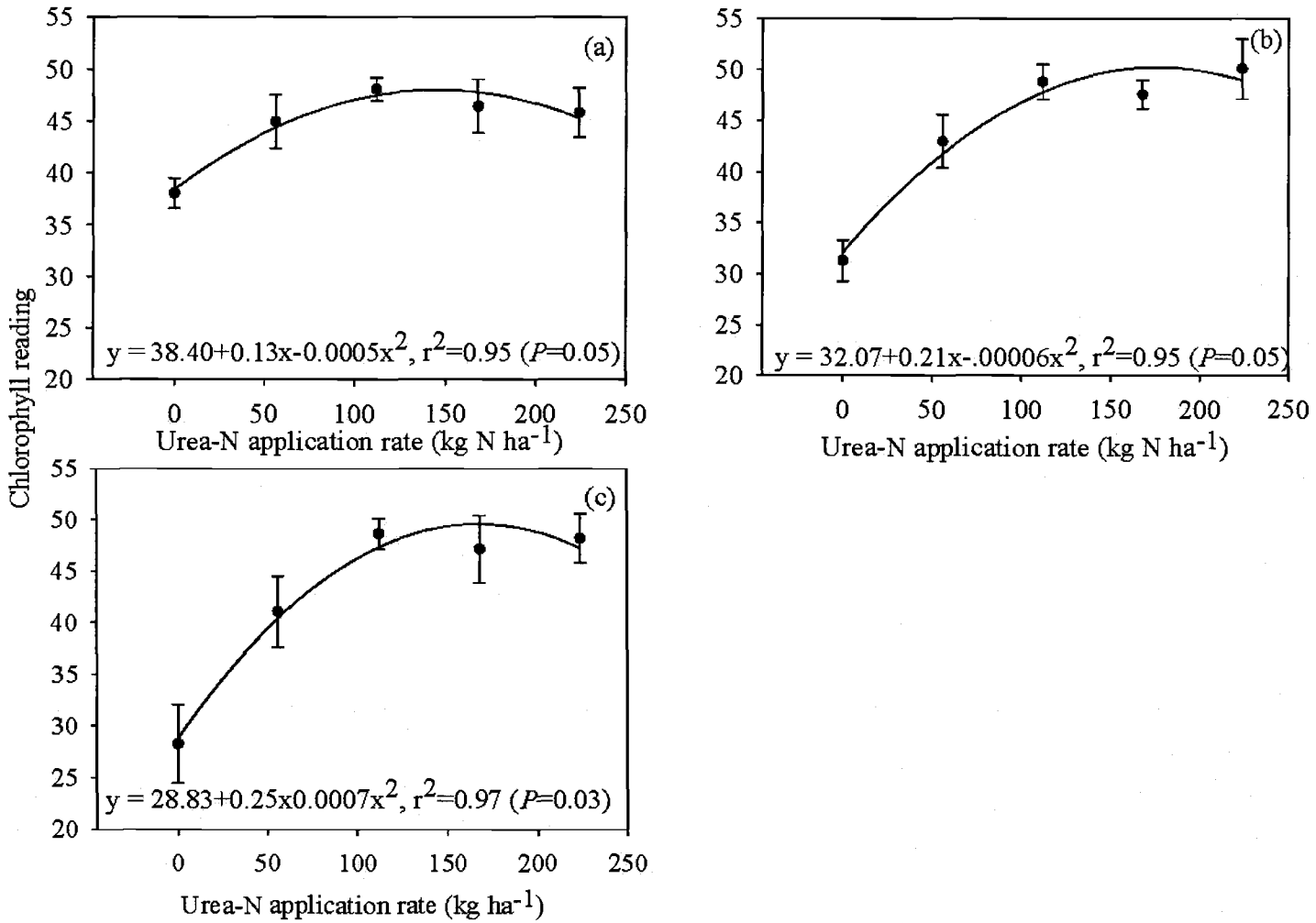


Fig. 3.4 SPAD chlorophyll reading as a function of urea N-application rate collected at 27 July 2004 or Vegetative stage at tasseling (VT) (a), 10 August 2004 or Reproductive stage between blister and milk (R1-2) (b), and 30 August 2004 or Reproductive stage at milk (R3) (c). A quadratic pleateau model was fit to average values (n=4).

Table 3.7. Plant-available N from organic amendments in the second year after application according to the fertilizer equivalence approach, using crop parameter at the North Willamette Research Extension Center, OR (mean and SE). Page 1/2.

Treatment	Total N applied in 2003	Total N as inorganic N applied in 2003	Full season in 2003†	FNE from full season in 2004‡	Full season in 2004†	Ear yield	SPAD§
	kg N ha^{-1}	%	%	kg N ha^{-1}	%	%	%
NWREC, OR							
			Other treatments (field data only)				
Composted dry broiler litter (CC)	168	21.9	40.0	22.3 (11.31)	13.2 (6.72)	-1.5 (4.62)	12.9 (8.81)
Dry broiler litter (CM)	173	13.9	47.7	-0.5 (12.68)	-0.3 (7.34)	-3.5 (3.12)	2.1 (7.61)
Rabbit manure (RM)	408	29.8	29.2	28.8 (8.61)	7.1 (2.11)	-0.5 (1.64)	4.2 (3.42)
Yard-trimmings (YT)	273	17.1	22.1	19.0 (12.74)	6.9 (4.67)	8.7 (6.96)	11.3 (5.22)
			Treatment selected for N mineralization study§				
Anaerobically digested dairy solid (AD)	789	13.0	13.1	47.0 (11.39)	6.0 (1.44)	2.9 (2.01)	6.2 (0.64)
Composted dairy solids (DC)	682	2.9	5.5	68.1 (15.09)	10.0 (2.21)	3.2 (1.31)	6.3 (0.98)
Dairy solids (DS)	507	8.0	7.2	27.3 (15.79)	5.4 (3.12)	10.4 (2.57)	9.7 (1.01)
Peppermint hay (PH)	698	1.1	7.4	37.7 (7.44)	5.4 (1.06)	3.8 (2.99)	6.3 (1.27)
Composted rabbit manure (RC)	349	10.6	24.9	14.6 (7.16)	4.2 (2.05)	-0.1 (2.07)	0.2 (2.25)
Composted yard-trimmings (YTC)	505	5.3	14.5	29.5 (17.14)	5.8 (3.39)	1.6 (0.77)	6.2 (2.20)

† % PAN from full season obtained from crop N uptake + soil NO_3-N post-harvest.

‡ FNE values were obtained by the inverse prediction method from Eq. [1], and then these values were subtracted with amount of urea N applied before planting (56 kg N ha^{-1}).

§ % PAN from SPAD reading obtained from the average of three SPAD meter readings during the growing season.

¶ Treatments with highest total N application rates in 2003 (ranging from 349 to 789 kg N ha^{-1}) selected for additional N mineralization testing.

Table 3.7. Plant-available N from organic amendments in the second year after application according to the fertilizer equivalence approach, using crop parameter at the Washington State University Puyallup Research Center, WA (mean and SE). Page 2/2.

Treatment	Total N applied in 2003	Total N as inorganic N applied in 2003	Full season in 2003†	FNE from full season in 2004‡	Full season in 2004†
	kg N ha^{-1}	%	%	kg N ha^{-1}	%
Puyallup, WA					
		Other treatments (field data only)			
BioGro (BG)	123	1.2	59.9	15.0 (3.52)	12.3 (2.87)
Canola meal (CAN)	156	0.2	60.4	15.3 (16.11)	9.8 (10.36)
Composted dry broiler litter (CC)	169	22.8	42.8	2.7 (7.97)	1.6 (4.71)
Dry broiler litter (CM)	178	14.7	37.4	13.0 (5.89)	7.3 (3.31)
Rabbit manure (RM)	304	21.2	25.0	-10.9 (8.16)	-3.6 (2.69)
Yard-trimmings (YT)	353	24.4	27.9	45.6 (9.70)	12.9 (2.75)
		Treatment selected for N mineralization study§			
Dairy solids (DS)	429	15.5	17.4	28.0 (4.84)	6.5 (1.13)
Composted dairy solids (DC)	622	3.9	15.9	27.1 (11.39)	4.4 (1.83)
On-farm compost (OFC)	768	7.7	13.2	41.5 (13.64)	5.4 (1.78)
Composted rabbit manure (RC)	321	6.1	19.3	38.5 (24.67)	11.9 (7.68)
Composted yard-trimmings (YTC)	605	8.4	19.5	43.9 (13.04)	7.3 (2.16)

† % PAN from full season obtained from crop N uptake + soil NO_3-N post-harvest.

