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In western Washington, the land application of composts and minimally processed yard trimmings (MPYT) is steadily increasing. Currently, nitrogen (N) release data is unavailable to growers interested in land applying MPYT.

Two studies were conducted to determine N mineralization from composted and fresh yard trimmings. In study one (Chapter 2) the long-term effects of a one-time, high-rate compost application on soil N and crop apparent N recovery were determined. In study two (Chapter 3) the quantity of MPYT N release quantity over time and its relation to initial MPYT total N concentration; carbon to nitrogen ratio (C:N) and facility storage time was determined.

In study one, a seven-year (1993-1999) field experiment was conducted using food waste composted with yard trimmings and paper or wood residuals. Compost was applied at a rate of 1500 to 3000 kg total N ha^{-1}. Grass was harvested at early boot stage, at 30 to 45 day intervals, to determine both yield and N uptake. Periodically, mineralizable soil N was measured via anaerobic incubation for seven days at 40°C. Compost application increased grass yield and N uptake throughout the study. In the 0-8 cm depth, organic matter and soil total N increased in response to compost application. Our study confirmed that compost provided slow-release N and organic matter enhancement within the zone of compost application for many years.

In the study two, MPYT samples were collected from four Western WA composting facilities in 1999. Samples were incorporated into Puyallup fine sandy loam and incubated for 68d, 98d or 168d. Total N concentrations of collected MPYT samples ranged from 8 to 37 g kg^{-1}. The C:N ratios ranged from 11:1 to 34:1. Experimental soils were sub-sampled periodically for nitrate (NO_3-N) and ammonium (NH_4-N) concentrations. During the initial 7 to 21d incubation period, net N immobilization ranged from –34 to –1 mg (NO_3-N + NH_4-N) kg^{-1}. Following initial immobilization and continuing through the remainder of the incubation, mineralization was observed for all but one of the facility samples. The highest concentrations of mineralized N (NO_3-N + NH_4-N) were associated with samples containing the highest proportion of grass. Samples with initial N concentrations greater than 15 g kg^{-1} and C:N ratios of less than 15:1, released more N over time. As storage time at a facility increased (0 to 4 weeks), MPYT N release after 98d decreased (78-252 mg (NO_3-N + NH_4-N) kg^{-1}).

NITROGEN MINERALIZATION FROM COMPOSTED AND FRESH YARD TRIMMINGS

by

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Dedicated to my daughter, Mandy

You are the love of my life

Nitrogen Mineralization from Composted and Fresh Yard Trimmings

INTRODUCTION

Nationwide, municipalities are increasing their composting efforts to deal with landscape trimmings, food, paper and wood residuals (Glenn, 1999). The production and land application of compost is considered to be a sustainable environmental practice (Martin and Gershuny, 1992) that enhances soil quality (Doran and Parkin, 1994). Municipally derived compost products are being sought increasingly in both horticulture and commercial agriculture (Gilmour, 1998). There is minimal information on the effects of compost on long-term soil nitrogen (N) mineralization rates. Currently, N release data is unavailable to growers interested in the land application of MPYT.

This set of two research papers seeks to answer questions that pertain to both the long-term and immediate effects of applying municipal composts and landscape trimmings (MPYT). The initial study (Chapter 2), discusses the long-term benefits of municipal compost application in a perennial grass cropping system. Due to the difficulty and expense inherent in long-term field studies (Paul, et al., 1997), most research has focused on the short-term benefits of compost application in either container media (Chen, et al., 1988) or annual cropping systems (Stoffella, et al., 1998). The major objective of this study was to determine the long-term effects of a one-time, high-rate municipal compost application on: 1) crop apparent N recovery (ANR) and 2) soil C and N in the zone of application (0-8 cm depth) over an extended period of seven years.

The final study (Chapter 3), evaluated net N mineralization after "Minimally Processed Yard Trimmings" (MPYT) were incorporated into soil. It must be understood that MPYT is not a mature "compost" product. It is typically utilized as a feedstock component of municipal composts. However, in the case of our study, it has not been subjected to the rigorous treatment methods needed to produce biologically mature compost. The composts in our initial study (Chapter 2) were biologically stable composts. Despite the immature nature of MPYT, it is desirable for cropland application since it may help increase soil organic matter content and provide an additional source of crop N.

In western Washington, composting facilities are faced with seasonal overflows of landscaping materials that they are unable to compost efficiently. This overflow causes odor problems and may negatively impact facility operations. The increased use of MPYT as a soil amendment is of economic and environmental importance to both farmers and composting facilities. However, more information is needed to determine the N availability of incorporated MPYT. The major objectives of this study were to: 1) determine the quantity of net N mineralized after MPYT application to soil and its relation to initial MPYT total N and C; 2) determine the impact of facility storage periods on MPYT nitrogen release; and 3) evaluate the correlation of CO_2-C evolution and aerobic net N mineralization for soil incorporated MPYT.

The goal of these combined studies is to contribute to our further understanding of the long-term effects of land applying compost and the immediate N release available from soil incorporated MPYT. This information will be useful to growers that apply soil amendments, such as compost and MPYT.

CHAPTER 1

LITERATURE REVIEW

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DECOMPOSITION OF PLANT RESIDUES

Addition of Plant Residue to Soil

Adding plant residues prior to crop planting is an integral part of many farming systems. Organic matter amendments, in the form of decomposing plant residue, can improve the overall quality of soil. While the main impetus of plant residue addition is to increase soil organic matter (SOM) content, this practice can serve as either an augmentation or replacement of commercial nitrogen (N) fertilizer in some cropping systems. Despite the long-term benefits of adding plant residues, there may be a short time immediately after field application where plant-available nitrogen (PAN) is immobilized in the tissues of soil microorganisms. Due to this initial N immobilization, early plant development may be compromised. Thoughtful consideration regarding the decomposition rate of organic residue and the environmental conditions that limit or enhance the degradation process must take place when organic residues are applied in agricultural production systems.

Importance of Soil Organic Matter (SOM)

Soil organic matter formation and residue decomposition are closely linked. Although SOM comprises a relatively small proportion of the soil, it has a great influence on the productivity of a given soil. The chemical, physical and biological characteristics of a given soil are dramatically influenced by SOM (Wagner and Wolf, 1998). In mineral soils, 20 to 80% of the cation exchange capacity (CEC) is derived from SOM (Sparks, 1995). The phenolic and carboxylic components existing in SOM assist in buffering soil pH (Sposito, 1989). It slowly releases plant nutrients including N, P and S. Chelation of metals is promoted by SOM, which renders trace elements more available for plant uptake. It adsorbs toxic organic compounds that could be absorbed by plants (Sposito, 1989). The SOM content assists in the solubilization of nutrients from insoluble mineral forms (Sposito, 1989). Physically, SOM contributes to greater aggregation of soil particles, which improves the structure of a soil (Buller, 1999). It reduces bulk density by increasing pore space (Hillel, 1998). The dark color of SOM assists in heat absorption (California Fertilizer Association, 1995). Because SOM also increases soil water holding capacity (WHC), more heat energy may be needed to warm the soil. In some cases however, SOM may decrease soil water availability to plant roots and microorganisms (Kutilek and Nielsen, 1994). The decrease in plant-available water (water held between 10 and 33 kPa) is attributed to a greater tensile pull upon available soil water by SOM (Hillel, 1998). Biologically, SOM supports microbial populations by providing C as an energy source (Paul et al., 1997). Since SOM supports a wide variety of microbial populations, it may enhance production of plant disease suppressing compounds (Chen et al., 1988) and beneficial compounds that promote plant health (Chen et al., 1999). The concept of soil quality as proposed by Doran and Parkin (1994) was defined as: "The capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health." Recycling organic residues through land application is a positive way to influence soil quality.

Incorporation of Cover Crop Residues

Cover crops enhance soil quality by playing a pivotal role in carbon (C) and N dynamics (Wagger et al., 1998). The benefits of planting a cover crop after a primary crop harvest are to: prevent soil loss from wind and water erosion, reduce nitrate (NO_3-N) leaching and increase or maintain SOM content (Ndiaye et al., 2000). Cover crops augment or maintain the SOM content of intensively managed soils. Cover crop residues also provide a C substrate for soil microbes. Plant-available N (PAN) released by the mineralization of cover crop residues can substitute for commercial N fertilizer requirements.

Decomposition Processes in the Soil

C Decomposition

The chemical form and content of carbon (C) in plant residue will impact its rate of decomposition (VanSoest, 1982). Approximately 40 to 44% of plant dry matter is C (Vigil and Kissel, 1991). Plant residues contain easily degradable and recalcitrant forms of C. This total C source is made up of simple sugars and starches (5 to 30% of total C), proteins (1 to 20%), as well as recalcitrant C polymers of hemicellulose (10 to 30%), cellulose (10 to 50%) and lignin (5 to 30%) (Lieth, 1975; VanSoest, 1982). The efficiency of microbes to incorporate residue C into biomass can be as high as 65% for soluble C fractions, or in the case of resistant lignin, 10% (Wagner and Wolf, 1998). Dead microbial biomass is considered to be an easily degradable substrate source for successive microbial populations (Recous et al., 1995).

A given organic residue does not decompose at a single rate constant. Several studies have described decomposition in this manner (Schomberg et al., 1994; Kuo et al., 1997). A more realistic approach would develop rate equations for each actively decomposing fraction of crop residue (Ajwa and Tabatabai, 1994; Gilmour et al., 1998). Such models partition C components into separate rapid and slow decay pools.

The different organic compounds that make up crop residue are susceptible to specific enzymes produced by certain soil microbes (Wagner, 1975). Acting in concert, microbes degrade the residue in parts (Sylvia et al., 1998). Initially, soluble sugars serve as the substrate for many soil microbe groups. Opportunistic microbial populations that are capable of rapid growth are generally first to utilize these soluble sugars. In time, the more resistant biopolymer constituents, such as lignin, become the predominant form of C. Also, free radicals or highly reactive benzene rings (phenolic compounds) form as the decomposition process proceeds (Wagner and Wolf, 1998). These compounds are subject to condensation reactions and form unique polymers that are even more recalcitrant than the initial plant residue. This transformation from organic residue to SOM is known as humification (Sparks, 1995).

N mineralization

Mineralization is the process by which microbes decompose an organic substrate, such as plant residue, and release inorganic nutrients into the soil environment (Bittman et al., 1999). Under optimal environmental conditions, the proteins present in organic residues are broken down into amino acids. The amino N is used by soil microorganisms for energy and cell maintenance. These amino compounds are converted to ammonia (NH_3) and ammonium (NH_4). Low NH_3 concentrations are toxic to microbes, however not much NH_3 is accumulated because conversion to other N forms is rapid. Following mineralization to NH_4, two groups of bacteria, known as *Nitrosomonas* and *Nitrosococcus* convert NH_4 to nitrite (NO_2):

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+ + \text{energy}$$

The NO_2 formed in the above reaction is then converted to nitrate (NO_3) by the bacteria, *Nitrobacter*. In this reaction, NO_2 is oxidized to NO_3:

$$2NO_2^- + O_2 \rightarrow 2NO_3^- + \text{energy}$$

Hageman (1984) observed that plant yield response was higher with mixtures of both NH_4 and NO_3. In well-drained soils, the conversion from NH_4 to NO_3 is very rapid. For this reason, NO_3 is often taken up in greater quantities by the plant (Prasad and Power, 1997). Soil microbes utilize NH_4 and NO_3 as N sources, however NH_4 is usually preferred (Laegried et al., 1999).

Optimal Environmental Conditions for Mineralization

The heterotrophic microbial populations that accomplish residue decomposition are influenced by five major environmental factors: moisture, aeration, temperature, pH and nutrient availability. The conditions that promote accelerated decomposition activity and microbial biomass accumulation are: low lignin plant residues with small particle size, low Carbon to Nitrogen (C:N) residue, soil pH in the neutral range, adequate soil aeration and moisture and optimal soil temperatures of 30 to 45°C (Wagner and Wolf, 1998).

Soil Temperature

Soil temperature at time of incorporation affects residue decomposition. There is often a linear relationship between microbial activity and increasing temperature (Parr and Papendick, 1978). Very cold temperatures and dry conditions limit microbial activity. According to Wagner and Wolf (1998), microbial response to increasing temperature is greatest between 3 to 19°C with moderate activity in the 20 to 25°C range. Nitrogen mineralization has been linked to soil temperature by utilizing heat units or degree-days (Honeycutt et al., 1988; Honeycutt and Potaro, 1990; Honeycutt, 1994).

Soil Moisture

Soil moisture has a great impact on the N mineralization of incorporated plant residues. The soil matric potential of –20 to –50 kPa, or approximately 60% of water-holding capacity, corresponds to the soil moisture content for optimal decomposition rates (Mahli and McGill, 1982). Nitrogen mineralization is most rapid in soils near field capacity: -33 kPa for medium to heavy textured soil, and 0 to -10 kPa for light sandy soils (Prasad and Power, 1997). Griffin (1972) observed that at low water contents bacterial motility was compromised, thus reducing their biological activity. He also observed that some fungi may be unable to grow in saturated soil conditions. At optimal water- holding capacity, adequate aeration and moisture is provided to most heterotrophic microbial groups that are active participants in residue decomposition (Dickinson, 1974).

Relationship between C Decomposition and N Mineralization Rates

As microbes utilize crop residue C, essential nutrients such as N are needed to maintain growth. The N required by fungi is one-half that required by bacteria (Sylvia et al., 1998). Residues with low N concentrations do not provide sufficient N supply to support microbial growth. As a result of incorporating residues with low N organic concentrations, microbes aggressively scavenge the inorganic N soil pool to meet their maintenance needs. This assimilation of available inorganic soil N into microbial tissues is known as immobilization. This temporary condition decreases the available supply of N to growing plants and is a major concern when adding organic residues in a cropping system. If an added residue is high in N content, then net N mineralization will occur (Greenwood et al., 1996).

INFLUENCE OF ORGANIC AMENDMENT COMPOSITION

Soluble Organic Compounds

Water Soluble Organic Compounds

Plant residues contain water-soluble organic compounds, which include readily available organic acids, sugars and free amino acids. These soluble organic compounds are quickly decomposed by the rapidly growing microbial populations, such as: *Mucor* spp., and *Rhizopus* spp., existing in the rhizosphere. The water soluble organic fraction is immediately available to soil microbes (Curtin and Wen, 1999). The determined values of water soluble C are related to both the maturity and N content of a residue. Bremer et al. (1991) analyzed lentil green manure, lentil straw and wheat straw and found water-soluble C percentages of 34, 22 and 12, respectively.

Proteins

Plant residue protein content ranges from less than 1% in wood tissue and up to 22% in grass leaves and seeds (Paul and Clark, 1996). The proteins contained in plant residues are amino acid polymers bonded by peptide links. Proteins are readily broken down in the soil by microbial production of proteolytic enzymes, such as protease and peptidase. The hydrolyzed proteins are broken into singular amino acids that can be transported into microbial tissues for growth or catabolism.

Plant Cell Wall Composition

Cellulose

In plant residue, the predominant form of C is in the structural polysaccharide, cellulose. Cellulose dry matter content in plant residue ranges from 13 to 51% (Paul and Clark, 1996). These complex carbohydrates provide rigidity to the cell walls of plants. Cellulose is a linear chain of glucose units connected by β 1-4 linkages. Each molecule of cellulose can be up to 10,000 glucose units long. As a plant matures, the cellulose content increases. In young plants, cellulose is about 15% of total C, but in mature plants, it may be greater than 50 % (Raven et al.,, 1992). Cellulose is also a component of decomposing microbes, such as fungi. The chemical structure of cellulose makes it more difficult to degrade; it must be broken down into smaller units (2 to 3 glucose unit chains) that the microbes can assimilate. Soil fungi produce cellulose-degrading enzymes (β 1-4-endoglucanase, β 1-4-exoglucanase and cellobiase). Important soil fungi participating in this phase of decomposition are *Aspergillus, Penicillium, Fusarium* and *Trichoderma, Agaricus* and *Chaetomium* (Dickinson and Pugh, 1974). Important cellulose degrading soil bacteria are *Bacillus, Streptomyces, and Pseudomonas* (Wagner and Wolf, 1998). Especially important in aerobic degradation are *Cellulomonas, Cellovibrio, Thermomonospora* and *Cytophaga* (Paul and Clark, 1996). In anaerobic conditions, *Acetovibrio, Bacteroides, Clostridium* and *Ruminococcus* degrade cellulose (VanSoest, 1982; Paul and Clark, 1996).

Hemicellulose

The hemicellulose dry matter content of plant residue ranges from 2 to 40% (Paul and Clark, 1996). This polysaccharide is made up of about 50-200 branched sugar units, in contrast to the linear structure of the cellulose molecule. The breakdown of hemicellulose occurs at a more rapid pace than cellulose decomposition.

Pectic Substances

Pectin resides in the middle lamella of plant cell walls (VanSoest, 1982). It is an important cementing agent of plant cell walls (Raven et al., 1992). Microbes produce pectinases that degrade these galacturonic acid chains. The soil microbes that degrade cellulose are also responsible for breaking down pectic substances. The N_2-fixing bacteria (*Rhizobium* and *Bradyrhizobium*) and mychorrhizal fungi (*Glomus*) produce pectinases in their root colonizing activities (Sylvia et al., 1998).

Lignin

Lignin resides in the fibrous tissues of plants. As a plant matures, its lignin content increases. Immature plant tissue contains about 5% lignin, whereas a mature plant may be composed of up to15% lignin. Woody tissues contain up to 35% lignin. The content of lignin in a given residue effectively retards the decomposition process (Muller et al. 1988; De Neve and Hofman, 1996). Another consideration is that lignin protects easily degradable, soluble C components "hiding" inside its recalcitrant structure. The result is that lignin provides a physical barrier to microbial decomposition (Cheshire et al., 1988). Lignin is made up of 500-600 randomly condensed cross-linked phenylpropene units (VanSoest, 1982). The basic building blocks of these phenylpropene units are benzene rings with linear three-C side chains. The cross linkage between side chains, benzene rings or side chains to rings, is usually an ether (C-O-C) or double (C-C) bond (Wagner and Wolf, 1998). The chemical structure of lignin varies greatly among plant species. This structural complexity makes lignin very recalcitrant to microbial decomposition. Lignin can be degraded under anaerobic conditions (Sylvia et al., 1998). However, this is not an efficient process and lignin can accumulate in the soil profile (peat bogs). The fungi, *Basidiomycetes* and the *Actinomycetes*, and *Streptomyces* spp., are the major groups responsible for lignin degradation. It appears that fungi serve to initiate the degradation process, but the activity of the actinomycetes group is one of prolonged attack. The decomposition of lignin by microbes is considered inefficient, about two-thirds of this C is lost as CO_2, with the remaining one-third being incorporated into the SOM pool as recalcitrant C complexes and microbial tissue (Sylvia et al., 1998).

Effect of Organic Amendment Composition on SOM Accumulation

In terms of building SOM over the long-term, biosolids and animal manure may be superior to plant residues. Biosolids and animal manure are "secondary" organic amendments, which initially have been decomposed through digestive processes. Residues have higher proportions of complex organic compounds, such as lignin, which are difficult to degrade. This may provide more cyclic monomers that could serve as humic acid building blocks. In an incubation study comparing manure and plant residue amendments, Corbeels et al. (1999), suggested that large discrepancies in mineralization results were due to the differences in allocation of N in animal manures compared to plant residues.

Carbon to Nitrogen (C:N) Ratio

The synchrony of organic residue addition and microbial decomposition is important to consider when determining whether adequate N will be available to a growing crop (Magdoff et al., 1997; Lagreid et al., 1999). Soil bacteria have a C:N of 4:1 to 5:1, and fungi can be up to 15:1 (Myrold, 1998). Since fungi comprise about two-thirds and bacteria one-third, of the total microbial biomass in soil, the C:N of soil microbial biomass is around 8:1 (Myrold, 1998). When organic residues are added to the soil, the decomposition process is invariably affected by the C:N of the microbial population.

The C:N of stable SOM is about 10:1 (Foth, 1984; Greenwood et al., 1996), and despite the variability existing in soils, this value is similar around the world (Paul and Clark, 1996). The rate at which stable SOM degrades varies depending on the environment to which it is subjected (Campbell et al., 1984).

The rate of mineralization is greatly dependent on the C:N ratio of the organic matter being added to the soil (Henry and Harrison, 1996). In the process of breaking down added organic materials, such as plant residue, soil microbes will utilize available soil N. According to Bittman et al. (1999), plant residue C:N values that are greater than 25, immobilize soil N. Gilmour (1998) found that a C:N greater than 15:1, immobilized soil N. Microbial immobilization creates a temporary shortage of plant-available N for the subsequent crop. According to Foth (1984), if organic material added to soil has a C:N greater than 30:1, immobilization will exceed mineralization; if C:N is between 15:1 to 30:1, immobilization and mineralization rates are equalized; and if C:N is less than 15:1, mineralization will exceed immobilization. The general consensus is that the "break-even" C:N is approximately 20:1 (Myrold, 1998), this means that residues of less than 20:1 will usually have net inorganic N production, and residues greater than 20:1 will usually immobilize N.

Decomposition of Plant Residue Mixtures

It is important to note that a mixture of crop species may compose a plant residue amendment. This will affect the C:N ratio accordingly. Kuo et al. (1998), found that the relative amounts of legume and non-legume making up a cover crop mixture affected decomposition dynamics.

Both the C composition of plant tissue and plant residue maturity stage influences C:N ratio. The decomposition of mature growth, where plant stems compose a majority of the biomass (high C:N), will be slower than the same crop at an early vegetative stage (leafy biomass prevails), which has a low C:N (Quemada and Cabrera, 1995).

PREDICTING MINERALIZABLE SOIL C AND N

Incubation Studies

Laboratory incubation studies are useful to determine the rate at which a specific organic residue will contribute plant-available N during the decomposition process (Stanford, 1982). Laboratory incubation methods take place under the controlled, optimal moisture, aeration and temperature conditions for microbial decomposition. While this is a valuable and indispensable method of determining the mineralization rate of a plant residue, it is a limited indicator since optimal environmental conditions are not always present in field situations (Stanford, 1982). Despite its limitations, incubation studies are used to develop mineralization rate constants that can be used to predict N mineralization under variable field conditions. Laboratory incubations are important tools to understand how much PAN an incorporated residue will yield over time. Often the data found from these studies are used in computer simulation models to predict N mineralization under varying field conditions.

Microbial Biomass Determination

Microbial biomass in soil is typically in the range of 1,500 kg ha^{-1} and can be determined by soil fumigation-incubation studies (Collins et al., 1997; Sylvia et al, 1998). In this method, a soil sample is fumigated in a vacuum with chloroform for 24 hours to kill the existing microbial populations. The vapor is removed and the soil is re-inoculated with fresh soil. The fresh/fumigated soil mixture is incubated for 10 days in a sealed jar with an open alkaline trap to collect evolved CO_2. During this time, microbes rapidly decompose the senescent tissues of the initial population liberating CO_2 from this C substrate source. This CO_2 release can be quantitatively measured and represents approximately 41% of the microbial biomass C that was present in the original soil sample (Wagner and Wolf, 1998).

Microbial Population Determination

The activity of a microbial population involved in decomposition can be determined by a continuous monitoring of soil CO_2 evolution over time. Respiration measurements do not distinguish between the distinct groups acting upon the residue. Alternately, microbial populations actively degrading the residue can be isolated. Fluctuations in their respective population sizes can be observed over time. In a study by Broder and Wagner (1988), after early summer residue additions, bacterial populations increased, then rapidly declined as decomposition continued through fall and winter. In the following spring, this population remained stable but there was a significant increase in fungal populations, which did not decrease for several months. This shows the microbial populations are influenced by seasonal cycles and that populations are transitional and do not remain stagnant throughout the decomposition process.

Respiration occurs concomitantly with new microbial tissue production. However, the rate of CO_2 liberation is not equal to the C utilization rate of microbes as they decompose introduced substrate material. It is important to consider both microbial biomass changes and relative decomposition efficiencies. Paul and VanVeen (1978) showed that decomposition rates of residues could be greatly underestimated or overestimated in short term incubation studies when the efficiency of substrate-utilization is not considered.

Radio-labeled CO_2 Production

The released CO_2 from soil is the combined metabolic activity of microbes, animals and plants. Another approach to measure residue decomposition is to add radioactive ^{14}C to the residue to be decomposed. By labeling the substrate, measurements can be made that isolate the source of the evolved CO_2. This approach has been used in several studies to follow the degradation pattern of various substrates. Haider and Martin (1975) studied the decomposition of labeled caffeic and benzoic acids contained in lignin and cellulose. This study demonstrated that lignin decomposed at a rate four times slower than cellulose.

Studies using this method have found that as the substrate is consumed, the rate of $^{14}CO_2$ evolved decreases. The amount of $^{14}CO_2$ evolved never reaches 100% of the total C present in the substrate (Buyanovsky and Wagner, 1987). This is due to the conversion of a portion of the total C into recalcitrant microbial tissues or SOM.

Residue Decomposition Kinetics

The decomposition rate of organic residues added to soil is not a linear relationship over time. Predictive models have been developed which use a separate rate constant for the rapid and slow decomposable fractions of organic residue. This describes the decomposition dynamics more accurately than using a single rate constant (Collins, 1997; Sylvia et al., 1998).

The rate of decomposition decreases over time as microbes feed upon the substrate. This decomposition pattern is considered to be a first-order reaction. Residues with different C components that degrade at differing rates will typically be described with several rate constants to characterize the decomposition kinetics of a given residue (Gilmour et al., 1985; Gilmour et al., 1998).

Short-term incubations of crop residues can provide both a C and N mineralization rate constant (Ajwa and Tabatabai, 1994; Corbeels et al., 1999). These rate constants may be used to describe how specific organic residues will release PAN over time.

Apparent N Recovery

One method to estimate the N availability from organic residue incorporation is to calculate the Apparent N Recovery (ANR). Utilizing plant N uptake from amended and non-amended treatments, ANR estimates the net mineralization of the added amendment (Sullivan et al., 1998), where ANR equals the crop N uptake (amended treatment) minus the crop N uptake (non-amended treatment). Sullivan et al. (1998) used the ANR concept to describe PAN for a long-term compost application field trial. Recovered N from plant uptake ranged from 8 to 11 % of the initial N applied in the compost. An estimate of fertilizer N uptake efficiency by the crop can be used together with ANR, to roughly estimate N availability from compost addition. The N availability estimates utilizing the ANR method are not as definitive as the ^{15}N labeling studies. However, the ANR method is a practical approach to estimate PAN.

Q_{10} versus Thermal Units (GDD)

Soil temperature data can be converted to degree-days and used to describe C and N decomposition dynamics (Honeycutt and Potaro, 1990; Honeycutt, 1994). The effects of temperature on the rate of N mineralization have been explored using the concepts of Q_{10} and thermal units, also referred to as “growing degree days.” Both of these methods have been employed in numerous studies to estimate the effects of temperature on N mineralization.

The calculated ratio of the mineralization rates of an amended and unamended soil for each 10°C temperature interval is referred to as Q_{10}. The Q_{10} concept was proposed initially by Stanford et al. (1973). Studies have found that Q_{10} values decrease, as temperature increases (Vigil and Kissel, 1995). In the Stanford et al. (1973) study, the reported range of Q_{10} was 1.2 to 3.0. The Q_{10} value for native SOM was found to be approximately 2, for the temperature range between 5 and 35°C. Departures from this Q_{10} value range have been reported, 2.5 to 4.1 (Tabatabai and Al-Khafaji, 1980). Addiscott (1983) found that Q_{10} values changed for different temperature ranges. For the temperature interval 5 and 15°C, the Q_{10} range was 2.3 to 3.2, for temperatures between 15 and 25°C, the measured Q_{10} range was 1.8 to 2.6. This variability in Q_{10} is an important consideration when predicting N mineralization in field studies, where fluctuating soil temperatures occur. In a study by Campbell et al. (1984), it was found that Q_{10} values are lower in tropical southern zones than in the temperate northern zones. Several studies indicate that Q_{10} values increase with decreasing temperatures (Hegarty, 1973; Campbell et al., 1981; Addiscott, 1983). The limitations of Q_{10} seems to be that it is a variable measurement and depends on factors such as residue C: N and incubation time (Vigil and Kissel, 1995), and a single Q_{10} value may not be the best way to describe the effect of temperature on N mineralization.

Honeycutt et al. (1988) proposed the concept of employing thermal units to predict N mineralization. Growing degree days are thermal units (°C day^{-1}) for each day in a growing season. Typically, thermal units are accrued for each day, beginning with a 0°C base, corresponding to the temperature at which plants do not grow (Honeycutt et al., 1988). In this summed form, they are referred to as cumulative degree days (CDD). Douglas and Rickman (1992) used this concept to explain how incorporated and surface applied crop residues decomposed in the field. Miller (1974), observed that CO_2 evolution rate from biosolids samples correlated well with degree days between days 30 and 90 of his incubation study.

Influence of Particle Size on Microbial Degradation

Particle size of incorporated plant residue affects its decomposability (Bending and Turner, 1999). The increased exposure of recalcitrant components of the residue to the soil matrix allows greater microbial access to lignin and cellulose (Bremer et al., 1991; Jensen, 1994; Sorensen et al., 1996; Bending and Turner, 1999).

Most incubation studies utilize ground and dried plant residue when determining decomposition via N mineralization and CO_2 evolution analyses. Several studies have observed the effect of residue particle size on N mineralization (Bremer et al., 1991; Jensen, 1994; Bending and Turner, 1999) and CO_2 evolution (Bremer et al., 1991; Jensen, 1994; Sorensen et al., 1996; Bending and Turner, 1999). Bending and Turner (1999) observed that the C:N ratio of the material had a greater impact on mineralization than particle size. Residues with a low C:N ratio of 10:1, with a small particle size, displayed no difference in net mineralization or microbial activity, in comparison to larger size residue particles. However, in medium biochemical quality residues (15:1, C:N), smaller particle size increased net mineralization in the initial decomposition stage and reduced net N mineralization in later stages.

Simulation Models

Computer simulation models may be useful in predicting N mineralization of incorporated cover crop residues. The value of computer models lies in their ability to vary the parameters affecting the N mineralization process. Initially, the computer model combines information from field and laboratory studies and attempts to validate specific experimental findings within the given parameters. After validation of experimental data, the model can be a useful tool in predicting the decomposition dynamics of different plant residues over a range of varying environmental conditions.

The CERES-N model has been used by researchers to understand plant residue decomposition. In this model, the subroutine called MINIMO partitions C into different sized C "pools" made up of carbohydrates, cellulose and lignin. This is a powerful way to grasp the decomposition dynamics of incorporated crop residues, for it is the introduction of differing pools of organic C that drives the N mineralization process in soils. The model may accurately predict N mineralization for some, but not all residues (Vigil and Kissel, 1991).

The NCSOIL model, similar to CERES-N partitions the C components of incorporated residue into various decomposition pools (Corbeels et al., 1999). This model uses a VanSoest C fractionation scheme, a typical analysis for feedstuffs (VanSoest, 1982; Holland and Kezar, 1990). Upon validation, Corbeels et al. (1999), found that the model explained C decomposition based on the C characteristics of a given residue. However, the model underestimated N mineralization. The authors suggested the need for N fractionation methodology.

The DECOMPOSITION model proposed by Gilmour (1998), evaluated three organic waste products to determine their contribution to

SOM and plant-available N (PAN) over time. The model simulated several years, utilizing a weather data set for Baltimore, MD and a field application date of April. It was determined that annually applied stable composts increased SOM and were a source of PAN over an extended period of several years. Validation of the model was accomplished by comparing actual and predicted values of PAN. There was good agreement between actual and predicted PAN values.

