Nitrogen Mineralization of Dairy Manure in a Calcareous Soil Under Field Conditions

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Presented in Partial Fulfillment of the Requirements for the
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Major in Soil Science and Land Resources
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by David Theodore Graybill

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Authorization to Submit Thesis

This thesis of David Theodore Graybill, submitted for the degree of Master of Science with a Major in Soil Science and Land Resources and titled "Nitrogen Mineralization of Dairy Manure in a Calcareous Soil Under Field Conditions," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

Understanding N transformations in fields receiving dairy manure applications is an important component of managing this nutrient source to maximize crop profitability and reduce environmental damage. The objective of this study was to determine the net N mineralization from field applied dairy cow manure to a Portneuf silt loam as affected by applications of varying rates, application intervals, and naturally fluctuating temperatures throughout the growing season. This study was conducted in a field located at the USDA Agricultural Research Service (ARS) Northwest Soil Research Laboratory (NWISRL) station in Kimberly, Idaho. Soil treatments included three manure rates (17.3, 34.7, 52.0 Mg ha^{-1}, dry basis applied at two recurrence intervals (annual or biennial fall applications). The field was sprinkler-irrigated under spring barley (*Hordeum vulgare L.)* in 2013 and sugar beets (*Beta vulgaris L.*) in 2014. We monitored net N mineralization in the 2013 and 2014 growing seasons using the buried bag technique (amended soils were placed in polyethylene tube shaped bags and incubated in the field). Soil-filled incubation bags were destructively sampled monthly or biweekly from March to October and analyzed for nitrate and ammonium. Predictive models were fit based on the analyses results. Crop N uptake was determined from end of season plant tissue analyses. Crop N uptake correlated well with N mineralization monitored in the buried bags yielding a linear regression r-square of 0.74. Manure that was fall-applied in 2012 resulted in significant increases in preplant soil inorganic N concentrations in 2013. In addition, manure treatments that either did or did not receive additional fall-applied manure in 2013 resulted in significant increases in preplant soil inorganic N concentrations in 2014.The zero-order linear model was selected for estimating N mineralization rate (k), N mineralization amount, the y-intercept, and data variability (r-square) over the growing seasons of 2013 and 2014 separately. The linear N mineralization rate showed a consistent increase in the release of N from April to September at one and two years after application as well as after two years of repeated fall applications. Increasing manure application rates also resulted in a linear increase in net N mineralization rates (k values) one and two years after a fall application, as well as after two years of repeated fall applications at the 0-30 cm soil depth.

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Chapter 1 – Introduction

Background

Idaho had a standing herd of 587,000 lactating dairy cows in 2015 (NASS, 2015). Daily excretion rate for a lactating cow is approximately 75.2 kg day^{-1} animal^{-1} manure (feces and urine, wet weight) and 0.491 kg day^{-1} total nitrogen (N) (Nennich, et al., 2005). This results in an estimated 44,000 Mg of manure and 288 Mg total N that is produced daily in Idaho. Considering a potential 80% efficiency of collecting and removing this manure from the dairy farm (USDA, 1994), 230 Mg N day^{-1} could be recovered and managed. Calculated from 2014 market value of urea at \$484 Mg^{-1} (Patterson and Painter, 2014), this total N is valued at \$1,039 Mg^{-1}. As a result, the N fertilizer contained in this dairy livestock byproduct is estimated to be valued at \$87 million year^{-1}. Applying dairy manure to fields, to supplement commercial fertilizer applications, could be a valuable technique to lower fertilizer inputs, while maintaining crop yields and quality. Developing this technique will contribute to keeping southern Idaho crop producers profitable and competitive into the future.

Barley and sugar beet sensitivity to nitrogen release

Idaho crop producers interested in using dairy manure as a N source are often unsure of the quantity to apply, how often to apply, and when to apply manure in specific crop rotations. These questions are important, considering the conversion of organic N to inorganic N from manure, throughout the growing season and the effect this labile N pool can have on specific crop response, (i.e., yield and quality) as well as overall profitability.

Spring barley grain yield and quality are influenced by plant available N (PAN) (Mohammed et al., 2013). Applying excess PAN to barley may produce lodging, a result of more fine-stemmed tillers, increased plant height, increased grain, and reduced stem strength (Robertson et al. 1993). Specifications for malting barley vary somewhat between maltsters, depending on end use, but typically malting barley protein levels must fall between 12 and 14%. Increasing levels or mistimed availability of PAN can result in barley protein content above this range; conversely, too little PAN can result in barley protein content below this range. Understanding the amount and timing of PAN released from dairy manure is critical to increase N-use efficacy, which in turn, will foster greater crop producer confidence in the practice of recycling manure nutrients. Sugar beet profits are primarily dependent on three production parameters; beet yield, sucrose content, and sucrose extraction efficiency. Successful N management is critical to optimize these parameters (Moore et al. 2009). Sugar beets are sensitive to under and over-applications of N. Applying too little N results in decreased root yields; while applying too much N results in decreased root quality and reduces sucrose extraction efficiency (Tarkalson. 2012). Timing is also an important factor in proper N management. Avoiding excessive release of late season (mid-July to September) PAN is important to reduce brie nitrates, salts, and other impurities in the beet. These impurities reduce the amount of sugar produced and also increase the sugar extraction costs (Moore et al. 2009).

Using dairy manure as a source of essential crop nutrients could provide considerable benefits to crop producers, dairy operators, and surrounding communities. Crop producers save money on fertilizers by supplementing traditional fertilizer inputs with dairy manure. Dairy producers are able to turn their stockpiled cattle waste into a commodity or, at minimum, lower waste management costs by cooperating with crop producers to dispose of the waste. Surrounding communities would benefit from increased surface and ground water quality by dispersing constituents in manure, which can pollute their water resources.

Environmental and human health

The Idaho Department of Environmental Quality (IDEQ) reports that the primary sources for nitrate contamination in Idaho are N fertilizer, septic systems and livestock operations (IDEQ, 2016). The IDEQ, the Idaho Department of Water Resources (IDWR), and the Idaho State Department of Agriculture (ISDA) have designated 34 nitrate priority areas in Idaho as of 2014. These areas are characterized by more than 25% of wells having at or above 5 mg nitrate L^{-1}, which is one-half the drinking water standard of 10 mg nitrate L^{-1} (IDEQ, 2014).

Out of the 34 nitrate priority areas, 21 are located wholly or partially in 13 primary dairy-producing counties, characterized as having more than 2,000 milking cows (IDEQ, 2014; USDA, 2012). These 13 counties include: Gooding, Jerome, Twin Falls, Cassia, Minidoka, Elmore, Owyhee, Ada, Canyon, Payette, Gem, Bingham, and Jefferson. These 13 counties contain 85% of Idaho's total dairy cattle count in 2012; as well as 47% of Idaho's beef cattle count totaling 229,731 in 2012 (IDEQ, 2014; USDA, 2012). These 13 counties also contain 51% of the over 6 million acres of industrial farmland in Idaho that regularly receives N-fertilizers (USDA, 2012). Based on a 1990 census report adjusted by county for population growth from 1990 to 2015, it is estimated that these 13 counties also contain 49% of Idaho's on site waste water systems, totaling 115,000 septic systems (Idaho, 2015; Burnell and Thomas, 1990). Due to the occurrence of dairy and beef operations, industrial farming, and septic systems near nitrate priority areas, the use and development of best management practices is important to protect human health and the environment.

Nitrogenous pollution of surface and groundwater resources is a health concern for residents that live in or near Idaho nitrate priority areas and depend on their water resources for consumptive uses. Methemoglobinemia, commonly referred to as blue baby syndrome, results from nitrate being converted to nitrite. Nitrite interacts with hemoglobin in the blood resulting in methoglobin (MHb), which results in decreased oxygen availability to cells. Other nitrate toxicities include increased respiratory infections, inhibition of iodine uptake by the thyroid, and potential negative effects on reproductive health (Follet and Follet, 2008).

Nitrate entering surface water resources is also an environmental concern due to associated damage to aquatic ecosystems. When nutrient concentrations are high, a water body is considered eutrophic. Eutrophication can result in deleterious effects on aquatic ecosystem health. If excessive amounts of nitrate are present in water, plants and macrophytes become over-abundant. This results in an increase in organic matter deposition on the floor of the water body. As microbes decompose the organic matter oxygen is consumed, which can result in an anoxic state of the water. This anoxic state decreases the success of plant and animal life that need oxygen to survive, which results in negative changes to native plant and animal communities (Hoagland and Franti, 2008; Harper, 1992).

Nitrogen mineralization

Over 90% of N in stockpiled dairy manure is in the form of organic N compounds (Pettygrove et al., 2010). Organic N contained in dairy manure can be separated into three fractions; which are microbial N from the gut of the cattle, N excreted from intestinal walls, and structural N contained in plant cell walls that have passed through the cattle (Chadwick et al., 2000). Mineralization of these organic N forms is required before N is available for plant uptake; monitoring this process is of primary importance in the present study. Organic N mineralizes to nitrate and ammonium in soil (Norton and Schimel, 2012). In agricultural systems, understanding N transformations is important if maximum use of manure N is to be achieved.

The initial step of manure N mineralization is aminization, where N containing compounds are broken down by heterotrophic microorganisms and fungi through enzymatic processes, producing amines and amino acids (Semoka, 2008). These amines, amino acids and other N containing compounds are further transformed through the process of ammonification by microorganisms.

Ammonification is carried out by many diverse groups occurring in very large numbers of both aerobic and anaerobic heterotrophic soil microorganisms. Ammonification usually occurs by direct removal of the free amino group or ammonia is released following soil organism cell death. Protons from soil water bind to ammonia resulting in ammonium (Myrold and Bottomley, 2008). The ammonium molecule can be consumed by plants and soil organisms, thus entering amino acid biosynthesis resulting in immobilization of the molecule. In our research, monitoring the net production of ammonium is an important component of understanding nitrogen transformations from dairy manure. In addition to consumption by plants and soil organisms, ammonium can also be transformed to nitrate through the process of nitrification (Albino and Andrade, 2006).

Nitrification is the oxidation of reduced forms of N of ammonia and ammonium to nitrite and nitrate (Prosser, 2007). In most agricultural soils, ammonium is rapidly converted to nitrate, which generally results in increased accumulations of nitrate relative to ammonium. Aerobic chemolitho-autotrophic bacteria are considered the primary drivers of nitrification. These autotrophic soil-dwelling bacteria occur in smaller less diverse groups than their heterotrophic counterparts and require oxygen to transform N-containing compounds. These bacteria gain energy from the oxidation of N and fix inorganic C in the form of carbon dioxide (Norton, 2008). There are two steps in autotrophic nitrification: first, ammonia-oxidizing bacteria such as *Nitrosomonas* or *Nitrosopira* transform ammonia or ammonium to nitrite; second, nitrite-oxidizing bacteria such as *Nitrobacter* or *Nitrospira* transform nitrite to nitrate (Norton, 2008). Among other fates, nitrate can then be utilized by plants and soil organisms (Prosser, 2007). Monitoring the net production of nitrate, in addition to ammonium, is important in developing models that predict concentration and release timing of plant available forms of N for Idaho manure amended croplands.

Monitoring nitrogen mineralization under laboratory conditions

Numerous researchers have conducted laboratory incubation studies to determine the rate of N mineralization in different agricultural soils that received organic amendment applications (Zhengxia et al., 1996; Chae and Tabatabai, 1986; Honeycutt et al., 2005a; Van Kessel and Reeves, 2002). Nitrogen mineralization laboratory incubations consist of taking a soil that is amended with an organic material and placed in a constant temperature in an incubator for a predetermined amount of time. The soil samples are removed at a given time or multiple times and analyzed for ammonium and/or nitrate production. This method provides ideal conditions for soil organisms to act on nitrogenous materials mineralizing organic N into inorganic forms. The primary utility of this method is that temperature, soil moisture, N leaching, plant uptake of N, or any other processes that remove N from the system are controlled.

Lab incubations have been utilized by numerous researchers to study N mineralization of cattle manure applied to a soil (Morvan et al., 2006; Eneji et al., 2002; Van Kessel et al., 2002 and 2000; Douglas and Magdoff, 1991; Chae and Tabatabai, 1986; Castellanos and Pratt, 1981). Several studies have determined that the laboratory incubation technique can overestimate the rate of N mineralization that actually occurs under field conditions (Sistani et al., 2008; Honeycutt, 1999; Cabrera and Kissel, 1988; Adams and Attiwill, 1986;). The over-estimation of PAN from these studies is likely a result of using a single incubation temperature of 22-25 °C (Van Kessel and Reeves, 2002; Gale et al., 2006; Honeycutt et al., 2005), which is considered ideal for N mineralization and other microbial driven processes in soil. As a result, in-situ incubation techniques have been shown to provide more accurate N mineralization rate measurements, due to fluctuating soil temperature and conditions influenced by crop production management strategies (Stenger et al., 1996; Hanselman et al., 2004).

The three most frequently used field techniques to monitor N mineralization are the buried bag method (Eno, 1960), the covered cylinder method (Subler et al., 1995), and the resin trap method (Khanna and Raison, 2013; DiStefano and Gholz, 1986). There are benefits and limitations to each of these in-situ techniques. The covered cylinder method includes PVC or metal pipes sealed on the top with a cap. The covered cylinder is open to the soil on the bottom to allow gas exchange and some water diffusion between the encased soil and the surrounding field soil. Some researchers cut holes in the sides of the tubes to allow increased gas exchange (Dou et al., 1997). Subler et al., (1995) found limitations in the covered cylinder method in that mineral N could be lost through the cut holes or out of the bottom of the cylinder by diffusion and mass flow. Plant roots are also able to remove mineral N by growing into the covered cyclinder. The resin trap method has the advantage that the containment artifact is an open tube that is subject to water infiltration, leaching processes, and gas exchange between the incubated soil and the surrounding field soil. The primary limitation of the ion exchange resin method is that nitrates can be lost to the field through ion competition, resin saturation, and bypass flow of cylinder leachate (Schnabel, 1983, 1995; Schnabel et al., 1993; Wyland and Jackson, 1993; Kjonaas, 1999a, 1999b).

Monitoring nitrogen mineralization under field conditions with the buried bag technique

The buried bag technique was developed in 1960 (Eno, 1960) and applied in two studies (Westermann and Crothers, 1980; Smith et al., 1976). In both studies, the researchers concluded that the buried bag method was appropriate to estimate mineralizable soil N under their specific conditions. The primary utility of the buried bag method is that mineralized N from soil inside the low density polyethylene bags is not susceptible to being removed during the field incubation period, due to the N remaining contained within the bags. In southern Idaho agriculture soils, nitrate is lost from the system through nitrate leaching and plant N uptake. The polyethylene bags act as a barrier, thus holding the soil, nitrate and ammonium and water in place at a bag thickness of 0.10 mm. In addition, a film thickness of 0.10 mm results in an adequate barrier, inhibiting plant roots from penetrating the bags to access nutrients (Lehrsch, 2016). The bags act effectively as small incubation chambers, providing an adequate estimation of N that has mineralized over the incubation period (Lentz et al., 2014; Lentz and Lehrsch, 2012; Lentz and Lehrsch, 2011; Meek et al., 1994; Westermann and Crothers, 1993).

There are concerns that N mineralization rates in the polyethylene bags would not reflect those in the field due to an eventual lack of oxygen and elevated carbon dioxide (Hanselman et al., 2004; Subler et al., 1995). However, a southern Idaho study that compared in-situ nitrate concentrations in the buried bags with nitrate concentrations in nearby irrigated fallow soils determined that the buried bag method provided similar results. An r-square of 0.95 was calculated when nitrate concentrations from soils within the buried bags were regressed with nitrate concentrations of the fallow soils (Westermann and Crothers, 1980). In a study where Portneuf silt loam soils were amended with dairy manure and nitrogen mineralization was monitored with buried bags with the same 0.10 mm bag thickness, the authors concluded that oxygen can diffuse from the bulk soil into the encased soil within the bags, and that carbon dioxide can diffuse out of the bags (Lehrsch, et al., 2016).

There have been concerns that the activity of soil microorganisms that reduce nitrate and/or ammonium pools through the processes of immobilization (Binkley and Hart, 1989) and denitrification (Raison, 1987) could be accelerated relative to the surrounding field soil, due to a feedback response caused by nitrate and ammonium accumulation in the soils. Although immobilization and denitrification were not monitored in this study, their rates are assumed to be similar to those of the surrounding field soil.

In a N transformation study using ^{15}N isotopes in three different forest soils to compare the ion exchange method, which is open to leaching processes, and the buried bag method, which is closed to leaching processes, the authors concluded that the potential difference in immobilization rates between the methods was insignificant. The authors showed that net N mineralization was near three quarters of gross N mineralization across sites and methods (Binkley, 1992). These results indicate that immobilization is not accelerated in the bag-encased soils buried in the field.

Factors that control denitrification rates in soil include: oxygen, water content, availability of organic carbon, pH, temperature, inhibitory substances, and nitrate concentrations (Knowles,1981). The dominating environmental factor that facilitates denitrification in soil is anoxia caused by high water content and the resulting inhibition of gas exchange (Coyne, 2008). Aeration driven denitrification is well correlated with the water filled pore space (WFPS) of a soil across soil textures (Aulakh, 1991). In general, a WFPS above 60% denitrification increases linearly with increasing soil water, though denitrification rates remain low relative to those at or above a WFPS of 80% where denitrification conditions become dominant (Linn and Doran 1984).

Some researchers have found that high nitrate concentrations result in increased nitrate diffusion to anaerobic microsites, resulting in increased denitrification (Burford and Greenland, 1970). Although, this correlation has primarily been shown in soils that are water logged. When Cameron et al., (1978) applied ammonium nitrate fertilizer at rates of 0 (control), 80, and 255 kg N ha^{-1} to a Bainsville clay loam soil with a 33% WFPS, denitrification rates in fertilized soils did not exceed those in control soils. In this case, control soils contained more than 10 mg nitrate kg^{-1}, which is thought to be at or above the rate limiting concentration for denitrification to occur (Cameron et al., 1978). Similar results were reported after potassium nitrate treatments equivalent to 0 (control), 50 and 100 kg N ha^{-1} to Hord silt loam and Yolo silt loam at a WFPS of 60%. The results showed that the percent reduction in the nitrate pool due to denitrification remained below 6.3% in the Hord silt loam and below 0.9% in the Yolo silt loam (Weier, 1993). Other researchers using the buried bag technique to study dairy manure N mineralization in a adequately aerated Portneuf silt loam soil (Lentz et al., 2011) and a Greenleaf silt loam (Lehrsch et al., 2016) have concluded that soils within the buried bags contain adequate aeration to prevent appreciable rates of denitrification. Consequently, the authors concluded that immobilization is likely the dominant microbial process that reduces the inorganic N pool in soils encased in buried bags.

A number of researchers employed the buried bag method to derive satisfactory estimates of field net N mineralized in irrigated, organics-amended Portneuf silt loam soils of southern Idaho (Lehrsch et al., 2016; Lentz et al., 2014; Lentz and Lehrsch, 2012; Lentz and Lehrsch, 2011; Meek et al., 1994). Data from new N mineralization studies that employed the buried-bags would be directly comparable with that of these past studies, potentially expanding the scope and application of the new data.

Nitrogen mineralization as affected by constant moisture

The effects of soil moisture on N mineralization have been investigated extensively (Goncalves and Carlyle, 1994; Stanford and Epstein, 1974; Quemada and Cabrera, 1997; Sierra, 1997: Campbell et al., 1974). Soil moisture influences nitrogen mineralization by altering physical, chemical and biological processes: 1) nutrient diffusion and mass flow; 2) movement and availability of dissolved gasses, and heat; 3) locomotion of bacteria and their predators; and 4) soil pH and redox potential. Factors 1-4 all influence microbial activity, and in turn, net N mineralization (Standing and Killham, 2007; Campbell, 1978).

Due to irrigation and precipitation events, the moisture content of manured agricultural soils fluctuates throughout the growing season. Conversely, soils encased within the polyethylene bags maintain constant moisture. Wetting and drying can stimulate N mineralization in soils, a phenomenon known as the “Birch effect” (Birch, 1958). Studies investigating the Birch effect have shown that N mineralization rates in soils with fluctuating water content exceed those of soils with constant moisture content, but only for a few days (Jarvis et al., 2007; Saetre and Stark, 2005; Birch, 1958). In addition, the Birch effect involves soils that are dry due to prolonged drought conditions. Scenarios where polyethylene soil filled bags are buried in irrigated and cropped field soils do not ordinarily undergo prolonged drought conditions. Numerous laboratory and field studies have assessed the effect of soil drying and wetting on N mineralization rates and other involved mechanisms. Griffin et. al., (2002) found that differences in water status had no significant impact on manure N mineralization in liquid dairy manure amended soils subject to either constant (30%) or fluctuating (30-60%) WFPS. Similarly, in a N mineralization study of broiler litter, the researchers showed no significant difference in mineralization rates between a constant WFPS of 60% and WFPS fluctuating from 30-60% (Sistani et al., 2008).

The effect of constant soil moisture conditions on N mineralization processes does not differ significantly from fluctuating soil moisture conditions as long as there is adequate soil water content for microbial activities. Therefore, it is reasonable to conclude that soils encased in polyethylene films can provide N mineralization estimates, which reflect those of field soils when soil water content is not limiting N mineralization.

Nitrogen mineralization as affected by dairy manure composition

A wide variety of organic amendments may be applied to the soil to supply N to crops. These amendments include crop residues, municipal yard wastes, biosolids, wastes from dairy, vegetable, fish, meat and poultry processing industries, plant and animal derived composts, and animal manures. Decomposition of these N-containing soil amendments is determined by the interaction between amendments, soil organisms, and abiotic conditions. The type of amendment is an important determinant in the rate of N mineralization required for nearly complete mineralization of organic N compounds. These rates can range from weeks as found with soils receiving broiler litter (Gordillo and Cabrera, 1997), to years as found with soils receiving dairy cattle manure (Lentz and Lehrsch, 2012). This variability in decomposition rate is largely due to the amount of C and N contained within the amendment and the amendment's inherent resistance to decomposition.

There are numerous approaches to mechanistically parameterize an organic materials inherent resistance to decomposition in soil. These mechanistic approaches include an accounting of the number of steps required by a soil organism or enzyme to release one carbon atom from an organic material (Bosatta and Agren, 1999), amount of energy contained in a material's chemical bonds that can be liberated upon oxidation and combustion (Talbot et al., 2008), oxidation state of the organic material (Hockaday et al., 2009), and size of a molecule relative to a microbial cell or an extracellular enzyme (Alexander, 1981). Operationally, an organic material's inherent resistance to decomposition can be parameterized by the residence time in soil required for the products of decomposition, such as inorganic N, to appear. This definition defines recalcitrant as well as labile manure N fractions in this study.

Organic amendments vary in their degree of heterogeneity, resulting in various fractions within a material, with each fraction possessing a unique inherent resistance to decomposition. There are two typical operational methods to investigate the effects of dairy manure properties on N mineralization in a soil, investigation of whole manures or of single dairy manure components (Van Kessel et al., 2000). Several studies have sought to determine a dairy manure decay series; an approach illustrating the fraction of applied N that mineralizes during the first, second, and subsequent years after application. For example, a decay series of 0.20-0.15-0.10 of a manure N application of 1000 kg N ha^{-1} would result in a first, second, and third year mineral N of 200, 150, and 100 kg N ha^{-1} inorganic N, respectively. Some of the decay series of fresh whole dairy cattle manure include 0.75-0.15-0.10-0.05 (Pratt et al. 1973), 0.50-0.15-0.05 (Willrich et al., 1974), 0.21-0.09-0.03-0.03 (Klausner et al., 1994), and 0.23-0.12-0.10-0.09-0.08 (Lentz and Lehrsch, 2012). To reduce N mineralization variability between sites and better understand the labile and recalcitrant manure N pools, Klausner et al., (1994) determined the decay series for the recalcitrant pool separately. The researchers did this by promoting ammonia volatilization under anaerobic soil conditions. The study determined a recalcitrant manure N decay series of 0.16-0.10-0.03-0.02. Understanding the interaction between dairy manure composition and the time N mineralization occurs is an important part of safe and efficient management of this nutrient resource.

Table 1-1 Past research results of dairy cattle manure decay series illustrating the percent of applied N that mineralizes during the first, second, and subsequent years after application.