‡ FNE values were obtained by the inverse prediction method from Eq. [1], and then these values were subtracted with amount of urea N applied before planting (56 kg N ha^{-1}).

§ Treatments with highest total N application rates in 2003 (ranging from 321 to 768 kg N ha^{-1}) selected for additional N mineralization testing.

Plant-available nitrogen (PAN): All amendment treatments were only in 2003, but not in 2004. Therefore, PAN presented in this study is for the second year after amendment application. Plant-available N in the field studies was determined by using net FNE divided by total N applied. For example, in Table 3.4, N recovery (crop + soil) from dairy solids treatment at NWREC site was 130 kg N ha^{-1}. Based on the regression curve and the corresponding equation (Fig 3.2 and Eq. [1] in Methods and Materials), FNE of the organic amendment was obtained by using the inverse prediction method between urea-N application rate and response variables. In the 2004 field experiment, all organic amendment treatments and the no-amendment control treatment received a blanket urea application of 56 kg N ha^{-1}. Therefore, FNE values were subtracted from the amount of urea N applied before planting (56 kg N ha^{-1}) to obtain net FNE values. Plant-available N from dairy solids was equivalent to 27 kg urea-N ha^{-1} (equivalent to 83 kg urea-N ha^{-1} from regression minus 56 kg N ha^{-1} urea-N applied). After dividing by total N applied in 2003, the 2004 dairy solids N recovery (crop + soil) was calculated to be equivalent to 5.4% of total N applied in 2003 (Table 3.7 and Eq. [4]).

Nitrogen recovery from crop N uptake + soil NO_3-N after harvest, ear yield or SPAD meter readings parameter were used to calculate PAN values for organic amendments in the second year after application in NWREC site. Only N recovery from crop N uptake + soil NO_3-N after-harvest parameter was used to calculate PAN in Puyallup site (Table 3.7). Estimates amount of PAN from N recovery (crop + soil) and SPAD meter readings had similar patterns, while ear yield was not consistent with other measurements. Munoz et al. (2004) argued that N uptake is accumulated and taken by the crop through the whole season. In addition, Jokela, (1992) found the N uptake model is more responsive than in the yield response model. Yields were increased by N fertilizer at the rate of 112 kg N ha^{-1}. In contrast with crop N uptake, ear yield depends not only on N available from organic amendment but also weather or management during the reproductive stage. As with ear yield response, SPAD

meter readings do not increase with N supply after leaves reach maximum chlorophyll content or greenness at high fertilization application rate (Schepers et al., 1992).

The estimate of PAN in the second-year after amendments application was not significantly different among organic treatments ranging from -0.3 to 13.2% (average 6.4%) of total N applied in 2003 at the NWREC site, and ranging from -3.6 to 12.9% (average 6.9%) of total N applied in 2003 at the Puyallup site. Nitrogen availability in the second year after application is much less affected by the source of organic amendment and properties of soil than in the year of application.

Estimates of PAN under field conditions are subject to high variability (Cusick et al., 2002). In our study, some of the measured variability in crop response to the N supply is probably associated with variation in the plant population. At the NWREC site, whole-plants harvested from different treatments ranged from 44 to 62 thousand of plants ha^{-1} due to the variability in seeding emergence (Table 3.4). The harvested plant population in 2004 was less than observed at the same site in 2003. Plant populations in 2003 ranged from 84 to 99 thousand of plant ha^{-1} (Gale, 2005). Estimates of PAN for ear yield response were lower than those of PAN for N recovery from crop N uptake + soil NO_3-N after harvest. These results suggested that a substantial portion of PAN from amendments was mineralized late in the growing season after critical growth stages that determine ear yield.

Incubation methods

Three incubation methods including field microplot, laboratory aerobic incubation and anaerobic incubation also were conducted to further evaluate N mineralization in the second year after application. Organic amendments were included in the additional N mineralization study had higher rates application in Year 1 (2003) ranging from 321 to 789 kg total N ha^{-1} (average 571 kg total N ha^{-1}). Nitrogen mineralization was determined for these treatments: anaerobically digested dairy solids, composted dairy solids, dairy solids, peppermint hay, composted rabbit manure, and composted yard trimmings at the NWREC site; dairy solids, composted dairy solids, on-farm compost, composted rabbit manure, and composted yard trimmings at the Puyallup site. The overall results of these methods are shown in Table 3.8. Table 3.8a and Table 3.8b show estimates of PAN from the field microplot and the laboratory incubation method at NWREC site and Table 3.8c from Puyallup site. Organic amendment treatments were compared using least-significant differences technique when ANOVA indicated a significant difference among treatments at $P<0.05$. All organic amendment treatments were compared with no-amendment using contrast technique. Amendments included in all experiments (field FNE, field microplot, lab aerobic, lab anaerobic) were compared to a no-amendment control treatment (56 kg fertilizer N ha-1). These treatments (N fertilizer or amendment) were applied in 2003 only; the amendments and fertilizer treatments were not re-applied to the same plots in 2004. In the 2004 field experiment, all amendment treatments and the no-amendment control treatment (56 N) received blanket broadcast N fertilization at the rate of 56 kg N/ha just prior to seeding. For microplot, lab aerobic and lab anaerobic measurements, soil was collected prior to blanket N fertilization (Table 3.3).

Table 3.8(a). Estimates of plant-available N in the second year after application by field microplot and laboratory incubation methods at the North Willamette Research Extension Center, OR (mean and SE)†. Page 1/3.

Treatment	Field microplots 30 d‡	Aerobic incubation 90 d	Anaerobic incubation 7 d
	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
NWREC, OR			
Urea (56 kg N ha^{-1})	12.8	33.1	13.8
Urea (112 kg N ha^{-1})	17.2	34.4	15.1
Anaerobically digested dairy solid (AD)	32.5	61.6	40.7
Composted dairy solids (DC)	31.4	56.0	27.6
Dairy solids (DS)	31.1	51.2	29.7
Peppermint hay (PH)	32.3	61.7	21.9
Composted rabbit manure (RC)	22.3	42.1	18.7
Composted yard-trimmings (YTC)	23.0	45.9	19.8

†Amount of NO_3-N determined for field microplots and aerobic incubation methods, while amount of NH_4-N determined for anaerobic incubation method.
‡Field microplot data for 30 d at NWREC presented because data for 60 and 90 d was invalidated by root growth into microplots. Accumulated degree days from microplot placement into field at 30 d =535.

Table 3.8(b). Estimates of plant-available N in the second year after application by field microplot and laboratory incubation methods at the North Willamette Research Extension Center, OR (mean and SE)†. Page 2/3.

Treatment	Field microplots 30 d‡	Aerobic incubation 90 d	Anaerobic incubation 7 d
	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
	Net amount of N available§		
Anaerobically digested dairy solid (AD)	19.7 (2.47)	28.5 (2.61)	26.3 (2.62)
Composted dairy solids (DC)	18.6 (3.55)	22.9 (3.12)	13.9 (1.56)
Dairy solids (DS)	18.4 (0.92)	18.1 (1.05)	15.1 (3.68)
Peppermint hay (PH)	19.5 (2.09)	28.6 (3.75)	8.1 (1.72)
Composted rabbit manure (RC)	9.6 (1.63)	9.0 (1.70)	2.9 (1.31)
Composted yard-trimmings (YTC)	10.2 (2.35)	12.8 (1.28)	4.2 (1.45)
Significant¶	**	**	**
LSD (0.05)	7.65	6.73	5.85
Urea vs. Amendment	**	**	**
U50 vs. U100	NS	NS	NS
U50 vs. All dairy solids treatment	**	**	**
U50 vs. PH	**	**	**
U50 vs. RC	*	*	NS
U50 vs. YTC	*	**	*

NS,*, ** Not significant, Significant at the 0.05 and 0.01 probability levels, respectively.