CONCLUSIONS

The accurate assessment of the amount of N that becomes available after plant residue incorporation will encourage farm managers to utilize organic sources of N, as a supplemental N source (Douglas and Magdoff, 1991). Crop residue decomposition dynamics are greatly influenced by the C:N ratio (Hu et al., 1997), maturity and composition of the residue and environmental conditions (Douglas and Magdoff, 1991).

The investigative combination of laboratory incubations, field trials and computer model simulations form a powerful triumvirate to understand the contribution of plant residue incorporation to the rate of N mineralization and SOM accumulation. Increased research into computer simulation models utilizing existing lab and field data will provide greater insight into plant residue decomposition dynamics. This understanding will encourage the restorative cropping practice of adding plant residues, such as MPYT, to soil.

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CHAPTER 2

LONG-TERM EFFECTS OF COMPOSTS ON GRASS YIELD, PLANT-AVAILABLE N AND SOIL ORGANIC MATTER

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ABSTRACT

Municipal composts are increasingly being used in horticultural and agricultural production. Although there is much information on the short-term effects of compost on annual crops, more information is needed to determine the long-term effects of compost application to perennial crops, such as grasses.

From 1993 to 1999, we conducted a field study to determine long-term effects of composted food residuals on the yield of tall fescue, crop N uptake, and soil C and N. Our objectives were to determine the long-term effects of a one-time, high-rate compost application on: 1) crop apparent N recovery; and 2) soil C and N in the zone of application.

In 1993, three composts containing 10 to 18 g N kg^{-1} were applied one time (before seeding) at a rate of approximately 155 Mg ha^{-1}, supplying 1500 to 3000 kg total N ha^{-1}. Grass was harvested at the early boot stage, at 30 to 45 day intervals, to determine yield and N uptake. Periodically, we measured mineralizable soil N via anaerobic incubation for 7 days at 40° C.

Grass yield and N uptake increased in response to compost application throughout the study. Compost increased mineralizable soil N (0-8 cm). The amount of available N release was directly related to initial compost N concentrations. Cumulative apparent N recovery (percent of compost N applied) ranged from 15 to 20% over the study period. Organic matter and soil N significantly increased in response to compost application. This study confirmed that compost provides a perennial crop with both slow-release N and organic matter enhancement, within the zone of compost application, for many years.

Key Words: compost, food waste, grass, N uptake, soil C, soil N, tall fescue

INTRODUCTION

Nationwide, states are increasing their composting efforts to deal with organic refuse (Glenn, 1999). Municipal composts are being used increasingly in horticulture and commercial agriculture (Gilmour, 1998). In order to insure the wise and continued use of these composted products, research is needed to determine the long-term effects of compost application.

Compost has both short-term (Martin and Gershuny, 1992) and long-term benefits (Larney and Janzen, 1996). However, due to the difficulty and expense inherent in long-term field studies (Paul et al., 1997), most research has focused on the short-term benefits of compost application in either container media (Chen et al., 1988) or annual cropping systems (Stoffella et al., 1998). Therefore, longer-term compost application studies are needed.

As urban population centers continue to grow, landscaping and home gardening markets drive the demand for reliable compost products (Eriksen et al., 1999). In commercial agriculture, compost can assist in the maintenance of organic matter content and soil productivity (Paul, et al. 1997). In both commercial and urban markets, N release and immobilization during the first season after compost application are concerns (Beloso et al., 1993). Longer-term concerns are the persistence of soil organic matter (Korschens, 1992) and the continued release of plant-available N (Prasad and Power, 1997).

Characteristics such as initial N content and C:N ratio are known indicators of N release potential (Sims, 1995). Yield reductions have been observed during the first year after applying composts with a low N content and a C:N ratio of 30:1 or greater (Shiralipour et al., 1992). Reductions in crop production can be attributed to microbial immobilization of available N after adding organic amendments (Schomberg et al., 1994).

Since most compost application studies have focused on short-term N availability (Roe et al., 1997; Stoffella et al., 1998) and C decomposition (Eriksen et al., 1999), the major goal of this study was to determine the influence of compost on long-term N availability and soil organic matter content. The major objectives of this study were to determine the long-term effects of a one-time, high-rate compost application on: 1) crop apparent N recovery; and 2) soil C and N in the zone of application over seven years.

MATERIALS AND METHODS

Compost Production

In January 1993, food waste was collected from pre- and post-consumer sources over a 10-day period in Seattle, WA. Major components were vegetables, meat, fish, dairy and bakery residuals. Upon delivery to the processing facility (Cedar Grove Composting Company; Maple Valley, WA), the food materials were mixed thoroughly with a front-end loader before addition of the bulking agents.

Due to their wet nature, the food materials were composted with various bulking agents. These bulking agents were yard trimmings (FY); yard trimmings and mixed paper waste (FYP); and wood waste and sawdust (FW). All materials, except sawdust, were reduced in size (11 mm or less) utilizing a commercial-scale hammer mill. Prior to grinding, the mixed paper waste was combined with the yard trimmings to facilitate easier grinding of the paper component. As a consequence of a major Puget Sound windstorm on 20-Jan-93, the largest component of the yard trimmings bulking agent was shredded conifer needles and branches. The paper was derived from post-consumer mixed waste paper. Chipped pallets were the major component of the wood waste. Equal proportions of wood waste and softwood sawdust were used to increase moisture absorbency of this bulking agent.

The bulking agents and composting methods involved in the compost production are shown in Table 2.1. The food waste and respective bulking agents initially were combined to make three separate piles. The food waste component made up approximately 25% of the initial volume of the pile. A Scarab windrow turner (Scarab Mfg., White Deer, Texas), was used to uniformly mix the piles. Each mixture was subsequently composted using an Aerated Turned Windrow (ATW) method. In this method, forced aeration was combined with weekly turning. Additional coarse yard trimmings (greater than 11 mm) were used to cover the aerated static piles, which later became incorporated in the final compost product. Initial pile volumes, prior being subjected to the composting process, were about 19 m^3.

Compost piles were formed in unheated shelters on 3-Feb-93. The composts were turned ten times over a period of 70 days. Active composting temperatures ranged from 30° to 80°C, and exceeded 55°C in all piles for a minimum of five days. Following 70 days of active composting, all composts were cured in passively aerated piles for an additional 36 days. All piles were turned twice during curing. After curing, the composts were screened to pass an 11 mm mesh screen. The composts were analyzed for chemical and physical parameters previously described by Sullivan et al. (1998). The total C and N of the applied composts are listed in Table 2.1.

Field Growth Trial

The field growth trial was conducted at the Washington State University Puyallup Research Center located in Puyallup, WA. The soil was a Puyallup fine sandy loam soil (coarse-loamy over sandy, mixed, mesic Vitrandic Haploxerolls). The year previous to our study (1992), this site had been cropped silage corn, followed by fall seeded triticale (X *Triticosecale* Witt.) cover crop. Seven days prior to compost application, the triticale was cut (8 cm above ground level) and the biomass was removed. After triticale harvest, the site was moldboard plowed and disked.

Prior to compost application, soil samples were collected and analyzed using routine agricultural soil testing methods (Gavlak et al., 1994). Analysis of pre-application soil test values (0-30 cm) were: NO_3-N, 0.7 mg kg^{-1}; pH, 5.8; Bray-1 extractable P, 315 mg kg^{-1}; ammonium

Table 2.1. Treatment description: Compost feedstocks and supplemental N fertilization for field experiment. Long-term compost experiment.

Field Experiment Compost ID	Compost Production Feedstocks Description†	Compost Application Rates in Field Experiment					Field Trial N fertilizer rate
		Dry Matter††	Total C	Total N	NO_3-N	NH_4-N	
		Mg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1} $harvest^{-1}$
B1	FY	145	50170	2660	64	< 1	34
B2	FYP	172	53320	3007	90	< 1	34
B3	FW	148	59644	1540	3	< 1	34
N	none	none	none	none	none	none	34
NON	none	none	none	none	none	none	0

† FY = Food residuals + Yard trimmings; FYP = Food residuals + Yard trimmings + Paper waste; FW = Food residuals + Wood waste

††Target application rate was 155 Mg ha-1, actual rates varied due to compost moisture content differences

acetate extractable K, Ca and Mg; 0.57 mg kg^{-1}, 4.5 mg kg^{-1} and 0.83 cmol (+) kg^{-1}, respectively. Soil test values indicated that only N fertilization was needed for near maximum perennial grass production (Hart et al., 1996). For the years 1997 to 1999, average soil test values (0-8 cm) were 134 mg kg^{-1}, 4.9 mg kg^{-1} and 0.8 cmol (+) kg^{-1} for K, Ca and Mg, respectively. Soil pH was 5.7. All plots, except the no compost, no N fertilizer control (NON) received a broadcast application of ammonium nitrate fertilizer (34-0-0) at a rate of 34 kg N ha^{-1} prior to seeding. In addition, a no compost, N fertilizer added control (N) was used in our study. The field plot design was a randomized complete block design with eight treatments, replicated four times. Treatments are shown in Table 2.1. Experimental units (subplots) were 2 x 8 m. Growth trial data was analyzed using analysis of variance procedures (SAS Institute, 1998).

The composts were applied 27-May-93 at a target application rate of 155 Mg ha^{-1}. Compost was weighed for each plot using a permanent truck scale. Compost samples were collected at application to analyze for total solids and N content. Actual compost application rates (Table 2.1) varied from 148 to 172 Mg ha^{-1} due to variability in total solids content. After application, compost was incorporated into soil via disking to a depth of 8 to 10 cm..

A cool season perennial grass (forage type tall fescue: *Festuca arundinacea* Schreb. 'A.U. Triumph') was seeded the day after compost application. After grass establishment, the plot area was mowed to 8 cm height on 13-July-93, prior to data collection.

Grass was managed to maintain active growth throughout the growing season. Plots were sprinkler irrigated during the summer. Broadleaf weeds were controlled as needed with herbicides. Fertilizer N (ammonium nitrate; 34-0-0) was broadcast applied after each grass harvest (except the final fall harvest), and about 30 days before the first harvest for each year. The rate of fertilizer N (34 kg N ha^{-1} per application) was the same for all treatments except the NON treatment which received no additional N fertilizer (Table 2.1).

Supplemental fertilizers were applied to all plots to eliminate possible nutrient deficiencies. Blanket applications of gypsum ($CaSO_4$), sulfate of potash (K_2SO_4) or magnesium sulfate ($MgSO_4$) were applied each year to maintain an adequate supply of K, Mg and S. Annual applications were approximately 140 kg K ha^{-1}, 40 kg S ha^{-1} and 8 kg Mg ha^{-1}.

Plant Sampling and Analysis

Grass Harvest

Grass was harvested at the early boot growth stage (45 to 60 cm height) with a small plot forage harvester. The usual harvest interval was 30 to 45 days during the growing season (Table 2.2). At each harvest, a 1 x 6 m swath (8 cm above ground level) was mowed from the center of each plot. Wet grass yields were determined in the field. Wet yield was converted to a dry weight basis based on the solids content of the grass sub-sample dried at 60°C.

Plant Tissue Analysis

The grass N concentration of each composite sample was determined via a combustion N gas analyzer (LECO Instruments, St. Joseph, Michigan; Sweeney, 1989).

Soil Sampling and Analysis

Soil Sampling

Soil samples were collected using a hydraulic hollow core probe (Giddings, Inc., Fort Collins, Colorado) with an inside diameter of 4 cm. At the time of sampling, nine cores were collected from each plot in 0-8, 8-15 and 15-30 cm depth increments. The 15 to 30 cm depth was collected only in 1998. Samples were dried at 30°C, and ground to pass a 2 mm sieve. Post-harvest composite samples (25-Sept-1994; 13-Oct-95; 16-Oct-98; 4-Oct-99) were dried at 30°C, and ground to pass a 2 mm sieve.

Soil Analysis

Soil total N and C concentration was determined for the 0-8 and 8-15 cm soil depths for the years 1994, 1995, 1998 and 1999. In 1994, total C was determined using the Walkley-Black method (Horneck et al., 1989) and total N by the Kjeldahl method (Horneck et al., 1989). For all other years, samples were analyzed with a combustion C and N gas analyzer (LECO Instruments, St. Joseph, Michigan; Gavlak et al., 1994).

Table 2.2. Harvest number order and corresponding harvest dates (1993-1999). Long-term compost experiment.

Year	Consecutive Harvest Number	Grass Harvest Dates†						
		Apr	May	June	July	Aug	Sept	Oct/Nov
1993	1 to 3					10-Aug-93	17-Sep	2-Nov
1994	4 to 9	5-Apr	26-May	23-Jun	21-Jul	23-Aug-94	20-Sep	
1995	10 to 15	13-Apr	16-May	29-Jun	27-Jul	29-Aug-95		13-Oct
1996	16 to 21	10-Apr	15-May	19-Jun	19-Jul	19-Aug-96	23-Sep	
1997	22 to 27	17-Apr	15-May	16-Jun	17-Jul	18-Aug-97	23-Sep	
1998	28 to 34	2-Apr	4-May	3-Jun	6-Jul	5-Aug-98	3-Sep	16-Oct
1999	35 to 40	22-Apr	24-May	21-Jun	21-Jul	24-Aug-99		4-Oct

		Grass Growth Period††						
		d^{-1}	d^{-1}	d^{-1}	d^{-1}	d^{-1}	d^{-1}	d^{-1}
1993	1 to 3					-	38	46
1994	4 to 9	-	51	28	28	33	28	
1995	10 to 15	-	33	44	28	33		45
1996	16 to 21	-	35	35	30	31	35	
1997	22 to 27	-	28	32	31	32	36	
1998	28 to 34	-	32	30	33	30	29	43
1999	35 to 40	-	32	28	30	34		41

†Compost applied 27 May 1993. Grass seeded 28 May 1993. Yield and N uptake not determined for the first harvest after seeding, 13 July 1993.

††Growth period for first spring harvest varied among years. Grass was cut to 8 cm in February, without data collection. First N fertilizer application took place March 1st to 15th, each spring.

Mineralizable N was determined for the 0-8 and 8-15 cm soil depths for the years 1994, 1995 and 1998. The dried and ground post-harvest composite samples were mixed with 50 mL distilled water and incubated for seven days at 40°C. After seven days, the soil-water mixture was extracted with 2M KCl and analyzed for NH_4-N with an ALPKEM rapid flow analyzer RF-300 (Horneck et al., 1989). Ammonium (NH_4-N) was determined via a salicylate and hypochlorite reaction to form indophenol blue; sodium nitroprusside was used to intensify the blue color which is read at 660 nm (RFA methodology, 1985). Nitrate (NO_3-N) was determined via cadmium reduction (RFA methodology, 1990).

N Recovery Equations

N recovery equations were used to summarize the grass N uptake data. N recovery was calculated for the years from 1993 to 1999.

The calculation of the N removed via grass harvest is represented by:

$$N_{upt} = (A * B) / 1000 \qquad \text{Eq. [1]}$$

where:

N_{upt} = grass N uptake (kg ha^{-1})

A = grass yield, dry matter basis (kg ha^{-1})

B = grass N concentration, dry matter basis (g kg^{-1})

The calculation of the increase in grass N uptake attributed to compost application is represented by:

$$ANR = C - D \qquad \text{Eq. [2]}$$

where:

ANR = apparent N recovery (kg ha^{-1})

C = grass N uptake for compost treatment (kg ha^{-1})

D = grass N uptake for no compost (N) treatment (kg ha^{-1})

with both treatments receiving the same fertilizer N rate (34-0-0)

The calculation of the additional grass N uptake attributed to compost application as a percentage of the total compost N applied is represented by:

$$ANR = (C - D) / E * 100 \qquad \text{Eq. [3]}$$

where:

ANR = apparent N recovery (% of compost applied)

C = grass N uptake for compost treatment (kg ha^{-1})

D = grass N uptake for no compost (N) treatment (kg ha^{-1})

E = compost N applied (kg ha^{-1})

with both treatments receiving the same fertilizer N rate (34-0-0)

Statistical Analysis

Statistics were calculated using analysis of variance (ANOVA) and regression procedures (SAS, 1998). Least-significant differences were calculated following a significant ($P < 0.05$) F-test for the ANOVA. Contrasts between selected treatments were investigated when significant differences ($P < 0.05$) were determined with ANOVA procedure.

RESULTS AND DISCUSSION

Compost Quality

Following the end of the active composting and curing process (106d), compost respiration rates were measured at less than 3 mg CO_2-C g^{-1} compost-C day^{-1}, indicating a stable product had been attained. Across composting methods and feedstocks, compost chemical and physical properties were similar (Herrera, 1994). Only particle size and N concentration were different. In general, the composts with the highest proportion of food and yard trimmings had the highest total N (Table 2.1).

Soil N: Grass Yield and N Uptake

The first objective of our study was to determine the long-term effect of a one-time, high-rate compost application on crop apparent N recovery (ANR). In our study, crop ANR measures the difference in grass N uptake between the compost treatment and the N treatment (Materials and Methods, Eq. [2]) .

In grass systems, seasonal fluctuations in N uptake and biomass production take place. In our trial, the first harvest of every year had the highest yield and N uptake. Since reproductive tillers in grass are initiated in fall, the resultant growth may be expressed in the subsequent harvest of the following spring (Fransen, 1999, personal communication).

After seven years, there was a continued highly significant yield response (P = <0.0001) to compost application (Table 2.3). The release of plant-available N from the native soil organic matter is the source of N in the NON treatment. In the N treatment, plant-available N comes from both fertilizer N and the native soil. In our experiment, the grass crop benefited from the additional N provided by fertilizer in the compost and N treatments. The addition of compost increased total yield and total N uptake (P = <0.0001) in comparison to the N treatment (Tables 2.3 and 2.4).

Over the trial period, it was determined that the initial high rate of compost application increased grass N uptake (Table 2.4) in contrast to the N and NON treatments. Compost application had a highly significant effect on grass N uptake for all years except 1993 and 1996 (Table 2.4).

Throughout the trial period, the coefficient of variation for N uptake was low in terms of a long-term field experiment. The highest CV, 18%, was in 1996; in 1993, the CV was 14% which reduced our ability to detect an N uptake response due to compost. The CV also was very low for the other years, ranging from 7-9%.

Crop Apparent N Recovery

The decomposition of organic residues added to soil is not a linear relationship. The rate of decomposition decreases over time as microbes feed upon the substrate. This decomposition pattern is considered to be a first-order reaction. Conversely, cumulative ANR shows that as the substrate is decomposed, N is released and available for plant uptake over time. Essentially two major processes are intertwined, the first-order decay occurring from compost decomposition and the resultant N uptake and biomass increase process. These kinetics are linked closely, each influencing the other. In terms of apparent N recovery, from harvests 0-20 there is a sigmoidal curve over time (Figure 2.1). The first four harvests represent the slow establishment of the grass stand, as well as the stabilization of compost in the soil (no net mineralization); in this case, the N applied may be not harvested in the above-ground biomass since it is being allocated to root production (Whitehead, 1995). At harvests 5 to 15,

Table 2.3. Compost effects on annual grass yield (1993-1999). Long-term compost experiment.

Compost	Fertilizer N	df	Grass Yield 1993	1994	1995	1996	1997	1998	1999	Total
	kg ha^{-1} harvest^{-1}		Mg ha^{-1}	Mg ha^{-1}	Mg ha^{-1}	Mg ha^{-1}	Mg ha^{-1}	Mg ha^{-1}	Mg ha^{-1}	Mg ha^{-1}
B1	34		6.4	14.6	12.5	11.6	12.0	11.2	10.6	79.0
B2	34		7.1	14.7	11.9	10.6	12.4	11.1	10.4	78.2
B3	34		6.3	12.6	10.4	10.4	12.0	10.6	10.7	73.0
N	34		6.6	11.4	9.1	9.4	10.1	8.9	9.0	64.4
NON	0		5.6	5.7	5.5	5.5	7.2	4.6	4.3	38.4

ANOVA

Source of variation	df	1993	1994	1995	1996	1997	1998	1999	Total
Treatment	4	*	**	**	**	**	**	**	**
Contrasts	2								
N vs. NON	1	*	**	**	**	**	**	**	**
Compost vs. N	1	NS	**	**	*	**	**	**	**
LSD, 0.05		0.93	1.10	1.10	1.50	1.05	0.85	1.02	4.84
CV, %		10	6	7	10	6	6	7	5

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

Table 2.4. Compost effects on annual N uptake (1993-1999). Long-term compost experiment.

Compost	Fertilizer N	df	Grass N Uptake							
			1993	1994	1995	1996	1997	1998	1999	Total
	kg ha^{-1} harvest^{-1}		kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}
B1	34		165	358	298	264	288	286	241	1900
B2	34		173	344	268	234	291	277	235	1822
B3	34		146	287	220	223	282	264	244	1667
N	34		155	216	169	199	226	214	195	1373
NON	0		116	101	112	109	139	100	81	758
						ANOVA				
Source of variation										
Treatment		4	*	**	**	**	**	**	**	**
Contrasts		2								
N vs. NON		1	*	**	**	**	**	**	**	**
Compost vs. N		1	NS	**	**	NS	**	**	**	**
LSD, 0.05			30.0	27.4	29.6	55.1	33.1	26.1	27.9	161.2
CV, %			14	7	9	18	9	7	9	7

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

the years between 1993 to 1995, the curve starts a steep ascent, signifying the increase in N availability for grass production. This growth is indicative of a higher available N supply from compost. The harvests 20 to 40, years between 1996 to 1999, are linear. The curve is not as steep as that seen previously. Each successive harvest appears to have similar N recovery rates as the previous one. This indicates that slow N release is occurring at a steady rate.

Our study found a small difference between the compost treatments over time for cumulative ANR as a percentage of compost-N applied (Materials and Methods, Eq. [3]). In Figure 2.2, composts B1 and B2, had similar values of 20% and 19%, respectively. Compost B2 had the smallest recovery of 15%.

Soil C and N in the Zone of Compost Application

The second objective of our study was to determine the effect of a one-time, high-rate compost application on soil C and N in the zone of application over time. Measurements of total C and N over time can serve as indicators of long-term compost decomposition.

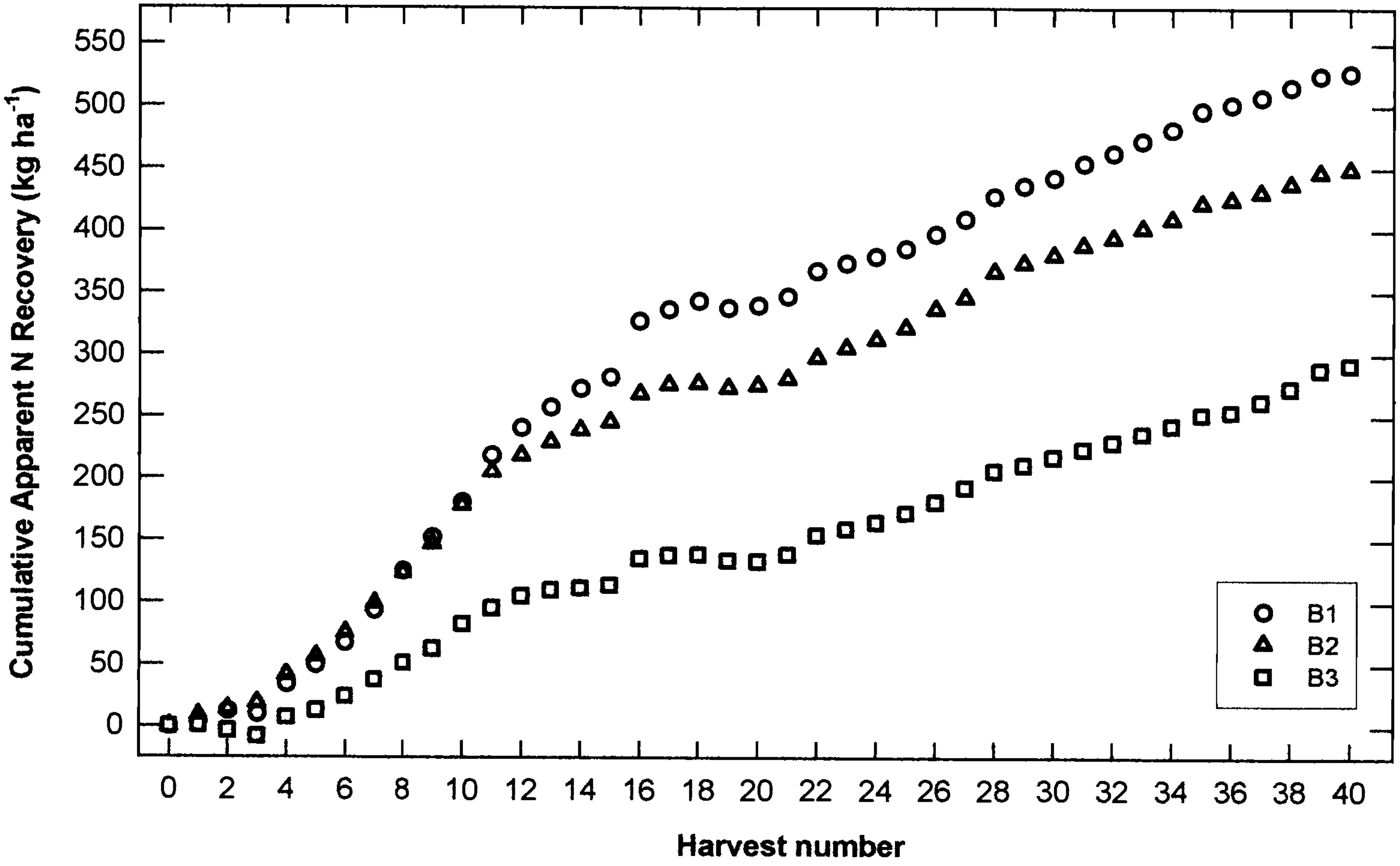

Figure 2.1. Cumulative Apparent N Recovery for harvests 1 to 40. Long-term compost experiment.

Soil C

Compost provided additional C in the system compared to the N and NON treatments. A portion of this additional C remained in the zone of compost application through the seventh year (Table 2.5). In the 0-8 cm soil depth, soil C was significantly increased in the compost treatments after seven years (1999), when compared to N and NON treatments.

In the 8-15 cm depth, there was no significant difference in soil C after seven years. However, the 1998 compost treatments showed that soil C in the 8-15 cm depth was significantly increased. This could mean that some of the organic matter in the compost had been incorporated further into the soil profile by plant root and macro-organism activity. This difference was not observed in 1999 results.

Soil N

Over the long term, compost application provided additional N in the system over the N and NON treatments. Some of this additional N continued to remain in the zone of compost application through the seventh year (Table 2.6).

There was higher soil N with compost application in the 0-8 cm soil depth after seven years in comparison to the N and NON treatments. This

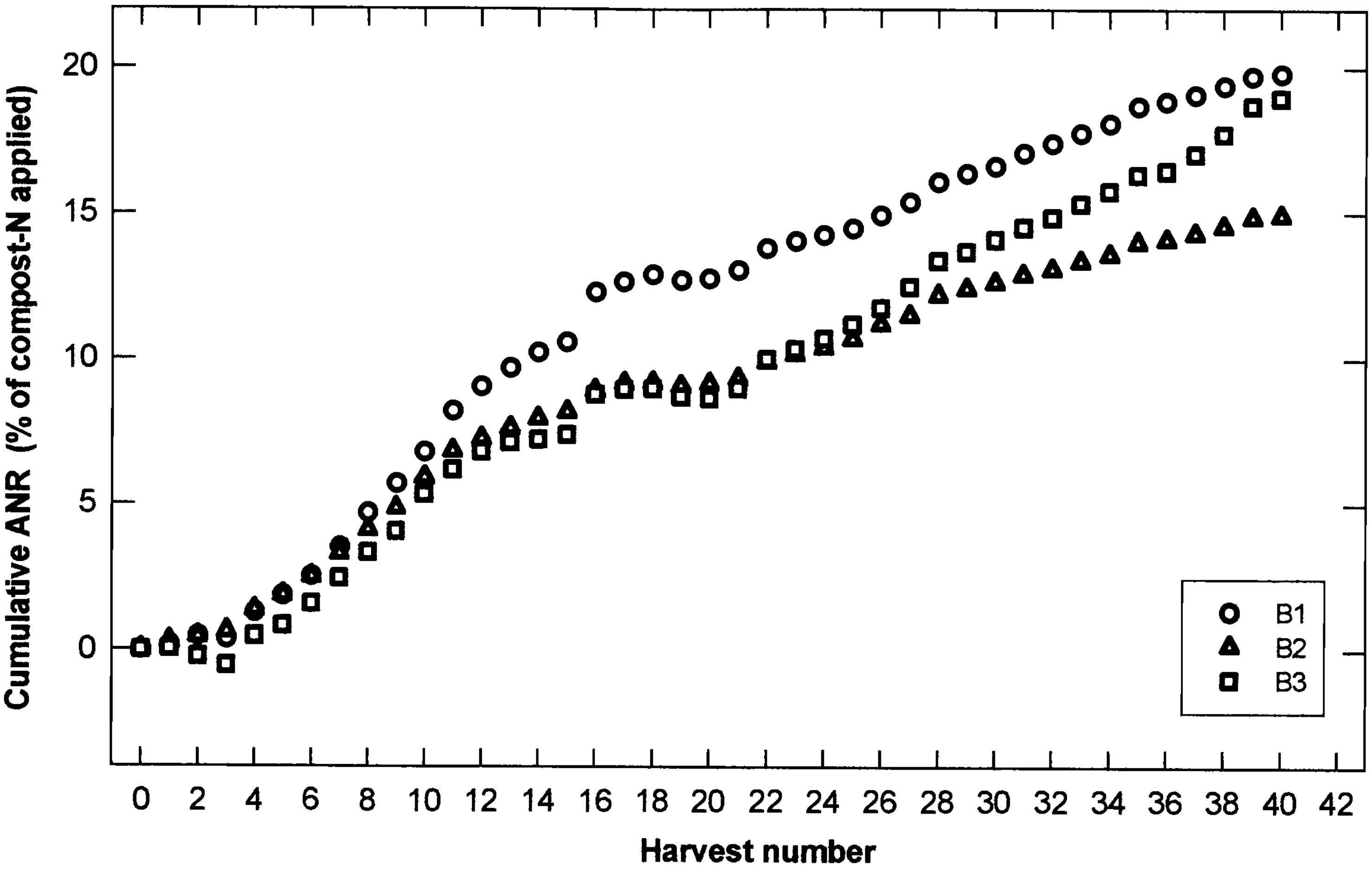

Figure 2.2. Cumulative Apparent N Recovery (percent of compost-N applied) for harvests 1 to 40. Long-term compost experiment.

Table 2.5. Compost effects on soil total C (0-8 and 8-15 cm depth). Sampled Fall 1994, 1995, 1998 and 1999 (post-harvest). Long-term compost experiment.