	Pratt et al., 1973	Willrich et al., 1974	Klausner et al., 1994	Lentz and Lehrsch, 2012
Year 1	0.75	0.50	0.21	0.23
Year 2	0.15	0.15	0.09	0.12
Year 3	0.10	0.05	0.03	0.10
Year 4	0.05	----	0.03	0.08
Year 5	----	----	----	0.08

Stockpiled dairy manure is comprised of urine, feces, and straw bedding, as well as materials and liquids removed from stalls and stockpiled with the dairy manure. The dominant form of N in dairy cattle urine is urea. Nitrogen contained within feces includes undigested or indigestible feedstuffs, microbial matter from ruminal and hindgut fermentation, and sloughed intestinal cells (Van Der Meer et al., 1987). Undigested feedstuff typically include fibrous materials that originated from lignocellolosic structural components. These fibrous materials are relatively resistant to decomposition. The easily digested fiber from forage is broken down by fibrolytic enzymes in the animal’s digestive system (Liao et al., 2004). As a result, the fibers that pass through the digestive system are complex and resistant to degradation.

These lignocellulosic structural components have been defined and quantified in a number of ways, neutral detergent fibers (NDF)(Honeycutt and Griffin, 2005b; Goering and Van Soest, 1970), acid detergent fibers (ADF) (Van Soest, 1963), cellulose and hemicellulose (Liao et al., 2004; Van Kessel et al., 2002), lignin (Van Kessel and Reeves, 2002) and crude fiber (Kyvsgaard et al., 2000). Researchers interested in finding a predictive correlation between dairy manure components and N transformations in soil asses both single components (i.e., ADF , lignin) and ratios of components (i.e., total N:hemicellulose, total

C:total N). These approaches have resulted in some useful conclusions, though reasonably accurate N mineralization predictions based on dairy manure composition alone are lacking.

The C to N (C:N) ratio in an organic amendment is often used as an indicator in predicting the net outcome of the mineralization-immobilization cycle after the amendment is applied to soil. Soil dwelling microorganisms typically have a C:N ratio that ranges from 4:1 to 9:1. The C:N ratio of manures and plant materials is much more variable, ranging from 10:1 to 100:1 (Brady, 1990). In general, soil organisms that decompose organic matter require a C:N near 8:1 to build and maintain cellular components.

When the available substrate has a C:N ratio that falls below this threshold, soil organisms obtain N from other sources, resulting in immobilization of N. Under these conditions, microorganism reproduction leads to a rapid consumption of available N (immobilization) and organic decomposition is inhibited. Gale et al., (2006) studied N mineralization rates from manure and plant residues with C:N ratios ranging from 4:1 to 32:1 under a mesic temperature regime (like that of Portneuf silt loam in the present study). The organic materials generated negative net N mineralization (immobilization) when their C:N ratios exceeded 15:1, and positive N mineralization at amendment C:N ratios below 15:1 (Gale et al., 2006). In an aerobic incubation study, applying nine different dairy manures to soils with C:N ratios from 6:1 to 32:1 were found to have a correlation coefficient of 0.86 with nitrate concentrations at day 176 of the incubation (Honeycutt and Griffin, 2005b). Van Kessel et al., (2000) showed that there was a positive linear relationship between positive N mineralization and C:N ratio decreasing below 41:1. The C:N ratio of an organic amendment can give a general indication of its N mineralization potential in a soil, though it is not without limitations.

Van Kessel and Reeves (2002) conducted a 56 day incubation study of 107 different dairy manures, finding that the percent N mineralized from materials averaged 12%, but was highly variable, ranging between -29.2% and 55% (figure 1-2). The researchers found a correlation coefficient of 0.35 between the C:N ratio and N mineralization and concluded that the N mineralization variability could not be predicted by the C:N ratio of the dairy manure. In a study where soil received various manures including those from laying hens, beef cattle, dairy cattle, swine, and broiler litter that no significant correlation was found between the fraction of organic N mineralized and the C:N ratio of manure (Eghball et al., 2002). The authors concluded that the chemical composition of fecal components containing nitrogen and/or carbon in a manure is more critical than C:N ratio (Eghball et al., 2002).

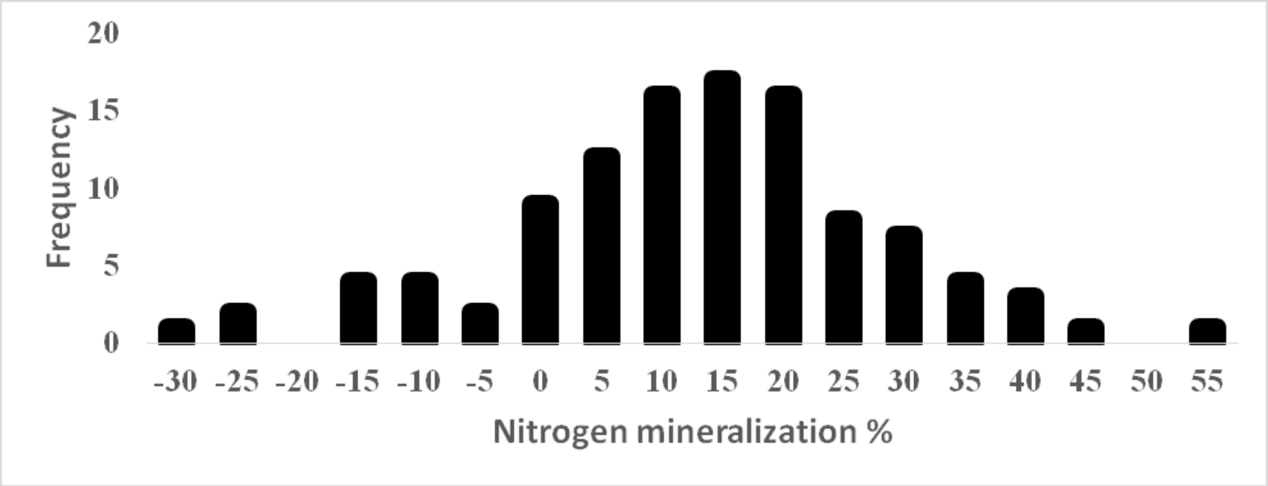

Figure 1-1 Histogram of the percentage of mineralized organic N from 107 dairy manures collected from different sources. Each bar is the mean mineralized organic N data used in an 8 week aerobic incubation study. Adapted from Van Kessel and Reeves, 2002.

Researchers have found the N mineralization of organic materials are correlated with their lignocellulosic content, e.g. hemicellulose content of leguminous tree leaves (Lupwayi and Haque, 1998), lignin content of hardwood tree leaf litter (Melillo et al., 1982), and lignin content of maize, barley straw, and blue grass (Mueller et al., 1998). These components also occur in the feedstuffs consumed and in turn excreted by dairy cattle, and therefore contribute to the properties of dairy cattle manure.

Due to the difficulty of separating manure components without altering the composition of those components, some researchers have used other materials as a proxy for individual manure components. These other materials have similar chemical composition as dairy manure components. Van Kessel et al., (2000) showed that manure components did have a significant influence on N mineralization. The components investigated were those from feedstuffs (immature and mature forages, protein supplements, acid detergent fiber and neutral detergent fiber) and animal metabolism (simple N compounds, ruminal bacteria and colonic cells). The results of their research showed that some components such as urea, simple peptides, amino acids, protein supplements, ruminal bacteria, and colonic cells were readily available for N mineralization. More complex components such as immature and mature forages were intermediate slow release sources of N. Manure components that were low in N and high in C such as the acid and neutral detergent fibers were strong immobilizers of N.

Ratios of different plant components have also been found to influence N mineralization rates and include: hemicellulose:total N of leguminous tree leaves (Lupwayi and Haque, 1997) and lignin:total N of maize, barley straw and blue grass (Mueller et al., 1998). Similarly, Griffin et al., (2005) determined that ratios of dairy manure components influence N mineralization. These ratios include total carbon:extractable ammonium, NDF:total N, NDF:organic N, and NDF:extractable ammonium. These findings contrasted with those of Van Kessel and Reeves (2002) who reported that, among 107 different dairy manures collected from five states with a wide range of dairy production practices, no simple relationships between N mineralization rates and manure components were found, including, lignin, hemicellulose, cellulose, ADF and NDF (Figure 1-2). The authors concluded that due to the variability in N mineralization rates between regionally unique dairy manures, that N mineralization potential should be assessed for each dairy manure representative of a particular region's dairy management practices.

Thus dairy cattle manure composition is variable on both regional and macroscopic scales due to different management practices and different mineralization potential of individual manure components. These components include labile materials such as urea, simple peptides and amino acids, protein supplements, and ruminal bacteria to a range of recalcitrant lignocellulosic materials. Although the interactions are not completely understood, there is evidence that the fibrous carbon fraction of dairy manure can result in immobilization and/or a decrease in the mineralization rate of manure N. This recalcitrant fraction of dairy manure facilitates the slow release of manure N over the course of years. It is hypothesized that the hemicellulose, cellulose, and lignin content of a mineralizable substrate influences mineralization immobilization turnover due to feedback controls on microbial activities (Moorhead and Sinsabaugh, 2006) and physical protection of N compounds as a result of N complexing with the fibrous materials (Cheever et al., 2013; Zaccheo et al., 2002; Sorensen, 1962). Understanding when southern Idaho amendments release mineral N is an important part of safe and efficient management of this plant nutrient resource.

Nitrogen mineralization as effected by temperature

Soil's physical, chemical, and biological properties interact uniquely with soil temperature and in turn N mineralization. In addition, the properties of the N-containing substrate also interact with soil temperature to drive N mineralization. Regionally relevant studies conducted under field conditions are necessary to accurately predict N mineralization from organic additions.

Temperature affects metabolic rates of organisms (Oertli, 2008). This effect is primarily due to the dependence of chemical and enzymatic reactions on temperature (Davidson and Janssens, 2006). Frasier et al., (2013) found that heat catalyzes the degradation rate of proteins, polypeptides, and urea due to increased enzyme activity associated with rising temperatures.

In an incubation study evaluating soils amended with dairy, poultry, and swine manures at different temperatures, the researchers found that a 10-24 °C temperature increase produced a 50-70 mg kg^{-1} in net nitrate concentration (Griffin and Honeycutt, 2000). Researchers amending soils with alfalfa pellets, blood meal, and chicken manure showed that increasing temperature from 10 to 20 °C significantly increased net N mineralized by 25, 10, and 13%, respectively. In addition, the study showed that N mineralization rates from soil organic matter increased three fold for every 10 °C increase in temperature (Agehara, and Warncke, 2005).

As temperature increases, the microbial community dynamics within the soil also change (Richards et al. 1985; Carreiro and Koske, 1992). Other researchers found that as microbial community composition changed with temperatures between 5 and 25 °C that respiration also changed proportionally. The study showed that the increase in net mineralized N at high temperatures reflected microbial communities succeeding by metabolizing substrates that were not consumed at lower temperatures (Zogg at al, 1997). Temperature effects on soil microorganism community dynamics and in turn N mineralization have been found to be dependent on a multitude of factors.

The effect of temperature on N mineralization has been found to be influenced by the temperature regime of a soil, due to microorganism's physiological adaptations to varying habitats (Ellert and Bettany, 1992; Grundmann et al., 1995). Soils that originate from colder climates were reported to exhibit a greater N mineralization response to temperature than soils from warmer climates. This finding was attributed in part to physiological adaptations of microbial communities to their habitat conditions (Dessureault-Rompre, 2010). In-situ N mineralization studies conducted in warmer climates may not be applicable to the cool climate of southern Idaho, thus warranting regionally specific N mineralization investigations.

The effect of temperature on N mineralization is influenced by the relative complexity of various N-containing substrate fractions. Temperature sensitivity increases with increasing complexity of soil organic matter. Stabilized substrates have higher activation energies, and hence are less reactive in cooler soils. In other words, the recalcitrant N pool is more temperature sensitive then the labile N pool (Lutzow and Kogel-Knabner, 2009). Agehara and Warncke (2005) amended soils with alfalfa pellets, blood meal, and chicken manure at varying temperatures and determined that soil temperature influenced N availability from organic N materials differently depending on the source of N. Alfalfa pellets relative to the other amendments are more recalcitrant and the percent of N mineralized out of the total N applied was found to be similar to that of chicken manure and blood meal at 10 °C. Conversely, at 25 °C alfalfa meal was found to mineralize a significantly higher percent of the total N applied than that of chicken manure and blood meal. This suggests that this stable N source is more temperature sensitive than the relatively labile amendments. Since dairy manure contains a relatively large fraction of recalcitrant components, monitoring N mineralization rates under field conditions may be necessary to fully understand in-situ temperature effects on N availability.

The effect of temperature on N mineralization is influenced by the texture of the soil. In N mineralization studies from soil organic matter, a Q_{10} of 2.12 was determined for fine-textured soils (Campbell et al., 1984), while a Q_{10} of 2.85 was determined for silt textured soils (Dessureault- Rompre et al., 2010). Nitrogen mineralization in fine textured soils has less of a temperature response than in coarser sandy soils (Campbell et al., 1981; Dessureault-Rompre et al., 2010). In addition, the quantity and type of clay mineral in a soil affects N mineralization (Fortuna et al., 2012).

Soil temperature also influences net N mineralization via an interaction with soil matric potential and by affecting the diffusion of soluble substrates. These factors in turn influence the activity of soil microorganisms. Zak et al., (1999) reported that net N mineralization declined as soil matric potential decreased from -0.01 to -0.30 MPa, and the rate of decline was greatest at 25 °C. When soil temperatures decreased incrementally below 25 °C, researchers also observed an incremental decline in the slope of the net N mineralization by a matric potential interaction response (Zak et al., 1999). Similarly Cassman and Munns, (1980) reported that net N mineralization declined between -0.01 and -0.20 MPa. In addition, the authors reported a significant interaction between matric potential and soil temperature, in which the decline in the net N mineralization rate in soils with matric potential ranging from -0.01 to -0.20 MPa was greatest at the warmer soil temperature of 30 °C relative to soil temperatures of 15, 20, and 25 °C. Nicolardot et al., (1994) also found that as soil temperature increases from 4 to 28 °C, diffusion of soluble substrates also increases.

Temperature influence on N mineralization is unique for a given soil due to the soils physical, chemical, and biological properties. All of these relationships result in variable N mineralization rates. For this reason, monitoring N mineralization in a regionally relevant soil under field conditions is critical to adequately predict inorganic N release from dairy manure in southern Idaho.

Nitrogen mineralization as effected by quantity of dairy manure

Understanding how dairy manure application rates influence N mineralization is important for efficient management of this nutrient resource. Applying dairy manure N at rates that do not exceed the quantity that plants can use will minimize offsite transport of manure N. Determining if the rate of N mineralization corresponding with changes in dairy manure application rates is a principal interest of this study. Studies have evaluated net N mineralization from one time dairy manure additions to a Portneuf silt loam in southern Idaho. Lentz and Lehrsch, (2012) found that after two dairy manure application rates of 21.7 and 68.9 Mg (dry wt.) resulted in average inorganic N estimated for the time period between spring and fall to be 26.1 mg N kg^{-1} (low rate) and 51.1 mg N kg^{-1} (high rate). Other researchers fall applied dairy manure at two rates of 21.9 and 43.8 Mg (dry wt.) to Greenleaf silt loam and found that inorganic N measured at the end of the growing season for the lower manure quantity was 13 mg kg^{-1} and 20.4 mg kg^{-1} for the larger manure quantity. This study was repeated the following year, though researchers applied 22.8 and 45.6 Mg ha^{-1} dairy manure (dry wt.) and found inorganic N concentrations of 20 mg N kg^{-1} for the lower quantity and 29.4 mg N kg^{-1} for the higher quantity (Lehrsch et al., 2016).

In another study conducted in a southern Idaho Portneuf silt loam soil, Lentz et al., (2011) fall applied dairy manure in 2002 at 23.3 and 45.7 Mg ha^{-1} (dry wt.) with a manure N content of 433 and 850 kg ha^{-1}, respectively. Net N mineralization rates followed a general trend that started off low to moderate during winter through spring, decreased in early summer due to immobilization, then increased to the peak concentration in late summer, followed by a decrease in the fall. Lentz et al., (2011) showed that net N mineralization between spring (April 04, 2013) and late summer (July 21, 2003) after fall dairy manure applications of 23.3 and 45.7 Mg ha^{-1} was 30.5 and 46.1 mg kg^{-1}, respectively. Net N mineralization between the spring (April 04, 2003) and the fall (Sept. 09, 2003) after fall dairy manure applications of 23.3 and 45.7 Mg ha^{-1} was 32.6 and 31.9 mg-N kg^{-1}, respectively (Lentz et al., 2011).

The similar methodology used in the current study and by those of Lentz et al., (2011) and Lehrsch et al., (2016), will facilitate comparisons between studies and the combining of results, and lead to the development of broader recommendations for efficient dairy manure application practices and future dairy manure research in southern Idaho soils. Monitoring the effect of different manure amendment rates on soil N mineralization contributes important information toward the development of efficient and safe dairy manure application practices.

Nitrogen mineralization as affected by dairy manure application interval

Nitrogen mineralization after first time dairy manure applications has been studied by numerous researchers. The rate of manure N still mineralizing 2 years after application is not as well researched or understood and study findings have varied.

Several studies have sought to determine a dairy manure decay series, an approach illustrating the fraction of applied N that mineralizes during the first and second years (1^{st} year-2^{nd} year) after application. Some of the decay series of fresh whole dairy cattle manure include: 0.75-0.15 (Pratt et al. 1973), 0.50-0.15 (Willrich et al., 1974), 0.40-0.20 (Gilberton et al., 1979), and 0.23-0.12 (Lentz and Lehrsch, 2012). This variability in N mineralization rates one or two years after application could result in over or under application of manure N.

In a study monitoring soil inorganic N in the first and second year after annual and biennial beef cattle feedlot manure applications to a typic Argiudoll under corn (*Zea mays L.*) Eghball (2002) showed both a treatment and soil depth interaction one year after application as well as a treatment, timing, and soil depth interaction two years after application. In the fall of 1992 and 1993, annual manure plots received cattle manure at a rate of 46.9 and 18.5 (dry wt.) Mg ha^{-1}, respectively with a N content of 378 and 189 kg ha^{-1}. In the fall of 1992, biennial manure plots received cattle manure at a rate of 93.9 (dry wt.) Mg ha^{-1} with an N content of 756 kg ha^{-1}. The quantity of nitrate was determined at a soil depth from 0-120 cm. Annual manure treatments contributed soil nitrate in the fall of 1993 and 1994 of 55 and 15 kg N ha^{-1}, respectively. Biennial manure treatments had soil nitrates occurring in the fall of 1993 and 1994 of 85 and 22 kg N ha^{-1}, respectively. Soils that did not receive manure had nitrates occurring in the fall of 1993 and 1994 of 21 and 13 kg N ha^{-1}, respectively (Eghball, 2002). This study showed that one time beef cattle manure N applied at a rate of 756 kg N ha^{-1} was mineralizing two years after application at similar or greater rates than the repeated cattle manure N applications that cumulated to 567 kg N ha^{-1}.

The method in which Eghball, (2002) determined nitrate production in manured soils likely yielded results that were lower than the nitrate concentrations that actually occurred in the soil. The researchers tested soils directly after corn harvest. The nitrates that resulted from mineralization in the soil were subject to leaching processes as well as direct uptake by corn. Though this study may not have direct application to southern Idaho conditions, the findings are relevant due to showing that first time applications of manure N is still mineralizing at appreciable rates in the second year relative to repeated manure N applications the first and second years.

In a study on Portneuf soil in southcentral Idaho, researchers monitored N mineralization in the first and second year after one time dairy manure additions. This one time manure addition was applied at the rates of 21.7 and 68.9 Mg ha^{-1} (dry wt.). The N mineralization decay series differed depending on manure application rate, being 0.23-0.12 for the lesser manure rate and 0.20-0.08 for the greater (Lentz and Lehrsch, 2012). Thus, an improved understanding of dairy manure application rate and interval effects on N mineralization should be an important component of future research.

Slow N release from dairy manure is also important when considering annual or repeated applications. Understanding cumulative N mineralization effects after two fall applications of dairy manure will be important for efficient management of dairy manure resources. Research on repeated dairy manure applications in southern Idaho is lacking and more research on the topic is warranted. Monitoring N mineralization in the second year after different rates of first time fall applied dairy manure applications is important in developing manure application recommendations that are both environmentally sound and that optimize yield and quality of valuable crops in southern Idaho.

Research objectives

When using dairy manure as a plant N source, an accurate estimate of manure-derived plant available N is needed to maximize its agronomic benefit while minimizing environmental damage. Improved plant available N crediting of dairy manure applications can increase crop producer confidence in, and utilization of, dairy manure as a nutrient source. The objectives of this study are to:

1) Evaluate soil inorganic N and net N mineralization in Portneuf silt loam under field conditions for the growing season following one single fall application of dairy manure (several rates). Measurements will be made at two soil depths (0-30 and 30-60 cm) utilizing an *in-situ* buried bag method,
2) Evaluate soil inorganic N and net N mineralization in a Portneuf silt loam under field conditions for the growing season following annual or biennial fall applications of dairy manure (several rates). Measurements will be made at two soil depths (0-30 and 30-60 cm) utilizing an *in-situ* buried bag method,
3) Determine factors that impact variability of inorganic N accumulations in the buried bags,
4) Evaluate the efficacy of the buried bag method by correlating barley and sugar beet N uptake to buried bag soil nitrate accumulations.

Works Cited

Adams, M.A., and P.M. Attiwill. 1986. Nutrient cycling and nitrogen mineralization in eucalypt forests of south-eastern Australia. Plant Soil 92:341-62.

Agehara, S., and D.D. Warncke. 2005. Soil moisture and temperature effects on nitrogen release from organic nitrogen sources. Soil Sci. Soc. Am. J. 69:1844-855.

Albino, U.B., and G. Andrade. 2006. Evaluation of functional group microorganisms as bioindicators on the rhizosphere microcosm. In: M. K. Rai, editor, The handbook of microbial biofertilizers. Food Products, Binghamton, NY. p.29-32.

Alexander, M. 1981. Biodegradation of chemicals of environmental concern. Science 211:132-38.

Aulakh, M.S.,J.W. Doran, D.T Walters, and J.F Power . 1991. Legume residue and soil water effects on denitrification in soils of different textures. Soil Biol. Biochem, 23:1161-167.

Binkley, D., and S. Hart, 1989. The components of nitrogen availability assessments in forest soils. Adv. Soil Sci. 10:57-112.

Binkley, D., R. Bell, and P. Sollins. 1992. Comparison of methods for estimating soil nitrogen transformations in adjacent conifer and alder–conifer forests. Can. J. For. Res. 22:858-63.

Birch, H. F. 1958. The effect of soil drying on humus decomposition and nitrogen availability. Plant Soil 10:9-31.

Bosatta, E., and G.I. Agren. 1999. Soil organic matter quality interpreted thermodynamically. Soil Biol. Biochem. 31:1889-91.

Brady, N.C.1990.Organisms of the soil. In The nature and properties of Soil. 10th ed. Macmillan, New York, NY.p.254-76.

Burford, J. R., and D. J. Greenland. 1970. Denitrification under an annual pasture. In: Proc. of International Grassland Conference, Surfers Paradise Queensland University, St. Lucia, Australia.

Burnell, B., and M. Thomas. 1990. Integrated Database: Idaho. Idaho Department of Health and Welfare DEQ. http://www.nesc.wvu.edu/septic_idb/idaho.htm#septicstats (accessed 19 Sept. 2016).

Cabrera, M.L., and D.E. Kissel. 1988. Evaluation of a method to predict nitrogen mineralized from soil organic matter under field conditions. Soil Sci. Soc. Am. J. 52:1027-031.

Cameron, D.R., C.G. Kowalenko, and K. C. Ivarson. 1978. Nitrogen and chloride distribution and balance in a clay loam soil. Can. J. Soil. Sci. 58.1:77-88.

Campbell, C.A., R.J. Meyers, and K.L. Weir. 1981. Potentially mineralizable nitrogen, decom-position rates and their relationship to temperature for five Queensland soils. Aust. J. Soil Res. 19:323-32.

Campbell, C.A., 1978. Soil organic carbon, nitrogen and fertility. Soil organic matter. In: M. Schnitzer and S. U. Khan, editors, Developments in soil science 8. 1978. Elsevier, Amsterdam. p. 220-25.

Campbell, C.A., D.W. Stewart, W. Nicholaichuk, and V.O. Biederbeck. 1974. Effects of growing season soil temperature, moisture and NH_4-N on soil nitrogen. Can. J. Soil Sci. 54:403-12.

Campbell, C.A., Y.W. Jame, and G.E. Winkleman. 1984. Mineralization rate constants and their use for estimating nitrogen mineralization in some Canadian prairie soils. Can. J. Soil Sci. 64:333-43.

Carreiro, M.M., and R.E. Koske. 1992. Room temperature isolations can bias against selection of low temperature microfungi in temperate soils. Mycologia 84.6:886-900.