†Amount of NO_3-N determined for field microplots and aerobic incubation methods, while amount of NH_4-N determined for anaerobic incubation method.

‡Field microplot data for 30 d at NWREC presented because data for 60 and 90 d was invalidated by root growth into microplots. Accumulated degree days from microplot placement into field at 30 d =535.

§Net amount of NO_3-N available was calculated by Inorganic N content from amended – Inorganic N content from control (urea at rate of 56 kg N ha^{-1}).

¶ Statistical analysis and LSD (0.05) was performed by using raw data.

Table 3.8(c). Estimates of plant-available N in the second year after application by field microplot and laboratory incubation methods at the Washington State University Puyallup Research Center, WA (mean and SE)†. Page 3/3.

Treatment	Field microplots 90 d	Aerobic incubation 90 d	Anaerobic incubation 7 d
	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
Puyallup, WA			
Urea (56 kg N ha^{-1})	31.4	47.5	19.8
Urea (112 kg N ha^{-1})	37.5	44.9	19.4
Dairy solids (DS)	47.7	65.9	29.9
Composted dairy solids (DC)	41.3	65.1	29.1
On-farm compost (OFC)	53.8	66.4	26.5
Composted rabbit manure (RC)	32.2	64.0	20.4
Composted yard-trimmings (YTC)	38.7	74.8	29.0
	Net amount of N available‡		
Dairy solids (DS)	16.3 (1.32)	18.4 (1.87)	10.1 (1.62)
Composted dairy solids (DC)	10.0 (6.48)	17.6 (3.12)	9.2 (5.94)
On-farm compost (OFC)	22.4 (5.23)	18.9 (1.78)	6.7 (0.77)
Composted rabbit manure (RC)	0.8 (10.90)	16.5 (3.67)	0.7 (2.09)
Composted yard-trimmings (YTC)	7.3 (13.88)	27.3 (5.86)	9.3 (2.38)
Significant§	NS	**	*
LSD (0.05)	22.20	9.96	8.62
Urea vs. Amendment		**	**
U50 vs. U100		NS	NS
U50 vs. All dairy solids treatment		**	*
U50 vs. OFC		**	NS
U50 vs. RC		**	NS
U50 vs. YTC		**	*

NS,*, ** Not significant, Significant at the 0.05 and 0.01 probability levels, respectively.

† Amount of NO_3-N determined for field microplots and aerobic incubation methods, while amount of NH_4-N determined for anaerobic incubation method.

‡ Net amount of NO_3-N available was calculated by Inorganic N content from amended – Inorganic N content from control (urea at rate of 56 kg N ha^{-1}).

§Statistical analysis and LSD (0.05) was performed by using raw data.

Microplots were installed in different locations relative to corn rows at the two sites. At the NWREC site, microplots were placed within corn rows, while at the Puyallup field sites; they were positioned in center in inter-row (30 to 40 cm perpendicular to row) between corn rows (Fig 3.1). The development of roots interfered to absorption of resin installed with in corn rows in NWREC, OR after Day 30. Hart et al. (1994) argued that roots probably used resin as a nutrient source and severely influence the estimate of mineralized N. In addition, dried soil ranging from 0.13 to 0.21 g g^{-1} (average 0.17 g g^{-1}; Table 3.9) in some of the microplots probably also affected resin adsorption of NO_3 ion. Lajtha (1988) suggested that the ion resin method is more suitable for measurement of net N mineralization in moist soil since resins are able to capture NO_3-N by percolated water. Because of root interference, the amounts of net NO_3-N available were determined for only Day 30 in NWREC site.

Across from both locations, Table 3.8b and Table 3.8c showed that there was no significant difference in amount of net NO_3-N available from the previous season of urea-N application rate at 56 and 112 kg N ha^{-1}. However, amounts of net NO_3-N available were significantly different between all organic amendment treatments and the control from both the field experiment and laboratory incubations. As found in FNE method, PAN estimates based on field microplots and laboratory incubation were not affected by organic amendments.

The amounts of NO_3-N accumulation from aerobic incubation at NWREC site are showed in Fig 3.5 and the Puyallup site in Fig 3.6. The accumulation of N mineralization from organic amendments had typical patterns during the aerobic incubation period in all treatments and both sites. The amount of net N available from organic amendments did not vary much after 2,400°C degree day (0°C base temperature) of the second year after organic amendment application, average 20 mg kg^{-1} or approximately 6% of total N applied in 2003 for both the NWREC site and the Puyallup site. At Day 90, there was significant difference between treatments when compared with control (P<0.0001).

Table 3.9. Measurement of soil moisture content from microplots incubation (mean and SE).

Sample date	Soil moisture†
	$g\ g^{-1}$
NWREC, OR	
June 24, 2004	0.17 (0.004)
June 30, 2004	0.16 (0.000)
July 13, 2004	0.21 (0.010)
July 28, 2004	0.13 (0.000)
August 12, 2004	0.17 (0.010)
August 31, 2004	0.15 (0.000)
September 22, 2004	0.16 (0.010)
Puyallup, WA	
June 11, 2004	0.15 (0.002)
July 12, 2004	0.10 (0.005)
August 11, 2004	0.27 (0.012)
September 10, 200	0.36 (0.007)

†Soil moisture was averaged across all treatments.

Table 3.10 shows mineralization rate constants of organic amendment treatments defined by using a linear regression equation. The mineralization rate constants were similar in all treatments at average 0.0064 mg kg^{-1} degree day^{-1}.

When compared across experiments, PAN estimates based on laboratory incubation and field experiments were similar as shown in Table 3.11. There was no affect by organic amendments on net NO_3-N available in both sites. However, the amount of net mineralizable N (NH_4-N) from 7-d anaerobic incubation was lower than that of other experiments. Carlyle et al. (1998) argued that field measurements represented the net N mineralization under aerobic incubation, while the anaerobic incubation probably measured N released in part of the microbial biomass.