Compost	Fertilizer N	df	Soil Carbon							
			0-8 cm depth				8-15 cm depth			
			1994	1995	1998	1999	1994	1995	1998	1999
	kg ha^{-1} harvest^{-1}		g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}
B1	34		45.8	40.6	28.8	26.7	-	26.5	17.6	16.8
B2	34		36.3	36.2	25.7	25.2	-	20.9	17.3	17.2
B3	34		35.5	35.4	24.0	24.3	-	20.0	16.9	16.8
N	34		19.5	21.8	19.0	18.6	-	18.1	16.2	16.4
NON	0		-	-	18.5	18.9	-	-	16.4	15.8

ANOVA

Source of variation	df	0-8 cm 1994	0-8 cm 1995	0-8 cm 1998	0-8 cm 1999	8-15 cm 1994	8-15 cm 1995	8-15 cm 1998	8-15 cm 1999
Treatment	4	*	*	**	**	-	NS	*	NS
Contrasts	2								
N vs. NON	1	-	-	NS	NS	-	-	NS	NS
Compost vs. N	1	**	**	**	**	-	NS	*	NS
LSD, 0.05		8.26	12.5	3.55	3.08	-	7.18	1.19	1.43
CV, %		15	25	10	9	-	24	5	6

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

Table 2.6. Compost effects on soil total N (0-8, 8-15 cm depth). Sampled Fall 1994, 1995, 1998 and 1999 (post-harvest). Long-term compost experiment.

Compost	Fertilizer N	df	Soil Nitrogen							
			0-8 cm depth				8-15 cm depth			
			1994	1995	1998	1999	1994	1995	1998	1999
	kg ha^{-1} harvest^{-1}		g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}
B1	34		4.3	3.5	2.6	2.5	-	2.1	1.6	1.5
B2	34		3.4	3.1	2.3	2.3	-	1.8	1.6	1.5
B3	34		3.0	2.7	2.0	2.1	-	1.7	1.5	1.5
N	34		1.8	1.8	1.7	1.7	-	1.6	1.5	1.4
NON	0		-	-	1.7	1.7	-	-	1.5	1.4
						ANOVA				
Source of variation										
Treatment		4	**	*	**	**	-	NS	*	NS
Contrasts		2								
N vs. NON		1	**	-	NS	NS	-	-	NS	NS
Compost vs. N		1	**	**	**	**	-	NS	NS	NS
LSD, 0.05			0.83	1.01	0.30	0.28	-	0.57	0.12	0.13
CV, %			17	25	9	9	-	22	5	6

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

is an indication of the slow N availability of these composts. In the 0-8 cm depth, there was a significant increase in soil N as a result of compost application in 1995, 1998 and 1999.

In the 8-15 cm depth, there was no significant increase due to compost application for all compost treatments. For all analysis years, soil N was greater with compost compared to the NON and N treatments. There was no significant response to compost application after seven years in the 8-15 cm depth. In the 8-15 cm depth, the soil N levels of the compost treatments were similar over the seven year period. There does not appear to be any accumulation of fertilizer N in the soil. This is indicated by the similar values of soil N when comparing the N and NON treatments for 1998 and 1999 (Table 2.6).

Mineralizable Soil N

In order to assess the amount of soil total N that will become plant-available, a seven-day anaerobic soil test was performed on the treatment soil samples collected for the years 1995 and 1998.

In the 0-8 cm depth, mineralizable N was significantly higher in response to compost application in 1995 and 1998. In 1998, there was no significant difference between the mineralizable N found in the N and NON treatments at the 0-8 cm depth. In Table 2.7, The CV for mineralizable N ranged from 20-32%, whereas the range was 9-25% for the soil N analysis of the same samples (Table 2.6). The high variability of this soil N test, in the 0-8 cm depth, made it a less reliable measurement in our study.

In 1998, the 15-30 cm depth was analyzed and there was a significantly higher amount of mineralizable N for compost treatments. Since this was the only year we collected this sample we can only make assumptions based on this data. This may be the result of both microbial biomass cycling and root redistribution of available soil N (Paul et al, 1997). It appears that mineralizable N derived from the compost remains mostly in the 0-8 cm depth. Total soil N measurements (Table 2.6) were a better assessment of compost effects on soil N over time.

Table 2.7. Compost effects on mineralizable N (0-8, 8-15 and 15-30 cm depth). Sampled Fall 1995 and 1998 (post-harvest). Long-term compost experiment.

Compost	Fertilizer N	df	Mineralizable N 0-8 cm depth 1995	 0-8 cm depth 1998	 8-15 cm depth 1995	 8-15 cm depth 1998	 15-30 cm depth 1998
	$kg\ ha^{-1}\ harvest^{-1}$		$mg\ kg^{-1}$	$mg\ kg^{-1}$	$mg\ kg^{-1}$	$mg\ kg^{-1}$	$mg\ kg^{-1}$
B1	34		160	117	76	45	40
B2	34		165	79	72	48	38
B3	34		178	123	63	39	35
N	34		78	62	53	35	31
NON	0		-	64	-	46	34
					ANOVA		
Source of variation							
Treatment		4	NS	**	*	NS	NS
Contrasts		2					
N vs. NON		1	-	NS	-	NS	NS
Compost vs. N		1	**	*	NS†	NS	*
LSD, 0.05			69.9	26.2	22.3	13.4	6.3
CV, %			32	20	23	13	7

NS, *, ** Not Significant, Significant at the 0.05 and 0.01 probability levels, respectively
†Significant at the 0.06 probability level

SUMMARY AND CONCLUSIONS

Compost provided a source of slow-release, plant-available N to our grass crop, for many years after the initial compost application. In addition, an increase in soil organic matter content over time was measured in treatments that received compost.

One of our objectives was to determine the effect of an initial high rate compost application on crop apparent N recovery (ANR). In our study it was determined that municipal compost has a measured and beneficial effect on grass ANR. Since ANR is dependent on a combination of crop yield and N uptake, our study demonstrated that a significant long-term yield and N uptake response occurred due to the initial high rate compost application. This response was seen across all compost treatments, despite the differences in their feedstock composition and composting method. There were differences in the quantity of plant-available N provided by the composts. This difference can be related to the initial amount of N provided by the different composts. Overall, the highest N content of the composts was B2, followed by B1, then B3. Composts B1 and B2 had the highest cumulative ANR. Compost B3, recovered nearly one-third less than B1 and B2 over the duration of the study.

Our second objective was to determine whether an initial high rate compost application had a long-term effect soil C and N in the zone of application over our study period of seven years. Based on periodic soil C measurements, our study demonstrated that compost application had a long term effect on soil C and N in the zone of compost application (0-8 cm depth). Total soil C and N decreased with time after compost application, but differences were still measured after seven years.

Mineralizable soil N was of limited value as an indicator of compost and soil N mineralization potential, due to its high variability. However, soil mineralizable N was higher after compost application for 1995 and 1998.

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CHAPTER 3

QUANTIFYING N RELEASE FROM MINIMALLY PROCESSED YARD TRIMMINGS

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ABSTRACT

Applying “Minimally Processed Yard Trimmings” (MPYT) to cropland can be a beneficial option for both farmers and municipalities. However, more information is needed to determine the N availability of incorporated MPYT. The major objectives of this study were to: 1) determine the quantity of net N mineralized after MPYT application to soil and its relation to initial MPYT-total N and C (N release, experiment 1); 2) determine the impact of storage periods on MPYT nitrogen release (MPYT storage, experiment 2); and 3) evaluate the correlation between CO_2-C evolution and aerobic net N mineralization for soil incorporated MPYT (CO_2-C quick test, experiment 3).

MPYT samples were collected from four Western WA composting facilities in 1999. All collected MPYT samples were incorporated into Puyallup fine sandy loam and incubated for 168d (experiment 1), 98d (experiment 2) and 68d (experiment 3). All experimental soils were sub-sampled periodically for nitrate-N (NO_3-N) and ammonium-N (NH_4-N) content. In addition, a carbon dioxide (CO_2-C) evolution study of selected incubated MPYT samples was performed. CO_2-C evolution was measured for 68d in experiment 3.

This study found that the MPYT produced at the four facilities had different mineral N (NO_3 -N + NH_4-N) release and CO_2-C loss results.

However, these results did not differ greatly among the samples collected within a given facility. This means that the MPYT available from each facility is of a consistent quality. In experiment 1, over one-half of the sample population experienced net N immobilization during the initial 7-21d incubation period, with one facility sample immobilizing N during the entire 168d incubation period. During the 7-21d incubation period, the range of net N immobilization was between –34 to –1 mg (NO_3-N + NH_4-N) kg^{-1}. Samples that contained the highest proportion of grass released the greatest amount of N (up to 195 mg (NO_3-N + NH_4-N) kg^{-1}) over the 168d incubation period. The MPYT total N and C concentration were related to N-release over time. For the collected samples, total N concentration ranged from 8 to 37 g kg^{-1}. Samples with N contents greater than 15 g kg^{-1} released more N over time. The MPYT C:N ratio ranged from 11:1 to 34:1. There was greater N release from MPYT samples with a C:N ratio of less than 15:1. In experiment 2, the length of storage time affected the quantity of MPYT-N release over time. The longer samples were held at the facility, the lower the potential MPYT-N release over the 98d incubation period. In experiment 3, CO_2-C evolution and aerobic incubation mineralization data from experiments 1 and 2 were used to correlate C loss and N release of select MPYT samples. Net N mineralized results for 68d, were higher in experiments 1 and 2 than in experiment 3. Samples with high N concentrations (greater than 15 g kg^{-1}) had the greatest respiration rates

and net N mineralized quantities. Sample respiration rates ranged from 200 to 400 mg C g^{-1} residue–C added. In order to encourage the land application of MPYT as a soil conditioner and N fertilizer source, MPYT characterization and N release data is needed.

Key Words: MPYT, Minimally Processed Yard Trimmings, Municipal, Carbon dioxide evolution, Aerobic N incubation, N release, N mineralization.

INTRODUCTION

Nationwide concern over landfill capacity in the late 1980's and early 1990's, prompted more than 20 states to ban the landfill disposal of yard trimmings (Stoffella et al., 1998). In an effort to recycle organic materials, municipalities are turning to compost facilities to help deal with increased volumes of landscape yard trimmings (Glenn, 1999). Yard trimmings are a non-homogenous mixture of wood and grass materials. During the late spring and summer months, lawn clippings are a major component of yard trimmings (Bary et al., 1999). The volume of yard trimmings varies seasonally (Eriksen et al., 1999). According to Sullivan (2000), peak amounts of yard trimmings are received in the late spring and summer months. The annual volume of yard trimmings to Western WA facilities averages about 210,000 tons, with nearly one-half of the volume received from April to August (Sullivan, 1999, personal communication). In the peak volume months, yard trimmings are predominantly composed of grasses with a high moisture content (Martin and Gershuny, 1992) and high biological oxygen demand (The Composting Council, 1994). Due to the odorous nature of grass in yard trimmings, problems are caused when incoming volumes exceed the facilities ability to compost it in a timely manner (The Composting Council, 1994).

Land application of "Minimally Processed Yard Trimmings" (MPYT) to cropland can be beneficial to both farmers and compost operations. It can help composting facilities to prevent operation and odor problems, as well as provide farmers with an alternative source of organic matter and crop nutrients (Sullivan, 2000). Several pilot field projects are being conducted in Western Washington (Bary et al., 1999). Bary et al. (1999) found that Puget Sound MPYT, at application rates of 20 dry T ac^{-1}, adequately replaced nitrogen (N) fertilizer requirements for silage corn production. Yard trimmings compost is known to be beneficial in the production of container nursery plants. (Hummel et al., 1995), turf industry (Stahnke and Bary, 1995) and field crop production (Zibilske, 1998). Use of landscape yard trimmings (MPYT) may serve as a practical N supplement or replacement, erosion barrier and soil organic matter amendment in many agricultural systems (United States Department of Agriculture, 1978).

More information on the N availability of MPYT is needed to provide reliable information to growers interested in using this amendment. Laboratory incubations are an established method to estimate the quantity of residue N availability. Kuo and Sainju (1998) utilized an aerobic incubation method to determine the N availability of incorporated cover crops. De Neve and Hofman (1996) investigated the N release from vegetable crop residue; Boyle and Paul (1989) studied biosolids. From these studies, N mineralization rates were determined and the relationship between carbon mineralization and N release was discussed. In many residue-N release studies, the influence of residue C:N content is determined by relating initial C:N to net N mineralization. It was determined by Gilmour et al. (1998), that initial decomposition in the first two weeks of incorporation was related to residue C:N ratio. In that study, C:N ratio did not impact decomposition after 2 weeks. The influence of incubator temperature and C:N ratio on N release has been investigated by Vigil and Kissel (1995). They found that at 25°C, crop residues with C:N ratios of 28:1 and 38:1 immobilized N up to 106d after incorporation.

Despite the information gathered from an incubation study, this method of estimating N availability is expensive, laborious and time consuming (Stanford et al., 1974). In addition, there are variables such as incubation duration and temperature (Vigil and Kissel, 1995), moisture (Wagner and Wolf, 1998) and residue preparation (Bending and Turner, 1999), which may confound the results. Gilmour et al. (1998) found that the same residue incubated in different soils resulted in different N mineralization rates.

An alternative to the long-term incubation method is to conduct a short-term incubation study to measure CO_2-C evolution. N availability can be determined from residue-amended soils by measuring biological respiration during the initial period of residue decomposition (68d). Marstop (1997) proposed that respiration (evolved CO_2-C) measurement could be a valuable tool to predict N availability from soils amended with organic residues. According to Wagger et al. (1998), short-term carbon dioxide (CO_2-C) evolution studies are considered a viable option to determine N mineralization of incorporated residues.

The intimate relationship between C decomposition and N release is well recognized. However, it is not a single-factor relationship and the extent of residue C decomposition and N release is typically understood through use of computer models. Gilmour (1998) developed and utilized a carbon (C) decomposition model to estimate plant-available N (PAN) over time. In companion with a C decomposition model, a seven-day CO_2-C quick test was used by Gilmour et al. (1996) to estimate net N mineralization of biosolids. Wu and McGechan (1998), reviewed four computer models that simulated N mineralization. They determined that soil mineralization processes were dependent on added residue-C quantity and chemical composition. All the models reviewed paralleled N behavior with C decomposition.

Although much work has been accomplished to predict the N release for various residues, MPYT characterization and N release data are still needed. Unlike organic products, such as biosolids or compost, MPYT has not been subjected to intensive processing to produce a stable soil amendment. Manure is also different from MPYT, since manure is partially decomposed in the digestive systems of livestock. Plant residue N release data is most closely related to MPYT, however most N release data is for either late vegetative stage cover crops or mature plant tissues, such as stalks, straw or stubble. The major component of MPYT, in the spring and summer months, are relatively immature grass leaves and stems. In contrast to late maturity plant tissue, which has increased lignin content, immature plant tissue has higher soluble sugar content (Smith, 1982). Since soluble sugars serve as a rapid energy source for soil organisms (Curtin and Wen, 1999), MPYT decomposition may occur rapidly. The grass clippings in MPYT may have a high N concentration (Fritz and Graves, 1992), this characteristic will influence N release upon soil application. Since MPYT characterization and N release has not been determined, the major objectives of this study are to: 1) determine the quantity of net N mineralized after MPYT application to soil and its relation to initial MPYT-total N and C; 2) determine the impact of storage periods on MPYT nitrogen release and 3) evaluate the correlation between CO_2-C evolution and aerobic net N mineralization for soil incorporated MPYT.

MATERIALS AND METHODS

Minimally Processed Yard Trimmings Collection

Residue Sampling Protocol

Three replicate residue samples were collected from each of four designated composting facilities (BF-Snohomish, WA; CG-Maple Valley, WA; LRI-Puyallup, WA; SC-Covington, WA) on two dates in April and May. The purpose of sampling on two different dates was to determine if MPYT N release was influenced by date of sample collection. Samples were composed of a minimum of fifteen grab samples (approximately 4 L) collected from different pile locations and depths. At the BF facility, freshly ground yard trimmings were sampled from 45 m^3 pile. A front-end loader was utilized to remove 1 m^3 of yard trimmings from the center of the pile. Grab samples were taken from three sections in the center of the pile. Each exposed section represented a replicate (A, B and C). At the CG facility, day-old ground yard trimmings were sampled from a 50 m^3 section of the freshly exposed front of a MPYT pile approximately 200 m^3 in volume. The 50 m^3 section was divided into three replicate sections. Grab samples were collected from various depths and locations of each replicate section. At the LRI facility, ground and sieved yard trimmings, up to one week old, were sampled on the freshly exposed front of a MPYT pile, approximately 180 m^3. The exposed face was divided into three replicate sections. Grab samples were collected from various depths and locations of each replicate face. At the SC facility, fresh, unground yard trimmings were "source-separated" into "grassy" and "woody" fractions. Only the grassy piles were sampled in our study. The grassy fraction was in a pile volume of 10 m^3. This pile was divided in half by a front-end loader and grab samples were collected from each exposed section. The third replicate was collected by excavating into the pile, at a depth of approximately 1 m^3.

MPYT Sample Fractionation

The collected grab samples for each replicate were combined in a 60 L plastic container, then emptied onto a tarp and mixed thoroughly. Samples were hand-sorted, based on particle size and composition into 3 classes: coarse-woody, coarse-green and fine. The coarse-woody fraction is made up of woody material with a diameter of 5 mm or greater. The coarse-green fraction is made up of foliage and small stems that do not pass through an 11 x 22 mm mesh screen. The fine fraction is made up of leaves, plant foliage and other plant and soil-like debris that will pass through an 11 x 22 mm mesh screen.

Residue Analysis

Collected residue samples were dried at 60°C and ground to pass a 2 mm sieve. The total carbon (C) nitrogen (N) concentration of each sample was determined via a combustion C and N gas analyzer (LECO Instruments, St. Joseph, Michigan; Sweeney, 1989).

N Release and MPYT Storage Experiments

Selected MPYT samples were included in a 168d aerobic incubation experiment (N release experiment 1). In addition, a second 98d aerobic incubation experiment was conducted to determine the impact of facility storage on MPYT-N release (MPYT storage experiment 2). In both these experiments, the samples were individually mixed with Puyallup fine sandy loam (coarse-loamy over sandy, mixed, mesic, Vitrandic Haploxerolls) soil and sub-sampled periodically for NO_3-N and NH_4-N content. A non-amended soil control was included in both trials to determine net mineralization of the residue-amended soils. The composite sub-samples were extracted with 2 M KCl and analyzed by OSU Central Analytical Lab (Corvallis, OR) with an ALPKEM rapid flow analyzer No. RFA-300 NH_4-N was determined via a salicylate and hypochlorite reaction to form indophenol blue; sodium nitroprusside is used to intensify blue color that is read at 660 nm (RFA methodology, 1985). NO_3-N was determined via cadmium reduction (RFA methodology, 1990).

Aerobic Incubation Method

Soil was dried at 30°C and ground to pass a 2 mm sieve. To avoid N limiting conditions, reagent grade potassium nitrate (KNO_3) was used as a fertilizer N source. Fertilizer solution was applied to soil at rate of 100 mg NO_3-N kg^{-1} oven-dry soil. Soil was moistened with a mixture of fertilizer and distilled water to 21.5 % gravimetric moisture content. Moistened soil was placed in a 3.8 L, 26 x 28 cm polyethylene storage bag (Ziploc ®, SC Johnson & Son, Inc.) for the N release experiment, and in a 18 x 20 cm, 0.9 L plastic polyethylene storage bag (Ziploc ®, SC Johnson & Son, Inc.) for the MPYT storage experiment.

For the N release experiment, MPYT residue was added to pre-moistened soil at a rate of 20 g 1000 g^{-1} dry soil. For the MPYT-storage experiment, MPYT residue was added to pre-moistened soil at a rate of 6 g

300 g^{-1} dry soil. After adding soil, water and fertilizer, the bags were shaken thoroughly to ensure thorough mixing. Bag openings were not sealed. Eight bags, containing an initial weight of 1000 g dry soil (N-release experiment 1) or fifteen bags, containing an initial weight of 300 g dry soil (MPYT storage experiment 2) were placed on a moistened foam pad. The foam pad was moistened by the addition of 100 mL of distilled water placed in a 60 L incubation container with a removable lid. The container lids were left askew to allow aeration to occur. The containers were checked bi-weekly to re-moisten foam pads, up to 100 mL of distilled water was added to maintain container moisture conditions. The samples were placed in a growth chamber and incubated at 25°C (Model CEL 38-15, Shearer Co., Asheville, NC).

Soil Sub-sampling and Analysis

At each sampling time, moist soil sub-samples were taken from the bags in triplicate. Prior to sampling, the bags were shaken thoroughly to insure uniformity. For sample periods 0, 7, 14, 21, 49, 56, 77 and 168d, three 10g composite sub-samples were collected from each bag. Based on the uniformity of NH_4 + NO_3-N analyses within bags observed for days 0 to 77, only one sub-sample per bag was taken at 98, 112, 126, 140 and 154d. However, for all sampling times, the MPYT reference and Puyallup control soil bags were sub-sampled in triplicate. Collected sub-samples were analyzed for NO_3-N + NH_4-N concentration for all sampling times.

A sub-sample of moist soil was collected at each sampling. The gravimetric moisture was determined to express N concentrations on a dry soil basis. Soil moisture content was measured for subsamples from each bag. Soils were brought up to 21.5 to 24% gravimetric moisture content, immediately after each sampling date.

Nitrogen Mineralization Equations

We refer to quantity of N mineralized relative to the soil only control as net mineralization:

$$Net\ Nmin = A - B \qquad \text{Eq. [1]}$$

where

A = Soil + residue treatment N concentration ($mg\ NO_3\text{-}N + NH_4\text{-}N\ kg^{-1}$)

B = Soil only control N concentration ($mg\ NO_3\text{-}N + NH_4\text{-}N\ kg^{-1}$)

Net N mineralization can also be expressed as a percentage of the total MPYT-N applied:

$$Nmin(\%) = (Net\ Nmin / C) * 100 \qquad \text{Eq. [2]}$$

where

$Nmin(\%)$ = Nmin (% of MPYT-N applied)

$Net\ Nmin$ = Net N mineralized (mg NO_3-N + NH_4-N kg^{-1}), from Eq. [1].

C = MPYT-N applied (mg N kg^{-1})

Carbon Dioxide Evolution Experiment

Sample Preparation

MPYT residue was added to the same pre-moistened soil as described in experiments 1 and 2, at a rate of 1 g 50 g^{-1} dry soil (20 g kg^{-1} dry soil). The residue and moistened soil was mixed thoroughly in a 0.95 L glass jar (Mason Company ©, Muncie, Indiana) with a glass stirrer. A plastic vial containing 20 mL of 1M NaOH solution was left open in each jar prior to sealing the jar with an air-tight lid. The sealed jars with open NaOH traps were incubated at 25° C (Model CEL 38-15, Shearer Co., Asheville, NC). The traps were removed and replaced at each sampling time: 1, 3, 5, 7, 14, 21, 28, 34, 43, 52, 60 and 68d. There were three replicate jars for each sample. Two additional sets of identical glass jars were prepared and destructively sampled to determine soil NO_3-N and NH_4-N content at 7 and 21d.

Soil Analysis

Jar contents were emptied and mixed thoroughly prior to analysis. For sample periods 7, 14 and 68d, 10 g composite soil samples were collected and analyzed for NO_3-N + NH_4-N.

CO_2-C Evolution Determination

After each sampling period, a titration method was used to determine the hydroxide (OH) remaining after exposure to carbon dioxide (CO_2). One mL of the NaOH trap aliquot was added to 10 mL of 1.5 M $BaCl_2$ solution to precipitate carbonate (CO_3^{2-}) as barium chloride ($BaCO_3$). The remaining sodium hydroxide (NaOH) was immediately titrated with 0.11 M standardized hydrochloric acid (HCl). The end point titration volume was recorded and used to calculate the amount of CO_2-C evolved.

Carbon Dioxide Evolution Equations

Carbon dioxide evolution via HCl titration of base traps can be determined by equations [3] and [4]. The first step is to determine the gross rate of CO_2-C evolved:

$$\textit{Gross } CO_2\textit{-C evolved (mg)} = (D - E) * F * G * H \qquad \text{Eq. [3]}$$

where

D = HCl volume used in titration for the air only control (mL)

E = HCl volume used in titration for the treatment or the Puyallup soil-only control (mL)

F = Molarity of HCl (mM)

G = Milliequivalent weight of CO_2 (6 mg C mM^{-1} C)

H = Ratio of volume of NaOH contained in trap (20 mL) to volume of NaOH titrated (1 mL)

The second step is to determine the net rate of CO_2-C evolved:

$$\textit{Net } CO_2\textit{-C evolved (mg)} = I - J \qquad \text{Eq. [4]}$$

where

I = Treatment gross CO_2-C evolved (mg), from Eq. [3].

J = Puyallup control soil gross CO_2-C evolved (mg), from Eq. [3].

Net CO_2-C evolution can also be determined as a percentage of C applied with the MPYT residue:

$$CO_2\text{-}C\ evolved_{\%\ MPYT\text{-}C\ applied} = (K / L) * 100 \qquad \text{Eq. [5]}$$

where

K = Treatment CO_2-C evolved (mg), from Eq. [4].
L = MPYT-C applied (mg)

RESULTS AND DISCUSSION

MPYT N Release (Experiment 1)

There is limited information on the amount of N released or mineralized from MPYT soil incorporation. The objective of this study was to determine the quantity of MPYT nitrogen (N) release over time and its relation to initial MPYT-total N and C.

The MPYT collected at the four Puget Sound facilities varied in composition. The SC samples were predominantly grass with minimal woody debris. The BF, CG and LRI samples contained more woody debris. Across facilities, the samples collected for this experiment varied in total N content and C:N ratio (Table 3.1). The SC samples had the highest N concentration (17 to 32 g N kg^{-1}) and lowest C:N ratio (less than 15:1) of all the MPYT samples analyzed. The CG samples had the lowest N concentration (8 to 14 g N kg^{-1}) and the highest C:N ratios (greater than 31:1). The BF facility receives both yard trimmings and horse manure. The manure can get mixed into the yard trimmings piles at the BF facility. Although not evaluated separately in this study, the manure component may affect the N release quantity of BF samples. Both the LRI and BF samples were in the mid-range of N content and C:N ratios among the samples investigated. Based on these initial characteristics, CG samples would be expected to immobilize N upon incorporation. Conversely, SC samples would be expected to mineralize N quickly. Several investigators have determined that N content and C:N ratio influence plant-available N release over time (Wagger et al., 1998).

Soil Net N Mineralized

Soil net N (NO_3-N + NH_4-N) mineralized was determined via equation [1]. In Figure 3.1, all samples except SC (28-Apr-99) and BF (30-Apr-99), experienced immobilization periods, from day 7 to 21. CG (28-Apr-99) did not mineralize N throughout the entire experimental period (0-168d). Samples from SC and BF facilities had the highest N mineralized over the incubation period. The quantity of N release from residues collected at the two different sampling dates did not differ greatly within each facility.

Table 3.1. MPYT sample characteristics. Total C, N and C:N ratio. Experiments 1, 2 and 3.

MPYT Collection Facility	Replicate Sample	Sample Collection Date	Residue Analysis			Incubation Experiments†		
			C	N	C:N	1	2	3
			g kg^{-1}	g kg^{-1}				
BF	A	30-Apr-99	305	17	18	x	-	-
BF	B	30-Apr-99	305	17	18	x	-	x
BF	C	30-Apr-99	290	16	18	x	-	-
BF	A	19-May-99	267	15	17	x	-	-
BF	B	19-May-99	335	19	18	x	-	x
BF	C	19-May-99	339	20	17	x	-	-
CG	A	28-Apr-99	335	11	31	x	-	-
CG	B	28-Apr-99	263	8	32	x	-	x
CG	C	28-Apr-99	292	9	34	x	-	-
CG	A	18-May-99	300	14	21	x	-	-
CG	B	18-May-99	290	14	20	x	-	x
CG	C	18-May-99	255	12	21	x	-	-
LRI	A	26-Apr-99	314	16	20	x	-	-
LRI	B	26-Apr-99	285	14	20	x	-	x
LRI	C	26-Apr-99	253	12	21	x	-	-
LRI	A	18-May-99	306	18	17	x	-	-
LRI	B	18-May-99	309	18	17	x	-	x
LRI	C	18-May-99	328	18	18	x	-	-
LRI-reference	-	-	291	16	18	x	-	x
SC	A	28-Apr-99	366	28	13	x	x	-
SC	B	28-Apr-99	415	32	13	x	-	x
SC	C	28-Apr-99	349	25	14	x	-	-
SC	A	18-May-99	302	22	14	x	-	-
SC	B	18-May-99	334	26	13	x	-	x
SC	C	18-May-99	252	17	15	x	-	-
SC[a]	A	22-July-99	432	41	10	-	x	-
SC[a]	B	22-July-99	425	37	11	-	x	x
SC[a]	C	22-July-99	427	37	11	-	x	-
SC[b]	A	29-July-99	440	30	15	-	x	-
SC[b]	B	29-July-99	434	33	13	-	x	-
SC[b]	C	29-July-99	428	28	15	-	x	-
SC[c]	A	5-Aug-99	394	30	13	-	x	-
SC[c]	B	5-Aug-99	419	31	13	-	x	x
SC[c]	C	5-Aug-99	400	36	11	-	x	-
SC[d]	A	12-Aug-99	376	29	13	-	x	-
SC[d]	B	12-Aug-99	403	32	13	-	x	-
SC[d]	C	12-Aug-99	397	30	13	-	x	-
SC[e]	A	19-Aug-99	335	31	11	-	x	-
SC[e]	B	19-Aug-99	329	29	11	-	x	x
SC[e]	C	19-Aug-99	334	28	12	-	x	-

†N release (experiment1); MPYT storage (experiment. 2); CO_2-C quick test (experiment 3).

[a] Referred to as SC-week 0 in MPYT storage experiment 2.

[b] Referred to as SC-week 1 in MPYT storage experiment 2.

[c] Referred to as SC-week 2 in MPYT storage experiment 2.

[d] Referred to as SC-week 3 in MPYT storage experiment 2.

[e] Referred to as SC-week 4 in MPYT storage experiment 2.

Soil NO_3-N + NH_4-N

Soil NO_3-N + NH_4-N differences were observed when comparing MPYT samples from the four facilities. Average soil NO_3-N after day 49, was highest in the SC samples, followed by BF, LRI, and lowest in the CG samples (Figure 3.2). Average initial soil NH_4-N (Figure 3.3) was highest in the LRI samples, followed by SC, CG and BF samples. After day 14, there was a decrease in NH_4-N over time in all samples, except in the SC-1 sample. However, differences in NH_4-N, did not greatly influence the mineral N (NO_3-N + NH_4-N) concentrations of the facility samples (Figure 3.1).

The MPYT samples were collected from fresh yard trimmings piles at each facility during two peak flow sample dates in April and May. The results from both figures 3.2 and 3.3 show that the time of sample collection did not affect the soil N (NO_3-N + NH_4-N) release results within each facility.