Carter, J.N., and D.J. Traveller. 1981. Effect of time and amount of nitrogen uptake on sugarbeet growth and yield. Agron. J. 73:665– 671.

Cassman, K.G., D.N., Munns. 1980. Nitrogen mineralization as affected by soil moisture, temperature and depth. Soil Sci. Soc. Amer. J. 44:1233-237.

Castellano, M.J., D.B. Lewis, D. M. Andrews, and M. D. McDaniel. 2012. Coupling biogeochemistry and hydropedology to advance carbon and nitrogen cycling science. In: H. Lin, editor, Hydropedology. Academic, Waltham, MA. p. 711-35.

Castellanos, J.Z., and P.F. Pratt. 1981. Mineralization of manure nitrogen correlation with laboratory indexes. Soil Sci. Soc. Amer. J. 45:354–357. doi:10.2136/sssaj1981.03615995004 500020025x

Chadwick, D.R., F. John, B.F. Pain, B.J. Chambers, and J. Williams. 2000. Plant uptake of nitrogen from the organic nitrogen fraction of animal manures: a laboratory experiment. J. Agric. Sci. (Cambridge)134:159-68.

Chae, Y.M., and M.A. Tabatabai. 1986. Mineralization of nitrogen amended with organic wastes. J. Environ. Qual. 15:193-98.

Coyne, M. S. 2008. Biological denitrification. In: J.S. Schepers and W.R. Raun, editors, Nitrogen in agricultural systems. Agron. Monogr. 49. ASA, Madison, WI. p. 201-53.

Davidson, E.A., and I.A. Janssens. 2006. Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. Nature 440:165-73. doi:10.1038/nature04514

Davis, J.G., K.V. Iverson, and M.F. Vigil. 2002. Nutrient variability in manures: implications for sampling and regional database creation. J. Soil Water Conserv. 57:473-78.

Dessureault-Rompre, J., B.J. Zebarth, A. Georgallas, and D. Burton. 2010. Temperature depend-ence of soil nitrogen mineralization rate: comparison of mathematical models, reference tem-peratures and origin of soils. Geoderma 157:97-108. doi:10.1016/j.geoderma.2010.04.001

DiStefano, J.F., and H.L. Gholz. 1986. A proposed use of ion exchange resins to measure nitro-gen mineralization and nitrification in intact soil cores. Commun. Soil. Sci. Plant Anal. 17:989-098.

Douglas, B.F., and F.R. Magdoff. 1991. An evaluation of nitrogen mineralization indices for or-ganic residues. J. Environ. Qual. 20:368-72.

Dou, H., A.K. Alva, and B.R. Khakural. 1997. Nitrogen mineralization from citrus tree residues under different production conditions. Soil Sci. Soc. Am. J. 61:1226–232.

Eghball, B. 2002 Soil properties as influenced by phosphorous and nitrogen based manure and compost applications. Agron. J. 94:128-35.

Eghball, B., B.J. Wienhold, J. E. Gelley, and R. A. Eigenberg. 2002 Mineralization of manure nutrients. J. Soil Water Conserv. 57.6:470-73.

Ellert, B.H. and J.R. Bettany. 1992. Temperature dependence of net nitrogen and sulfur mineralization. Soil Sci. Soc. Amer. J. 56:1133-141.

Eneji, A.E., T. Honna, S. Yamamoto, T. Saito, and T. Masuda. Nitrogen transformation in four Japanese soils following manure+urea amendment. Commun. Soil. Sci. Plant Anal. 33:53-66.

Eno, C.F. 1960. Nitrate production in the field by incubating the soil in polyethylene bags. Soil Sci. Soc. Amer. J. 24:277-99.

Follet, J.R., and R.F. Follet. 2008. Relationships of environmental nitrogen metabolism to human health. In: J. L. Hatfield and R. F. Follet, editors, Nitrogen in the Environment: sources, problems, and management. Elsevier, San Diego, CA. p. 71-72.

Fortuna, A.M., C.W. Honeycutt, G. Vandemark, T.S. Griffin, R.P. Larkin, Z. He, B.J. Wienhold, K.R. Sistani, S.L. Albrecht, B.L. Woodbury, H.A. Torbert, J.M. Powell, R.K. Hubbard, R.A. Eigenberg, R.J. Wright, J.R. Alldredge, and J.B. Harsh. 2012. Links among nitrification, nitrifier communities, and edaphic properties in contrasting soils receiving dairy slurry. J. Environ. Qual. 41:262-72.

Frasier, F.C., P.D. Hallett, P.A. Wookey, and I.P Hartley. 2013. How do enzymes catalysing soil nitrogen transformations respond to changing temperatures? Biol. Fertil. Soils. 49:99-103.

Gale, E.R., M. Dan, C. G. Cogger, and A.I. Bary. 2006. Estimating plant available nitrogen re-lease from manures, composts, and specialty products. J. Environ. Qual. 35:2321-332.

Goering H.K., and P.J. Van Soest. 1970. Forage fiber analysis (apparatus, reagents, procedures, and some applications). U.S. Government Printing Office, Washington, DC.

Goncalves, J.L., and J.C. Carlyle. 1994. Modeling the influence of moisture and temperature on net nitrogen mineralization in a forested sandy soil. Soil Biol. Biochem. 26:1557-564.

Gordillo, R.M., and M.L. Cabrera. 1997. Mineralizable nitrogen in broiler litter II. Effect of se-lected soil characteristics. J. Environ. Qual. 26:1679-686.

Griffin, T.S., and C.W. Honeycutt. 2000. Using the growing degree days to predict nitrogen availability from livestock manures. Soil Sci. Soc. Am. J. 64:1876-882.

Griffin T.S, Honeycutt C.W, and Z. He. 2002. Effects of temperature, soil water status, and soil type on swine slurry nitrogen transformations. Biol. Fertil. Soils 36, 442-46.

Grundmann G.L., P. Renault, L. Rosso, and R. Bardin. 1995. Differential effects of soil water content and temperature on nitrification and aeration. Soil Sci. Soc. Am. J. 59:1342-349.

Hanselman, T.A., D.A. Graetz, and T.A. Obreza. 2004. A comparison of in situ methods for measuring net nitrogen mineralization rates of organic amendments. J. Environ. Qual. 33:1098-105.

Harper, D. 1992. The biological effects of eutrophication. In: Eutrophication of freshwaters principles, problems and restoration.Chapman & Hall, London. p. 117-37.

Hoagland, Kyle D., and Thomas G. Franti. 2008. Eutrophication. In: S.W. Trimble, editor, Encyclopedia of water science. 2nd ed.Taylor & Francis Group, LLC, Boca Raton, FL. p. 304-05.

Hockaday, C.A. Masiello, J.T. Randerson, R.J. Smernik, J.A. Baldock, O.A. Chadwick, and J. W. Harden. 2009. Measurement of soil carbon oxidation state and oxidative ratio by ^{13}C nuclear magnetic resonance. J. Geophys. Res. 114-28.

Honeycutt, C.W., T.S. Griffin, B.J. Wienhold, B. Eghball, S. L. Albrecht, J. M. Powell, B.L. Woodbury, K. R. Sistani, R. K. Hubbard, and H. A. Torbert. 2005b. Protocols for nationally coordinated laboratory and field research on manure nitrogen mineralization. Commun. Soil. Sci. Plant Anal. 36:2807-822.

Honeycutt C.W., T.S. Griffin, and Z. He. 2005a. Manure nitrogen availability: dairy manure in northeast and central U.S. soils. Biol. Agric. Hortic. 23:199-214.

Honeycutt, C.W. 1999. Nitrogen mineralization from soil organic matter and crop residues: field validation of laboratory predictions. Soil Sci. Soc. Am. J. 63:134-41.

Idaho 2015 Census tables. 2015. Census: Idaho Department of Labor. https://lmi.idaho.gov/census (accessed 07 Oct. 2016).

IDEQ. 2016. Nitrate in ground water. IDEQ. http://www.deq.idaho.gov/water-quality/ground-water/nitrate/ (accessed 09 Sept. 2016).

IDEQ. 2014. Water Quality Division. Nitrate priority area delineation and ranking process. IDEQ (Boise). https://www.deq.idaho.gov/media/1117845/nitrate-priority-area-delineation-ranking-2014.pdf (accessed 05 Sept. 2016).

Jarvis, P., A. Rey, and C. Petsiko. 2007. Drying and wetting of Mediterranean soils stimulates decomposition and carbon dioxide emission: the Birch Effect? Tree Physiol. 27:929-40.

Katterer, T., M. Reichstein, O. Andren, and A. Lomander. 1998. Temperature dependence of or-ganic matter decomposition: a critical review using literature data analyzed with different mod-els. Biol. Fertil. Soils 27:258-62.

Khanna P.K., Raison R.J. 2013. In situ core methods for estimating soil mineral-N fluxes: re-evaluation based on 25 years of application and experience. Soil Biol Biochem 64:203-10.

Klausner, S.D., V.R. Kanneganti, and D.R. Bouldin. 1994. An approach for estimating a decay series for organic nitrogen in animal manures. Agron. J. 86:897-903.

Kjonaas, O.J. 1999a. Factors affecting stability and efficiency of ion exchange resins in studies of soil nitrogen transformation. Commun. Soil. Sci. Plant Anal. 30:2377-397.

Kjonaas, O.J. 1999b. In situ efficiency of ion exchange resins in studies of nitrogen transformation. Soil Sci. Soc. Am. J. 63:399-409.

Knowles, R. 1981. Denitrification. In: F.E. Clark and T. Rosswall, editors, Terrestrial nitrogen cycles. Vol. 33.: Ecol. Bull, Stockholm. p. 315-29.

Kyvsgaard, P., P. Hensen, E. Moller, and J. Magid. 2000. Nitrogen mineralization from sheep faeces can be predicted from the apparent digestibility of the feed. Nutr. Cycl. Agroecosyst. 57.3:207-14.

Lehrsch, G.A., B. Brown, R.D. Lentz, J.L. Johnson-Maynard, and A.B. Leytem. 2016. Winter and growing season nitrogen mineralization from fall applied composted or stockpiled solid dairy manure. Nutr. Cycl. Agroecosyst. 104:125-42.

Lentz, R.D., and G.A. Lehrsch. 2012. Net nitrogen mineralization from past years' manure and fertilizer applications. Soil Sci. Soc. Am. J. 76.3:1005-015.

Lentz, R.D., G.A. Lehrsch, and B. Brown. 2011. Dairy manure nitrogen availability in eroded and noneroded soil for sugarbeet followed by small grains. Agron. J. 103.3:628-43.

Lentz, R.D., J.A. Ippolito, and K.A. Spokas. 2014. Biochar and manure effects on net nitrogen mineralization and greenhouse gas emissions from calcareous soil under corn. Soil Sci. Soc. Am. J. 78.5:1641-655.

Liao, W., Y. Liu, C. Liu, and S. Chen. 2004. Optimizing dilute acid hydrolysis of hemicellulose in a nitrogen-rich cellulosic material--dairy manure. Bioresour. Technol. 94:33-41.

Linn, D. M., and J. W. Doran. 1984. Effect of water-filled pore space on carbon dioxide and nitrous oxide production in tilled and nontilled soils. Soil Sci. Soc. Am. J 48:1267-272.

Lupwayi, N.Z., and I. Haque. 1998. Mineralization of N, P, K, Ca and Mg from sesbania and leucaena leaves varying in chemical composition. Soil Biol. Biochem. 30:337-43.

Lutzow, M. V., and I. Kogel-Knabner. 2009. Temperature sensitivity of soil organic matter de-composition — what do we know? Biol. Fertil. Soils. 46:1-15.

Meek, B.D., D.L. Carter, and D.T. Westermann. 1994. Root-zone mineral nitrogen changes as affected by crop sequence and tillage. Soil Sci. Soc. Am. J. 58:1464-469.

Melillo, J.M., J.D. Aber, and J.F. Muratore. 1982. Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. Ecology. 63:621-26.

Mohammed, Y.A., J. Kelly, B.K. Chim, E. Rutto, K. Waldschmidt, and G. Torres. 2013. Nitro-gen fertilizer management for improved grain quality and yield in winter wheat in Oklahoma. J. Plant Nutr. 36:749-61.

Moore, A.D, J. Stark, B. Brown, and B. Hopkins. 2009. Southern Idaho fertilizer guide sugar beets. Idaho Nutrient Management. University of Idaho Extension.

Morvan, T., B. Nicolardot, and L Pean. 2006. Biochemical composition and kinetics of C and N mineralization of animal wastes: a typological approach. Biol. Fertil. Soils. 42:513-22.

Mueller, T., L.S. Jensen, N.E. Nielsen, and J. Magid. 1998. Turnover of carbon and nitrogen in a sandy loam soil following incorporation of chopped maize plants, barley straw and blue grass in the field. Soil Biol. Biochem. 30:561-71.

Myrold, D.D. and P.J. Bottomley. 2008. Nitrogen mineralization and immobilization. In: J.S. Schepers and W.R. Raun, editors, Nitrogen in agricultural systems. Agron. Monogr. 49. ASA, Madi-son, WI. p. 157-72.

NASS. 2015. State agriculture overview: Idaho. USDA NASS, Washington, DC. http://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=IDAHO. (ac-cessed 26 Aug 2016).

NASS. 2012. Idaho State and County Data Vol.1: County Summery Highlights. 2012 Census of Agriculture. USDA NASS, Washington, DC. https://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_2_County_Level/Idaho/st16_2_001_001.pdf (accessed 19 Oct. 2016).

Nennich T.D., J.H. Harrison, L.M. VanWieringen, D. Meyer, A.J. Heinrichs, W.P. Weiss, N.R. St-Pierre, R.L. Kincaid, D.L. Davidson, and E. Block. 2005. Prediction of manure and nutrient excretion from dairy cattle. J. Dairy Sci. 88:3721–733.

Nicolardot B., G. Fauvet, and D. Cheneby. 1994. Carbon and nitrogen cycling through soil mi-crobial biomass at various temperatures. Soil Biol. Biochem. 26:253-61.

Norton, J.M., and J.P. Schimel. 2012. Nitrogen mineralization-immobilization turnover. In: P.M. Hong, Y. Li, and M. E. Summer, editors, Handbook of soil sciences: properties and processes. Taylor and Francis Group, Boca Raton, FL. p. 27.

Norton, J.M. 2008. Nitrification in agricultural soils. In: J.S. Schepers and W.R. Raun, editors, Nitrogen in agricultural systems. Agron. Monogr. 49. ASA, Madi-son, WI. p. 173-99.

Oertli, J.J. 2008. Soil fertility. In: W. Chesworth, editor, Encyclopedia of soil science. Springer, Dordrecht, Holland. p. 656-68.

Patterson P.E., and K.M. Painter. Idaho Crop Input Price Survey for 2014. 2014. Agricultural Economics Extension Series No. 14-04. Department of Agricultural Economics and Rural Sociology. https://www.uidaho.edu/~/media/UIdaho-Responsive/Files/cals/Programs/ID-Agbiz/crop-budgets/crop-input-price-summary/Crop-Input-Price-Survey-2014.ashx. (accessed 16 Sept. 2016).

Pettygrove, G.S., A. L. Heinrich, and A. J. Eagle. 2010. Dairy Manure Nutrient Content and Forms. University of California Cooperative Extension Manure Technical Bulletin Series. http://manuremanagement.ucdavis.edu/files/134366.pdf. (accessed 05 Oct. 2016).

Pratt, P.F., F.E. Broadbent, and J.P. Martin. 1973. Using organic wastes as nitrogen fertilizers. Calif. Agr. 27:10–13.

Prosser, J.I. 2007. Microorganisms cycling soil nutrients and their diversity. In: J. D. Van Elsas, J. K. Jansson, and J. T. Trevors, editors, Modern soil microbiology. Taylor and Francis Group, LLC, Boca Raton, FL. p. 237-61.

Quemada, M., and M.L. Cabrera. 1997. Temperature and moisture effects on C and N minerali-zation from surface applied clover residue. Plant Soil 189:127-37.

Raison, R., M. Connell and P. Khanna 1987. Methodology for studying fluxes of soil mineral-N in situ. Soil. Biol. Biochem. 19:521-30.

Richards, B.N., J.E. Smith, G. J. White, and J. L. Charlie. 1985. Mineralization of soil nitrogen in three forest communities from the New England region of New South Wales. Aust. J. Ecol. 10:429-41.

Robertson, L.D., and J.C. Starke. 1993. Idaho Spring Barley Production Guide. Idaho Nutrient Management. University of Idaho Extension.

Saetre, P., and J.M. Stark. 2005. Microbial dynamics and carbon and nitrogen cycling following re-wetting of soils beneath two semi-arid plant species. Oecologia 142:247-60.

Schnabel, R.R., S.R. Messier, and R.F. Purnell. 1993. An evaluation of anion exchange resin used to measure nitrate movement through soil. Commun. Soil. Sci. Plant Anal. 24:863-79.

Schnabel, R.R., 1983. Measuring nitrogen leaching with ion exchange resin: a laboratory assessment. Soil Sci. Soc. Am. J. 47:1041-042.

Schnabel, R.R., 1995. Nitrate and phosphate recovery from anion exchange resins. Commun. in Soil Sci. Plant Anal. 26:531-40.

Semoka, J. 2008. Nitrogen cycle. In: W. Chesworth, editor, Encyclopedia of soil science. Springer, Dordrecht, Netherlands. p. 491-94.

Sierra, J. 1997. Temperature and soil moisture dependence of N mineralization in intact soil cores. Soil Biol. Biochem. 29:1557-563.

Sistani, K.R., A. Adeli, S.L. Mcgowen, H. Towolde, and G.E. Brink. 2008. Laboratory and field evaluation of broiler litter nitrogen mineralization. Bioresour. Technol. 99:2603-611.

Smith, S.J., L.B. Young, and G.E. Miller. 1976. Evaluation of soil nitrogen mineralization potentials under modified field conditions. Soil Sci. Soc. Am. J. 41:74-76.

Standing, D., and K. Killham. 2007. The soil environment. In: J. D. Van Elsas, J. K. Jansson, and J. T. Trevors, editors, Modern soil microbiology. Taylor & Francis Group, LLC, Boca Raton, FL. p. 1-22.

Stanford, G., and E. Epstein. 1974. Nitrogen mineralization water relations in soils. Soil Sci. Soc. Am. J. 38:103-07.

Stenger, R.E., E. Priesack, and F. Beese. 1996. In situ studies of soil mineral N fluxes: some comments on the applicability of the sequential soil coring method in arable soils. Plant Soil 183:199-211.

Subler, S., R.W. Parmelee, and M.F. Allen. 1995. Comparison of buried bag and PVC core methods for *in situ* measurements of nitrogen mineralization rates in an agricultural soil. Com-mun. Soil. Sci. Plant Anal. 26:2369-381.

Talbot, J.M., S.D. Allison, and K.K. Treseder. 2008. Decomposers in disguise: Mycorrhizal fungi as regulators of soil C dynamics in ecosystems under global change. Funct. Ecol. 22:955-63.

Tarkalson, D.D. 2012. Nitrogen requirement for sugar beets: A summary of past and present re-search findings. Proceedings of the Idaho Nutrient Management Conference. p. 15-19. March 6, 2012. Jerome, ID.

USDA. 1994. RCA Appraisal 1994. Soil and Water Resources Conservation Act. Washington, DC: USDA.

Van Der Meer, H.G., R.J. Unwin, and T.A. Van Dijk. 1987. Animal manure on grassland and fodder crops. Fertilizer or waste? In Developments in plant and soil science. Martinus Nijhoff Publishers, Wageningen, Netherlands.

Van Kessel, J.S., J.B. Reeves, and J.J. Meisinger. 2000. Nitrogen and carbon mineralization of potential manure components. J. Environ. Qual. 29:1669-677.

Van Kessel, J.S, and J.B. Reeves. 2002. Nitrogen mineralization potential of dairy manures and its relationship to composition. Biol. Fertil. Soils 36:118-23.

Van Soest, P.J.1963. Use of detergents in the analysis of fibrous feeds. II. A rapid method for the determination of fiber and lignin. J. Assoc. Off. Anal. Chem.46:829-35.

Weier, K.L., J.W. Doran, J.F. Power, and D.T. Walters. 1993 Denitrification and the dinitrogen/nitrous oxide ratio as effected by soil water, available carbon, and nitrate. Soil Sci. Soc. Am. J 57:66-72.

Westermann, D.T., and S.E. Crothers. 1980. Measuring soil nitrogen mineralization under field conditions. J. Am. Soc. Agron. 72:1009-012.

Westermann, D.T., and S.E. Crothers. 1993. Nitrogen fertilization of wheat no-till planted in alfalfa stubble. J. Prod. Agric. 6:404-08.

Willrich T.L., D.O. Turner, and V.V. Volk. 1974. Manure application guidelines for Pacific Northwest. ASAE Paper No. 74-4601, Am. Soc. Agric. Eng. St. Joseph, MI

Wyland, L.J., and L.E. Jackson. 1993. Evaluating nitrate recovery by ion exchange resin bags. Soil Sci. Soc. Am. J. 57:1208-211.

Zak, D.R., W.E. Holmes, N.W. McDonald, and K.S. Pregitzer. 1999. Soil temperature, matric potential, and the kinetics of microbial respiration and nitrogen mineralization. Soil Sci. Soc. Am. J. 63:575-84.

Zhengxia, D., J.D. Toth, J.D. Jabro, R.H. Fox, and D.D. Fritton. 1996. Soil nitrogen mineralization during laboratory incubation: Dynamics and model fitting. Soil Biol. Biochem. 28:625-32.

Zogg, G.P., D.R. Zak, D.B. Ringelberg, D.C. White, N.W. Macdonald, and K.S. Pregitzer. 1997. Compositional and functional shifts in microbial communities due to warming. Soil Sci. Soc. Am. J. 61:475-81.

Chapter 2: Nitrogen Mineralization of Dairy Manure in a Calcareous Soil Under Field Conditions

Abstract

Understanding N transformations in fields receiving dairy manure applications is an important component of managing this nutrient source to maximize crop profitability and reduce environmental damage. The objective of this study was to determine net N mineralization from field applied dairy cow manure to a Portneuf silt loam as affected by applications of varying rates, application intervals, and naturally fluctuating temperatures throughout the growing season. This study was conducted in a field located at the USDA Agricultural Research Service (ARS) Northwest Soil Research Laboratory (NWISRL) station in Kimberly, Idaho. Soil treatments included three manure rates (17.3, 34.7, 52.0 Mg ha^{-1}, dry basis applied at two recurrence intervals (annual or biennial fall applications). The field was sprinkler-irrigated under spring barley (*Hordeum vulgare L.*) in 2013 and sugar beets (*Beta vulgaris L.*) in 2014. We monitored net N mineralization in the 2013 and 2014 growing seasons using the buried bag technique (amended soils were placed in polyethylene tube shaped bags and incubated in the field). Soil filled incubation bags were destructively sampled monthly or biweekly from March to October and analyzed for nitrate and ammonium. Predictive models were fit based on the analyses results. Crop N uptake was determined from end of season plant tissue analyses. Crop N uptake correlated well with N mineralization monitored in the buried bags yielding a liner regression r-square of 0.74 ($P <$ 0.0001). Manure that was fall-applied in 2012 resulted in significant increases in preplant soil inorganic N concentrations in 2013 corresponding with increases in manure application from 0 (control), 17.3. 34.7, and 52.0 Mg ha^{-1}(dry wt.). In addition, treatments that either did or did not receive additional fall-applied manure in 2013 resulted in significant increases in preplant soil inorganic N concentrations corresponding with increases in manure applications from 0 (control), 17.3, 34.7 and 52 Mg ha^{-1} (dry wt.). The zero-order linear model was selected for estimating N mineralization rate (k), N mineralization amount, the y-intercept, and data variability (r-square). The linear N mineralization rate of the present study shows a consistent increase in the release of N from April to September at 1 and 2 years after application as well as after 2 years of repeated fall applications. Increasing manure application rates also resulted

in a linear increase in net N mineralization rates (k values) 1 and 2 years after a fall application, and after 2 years of repeated fall applications at the 0-30 cm soil depth.

Introduction

Idaho had a standing herd of 587,000 lactating dairy cattle in 2015 (NASS, 2015). Daily excretion rate for a lactating cow is approximately 0.491 kg day^{-1} total nitrogen (N) (Nennich, et al., 2005). Based on these values, an estimated 288 Mg of total N is produced daily in Idaho by lactating dairy cattle. Calculated from 2014 market value of urea at \$484 Mg^{-1} (Patterson and Painter, 2014), this total N was valued at \$1,039 Mg^{-1}. As a result, the N fertilizer contained in this dairy livestock byproduct is estimated to be valued at \$109 million year^{-1}. Applying dairy manure to fields to supplement commercial fertilizer applications could be a valuable technique to lower fertilizer inputs while maintaining crop yields and quality. Understanding plant available N released from manure N will contribute to keeping southern Idaho crop producers profitable and competitive into the future.