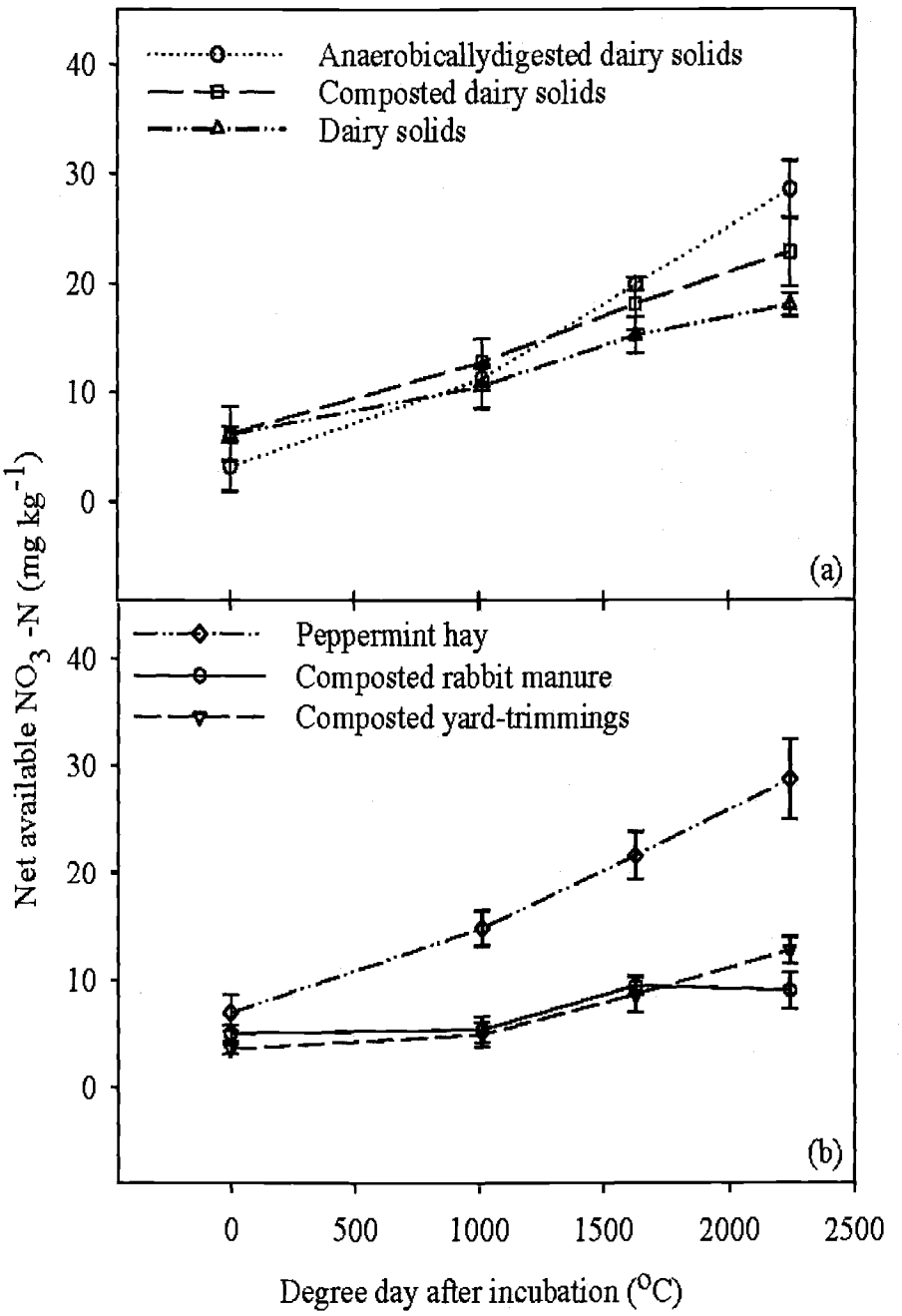


Fig. 3.5. The relationship between amount of NO_3 -N accumulation from aerobic incubation and degree day after incubation at the North Willamette Research Extension Center, OR.Net NO_3-N available were determined by the difference between inorganic N content from amended and inorganic N content from control. The vertical bars are standard errors (n=4).

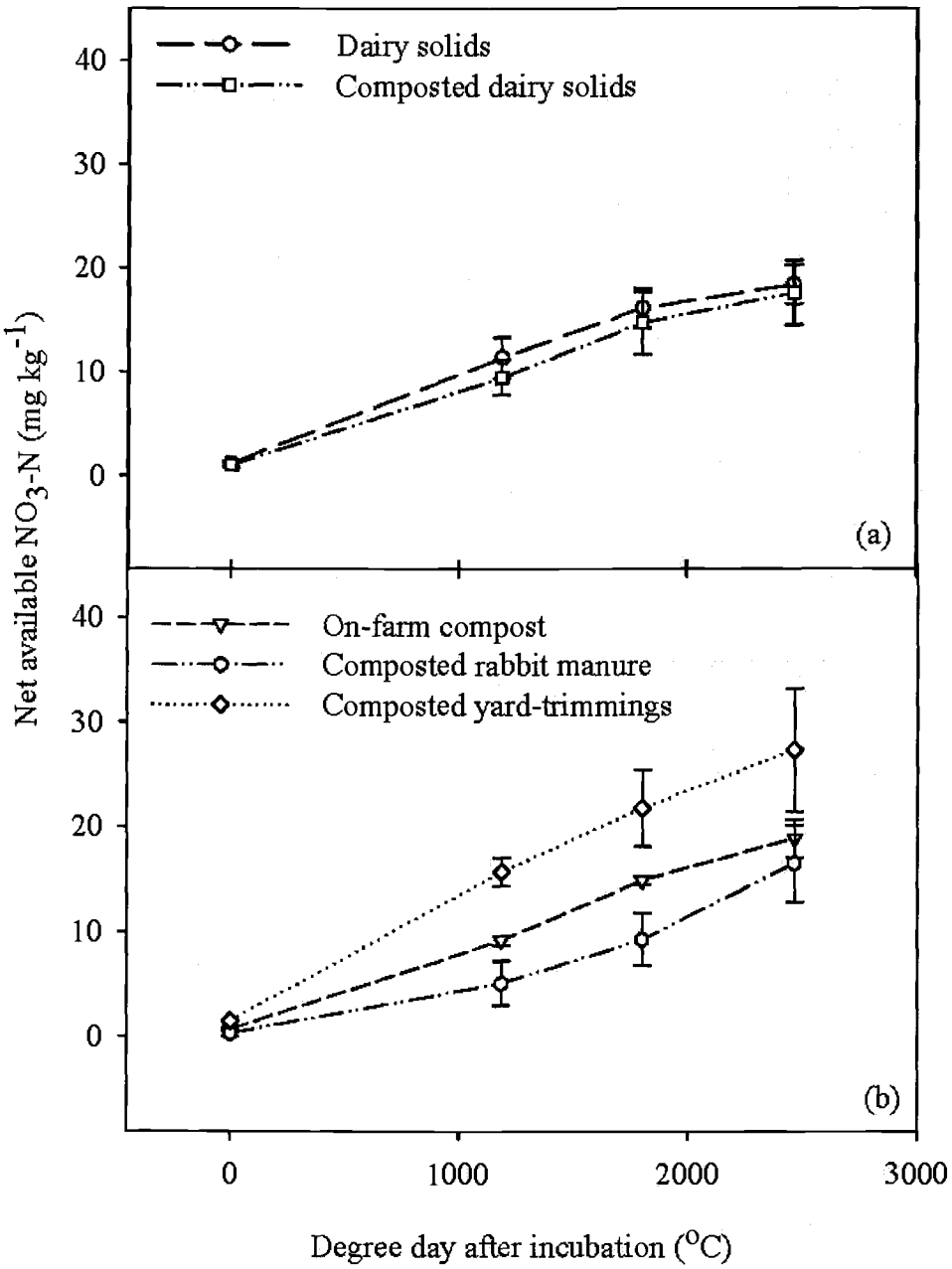


Fig. 3.6. The relationship between amount of NO_3-N accumulation from aerobic incubation and degree day after incubation at the Washington State University Puyallup Research Center, WA. Net NO_3-N available were determined by the difference between inorganic N content from amended and inorganic N content from control. The vertical bars are standard errors (n=4).

Table 3.10. Linear regressions relations between net available N and growing degree day for laboratory aerobic incubation.

Treatment	Intercept	Slope	Adjusted Slope†	R^2	*P*
NWREC, OR					
Anaerobically digested dairy solid (AD)	1.94	0.0113	0.0072	0.98	0.0109
Composted dairy solids (DC)	5.90	0.0075	0.0055	0.99	0.0019
Dairy solids (DS)	5.87	0.0055	0.0054	0.99	0.0061
Peppermint hay (PH)	6.24	0.0096	0.0069	0.99	0.0052
Composted rabbit manure (RC)	2.50	0.0041	0.0059	0.89	0.0548
Composted yard-trimmings (YTC)	4.66	0.0021	0.0021	0.75	0.1364
Puyallup, WA					
Dairy solids (DS)	1.93	0.0072	0.0084	0.97	0.0126
Composted dairy solids (DC)	1.25	0.0069	0.0055	0.99	0.0047
On-farm compost (OFC)	0.62	0.0075	0.0049	0.99	0.0019
Composted rabbit manure (RC)	-0.90	0.0064	0.0100	0.94	0.0303
Composted yard-trimmings (YTC)	2.13	0.0106	0.0088	0.99	0.0035

† Slopes were adjusted for total N application rate by assuming total N application at rate 500 kg N ha^{-1}.