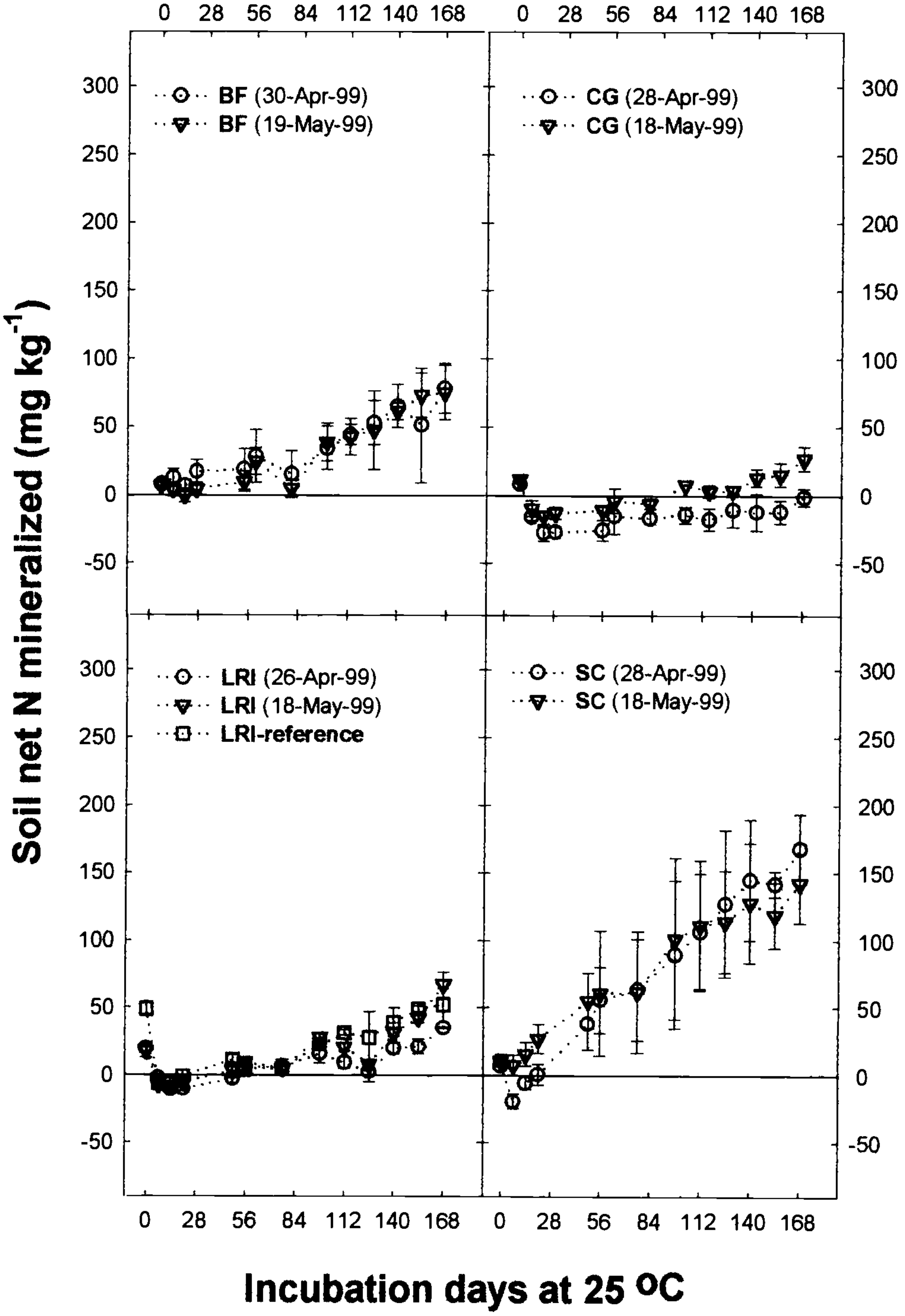

Figure 3.1. Soil net N mineralized following incorporation during incubation period (0-168d). N release experiment 1. Error bar is standard deviation for replicate MPYT samples A, B and C.

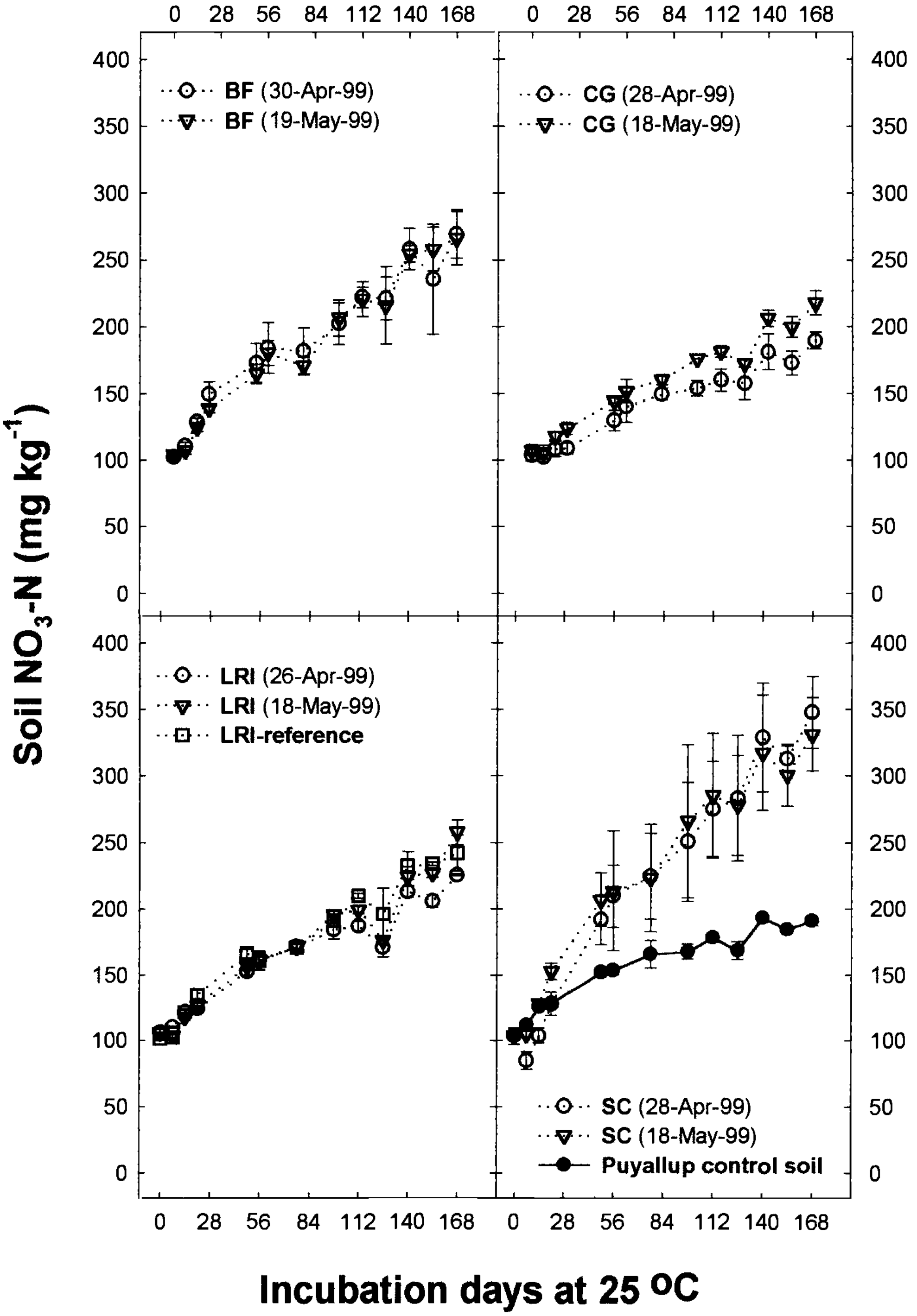

Figure 3.2. Soil NO_3-N mineralized following incorporation during incubation period (0-168d). N release experiment 1. Error bar is standard deviation for replicate MPYT samples A, B and C.

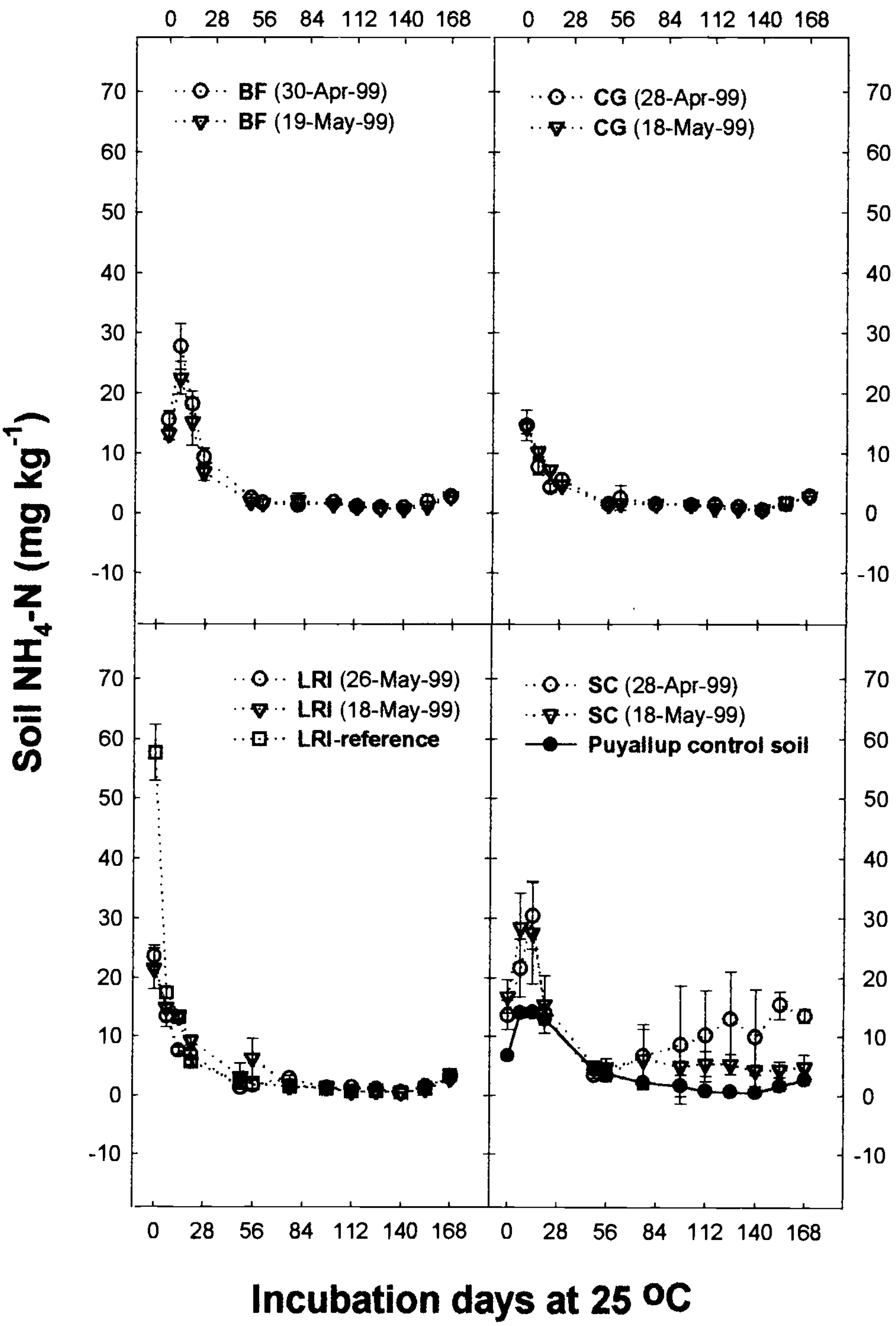

Figure 3.3. Soil NH_4-N mineralized following incorporation during incubation period (0-168d). N release experiment 1. Error bar is standard deviation for replicate MPYT samples A, B and C.

Effect of Initial MPYT Total N Concentration

Total N concentration, in great part, determines the quantity of N release for our samples (Figure 3.4). The samples with a total N concentration of 15 g kg^{-1} or less appeared to have the least N mineralized for 49, 98 and 168d sampling periods. At 14d, initial total N concentration did not seem to influence the quantity of N mineralized. N immobilization was experienced by 17 of the 25 samples during the 14d sample date. However, in the later sample dates (49, 98 and 168d), it was observed that the amount of N mineralized was highly influenced by the total N concentration of the MPYT samples.

At day 168, there is a strong linear relationship between the N mineralization of a sample and its initial N concentration (Figure 3.4). The initial total N concentration of collected MPYT samples differed, depending on the facility source (Table 3.1). The highest total N concentrations belonged to the SC samples. The influence of initial total N concentration on the quantity of N mineralized is apparent, when one considers that the SC samples had the highest N mineralized (Figure 3.4) over the 168d period. Conversely, the CG samples had the lowest N mineralized over the 168d incubation period (Figure 3.4), and also had the lowest initial total N concentration.

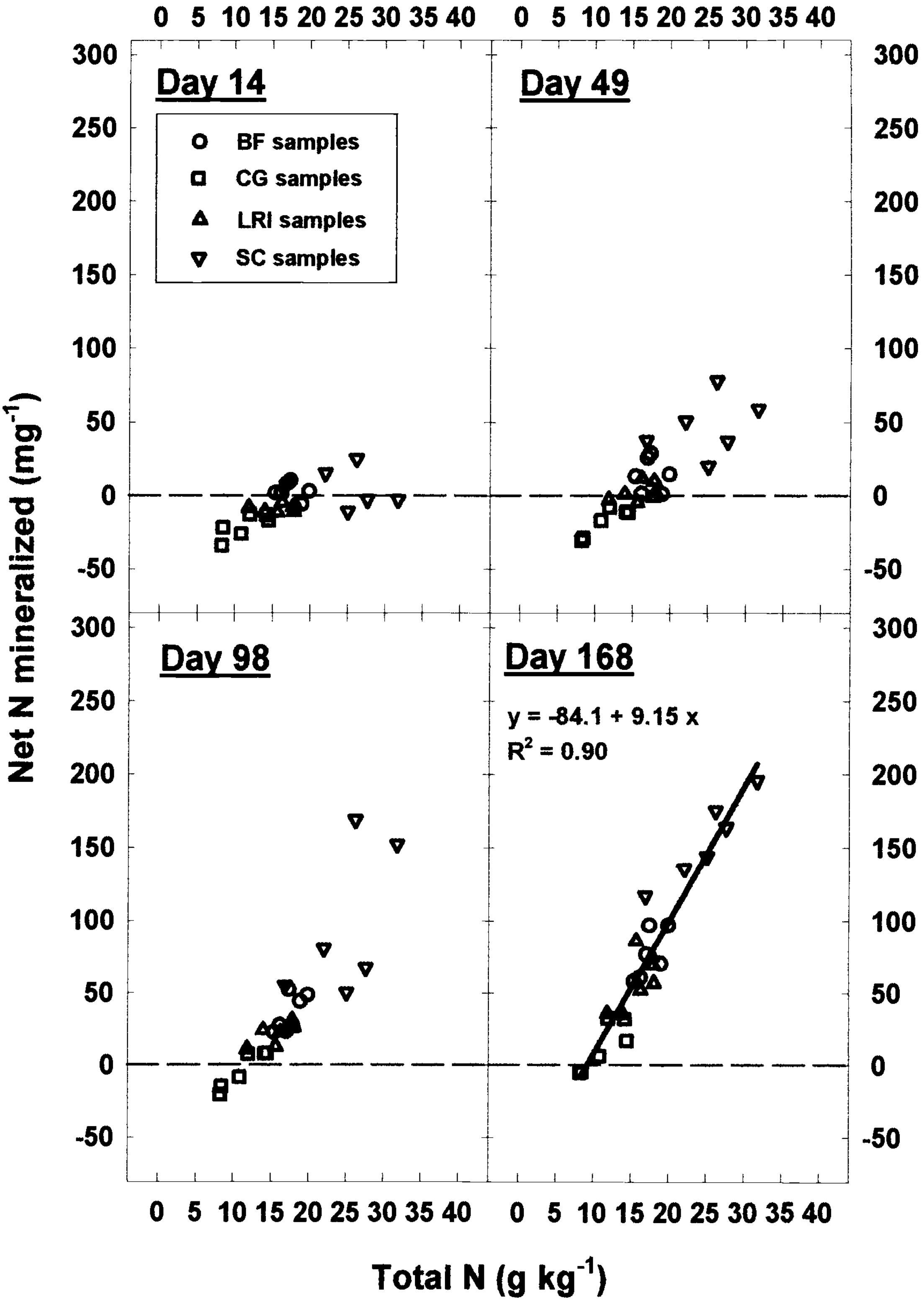

Figure 3.4. Influence of initial N concentration of MPYT on net N mineralized. N release experiment 1.

Effect of Initial MPYT Carbon to Nitrogen (C:N) Ratio

The initial C:N ratio of the collected MPYT samples differed, depending on the facility source. Samples with C:N ratios less than 15:1, had the most N mineralized (Figure 3.5). At day 14, C:N ratio did have a large effect on quantity of N mineralized, the BF and SC samples had net N mineralization ranging from 1 to 24 mg kg^{-1}. The other samples immobilized N with net N mineralization at 14d ranging from –34 to –3 mg kg^{-1}. At later sample dates of 49, 98 and 168d (Figure 3.5), the amount of net N mineralized was highly influenced by the C:N ratio of the MPYT samples. Rather than the linear relationship as seen in 168d example of N content to net N mineralized (Figure 3.4), there was a curvilinear relationship between initial C:N ratio and the quantity of net N mineralized on day 168. In Figure 3.5, the SC samples had the highest N mineralized and the lowest C:N ratios. The CG samples had the lowest N mineralized over the 168d incubation period and also had the lowest initial C:N ratio. All of the samples, except CG, were out of the net N immobilization phase by 98d (Figure 3.5). Initial C:N ratio is an important consideration when applying MPYT to crops. This knowledge can assist in determining when and how to apply MPYT to avoid N immobilization.

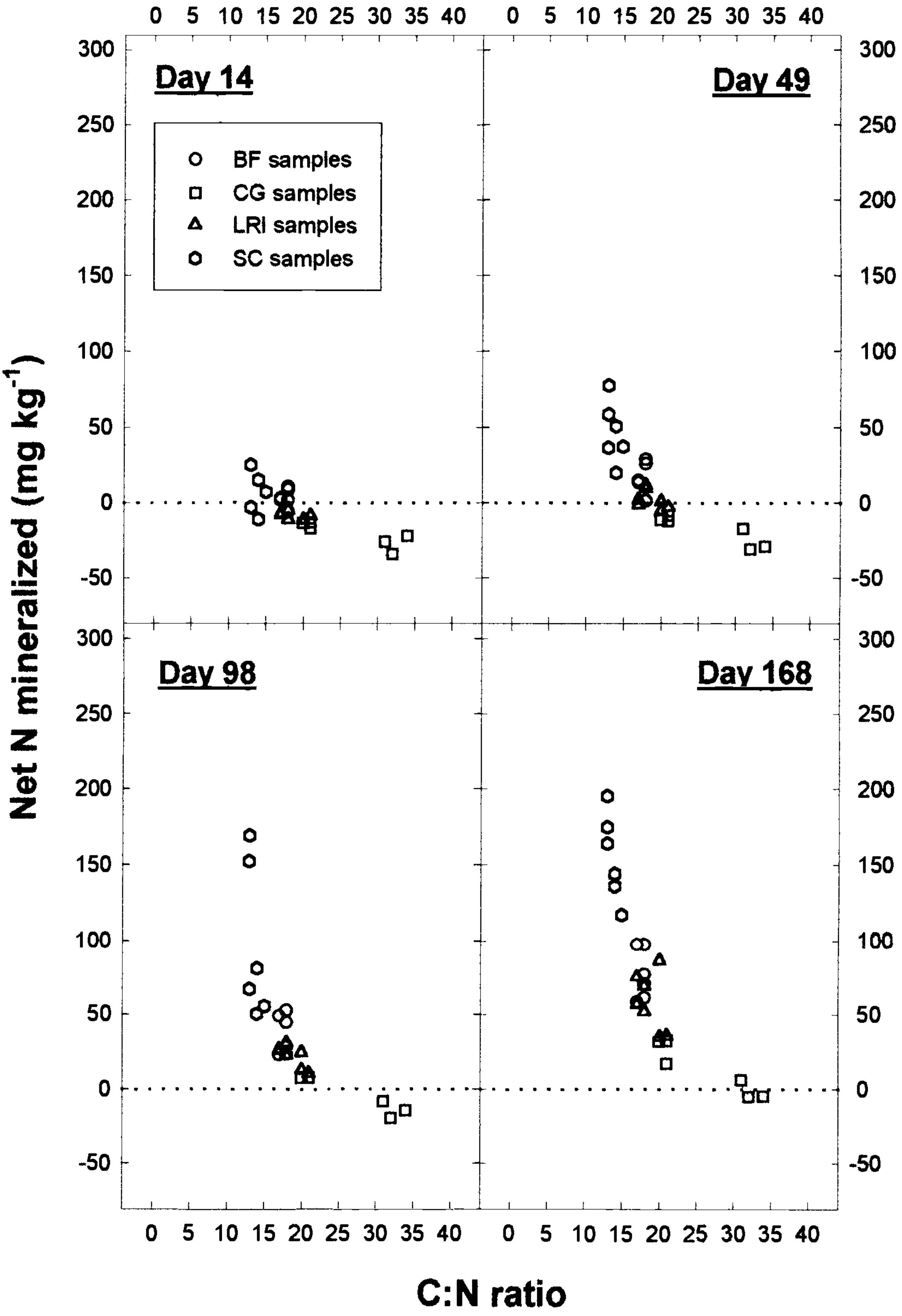

Figure 3.5. Influence of initial MPYT C:N ratio on net N mineralized. N release experiment 1.

The Impact of MPYT Storage on Quantity of N Mineralized (Experiment 2)

Length of Facility Storage Time of MPYT

The length of time a facility stores MPYT may change the quantity of N mineralized from MPYT. Samples were collected weekly from one pile located at the SC facility for a one-month period. These samples were incubated in the same manner as the N release experiment, except for a shorter period of 98d. The objectives of this study were to determine the effect of facility storage period on MPYT nitrogen release.

Effect of MPYT Storage on Soil Net N Mineralization

There was a definite increase or decrease in MPYT net N mineralized, as facility storage time of the MPYT is increased (Figure 3.6). Soil net N mineralized in 98d (average of reps A, B and C) was highest for the SC-week 0 treatment: 252 mg kg^{-1}, followed by the SC-week 1 treatment: 172 mg kg^{-1}; SC-week 2 treatment: 135 mg kg^{-1}, SC-week 3 treatment: 78 mg kg^{-1}, and SC-week 4 treatment: 79 mg kg^{-1}, treatments (Figure 3.6). The SC-week 0 was the only sample that did not immobilize N during the incubation study. The SC-week 3 and SC-week 4 treatments mineralized similar N quantities by the end of the 98d period. The time

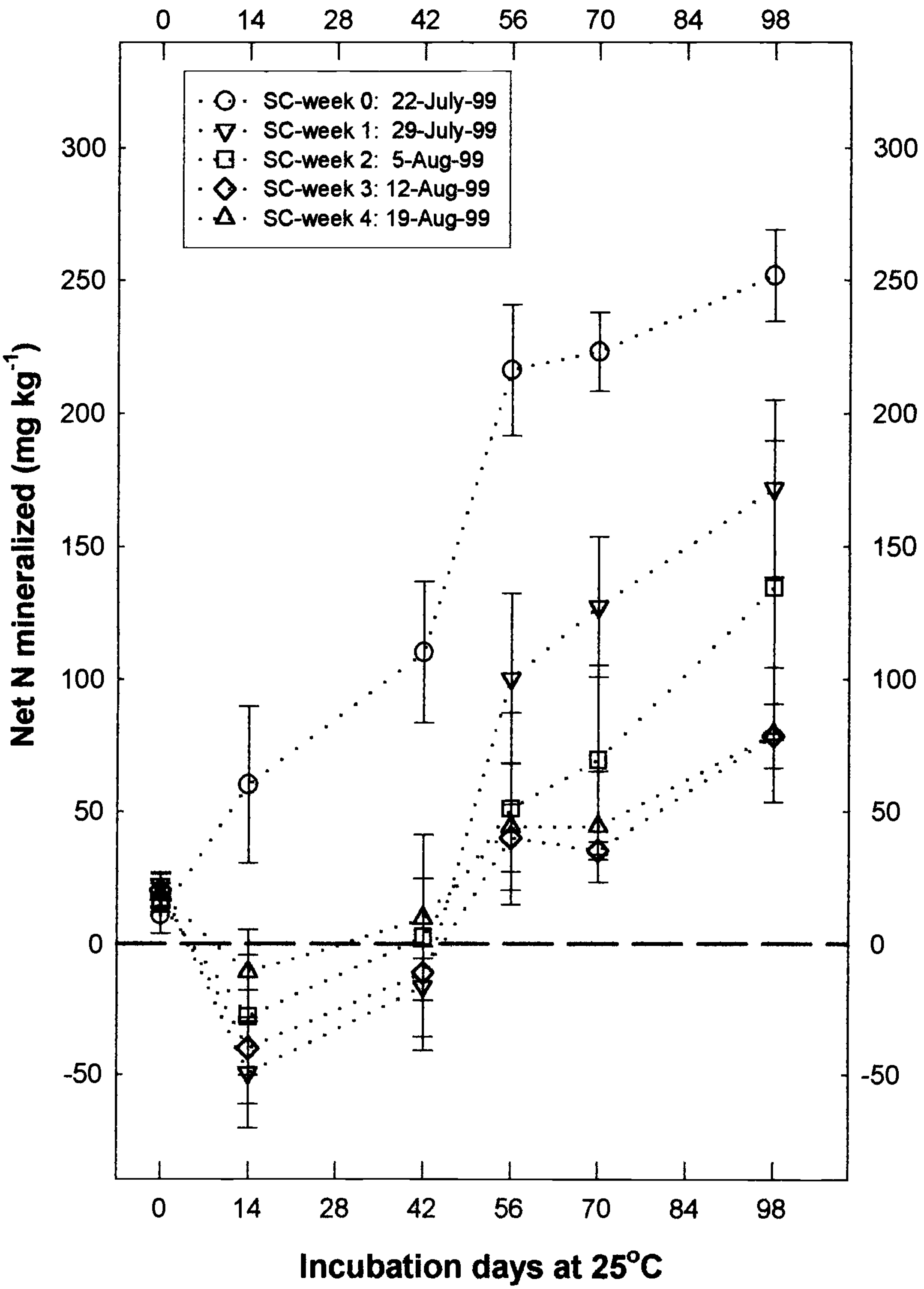

Figure 3.6. Soil net N mineralized during incubation period (0-98d). MPYT storage experiment 2. Error bar is the standard deviation for replicate MPYT samples A, B and C.

period between 0d and 42d had the greatest occurrence of N immobilization. After 42d, the SC-week 0 and SC-week 1 treatments have the steepest ascent in the quantity of N mineralized, tapering out after 56d. There was a two-fold difference in the net soil N mineralized when comparing the results from the SC-week 0 and SC-week 4 treatments (Figure 3.6). The main reason for this occurrence may be due to the change in the forms of C, as well as the availability of N as MPYT storage time increased. The SC-week 0 sample most likely had a higher concentration of soluble C compounds immediately available to assist soil microbes in the decomposition process. For all sample dates (weeks 0 to 4), our samples had high initial N concentrations, so N mineralization was most likely limited by the availability of easily degradable forms of C, as an energy source for decomposers. As storage time increased, MPYT samples may have had a higher proportion of recalcitrant C which is harder for soil microbes to degrade. Although our study did not measure changes in the form of C, it appears that as the MPYT matured in the collection pile, organic matter in the MPYT became more stable. The SC-week 0 treatment had the highest average N concentration of 39 g kg^{-1} and lowest C:N of 11:1; SC-week 1, 30 g N kg^{-1}, C:N of 14:1; SC-week 2, 32 g kg^{-1}, C:N of 12:1; SC-week 3, 30 g kg^{-1}, C:N of 13:1; and SC-week 4, 29 g kg^{-1},C:N of 11:1 (Table 3.1). Despite the narrow range in the sample characteristics, there still was an evident reduction in the net N mineralized from the samples collected from the initial week (SC-week 0) to final week (SC-week 4).

Effect of MPYT Storage on Soil NO_3-N + NH_4-N

Since nitrate was the main component of inorganic N, nitrate-N levels (Figure 3.7) mirrored net N mineralized. Ammonium levels after day 0, were generally much lower than nitrate, indicating that ammonium was quickly assimilated or nitrified during the incubations. The SC-week 0 sample was the freshest MPYT material and had the highest levels of ammonium throughout the incubation period (98d). As storage time increased, there was a reduction in soil NO_3-N results (Figure 3.7). This trend was also mirrored in the soil NH_4-N content (Figure 3.8). Interestingly, the NH_4-N content of the SC-week 0 treatment, greatly increased at 14d, dropped dramatically between 14d and 42d, then began to increase again after 42d. The MPYT-amended soil NH_4-N results for SC samples collected on weeks 2, 3 and 4, behaved in an opposite manner, displaying a rapid drop by 14d with no rebound in soil NH_4-N content.

Correlation of MPYT Storage to N Mineralization

There is a relationship between net N mineralized and total N concentration of the stored MPYT samples. As total N concentration increases, the quantity of N mineralized increases (Figure 3.9). There is a linear relationship between total N concentration and net N mineralized for these samples, however it is of limited value. This is due to the very narrow range of N content values of the samples, no practical assessment on storage time impact can be made from this relationship.

The C:N ratios of experiment 3 samples can be found in Table 3.1. In Figure 3.10, the MPYT samples with the highest C:N ratio (15:1), had the least quantity of N mineralized over the 98d incubation period. However, it is important to note that all of the samples had N contents of greater than 15 g kg^{-1}, and C:N ratios of 15:1 or less. Data from the MPYT N release study showed that these MPYT-C and N characteristics have the highest quantities of N mineralized over a 168d incubation period. It is observed in Figure 3.10, that the SC-week 0 samples (reps A, B,C) and SC-week 2 (rep B) were the only samples at 14d which did not immobilize soil N. This is an important consideration when applying MPYT residue to soils. There does not appear to be a clear linear relationship between net N mineralized and C:N ratio, in the case of the storage samples for 98d.