Nitrogen is an essential element for plant growth and is the most limiting nutrient in most cropping systems. Idaho crop producers that are interested in using dairy manure field applications to supply N to crops are often unsure about how much N from the manure will be plant available, as well as when the N will be plant available. These questions are important because crop quality and yield are often reduced if plant available N (PAN) occurs in concentrations that are inadequate, in excess, or miss-timed as dictated by a crops specific nutrient requirements. Furthermore, excess PAN in soil can leach from manured soils, contaminate surface and groundwater supplies, and negatively impact the environment and human health. The Idaho Department of Environmental Quality (IDEQ) reports that the primary sources for nitrate contamination in Idaho are N based fertilizers, septic sewer systems and livestock operations (IDEQ, 2016). The Idaho Department of Environmental Quality (IDEQ), the Idaho Department of Water Resources (IDWR), and the Idaho State Department of Agriculture (ISDA) have designated 34 nitrate priority areas in Idaho as of 2014 (IDEQ, 2014). These areas are characterized by having greater than 25% of wells having at or above 5 mg nitrate-N L^{-1}, which is one-half the drinking water standard of 10 mg L^{-1} (IDEQ, 2014).

Out of the 34 nitrate priority areas, 21 are located wholly or partially in the thirteen dairy-producing counties that have a standing herd of more than 2000 lactating cows (IDEQ, 2014; NASS, 2012). These counties include, Gooding, Jerome, Twin Falls, Cassia, Minidoka, Elmore, Owyhee, Ada, Canyon, Payette, Gem, Bingham, and Jefferson. These 13 counties contain 85% of Idaho's total dairy cattle count in 2012 as well as 47% of Idaho's beef cattle count totaling 229,731 in 2012 (IDEQ, 2014; NASS, 2012). This region also contains 51% of the industrial farm land in Idaho, totaling over 6 million acres (NASS, 2012). Based on a 1990 census report adjusted by county for population growth from 1990 to 2015, it is estimated that these 13 counties also contain 49% of Idaho's on site waste water systems totaling near 115,000 septic systems (Idaho, 2015; Burnell and Thomas, 1990). Best N management practices need to be developed and used in areas that have high concentrations of N-emitting systems in order to protect human health and the environment. Field applying dairy manure is a valuable means of recycling dairy manure nutrients, but proper management is needed to ensure that crop nutrients are applied at rates that do not exceed crop nutrient uptake capacity. An inability to match manure applications with crop N requirements is most commonly due to inaccurate crediting of N in the manure (Beegle et al. 2008).

Accurate crediting of PAN from dairy manure is important to maximize the agronomic benefit of dairy manure as a fertilizer. Several crops grown in Southern Idaho are sensitive to excessive release of N from organic N compounds in the soil. For example, spring barley grain yield and quality are influenced by PAN, excess PAN can result in lodging by causing more fine-stemmed tillers, increased plant height, increased grain, and reduced stem strength (Robertson and Starke, 1993). Specifications for malting barley protein levels fall between 11.5 and 14% (American Malting Barley Association. 2016). Increasing levels or miss-timed availability of PAN can result in barley protein content above this range (Thompson et al., 2004; Robertson and Starke, 1993). Managing dairy manure applications for optimal manure N mineralization is also important concerning crops in southern Idaho, such as sugar beets. Sugar beet profits are based on beet yield, sucrose content, and sucrose extraction efficiency. A limited N supply decreases beet root yields, while too much N decreases sugar content and sucrose extraction efficiency (Tarkalson, 2012). Timing is also an important factor in proper N management. Avoiding excessive release of late season (mid-July to October) PAN is important to reduce brie nitrates, salts, and other impurities in the beet. These impurities reduce the amount of sugar produced and also increase the sugar extraction costs (Moore et al. 2009). Understanding the amount of PAN released from dairy manure and when it is released is critical to increase confidence in the practice of recycling nutrients contained in manure.

Net N mineralized results from a combination of potentially simultaneous microbial N transformations. The primary transformations include ammonification and nitrification that add to a soils inorganic N pool, and immobilization and denitrification that reduce a soil's inorganic N pool (Norton, 2008). When the magnitude of ammonification and nitrification are greater than that of immobilization and denitrification, net N mineralization is positive. Mineralization of dairy manure is a result of complex interactions between soil organisms and substrates containing N. Factors that typically have the greatest influence on N mineralization are: soil temperature (Griffin and Honeycutt, 2000; Cassman and Munns, 1980), soil moisture (Sierra, 1994), carbon to nitrogen ratio of the organic amendment (Brady, 1990) and proportion of labile and recalcitrant components of the organic amendment (Van Kessel and Reeves, 2002).

Dairy manure contains both labile and recalcitrant components. This composition results in manure N mineralizing over the course of several years (Lentz and Lehrsch, 2012). Stockpiled dairy manure in Southern Idaho is typically comprised of urine, feces and straw bedding. Chen et al., (2003) analyzed dairy manure collected at the Dairy Center of Washington State University (WSU) for fiber content and found that dry basis of whole dairy manure percentages of organic N containing compounds were 18% crude protein and 8% amino acid. In manure collected from eight dairy farms in Maine, organic N comprised 61 to 89% of the manure's total N content (Griffin and Honeycutt, 2005). Undigested feedstuff in dairy manure is comprised of fibrous materials that originated from lignocellulosic plant structural components. This fiber material was found to contain on a dry wt.basis, 12 % hemicellulose, 27 % cellulose, and 13 % lignin (Chen et al., (2003), and is primarily comprised of C, H, and O (Killham, 1994). Relative to hemicellulose and cellulose, the decomposition of lignin is slow due to its size and complexity (Wolf and Wagner, 2005). The net outcome of the mineralization-immobilization cycle of organic N is influenced by the decomposition of these complex carbonaceous fibers, though the mechanistic link is not well understood (Moorhead and Sinsabaugh, 2006). It is hypothesized that the hemicellulose, cellulose and lignin content of a mineralizable substrate influences mineralization of N due to feedback controls on microbial activities (Moorhead and Sinsabaugh, 2006) and physical protection of N compounds as a result of N complexing with the fibrous materials (Cheever et al., 2013; Zaccheo et al., 2002; Sorensen, 1962).

Researchers have shown that dairy manure components can have a significant influence on the N mineralization rates (Van Kessel et al., 2000). Whole materials that were used as a proxy for individual dairy manure components were investigated, including those of feedstuffs (immature and mature forages, protein supplements, acid detergent fiber and neutral detergent fiber) and animal metabolism (simple N compounds, ruminal bacteria, and colonic cells) (Van Kessel et al., 2000). The results of their research showed that simple materials such as urea, simple peptides, amino acids, protein supplements, ruminal bacteria, and colonic cells were readily available for N mineralization. More complex materials, such as immature and mature forages were intermediate to slow release sources of N, and the most complex materials such as acid and neutral detergent fibers were shown to be strong immobilizers of N (Van Kessel et al., 2000).

On a broad scale of organic amendments containing N such as crop residues, plant and animal derived composts, and stockpiled animal manures, predicting if the net outcome will be positive N mineralization or immobilization of N can be achieved based on the C:N ratio of the amendment. Within an amendment type (i.e., dairy manure) predicting N mineralization kinetics with precision based composition has been found to be difficult. Van Kessel and Reeves, (2002) showed in an aerobic incubation study that after amending soils with 107 dairy manures with varying chemical and physical properties that there was not a detectable correlation between manure properties and N mineralization including the C:N ratio. These discrepancies highlight the challenge that crop producers face when recycling manure nutrients to supplement crop fertilizer requirements, as well as show the importance of regionally specific manure nutrient management research.

Slow N release from dairy manure is also important when considering annual applications. Research on repeated dairy manure applications in southern Idaho Portneuf silt loam soils is lacking and more research on the topic is warranted. It is assumed that repeated applications of manure result in a compounding effect on Portnef silt loam soil N fertility though the magnitude of that effect is not well understood. Study results from other regions have shown that the N mineralization potential of soils typically increases with repeated annual applications of manure. One of the first studies to show this phenomenon occurred at the Rothemsted experimental station in the U.K where cattle manure was applied annually at 35 Mg ha^{-1} (wet wt.) from 1856-1901. Johnston and Poulton, (1977) reported that the percent of total N in the manured Rothemsted soil was estimated to increase from 0.120 % in 1876 to 0.192% in 1901. Chang et al., (1991) showed that accumulation of nitrate to a depth of 150 cm increased with 11 years of annual applications of cattle manure. Similarly, Whalen et al., (2001) reported that the N mineralization potential from partially decomposed manure increases with cumulative manure applications ranging from 5 to 25 annual applications. Gaining a better understanding of N mineralization potential after repeated fall applications of dairy manure to Portneuf silt loam soils will aid in maximizing the agronomic utility of dairy manure as well as minimize potential damage to the environment and human health.

Another nutrient management challenge is accurately predicting plant available N 1 and 2 years after a first time fall application of dairy manure to a Portneuf silt loam soil. Lehrsch et al, (2016), Lentz and Lehrsch (2012), and Lentz et al., (2011) conducted similar N mineralization studies in southern Idaho manured soils. These researchers investigated net N mineralization for specific time periods (i.e., October to March, April to September) by field incubating manured soils at different times throughout the study period yielding discrete plant available N values for a single time period of interest. This is contrasted by the researchers' approach in the present study where cumulative net N mineralization is monitored by field incubating the same composite manured soil buried the same day in the spring and destructively sampling monthly or biweekly throughout the growing season. This approach yields simple growing season N mineralization predictive models with a single rate coefficient for each manure application rate, providing continuous plant available N values for all time periods throughout the growing season. This experimental design also allows for analysis of both N mineralization as affected by time as well as N mineralization as affected by dairy manure application rate. Analysis of the results of the present study and the results of Lehrsch et al, (2016), Lentz and Lehrsch (2012), and Lentz et al., (2011) will allow for comparing and combining of results, and lead to a better understanding of N mineralization potential of Portneuf silt loam soils 1 and 2 years after receiving a single dairy manure application in the fall.

Lehrsch et al, (2016) showed that organic N in dairy manure applied in the fall to a Greenleaf silt loam at 0, 350, and 701 kg ha^{-1} mineralized to produce 24, 37, and 30 mg N kg^{-1} soil, respectively, between April and September. Lentz et al., (2011) found that the 2012-2013 manure N applications resulted in 2014 growing season net inorganic N to be 6.8, 27.7 and 34.2 mg kg^{-1}, respectively. Lentz and Lehrsch, (2012) showed that dairy manure fall applied to a Portneuf silt loam at three manure N rates of 0, 310 and 970 kg ha^{-1} that net inorganic N resulting from mineralization between April and October after fall manure application to be 11.4, 19.3 and 60.8 mg kg^{-1}, respectively. Lentz and Lehrsch, (2012) found that fall manure N applications resulted in the second growing season after application (April to October) net inorganic N to be 14.6, 23.7 and 28.5 mg kg^{-1}, respectively.

Eghball (2002) measured soil inorganic N in the second year after beef feedlot cattle manure was fall applied annually (378 kg N ha^{-1} in year one; 189 kg N ha^{-1} in year two), or fall applied biennially (756 kg N ha^{-1} in year one), to a Typic Argiudoll under corn (*Zea mays L*.). The researchers showed that cattle manure applied biennially was mineralizing 2 years after application at similar rates as cattle manure applied annually (Eghball, 2002).

Several studies have been conducted with the purpose of illustrating dairy manure decay series in varied soils, an approach illustrating the fraction of applied N that mineralizes during the first and second years (1st year-2nd year) after application. Decay series of fresh whole dairy cattle manure include: 0.75-0.15 (Pratt et al. 1973), 0.50-0.15 (Willrich et al., 1974) and 0.40-0.20 (Gilberton et al., 1979). In a study monitoring N mineralization in the first and second year after one time dairy manure additions to a Portneuf silt loam, the authors found that manure N application rates of 310 and 970 kg N ha^{-1} resulted in different 2 year decay series of 0.23-0.12 for the smaller manure quantity and 0.20-0.08 for the larger quantity (Lentz and Lehrsch, 2012). This variability in first and second year N mineralization rate predictions could result in over or under application of manure N. The similar methodology, climate and soil type used in the current study and by those of Lehrsch et al, (2016), Lentz and Lehrsch (2012) and Lentz et al., (2011) will facilitate comparisons between studies and the combining of results, and lead to the development of broader recommendations for efficient dairy manure application practices, and future dairy manure research in south central Idaho soils.

Numerous studies have used laboratory incubations to determine N mineralization rates in agricultural soils that received organic amendments (Zhengxia et al., 1996; Chae and Tabatabai, 1986; Honeycutt et al., 2005a; Van Kessel and Reeves, 2002). However, the laboratory incubation technique tends to overestimate field N mineralization rates (Adams and Attiwill, 1986; Honeycutt, 1999; Sistani et al., 2008; Cabrera and Kissel, 1988) because incubations typically are conducted at a constant temperature ideal for N mineralization, 22-25 °C (Van Kessel and Reeves, 2002; Honeycutt et al., 2005b; Gale et al., 2006). In-situ incubation techniques give mineralization estimates that are more representative of field conditions because they account for naturally fluctuating soil temperatures (Stenger et al., 1996; Hanselman et al., 2004). Three frequently used field techniques to monitor N mineralization include the buried bag method (Eno, 1960), the covered cylinder method (Subler et al., 1995) and the ion exchange resin method (Khanna and Raison, 2013; DiStefano and Gholz, 1986). The primary limitation of the covered cylinder and ion exchange resin methods is that mineral N can be lost or removed by mass flow and/or direct uptake by plants (Kjonaas, 1999a, 1999b; Subler, 1995; Wyland and Jackson, 1993; Schnabel, 1983, 1993, 1995).

The buried bag method involves filling bags with composite soil, burying them in the field, then removing one or more of the bags at given dates throughout the study period at which point the inorganic N (nitrate + ammonium) in the soil at the date of bag removal less the inorganic N concentration at the date of bag placement is calculated. Cumulative net N mineralization is determined by measuring inorganic N concentrations in the soils contained in the bags from day one of the study until the bag is removed. A study conducted in a Portneuf silt loam soil that compared in-situ nitrate concentrations in buried bags with nitrate concentrations in nearby irrigated fallow soils determined that the buried bag method provided similar results yielding an r-square of 0.95 after regression of these parameters (Westermann and Crothers, 1980). Other researchers have shown that the buried bag method is a useful approach to provide adequate estimates of field net N mineralized in southern Idaho irrigated Portnuef silt loam soils receiving organic additions (Lentz et al., 2014; Lentz and Lehrsch, 2012; Lentz and Lehrsch, 2011; Meek et al., 1994).

The utility of the buried bag method is that mineralized N from soil inside the polyethylene bags is not susceptible to being removed during the field incubation from plant uptake or leaching due to the N remaining contained within the bags. Compounds such as oxygen and carbon dioxide can move from the bulk soil into the encased soil within bags of 0.10 mm thickness (Lehrsch et al., 2016). It is assumed that the gas exchange as well as fluctuating soil temperature allows microbes inside that bag to mineralize organic N at similar rates as outside the bag, thus providing adequate estimates of N mineralized during the incubation period (Lehrsch et al., 2016). There have been concerns that the activity of soil microorganisms that reduce the inorganic N pools through the processes of immobilization (Binkley, 1989) and denitrification (Raison, 1987) could be accelerated relative to the surrounding field soil due to a feedback response caused by mineral N accumulation in the bag encased soils. However, in a study comparing the ion exchange resin method which is open to leaching and the buried bag method, investigators showed that the potential difference in immobilization rates between the methods was insignificant (Binkley, 1992). Some researchers have found that high nitrate concentrations result in increased nitrate diffusion to anaerobic microsites resulting in increased denitrification (Burford and Greenland, 1970). This correlation though has primarily been shown in soils that are water logged. Studies have shown that soils receiving a range of N fertilizer rates in soils with a WFPS below 60% that denitrification rates in fertilized soils did not exceed those in control soils (Weier, 1993; Cameron et al., 1978). Researchers using the buried bag technique in a similarly aerated Portneuf silt loam soil (Lentz et al., 2011) and a Greenleaf silt loam (Lehrsch et al., 2016) concluded that soils within the buried bags contain adequate aeration to prevent appreciable rates of denitrification.

Zero-order kinetics used to model N transformations in soils is among the most commonly used type of kinetics. Other common kinetic types include: first order, second order, Michaelis-Menten and Monad kinetics (Cabrera et al., 2008). The primary limitation of zero-order models is that it does not account for multiple N pools. Dairy cattle manure is comprised of fractions of both labile and recalcitrant components (Van Kessel et al., 2000; Van Kessel and Reeves, 2002). First-order kinetics are often used to model the rapidly mineralizable fractions in dairy cattle manure while still describing the slow release portions with a single rate coefficient (Griffin and Honeycutt, 2002; Griffin and Honeycutt, 2005a). Gale et al. (2006) used sequential linear models to describe this same phenomenon of rapid and slow rate change for decomposition of dairy manure solids added to soils incubated in the laboratory. Researchers conducted an aerobic incubation study where repeated dairy manure solids were applied to two different soils and found that second-year N mineralization trends were most accurately estimated with zero-order kinetics (Kusonwiriyawong et al., 2014). Though a variety of different types of models can be fit to N mineralization trends, model selection is often based on how well the model predicts relative to measured values.

Use of plant uptake N measurements to validate in-situ N mineralization buried bag method

Soil inorganic N derived from dairy manure can be directly measured by determining N uptake in plants grown in dairy manure treated soils. This direct measurement can then be used to assess the efficacy of methods that estimate N mineralization such as the buried bag method. This assessment is achieved by regressing plant N uptake with inorganic N concentrations predicted by the estimation method. In order for this correlation to be useful the following plant characteristics must be true, the plant must be an efficient scavenger of N, the plant must be a luxury consumer of N, and the plant must acquire N from the same soil depth as in the estimation method. Nitrogen uptake by whole sugar beets has been shown to reflect plant available N in Porteneuf silt loam soils. Stanford et al., (1977) showed that sugar beets cropped in unfertilized Portneuf silt loam soils recovered 73% of the residual soil nitrate combined with the estimated inorganic N that mineralized over the growing season. These researchers showed that N uptake of sugar beets correlated well with residual soil nitrate and estimated inorganic N that mineralized over the growing season yielding an r-square of 0.80. In another study in Portneuf silt loam soils, fertilizer N rates of 0 (control), 112, 252, and 392 kg N ha^{-1} resulted in whole sugar beet N uptake of 130, 227, 335, and 419 kg N ha^{-1}, respectively (Carter and Traveller, 1981). This study showed that sugar beets are efficient at recovering N even at relatively high N rates.

Research objective

When using dairy manure as a plant N source, an accurate estimate of manure-derived plant available N is needed to maximize its agronomic benefit while minimizing environmental damage. Improved plant available N crediting of dairy manure applications can increase crop producer confidence in, and utilization of, dairy manure as a nutrient source. The objectives of this study are to:

1) Evaluate soil inorganic N and net N mineralization in Portneuf silt loam under field conditions for the growing season following one single fall application of dairy manure (several rates). Measurements will be made at two soil depths (0-30 and 30-60 cm) utilizing an *in-situ* buried bag method,
2) Evaluate soil inorganic N and net N mineralization in a Portneuf silt loam under field conditions for the growing season following annual or biennial fall applications of dairy manure (several rates). Measurements will be made at two soil depths (0-30 and 30-60 cm) utilizing an *in-situ* buried bag method,
3) Determine factors that impact variability of inorganic N accumulations in the buried bags,
4) Evaluate the efficacy of the buried bag method by correlating barley and sugar beet N uptake to buried bag soil nitrate accumulations.

Materials and methods

Study site and soils

The study was conducted in a field near the USDA Agricultural Research Service (ARS) Northwest Soil Research Laboratory (NWISRL) station in Kimberly, ID (42.550N, -114.354W, elevation 1188 m). The study field size was 48.8 x 146.4 m. Each of the 32 plots measured 12.2 x 18.3 m. The soil type is a Portneuf silt loam (Coarse-silty, mixed, superactive, mesic Durinodic Xeric Haplacalcid; (Soil Survey Staff, 2014). Dry beans were grown in the study field in the year (2012) before the start of the study. Bean residues were incorporated into the soil with disking after harvest. Historical 30-year average annual precipitation for Kimberly, Idaho was 203.7 mm and 20-year average annual temperature 7.7°C, based on daily precipitation and air temperature measurements collected from 1995 to 2015 (AgriMet Staff, 2016). The field was then seeded to spring malt barley (v. Moravian 69) in 2013 and sugar beets (STS-21RR25) in 2014. Barley and sugar beets were managed with standard production practices for the region (Moore et al., 2009; Roberts, 1993). The field was sprinkler irrigated during both study periods, with water application amounts of 31 cm in 2013 and 49 cm in 2014.

Table 2-1 Selected characteristics of 0-30 cm soil layer for Portneuf silt loam collected before planting from non-manure (control) plots on March 19, 2013.

	Soil depth	OM*	$CaCO_3$	pH	NO_3 N†	NH_4 N†
	cm	——%——			—mg kg^{-1}—	
Mean*	0-30	1.3	4.2	7.7	21.5	4.6
Std*	0-30	0.1	1.8	0.1	6.2	1.0
Mean*	30-60	0.8	17.5	7.8	-	-
Std*	30-60	0.1	0.6	0.1	-	-

*Mean values calculated from 4 composite soil samples from each depth; Std, standard deviation; OM, organic matter

†Ten samples from each of the 32 plots were composited on September 20, 2012 before dairy manure applications.

Soil temperature was monitored at a depth of 10 cm with a Thermistor model 44030 (YSI Inc., Yellow Springs, OH, USA) obtained from the Kimberly, Idaho Agrimet station located less than a mile from the study site (Agrimet Staff, 2016). Temperatures over the 2013 growing season were relatively warm compared to the 15 year average (Figure 2-1).

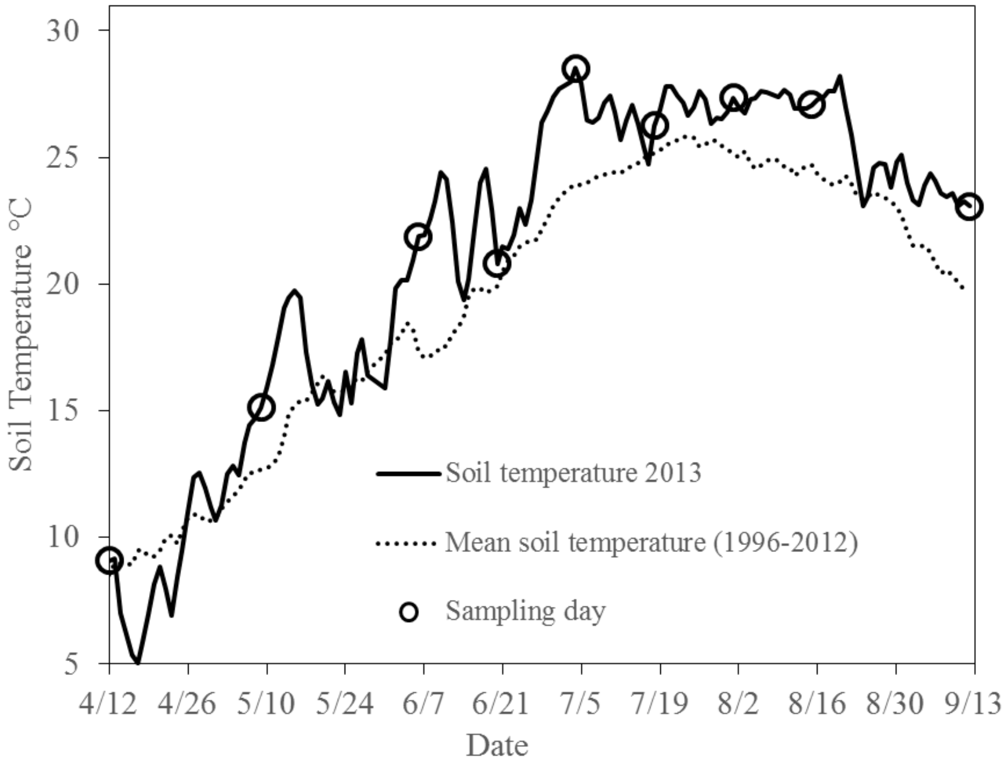

Figure 2-1 2013 Mean daily soil temperatures at a depth of 10 cm and 15 year mean daily soil temperature and buried bag removal dates.