Table 3.11. Summary estimates of plant-available N in the second-year after application by using fertilizer N equivalence, field microplots, laboratory incubation methods†.

Treatment	Laboratory		Field			Average
	Aerobic incubation 90 d	Anaerobic incubation	Field microplots‡	FNE from full season	SPAD	
	%	%	%	%	%	%
NWREC, OR						
Anaerobically digested dairy solid (AD)	7.2 (0.66)	6.7 (0.66)	5.0 (0.63)	6.0 (1.44)	11.4 (2.47)	7.2 (1.22)
Composted dairy solids (DC)	6.7 (0.92)	4.1 (0.46)	5.4 (1.04)	10.0 (2.21)	6.4 (1.55)	6.5 (1.10)
Dairy solids (DS)	7.1 (0.41)	6.0 (1.45)	7.2 (0.36)	5.4 (3.12)	13.8 (4.32)	7.9 (1.69)
Peppermint hay (PH)	8.2 (1.07)	2.3 (0.49)	5.6 (0.60)	5.4 (1.06)	6.6 (1.76)	5.6 (1.08)
Composted rabbit manure (RC)	5.2 (0.97)	1.7 (0.75)	5.5 (0.93)	4.2 (2.05)	0.2 (2.25)	3.3 (1.16)
Composted yard-trimmings (YTC)	5.0 (0.51)	1.7 (0.57)	4.1 (0.93)	5.8 (3.39)	8.2 (4.54)	4.9 (1.19)
Average‡	6.0 (0.53)	3.3 (1.04)	5.6 (0.65)	6.4 (1.26)	7.1 (2.81)	
Puyallup, WA						
Dairy solids (DS)	8.6 (0.87)	4.7 (0.75)	7.6 (0.62)	6.5 (1.13)		6.9 (0.83)
Composted dairy solids (DC)	5.7 (1.00)	3.0 (1.91)	3.2 (2.08)	4.4 (1.83)		4.0 (0.61)
On-farm compost (OFC)	4.9 (0.46)	1.8 (0.20)	5.8 (1.36)	5.4 (1.78)		4.5 (0.93)
Composted rabbit manure (RC)	10.3 (2.29)	0.4 (1.30)	0.5 (6.79)	11.9 (7.68)		5.8 (3.08)
Composted yard-trimmings (YTC)	9.0 (1.94)	3.1 (0.79)	0.4 (4.59)	7.3 (2.16)		5.4 (1.61)
Average§	8.4 (0.98)	2.8 (0.89)	3.4 (1.50)	7.5 (1.58)		

†Assuming that soil collected at 0-15 cm depth and soil bulk density at 1.3 g cm^{-3} for laboratory and field microplots incubation.

‡Field microplot data for 30 d (NWREC) and 90 d (Puyallup)

§Only composted dairy solids (DC), dairy solids (DS), Composted rabbit manure (RC), and Composted yard-trimmings (YTC) used in both sites were averaged.

CONCLUSIONS

Using the FNE method based on N recovery from crop N uptake + soil NO_3-N post-harvest, ear yield and SPAD reading meter readings were used to estimate PAN from organic amendments in the second year after application. Estimates of PAN based N recovery from crop N uptake + soil NO_3-N post-harvest and SPAD meter readings gave similar results. The PAN values based on ear year were consistently low when compared with other parameters indicating that some parts of PAN were mineralized late in the growing season. The N recovery (crop + soil) parameter was the best predictive model because this parameter incorporated both the amount of N actually taken up by plant and excessive PAN remaining in the soil. Of the *in situ* methods used in this study, the FNE method was most representative of actual field soil conditions. Our study showed that the amount of PAN from organic amendment treatments was relatively low in the second year after application. The average across all organic amendment treatments location were approximately 6% of total N applied in 2003 based on FNE, field microplots and laboratory incubations. In addition, these values were not affected by organic amendment treatments and soils. Laboratory aerobic incubation also confirmed that there was no affect of organic amendment treatments on NO_3-N available in the second year application average across organic treatments and locations approximately mineralized at 0.0071 mg N mineralized kg^{-1} dry soil degree day^{-1}. This finding is important because it means that N availability from organic amendments after the following year of application is not strongly influenced by the sources of organic amendment and soil properties. This effect is much less than in the year of application.

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CONCLUSIONS

This study found that the long-term application of organic amendments had an accumulative effect on N availability during the following year after application. The first study (Chapter 2) discussed soil with and without a history serial of screened dairy solids application. This study demonstrated that screened dairy solids were immobilized in the first year after application and then mineralized in the fall season. Screened dairy solids were mineralized in the following year after application. Soil applied manure for 2 to 3 previous years had a mineralization constant rate at 0.01 mg N kg^{-1} dry soil degree day^{-1}. Nitrogen mineralized from the current season manure application was additive to N mineralized from previous year manure applications.

The second study (Chapter 3) estimated plant-available N (PAN) from various organic amendments in the second year after application. Fertilizer N equivalence (FNE) method was calculated based on N recovery (crop + soil), ear yield and SPAD meter reading. N recovery (crop + soil) were used to estimate PAN from both sites since this crop response parameter was more responsive than other parameters. Organic amendment applied high rate in 2003 were selected to conducted field microplot, aerobic and anaerobic incubation. The PAN estimated from FNE based on N recovery (crop + soil), field microplot, aerobic, and anaerobic laboratory incubation generated similar values. The average across organic amendment treatments and locations was approximately 6% of total N applied in previous year. Organic amendments had a mineralization rate of constant approximately 0.0071 mg N mineralized kg^{-1} dry soil degree day^{-1}.

From both studies, laboratory aerobic incubation is more reliable than other approaches since PAN estimated from aerobic laboratory incubation was closely related with PAN measured from field methods. Laboratory anaerobic incubation was not suitable for soil that had received manure during the previous 30 d.

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APPENDIX

Appendix 1. Average of soil moisture content from microplots and aerobic incubation in fall season 2004 at Vegetable Research Farm (mean and SE).

Treatment	Sample date			
	0 d	107 d		
	g g^{-1}	g g^{-1}		
2004				
		Field microplots incubation		
Applied manure from 2001 to 2003	0.19 (0.009)	0.38 (0.010)		
Applied manure from 2001 to 2004	0.21 (0.009)	0.40 (0.007)		
First year application in 2004	0.20 (0.005)	0.36 (0.011)		
No amendment	0.17 (0.006)	0.36 (0.013)		
		Laboratory aerobic incubation		
	0 d	33 d	61 d	98 d
Applied manure from 2001 to 2003	0.19 (0.009)	0.28 (0.012)	0.24 (0.002)	0.27 (0.013)
Applied manure from 2001 to 2004	0.21 (0.009)	0.26 (0.012)	0.24 (0.010)	0.27 (0.019)
First year application in 2004	0.20 (0.005)	0.27 (0.010)	0.23 (0.005)	0.24 (0.016)
No amendment	0.17 (0.006)	0.25 (0.004)	0.23 (0.004)	0.26 (0.004)

Appendix 2. Measurement of soil moisture content from microplots incubation in fall season 2004 at Vegetable Research Farm.

Treatment	Sample date	
	0 d	107 d
	g g^{-1}	g g^{-1}
Applied manure from 2001 to 2003 (rep1)	0.19	0.38
Applied manure from 2001 to 2003 (rep2)	0.22	0.40
Applied manure from 2001 to 2003 (rep3)	0.18	0.35
Applied manure from 2001 to 2003 (rep4)	0.18	0.40
Applied manure from 2001 to 2004 (rep1)	0.21	0.42
Applied manure from 2001 to 2004 (rep2)	0.24	0.40
Applied manure from 2001 to 2004 (rep3)	0.21	0.39
Applied manure from 2001 to 2004 (rep4)	0.19	0.39
First year application in 2004 (rep1)	0.21	0.37
First year application in 2004 (rep2)	0.19	0.38
First year application in 2004 (rep3)	0.20	0.37
First year application in 2004 (rep4)	0.19	0.33
No amendment (rep1)	0.18	0.40
No amendment (rep2)	0.15	0.36
No amendment (rep3)	0.17	0.35
No amendment (rep4)	0.18	0.34

Appendix 3. Measurement of soil moisture content from aerobic incubation in fall season 2004 at Vegetable Research Farm.