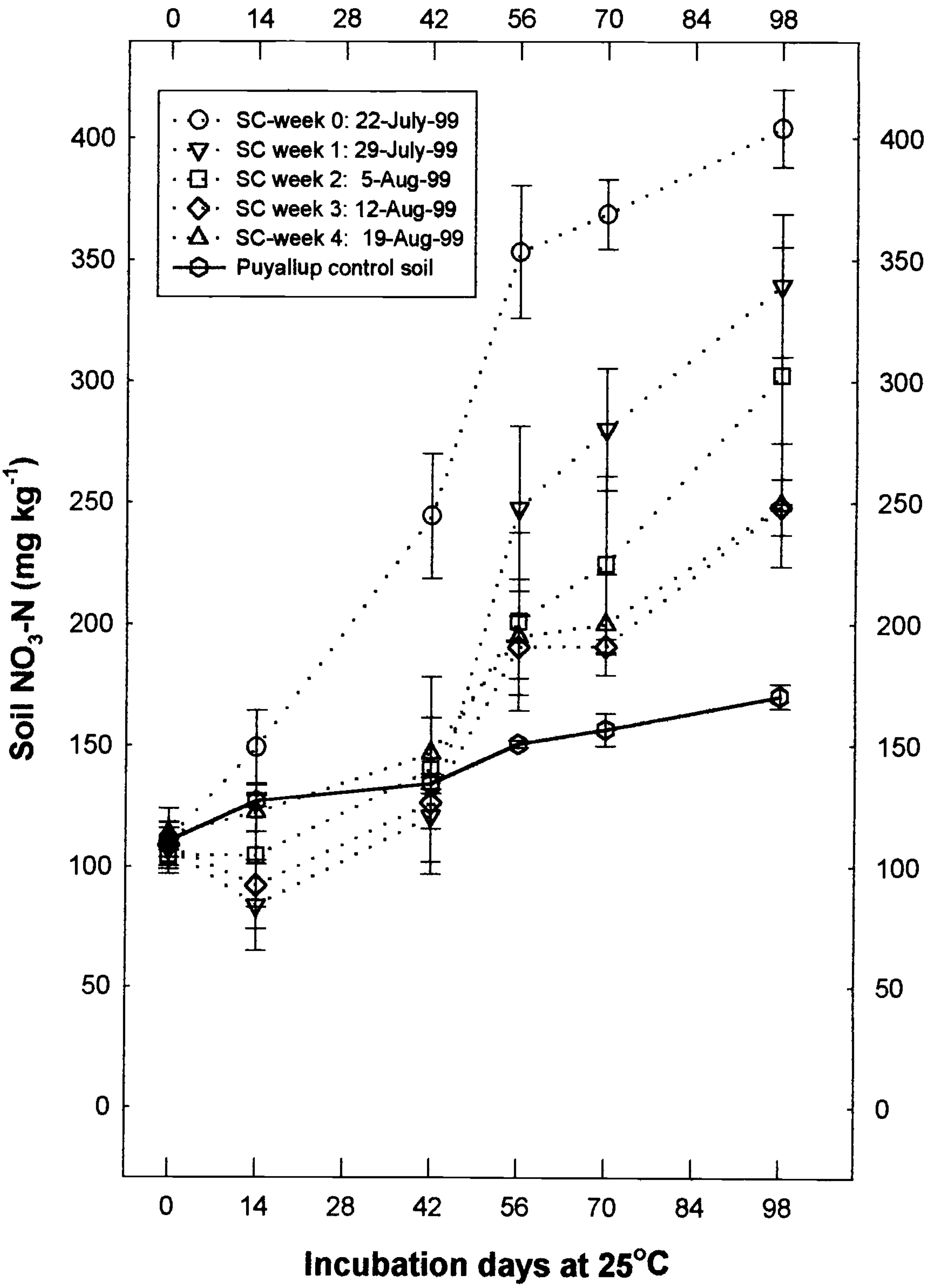

Figure 3.7. Soil NO_3-N mineralized during incubation period (0-98d). MPYT storage experiment 2. Error bar is the standard deviation for replicate MPYT samples A, B and C.

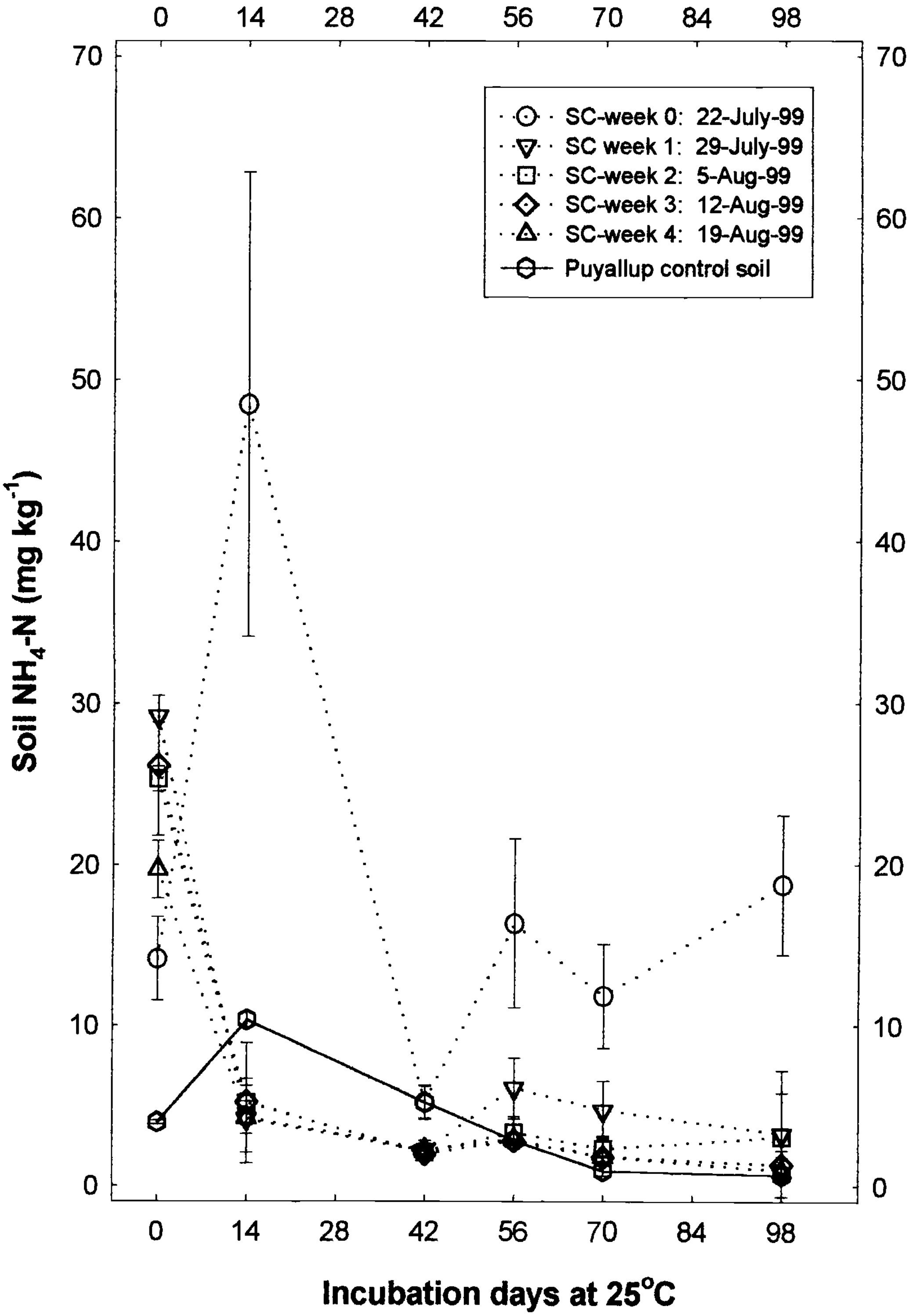

Figure 3.8. Soil NH_4-N mineralized during incubation period (0-98d). MPYT storage experiment 2. Error bar is the standard deviation for replicate MPYT samples A, B and C.

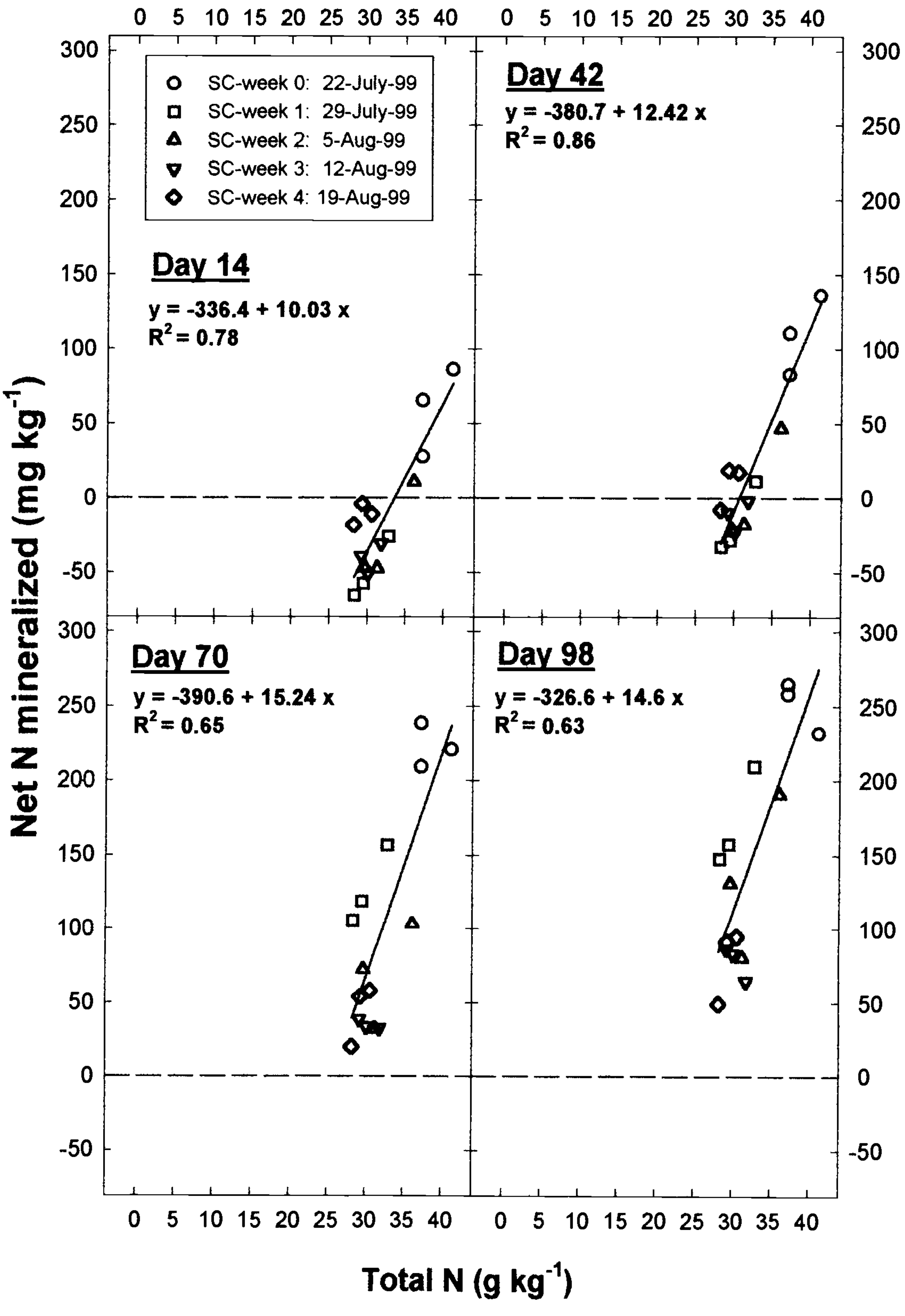

Figure 3.9. Influence of initial MPYT N concentration on net N mineralized. MPYT storage experiment 2.

The C:N ratio did not change dramatically as the MPYT material aged in the storage pile. The reduction in N mineralization that occurred as storage time increased did not seem to depend on the C:N ratio. It appears that the changing nature of the organic (C) substances in the MPYT was affecting the quantity of N mineralized. Although we did not include this aspect in our study, it appears that as the stored pile matured, transformation from labile (water soluble compounds and proteins) to recalcitrant (cellulose and lignin) compounds was taking place. In Figure 3.10, the maturity of MPYT residue is shown to have a greater effect on net N mineralized than the C:N ratio.

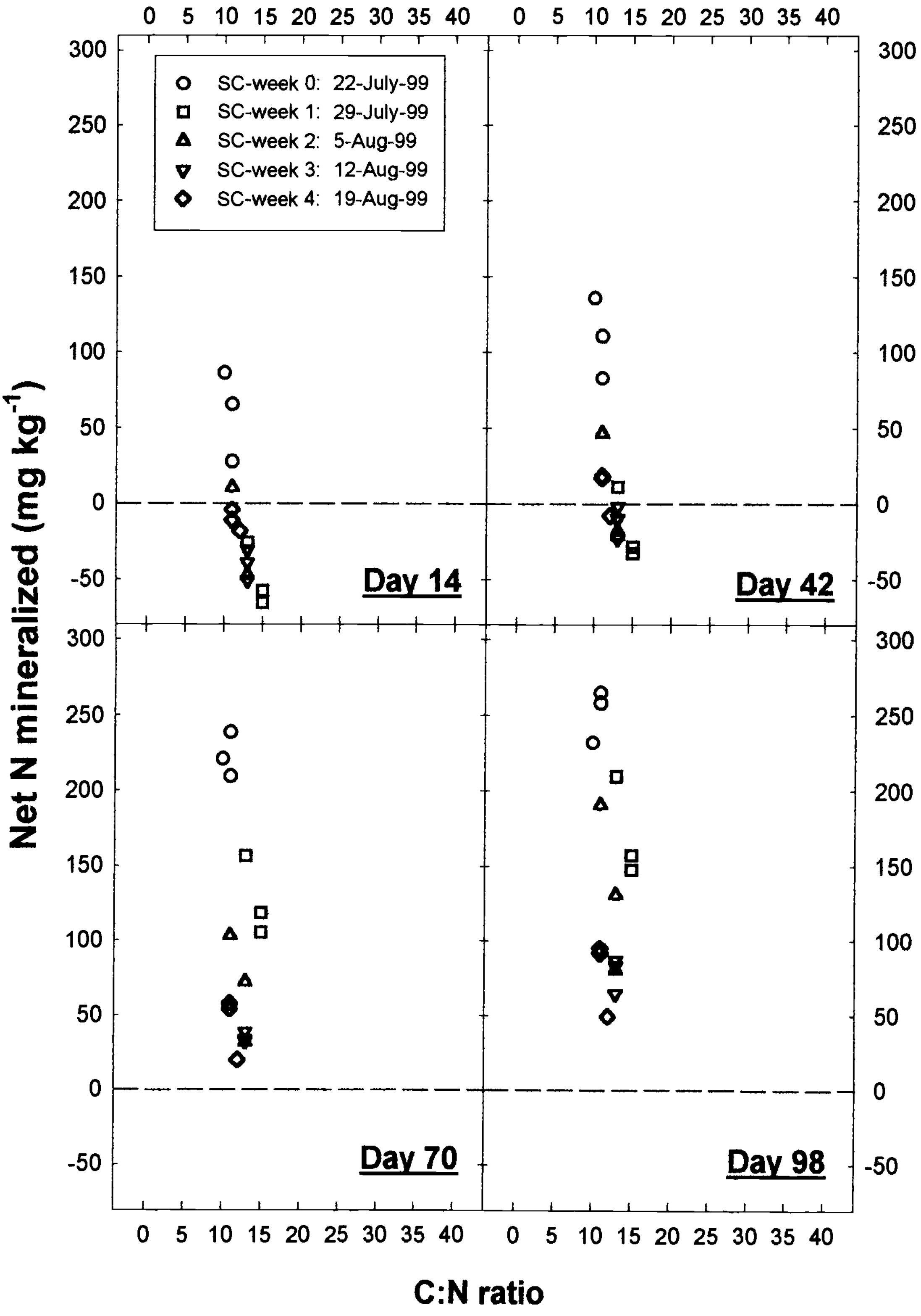

Figure 3.10. Influence of initial MPYT C:N ratio on net N mineralized. MPYT storage experiment 2.

N Release Predictive Tool: Carbon Dioxide Quick Test (Experiment 3)

In both the N release (experiment 1) and MPYT storage (experiment 2) studies, aerobic incubation was a reliable method in quantifying N availability from incorporated MPYT. However, this method is both time and labor intensive. A CO_2-C evolution method may be a more viable method to predict nitrogen release. This method is relatively inexpensive and requires only a brief incubation period.

Selected MPYT samples (rep B only) from both the N release and MPYT storage studies were included in this CO_2-C quick test study. Also, due to concern that oven drying and grinding samples may affect the quantity of N mineralized, CO_2-C evolution from both fresh-frozen and oven dried samples from the N release study were compared. “Fresh-frozen” samples were immediately frozen after being collected, and were not ground. The oven-dried samples were used in all the other experiments, including this one, which is why this was important to determine. The objective of this study was to evaluate the correlation between CO_2-C evolution and aerobic net N mineralization for soil-incorporated MPYT.

Cumulative CO_2-C Evolved

The cumulative CO_2-C evolved from the various MPYT samples were similar across facility sites for the May sample collection date (Figure 3.11). There were more distinct differences among sites for the April collection date. For samples collected in April, SC had the highest respiration rate, followed by BF and LRI. The lowest respiration rate occurred with the CG sample. Figure 3.11, also compares cumulative respiration rate between oven-dried and fresh-frozen samples for the April collection date.

Comparing net N mineralized results from experiment 2, with CO_2-C evolution results for the same MPYT samples used in experiment 3, shows that there is a relationship between N mineralized and CO_2-C evolution from MPYT. The MPYT storage samples showed the highest respiration rate for the SC-week 0 treatment, followed by SC-week 2, then SC-week 4 treatments (Figure 3.12). This CO_2-evolution behavior is similar to net N mineralized results. From experiment 2, SC-week 0 had the highest N mineralized, then SC-week 2 and finally, SC-week 4. This demonstrates that storage decreased CO_2-C evolution rates and is further evidence that organic compounds in the MPYT are becoming more stable as storage time increases.

The CO_2-C evolution data shows that there is a relationship between cumulative CO_2-C evolved at 68d and the CO_2-C evolved after 3 to 7d. In Figure 3.13, the linear regression ($R^2 = 0.95$) showed that cumulative CO_2-C loss at the end of the experiment (68d) was 1.14 times the CO_2-C evolved at 7d. At day 3, about one-half of the cumulative CO_2-C evolved in 68d, was already evolved. There is also a good correlation at the 5d and 7d sampling periods. This suggests that a short term incubation can be used to predict MPYT decomposition over a longer period. If a similar relationship exists between short term CO_2-C evolution and net N mineralized for these samples, a CO_2-C quick test could be used to estimate N mineralization potential of incorporated MPYT samples.

Correlating CO_2-C Data to Predict N Mineralization

In order to determine if there was a relationship between N mineralization and CO_2-C evolved, two sets of duplicate sample jars from the CO_2-C quick test experiment, were destructively sampled for net soil N mineralized at 7d and 21d. Additionally, at the end of the 68-day experiment, net N mineralized was determined on the MPYT amended soil from all the sample jars used for the CO_2-C quick test (experiment 3).

In Figure 3.14, net N mineralized from the N release and MPYT storage studies (experiment 1 and 2) were compared to matching samples

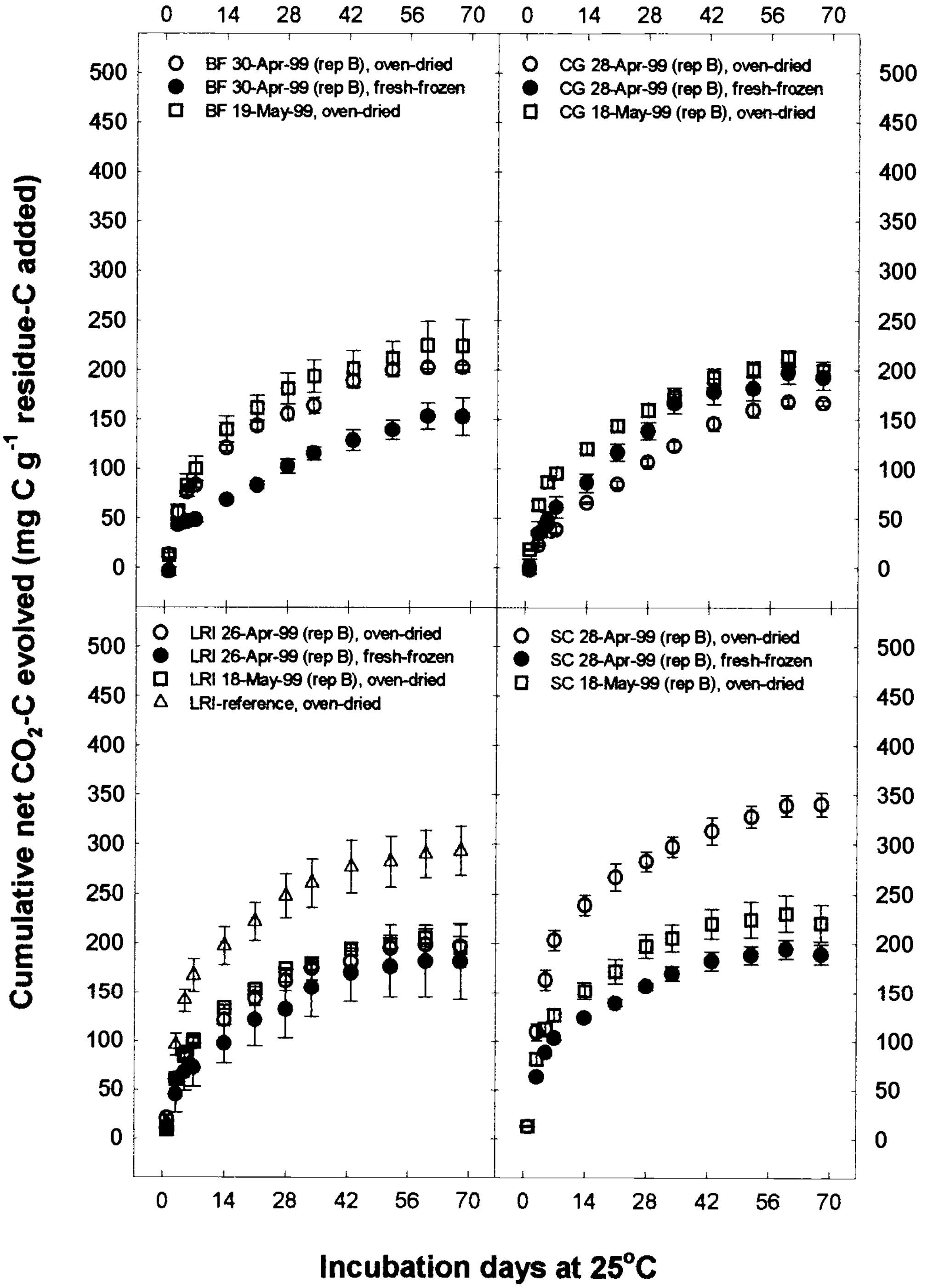

Figure 3.11. Cumulative CO_2-C evolved. Error bar is the standard deviation of 3 replicates for each MPYT incubation sample. Comparison of oven-dried and fresh-frozen MPYT samples. CO_2-C quick test experiment 3.

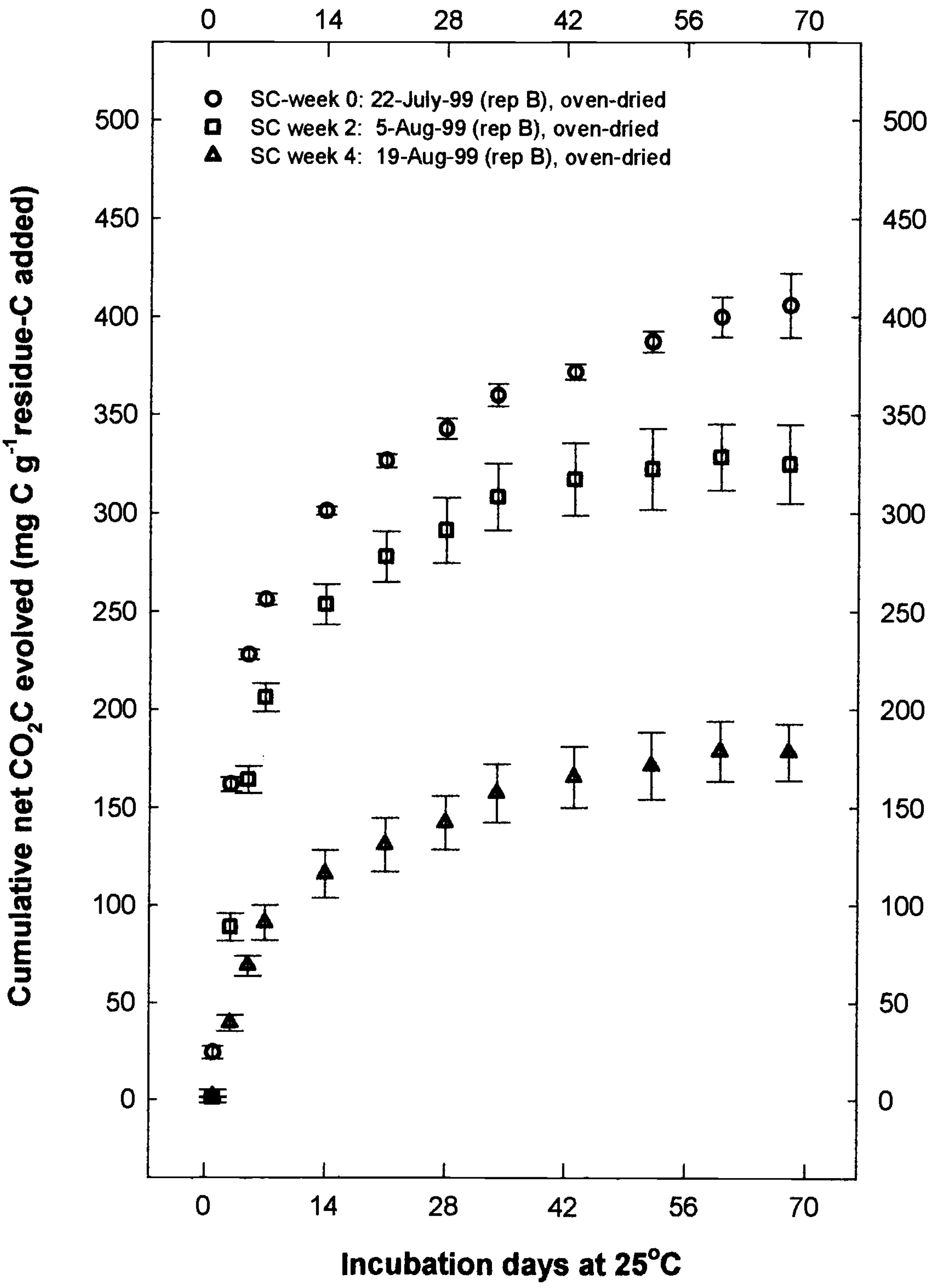

Figure 3.12. Cumulative CO_2-C evolved. Error bar is the standard deviation of 3 replicates for each MPYT incubation sample. CO_2-C quick test experiment 3.

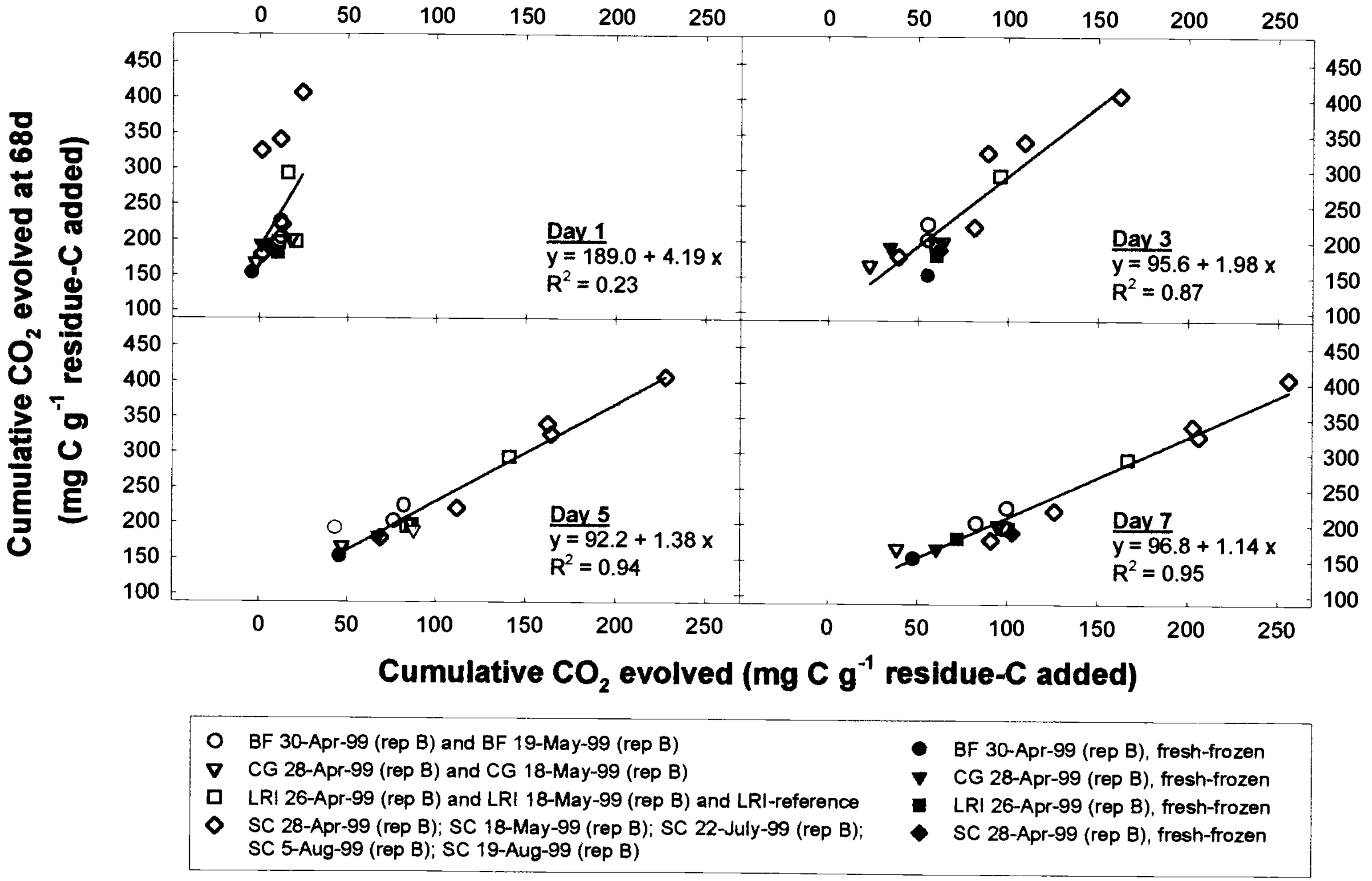

Figure 3.13. Linear relationship 0-7d CO$_2$ loss to cumulative CO$_2$ loss at 68d. CO$_2$-C quick test experiment 3.

used to determine the net N mineralized in the CO_2-C quick test study for 7, 21 and 68d. A comparison of the matching samples shows that this study had a lower N mineralized quantity than the samples from experiments 1 and 2. This can be explained partly by the aerobic incubation method used in experiments 1 and 2. The bags were left open in the incubator and at each sampling time, the bags were mixed thoroughly, thus introducing oxygen into the system. Experiment 3 was conducted in sealed jars, and no shaking occurred at the sampling times. Since mineralization is an aerobic process, it is logical that more N was mineralized due to the procedure used in experiments 1 and 2. Also, shaking the bags simulated tillage effects, which could have stimulated mineralization.

From our study there appears to be a weak relationship between the net N mineralized at 68d and CO_2-C evolved in a 3 to 7d quick test (Figure 3.15). This is again the case, as seen in Figure 3.16, when comparing the net N mineralized from experiment 1 (98d and 168d) to cumulative CO_2-C evolved at day 7 from experiment 3.