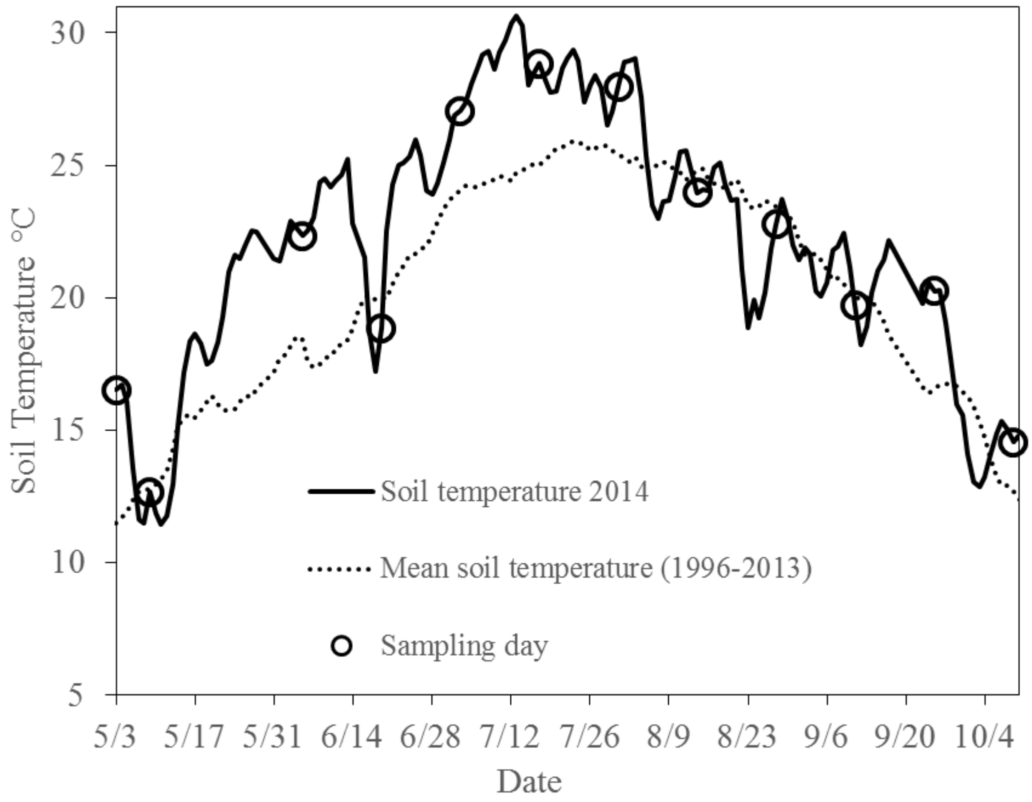

Figure 2-2 2014 Mean daily soil temperatures at a depth of 10 cm and 15 year mean daily soil temperature and buried bag removal dates

Treatment structure and experimental design

Treatments used in this study were dairy manure application frequency (annual or biennial), dairy manure application rate (17.3, 34.7, and 52.0 Mg ha^{-1}, on a dry weight basis), fertilizer treatment (chemical fertilizer applied at agronomic rates based on UI fertilizer guides), and a control treatment (no nutrient source applied) (Table 2-2). Therefore 8 treatments ((2 timings X 3 rates) + 1 fertilizer trt + 1 control trt) were included in the study. Treatments were replicated four times in a randomized complete block design, which equated to 32 experimental units in the study. Blocks were oriented from east to west due to apparent soil erosion in the field spanning north to south from repeated furrow irrigation events conducted prior to the study.

A typical stockpiled dairy cattle manure from the same dairy was used as the dairy manure source in 2012-2013 (annual and biennial treatments) and 2013-2014 (annual treatments only) of the study. This study was a long term manure study the results of year oner and two are reported in this work. The dairy manure was transported to the study field the first year on October 14, 2012, and on October 25, 2013 the second year. Dairy manure was applied to the study field at three rates (17.3, 34.7 and 52.0 Mg ha^{-1}, dry weight basis) on October 18, 2012 and November 7, 2013. Manure amounts for each plot were weighed in the spreader using a vehicle scale. The manure was applied with a Frontier Equipment small plot manure spreader model MS1117 (Frontier Equipment, Olathe, KS). Manure was evenly spread throughout the plot using a hand rake to insure uniform manure distribution following application. Manure was incorporated with a disk to a 15 cm depth on the same day as the application or one day after application to avoid ammonia volatilization losses. Annual and biennial manure treatment plots received manure in the fall of 2012; annual treatment plots received manure application in the fall of 2013.

On April 2, 2013, mono-ammonium phosphate (11 % N) and urea (46 % N) were applied to all plots except control plots. Mono-ammonium phosphate was applied at a N rate of 19 kg N ha^{-1} and P rate of 89 kg ha^{-1}; urea was applied at N rate of 62 kg N ha^{-1}. The fertilizer was applied with a drop down spreader with a 3.4 m spread. Fertilizer was incorporated into the soil to 10 cm with a roller harrow. Fertilizer rates were based on the Idaho spring barley production guide (Robertson and Starke, 1993). In the spring of 2014, urea (46% N) was applied to selected plots based on pre-plant soil tests (Table 2-2). Fertilizer was applied with a Barber spreader to the study field. The field was then roller harrowed directly after fertilizer was applied. Fertilizer rates were based on the University of Idaho sugar beet fertilizer guide (Moore et al., 2009).

Table 2-2 Manure application rates for 2012-2013 and 2013-2014 study years. Soil depth was 0-30 cm.

Study year	Manure application rate (dry wt.)	Cumulative manure application rate (dry wt.)	Manure N application rate	Cumulative manure N application rate	Fertilizer N application rate	Application interval
	——Mg ha^{-1}——		————kg N ha^{-1}————			
2012-2013	17.3	17.3	290	290	62	Annual
2012-2013	34.7	34.7	584	584	62	Annual
2012-2013	52.0	52.0	874	874	62	Annual
2012-2013	17.3	17.3	290	290	62	Biennial
2012-2013	34.7	34.7	584	584	62	Biennial
2012-2013	52.0	52.0	874	874	62	Biennial
2012-2013	Fertilizer	-	0	-	62	-
2012-2013	Control	-	0	-	0	-
2013-2014	17.3	34.7	258	548	84	Annual
2013-2014	34.7	69.4	518	1102	0	Annual
2013-2014	52	104.0	776	1650	0	Annual
2013-2014	0	17.3	0	290	84	Biennial
2013-2014	0	34.7	0	584	50	Biennial
2013-2014	0	52.0	0	874	0	Biennial
2013-2014	Fertilizer	0	0	0	84	-
2013-2014	Control	0	0	0	0	-

Monitoring N mineralization under field conditions using the buried bag method

We utilized the buried bag technique adapted from the method developed by Eno (1960) to measure inorganic N accumulations under field conditions. Nine (April 12, 2013) and twelve (May 3, 2014) 5.7 cm diameter soil cores were collected using a 5.7-cm bucket auger within each study plot. In 2013, six of the holes were augured from the 0-30 cm soil depth while three of the holes were augured from the 0-30 and 30-60 cm soil depths. All soils from the 0-30 cm depth were composited separately from soils composited from the 30-60 cm soil depth. On May 3, 2014, nine holes were augured from the 0-30 cm soil depth and four holes were augured from the 0-30 and 30-60 cm depth. Soils in each plot were composited separately by depth. Holes were augured in equal spacing near 1 m in distance apart in a single row placed equidistant between planted barley or sugar beet rows, and spanned from east to west in line parallel to the planted rows. Sugar beet rows were planted with 0.56 m spacing, thus holes were augured 0.28 m from sugar beets planted to the north and south. In 2013 the buried bag row was spaced 4.9 m from the east and west plot borders and 1.8 and 10.4 m from the south and north plot borders, respectively. In 2014, the buried bag row was spaced 3 m from the east and west plot borders and 3 and 9.2 m from the south and north plot borders, respectively.

Composited soil from each plot and each depth were used to fill low density (0.10 mm thickness) polyethylene tube shaped bags (Wagner Packaging Solutions (Stock No. PT0304)). Tubes were cut by hand to a length of 62.2 cm for the 0-30 soil depth bags; 106.6 cm length tubes were cut for the 0-30 and 30-60 combination tubes. Soil was packed into the bags with vertical hand shaking. The dimensions of the soil filled tubing were 28 cm with a 5.7 cm diameter. A simple knot was tied to seal the top and bottom of each bag, leaving 15 cm at the top to allow for an adequate hand gripping surface during bag removal. One meter of neon marking tape was tied to the top of each bag to later assist personnel in locating the bags. Bags were then placed back into the holes corresponding with the depth from which they were originally removed from. The extra 15 cm bag length was folded downwards then secured by pushing the piece by hand down between the buried bag and the field soil, to prevent pooling of precipitation and irrigation water and to also prevent snagging on field equipment. The auger holes containing the buried bags were then hand covered with 5-10 cm of soil leaving only the marking tape protruding and visible on the soil surface. Composite soil samples were collected in quart sized zip-lock bags from the same soil used to fill the incubation bags from each plot at both the 0-30 cm and 30-60 cm soil depths. These soils were analyzed for ammonium-N and nitrate-N, provide the initial (time=0) inorganic N concentrations from which measured inorganic N concentrations monitored later (time=x) resulting in cumulative net N mineralization data.

The total number of bags that were buried in 2013 was 384, with 192 “short bags” buried at the 0-30 cm soil depth and 96 “long bags” buried at the 0-30 and 30-60 cm soil depth. The total number of soil filled bags that were buried in 2014 was 512, with 384 “short bags” buried at the 0-30 cm soil depth and 128 “long bags” buried at the 0-30 and 30-60 cm soil depth. Soil filled polyethylene bags buried at the 0-30 cm depth were removed at monthly (April and May) and biweekly (June, July, August, September, and October) time intervals throughout the study season (Appendix Table 2-4). Bags were sampled at monthly intervals instead of biweekly intervals in April and May, because N mineralization rates in the early growing season were not expected to change as quickly relative to the later heat intensive months of the growing season. In 2013 soil filled bags buried at the 30-60 cm depth were removed monthly in June, July, and August. In 2014 soil filled bags were similarly removed in June, July, August, and September (Appendix Table 2-4). Soil moisture content was near field capacity in both years with the gravimetric soil water content at the time of bag construction averaging 19.6% (standard deviation 1.1%) and 19.2% (standard deviation 2.7%) in 2013 and 2014, respectively.

Plant N uptake and buried bag soil nutrient analysis

At each collection date, nitrate-N and ammonium-N were extracted with 25 ml of 2 M potassium chloride from 5.0 grams of field moist soil from each polyethylene bag (Mulvaney, 1996). Soil solution samples were then shaken for 30 minutes in an Eberbach variable speed shaker at 160 rpm with a 3.8 cm orbit (Eberbach Corp., Ann Arbor, Michigan). Soil solution samples were settled for 20 minutes, filtered through #40 Whitman filter paper into 25 ml scintillation vials, and stored in a freezer at -10 °C. Extracts were analyzed after the growing season with a Lachat Quickchem 8500 series Flow Injection Analyzer (Lachat Instruments, Loveland, Colorado) for nitrate-N and ammonium-N. Nitrate-N concentration was analyzed using the cadmium reduction method (Method 12-107-04-1-B); ammonium-N concentration was determined using the salicylate-hypochlorite method (Method 12-107-06-2-A). A moisture correction was used for accurate determination of nitrate and ammonium concentrations, as field-moist soils were used for potassium chloride extractions to avoid ammonia loss during the soil drying process

Preplant soils, plant and dairy manure collection and analyses

Composite soil samples were collected on March 19, 2013 in eight quart sized zip-lock bags by compositing 10 hand augured samples from the 0-30 cm soil depth and 5 samples from the 30-60 cm soil depth. These soils were collected from non-manured (control) soils. This collection scheme was repeated in each of the four replications totaling 40, 0-30 cm samples and 20, 30-60 cm samples. Total soil organic matter was determined by the Sims/Haby colorimetric method (Sims, 1971) using a Milton Roy Spectronic 301 spectrophotometer (Milton Roy Co., Warminster, PA). A modified pressure calcimeter method was used to determine the percent of calcium carbonate in the soil (Gavlak, 2005). Soil pH was measured with a digital Orion pH meter (Thermo Scientific, Waltham, MA) following saturated paste method.

Spring barley and sugar beets were planted in the study site field in 2013 and 2014, respectively. Barley tops (grain and vegetative portions combined) were sampled at medium milk stage (Feekes scale 11) on July 24, 2013, 12 days prior to barley harvest. The above-ground barley biomass was sampled from two randomly selected locations within 1.5 m of the plot boundary. Each sample was collected from a 0.18 m row, 0.91 m long resulting in a total sampling area of 0.33 m^2. Above-ground plant tissue was collected by clipping plants at the soil level and weighing. Subsamples of the clipped biomass collected by grabbing random handfuls (representative of tillers, stem and heads) were weighed, dried at 60 °C for 72 hours, and weighed again. Above ground biomass yield and whole plant moisture content were calculated.

Sugar beet tops and roots were destructively sampled from each plot on September 30, 2014, 3 days prior to sugar beet harvests. The sampling scheme consisted of five adjacent whole beet plants from a section of 0.56 m by 0.70 m within a single row (area =0.39 m^2), located 3 m from the east plot edge, and 4.45 m (9th 0.56 m beet row) from the south edge of the plot. The plant top portion (leaves, petioles, and crowns) was separated from the sugar beet at the crown of the plant by hand with a beet knife. Wet weights for tops and roots were collected separately at the field site to estimate biomass yield for tops and roots. Approximately 15-25 leaves from the tops sample were subsampled, weighed, dried for 72 hours at 60 C, and weighed again to estimate moisture content and dry matter yield. Roots were washed to remove soil, subsampled by cutting each beet in half lengthwise, discarding one of the halves, and cutting the remaining half into 2.5 cm cubes by hand. Field moist 2.5 cm-sized root cubes were ground using a Vitamix blender (Vitamix Corporation, Cleveland, OH, USA) on high for 3 to 5 minutes, with addition of distilled water from 10 to 50 ml to assist with blending of the beet root, as needed. The root “puree” was then spread on parchment paper at a thickness of 0.25 to 0.50 cm and dried for 72 hours at 60°C. A separate subsample of field moist root cubes were weighed, dried for 72 hours at 60 C, and weighed again to estimate root yield (dry weight basis) and moisture content.

Dried barley (above ground grain and vegetation) and sugar beet (tops and roots) samples were ground with a Wiley mill model number two to pass a 1 mm screen. Dried and ground tops and roots were analyzed for total N through combustion analysis (LECO Corporation, 1998). Barley and sugar beet N uptake was calculated by multiplying dry matter yield by the plant tissue N concentration (dry weight basis). This calculation was done for sugar beet roots and tops separately, which were summed to determine total N uptake of the whole sugar beet plant.

Composite dairy manure samples were collected on October 18, 2012 the first study year and on November 6, 2013 the second study year in three quart sized zip-lock bags manually by collecting between 6 and 8 subsamples from the manure pile. Dairy manure samples were stored in a fridge until they were placed in a cooler with ice packs for a period of 1-2 weeks and mailed overnight to SoilTest laboratories in Moses Lake, Washington for analysis. The amount of water contained in manure was determined gravimetrically on 100 g sub-sample by drying at 105°C for 8 hours. Total N and C concentration of the dairy manure were analyzed using the dry combustion method on moist sub samples with the LECO CHN 628 analyzer (method B-2.2) (Gavlak, 2005). Total N and C data were then used to determine the manure C to N ratio. Nitrate and ammonium concentrations of the manure was measured (5 g manure: 25 mL extractant) using 2 M KCl extraction (Gavlak et al., 2005). An automated flow injection analyzer was used to measure the supernatant for nitrate and ammonium concentrations. Nitrate–N concentration was determined with cadmium reduction (Lachat Method 12-107-04-1-B) and ammonium–N concentration was determined with the salicylate hypochlorite method (Lachat Method 12-107-06-2-A) (Lachat Instruments, Loveland, CO). Ash content was calculated by loss on ignition (Gavlak, 2005) using a muffle furnace. Measured manure characteristics are presented in Table 2-3.

Table 2-3 Properties of composited dairy manure that was applied to the N Mineralization study field on October 18, 2012 and November 7, 2013.

	Total N	Total C	C:N	NO_3-N	NH_4-N	Moisture	Ash
	—— % ——			— mg kg^{-1} —		—— % ——	
October 18, 2012							
Mean	1.78	30.3	17.0	14.9	2238.4	41.0	36.4
Std	0.20	3.4	1.5	3.7	1572.9	15.5	7.2
November 7, 2013							
Mean	2.87	37.1	13.0	55.0	2836.0	46.0	31.2
Std	0.50	3.1	1.7	68.6	1365.9	25.5	1.3

* Std, standard deviation

Zero-order modelling of net N mineralization

The quantity of N mineralized in sequentially exhumed buried bag soils, (cumulative net N mineralization) was determined for each plot by subtracting initial inorganic N values from inorganic N at a given time, t (days incubated), where;

Cumulative net N mineralization (mg kg^{-1} soil) = Inorganic N_t – Inorganic $N_{t=0}$ [Eq. 1]

Cumulative net N mineralization kinetics were fit to a zero-order linear model (Cabrera et al., 2008). Rate coefficients of cumulative net N mineralization were calculated from fitting the zero order model to cumulative net mineralization versus time (t) using SAS PROC REG (SAS Institute, 2013).

Cumulative net N mineralization of manure (mg kg^{-1} soil) = k * t+b [Eq. 2]

where

k is the rate coefficient of net N mineralization (mg inorganic N kg^{-1} day^{-1}),

b is the net N mineralization at time zero

Rate coefficients (k) were determined for individual treatments by year and by soil depth (0-30 and 30-60 cm).

Statistical analysis

The SAS 9.3 software package was used to conduct various statistical analyses of this dataset (SAS Institute, 2013). Significance was determined at the 0.05 probability level. We analyzed data from 2013 and 2014 separately. The generalized linear model (PROC GLM) was used to determine the effect of dairy manure application rate and application interval on soil inorganic N concentrations at the initial (spring) and final (fall) soil sampling dates for the 0-30 and 30-60 cm soil depths. Included contrast statements tested for potential linear or curvilinear (quadratic) effects of manure rate (no manure-control, 17.3 Mg ha^{-1}, 34.7 Mg ha^{-1}, and 52.0 Mg ha^{-1} rate) on soil inorganic N, for annual, then biennial applications. We included an additional contrast to test for differing effects of the two no-manure treatments control vs. fertilizer, on soil inorganic N.

The generalized linear model (PROC GLM) was used to determine the effect of dairy manure application rate and application interval on net N mineralization by fitting a linear equation to the observed data for the 0-30 and 30-60 cm soil depths. Replications were not averaged for these estimations. The zero-order linear model was selected for estimating N mineralization rate (k), N mineralization amount, the y-intercept, and data variability (r-square). As described above, linear or quadratic trend contrasts describing the effect of increasing factor levels ((2 timings X 3 rates) + 1 control trt) on the response variable (zero order model parameter k) were estimated separately for annual and biennial treatment rates. An additional contrast was included to test for equivalence in k values between individual treatments concerning 2013 data at the 0-30 cm and 30-60 cm soil depths separately for control vs. fertilizer (0-30 and 30-60cm). Similarly, additional contrasts were included to test for equivalence in k values between individual treatments and between groups of treatments concerning 2014 data at the 0-30 cm and 30-60 cm soil depths separately and are as follows: control vs. fertilizer (0-30cm and 30-60 cm), 17.3 annual vs. 34.7 biennial (0-30 and 30-60 cm), 17.3 biennial vs. control (0-30cm), 34.7 biennial vs. control (0-30cm), 52.0 biennial vs. control (0-30 cm), 52.0 annual vs. control (30-60 cm), 52.0 biennial vs. control, all annual treatments as a group vs. control and fertilizer as a group, and all biennial treatments as a group vs. control and fertilizer as a group.

The generalized linear model (PROC GLM) as described above was also used to calculate the standard error, which was used to calculate the 95% confidence interval error bars for the zero order model parameter k, by multiplying the standard error by 1.96 yielding estimated k value plus or minus that amount.

The correlation between plant N uptake and estimated soil inorganic N amount at the time of destructive plant sampling (0-60 cm depth) was determined with linear regression in addition to Pearson and Spearman correlations using PROC REG and PROC CORR, respectively.

Results and discussion

Growing season treatment effects following first time fall –applied amendments

Spring and summer in-situ nitrogen mineralization (0-30 and 30-60 cm soil depth)

Annual and biennial manure plots received the same manure treatments in fall, 2012 and therefore produced similar N mineralization results in 2013. To avoid redundancy only results from annual manure treatments in 2013 will be discussed unless explicitly noted. Year one and year two are discussed in the present study, where annual plots receive manure every fall and the biennial plots receive manure every other fall. To maintain consistency between study years the annual and biennial labeling are used in this document.

Where manure was applied, both the starting (April 12, 2013) and ending inorganic N concentrations at 0-30-cm depths increased linearly with manure rate (Tables 2-4 and 2-5, Fig. 2-3). This finding indicates definite nitrification of ammonia compounds, and potential ammonification of readily mineralizable organic N compounds. For the period between fall manure application and spring soil sampling, mean soil temperature at a soil depth of 10 cm was above 5 °C for 40 days of the 176 day (Agrimet Staff, 2016). Nitrogen mineralization has been described to occur above a temperature of 5°C (Campbell, 1972; Stanford et al., 1973; Sierra, 1997; Katterer et al., 1998). This finding suggests that Portneuf silt loam soils can be sufficiently warm over the winter for positive net N mineralization to occur. It should be noted that N fertilizers had been applied to treatments in addition to manure amendments. However, the urea and MAP fertilizers were applied at the same rate of 62.0 kg N ha^{-1} to all manure treatments and to the fertilizer treatment in the spring of 2013, therefore the effect of adding manure on winter N mineralization can be made here.

Researchers in southern Idaho directly monitoring overwinter net N mineralization from fall applied dairy cattle manure at two rates of 21.9 and 43.8 Mg ha^{-1} (dry wt.) with a manure N content 350 and 701 kg ha^{-1} to a Greenleaf silt loam reported that net N mineralized over the winter was negligible (Lehrsch et al., 2016). Other researchers directly monitored over-winter N mineralization in noneroded and eroded Portneuf silt loam soil after fall dairy manure applications (0 to 45.7 Mg ha^{-1}dry wt., with a manure N content of 0 to 850 kg N ha^{-1}) (Lentz et al., 2011). They found that net N mineralization increased with increasing manure applied, but only in the eroded soil (R.D. Lentz, personal communication, 2017). Researchers in both of these studies concluded that increased immobilization was likely the cause for low over-winter net inorganic N concentrations. These varied results indicate that fall dairy manure applications can result in negative, zero or positive net N mineralization, depending on factors such as winter soil temperatures, dairy manure application rate, and dairy manure composition. Therefore, winter temperatures, dairy manure composition, and the dairy manure application rate should be considered when estimating manure N contribution to the spring inorganic N pool. More research is needed to better understand overwinter N mineralization potential of fall applied dairy manure.

Table 2-4 Mean inorganic N concentrations in a Portneuf silt loam (0-30 cm depth) incubated in the field at the same soil depth in polyethylene bags near Kimberly, Idaho over the 2013 growing season. Dairy manure was applied on October 18, 2012. Experimental design is a RCBD with four replications.

Manure application rate (dry)	Manure N application rate	Fertilizer N application rate	Application interval	Starting inorganic N 04/12/2013	Ending inorganic N 9/12/2013
Mg ha^{-1}	——kg ha^{-1}——			——mg kg^{-1}†——	
17.3	290	62	Annual	26.9	49.5
34.7	584	62	Annual	26.1	54.9
52.0	874	62	Annual	35.7	71.8
17.3	290	62	Biennial	27.7	52.6
34.7	584	62	Biennial	27.2	50.8
52.0	874	62	Biennial	31.0	62.5
Fertilizer	0	62	-	25.5	43.9
Control	0	0	-	18.0	36.3

† Multiply mg kg^{-1} values by 4.5 to convert to kg ha^{-1}, assuming a soil bulk density of 1.48 g cm^{-3}

Table 2-5. Statistical tests to determine if the effect of manure rate on 2013, 0-to-30-cm cumulative N mineralization values is linear or curvilinear (quadratic), and if control and fertilizer treatments are equivalent. Annual and biennial manure effects are tested separately and soil inorganic N responses are assessed at the beginning (April 12) and end (Sept. 12) of the 2013 growing season. Dairy manure was applied on October 18, 2012.