Treatment	Sample date			
	0 d	33 d	61 d	98 d
	$g\ g^{-1}$	$g\ g^{-1}$	$g\ g^{-1}$	$g\ g^{-1}$
Applied manure from 2001 to 2003 (rep1)	0.19	0.25	0.25	0.29
Applied manure from 2001 to 2003 (rep2)	0.22	0.28	0.24	0.24
Applied manure from 2001 to 2003 (rep3)	0.18	0.26	0.24	0.29
Applied manure from 2001 to 2003 (rep4)	0.18	0.31	0.24	0.25
Applied manure from 2001 to 2004 (rep1)	0.21	0.23	0.23	0.23
Applied manure from 2001 to 2004 (rep2)	0.24	0.28	0.23	0.28
Applied manure from 2001 to 2004 (rep3)	0.21	0.28	0.27	0.32
Applied manure from 2001 to 2004 (rep4)	0.19	0.24	0.24	0.27
First year application in 2004 (rep1)	0.21	0.26	0.23	0.25
First year application in 2004 (rep2)	0.19	0.26	0.23	0.20
First year application in 2004 (rep3)	0.20	0.29	0.24	0.28
First year application in 2004 (rep4)	0.19	0.25	0.22	0.23
No amendment (rep1)	0.18	0.26	0.24	0.25
No amendment (rep2)	0.15	0.25	0.24	0.26
No amendment (rep3)	0.17	0.26	0.23	0.25
No amendment (rep4)	0.18	0.24	0.22	0.27

Appendix 4. Accumulation of NO_3-N from soil and resins from microplots incubation in fall season 2004 at Vegetable Research Farm.

Treatment	Sample date†					
	0 d			107 d		
	Soil	Resin	Soil +Resin	Soil	Resin	Soil +Resin
	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
Applied manure from 2001 to 2003 (rep1)	6.3	-	6.3	2.6	47.3	49.8
Applied manure from 2001 to 2003 (rep2)	10.6	-	10.6	2.6	28.1	30.7
Applied manure from 2001 to 2003 (rep3)	10.5	-	10.5	1.9	27.9	29.8
Applied manure from 2001 to 2003 (rep4)	7.6	-	7.6	4.8	35.5	40.3
Applied manure from 2001 to 2004 (rep1)	6.5	-	6.5	3.9	26.7	30.6
Applied manure from 2001 to 2004 (rep2)	18.3	-	18.3	2.3	32.3	34.6
Applied manure from 2001 to 2004 (rep3)	19.1	-	19.1	3.2	44.9	48.1
Applied manure from 2001 to 2004 (rep4)	3.2	-	3.2	2.7	27.5	30.3
First year application in 2004 (rep1)	5.5	-	5.5	1.3	25.8	27.1
First year application in 2004 (rep2)	4.0	-	4.0	1.7	33.8	35.5
First year application in 2004 (rep3)	12.4	-	12.4	1.4	35.2	36.6
First year application in 2004 (rep4)	11.0	-	11.0	1.4	24.3	25.8
No amendment (rep1)	5.2	-	5.2	1.3	22.8	24.1
No amendment (rep2)	3.0	-	3.0	1.7	22.5	24.2
No amendment (rep3)	5.3	-	5.3	1.1	17.8	18.8
No amendment (rep4)	7.6	-	7.6	1.5	25.0	26.5

† Microplots were installed in October 14, 2004 (Day 0) and harvested in January 29, 2004 (Day 107) or at 0 and 709 degree day (0°C base temperature), respectively. This degree day obtained from http://pnwpest.org/cgi-bin/ddmodel.pl.

Appendix 5. Average of soil NO_3-N from microplots and aerobic incubation in fall season 2004 at Vegetable Research Farm (mean and SE).

Treatment	Sample date			
	0 d	107 d		
	mg kg^{-1}	mg kg^{-1}		
		Field microplots incubation		
Applied manure from 2001 to 2003	8.8 (1.07)	37.7 (4.70)		
Applied manure from 2001 to 2004	11.8 (4.05)	35.9 (4.18)		
First year application in 2004	8.2 (2.04)	31.2 (2.80)		
No amendment	5.3 (0.95)	23.4 (1.61)		
		Laboratory aerobic incubation		
	0 d	33 d	61 d	98 d
Applied manure from 2001 to 2003	8.8 (1.07)	23.7 (1.75)	36.0 (1.43)	45.9 (3.58)
Applied manure from 2001 to 2004	11.8 (4.05)	30.8 (8.05)	43.0 (10.26)	55.1 (11.36)
First year application in 2004	8.2 (2.04)	19.9 (3.44)	31.2 (3.49)	40.3 (4.17)
No amendment	5.3 (0.95)	15.2 (1.30)	23.6 (1.74)	29.1 (1.44)

Appendix 6. Measurement of soil NO_3-N from aerobic incubation in fall season 2004 at Vegetable Research Farm.

Treatment	Sample date†			
	0 d	33 d	61 d	98 d
	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
Applied manure from 2001 to 2003 (rep1)	6.3	20.2	32.8	38.8
Applied manure from 2001 to 2003 (rep2)	10.6	22.5	35.1	41.6
Applied manure from 2001 to 2003 (rep3)	10.5	23.6	36.6	48.3
Applied manure from 2001 to 2003 (rep4)	7.6	28.5	39.6	54.8
Applied manure from 2001 to 2004 (rep1)	6.5	18.0	26.7	37.0
Applied manure from 2001 to 2004 (rep2)	18.3	29.4	40.5	51.2
Applied manure from 2001 to 2004 (rep3)	19.1	53.9	72.5	88.1
Applied manure from 2001 to 2004 (rep4)	3.2	22.0	32.1	44.1
First year application in 2004 (rep1)	5.5	13.3	25.4	34.0
First year application in 2004 (rep2)	4.0	16.0	27.2	35.6
First year application in 2004 (rep3)	12.4	29.0	41.1	52.3
First year application in 2004 (rep4)	11.0	21.2	31.3	39.2
No amendment (rep1)	5.2	15.3	23.8	30.5
No amendment (rep2)	3.0	11.9	19.8	26.3
No amendment (rep3)	5.3	18.3	28.2	32.5
No amendment (rep4)	7.6	15.2	22.8	27.2

†Soils were incubated at 22°C in October 14, 2004 (Day 0), November 16, 2004 (Day 33), December 14, 2004 (Day 61) and January 20, 2004 (Day 98) at 0, 726, 1342 and 2156 degree day (0°C base temperature), respectively.

Appendix 7. Degree day during the growing season at Vegetable Research Farm in 2003. Page1/2†.