In our study, the 7-day CO_2-C evolution method was not a good predictor of net N mineralized. However, the data that was collected on CO_2-C evolution can be used in a several computer models, in particular DECOMPOSITION (Gilmour, 1998), to predict indirectly, N mineralization

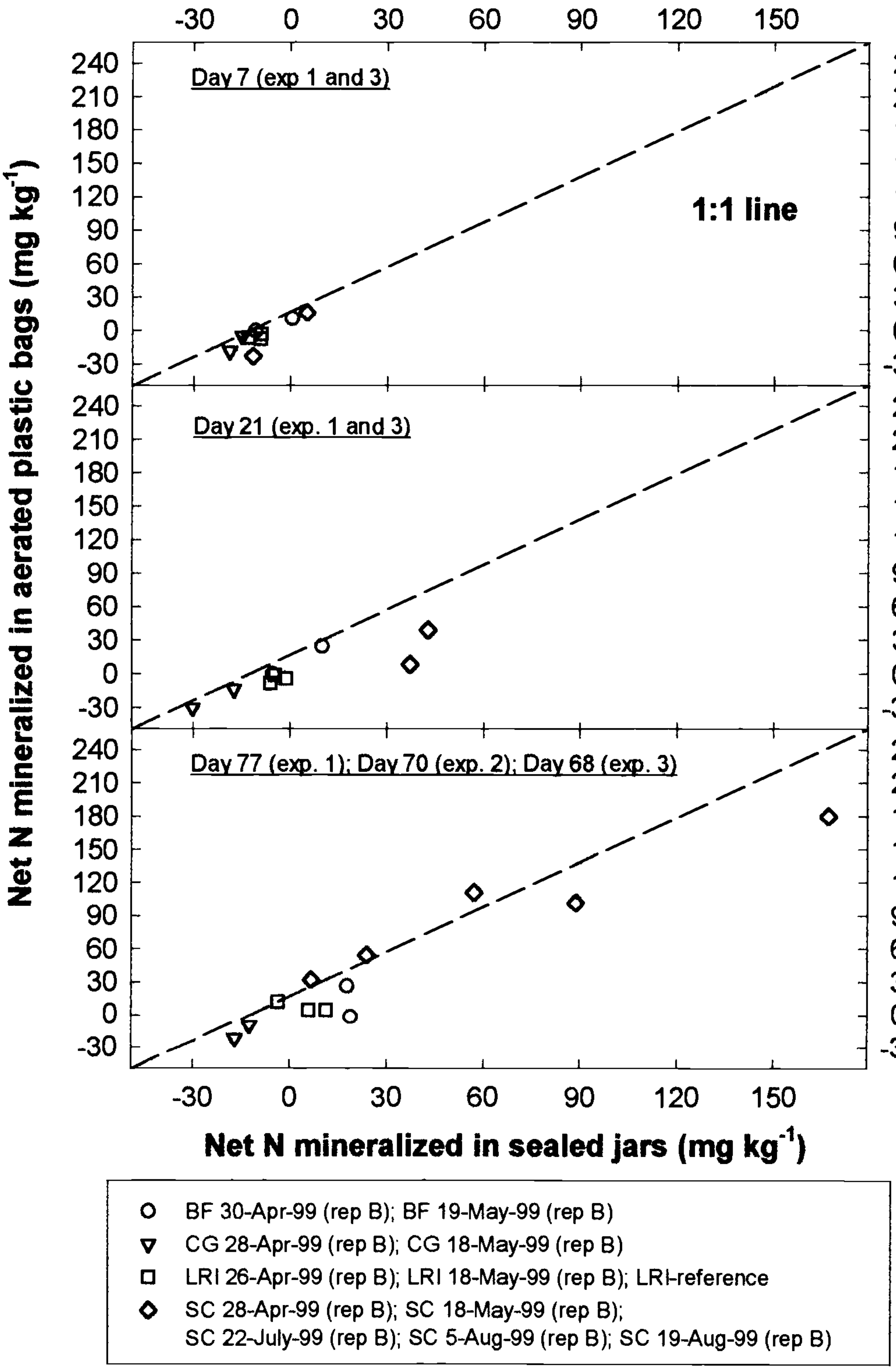

Figure 3.14. Comparison of net N mineralized from matching MPYT samples used in different incubation methods. Net N mineralized from sealed jar method (CO_2-C quick test experiment 3) versus Aerated plastic bag method (N release experiment 1; MPYT storage experiment 2).

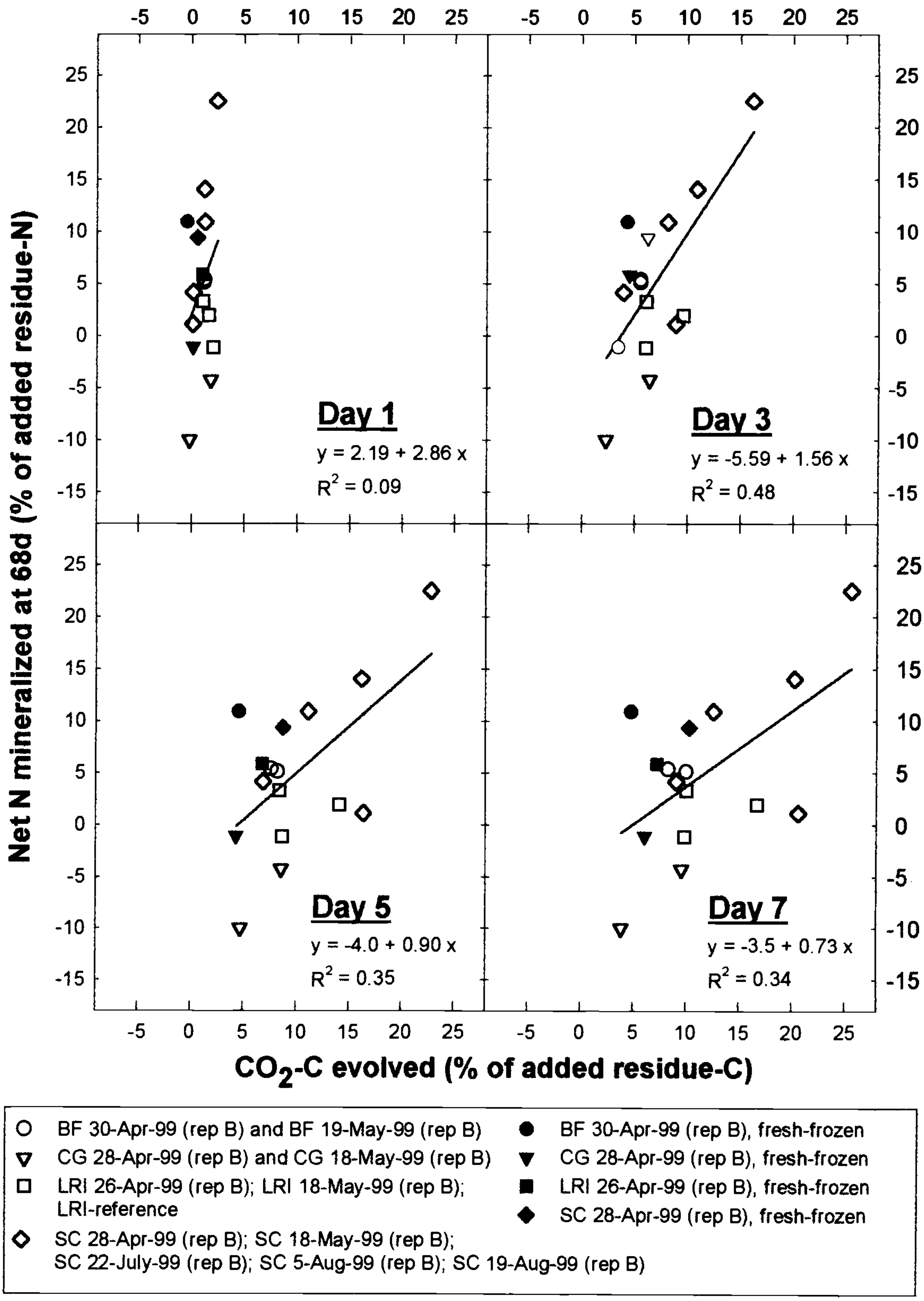

Figure 3.15. Linear relationship of net N mineralized (68d) versus CO_2-C evolved in 7 days. CO_2-C quick test experiment 3.

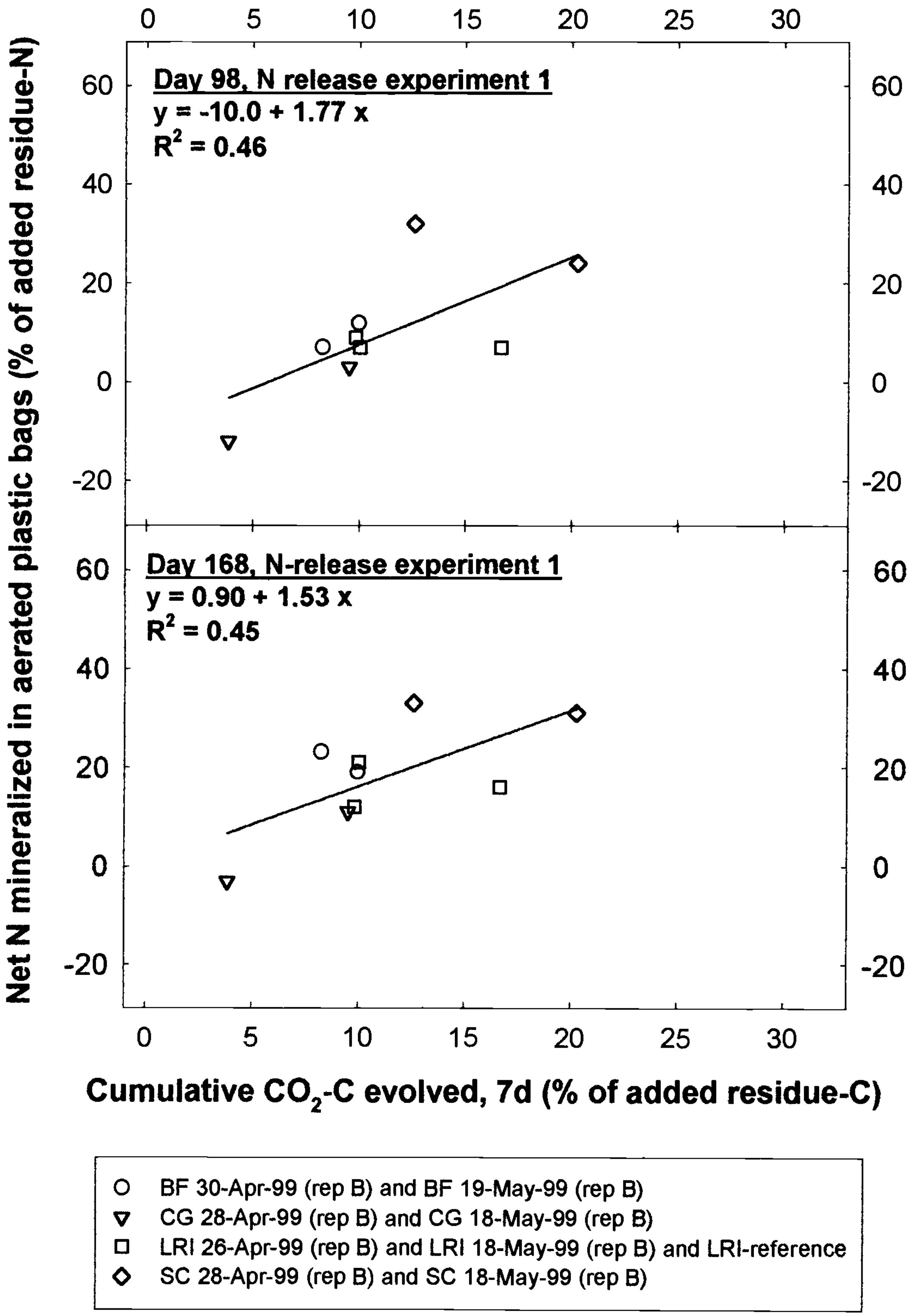

Figure 3.16. CO_2-C evolved (CO_2-C quick test experiment 3) versus Net N mineralized in aerated plastic bags (N release experiment 1).

from our MPYT residue using collected CO_2-C data. It was not in the scope of this study to conduct a model. Future goals are to fit our data into a model such as DECOMPOSITION.

SUMMARY AND CONCLUSIONS

In the N release study (experiment 1), MPYT was found to be a source of plant-available N. However, the amount of N available is highly dependent on the source of the material. SC had the highest N release, followed by BF, LRI. CG had the lowest N release over time. There was a strong correlation between initial MPYT-total N and N mineralized. As MPYT-total N content increased, so did the quantity of N mineralized. There was also a good correlation between MPYT C:N ratio and N mineralized. This is useful information since a total N and C analysis can be taken prior to MPYT field application and this could assist in determining the proper management needed to avoid N immobilization.

In all but one case (SC samples), MPYT incorporation immobilized N during the first three weeks after soil incorporation, in our experiment. This is an important consideration when choosing MPYT amendments. Cropping operations may need to incorporate the MPYT several weeks prior to planting. Also, the results achieved in the laboratory study are based on 168d at 25°C. This translates to 4,200 growing degree days

(GDD's) with a 0°C base temperature. In western Washington, a typical cropping season accumulates 2000 GDD's. Based on our laboratory data, MPYT N immobilization for most samples occurred from 14d to 21d. This translates to 350 GDD to 525 GDD. This means that immobilization may occur well into the summer of the cropping season of the first year, with the mineralized N having the potential of loss in the late fall. This is a reasonable assumption under optimal conditions of moisture, aeration and N fertility.

In terms of translating our findings into useful agronomic rates, this can be done by utilizing our calculation for mineralized N (% of MPYT-N added). For each of these samples, mineralized N (% of MPYT-N added) was calculated for experiment 1 (Appendix 10), experiment 2 (Appendix 17). In general, a grower can analyze MPYT material for N content (g kg^{-1} or %) and moisture content (Total solids, %) to find out how much initial N is in the MPYT volume to apply. This value can be multiplied by our calculations for mineralized N (% of MPYT-N added) to estimate how much N will be available over the season, based on growing degree days. Once more, consideration should be made to make sure that the "days" in our experiment are not directly translated to calendar days.

Based on our data, if a grower applied an SC sample, with a N content of 2.25%, with a total solids of 30% (moisture content, 70%) at a rate of 67 wet Mg ha^{-1} (30 wet T ac^{-1}), for incubation day 21 (GDD 525), 7% of the MPYT-N would be mineralized (plant-available). This amounts to 31 kg plant-available N ha^{-1} (28 lb ac^{-1}). This does not seem impressive, however, the grower should realize that adding organic amendments, such as MPYT, has the benefit of enhancing soil organic matter content. The benefit of increasing or maintaining soil quality makes MPYT application a desirable option to growers.

MPYT C and N quality can be reliably used to predict MPYT N availability. There was an excellent relationship between MPYT total N, and N availability over time. This relationship was clearly demonstrated in both the N release and MPYT storage experiments. Samples with total N concentrations of greater than 15g kg^{-1}, had the highest N availability. MPYT C:N ratio may also be a reliable predictor of N release. Samples with C:N ratios of less than 15:1, had the highest N availability. The ease of obtaining a total N and C analysis, make this an important finding that will assist in determining the best management necessary for MPYT land application.

Based on the MPYT storage study results, the duration of facility storage greatly influences N availability. The longer the MPYT is stored at the facility, the less value it has as an N source. N concentration and availability of MPYT is reduced as storage time increases. Accordingly, the freshest samples of MPYT had the most available N. As storage time increased, greater reductions in MPYT N availability resulted. This is also a very important finding. This will encourage the use of fresh MPYT amendments.

The MPYT storage study alluded to the relationship between CO_2-C evolution (decomposition) and net N mineralized. There was a correlation ($R^2 = 0.48$) between net N mineralized (68d) and CO_2-C evolution (3d) results. From observation, the MPYT samples with the highest respiration rates had the highest N availability. Similarly, the MPYT samples with the lowest respiration rates had the lowest N availability. There appeared to be similar mineralized soil N results from the N release (experiment 1), MPYT storage (experiment 2) and CO_2-C quick test (experiment 3) studies. However more refinement is needed to use the CO_2-C evolution method to reliably predict N availability. Encouragingly modeling efforts have been made by others, that may allow our data to be used in a CO_2-C and N mineralization model.

Future research should focus on the development of a reliable CO_2-C quick test to predict N availability from MPYT. Efforts should be made to determine the long-term benefit of MPYT application.

ACKNOWLEDGEMENTS

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SUMMARY

Our research studies determined that the land application of municipal composts and MPYT had both long-term and immediate benefits. The initial study (Chapter 2) discussed the long-term benefits of a one-time, high-rate of municipal compost application in a perennial grass cropping system. From this work, we demonstrated that soil C and N was significantly higher in the zone of compost application for all amended treatments, over an extended period of seven years. Our work demonstrated that municipal composts provided a slow release N source over many years. In general, it was also found that the initial N content of the applied composts determined the extent of N release over time. In our study ANR was used to determine additional grass N uptake attributed to compost application. The higher ANR values associated with compost-amended treatments is directly related to the increased yield and N uptake response due to compost application. The methods of ANR and soil N were better assessments of plant-available N potential compared to the mineralizable soil N method.

The final study (Chapter 3), explored the immediate benefit of available N release after applying MPYT to soil. The initial C and N content of MPYT affected the quantity of MPYT-N released in our experiment. In this study, MPYT C and N differences were found between the four collection facilities. MPYT samples with greater than 15 g N kg^{-1} and a C:N of 15:1 or less, released the greatest quantities of N. Most of the MPYT N release (experiment 1) samples immobilized N during the first 21 days of the study.

Another objective of our second study was to determine the impact of facility storage time. We observed that as the facility storage period increased, MPYT-N release quantities decreased. In general, as pile storage time increased, N content and C:N ratio decreased. Although carbon decomposition was not studied, it appears that as storage time increased, changes occurred in the stability of the organic materials contained in MPYT. As we learned from the N release (experiment 1) both N and the C:N ratio affected the quantity of N released.

We evaluated the correlation of CO_2-C evolution and aerobic net N mineralization for soil incorporated MPYT. There were similar mineralized N results from the N release (experiment 1), MPYT storage (experiment 2) and CO_2-C quick test (experiment 3) studies. We observed that MPYT samples with the highest respiration rates, also had the highest N availability. Similarly, the MPYT samples with the lowest respiration rates had the lowest N availability. There appeared to be a relationship between N availability and CO_2-C evolution results. In the future, it is hoped that we may utilize our results in conjunction with a computer model that can simulate and predict N release from MPYT.

These combined studies contributed to our further understanding of the long-term effects of land applying municipal composts and the immediate N release quantity of soil incorporated MPYT.

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APPENDIX

Appendix 1. Average soil moisture. N release experiment 1.

Treatment	Average Soil Moisture (% by weight)												
	0d	7d	14d	21d	49d	56d	77d	98d	112d	126d	140d	154d	168d
BF 30-Apr-99 (rep A)	24	22	21	23	25	23	23	24	24	25	28	27	30
BF 30-Apr-99 (rep B)	23	20	23	28	26	23	24	8	24	24	24	26	27
BF 30-Apr-99 (rep C)	23	21	24	29	26	17	15	24	23	24	25	25	27
BF 19-May-99 (rep A)	24	21	22	23	25	21	23	20	23	24	24	25	25
BF 19-May-99 (rep B)	24	20	23	23	23	21	22	24	24	24	24	26	26
BF 19-May-99 (rep C)	23	19	22	22	17	23	19	24	24	24	25	26	24
CG 28-Apr-99 (rep A)	23	20	23	23	26	22	21	20	22	24	25	26	27
CG 28-Apr-99 (rep B)	23	20	22	23	22	20	20	23	24	24	24	26	27
CG 28-Apr-99 (rep C)	24	16	22	24	23	22	28	26	25	29	25	26	28
CG 18-May-99 (rep A)	23	20	22	23	22	21	21	25	22	24	23	26	27
CG 18-May-99 (rep B)	23	22	22	24	23	19	21	25	24	25	25	26	26
CG 18-May-99 (rep C)	23	22	21	25	22	24	22	21	22	24	25	26	27
LRI 26-Apr-99 (rep A)	24	24	23	24	25	17	23	24	24	24	24	26	35
LRI 26-Apr-99 (rep B)	23	21	23	24	25	21	24	25	24	23	25	26	26
LRI 26-Apr-99 (rep C)	24	23	25	24	25	23	23	22	24	23	24	26	29
LRI 18-May-99 (rep A)	23	23	24	22	24	23	22	25	22	24	24	25	26
LRI 18-May-99 (rep B)	25	21	23	24	17	19	23	24	24	25	25	26	29
LRI 18-May-99 (rep C)	23	22	23	21	22	21	21	23	24	25	25	25	27
LRI-reference	23	21	23	23	22	23	23	25	24	25	25	30	25
Puyallup control soil	24	21	23	23	23	21	21	24	23	25	24	24	25
SC 28-Apr-99 (rep A)	23	21	23	21	23	15	20	21	24	23	24	27	29
SC 28-Apr-99 (rep B)	23	22	25	22	25	21	21	25	17	23	25	25	27
SC 28-Apr-99 (rep C)	23	21	23	23	21	22	20	23	23	24	24	26	28
SC 18-May-99 (rep A)	24	21	23	24	22	22	21	22	22	23	24	24	28
SC 18-May-99 (rep B)	23	21	24	24	26	24	24	25	25	24	25	26	28
SC 18-May-99 (rep C)	23	22	24	23	22	18	21	23	23	24	26	27	26

Appendix 2. Average soil NO_3-N. N release experiment 1.

Treatment	Average Soil NO_3-N (mg kg^{-1})												
	0d	7d	14d	21d	49d	56d	77d	98d	112d	126d	140d	154d	168d
BF 30-Apr-99 (rep A)	104.01	113.67	130.80	152.70	182.34	199.31	190.80	219.91	227.20	239.53	274.04	268.21	287.96
BF 30-Apr-99 (rep B)	102.44	110.37	129.44	156.32	180.43	190.01	192.67	190.64	225.59	215.15	256.73	249.16	267.65
BF 30-Apr-99 (rep C)	100.46	108.42	126.02	138.75	156.08	162.86	162.08	195.72	213.12	208.77	243.23	188.92	251.82
BF 19-May-99 (rep A)	104.28	110.65	128.14	141.33	168.57	183.27	176.15	191.11	206.15	182.94	251.65	240.16	249.09
BF 19-May-99 (rep B)	105.24	106.22	121.96	134.85	156.42	169.50	163.00	212.24	231.62	237.23	261.21	262.06	261.22
BF 19-May-99 (rep C)	102.97	105.16	123.44	139.92	168.92	187.89	172.04	216.55	224.21	227.24	250.19	272.11	288.17
CG 28-Apr-99 (rep A)	100.15	103.84	108.98	113.06	138.18	152.87	151.51	159.92	169.52	170.43	196.42	183.08	196.76
CG 28-Apr-99 (rep B)	108.54	101.15	102.17	104.83	124.49	133.04	144.51	148.15	155.20	145.77	174.13	166.74	185.50
CG 28-Apr-99 (rep C)	102.28	102.54	114.10	108.88	125.87	133.44	152.17	153.38	155.11	156.36	172.49	168.54	186.17
CG 18-May-99 (rep A)	112.17	100.40	115.00	119.22	142.69	150.50	164.45	175.63	176.27	169.63	199.02	190.48	207.70
CG 18-May-99 (rep B)	105.46	110.47	119.45	123.70	144.26	143.97	156.84	175.96	183.55	172.25	209.82	203.89	222.67
CG 18-May-99 (rep C)	104.81	107.23	120.07	128.16	146.91	161.12	159.37	175.70	184.24	175.28	209.97	204.58	223.12
LRI 26-Apr-99 (rep A)	104.59	110.94	121.08	122.25	150.31	158.61	168.39	181.15	184.74	178.60	208.37	201.07	225.00
LRI 26-Apr-99 (rep B)	108.97	109.51	121.84	126.65	155.98	159.22	176.90	192.11	190.96	165.72	216.25	210.74	225.67
LRI 26-Apr-99 (rep C)	104.50	110.16	123.20	123.99	152.45	167.77	167.73	179.06	184.98	167.29	214.90	205.80	226.25
LRI 18-May-99 (rep A)	102.38	105.49	120.51	125.03	157.19	160.13	169.40	194.64	195.69	173.65	227.81	231.25	247.67
LRI 18-May-99 (rep B)	110.80	102.64	117.62	126.93	153.07	154.03	171.31	194.02	201.76	174.91	229.59	224.87	265.66
LRI 18-May-99 (rep C)	105.55	103.64	115.66	128.60	160.76	167.94	172.87	198.55	200.33	180.15	215.91	225.36	260.10
LRI-reference	101.31	102.28	121.87	134.97	166.03	160.89	170.79	190.92	209.65	196.08	232.50	233.99	242.08
Puyallup control soil	103.33	111.91	126.04	128.42	152.28	153.57	165.67	167.78	178.23	168.48	193.11	184.47	190.93
SC 28-Apr-99 (rep A)	101.44	89.86	110.29	126.30	190.24	195.73	224.46	231.92	273.05	275.37	318.71	316.88	343.03
SC 28-Apr-99 (rep B)	102.58	77.28	100.12	137.67	211.24	236.96	256.95	301.59	312.05	333.89	373.68	319.73	376.86
SC 28-Apr-99 (rep C)	106.80	87.59	101.44	120.50	173.56	196.44	192.38	218.22	240.40	240.64	293.90	301.38	323.64
SC 18-May-99 (rep A)	106.03	102.00	129.38	150.54	201.94	222.54	215.42	247.42	255.78	252.51	282.20	279.80	324.97
SC 18-May-99 (rep B)	100.88	107.00	128.08	159.54	229.30	253.43	266.95	330.43	339.05	321.10	366.00	326.03	361.72
SC 18-May-99 (rep C)	104.75	105.74	127.19	148.58	189.72	164.40	187.56	220.18	260.79	260.29	304.08	296.13	307.66

Appendix 3. Standard deviation soil NO_3-N. N release experiment 1.

Treatment	Standard Deviation--Soil NO_3-N (mg kg^{-1})											
	0d	7d	14d	21d	49d	56d	77d	98d	112d	126d	140d	154d	168d
BF 30-Apr-99 (rep A)	2.177	1.438	1.007	1.050	2.061	4.862	4.885						4.794
BF 30-Apr-99 (rep B)	0.720	0.711	1.097	0.168	1.257	2.878	3.554						2.141
BF 30-Apr-99 (rep C)	0.703	1.671	1.425	1.985	2.994	3.229	8.068						6.151
BF 19-May-99 (rep A)	5.271	0.905	1.513	2.004	2.177	8.679	2.687						2.674
BF 19-May-99 (rep B)	3.035	0.741	1.412	1.209	3.378	10.491	5.898						2.651
BF 19-May-99 (rep C)	5.741	0.751	0.390	1.860	0.536	3.067	5.862						10.036
CG 28-Apr-99 (rep A)	2.575	1.187	0.265	0.313	2.437	5.445	2.216						2.299
CG 28-Apr-99 (rep B)	6.383	1.159	0.754	0.483	0.494	4.867	2.304						1.475
CG 28-Apr-99 (rep C)	2.018	0.880	4.237	1.254	1.786	4.440	2.208						2.040
CG 18-May-99 (rep A)	13.708	2.232	0.549	1.410	0.753	2.391	4.471						2.957
CG 18-May-99 (rep B)	0.974	0.930	2.559	1.757	1.114	2.774	4.867						4.741
CG 18-May-99 (rep C)	2.498	0.642	5.540	3.175	0.931	6.338	2.746						4.457
LRI 26-Apr-99 (rep A)	5.173	1.621	0.503	3.121	1.128	13.557	2.818						5.893
LRI 26-Apr-99 (rep B)	14.645	1.724	1.702	0.690	0.821	4.073	2.569						0.672
LRI 26-Apr-99 (rep C)	3.353	0.654	1.607	1.484	0.822	2.935	1.265						4.746
LRI 18-May-99 (rep A)	1.516	0.362	0.558	2.274	0.527	3.289	2.854						0.933
LRI 18-May-99 (rep B)	1.966	*	2.788	0.886	4.567	4.810	3.816						1.497
LRI 18-May-99 (rep C)	2.066	1.208	0.944	4.080	1.546	12.964	2.886						1.999
LRI-reference	1.388	2.369	1.873	3.347	3.455	7.028	2.873	0.070	1.882	19.595	10.326	1.494	13.369
Puyallup control soil	6.451	3.027	2.494	2.282	3.113	3.166	10.139	5.609	3.618	6.739	2.541	3.033	3.604
SC 28-Apr-99 (rep A)	3.505	1.218	1.725	1.683	0.338	2.846	15.817						12.723
SC 28-Apr-99 (rep B)	0.421	1.996	0.815	4.616	0.703	5.955	7.931						3.647
SC 28-Apr-99 (rep C)	7.449	1.405	2.140	2.099	2.247	2.721	8.030						6.316
SC 18-May-99 (rep A)	10.156	1.236	1.682	4.566	0.998	1.828	9.845						3.471
SC 18-May-99 (rep B)	2.398	0.408	1.845	2.289	2.460	4.753	2.251						5.795
SC 18-May-99 (rep C)	0.830	1.695	0.954	0.398	2.150	0.613	17.697						7.465

* spilled 2 of the 3 extracts

Appendix 4. Average soil NH_4-N. N release experiment 1.

Treatment	Average Soil NH_4-N (mg kg^{-1})												
	0d	7d	14d	21d	49d	56d	77d	98d	112d	126d	140d	154d	168d
BF 30-Apr-99 (rep A)	15.75	31.99	19.60	7.73	3.10	2.20	1.31	1.95	0.90	0.83	1.42	1.30	2.86
BF 30-Apr-99 (rep B)	14.09	26.44	19.11	9.52	2.11	1.33	1.34	1.79	0.94	0.75	0.67	3.29	2.73
BF 30-Apr-99 (rep C)	16.90	24.65	15.74	10.67	2.26	1.41	1.12	1.46	1.31	0.90	0.50	0.99	2.84
BF 19-May-99 (rep A)	14.24	24.47	13.72	5.73	1.48	1.29	1.46	1.09	0.66	0.81	0.47	1.11	2.70
BF 19-May-99 (rep B)	12.76	19.38	12.16	6.16	1.42	1.27	3.44	1.61	1.41	0.78	0.95	1.14	2.76
BF 19-May-99 (rep C)	12.41	23.44	19.67	8.37	2.54	2.29	1.26	1.55	1.01	0.78	0.68	1.13	2.63
CG 28-Apr-99 (rep A)	17.55	8.82	4.94	5.76	1.45	4.88	1.28	1.21	1.23	0.58	0.47	0.79	2.82
CG 28-Apr-99 (rep B)	12.73	6.18	3.77	6.23	1.28	1.31	1.75	1.29	0.81	0.62	0.46	2.56	2.77
CG 28-Apr-99 (rep C)	13.63	7.96	4.12	4.49	1.68	1.29	1.41	1.45	2.13	1.66	0.47	0.90	2.74
CG 18-May-99 (rep A)	13.11	9.30	7.79	5.11	1.88	1.28	1.40	1.66	0.62	0.73	0.45	1.08	2.80
CG 18-May-99 (rep B)	14.59	10.30	7.15	4.13	1.01	1.31	1.26	1.28	0.90	0.79	0.77	1.44	2.76
CG 18-May-99 (rep C)	15.07	11.03	6.83	4.67	1.29	2.13	1.72	1.28	0.86	0.52	0.48	2.88	2.80
LRI 26-Apr-99 (rep A)	22.48	11.81	7.17	7.01	1.17	2.55	3.20	1.06	1.32	1.34	0.46	0.90	3.20
LRI 26-Apr-99 (rep B)	22.65	13.00	7.13	6.31	1.55	1.27	2.87	1.41	1.66	0.79	0.45	2.26	2.76
LRI 26-Apr-99 (rep C)	25.74	15.49	8.20	7.38	1.17	1.31	2.18	1.17	0.95	0.81	0.46	1.27	2.90
LRI 18-May-99 (rep A)	19.47	14.13	12.23	8.86	1.43	5.81	1.85	1.18	0.59	0.67	0.52	1.14	2.72
LRI 18-May-99 (rep B)	19.74	15.64	14.44	10.17	2.35	9.73	1.42	0.99	0.64	0.64	0.57	1.14	2.88
LRI 18-May-99 (rep C)	25.53	14.69	13.12	8.76	5.65	3.11	1.37	1.74	0.67	0.80	0.46	0.97	2.81
LRI-reference	57.65	17.44	13.35	5.63	2.17	2.00	1.47	1.14	0.66	0.75	0.47	1.15	3.35
Puyallup control soil	6.68	14.00	14.09	12.95	4.43	3.76	2.14	1.70	0.73	0.65	0.54	1.64	2.67
SC 28-Apr-99 (rep A)	15.60	23.03	26.74	15.26	3.32	2.55	5.60	4.39	12.35	15.44	0.47	17.58	14.41
SC 28-Apr-99 (rep B)	10.79	25.68	36.85	12.36	3.98	4.55	12.53	20.16	16.68	19.65	16.04	12.84	12.22
SC 28-Apr-99 (rep C)	14.40	16.17	27.69	14.14	2.91	3.17	1.98	1.38	1.58	4.05	13.11	15.76	13.97
SC 18-May-99 (rep A)	15.10	26.56	25.78	13.74	5.42	4.49	3.37	2.40	3.02	3.50	3.54	4.23	4.41
SC 18-May-99 (rep B)	15.31	34.89	36.90	21.06	5.05	6.26	12.00	7.99	6.22	5.47	5.16	5.79	7.00
SC 18-May-99 (rep C)	20.16	23.91	20.06	11.60	4.43	3.51	3.03	4.47	6.98	6.87	4.35	3.23	2.95

Appendix 5. Standard deviation soil NH_4-N. N release experiment 1.