Statistical analysis	Application interval†	Date	Pr > F
Control vs. fertilizer	-	4/12	0.0512
Linear	annual	4/12	0.0002
Quadratic	annual	4/12	0.8990
Linear	biennial	4/12	0.0028
Quadratic	biennial	4/12	0.2664
Control vs. fertilizer	-	9/12	0.3969
Linear trend	annual	9/12	0.0005
Quadratic trend	annual	9/12	0.7611
Linear trend	biennial	9/12	0.0174
Quadratic trend	biennial	9/12	0.7241

† Annual and biennial manure treatments received the same manure rate in 2013.

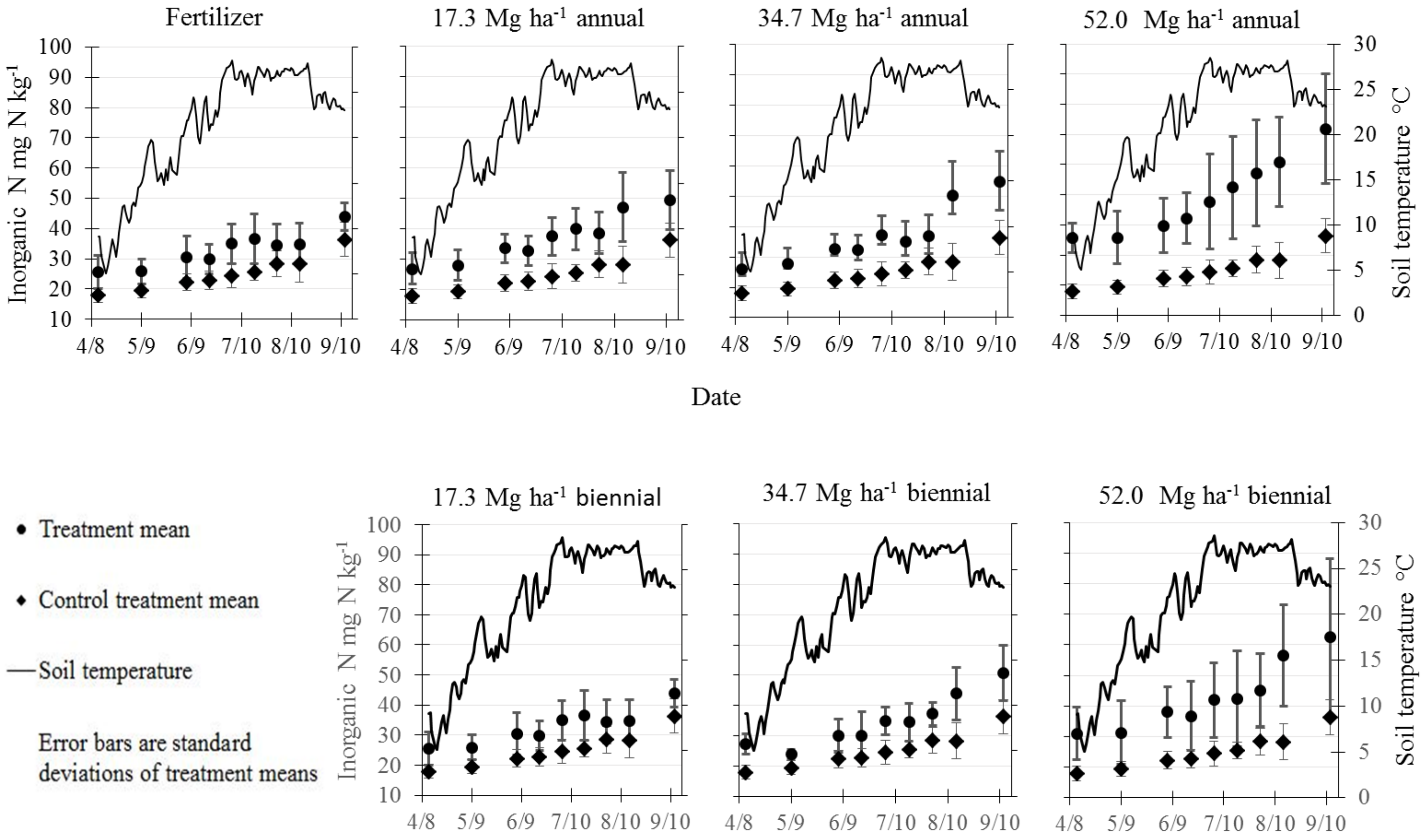

Figure 2-3 Inorganic N concentrations in a Portneuf silt loam (0-30 cm depth) incubated in the field at the same soil depth in polyethylene bags near Kimberly, Idaho in 2013. Dairy manure was applied on October 16, 2012. Experimental design is a RCBD with four replications.

Initial inorganic N concentrations at time zero (April 12, 2013) in soils receiving annual fall dairy manure applications at a depth between 30-60 cm increased following a quadratic pattern with increasing manure rates of 0, 17.3, 34.7 and 52.0 Mg ha^{-1} (Tables 2-6 and 2-7). This finding though does not provide adequate evidence that dairy manure applications up to 52.0 Mg ha^{-1} contributed appreciably to subsoil inorganic N pools because inorganic N concentrations were inconsistent between annual and biennial applications. One would expect to find a treatment response for both annual and biennial manure applications as manure was applied to annual and biennial study plots in the fall of 2012. In addition, annual manure treatments of 17.3 and 34.7 Mg ha^{-1} resulted in mean inorganic N concentrations that were less than control soils while the annual manure application of 52.0 Mg ha^{-1} resulted in a mean inorganic N concentration that was 6 mg kg^{-1} greater than that of the control treatment. Due to the relatively small difference in treatment effects these results are inconclusive.

Analysis results of inorganic N concentrations in soils at the 30-60 cm depth indicated that there was not a manure treatment effect for the last buried bag removal and sampling date of August 16, 2013 (Tables 2-6 and 2-7). These results show that growing season inorganic N crediting derived from fall applications of dairy manure past a 30 cm soil depth was not appropriate in this case.

Table 2-6 Mean 2013, inorganic N concentrations at 30-60-cm depth in initial spring soils and at growing season's end after incubation in polyethylene bags (at the same soil depth) . Dairy manure was applied on October 16, 2012. (n=4)

Manure application rate (dry)	Manure N application rate	Fertilizer N application rate	Application interval	Study start mean inorganic N 4/12/2013	Study end mean inorganic N 8/16/2013
Mg ha^{-1}	——kg ha^{-1}——			———mg kg^{-1}†——	
17.3	290	62	Annual	13.2	17.1
34.7	584	62	Annual	14.2	17.9
52.0	874	62	Annual	22.3	20.8
17.3	290	62	Biennial	16.1	20.0
34.7	584	62	Biennial	17.7	16.2
52.0	874	62	Biennial	16.0	20.7
Fertilizer	0	62	-	14.0	19.3
Control	0	0	-	16.6	18.5

† Multiply mg kg^{-1} values by 4.5 to convert to kg ha^{-1}, assuming a soil bulk density of 1.48 g cm^{-3}

Table 2-7 Statistical tests to determine if the effect of manure rate on 2013, 30-to-60-cm soil inorganic N concentrations is linear or curvilinear (quadratic), and if control and fertilizer treatments are equivalent. Annual and biennial manure effects are tested separately and soil inorganic N responses are assessed at the beginning (April 12) and end (Sept. 12) of the 2013 growing season. Dairy manure was applied on October 18, 2012.

Statistical analysis	Application interval†	Date	Pr > F
Control vs. fertilizer	-	4/12	0.4615
Linear	annual	4/12	0.1247
Quadratic	annual	4/12	0.0322
Linear	biennial	4/12	0.9680
Quadratic	biennial	4/12	0.8142
Control vs. fertilizer	-	8/16	0.8294
Linear	annual	8/16	0.5077
Quadratic	annual	8/16	0.4078
Linear	biennial	8/16	0.8141
Quadratic	biennial	8/16	0.5791

† Annual and biennial manure treatments received the same manure rate in 2013.

These results indicate that crop producers may need to credit both overwinter and growing season N release of dairy manure fall applied at rates of 17.3, 34.7, and 52.0 Mg ha^{-1} to a soil depth of 30 cm. For fall-manure applications, a preplant soil test in the following spring provides an accounting of overwinter N release. Note that crops with moderate to high N requirements may need supplemental N fertilizer if preplant soil tests are low or for manure applications ≤ 34.7 Mg ha^{-1}. Ultimately, N fertilizer application rates depend on a combination of factors that include; initial soil test N, dairy manure application rate, the crop being grown, the realistic yield expected from that crop and previous amendments and crop residues in the soil.

For example, based on the University of Idaho sugar beet fertilizer guide, sugar beets require between 146 and 370 kg N ha^{-1} depending on expected yield (Moore et al., 2009). In the present study, net nitrogen mineralized in the first season from one-time fall dairy manure applications (17.3 to 52.0 Mg ha^{-1} dry wt.) ranged from 25.0 to 126.0 kg N ha^{-1} (soil and fertilizer inorganic N subtracted)(Table 2-4). Thus, soil amended with 52.0 Mg ha^{-1} manure could provide 324 kg N ha^{-1} total plant available N over the growing season, including 198 kg ha^{-1} from soil and fertilizer and 126 kg ha^{-1} from manure (Table 2-4). Inorganic N amounts shown in kg ha^{-1} were calculated by multiplying the inorganic N concentration (mg kg^{-1}) by 4.51 considering a soil bulk density of 1.48 g cm^{-3}. While this amount of N is adequate for optimum growth and yield for most Idaho crops, one must also consider the pattern of season-long N availability relative to that of crop uptake when determining dairy manure and fertilizer application rates. For example, sugar beet yields can be diminished greatly if there is not enough early season N available (Carter and Traveller, 1981). Additionally, sugar beet quality can be reduced if there is too much late season N resulting in sugar losses and increased nitrate impurities (Tarkalson, 2012). Determining the in-season N mineralization potential of dairy manure is critical in maximizing agronomic benefit of this plant nutrient source.

Growing season in-situ net N mineralization (0-30 cm soil depth) in 2013

Soil net N mineralized in sequentially exhumed buried bags increased linearly at the alpha 0.01 level throughout the sampling period for all treatments at the 0-30 cm depth. Also, nitrogen mineralization rate (k value) in soils receiving fall dairy manure applications at 0-to-30-cm depth increased linearly (and not quadratically) with increasing manure rates of 0, 17.3, 34.7 and 52.0 Mg ha^{-1} (Table 2-8). This finding further supports our conclusion that the linear zero-order model, rather than the first or second order models, best describes our N mineralization data.

Table 2-8 Statistical tests to determine if the effect of fall dairy manure rates (0 (control), 17.3, 34.7 and 52.0 Mg ha^{-1}) on 2013, 0-to-30-cm soil depth growing season cumulative net nitrogen mineralization rates (k value) is linear or curvilinear (quadratic), and if individual biennial manure treatments (17.3, 34.7 and 52.0 Mg ha^{-1}) k values are equivalent to control k values. In addition, control and fertilizer k values are tested for equivalence. Annual and biennial manure effects are tested separately. Dairy manure was applied on October 18, 2012.

	Application interval†	Pr > F
Control vs. fertilizer	-	0.9972
Linear trend	annual	<.0001
Quadratic trend	annual	0.5009
Linear trend	biennial	<.0001
Quadratic trend	biennial	0.8108

† Annual and biennial manure treatments received the same manure rate in 2013.

We used the zero-order model to estimate cumulative net N mineralization values for the 2013 ending-season (Sept. 12) buried bag soils; giving final values of 22, 26, and 33 mg N kg^{-1} for 17.3, 34.7 and 52.0 Mg ha^{-1} manure treatments, respectively (Table 2-9). Mean net mineralized N (mg kg^{-1}) from this study and other similar studies are illustrated with linear regression in Figure 2-4. This linear regression was derived by collecting secondary data from the literature concerning other studies on net N mineralization after fall applications of dairy manure to Portneuf silt loam or Greenleaf silt loam soils using the buried bag method over the spring to fall time period. The results of linear regression derived from the literature indicated that model fit was fair, with an r-square of 0.54. Based on the resulting model equation, net N mineralization increased by 2.4 mg N kg^{-1} for every 100 kg N ha^{-1} that was contained in dairy manure and was fall applied (Fig. 2-4). The regression analysis limited to the data in the present study was similar; with growing season net N mineralization increased by 1.9 mg N kg^{-1} for every 100 kg N ha^{-1} dairy manure N that was fall applied.

Soil temperatures during the 2013 growing season were relatively warm compared to the 15 year average (Fig. 2-1). Soil temperatures peaked and remained relatively high from

July 4 to August 15, 2013. Net nitrogen mineralization rates though did not appear to directly coincide with the rate of increasing soil temperature, but instead appeared to increase 4 to 6 weeks after temperature increased. When mean daily soil temperatures increased from 21 to 29 °C between June 20 and July 4, one may expect N mineralization rates to also increase for the same time period. The increase in N mineralization did occur though its onset was not until August 1, illustrating that nitrifier populations had a 4-6 week lag period to have high enough populations to support this increased rate of nitrification in the soil. Mean daily soil temperatures remained relatively warm through July and August with a range of 23 to 29 °C and mean of 27 °C. Net nitrogen mineralization rates remained high after the first of August and through the remainder of the sampling period. Treatment effects on cumulative net N mineralized in sequentially exhumed 0-30 cm buried bag are illustrated in Figure 2-5.

Nitrogen mineralization rates will likely fluctuate in future years from the 2013 values, as temperature will be different each year. Monitoring N mineralization as affected by fluctuating soil temperatures was not an objective of this study. Additional research is warranted to determine if accounting for unique soil temperatures for a given year will improve dairy manure nutrient management efficiency.

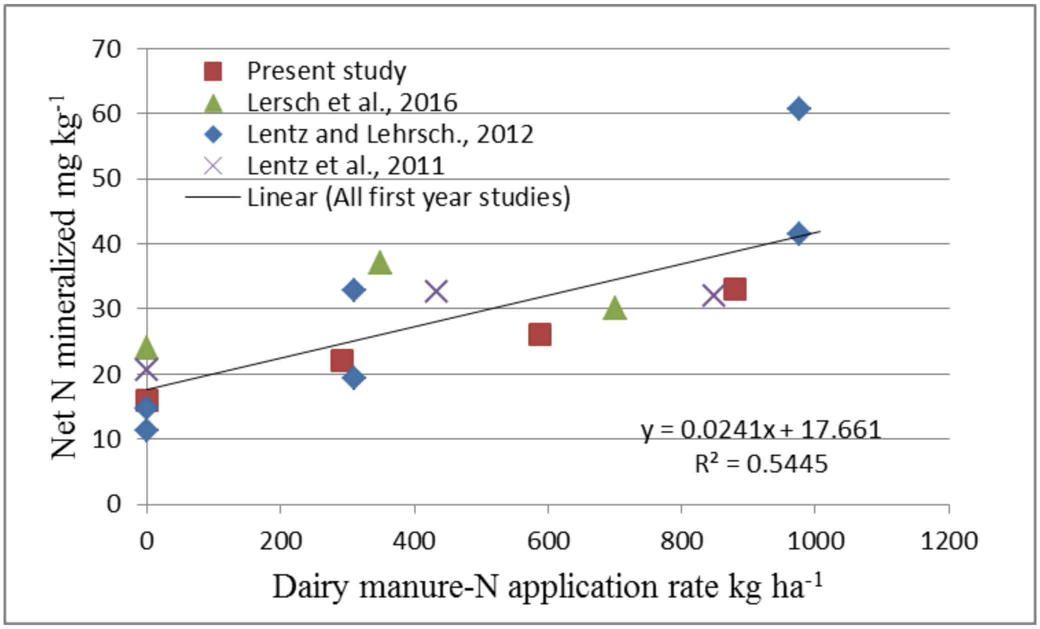

Figure 2-4 Literature review of soil net N mineralization and cumulative net N mineralization in southern Idaho conditions occurring between the spring and fall time period after first time dairy manure applications

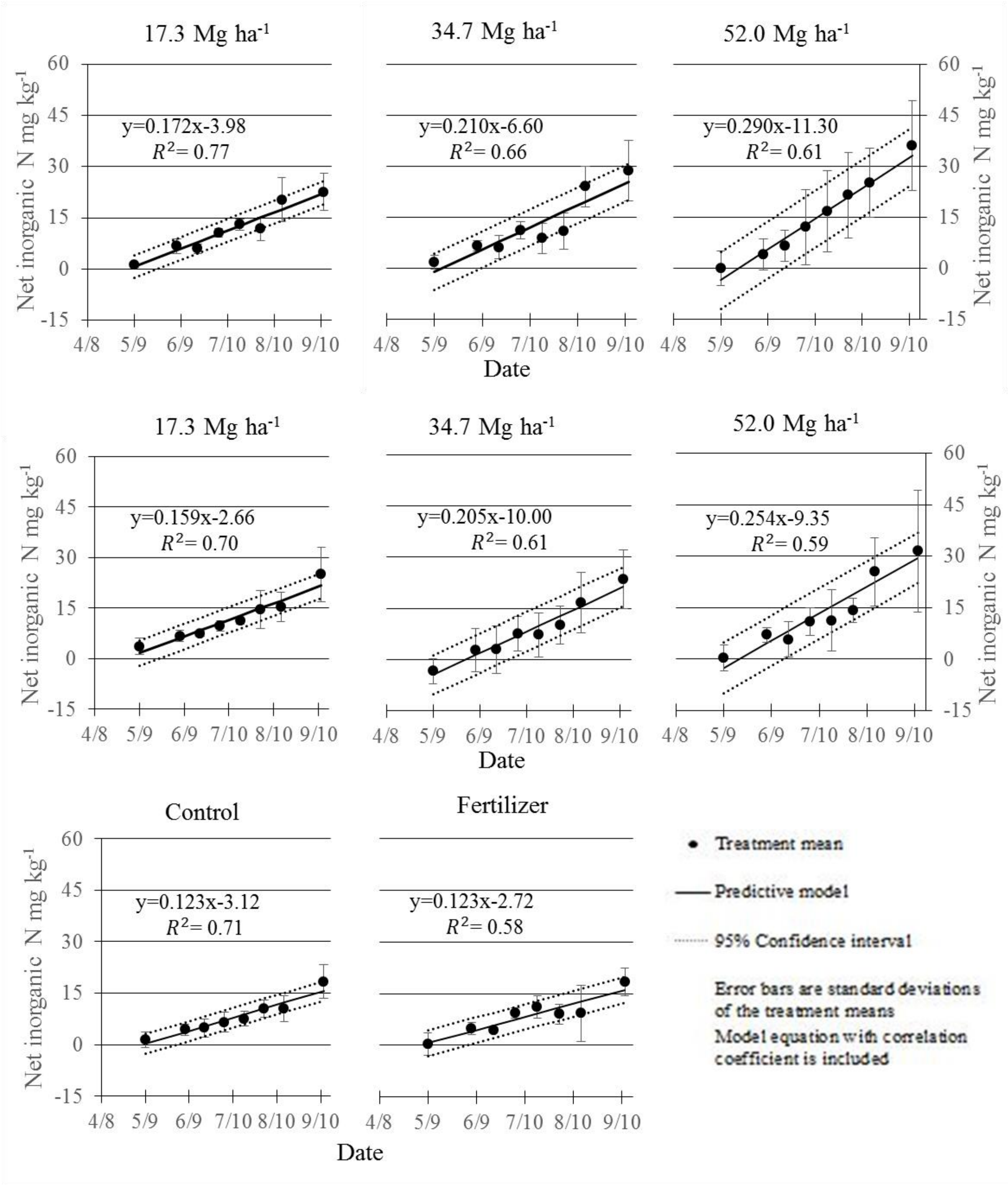

Figure 2-5 Treatment effects on cumulative net N mineralized in sequentially exhumed 0-30 cm buried bag soils for 2013 (n=4), with treatment regression lines (= zero-order models) and 95% confidence limits on predictions (n=24) Linear regression was calculated on replication values.

Table 2-9 Zero order model summary and measured and predicted cumulative net mineralized in a Portneuf silt loam (0-30 cm depth) incubated in the field over the 2013 growing season at the same soil depth in polyethylene bags near Kimberly, Idaho. Dairy manure was applied on October 16, 2012. Experimental design is a RCBD with four replications.

Manure rate (dry)	Manure application interval	Zero order rate coefficient (k)	Intercept	Predicted net inorganic N 7/18	Predicted Inorganic N released 7/18	Measured Net Mean Inorganic N 7/18	Predicted net inorganic N 9/12	Measured net mean inorganic N 9/12
Mg ha^{-1}		mg kg^{-1} day^{-1}	——mg kg^{-1}†——		% ‡	————mg kg^{-1}†————		
17.3	annual	0.172	-4.0	13	57	13	22	23
34.7	annual	0.210	-6.6	14	54	9	26	29
52.0	annual	0.290	-11.3	17	51	17	33	36
17.3	biennial	0.159	-2.7	13	59	11	22	25
34.7	biennial	0.205	-10.0	10	46	7	21	24
52.0	biennial	0.254	-9.3	15	52	11	29	31
Control	-	0.123	-3.1	9	56	8	16	18
Fertilizer	-	0.123	-2.7	9	57	11	16	18

‡ These values represent the predicted % inorganic N mineralized by July 18 of the total inorganic N predicted to mineralize at the end of the study on September 9.

† Multiply mg kg^{-1} values by 4.5 to convert to kg ha^{-1}, assuming a soil bulk density of 1.48 g cm^{-3}

The response of 2013 soil net N mineralization rate (k value) to increasing 2012 manure application rates is illustrated in Figure 2-6. The regression analysis indicated that net N mineralization rates increased linearly with manure rate, by 0.0028 mg kg^{-1} day^{-1} for each Mg ha^{-1} increase in manure application rate in 2013. Manure applied at the low rate of 17.3 Mg ha^{-1} mineralized at 1.4 and 1.3 times the mineralization rate of the control treatments (Table 2-9). Manure applied at the moderate rate of 34.7 Mg ha^{-1} had 1.7 times the mineralization of the control treatments. Manure applied at 52.0 Mg ha^{-1} (annual and biennial) had 2.4 and 2.1 times the mineralization rate as control treatments. The increase in N mineralization rates with increasing manure application rates is likely caused by increasing soil microbial activity. It is well documented that adding organic amendments such as manure results in increased microbial activity as well as microbial biomass (Hopkins and Shiel 1996; Ritz et al. 1997; Bossio and Scow 1998; Griffiths et al.1998; Simek et al. 1999; Parham et al. 2003). These results indicate that activity of ammonifying and nitrifying soil microorganisms is limited by mineralizable N containing substrates in Portneuf silt loam soils at manure N rates at least up to an application rate of 874 kg ha^{-1}, respectively (52 Mg ha^{-1} bulk manure, dry wt.).

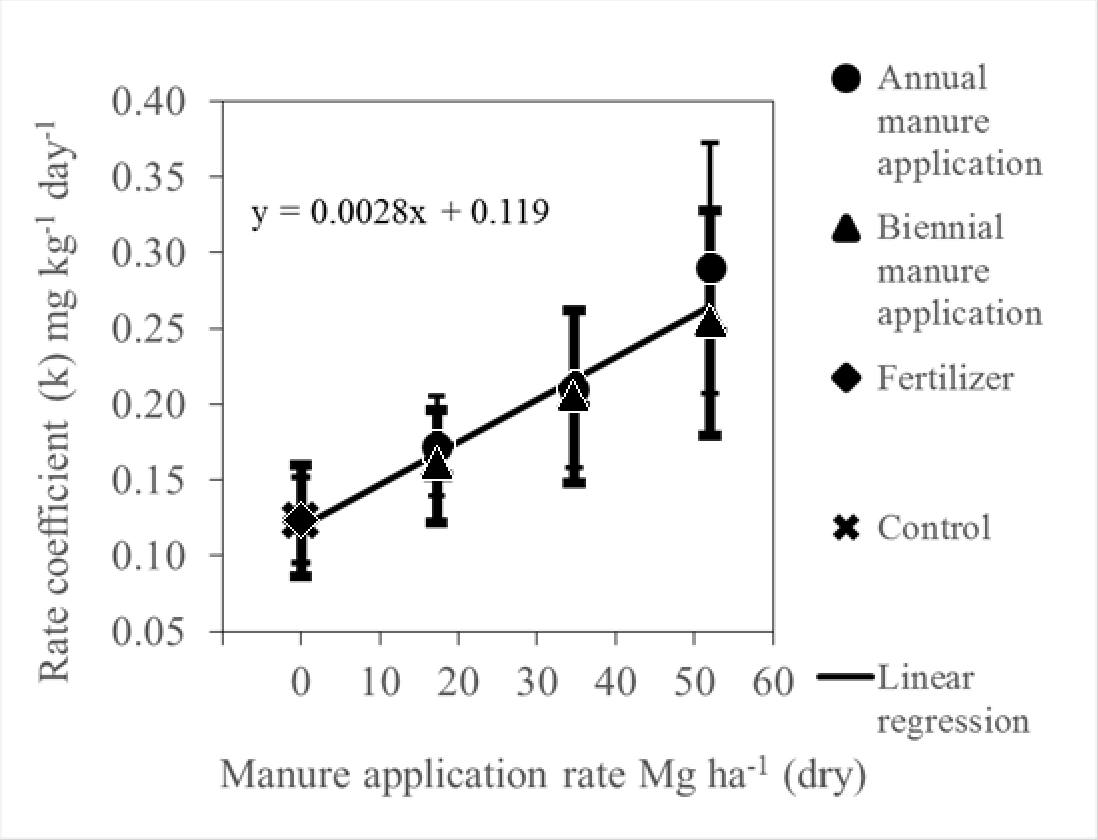

Figure 2-6 Comparison of rate coefficients (k) of zero order N mineralization predictive models from a Portneuf silt loam (0-30 cm depth) incubated in the field at the same soil depth in polyethylene bags near Kimberly, Idaho. Dairy manure was applied on October 16, 2012. Experimental design is a RCBD with four replications. Linear regression line includes both annual and biennial data.