Date	Air temperature		Precipitation	Degree Day	Cumulative Degree Day‡	
	Maximum	Minimum				
	(°F)	(°F)	(cm)	(°F)	(°F)	(°C)
July,10	84	50	0.00	35	71	22
July,11	85	50	0.00	36	107	42
July,12	81	50	0.00	34	141	60
July,13	77	59	0.00	36	177	80
July,14	84	47	0.00	33	210	99
July,15	79	52	0.00	33	243	117
July,16	79	59	0.00	37	280	138
July,17	86	53	0.00	38	318	159
July,18	91	50	0.00	38	356	180
July,19	92	50	0.00	39	395	202
July,20	91	53	0.00	40	435	224
July,21	95	63	0.00	47	482	250
July,22	93	59	0.00	44	526	274
July,23	86	53	0.00	37	563	295
July,24	84	51	0.00	35	599	315
July,25	83	50	0.00	34	633	334
July,26	84	46	0.00	33	666	352
July,27	92	54	0.00	41	707	375
July,28	98	55	0.00	44	752	400
July,29	100	53	0.00	45	797	425
July,30	98	54	0.00	44	840	449
July,31	91	52	0.00	40	880	471
August,1	85	52	0.00	37	917	491
August,2	72	64	0.00	36	953	511
August,3	79	57	0.00	36	989	531
August,4	88	50	0.00	37	1026	552
August,5	75	54	0.09	32	1058	570
August,6	79	48	0.01	31	1089	587
August,7	81	58	0.00	37	1126	608
August,8	80	54	0.00	35	1161	627
August,9	81	60	0.00	38	1200	649
August,10	80	53	0.00	34	1234	668
August,11	76	51	0.00	32	1266	685
August,12	80	46	0.00	31	1297	703
August,13	84	51	0.00	35	1332	722
August,14	92	56	0.00	42	1374	745
August,15	79	54	0.00	35	1408	765
August,16	81	50	0.00	34	1442	783
August,17	87	60	0.00	42	1484	806

Appendix 7. Degree day during the growing season at Vegetable Research Farm in 2003. Page 2/2†.

Date	Air temperature		Precipitation	Degree Day	Cumulative Degree Day‡	
	Maximum	Minimum				
	(°F)	(°F)	(cm)	(°F)	(°F)	(°C)
August,18	91	58	0.00	42	1526	830
August,19	83	52	0.00	36	1562	850
August,20	82	48	0.00	33	1595	868
August,21	89	48	0.00	37	1632	889
August,22	71	51	0.00	29	1661	905
August,23	77	55	0.00	34	1695	924
August,24	85	47	0.00	34	1729	943
August,25	90	49	0.00	37	1766	963
August,26	78	53	0.00	34	1800	982
August,27	77	56	0.00	35	1834	1001
August,28	85	52	0.00	37	1871	1022
August,29	86	48	0.00	35	1906	1041
August,30	91	50	0.00	38	1945	1063
August,31	86	49	0.00	35	1980	1082
September,1	85	48	0.00	34	2014	1101
September,2	92	51	0.00	40	2054	1123
September,3	93	53	0.00	41	2095	1146
September,4	96	52	0.00	42	2137	1169
September,5	93	51	0.00	40	2177	1191
September,6	71	54	0.00	30	2207	1208
September,7	71	53	0.17	30	2237	1225
September,8	67	49	0.04	26	2263	1239
September,9	69	53	0.42	29	2292	1256
September,10	69	58	0.02	31	2323	1273
September,11	72	56	0.00	32	2355	1291
September,12	71	48	0.00	27	2382	1306
September,13	80	50	0.00	33	2415	1324
September,14	79	46	0.00	31	2446	1341
September,15	70	41	0.00	23	2469	1354
September,16	62	48	0.33	23	2492	1367
September,17	68	43	0.00	23	2515	1380
September,18	77	40	0.00	26	2542	1394
September,19	74	56	0.00	33	2574	1412
September,20	75	49	0.00	30	2604	1429
September,21	78	49	0.00	31	2635	1446
September,22	87	51	0.00	37	2672	1467
September,23	81	53	0.00	35	2707	1486

† Degree day values obtained from http://pnwpest.org/cgi-bin/ddmodel.pl by using Corvallis Hyslop or Agrmt location.

‡ Cumulative degree day can be calculated by (Max.+ Min.)/2 –lower threshold in this study using 0°C as a lower threshold.

Appendix 8. Degree day during the growing season at Vegetable Research Farm in 2004. Page 1/2†.

Date	Air temperature		Precipitation	Degree Day	Cumulative Degree Day‡	
	Maximum	Minimum				
	(°F)	(°F)	(cm)	(°F)	(°F)	(°C)
June,27	79	49	0.00	32	32	0
June,28	83	49	0.00	34	66	19
June,29	82	50	0.00	34	100	38
June,30	83	49	0.00	34	134	57
July,1	80	49	0.00	32	167	75
July,2	79	47	0.00	31	198	92
July,3	78	58	0.00	36	234	112
July,4	78	51	0.00	32	266	130
July,5	82	51	0.00	35	301	149
July,6	84	53	0.00	36	337	170
July,7	73	54	0.00	31	369	187
July,8	75	47	0.00	29	398	203
July,9	74	46	0.00	28	425	219
July,10	73	50	0.00	30	455	235
July,11	81	48	0.00	32	487	253
July,12	90	59	0.00	42	530	276
July,13	83	57	0.00	38	567	297
July,14	85	52	0.00	37	604	318
July,15	81	51	0.00	34	638	337
July,16	87	53	0.00	38	676	358
July,17	87	55	0.00	39	715	379
July,18	88	52	0.03	38	753	400
July,19	81	56	0.01	36	789	421
July,20	82	61	0.00	39	828	442
July,21	87	59	0.00	41	869	465
July,22	96	58	0.00	45	914	490
July,23	102	64	0.00	51	964	518
July,24	98	58	0.00	46	1010	543
July,25	86	52	0.00	37	1047	564
July,26	85	51	0.00	36	1083	584
July,27	90	51	0.00	39	1122	605
July,28	91	54	0.00	40	1162	628
July,29	90	53	0.00	39	1202	650
July,30	82	53	0.00	36	1237	670
July,31	85	51	0.00	36	1274	690
August,1	85	55	0.00	38	1311	711
August,2	80	49	0.00	33	1344	729
August,3	82	49	0.00	33	1377	747
August,4	75	58	0.00	34	1412	766
August,5	76	55	0.00	33	1445	785

Appendix 8. Degree day during the growing season at Vegetable Research Farm in 2004. Page 2/2†.

Date	Air temperature		Precipitation	Degree Day	Cumulative Degree Day‡	
	Maximum	Minimum				
	(°F)	(°F)	(cm)	(°F)	(°F)	(°C)
August,6	72	56	0.10	32	1477	803
August,7	79	47	0.00	31	1508	820
August,8	95	59	0.00	45	1553	845
August,9	97	59	0.00	46	1599	871
August,10	93	56	0.00	43	1642	894
August,11	95	55	0.00	43	1685	918
August,12	91	55	0.00	41	1726	941
August,13	91	54	0.00	40	1766	963
August,14	89	57	0.00	41	1807	986
August,15	84	55	0.00	38	1845	1007
August,16	88	52	0.00	38	1882	1028
August,17	87	53	0.00	38	1920	1049
August,18	90	56	0.00	41	1961	1072
August,19	90	58	0.00	42	2003	1095
August,20	92	57	0.00	43	2046	1119
August,21	83	58	0.00	38	2084	1140
August,22	69	57	1.11	31	2115	1157
August,23	69	55	0.28	30	2144	1174
August,24	71	61	0.00	34	2178	1192
August,25	70	59	0.27	32	2211	1210
August,26	71	57	0.03	32	2243	1228
August,27	77	52	0.00	32	2275	1246
August,28	79	56	0.00	36	2311	1266
August,29	83	57	0.00	38	2349	1287
August,30	89	58	0.00	41	2390	1310

† Degree day values obtained from http://pnwpest.org/cgi-bin/ddmodel.pl by using Corvallis Hyslop or Agrmt location.

‡ Cumulative degree day can be calculated by (Max.+ Min.)/2 –lower threshold in this study using 0°C as a lower threshold.

Appendix 9. Degree day during the growing season at North Willamette Research Extension Center in 2004. Page 1/3†.