Treatment	Standard Deviation--Soil NH_4-N (mg kg-1)												
	0d	7d	14d	21d	49d	56d	77d	98d	112d	126d	140d	154d	168d
BF 30-Apr-99 (rep A)	0.561	1.471	0.182	0.274	0.195	0.119	0.028						0.419
BF 30-Apr-99 (rep B)	0.014	0.127	0.431	0.111	0.184	0.016	0.025						0.117
BF 30-Apr-99 (rep C)	0.265	1.096	0.348	0.402	0.647	0.374	0.017						0.017
BF 19-May-99 (rep A)	3.200	0.940	0.108	0.383	0.525	0.006	0.226						0.034
BF 19-May-99 (rep B)	2.111	0.640	0.030	0.219	0.429	0.034	3.714						0.017
BF 19-May-99 (rep C)	0.718	0.432	0.134	1.061	0.141	0.298	0.008						0.098
CG 28-Apr-99 (rep A)	0.118	0.712	0.435	0.021	0.452	1.162	0.023						0.035
CG 28-Apr-99 (rep B)	0.143	0.946	0.116	0.413	0.558	0.023	0.893						0.009
CG 28-Apr-99 (rep C)	0.703	0.112	0.169	0.443	0.230	0.028	0.003						0.202
CG 18-May-99 (rep A)	0.249	0.220	0.064	0.025	0.871	0.036	0.187						0.022
CG 18-May-99 (rep B)	0.288	0.275	1.032	0.270	0.220	0.066	0.024						0.021
CG 18-May-99 (rep C)	0.049	0.301	0.096	0.578	0.241	1.165	0.717						0.048
LRI 26-Apr-99 (rep A)	2.356	0.624	0.105	0.198	0.147	2.332	0.120						0.068
LRI 26-Apr-99 (rep B)	2.544	1.042	0.108	0.726	0.371	0.035	1.141						0.050
LRI 26-Apr-99 (rep C)	0.902	3.755	0.077	0.491	0.089	0.008	1.441						0.117
LRI 18-May-99 (rep A)	0.468	0.477	0.310	1.179	0.115	3.532	0.452						0.070
LRI 18-May-99 (rep B)	0.121	*	0.143	1.018	0.557	1.066	0.158						0.153
LRI 18-May-99 (rep C)	1.667	0.114	0.088	0.432	2.916	2.612	0.106						0.020
LRI-reference	4.728	0.876	0.647	0.504	0.327	1.000	0.511	0.032	0.057	0.178	0.016	0.367	0.922
Puyallup control soil	0.665	0.788	0.771	0.900	0.348	1.025	0.579	1.840	0.101	0.132	0.218	0.726	0.098
SC 28-Apr-99 (rep A)	0.555	2.759	0.278	0.263	0.118	0.202	1.021						0.992
SC 28-Apr-99 (rep B)	0.435	0.556	0.916	0.245	0.120	0.163	0.446						0.563
SC 28-Apr-99 (rep C)	0.350	1.182	2.316	0.307	0.103	0.350	0.112						0.517
SC 18-May-99 (rep A)	0.706	0.393	0.122	0.193	2.449	0.476	0.206						0.208
SC 18-May-99 (rep B)	0.101	0.641	0.095	0.726	0.417	0.104	0.116						0.230
SC 18-May-99 (rep C)	0.935	0.638	0.326	1.899	0.269	0.222	0.409						0.295

* spilled 2 of the 3 extracts

Appendix 6. Average soil N (NO_3-N + NH_4-N). N release experiment 1.

Treatment	Average Soil N (NO_3-N + NH_4-N) mg kg^{-1}												
	0d	7d	14d	21d	49d	56d	77d	98d	112d	126d	140d	154d	168d
BF 30-Apr-99 (rep A)	119.75	145.66	150.40	160.44	185.44	201.51	192.10	221.86	228.10	240.36	275.46	269.51	290.82
BF 30-Apr-99 (rep B)	116.53	136.80	148.55	165.84	182.54	191.34	194.01	192.44	226.53	215.90	257.40	252.46	270.39
BF 30-Apr-99 (rep C)	117.36	133.07	141.76	149.42	158.34	164.27	163.21	197.18	214.43	209.67	243.73	189.91	254.66
BF 19-May-99 (rep A)	118.52	135.12	141.87	147.07	170.05	184.56	177.60	192.20	206.81	183.75	252.12	241.27	251.79
BF 19-May-99 (rep B)	118.00	125.61	134.13	141.01	157.83	170.77	166.44	213.85	233.03	238.02	262.16	263.20	263.98
BF 19-May-99 (rep C)	115.38	128.60	143.11	148.28	171.46	190.18	173.30	218.10	225.22	228.02	250.87	273.24	290.80
CG 28-Apr-99 (rep A)	117.69	112.66	113.92	118.82	139.63	157.74	152.79	161.13	170.75	171.00	196.90	183.87	199.58
CG 28-Apr-99 (rep B)	121.27	107.33	105.94	111.07	125.77	134.35	146.26	149.44	156.01	146.39	174.59	169.30	188.27
CG 28-Apr-99 (rep C)	115.91	110.50	118.23	113.37	127.54	134.72	153.57	154.82	157.24	158.02	172.96	169.43	188.91
CG 18-May-99 (rep A)	125.29	109.71	122.79	124.33	144.58	151.78	165.84	177.29	176.88	170.37	199.47	191.56	210.50
CG 18-May-99 (rep B)	120.05	120.77	126.61	127.83	145.27	145.28	158.10	177.24	184.46	173.05	210.59	205.33	225.43
CG 18-May-99 (rep C)	119.88	118.26	126.91	132.83	148.20	163.25	161.09	176.98	185.10	175.80	210.44	207.46	225.91
LRI 26-Apr-99 (rep A)	127.06	122.75	128.25	129.25	151.47	161.17	171.59	182.20	186.06	179.94	208.84	201.97	228.20
LRI 26-Apr-99 (rep B)	131.62	122.51	128.97	132.96	157.53	160.50	179.77	193.52	192.62	166.52	216.70	213.00	228.43
LRI 26-Apr-99 (rep C)	130.24	125.65	131.40	131.37	153.62	169.08	169.91	180.23	185.93	168.10	215.36	207.07	229.16
LRI 18-May-99 (rep A)	121.86	119.62	132.74	133.89	158.62	165.94	171.25	195.82	196.28	174.32	228.33	232.39	250.39
LRI 18-May-99 (rep B)	130.54	118.28	132.06	137.10	155.42	163.76	172.74	195.01	202.39	175.55	230.16	226.00	268.54
LRI 18-May-99 (rep C)	131.08	118.33	128.78	137.37	166.41	171.06	174.24	200.29	201.00	180.95	216.38	226.33	262.90
LRI-reference	158.96	119.72	135.22	140.60	168.20	162.89	172.27	192.06	210.31	196.83	232.97	235.14	245.44
Puyallup control soil	110.01	125.91	140.14	141.38	156.71	157.33	167.81	169.47	178.96	169.13	193.65	186.11	193.60
SC 28-Apr-99 (rep A)	117.04	112.89	137.03	141.57	193.56	198.28	230.06	236.31	285.40	290.81	319.18	334.46	357.43
SC 28-Apr-99 (rep B)	113.37	102.96	136.96	150.02	215.22	241.51	269.49	321.75	328.72	353.54	389.72	332.57	389.08
SC 28-Apr-99 (rep C)	121.21	103.76	129.14	134.64	176.47	199.61	194.36	219.60	241.98	244.69	307.01	317.14	337.61
SC 18-May-99 (rep A)	121.14	128.56	155.17	164.29	207.36	227.03	218.80	249.82	258.81	256.01	285.74	284.03	329.37
SC 18-May-99 (rep B)	116.18	141.89	164.98	180.60	234.35	259.69	278.95	338.42	345.27	326.57	371.15	331.82	368.72
SC 18-May-99 (rep C)	124.91	129.65	147.25	160.17	194.14	167.91	190.59	224.65	267.78	267.16	308.43	299.36	310.61

Appendix 7. Standard deviation soil N (NO_3-N + NH_4-N). N release experiment 1.

Treatment	Standard Deviation--Soil N (NO_3-N + NH_4-N) mg kg^{-1}												
	0d	7d	14d	21d	49d	56d	77d	98d	112d	126d	140d	154d	168d
BF 30-Apr-99 (rep A)	2.738	1.208	1.167	1.283	1.975	4.888	4.858						4.744
BF 30-Apr-99 (rep B)	0.734	0.833	1.507	0.137	1.436	2.869	3.579						2.152
BF 30-Apr-99 (rep C)	0.439	2.178	1.675	1.638	3.464	3.513	8.051						6.138
BF 19-May-99 (rep A)	2.071	1.241	1.573	1.655	2.581	8.674	2.615						2.702
BF 19-May-99 (rep B)	5.146	1.179	1.432	1.058	3.481	10.457	5.889						2.647
BF 19-May-99 (rep C)	6.460	0.349	0.283	1.510	0.397	3.356	5.855						10.129
CG 28-Apr-99 (rep A)	2.693	1.883	0.596	0.325	2.817	6.602	2.196						2.330
CG 28-Apr-99 (rep B)	6.240	1.692	0.794	0.501	0.365	4.888	2.841						1.477
CG 28-Apr-99 (rep C)	1.315	0.852	4.390	0.956	1.614	4.432	2.211						1.848
CG 18-May-99 (rep A)	13.957	2.274	0.613	1.432	1.448	2.426	4.571						2.936
CG 18-May-99 (rep B)	0.686	1.064	1.889	1.732	1.315	2.839	4.878						4.759
CG 18-May-99 (rep C)	2.547	0.942	5.483	2.659	1.071	5.919	3.310						4.418
LRI 26-Apr-99 (rep A)	2.818	1.327	0.590	3.050	1.086	13.598	2.843						5.857
LRI 26-Apr-99 (rep B)	12.101	1.802	1.810	0.082	1.006	4.105	3.097						0.637
LRI 26-Apr-99 (rep C)	2.451	3.190	1.640	1.739	0.860	2.935	2.693						4.795
LRI 18-May-99 (rep A)	1.984	0.437	0.771	2.261	0.592	3.116	3.134						0.989
LRI 18-May-99 (rep B)	2.087	*	2.753	1.633	4.414	5.697	3.671						1.580
LRI 18-May-99 (rep C)	0.400	1.313	1.031	3.685	3.056	14.450	2.857						2.015
LRI-reference	5.211	3.057	2.269	3.562	3.339	7.106	3.264	0.038	1.891	19.419	10.326	1.861	12.512
Puyallup control soil	6.545	3.298	3.202	3.042	2.958	3.903	10.162	6.282	3.648	6.837	2.499	3.147	3.638
SC 28-Apr-99 (rep A)	4.060	3.587	1.931	1.946	0.381	2.958	15.765						13.536
SC 28-Apr-99 (rep B)	0.856	1.577	1.043	4.809	0.716	5.886	7.503						4.065
SC 28-Apr-99 (rep C)	7.098	2.401	0.363	2.040	2.341	2.816	8.039						5.954
SC 18-May-99 (rep A)	9.450	1.167	1.784	4.416	1.496	1.378	10.048						3.329
SC 18-May-99 (rep B)	2.499	0.632	1.872	3.012	2.874	4.655	2.199						5.597
SC 18-May-99 (rep C)	0.105	1.704	1.146	1.779	2.419	0.591	18.028						7.179

* spilled 2 of the 3 extracts

Appendix 8. Average net N mineralized. N release experiment 1.

Treatment	Average Net N Mineralized (NO_3-N + NH_4-N) mg kg^{-1}												
	0d	7d	14d	21d	49d	56d	77d	98d	112d	126d	140d	154d	168d
BF 30-Apr-99 (rep A)	9.74	19.75	10.26	19.06	28.73	44.18	24.29	52.39	49.14	71.23	81.81	83.40	97.22
BF 30-Apr-99 (rep B)	6.52	10.89	8.41	24.46	25.83	34.01	26.20	22.97	47.57	46.77	63.75	66.35	76.79
BF 30-Apr-99 (rep C)	7.35	7.16	1.62	8.04	1.63	6.94	-4.60	27.71	35.47	40.54	50.08	3.80	61.06
BF 19-May-99 (rep A)	8.51	9.21	1.73	5.69	13.34	27.23	9.79	22.73	27.85	14.62	58.47	55.16	58.19
BF 19-May-99 (rep B)	7.99	-0.30	-6.01	-0.37	1.12	13.44	-1.37	44.38	54.07	68.89	68.51	77.09	70.38
BF 19-May-99 (rep C)	5.37	2.69	2.97	6.90	14.75	32.85	5.49	48.63	46.26	58.89	57.22	87.13	97.20
CG 28-Apr-99 (rep A)	7.68	-13.25	-26.22	-22.56	-17.08	0.41	-15.02	-8.34	-8.21	1.87	3.25	-2.24	5.98
CG 28-Apr-99 (rep B)	11.26	-18.58	-34.20	-30.31	-30.94	-22.98	-21.55	-20.03	-22.95	-22.74	-19.06	-16.81	-5.33
CG 28-Apr-99 (rep C)	5.90	-15.41	-21.91	-28.01	-29.17	-22.61	-14.24	-14.65	-21.72	-11.11	-20.69	-16.68	-4.69
CG 18-May-99 (rep A)	15.28	-16.20	-17.35	-17.05	-12.13	-5.55	-1.97	7.82	-2.08	1.24	5.82	5.45	16.90
CG 18-May-99 (rep B)	10.04	-5.14	-13.53	-13.55	-11.44	-12.05	-9.71	7.77	5.50	3.92	16.94	19.22	31.83
CG 18-May-99 (rep C)	9.87	-7.65	-13.23	-8.55	-8.51	5.92	-6.72	7.51	6.14	6.67	16.79	21.35	32.31
LRI 26-Apr-99 (rep A)	17.05	-3.16	-11.89	-12.13	-5.24	3.84	3.78	12.73	7.10	10.81	15.19	15.86	34.60
LRI 26-Apr-99 (rep B)	21.61	-3.40	-11.17	-8.42	0.82	3.17	11.96	24.05	13.66	-2.61	23.05	26.89	34.83
LRI 26-Apr-99 (rep C)	20.23	-0.26	-8.74	-10.01	-3.09	11.75	2.10	10.76	6.97	-1.03	21.71	20.96	35.56
LRI 18-May-99 (rep A)	11.85	-6.29	-7.40	-7.49	1.91	8.61	3.44	26.35	17.32	5.19	34.68	46.28	56.79
LRI 18-May-99 (rep B)	20.53	-7.63	-8.08	-4.28	-1.29	6.43	4.93	25.54	23.43	6.42	36.51	39.89	74.94
LRI 18-May-99 (rep C)	21.07	-7.58	-11.36	-4.01	9.70	13.73	6.43	30.82	22.04	11.82	22.73	40.22	69.30
LRI-reference	48.95	-6.19	-4.92	-0.78	11.49	5.56	4.46	22.59	31.35	27.70	39.32	49.03	51.84
SC 28-Apr-99 (rep A)	7.03	-13.02	-3.11	0.19	36.85	40.95	62.25	66.84	106.44	121.68	125.53	148.35	163.83
SC 28-Apr-99 (rep B)	3.36	-22.95	-3.18	8.64	58.51	84.18	101.68	152.28	149.76	184.41	196.07	146.46	195.48
SC 28-Apr-99 (rep C)	11.20	-22.15	-11.00	-6.74	19.76	42.28	26.55	50.13	63.02	75.56	113.36	131.03	144.01
SC 18-May-99 (rep A)	11.13	2.65	15.03	22.91	50.65	69.70	50.99	80.35	79.85	86.88	92.09	97.92	135.77
SC 18-May-99 (rep B)	6.17	15.98	24.84	39.22	77.64	102.36	111.14	168.95	166.31	157.44	177.50	145.71	175.12
SC 18-May-99 (rep C)	14.90	3.74	7.11	18.79	37.43	10.58	22.78	55.18	88.82	98.03	114.78	113.25	117.01

Appendix 9. Standard deviation net N mineralized. N release experiment 1.

Treatment	Standard Deviation--Net N Mineralized (NO_3-N + NH_4-N) mg kg^{-1}												
	0d	7d	14d	21d	49d	56d	77d	98d	112d	126d	140d	154d	168d
BF 30-Apr-99 (rep A)	2.738	1.208	1.167	1.283	1.975	4.888	4.858						4.744
BF 30-Apr-99 (rep B)	0.734	0.833	1.507	0.137	1.436	2.869	3.579						2.152
BF 30-Apr-99 (rep C)	0.439	2.178	1.675	1.638	3.464	3.513	8.051						6.138
BF 19-May-99 (rep A)	2.071	1.241	1.573	1.655	2.581	8.674	2.615						2.702
BF 19-May-99 (rep B)	5.146	1.179	1.432	1.058	3.481	10.457	5.889						2.647
BF 19-May-99 (rep C)	6.460	0.349	0.283	1.510	0.397	3.356	5.855						10.129
CG 28-Apr-99 (rep A)	2.693	1.883	0.596	0.325	2.817	6.602	2.196						2.330
CG 28-Apr-99 (rep B)	6.240	1.692	0.794	0.501	0.365	4.888	2.841						1.477
CG 28-Apr-99 (rep C)	1.315	0.852	4.390	0.956	1.614	4.432	2.211						1.848
CG 18-May-99 (rep A)	13.957	2.274	0.613	1.432	1.448	2.426	4.571						2.936
CG 18-May-99 (rep B)	0.686	1.064	1.889	1.732	1.315	2.839	4.878						4.759
CG 18-May-99 (rep C)	2.547	0.942	5.483	2.659	1.071	5.919	3.310						4.418
LRI 26-Apr-99 (rep A)	2.818	1.327	0.590	3.050	1.086	13.598	2.843						5.857
LRI 26-Apr-99 (rep B)	12.101	1.802	1.810	0.082	1.006	4.105	3.097						0.637
LRI 26-Apr-99 (rep C)	2.451	3.190	1.640	1.739	0.860	2.935	2.693						4.795
LRI 18-May-99 (rep A)	1.984	0.437	0.771	2.261	0.592	3.116	3.134						0.989
LRI 18-May-99 (rep B)	2.087	*	2.753	1.633	4.414	5.697	3.671						1.580
LRI 18-May-99 (rep C)	0.400	1.313	1.031	3.685	3.056	14.450	2.857						2.015
LRI-reference	5.211	3.057	2.269	3.562	3.339	7.106	3.264	0.038	1.891	19.419	10.326	1.861	12.512
SC 28-Apr-99 (rep A)	4.060	3.587	1.931	1.946	0.381	2.958	15.765						13.536
SC 28-Apr-99 (rep B)	0.856	1.577	1.043	4.809	0.716	5.886	7.503						4.065
SC 28-Apr-99 (rep C)	7.098	2.401	0.363	2.040	2.341	2.816	8.039						5.954
SC 18-May-99 (rep A)	9.450	1.167	1.784	4.416	1.496	1.378	10.048						3.329
SC 18-May-99 (rep B)	2.499	0.632	1.872	3.012	2.874	4.655	2.199						5.597
SC 18-May-99 (rep C)	0.105	1.704	1.146	1.779	2.419	0.591	18.028						7.179

* spilled 2 of the 3 extracts

Appendix 10. Average net N mineralized (% of MPYT-N applied). N release experiment 1.

Treatment	Average Net N Mineralized (% of MPYT-N applied)												
	0d	7d	14d	21d	49d	56d	77d	98d	112d	126d	140d	154d	168d
BF 30-Apr-99 (rep A)	3	6	3	5	8	13	7	15	14	20	24	24	28
BF 30-Apr-99 (rep B)	2	3	2	7	8	10	8	7	14	14	19	19	23
BF 30-Apr-99 (rep C)	2	2	1	2	1	2	-1	9	11	13	16	1	19
BF 19-May-99 (rep A)	3	3	1	2	4	9	3	7	9	5	19	18	19
BF 19-May-99 (rep B)	2	0	-2	0	0	4	0	12	14	18	18	20	19
BF 19-May-99 (rep C)	1	1	1	2	4	8	1	12	12	15	14	22	24
CG 28-Apr-99 (rep A)	4	-6	-12	-10	-8	0	-7	-4	-4	1	1	-1	3
CG 28-Apr-99 (rep B)	7	-11	-21	-18	-19	-14	-13	-12	-14	-14	-11	-10	-3
CG 28-Apr-99 (rep C)	3	-9	-13	-16	-17	-13	-8	-9	-13	-7	-12	-10	-3
CG 18-May-99 (rep A)	5	-6	-6	-6	-4	-2	-1	3	-1	0	2	2	6
CG 18-May-99 (rep B)	4	-2	-5	-5	-4	-4	-3	3	2	1	6	7	11
CG 18-May-99 (rep C)	4	-3	-6	-4	-4	2	-3	3	3	3	7	9	13
LRI 26-Apr-99 (rep A)	5	-1	-4	-4	-2	1	1	4	2	3	5	5	11
LRI 26-Apr-99 (rep B)	8	-1	-4	-3	0	1	4	9	5	-1	8	10	12
LRI 26-Apr-99 (rep C)	8	0	-4	-4	-1	5	1	5	3	0	9	9	15
LRI 18-May-99 (rep A)	3	-2	-2	-2	1	2	1	7	5	1	10	13	16
LRI 18-May-99 (rep B)	6	-2	-2	-1	0	2	1	7	7	2	10	11	21
LRI 18-May-99 (rep C)	6	-2	-3	-1	3	4	2	9	6	3	6	11	19
LRI-reference	15	-2	-2	0	4	2	1	7	10	8	12	15	16
SC 28-Apr-99 (rep A)	1	-2	-1	0	7	7	11	12	19	22	23	27	30
SC 28-Apr-99 (rep B)	1	-4	0	1	9	13	16	24	24	29	31	23	31
SC 28-Apr-99 (rep C)	2	-4	-2	-1	4	8	5	10	13	15	23	26	29
SC 18-May-99 (rep A)	3	1	3	5	11	16	12	18	18	20	21	22	31
SC 18-May-99 (rep B)	1	3	5	7	15	19	21	32	32	30	34	28	33
SC 18-May-99 (rep C)	4	1	2	6	11	3	7	16	26	29	34	34	35

Appendix 11. Standard deviation net N mineralized (% of MPYT-N applied). N release experiment 1.

Treatment	Standard Deviation--Net N Mineralized (% MPYT-N applied)												
	0d	7d	14d	21d	49d	56d	77d	98d	112d	126d	140d	154d	168d
BF 30-Apr-99 (rep A)	0.787	0.347	0.336	0.369	0.568	1.406	1.397						1.364
BF 30-Apr-99 (rep B)	0.216	0.245	0.443	0.040	0.422	0.842	1.051						0.632
BF 30-Apr-99 (rep C)	0.136	0.676	0.519	0.650	1.075	1.090	2.499						1.906
BF 19-May-99 (rep A)	0.670	0.402	0.509	0.535	0.835	2.806	0.846						0.874
BF 19-May-99 (rep B)	1.360	0.312	0.379	0.280	0.920	2.764	1.556						0.700
BF 19-May-99 (rep C)	1.618	0.088	0.071	0.378	0.100	0.841	1.467						2.537
CG 28-Apr-99 (rep A)	1.229	0.860	0.272	0.148	1.286	3.015	1.002						1.064
CG 28-Apr-99 (rep B)	3.760	1.019	0.479	0.302	0.220	2.945	1.712						0.890
CG 28-Apr-99 (rep C)	0.770	0.499	2.572	0.560	0.945	2.596	1.295						1.083
CG 18-May-99 (rep A)	4.815	0.784	0.211	0.494	0.499	0.837	1.577						1.013
CG 18-May-99 (rep B)	0.241	0.374	0.663	0.608	0.462	0.997	1.713						1.672
CG 18-May-99 (rep C)	1.059	0.392	2.280	1.106	0.445	2.462	1.377						1.838
LRI 26-Apr-99 (rep A)	0.895	0.422	0.187	0.968	0.345	4.318	0.903						1.860
LRI 26-Apr-99 (rep B)	4.305	0.641	0.644	0.029	0.358	1.460	1.102						0.227
LRI 26-Apr-99 (rep C)	1.030	1.340	0.689	0.731	0.361	1.233	1.131						2.015
LRI 18-May-99 (rep A)	0.547	0.120	0.213	0.624	0.163	0.860	0.865						0.273
LRI 18-May-99 (rep B)	0.585	*	0.772	0.458	1.238	1.598	1.030						0.443
LRI 18-May-99 (rep C)	0.112	0.366	0.288	1.028	0.853	4.032	0.797						0.562
LRI-reference	1.596	0.936	0.695	1.091	1.023	2.177	1.000	0.012	0.579	5.949	3.163	0.057	3.833
SC 28-Apr-99 (rep A)	0.732	0.647	0.348	0.351	0.069	0.534	2.844						2.442
SC 28-Apr-99 (rep B)	0.135	0.248	0.164	0.756	0.113	0.926	1.180						0.639
SC 28-Apr-99 (rep C)	1.413	0.478	0.072	0.406	0.466	0.561	1.600						1.185
SC 18-May-99 (rep A)	2.141	0.264	0.404	1.000	0.339	0.312	2.276						0.754
SC 18-May-99 (rep B)	0.474	0.120	0.355	0.571	0.545	0.883	0.417						1.061
SC 18-May-99 (rep C)	0.031	0.505	0.340	0.527	0.717	0.175	5.344						2.128

* spilled 2 of the 3 extracts

Appendix 12. Soil moisture. MPYT storage experiment 2.

Treatment	Soil Moisture (% by weight)					
	0d	14d	42d	56d	70d	98d
Puyallup control soil	24	24	26	26	23	26
SC-control 28-Apr-99 (rep A)	24	24	26	28	27	29
SC-week 0, 22-July-99 (rep A)	24	24	29	32	24	28
SC-week 0, 22-July-99 (rep B)	24	23	27	29	27	29
SC-week 0, 22-July-99 (rep C)	24	24	28	28	25	27
SC-week 1, 29-July-99 (rep A)	23	25	32	32	31	29
SC-week 1, 29-July-99 (rep B)	23	25	29	29	27	28
SC-week 1, 29-July-99 (rep C)	23	24	28	*	27	28
SC-week 2, 5-Aug-99 (rep A)	23	24	28	28	29	27
SC-week 2, 5-Aug-99 (rep B)	24	23	28	22	22	27
SC-week 2, 5-Aug-99 (rep C)	23	23	26	25	25	29
SC-week 3, 12-Aug-99 (rep A)	24	23	26	27	21	27
SC-week 3, 12-Aug-99 (rep B)	24	23	28	30	20	26
SC-week 3, 12-Aug-99 (rep C)	24	24	28	28	24	29
SC-week 4, 19-Aug-99 (rep A)	23	24	29	31	27	27
SC-week 4, 19-Aug-99 (rep B)	24	23	28	28	27	27
SC-week 4, 19-Aug-99 (rep C)	24	23	25	27	24	28

* bag had a perforation that caused over-saturation of soil.

Appendix 13. Soil NO_3-N. MPYT storage experiment 2.

Treatment	Soil NO_3-N (mg kg^{-1})					
	0d	14d	42d	56d	70d	98d
Puyallup control soil	110.57	127.10	134.34	150.65	156.60	170.33
SC-control 28-Apr-99 (rep A)	110.07	136.88	144.56	179.91	196.34	240.47
SC-week 0, 22-July-99 (rep A)	107.00	163.57	269.98	363.79	370.53	385.74
SC-week 0, 22-July-99 (rep B)	116.17	150.76	244.76	373.86	382.15	412.41
SC-week 0, 22-July-99 (rep C)	110.69	132.87	218.58	322.33	353.81	414.11
SC-week 1, 29-July-99 (rep A)	109.76	76.47	109.19	223.55	270.85	327.73
SC-week 1, 29-July-99 (rep B)	103.30	105.28	148.23	271.61	308.68	373.05
SC-week 1, 29-July-99 (rep C)	109.53	69.60	105.14	*	260.86	317.92
SC-week 2, 5-Aug-99 (rep A)	107.25	85.83	116.49	181.27	227.04	301.34
SC-week 2, 5-Aug-99 (rep B)	99.84	88.40	119.65	178.72	187.28	250.13
SC-week 2, 5-Aug-99 (rep C)	106.80	139.01	184.34	243.40	259.46	355.91
SC-week 3, 12-Aug-99 (rep A)	116.96	93.92	128.01	204.01	194.34	255.94
SC-week 3, 12-Aug-99 (rep B)	110.44	100.06	136.02	189.01	188.27	234.99
SC-week 3, 12-Aug-99 (rep C)	98.32	82.48	115.00	178.53	189.73	253.66
SC-week 4, 19-Aug-99 (rep A)	108.58	121.80	154.21	212.00	212.53	265.63
SC-week 4, 19-Aug-99 (rep B)	112.41	130.47	156.48	204.70	211.19	261.77
SC-week 4, 19-Aug-99 (rep C)	118.81	114.51	129.91	167.46	175.90	219.87

* bag had a perforation that caused over-saturation of soil.

Appendix 14. Soil NH_4-N. MPYT storage experiment 2.