Zero-order models were used to estimate cumulative net N mineralized in the 2013 “early season” (April 12 to July 18) and “late season” (July 18 to Sept. 12) after the first-time, fall, 0-to-52-Mg ha^{-1} manure applications. The four application rates with manure N contents of 0, 292, 588, and 874 kg ha^{-1} produced net mineralized N amounts of 9, 13, 14, and 17 mg kg^{-1}, early in the season, and 7, 9, 12, and 16 mg kg^{-1} late in the season (Table 2-9 and Fig. 2-5). Spring barley and sugar beets require early season plant available N to facilitate stand establishment and crop growth resulting in maximum crop yield (Robertson and Stark, 1993; Hill and Ulrich, 1971). The results of this study show that an average of 54% of the total manure N that mineralized during the 153 day study period was released from April 12-July 18. This result shows that first time fall applied dairy manure contributed appreciably to crops early season N needs thus making dairy manure an effective early season N fertilizer. It is important to note that small grains are relatively poor scavengers of N, resulting in appreciable amounts of mineralized manure N being left in the field after harvest, potentially causing an environmental hazard due to possible offsite transport of manure nitrates. The release timing of mineral N from dairy manure is also important in the late season. Late season manure N release can likely be attributed to dairy cattle manure being comprised of significant recalcitrant and intermediary N release fractions such as lignin and cellulosic materials, respectively. Sugar beets are especially sensitive to late season N release resulting in decreased sugar content, increased nitrate impurities, both of which reduce sugar beet profitability. Late season manure N mineralization should be taken into account when determining dairy manure application rate the previous fall. Management of late season manure N release can be accomplished by either fall applying manure at a rate that is not likely to cause issue to sugar beets, or delay the planting of sugar beets until the second or third year after manure application.

Implications for crop producers

The results of this study show that a one-time fall application of dairy manure provided a portion of the N required for Idaho crops. These results could vary corresponding with variation in soil temperature and N content of applied dairy manure. This study showed supplemental N fertilizer is needed for first time manure rates at and below 52.0 Mg ha^{-1} when cropping with heavy N consumer plants such as potatoes and silage corn. Supplemental

N fertilizer would not be needed at manure application rates at or above 17.3 Mg ha^{-1} when cropping with low N consumer crops such spring barley and dry beans. Supplemental N fertilizers are needed for manure rates at and below 34.7 Mg ha^{-1} when cropping with moderate N consumer plants such as winter wheat. These estimates are based on N requirements as determined by Idaho crop yield averages in 2012 (NASS, 2014) and N requirements by crop outlined in University of Idaho (UI) fertilizer guides (Robertson and Stark, 1993; Brown et al., 2001; Stark et al., 2004; Brown et al., 2010; Brown et al., 2012) assuming an initial soil inorganic N concentration of 10 mg kg^{-1} and negligible crop residues in the soil from previous cropping. Calculations for spring barley are based on middle season July 18, 2013 mineral N release from dairy manure, all other calculations are based on the full season N release in 2013.

Growing season in-situ net nitrogen mineralization (30-60 cm soil depth)

Trend contrasts of zero order model parameters calculated from net N mineralization in soils at the 30-60 cm depth indicated that there was not a linear or quadratic trend with increasing manure applications for either annual or biennial application timings (Table 2-10, 2-11). Therefore, it is likely that organic-N from the dairy manure did not move down into the soil past a 30 cm depth after fall application and before the start of the buried bag study on April 12, 2013. Other researchers have found that fall applications of dairy manure to Portneuf silt loam soils resulted in growing season subsoil inorganic N concentrations that were not significantly different than those in control soils (Lentz and Lehrsch, 2012). These results show that growing season inorganic N crediting derived from fall applications of dairy manure that leached past a 30 cm soil depth was not appropriate in this case.

Table 2-10 Statistical tests to determine if the effect of fall dairy manure rates (0 (control), 17.3, 34.7 and 52.0 Mg ha^{-1}) on 2013, 30-to-60-cm soil depth growing season cumulative net nitrogen mineralization rates (k value) is linear or curvilinear (quadratic), and if control and fertilizer treatments k values are equivalent. Annual and biennial manure effects are tested separately. Dairy manure was applied on October 18, 2012.

	Application interval	Pr > F
Control vs. fertilizer		0.7664
Linear trend	annual	0.5982
Quadratic trend	annual	0.9165
Linear trend	biennial	0.8828
Quadratic trend	biennial	0.8228

Table 2-11 Zero order model summary and measured and predicted net inorganic N in a Portneuf silt loam (30-60 cm depth) incubated in the field at the same soil depth in polyethylene bags near Kimberly, Idaho. Dairy manure was applied on October 16, 2012. Experimental design is a RCBD with four replications.

Manure rate (dry)	Manure applicat-ion interval	Zero order rate coefficient (k)	Inter cept	Predicted net inorganic N 7/18	Measured net mean inorganic N 7/18	Predicted net inorganic N 8/16	Measured net mean inorganic N 8/16
Mg ha^{-1}		mg kg^{-1} day^{-1}	——mg kg^{-1}†—		————mg kg^{-1}†———		
17.3	annual	0.030	-0.2	2.7	2.3	3.6	3.8
34.7	annual	0.059	-3.7	2.1	2.1	3.7	3.7
52.0	annual	0.072	-10.6	-3.6	-3.7	-1.6	-1.5
17.3	biennial	0.055	-3.0	2.2	1.92	3.7	3.9
34.7	biennial	0.008	-2.5	-1.7	-1.9	-1.5	-1.4
52.0	biennial	0.061	-3.3	2.6	1.9	4.3	4.8
Control	annual	0.031	-2.0	0.9	0.9	1.8	1.9
Fertilizer	annual	0.058	-2.2	3.4	2.8	5.0	5.3

† Multiply mg kg^{-1} values by 4.5 to convert to kg ha^{-1}, assuming a soil bulk density of 1.48 g cm^{-3}

This lack of subsoil treatment effect may be due to a small amount of overwinter water infiltration at the study site. Total evapotranspiration (ET) frequently exceeded total precipitation (PT) over the winter and spring of 2012-2013 preventing mass flow of dairy manure N. Irrigation water was not applied to the field between the fall manure application and the installment of the buried bags in the spring. The total ET between the manure application on October 18, 2012 and the date of April 12, 2013 was 26.6 cm, the total PT in the same time period was 7.1 cm. There were 7days where PT exceeded ET of which the greatest precipitation event of 1.3 cm resulted in potential infiltration of 1.2 cm (Agrimet Staff, 2016). Winters with different PT and ET dynamics could result in increased movement of manure N and possible manure C after a one time fall application of dairy cattle manure.

Other researchers monitoring N mineralization in a Portneuf silt loam soil at a depth of 30-60 cm showed that fall applications of dairy manure of 0 (control) and 45.7 Mg ha^{-1} (dry wt.) with a manure N content of 0 and 850 kg ha^{-1} resulted in cumulative net N mineralization values that were not significantly different (Lentz et al. 2011). The authors hypothesized that soluble organic manure materials that contain both C and N leached into the subsoil at a C:N ratio that resulted in substantial immobilization as made evident by higher sub soil cumulative net N mineralization values of 33 mg kg^{-1} measured in November of the previous year and net inorganic N of 83.2 mg kg^{-1} measured in May. Consequently, the authors also hypothesized that surface soils contained less soluble C as evident by the positive net N mineralization that occurred for the same periods.

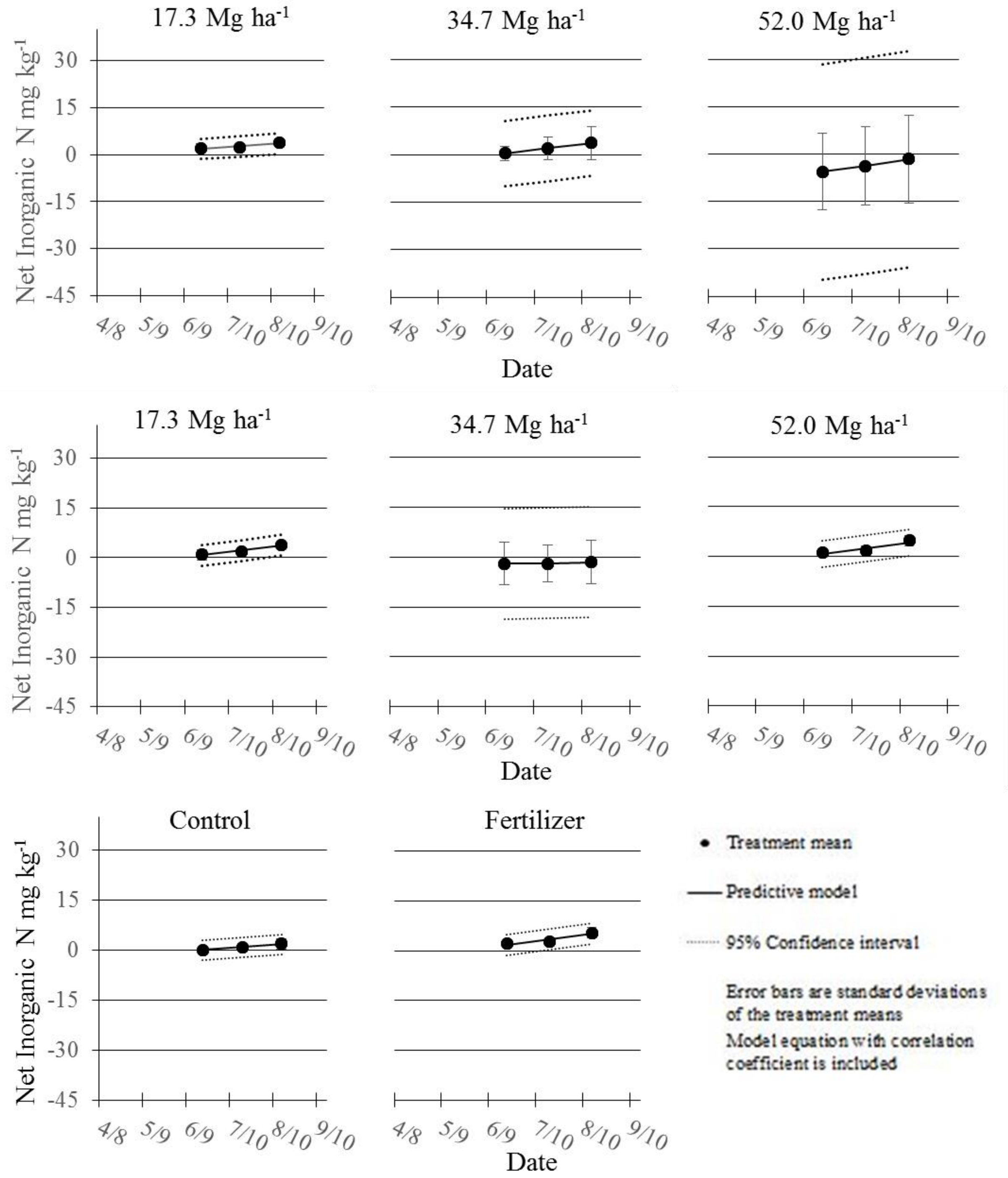

Figure 2-7 Net mean net N mineralized in a Portneuf silt loam (30-60 cm depth) incubated in the field at the same soil depth in polyethylene bags near Kimberly, Idaho during the 2013 growing season. Dairy manure was applied on October 16, 2012. Experimental design is a RCBD with four replications.

Growing season treatment effects following first time (biennial) or repeated (annual) fall-applied amendments monitored two years after the initial application (2014)

2014 spring in-situ N mineralization, following annual and biennial amendments

On November 6, 2013 dairy manure was applied again to annual manure plots at the rates of 17.3, 34.7 and 52.0 Mg ha^{-1} (dry wt.) but not to biennial manure plots. Thus by spring 2014, the annual manure treatments had received twice as much dairy manure as biennial manure plots (Table 2-2 and 2-12). Initial inorganic N concentrations on May 3, 2014 in soils receiving manure measured at both the 0-30 and 30-60 cm soil depths increased linearly with increasing biennial manure rates and cumulative annual manure rates (Table 2-13). These results show that activity of ammonifying and nitrifying soil microorganisms is limited by mineralizable N containing substrates in Portneuf silt loam soils at least up to cumulative annual manure N application rates of 1,650 kg ha^{-1}, respectively (103.6 Mg ha^{-1} dry wt.). These results also indicate that a portion of the applied manure N in the forms of nitrate and possibly organic N and C leached into the soil to at least a depth of 60 cm between the installation of the first study years buried bags on April 12, 2013 and the time of the installation of the second study years in-situ bag encased soils on May 3, 2014. Again, nitrates are unable to enter or exit the bag-encased soils after they are sealed and buried in the study field. Because there was not a subsoil dairy manure treatment effect detected in the first study years in-situ bag-encased soils that were all sealed in the spring of 2013, dairy manure derived N must have moved into the subsoil after the spring of 2013 and before the second study years buried bags were sealed in the spring of 2014. The downward movement of dairy manure N is likely caused by mass flow associated with water inputs to the study field from crop irrigation and precipitation. The contribution of precipitation to the downward movement of manure N in this study is thought to be minimal due to the infrequency of PT exceeding ET between the middle of September and early May in the region. It is worth noting that if there is appreciable soil water at the end of the irrigation season, mass flow associated with PT may be significant.

Quantifying the precise amount of overwinter inorganic N that originated from dairy manure was not possible, as the addition of varying rates of fertilizer N to different manure treatments occured in the spring of 2014, prior to soil sampling for the buried bag soil incubation (Table 2-13). The application of N fertilizer was determined based on preplant soil tests consistent with industry practices in southern Idaho.

The final (Oct. 10, 2014) inorganic N concentrations in soils receiving annual and biennial fall dairy manure measured at both the 0-30 and 30-60 cm soil depths increased linearly with increasing biennial manure rates of 0 to 52.0 Mg ha^{-1} and annual manure rates resulting in cumulative applications of 0 to 103.6 Mg ha^{-1} (Table 2-13 and Fig 2-8). These results indicate that crop producers should credit second year N release from dairy manure at a soil depth from 0-60 cm to both application intervals. In terms of nutrient per area at soil depth from 0-30 cm, annual dairy manure applications of 17.3, 34.7 and 52.0 Mg ha^{-1} resulted in approximate inorganic N amounts of 243, 309 and 396 kg N ha^{-1} and biennial manure applications resulted in inorganic N amounts of 149, 189 and 224 kg N ha^{-1}. Dairy manure fall applied annual or biennially at 17.3, 34.7 and 52.0 Mg ha^{-1} (dry wt.) can provide a portion or the entire amount of N required for Idaho crops. These results could vary corresponding with variation in soil temperature and N content of applied dairy manure.

When dairy manure applications do not meet all of a crops N needs a fertilizer should be applied to meet the nutrient deficit. Crops that are heavy consumers of N such as potatoes, sugar beets and silage corn require 269, 314, 303 kg N ha^{-1} for maximum yield and quality. These estimates are based on UI recommendations. Additionally moderate consumers of N such as winter wheat require 224 kg ha^{-1}. Low consumers of N such as spring barley, dry beans and onions require 179, 100 and 112 kg ha^{-1} kg-N ha^{-1}. These estimates are based on N requirements as determined by Idaho crop yield averages in 2012 (NASS, 2014) and N requirements by crop outlined in University of Idaho (UI) fertilizer guides (Robertson and Stark, 1993; Brown et al., 2001; Stark et al., 2004; Brown et al., 2010; Brown et al., 2012). Cumulative manure applications at or above 103.6 Mg ha^{-1} that result in plant available N at or above 300 kg ha^{-1} could cause a problem concerning yield and/or quality for all Idaho crops. Understanding the seasons potential total N release from dairy manure is important, though this analysis does not indicate the time during the growing season manure N is mineralized, a critical component of determining N fertilizer requirements.

Table 2-12 Mean inorganic N concentrations in a Portneuf silt loam (0-30 and 30-60 cm depths) incubated in the field at the same soil depth in polyethylene bags near Kimberly, Idaho. Dairy manure was applied two times on October 18, 2012 and November 7, 2013 to annual plots and one time on October 18, 2012 to biennial plots. Experimental design is a RCBD with four replications.

Manure rate applied (dry)	Manure N rate applied	Cumulative manure rate applied (dry	Cumulative manure N rate applied	Fertilizer N rate applied	Interval applied	Soil depth	Study start inorganic N 5/3/14	Study end inorganic N (10/9/14) 9/25/14
Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	—kg ha^{-1}—			cm	—mg kg^{-1}†—	
17.3	258	34.7	548	75	Annual	0-30	32.2	(53.8)
34.7	518	69.0	1102	0	Annual	0-30	42.2	(68.6)
52	776	103.6	1650	0	Annual	0-30	58.5	(87.9)
0	0	17.3	290	75	Biennial	0-30	22.3	(33.0)
0	0	34.7	584	45	Biennial	0-30	25.8	(42.0)
0	0	52	874	0	Biennial	0-30	30.7	(49.6)
Fertilizer	0	0	0	75	-	0-30	21.8	(27.7)
Control	0	0	0	0	-	0-30	10.1	(19.3)
17.3	258	34.7	548	75	Annual	30-60	9.1	11.6
34.7	518	69.0	1102	0	Annual	30-60	9.0	14.4
52	776	103.6	1650	0	Annual	30-60	13.9	18.9
0	0	17.3	290	75	Biennial	30-60	6.7	9.7
0	0	34.7	584	45	Biennial	30-60	8.1	11.2
0	0	52	874	0	Biennial	30-60	10.8	18.5
Fertilizer	0	0	0	75	-	30-60	6.0	9.6
Control	0	0	0	0	-	30-60	4.4	8.3

† Multiply mg kg^{-1} values by 4.5 to convert to kg ha^{-1}, assuming a soil bulk density of 1.48 g cm^{-3-1} to a soil depth of 30 cm

Table 2-13 Statistical tests to determine if the effect of manure rate on 2014, 0-to-30 and 30-to-60-cm cumulative N mineralization values is linear or curvilinear (quadratic), and if control and fertilizer treatments are equivalent. Annual and biennial manure effects were tested separately and soil inorganic N responses was assessed at the beginning (May 3) and end (Oct. 9) of the 2014 growing season. Dairy manure was applied two times on October 18, 2012 and November 7, 2013 to annual plots and one time on October 18, 2012 to biennial plots.

	Application interval	Date	Soil depth	Pr > F	Significance
			——cm——		
Control vs. fertilizer	-	5/3	0-30	0.0748	NS
Linear trend	annual	5/3	0-30	<.0001	***
Quadratic trend	annual	5/3	0-30	0.5302	NS
Linear trend	biennial	5/3	0-30	0.0055	**
Quadratic trend	biennial	5/3	0-30	0.4424	NS
Control vs. fertilizer	-	5/3	30-60	0.3618	NS
Linear trend	annual	5/3	30-60	<.0001	***
Quadratic trend	annual	5/3	30-60	0.9400	NS
Linear trend	biennial	5/3	30-60	0.0010	***
Quadratic trend	biennial	5/3	30-60	0.8654	NS
Control vs. fertilizer	-	10/9	0-30	0.3813	NS
Linear trend	annual	10/9	0-30	<.0001	***
Quadratic trend	annual	10/9	0-30	0.1694	NS
Linear trend	biennial	10/9	0-30	0.0063	**
Quadratic trend	biennial	10/9	0-30	0.5264	NS
Control vs. fertilizer	-	9/25	30-60	0.7576	NS
Linear trend	annual	9/25	30-60	0.0137	*
Quadratic trend	annual	9/25	30-60	0.8454	NS
Linear trend	biennial	9/25	30-60	0.0202	*
Quadratic trend	biennial	9/25	30-60	0.3133	NS

*** significant at alpha=0.01 ** significant at alpha=0.05 * significant at alpha=0.10

NS not significant

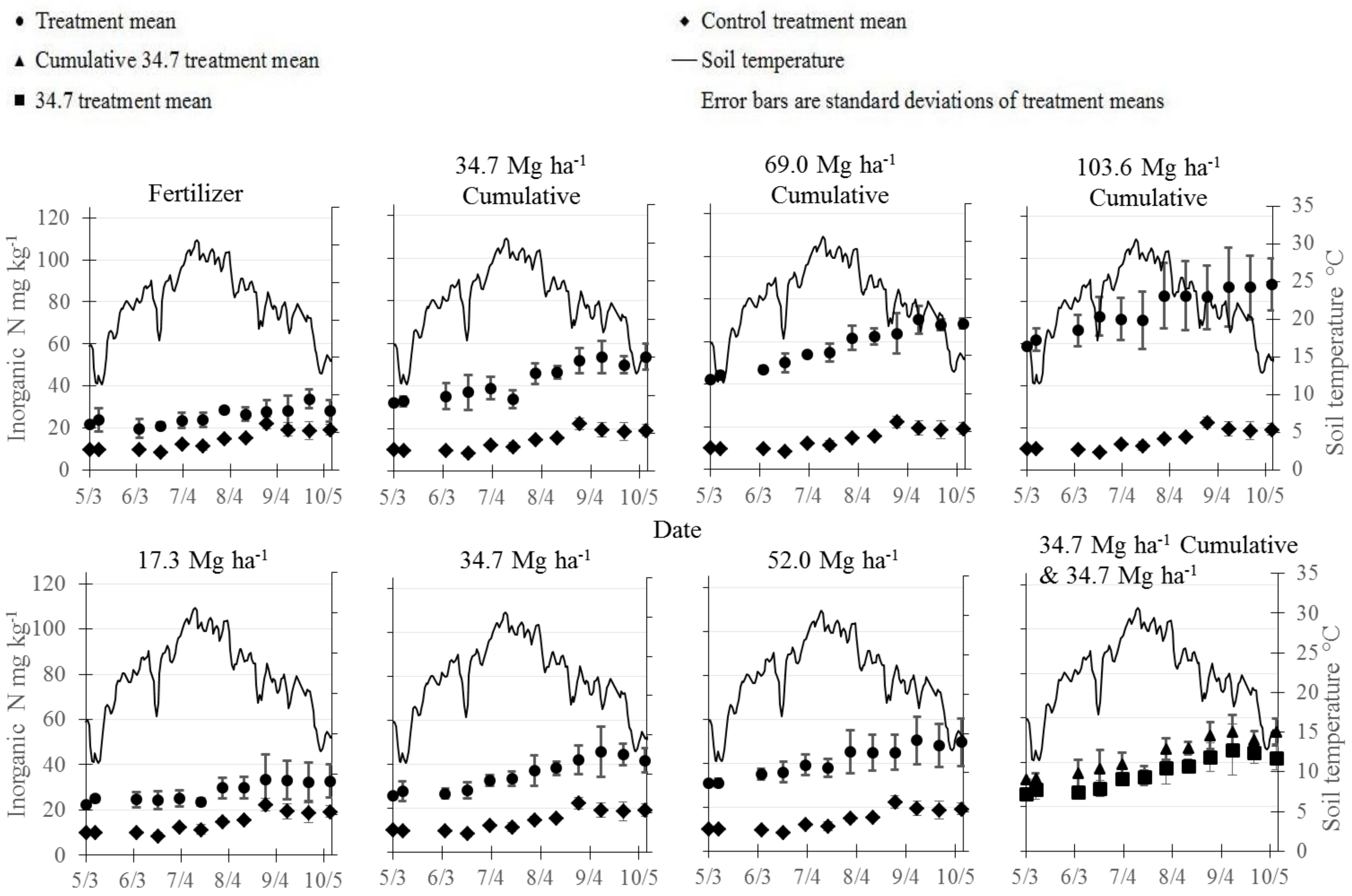

Figure 2-8 Mean inorganic N concentrations in a Portneuf silt loam (0-30 cm depth) incubated in the field at the same soil depth in polyethylene bags near Kimberly, Idaho. Dairy manure was applied on October 18, 2012 and again on November 7, 2013 to annual plots and one time on October 18, 2012 to biennial plots. Soil filled bags were analyzed for inorganic N throughout the growing season. Experimental design is a RCBD with four replications.