Date	Air temperature		Precipitation	Degree Day	Cumulative Degree Day‡	
	Maximum	Minimum				
	(°F)	(°F)	(cm)	(°F)	(°F)	(°C)
June,15	68	51	0.00	28	54	12
June,16	78	48	0.00	31	85	29
June,17	86	51	0.00	37	121	49
June,18	92	60	0.00	44	165	74
June,19	89	61	0.00	43	208	98
June,20	88	53	0.00	39	247	119
June,21	90	51	0.00	39	285	141
June,22	87	54	0.00	39	324	162
June,23	65	55	0.00	28	352	178
June,24	69	57	0.04	31	383	195
June,25	70	59	0.00	33	415	213
June,26	76	58	0.00	35	450	232
June,27	78	52	0.00	33	483	251
June,28	79	57	0.00	36	519	271
June,29	83	51	0.00	35	554	290
June,30	83	51	0.00	37	591	311
July,1	84	52	0.00	36	627	331
July,2	84	52	0.00	36	663	350
July,3	77	53	0.00	33	696	369
July,4	78	56	0.00	35	731	388
July,5	78	51	0.00	33	763	406
July,6	82	51	0.00	35	798	425
July,7	82	57	0.00	38	835	446
July,8	74	54	0.00	32	867	464
July,9	73	49	0.00	29	896	480
July,10	73	52	0.00	31	927	497
July,11	74	56	0.00	33	960	515
July,12	81	53	0.00	35	995	535
July,13	92	57	0.00	43	1037	558
July,14	85	59	0.00	40	1077	581
July,15	87	58	0.00	41	1118	603
July,16	82	56	0.00	37	1155	624
July,17	89	56	0.00	41	1195	646
July,18	83	60	0.00	40	1235	668
July,19	79	61	0.00	38	1273	689
July,20	80	61	0.00	39	1311	711
July,21	81	64	0.00	41	1352	733
July,22	87	57	0.00	40	1392	755
July,23	98	59	0.00	47	1438	781
July,24	100	63	0.00	50	1488	809

Appendix 9. Degree day during the growing season at North Willamette Research Extension Center in 2004. Page 2/3†.

Date	Air temperature		Precipitation	Degree Day	Cumulative Degree Day‡	
	Maximum	Minimum				
	(°F)	(°F)	(cm)	(°F)	(°F)	(°C)
July,25	85	59	0.00	40	1528	831
July,26	86	60	0.00	41	1569	854
July,27	85	52	0.00	37	1605	874
July,28	90	58	0.00	42	1647	897
July,29	91	57	0.00	42	1689	921
July,30	91	57	0.00	42	1731	944
July,31	79	59	0.00	37	1768	964
August,1	87	54	0.00	39	1807	986
August,2	88	55	0.00	40	1846	1008
August,3	82	55	0.00	37	1883	1028
August,4	82	57	0.00	38	1920	1049
August,5	76	60	0.24	36	1956	1069
August,6	76	56	0.00	34	1990	1088
August,7	73	57	0.22	33	2023	1106
August,8	78	57	0.00	36	2059	1126
August,9	95	58	0.00	45	2103	1151
August,10	99	63	0.00	49	2152	1178
August,11	95	58	0.00	45	2197	1203
August,12	96	61	0.00	47	2243	1228
August,13	93	60	0.00	45	2288	1253
August,14	90	59	0.00	43	2330	1277
August,15	89	61	0.00	43	2373	1301
August,16	84	58	0.00	39	2412	1322
August,17	87	57	0.00	40	2452	1344
August,18	88	57	0.00	41	2493	1367
August,19	89	61	0.00	43	2536	1391
August,20	91	60	0.00	44	2579	1415
August,21	90	60	0.00	43	2622	1439
August,22	83	59	0.34	39	2661	1461
August,23	70	59	0.32	33	2694	1479
August,24	70	58	0.16	32	2726	1496
August,25	70	60	0.60	33	2759	1515
August,26	69	58	0.00	32	2790	1532
August,27	74	59	0.08	35	2825	1551
August,28	76	58	0.00	35	2860	1571
August,29	77	55	0.00	34	2894	1590
August,30	81	57	0.00	37	2931	1610
August,31	89	59	0.00	42	2973	1634
September,1	89	57	0.00	41	3014	1656

Appendix 9. Degree day during the growing season at North Willamette Research Extension Center in 2004. Page 3/3†.

Date	Air temperature		Precipitation	Degree Day	Cumulative Degree Day‡	
	Maximum	Minimum				
	(°F)	(°F)	(cm)	(°F)	(°F)	(°C)
September,2	73	54	0.16	32	3045	1674
September,3	69	52	0.02	29	3074	1690
September,4	72	50	0.00	29	3103	1706
September,5	71	57	0.00	32	3135	1724
September,6	75	52	0.00	32	3166	1741
September,7	80	50	0.00	33	3199	1759
September,8	80	50	0.00	33	3232	1778
September,9	77	51	0.00	32	3264	1796

† Degree day values obtained from http://pnwpest.org/cgi-bin/ddmodel.pl by using Aurora or Mtr location.

‡ Cumulative degree day can be calculated by (Max.+ Min.)/2 –lower threshold in this study using 0°C as a lower threshold.

Appendix 10. Plant-available N from organic amendments in the second year after application according to the fertilizer equivalence approach, using crop N uptake parameter at the North Willamette Research Extension Center, OR (mean and SE). Page 1/2.

Treatment†	Total N applied in 2003	FNE from Crop N uptake in 2004‡	PAN from crop N uptake in 2004
	kg N ha^{-1}	kg N ha^{-1}	%
NWREC, OR			
Other treatments (field data only)			
Composted dry broiler litter (CC)	168	19.5 (13.84)	11.6 (8.22)
Dry broiler litter (CM)	173	-7.3 (14.04)	-4.2 (8.13)
Rabbit manure (RM)	408	16.3 (11.54)	4.0 (2.83)
Yard-trimmings (YT)	273	16.9 (15.77)	6.1 (5.78)
Treatment selected for N mineralization study			
Anaerobically digested dairy solid (AD)	789	47.3 (16.55)	6.0 (2.10)
Composted dairy solids (DC)	682	58.0 (8.12)	8.5 (1.19)
Dairy solids (DS)	507	23.4 (18.62)	4.6 (3.67)
Peppermint hay (PH)	698	34.1 (9.08)	4.9 (1.30)
Composted rabbit manure (RC)	349	5.0 (10.38)	1.4 (2.97)
Composted yard-trimmings (YTC)	505	29.7 (24.92)	5.9 (4.93)

† Treatments with highest total N application rates in 2003 (ranging from 349 to 789 kg N ha^{-1}) selected for additional N mineralization testing.

‡FNE values were obtained by the inverse prediction method from Eq. [2], and then these values were subtracted with amount of urea N applied before planting (56 kg N ha^{-1}).

Appendix 10. Plant-available N from organic amendments in the second year after application according to the fertilizer equivalence approach, using crop N uptake parameter at the Washington State University Puyallup Research Center, WA (mean and SE). Page 2/2.

Treatment†	Total N applied in 2003	FNE from Crop N uptake in 2004‡	PAN from crop N uptake in 2004
	kg N ha^{-1}	kg N ha^{-1}	%
Puyallup, WA			
Other treatments (field data only)			
BioGro (BG)	123	3.8 (5.51)	3.1 (4.50)
Canola meal (CAN)	156	6.5 (10.08)	4.2 (6.48)
Composted dry broiler litter (CC)	169	-9.2 (6.49)	-5.4 (3.84)
Dry broiler litter (CM)	178	-3.7 (1.70)	-2.1 (0.96)
Rabbit manure (RM)	304	-20.0 (1.96)	-6.6 (0.65)
Yard-trimmings (YT)	353	22.5 (10.23)	6.4 (2.90)
Treatment selected for N mineralization study			
Dairy solids (DS)	429	4.4 (2.63)	1.0 (0.61)
Composted dairy solids (DC)	622	7.6 (6.56)	1.2 (1.05)
On-farm compost (OFC)	768	9.2 (9.62)	1.2 (1.25)
Composted rabbit manure (RC)	321	20.1 (21.22)	6.3 (6.61)
Composted yard-trimmings (YTC)	605	5.2 (11.26)	0.9 (1.86)

† Treatments with highest total N application rates in 2003 (ranging from 321 to 768 kg N ha^{-1}) selected for additional N mineralization testing.

‡FNE values were obtained by the inverse prediction method from Eq. [2], and then these values were subtracted with amount of urea N applied before planting (56 kg N ha^{-1}).