Treatment	Soil NH_4-N (mg kg^{-1})					
	0d	14d	42d	56d	70d	98d
Puyallup control soil	3.94	10.36	5.17	2.81	0.95	0.68
SC-control 28-Apr-99 (rep A)	13.55	6.74	2.44	2.81	2.52	0.76
SC-week 0, 22-July-99 (rep A)	13.34	60.37	5.69	10.51	8.10	17.41
SC-week 0, 22-July-99 (rep B)	17.06	52.50	5.79	17.87	14.13	23.59
SC-week 0, 22-July-99 (rep C)	12.06	32.53	4.04	20.69	13.22	15.26
SC-week 1, 29-July-99 (rep A)	29.45	3.52	2.05	7.41	5.80	0.98
SC-week 1, 29-July-99 (rep B)	28.76	6.45	2.67	4.72	5.71	7.77
SC-week 1, 29-July-99 (rep C)	29.36	2.43	1.76	*	2.57	0.93
SC-week 2, 5-Aug-99 (rep A)	24.52	4.68	1.96	4.45	3.14	1.11
SC-week 2, 5-Aug-99 (rep B)	26.11	1.65	1.99	2.65	2.25	1.80
SC-week 2, 5-Aug-99 (rep C)	25.29	9.13	2.20	2.79	1.51	6.17
SC-week 3, 12-Aug-99 (rep A)	21.13	4.58	2.10	2.72	2.05	2.32
SC-week 3, 12-Aug-99 (rep B)	28.66	6.87	1.79	2.90	1.81	0.67
SC-week 3, 12-Aug-99 (rep C)	28.63	4.20	1.97	2.77	1.41	0.94
SC-week 4, 19-Aug-99 (rep A)	21.70	4.68	2.85	2.88	3.06	0.68
SC-week 4, 19-Aug-99 (rep B)	18.29	3.07	2.00	2.87	0.67	1.24
SC-week 4, 19-Aug-99 (rep C)	19.14	4.94	1.92	2.85	1.64	0.80

* bag had a perforation that caused over-saturation of soil.

Appendix 15. Soil N (NO_3-N + NH_4-N). MPYT storage experiment 2.

Treatment	Soil N (NO_3-N + NH_4-N) mg kg^{-1}					
	0d	14d	42d	56d	70d	98d
Puyallup control soil	114.52	137.45	139.51	153.46	157.54	171.02
SC-control 28-Apr-99 (rep A)	123.61	143.62	147.00	182.72	198.86	241.23
SC-week 0, 22-July-99 (rep A)	120.34	223.94	275.66	374.30	378.63	403.15
SC-week 0, 22-July-99 (rep B)	133.23	203.25	250.55	391.73	396.29	436.00
SC-week 0, 22-July-99 (rep C)	122.75	165.40	222.62	343.01	367.03	429.37
SC-week 1, 29-July-99 (rep A)	139.21	79.99	111.24	230.96	276.66	328.71
SC-week 1, 29-July-99 (rep B)	132.06	111.72	150.90	276.33	314.39	380.83
SC-week 1, 29-July-99 (rep C)	138.89	72.02	106.90	*	263.42	318.85
SC-week 2, 5-Aug-99 (rep A)	131.77	90.50	118.45	185.72	230.18	302.46
SC-week 2, 5-Aug-99 (rep B)	125.95	90.05	121.64	181.37	189.53	251.93
SC-week 2, 5-Aug-99 (rep C)	132.08	148.14	186.54	246.20	260.96	362.08
SC-week 3, 12-Aug-99 (rep A)	138.09	98.50	130.11	206.73	196.39	258.26
SC-week 3, 12-Aug-99 (rep B)	139.11	106.93	137.81	191.91	190.08	235.66
SC-week 3, 12-Aug-99 (rep C)	126.95	86.68	116.98	181.30	191.13	254.60
SC-week 4, 19-Aug-99 (rep A)	130.28	126.48	157.07	214.88	215.59	266.30
SC-week 4, 19-Aug-99 (rep B)	130.70	133.54	158.48	207.56	211.87	263.00
SC-week 4, 19-Aug-99 (rep C)	137.95	119.45	131.83	170.31	177.54	220.67

* bag had a perforation that caused over-saturation of soil.

Appendix 16. Soil net N mineralized. MPYT storage experiment 2.

Treatment	Soil Net N Mineralized (NO_3-N + NH_4-N) mg kg^{-1}					
	0d	14d	42d	56d	70d	98d
SC-control 28-Apr-99 (rep A)	9.09	6.17	7.49	29.26	41.32	70.21
SC-week 0, 22-July-99 (rep A)	5.82	86.49	136.15	220.84	221.09	232.13
SC-week 0, 22-July-99 (rep B)	18.71	65.80	111.04	238.27	238.75	264.98
SC-week 0, 22-July-99 (rep C)	8.23	27.95	83.11	189.55	209.49	258.35
SC-week 1, 29-July-99 (rep A)	24.69	-57.46	-28.27	77.50	119.12	157.69
SC-week 1, 29-July-99 (rep B)	17.54	-25.73	11.39	122.87	156.85	209.81
SC-week 1, 29-July-99 (rep C)	24.37	-65.43	-32.61	*	105.88	147.83
SC-week 2, 5-Aug-99 (rep A)	17.25	-46.95	-21.06	32.26	72.64	131.44
SC-week 2, 5-Aug-99 (rep B)	11.43	-47.40	-17.87	27.91	31.99	80.91
SC-week 2, 5-Aug-99 (rep C)	17.56	10.69	47.03	92.74	103.42	191.06
SC-week 3, 12-Aug-99 (rep A)	23.57	-38.95	-9.40	53.27	38.85	87.24
SC-week 3, 12-Aug-99 (rep B)	24.59	-30.52	-1.70	38.45	32.54	64.64
SC-week 3, 12-Aug-99 (rep C)	12.43	-50.77	-22.53	27.84	33.59	83.58
SC-week 4, 19-Aug-99 (rep A)	15.76	-10.97	17.56	61.42	58.05	95.28
SC-week 4, 19-Aug-99 (rep B)	16.18	-3.91	18.97	54.10	54.33	91.98
SC-week 4, 19-Aug-99 (rep C)	23.43	-18.00	-7.68	16.85	20.00	49.65

* bag had a perforation that caused over-saturation of soil.

Appendix 17. Soil net N mineralized (% of MPYT-N applied). MPYT storage experiment 2.

Treatment	Soil Net N Mineralized (% of MPYT-N applied)					
	0d	14d	42d	56d	70d	98d
SC-control 28-Apr-99 (rep A)	2	1	1	5	7	13
SC-week 0, 22-July-99 (rep A)	1	10	17	27	27	28
SC-week 0, 22-July-99 (rep B)	3	9	15	32	32	36
SC-week 0, 22-July-99 (rep C)	1	4	11	25	28	35
SC-week 1, 29-July-99 (rep A)	4	-10	-5	13	20	27
SC-week 1, 29-July-99 (rep B)	3	-4	2	19	24	32
SC-week 1, 29-July-99 (rep C)	4	-12	-6	*	19	26
SC-week 2, 5-Aug-99 (rep A)	3	-8	-4	5	12	22
SC-week 2, 5-Aug-99 (rep B)	2	-8	-3	4	5	13
SC-week 2, 5-Aug-99 (rep C)	2	1	7	13	14	26
SC-week 3, 12-Aug-99 (rep A)	4	-7	-2	9	7	15
SC-week 3, 12-Aug-99 (rep B)	4	-5	0	6	5	10
SC-week 3, 12-Aug-99 (rep C)	2	-8	-4	5	6	14
SC-week 4, 19-Aug-99 (rep A)	3	-2	3	10	9	16
SC-week 4, 19-Aug-99 (rep B)	3	-1	3	9	9	16
SC-week 4, 19-Aug-99 (rep C)	4	-3	-1	3	4	9

* bag had a perforation that caused over-saturation of soil.

Appendix 18. Average soil moisture. CO_2-C quick test experiment 3.

Treatment	Average Soil Moisture (% by weight)		
	7d	21d	68d
BF 30-Apr-99 (rep B)	22	17	18
BF 19-May-99 (rep B)	23	21	16
BF-frozen 30-Apr-99 (rep B)	25	19	17
CG 28-Apr-99 (rep B)	22	17	17
CG 18-May-99 (rep B)	22	21	16
CG-frozen 28-Apr-99 (rep B)	23	20	21
Control	23	18	18
LRI 26-Apr-99 (rep B)	22	21	17
LRI 18-May-99 (rep B)	22	23	18
LRI frozen 26-Apr-99 (rep B)	25	21	21
LRI-reference	23	18	18
paper sludge	21	19	23
peppermint	21	19	24
SC 28-Apr-99 (rep B)	23	21	18
SC 18-May-99 (rep B)	23	21	16
SC 22-July-99 (rep B)	24	23	18
SC 19-Aug-99 (rep B)	23	17	18
SC 5-Aug-99 (rep B)	23	18	19
SC-frozen 28-Apr-99 (rep B)	25	23	23

Appendix 19. Standard deviation soil moisture. CO_2-C quick test experiment 3.

Treatment	Standard Deviation--Soil Moisture (% by weight)		
	7d	21d	68d
BF 30-Apr-99 (rep B)	0.131	1.254	0.757
BF 19-May-99 (rep B)	0.231	3.345	1.007
BF-frozen 30-Apr-99 (rep B)	0.278	1.617	3.992
CG 28-Apr-99 (rep B)	0.249	1.195	0.705
CG 18-May-99 (rep B)	0.964	1.940	1.625
CG-frozen 28-Apr-99 (rep B)	0.427	0.942	1.276
Control	0.480	0.921	0.387
LRI 26-Apr-99 (rep B)	0.409	4.607	0.856
LRI 18-May-99 (rep B)	0.791	2.722	6.931
LRI frozen 26-Apr-99 (rep B)	0.505	0.619	1.899
LRI-reference	0.271	0.873	0.566
paper sludge	1.208	0.393	0.820
peppermint	1.068	1.824	3.121
SC 28-Apr-99 (rep B)	0.422	5.329	1.856
SC 18-May-99 (rep B)	0.559	1.781	2.483
SC 22-July-99 (rep B)	1.123	2.209	1.924
SC 19-Aug-99 (rep B)	0.636	0.946	0.258
SC 5-Aug-99 (rep B)	0.453	0.839	1.374
SC-frozen 28-Apr-99 (rep B)	0.210	0.611	0.776

Appendix 20. Average soil NO_3-N. CO_2-C quick test experiment 3.

Treatment	Average Soil NO_3-N mg kg^{-1}		
	7d	21d	68d
BF 30-Apr-99 (rep B)	103.73	114.41	157.91
BF 19-May-99 (rep B)	94.41	104.97	160.90
BF-frozen 30-Apr-99 (rep B)	107.64	130.69	165.90
CG 28-Apr-99 (rep B)	96.38	89.15	132.53
CG 18-May-99 (rep B)	98.96	105.56	134.08
CG-frozen 28-Apr-99 (rep B)	97.68	106.67	141.57
Control	111.07	111.62	131.67
LRI 26-Apr-99 (rep B)	101.79	105.53	134.88
LRI 18-May-99 (rep B)	98.28	102.94	144.47
LRI frozen 26-Apr-99 (rep B)	106.73	117.23	149.68
LRI-reference	93.15	101.06	145.91
paper sludge	109.30	121.43	148.85
peppermint	135.43	127.42	184.18
SC 28-Apr-99 (rep B)	80.61	83.28	155.21
SC 18-May-99 (rep B)	97.91	107.87	145.92
SC 22-July-99 (rep B)	80.06	46.56	163.81
SC 19-Aug-99 (rep B)	86.21	99.27	151.00
SC 5-Aug-99 (rep B)	49.96	32.81	151.92
SC-frozen 28-Apr-99 (rep B)	97.82	143.22	186.70

Appendix 21. Standard deviation soil NO_3-N. CO_2-C quick test experiment 3.

Treatment	Standard Deviation--Soil NO_3-N mg kg^{-1}		
	7d	21d	68d
BF 30-Apr-99 (rep B)	1.168	1.960	2.069
BF 19-May-99 (rep B)	0.322	4.127	8.744
BF-frozen 30-Apr-99 (rep B)	1.786	8.460	8.363
CG 28-Apr-99 (rep B)	4.789	4.058	6.161
CG 18-May-99 (rep B)	3.015	2.642	12.406
CG-frozen 28-Apr-99 (rep B)	2.208	7.752	2.347
Control	1.008	1.428	3.474
LRI 26-Apr-99 (rep B)	1.123	6.189	7.352
LRI 18-May-99 (rep B)	1.774	1.360	21.709
LRI frozen 26-Apr-99 (rep B)	0.961	6.149	9.189
LRI-reference	3.266	4.996	0.866
paper sludge	2.173	4.718	1.266
peppermint	0.506	23.259	4.609
SC 28-Apr-99 (rep B)	4.872	7.555	13.325
SC 18-May-99 (rep B)	2.497	4.177	3.451
SC 22-July-99 (rep B)	0.322	11.888	20.845
SC 19-Aug-99 (rep B)	22.657	9.086	5.632
SC 5-Aug-99 (rep B)	10.318	11.116	11.916
SC-frozen 28-Apr-99 (rep B)	3.308	5.984	8.705

Appendix 22. Average soil NH_4-N. CO_2-C quick test experiment 3.

Treatment	Average Soil NH_4-N mg kg^{-1}		
	7d	21d	68d
BF 30-Apr-99 (rep B)	18.35	29.86	12.51
BF 19-May-99 (rep B)	16.30	23.85	10.58
BF-frozen 30-Apr-99 (rep B)	23.99	32.69	23.26
CG 28-Apr-99 (rep B)	6.30	15.00	2.94
CG 18-May-99 (rep B)	7.59	11.32	5.93
CG-frozen 28-Apr-99 (rep B)	14.57	20.31	8.68
Control	10.48	22.68	20.87
LRI 26-Apr-99 (rep B)	10.56	22.55	13.97
LRI 18-May-99 (rep B)	13.94	29.94	19.33
LRI frozen 26-Apr-99 (rep B)	2.69	24.91	18.80
LRI-reference	15.29	28.41	12.44
paper sludge	7.55	6.51	1.86
peppermint	23.29	29.64	3.03
SC 28-Apr-99 (rep B)	29.30	88.21	86.10
SC 18-May-99 (rep B)	28.65	69.24	63.74
SC 22-July-99 (rep B)	63.99	152.86	155.68
SC 19-Aug-99 (rep B)	14.50	40.48	25.41
SC 5-Aug-99 (rep B)	18.00	44.76	7.29
SC-frozen 28-Apr-99 (rep B)	14.04	42.64	25.00

Appendix 23. Standard deviation soil NH_4-N. CO_2-C quick test experiment 3.

Treatment	Standard Deviation--Soil NH_4-N mg kg^{-1}		
	7d	21d	68d
BF 30-Apr-99 (rep B)	0.488	2.431	8.480
BF 19-May-99 (rep B)	0.859	0.902	2.060
BF-frozen 30-Apr-99 (rep B)	2.556	1.495	4.877
CG 28-Apr-99 (rep B)	0.842	0.526	0.172
CG 18-May-99 (rep B)	0.801	1.243	0.370
CG-frozen 28-Apr-99 (rep B)	3.352	5.639	5.546
Control	0.637	0.687	2.115
LRI 26-Apr-99 (rep B)	0.249	0.089	1.149
LRI 18-May-99 (rep B)	0.188	5.209	3.908
LRI frozen 26-Apr-99 (rep B)	0.025	4.848	6.528
LRI-reference	0.404	0.945	1.751
paper sludge	0.776	2.175	0.237
peppermint	1.352	4.647	0.433
SC 28-Apr-99 (rep B)	3.119	6.596	5.271
SC 18-May-99 (rep B)	2.028	5.919	2.285
SC 22-July-99 (rep B)	3.967	10.773	18.538
SC 19-Aug-99 (rep B)	1.477	6.088	8.643
SC 5-Aug-99 (rep B)	0.226	11.746	1.283
SC-frozen 28-Apr-99 (rep B)	7.710	8.508	5.554

Appendix 24. Average soil N (NO_3-N + NH_4-N). CO_2-C quick test experiment 3.

Treatment	Average Soil N (NO_3-N + NH_4-N) mg kg^{-1}		
	7d	21d	68d
BF 30-Apr-99 (rep B)	122.07	144.28	170.42
BF 19-May-99 (rep B)	110.70	128.82	171.48
BF-frozen 30-Apr-99 (rep B)	131.63	163.38	189.16
CG 28-Apr-99 (rep B)	102.68	104.14	135.47
CG 18-May-99 (rep B)	106.55	116.89	140.02
CG-frozen 28-Apr-99 (rep B)	112.25	126.99	150.25
Control	121.54	134.30	152.54
LRI 26-Apr-99 (rep B)	112.35	128.08	148.85
LRI 18-May-99 (rep B)	112.22	132.88	163.80
LRI frozen 26-Apr-99 (rep B)	109.42	142.14	168.48
LRI-reference	108.44	129.47	158.35
paper sludge	116.84	127.95	150.71
peppermint	158.72	157.05	187.21
SC 28-Apr-99 (rep B)	109.91	171.49	241.31
SC 18-May-99 (rep B)	126.56	177.11	209.66
SC 22-July-99 (rep B)	144.05	199.42	319.50
SC 19-Aug-99 (rep B)	100.71	139.74	176.41
SC 5-Aug-99 (rep B)	67.96	77.56	159.20
SC-frozen 28-Apr-99 (rep B)	111.86	185.86	211.70

Appendix 25. Standard deviation soil N (NO_3-N + NH_4-N).
CO_2-C quick test experiment 3.

Treatment	Standard deviation--Soil N (NO_3-N + NH_4-N) mg kg^{-1}		
	7d	21d	68d
BF 30-Apr-99 (rep B)	1.338	4.269	10.510
BF 19-May-99 (rep B)	0.992	5.029	8.857
BF-frozen 30-Apr-99 (rep B)	4.271	8.998	3.502
CG 28-Apr-99 (rep B)	5.355	3.558	5.989
CG 18-May-99 (rep B)	3.815	3.127	12.068
CG-frozen 28-Apr-99 (rep B)	3.464	13.280	7.891
Control	0.934	1.917	2.973
LRI 26-Apr-99 (rep B)	1.240	6.270	6.942
LRI 18-May-99 (rep B)	1.962	5.267	22.191
LRI frozen 26-Apr-99 (rep B)	0.938	7.606	5.050
LRI-reference	3.272	5.868	1.126
paper sludge	1.468	4.905	1.425
peppermint	1.751	18.826	4.980
SC 28-Apr-99 (rep B)	6.367	13.673	15.203
SC 18-May-99 (rep B)	0.612	9.390	1.982
SC 22-July-99 (rep B)	3.645	7.461	25.544
SC 19-Aug-99 (rep B)	21.667	3.132	3.073
SC 5-Aug-99 (rep B)	10.092	8.600	11.290
SC-frozen 28-Apr-99 (rep B)	10.331	14.473	3.225

Appendix 26. Average net N mineralized. CO_2-C quick test experiment 3.

Treatment	Average Net N Mineralized (NO_3-N + NH_4-N) mg kg^{-1}		
	7d	21d	68d
BF 30-Apr-99 (rep B)	0.57	9.98	17.92
BF 19-May-99 (rep B)	-10.80	-5.48	18.98
BF-frozen 30-Apr-99 (rep B)	10.13	29.08	36.66
CG 28-Apr-99 (rep B)	-18.82	-30.16	-17.03
CG 18-May-99 (rep B)	-14.95	-17.41	-12.48
CG-frozen 28-Apr-99 (rep B)	-9.25	-7.31	-2.25
LRI 26-Apr-99 (rep B)	-9.15	-6.22	-3.65
LRI 18-May-99 (rep B)	-9.28	-1.42	11.30
LRI frozen 26-Apr-99 (rep B)	-12.08	7.84	15.98
LRI-reference	-13.06	-4.83	5.85
paper sludge	-4.66	-6.35	-1.79
peppermint	37.22	22.75	34.71
SC 28-Apr-99 (rep B)	-11.59	37.19	88.81
SC 18-May-99 (rep B)	5.06	42.81	57.16
SC 22-July-99 (rep B)	22.55	65.12	167.00
SC 19-Aug-99 (rep B)	-20.79	5.44	23.91
SC 5-Aug-99 (rep B)	-53.54	-56.74	6.70
SC-frozen 28-Apr-99 (rep B)	-9.64	51.56	59.20

Appendix 27. Standard deviation net N mineralized. CO_2-C quick test experiment 3.

Treatment	Standard deviation--Net N Mineralized (NO_3-N + NH_4-N) mg kg^{-1}		
	7d	21d	68d
BF 30-Apr-99 (rep B)	1.338	4.269	10.510
BF 19-May-99 (rep B)	0.992	5.029	8.857
BF-frozen 30-Apr-99 (rep B)	4.271	8.998	3.502
CG 28-Apr-99 (rep B)	5.355	3.558	5.989
CG 18-May-99 (rep B)	3.815	3.127	12.068
CG-frozen 28-Apr-99 (rep B)	3.464	13.280	7.891
Control	0.934	1.917	2.973
LRI 26-Apr-99 (rep B)	1.240	6.270	6.942
LRI 18-May-99 (rep B)	1.962	5.267	22.191
LRI frozen 26-Apr-99 (rep B)	0.938	7.606	5.050
LRI-reference	3.272	5.868	1.126
paper sludge	1.468	4.905	1.425
peppermint	1.751	18.826	4.980
SC 28-Apr-99 (rep B)	6.367	13.673	15.203
SC 18-May-99 (rep B)	0.612	9.390	1.982
SC 22-July-99 (rep B)	3.645	7.461	25.544
SC 19-Aug-99 (rep B)	21.667	3.132	3.073
SC 5-Aug-99 (rep B)	10.092	8.600	11.290
SC-frozen 28-Apr-99 (rep B)	10.331	14.473	3.225

Appendix 28. Standard deviation net N mineralized (% of MPYT-N applied). CO_2-C quick test experiment 3.

Treatment	Standard Deviation--Net N Mineralized (% MPYT-N applied)		
	7d	21d	68d
BF 30-Apr-99 (rep B)	0.393	1.255	3.089
BF 19-May-99 (rep B)	0.262	1.330	2.343
BF-frozen 30-Apr-99 (rep B)	1.256	2.645	1.030
CG 28-Apr-99 (rep B)	3.229	2.146	3.612
CG 18-May-99 (rep B)	1.341	1.099	4.243
CG-frozen 28-Apr-99 (rep B)	2.089	8.009	4.759
LRI 26-Apr-99 (rep B)	0.442	2.233	2.472
LRI 18-May-99 (rep B)	0.551	1.479	6.230
LRI frozen 26-Apr-99 (rep B)	0.334	2.709	1.799
LRI-reference	1.003	1.799	0.345
SC 28-Apr-99 (rep B)	1.002	2.153	2.393
SC 18-May-99 (rep B)	0.116	1.782	0.376
SC 22-July-99 (rep B)	0.491	1.004	3.437
SC 19-Aug-99 (rep B)	3.699	0.535	0.525
SC 5-Aug-99 (rep B)	1.612	1.374	1.804
SC-frozen 28-Apr-99 (rep B)	1.626	2.279	0.508

Appendix 29. Average gross CO_2-C evolved. CO_2-C quick test experiment 3.

Treatment	Average Gross CO_2-C Evolved (mg)											
	1d	3d	5d	7d	14d	21d	28d	34d	43d	52d	60d	68d
Control	2.40	4.44	2.64	3.52	4.53	3.98	2.77	2.88	1.69	2.18	0.86	3.41
BF 30-Apr-99 (rep B)	6.14	17.53	9.04	5.48	16.06	10.76	6.51	5.39	9.31	5.50	1.67	3.50
BF-frozen 30-Apr-99 (rep B)	1.12	18.72	3.63	4.07	10.69	8.51	8.58	6.89	5.83	5.37	5.06	3.32
BF 19-May-99 (rep B)	6.40	19.03	11.59	9.39	17.86	11.29	9.28	7.06	4.25	5.59	5.41	3.15
CG 28-Apr-99 (rep B)	1.87	10.98	9.09	1.17	11.57	9.00	8.76	7.11	7.59	5.81	3.12	3.10
CG-frozen 28-Apr-99 (rep B)	2.66	13.22	4.99	8.12	11.04	12.17	8.45	10.23	4.82	3.12	4.93	2.13
CG 18-May-99 (rep B)	7.63	17.62	9.17	6.18	11.79	10.76	7.26	6.84	7.24	4.75	4.09	-0.20
LRI 26-Apr-99 (rep B)	8.29	15.69	10.23	6.80	10.96	10.10	8.27	6.40	3.63	6.12	1.80	3.06
LRI frozen 26-Apr-99 (rep B)	5.35	14.19	9.22	4.86	11.48	10.93	5.72	9.57	5.96	3.87	2.33	3.37
LRI 18-May-99 (rep B)	5.70	19.87	9.97	8.47	14.83	10.19	8.98	4.25	6.23	3.96	2.86	0.29
LRI-reference	7.06	27.61	15.86	11.02	13.24	11.02	10.43	6.67	6.45	3.78	3.04	4.38
paper sludge	2.66	9.35	-0.29	1.91	7.44	5.83	6.78	5.96	4.29	0.44	-0.09	0.99
peppermint	4.20	58.28	27.39	16.21	31.72	25.01	24.02	15.47	9.09	8.93	6.34	5.08
SC 28-Apr-99 (rep B)	7.37	44.77	24.71	20.39	19.18	15.82	9.42	8.95	8.29	8.18	5.46	3.94
SC-frozen 28-Apr-99 (rep B)	4.69	27.96	13.31	9.70	12.89	10.54	10.21	8.16	6.89	4.66	3.34	1.25
SC 18-May-99 (rep B)	6.62	27.39	12.87	8.29	13.07	10.54	11.22	5.74	6.49	3.52	2.99	0.15
SC 22-July-99 (rep B)	12.69	62.94	30.78	15.51	23.63	14.94	9.59	10.14	6.75	8.80	6.20	5.96
SC 19-Aug-99 (rep B)	3.06	20.70	15.33	13.00	15.27	10.41	7.66	9.35	5.26	4.66	4.05	3.23
SC 5-Aug-99 (rep B)	2.88	42.13	35.09	21.58	24.90	14.41	8.54	10.19	5.61	4.44	3.43	1.87

Appendix 30. Average net CO_2-C evolved. CO_2-C quick test experiment number 3.

Treatment	Average Net CO_2-C Evolved (mg)											
	1d	3d	5d	7d	14d	21d	28d	34d	43d	52d	60d	68d
BF 30-Apr-99 (rep B)	3.74	13.09	6.40	1.96	11.53	6.78	3.74	2.51	7.61	3.32	0.81	0.09
BF-frozen 30-Apr-99 (rep B)	-1.28	14.28	0.99	0.55	6.16	4.53	5.81	4.00	4.14	3.19	4.20	-0.09
BF 19-May-99 (rep B)	4.00	14.59	8.95	5.87	13.33	7.30	6.51	4.18	2.55	3.41	4.55	-0.26
CG 28-Apr-99 (rep B)	-0.53	6.53	6.45	-2.35	7.04	5.02	5.98	4.22	5.90	3.63	2.27	-0.31
CG-frozen 28-Apr-99 (rep B)	0.26	8.78	2.35	4.60	6.51	8.18	5.68	7.35	3.12	0.95	4.07	-1.28
CG 18-May-99 (rep B)	5.24	13.18	6.53	2.66	7.26	6.78	4.49	3.96	5.54	2.57	3.23	-3.61
LRI 26-Apr-99 (rep B)	5.90	11.24	7.59	3.28	6.42	6.12	5.50	3.52	1.94	3.94	0.95	-0.35
LRI frozen 26-Apr-99 (rep B)	2.95	9.75	6.58	1.34	6.95	6.95	2.95	6.69	4.27	1.69	1.47	-0.04
LRI 18-May-99 (rep B)	3.30	15.42	7.33	4.95	10.30	6.20	6.20	1.36	4.53	1.78	2.00	-3.12
LRI-reference	4.66	23.17	13.22	7.50	8.71	7.04	7.66	3.78	4.75	1.61	2.18	0.97
paper sludge	0.26	4.91	-2.93	-1.61	2.90	1.85	4.00	3.08	2.60	-1.74	-0.95	-2.42
peppermint	1.80	53.83	24.75	12.69	27.19	21.03	21.25	12.58	7.39	6.75	5.48	1.67
SC 28-Apr-99 (rep B)	4.97	40.33	22.07	16.87	14.65	11.84	6.64	6.07	6.60	6.01	4.60	0.53
SC-frozen 28-Apr-99 (rep B)	2.29	23.52	10.67	6.18	8.36	6.56	7.44	5.28	5.19	2.49	2.49	-2.16
SC 18-May-99 (rep B)	4.22	22.95	10.23	4.77	8.54	6.56	8.45	2.86	4.80	1.34	2.13	-3.26
SC 22-July-99 (rep B)	10.30	58.50	28.14	11.99	19.10	10.96	6.82	7.26	5.06	6.62	5.35	2.55
SC 19-Aug-99 (rep B)	0.66	16.26	12.69	9.48	10.74	6.42	4.88	6.47	3.56	2.49	3.19	-0.18
SC 5-Aug-99 (rep B)	0.48	37.69	32.45	18.06	20.37	10.43	5.76	7.30	3.92	2.27	2.57	-1.54

Appendix 31. Standard deviation net CO_2-C evolved. CO_2-C quick test experiment 3.

Treatment	Standard Deviation--Net CO_2-C Evolved (mg)											
	1d	3d	5d	7d	14d	21d	28d	34d	43d	52d	60d	68d
BF 30-Apr-99 (rep B)	2.075	1.273	0.859	0.229	1.677	0.332	1.259	0.735	0.403	0.332	0.735	0.866
BF 30-Apr-99 frozen (rep B)	1.320	0.476	0.464	0.202	0.202	0.751	0.879	0.332	1.470	0.305	0.999	1.854
BF 19-May-99 (rep B)	0.824	2.138	1.300	0.651	0.349	0.275	1.080	0.899	0.792	0.807	2.485	1.138
CG 28-Apr-99 (rep B)	0.152	0.664	0.735	0.773	0.651	0.624	0.803	0.457	0.727	0.575	2.197	0.952
CG 28-Apr-99 frozen (rep B)	1.981	1.854	1.056	0.528	0.500	0.403	0.624	0.403	0.927	0.332	0.651	1.792
CG 19-May-99 (rep B)	0.275	1.153	0.202	0.275	1.470	0.500	1.183	0.698	1.099	1.048	0.533	0.349
LRI 26-Apr-99 (rep B)	0.838	0.952	1.702	0.349	0.403	0.664	0.999	0.677	0.859	3.847	1.522	0.664
LRI 26-Apr-99 frozen (rep B)	2.252	3.002	0.264	0.275	0.152	2.075	0.698	0.500	0.924	0.807	1.746	0.803
LRI 18-May-99 (rep B)	0.152	1.025	0.500	1.198	0.349	0.305	0.533	0.332	0.396	1.378	1.273	0.651
LRI-reference	2.244	1.887	0.202	2.062	1.056	0.076	0.991	0.927	1.183	0.773	0.796	0.332
paper sludge	0.973	0.349	0.349	0.698	1.340	0.275	0.575	0.773	0.533	1.067	0.076	1.848
peppermint	1.831	5.176	2.554	1.355	1.300	1.123	1.959	0.773	0.807	0.936	0.464	0.803
SC 28-Apr-99 (rep B)	0.152	3.577	0.849	0.132	0.866	1.731	1.815	1.273	1.348	1.080	0.332	0.999
SC 28-Apr-99 frozen (rep B)	1.391	0.575	0.349	0.132	0.751	0.686	0.457	2.313	1.300	0.533	0.500	1.649
SC 18-May-99 (rep B)	0.275	1.868	0.677	0.275	0.936	0.997	0.651	0.664	0.396	1.460	0.528	0.076
SC 22-July-99 (rep B)	1.448	1.716	0.773	0.575	1.797	1.302	0.773	0.229	0.735	0.807	2.021	2.574
SC 19-Aug-99 (rep B)	1.099	1.829	0.533	1.259	1.335	0.575	0.849	0.824	0.275	0.651	0.575	0.457
SC 5-Aug-99 (rep B)	0.076	2.967	0.264	0.349	1.448	1.067	1.650	0.275	0.595	0.879	1.650	1.424