2014 Net N mineralization trends, following annual and biennial amendments (0-30 cm soil depth)

Soil net N mineralization increased linearly at the alpha 0.01 level throughout the sampling period for all treatments at the 0-30 cm depth (Fig. 2-9). Also, net N mineralization rates (k value) in soils receiving fall dairy manure applied either annually (2012 and 2013) or biennially (2012) measured at the 0-30 cm soil depths increased linearly with increasing biennial manure rates and cumulative annual manure rates (Table 2-14). The k values between manure applied annually at 17.3 Mg ha^{-1} and manure applied biennially at 34.7 Mg ha^{-1} were not significantly different. The k values between fertilizer and control treatments were not significantly different.

Mean cumulative net N mineralization values from 2014 sequentially exhumed bags are presented in Fig. 2-9. Net N mineralization values increased linearly corresponding with increasing manure rates, although appeared to decrease slightly compared to the previous sampling date for all treatments for the September 25th and October 10th sampling dates (Fig. 2-9). This apparent decrease in cumulative net N mineralization in the latter half of September and October indicates that immobilization exceeded mineralization from September 11th to at least October 10th. One can hypothesize that the decrease in N mineralization values is likely caused by either a decrease in N mineralization due to cooler soil temperatures and/or an increase in immobilization due to manure N becoming limited from previous assimilation by soil organisms. In 2014 soil temperatures peaked in the middle of July at 31 °C. Soil temperatures increased rapidly between June 19 and July 14 from 19 °C to 31 °C (Fig. 2-2), however a rapid increase in cumulative net N mineralization values did not occur until July 18. Similar to 2013, there appeared to be a 4-week lag between temperature increases above 21 °C and observed increase in net N mineralization. Soil temperatures above 20 °C often coincided with positive cumulative net N mineralization. On September 11, cumulative net N mineralization rates plateaued or declined. Soil temperatures on September 11 were 20 °C and in general decreased through the remaining study period measuring 15 °C on October 10.

This plateau or decline in N mineralization rates over the last 4 weeks of the study challenge the efficacy of employing zero order kinetics to describe N mineralization trends in manured Portneuf silt loam soils. Lentz et al. (2011) and Lehrsch et al. (2016) reported similar findings, though their decline in cumulative net N mineralization values started earlier, near the third week of August. Further investigation is warranted to determine a predictive modelling approach that may be more accurate across growing seasons with varying soil temperatures.

For all manure treatments in 2014, approximately 42-53 % of net N mineralized is produced between bag installation (May 3) and July 18, while only 34% of control soil inorganic N releases during the same time period (Table 2-15). This less early-season N mineralization in the control soil may be a result of a higher proportion of labile organic N compounds in manure treated soil resulting in increased N mineralization in the early season when soil temperatures are colder.

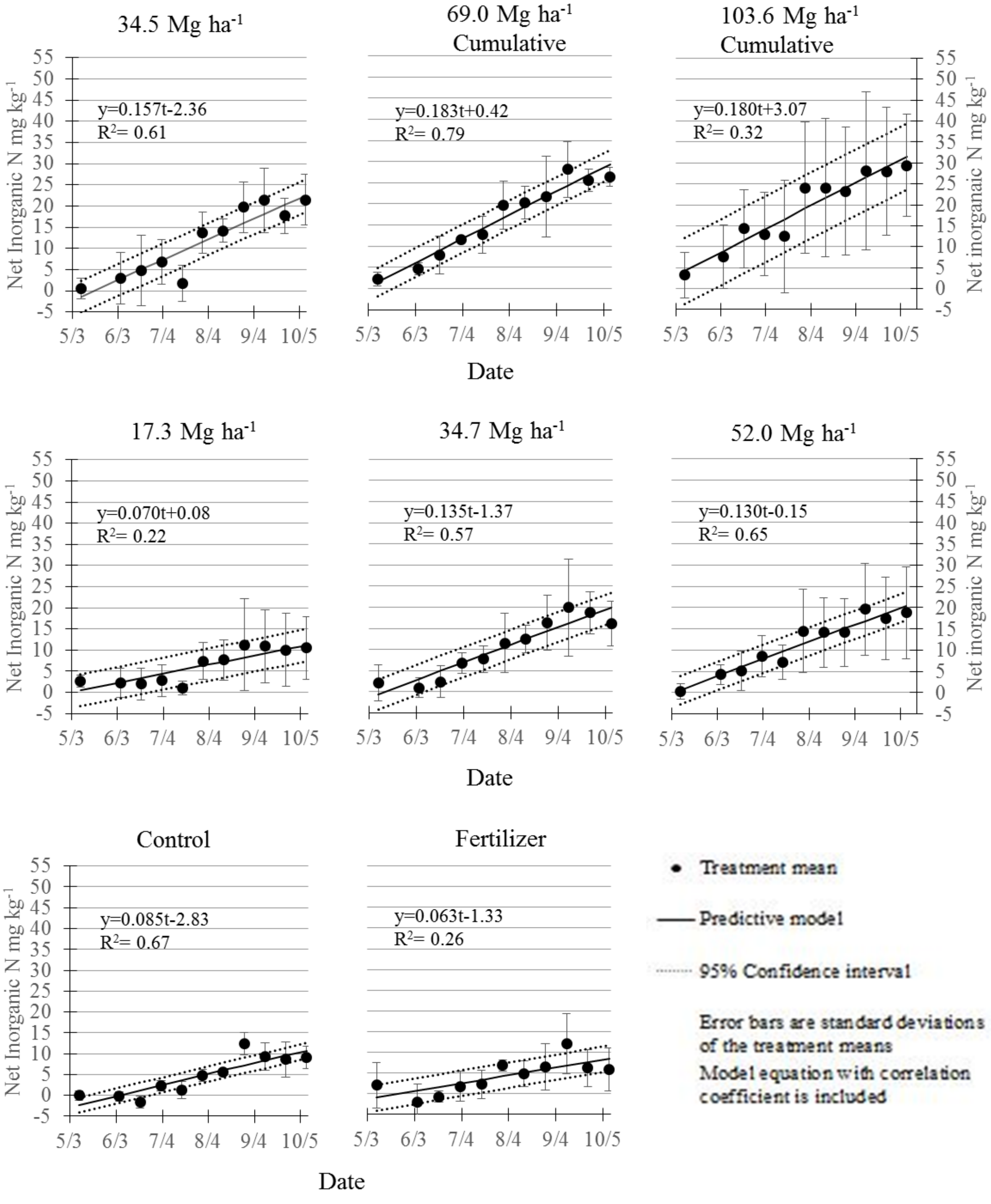

Figure 2-9 Cumulative net N mineralized in a Portneuf silt loam (0-30 cm depth) incubated in the field at the same soil depth in polyethylene bags near Kimberly, Idaho. Dairy manure was applied on October 16, 2012 to annual and biennial plots and again on November 7, 2013 to annual plots. Experimental design is a RCBD with four replications.

Table 2-14 Zero order model summary, measured and predicted cumulative net N minerlized in a manured Portneuf silt loam (0-30 cm depth) incubated in the field at the same soil depth in polyethylene bags near Kimberly, Idaho. Dairy manure was applied on October 16, 2012 to biennial plots. Experimental design is a RCBD with four replications

Cumulative manure application rate (dry)	Manure application interval	Zero order rate coefficient (k)	Intercept	Predicted net inorganic N 7/18	Predicted inorganic N released‡ 7/18	Measured net mean inorganic N 7/18	Predicted net inorganic N 10/9	Measured net mean Inorganic N 10/9
Mg ha^{-1}		mg kg^{-1} day^{-1}	——mg kg^{-1}——		%	—————mg kg^{-1}—————		
17.3	biennial	0.070	0.1	5	48	1	11	10
34.7	biennial	0.135	-1.4	9	44	8	20	16
52.0	biennial	0.130	-0.2	10	47	5	20	16
Control	-	0.086	-2.8	4	34	1	11	9
Fertilizer	-	0.063	-1.3	3	39	2	9	6

‡ These values represent the predicted % inorganic N mineralized by 7/18/2014 of the total inorganic N that was predicted to mineralize at the end of the study period on 10/9/2014.

†† Inorganic N reported in mg kg^{-1} can be converted to kg ha^{-1} with a conversion factor of 4.51 which is calculated considering a soil bulk density of 1.48 g cm$^{3-1}$ to a depth + 30.48 cm.

-Data is for biennial manure applications

Table 2-15 Zero order model summary, measured and predicted cumulative net N minerlized in a manured Portneuf silt loam (0-30 cm depth) incubated in the field at the same soil depth in polyethylene bags near Kimberly, Idaho. Dairy manure was applied to annual plots on October 16, 2012 and again on November 7, 2013

Cumulative manure application rate (dry)	Manure application interval	Zero order rate coefficient (k)	Intercept	Predicted net inorganic N 7/18	Predicted inorganic N released‡ 7/18	Measured net mean inorganic N 7/18	Predicted net inorganic N 10/9	Measured net mean Inorganic N 10/9
Mg ha^{-1}		mg kg^{-1} day^{-1}	——mg kg^{-1}——		%	————mg kg^{-1}————		
34.7	annual	0.157	-2.4	9	42	2	22	22
69.0	annual	0.183	0.4	14	48	14	29	30
103.6	annual	0.180	3.1	17	53	12	32	29
Control	-	0.086	-2.8	4	34	1	11	9
Fertilizer	-	0.063	-1.3	3	39	2	9	6

‡ These values represent the predicted % inorganic N mineralized by 7/18/2014 of the total inorganic N that was predicted to mineralize by the end of the study period on 10/9/2014.

† Inorganic N reported in mg kg^{-1} can be converted to kg ha^{-1} with a conversion factor of 4.51 which is calculated considering a soil bulk density of 1.48 g cm$^{3-1}$ to a depth of 30.48 cm.

-Data is for annual manure applications

Table 2-16 Statistical tests to determine if the effect of fall dairy manure rates (0 (control), 17.3, 34.7 and 52.0 Mg ha^{-1}) on 2014, 0-to-30-cm soil depth growing season cumulative net nitrogen mineralization rates (k value) is linear or curvilinear (quadratic). In addition, control vs. fertilizer, 17.3 annual vs. 34.7 biennial and 17.3 annual vs. control k values are tested for equivalence. Dairy manure was applied two times on October 18, 2012 and November 7, 2013 to annual plots and one time on October 18, 2012 to biennial plots.

	Application interval	Pr > F	Significance
Control vs. fertilizer	-	0.4317	NS
Linear trend	annual	0.0012	***
Quadratic trend	annual	0.0896	*
Linear trend	biennial	0.0496	**
Quadratic trend	biennial	0.8028	NS
†17.3 annual vs. 34.7 biennial	-	0.4583	NS
17.3 vs. control	biennial	0.6020	NS
34.7 vs. control	biennial	0.0982	*
52.0 vs. control	biennial	0.1661	NS

†Dairy cattle manure applications were applied one time in the fall of 2012-2013 at a rate of 34.7 Mg ha^{-1}, this is contrasted by repeated manure applications of 17.3 Mg ha^{-1} the fall of 2012 and 2013 resulting in a cumulative manure application rate of 34.7 Mg ha^{-1}

*** significant at alpha=0.01

** significant at alpha=0.05

* significant at alpha=0.10

NS not significant

Net N mineralization trends in 2014 (0-30 cm soil depth) in all treatments were fit to zero order kinetics (Fig. 2-9), and rate coefficients (k values) were determined by linear regression (Tables 2-14 and 2-15). The net N mineralization rate in 2014 for the 17.3 Mg ha^{-1} biennial manure application was less than that of control soils (Tables 2-16). Thus in the second growing season, the biennial, 17.3 Mg ha^{-1} manure application did little to enhance net N mineralization relative to the control. Conversely, biennial 34.7 Mg ha^{-1} manure applications produced k values greater than those in control soils 2 years after application. Net N mineralization rates generally declined in years following a one-time manure application, as indicated by k values for first- and second-year results from a one-time fall manure application (Fig. 2-10).

A general trend was observed that annual manure treatments resulted in k values that were greater than those of biennial manure treatments at the 0-30 cm depth (Table 2-14, Table 2-15). This finding suggests that there is a compounding effect of repeated manure applications on N mineralization. Therefore, the past manure history of a field is a factor that should be considered by growers applying dairy manure in semi-arid and cool climates when estimating N accumulations from fall dairy manure applications.

Comparing k values from the 2013 study season with those of the 2014 study season does have limited utility due to an apparent difference in overall net N mineralization rates as made evident by the difference in control soil k values between 2013 and 2014. Control soils in 2013 had a k value of 0.123 mg N kg^{-1} day^{-1}, while control soils in 2014 had a k value of 0.085 mg N kg^{-1} day^{-1} (Figure 2-12). It is presumed that because N mineralization rates in control soils were different between 2013 and 2014 that N mineralization rates in manured soils were also inherently different between the two study years. Further evidence of this phenomenon is that all treatment k value means estimated in 2014 after repeated fall applications of manure that resulted in cumulative rates followed a general trend of being lower than their corresponding k value means estimated in 2013 after a one time fall application of manure for annual manure treatments (Tables 2-9 and 2-16, Fig. 2-12). Without an inherent difference in net nitrogen mineralization rates between the 2013 and 2014 study years, one would expect two fall applications of manure to result in k values that were at least equal to a one time application of manure at the same rate. For example a single first time annual manure treatment of 34.7 Mg ha^{-1} resulted in a k value of 0.210 mg kg^{-1} day^{-1} contrasted by two repeated annual manure applications of 34.7 Mg ha^{-1} that resulted in a smaller k value of 0.183 mg kg^{-1} day^{-1}. This trend was similar for all manure application rates.

Soil temperature differences between the two study years was the first factor considered to explain the difference in control soil k values. The mean daily soil temperature at a depth of 10 cm between April 12, and October 10, was 20.6 in 2013 vs. 20.9 in 2014, which is relatively similar in terms of N mineralization processes. However, the 2013 growing season included 106 consecutive days when mean daily soil temperatures exceeded 20 °C, June 3 to September 17, and 55 days when the mean daily soil temperature exceeded 25 °C, from June 28 to August 22. Conversely, 2014 included only 63 consecutive days when the mean daily soil temperature exceeded 25 °C, June 20 to August 22, and 37 days when the mean daily soil temperatures exceeded 25 °C, from June 30 to August 5. These additional periods of warmer soil temperatures in 2013 compared to 2014 may have influenced soil microbial population dynamics resulting in increased microbial N mineralization efficiency. Additional research is warranted to determine if there is an interaction between the number of consecutive days where the soil temperature is above a specific temperature threshold and N mineralization potential of dairy manure.

Without a difference in soil temperature it is difficult to explain why control soils and manure treatments had a higher N mineralization rate in 2013 compared to the control rate in 2014. An alternative explanation is that residues left on the study field and/or applied N fertilizers from the 2012 bean crop could have influenced N mineralization dynamics in 2013. Regardless of explanation, the 2013 study year had increased mineralization of N containing compounds across control and fertilizer treatments and presumably manure treatments.

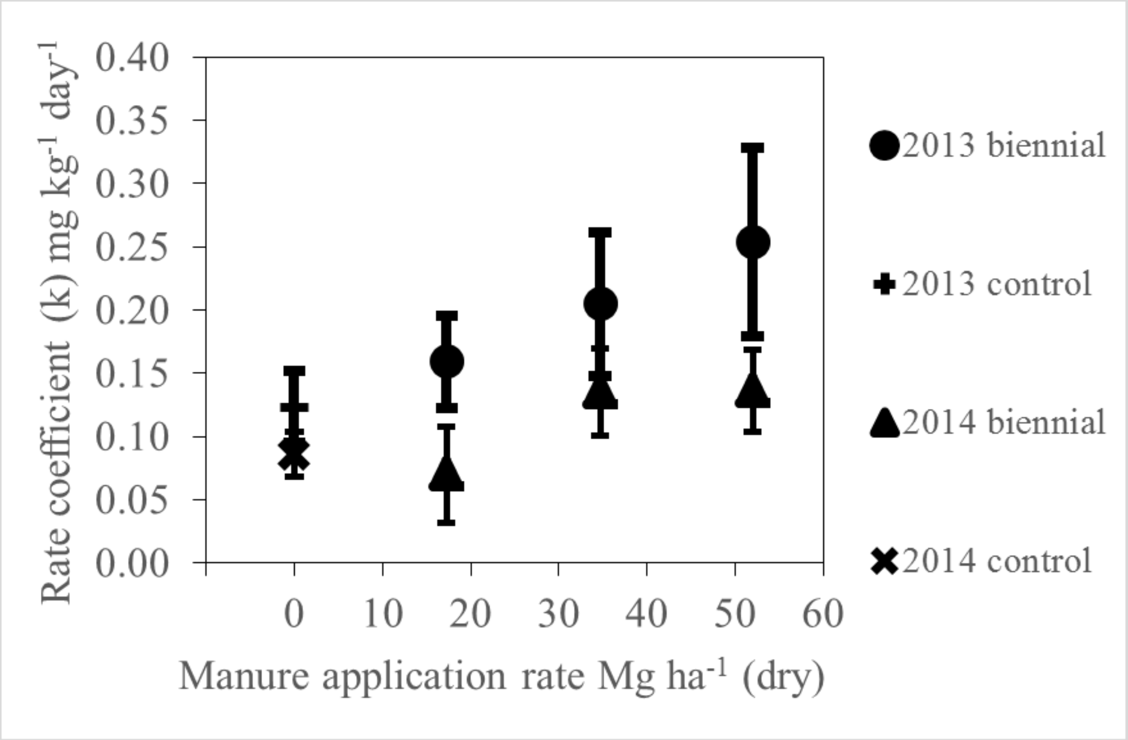

Figure 2-10 Comparison of rate coefficients of 2013 and 2014 biennial zero order N mineralization predictive models from a Portneuf silt loam (0-30 cm depth) incubated in the field at the same soil depth in polyethylene bags near Kimberly, Idaho. Dairy manure was applied on October 16, 2012 to annual and biennial plots. Experimental design is a RCBD with four replications

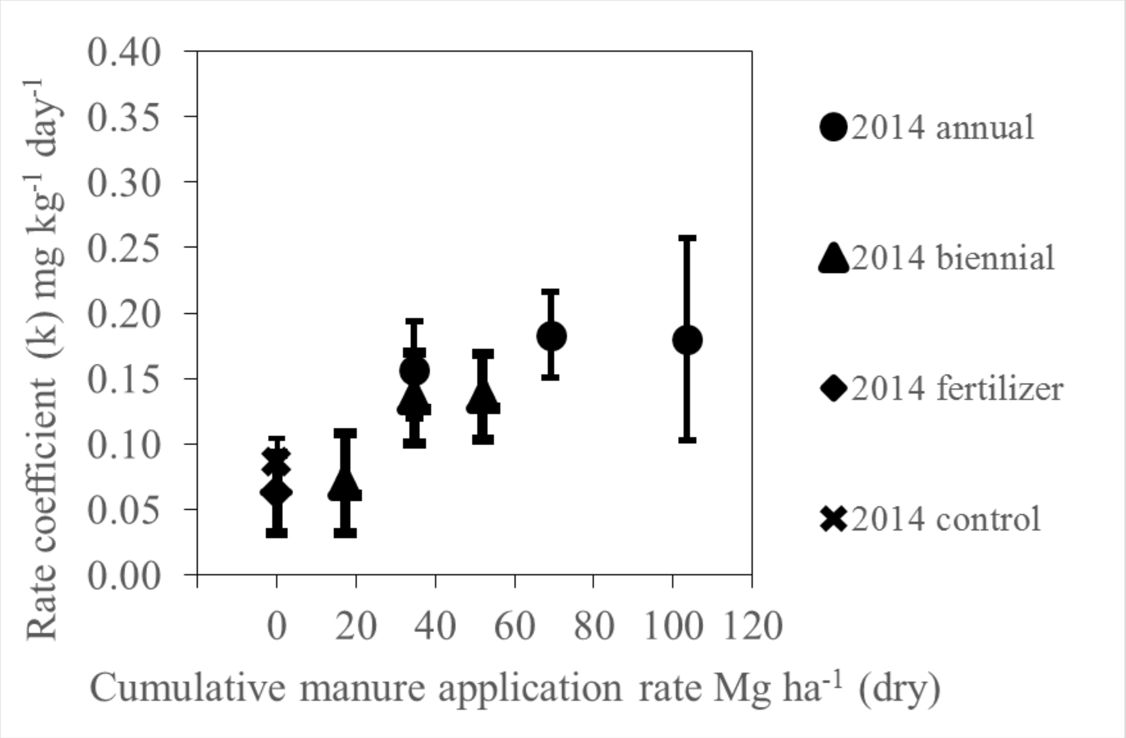

Figure 2-11 Comparison of rate coefficients of 2014 annual and biennial zero order N mineralization predictive models from a manured Portneuf silt loam (0-30 cm depth) incubated in the field at the same soil depth in polyethylene bags near Kimberly, Idaho. Dairy manure was applied on October 16, 2012 to annual and biennial plots and again on November 7, 2013 to annual plots. Experimental design is a RCBD with four replications**.**

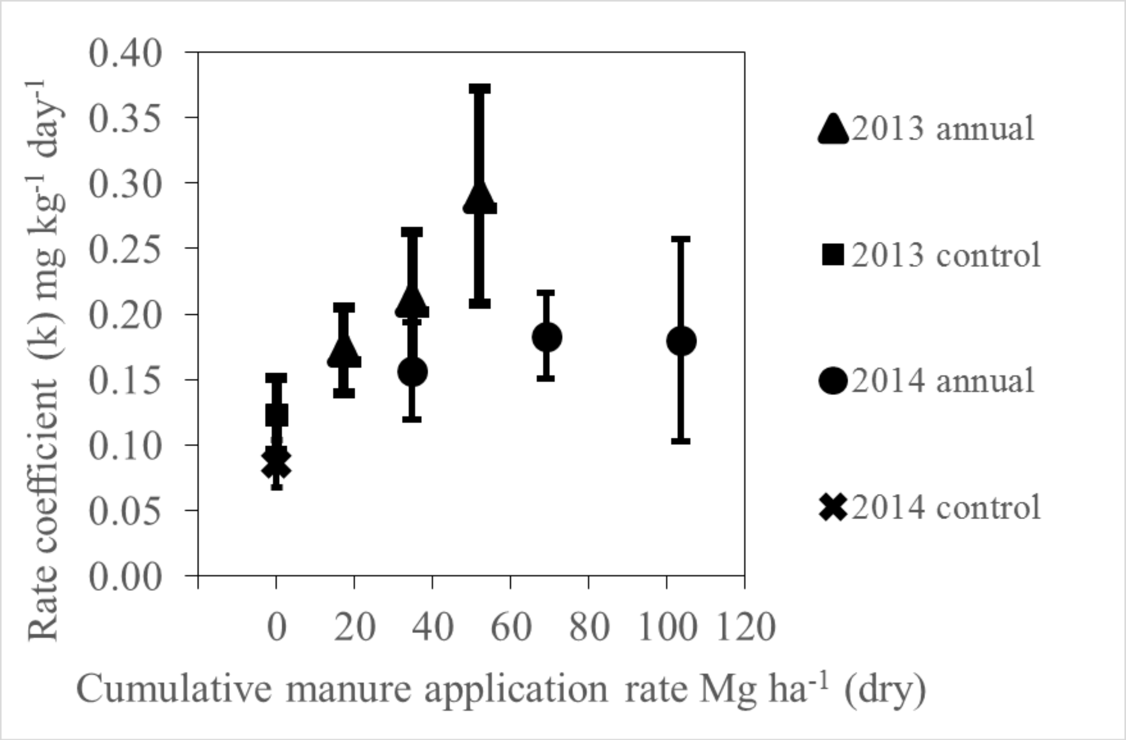

Figure 2-12 Comparison of rate coefficients of 2013 and 2014 annual zero order N mineralization predictive models from a manured Portneuf silt loam (0-30 cm depth) incubated in the field at the same soil depth in polyethylene bags near Kimberly, Idaho. Dairy manure was applied on October 16, 2012 to annual and biennial plots and again on November 7, 2013 to annual plots. Experimental design is a RCBD with four replications

Table 2-17 Summary statistics of soil temperature in Celsius measured at a 10 cm depth between April 12 and October 10 in 2013 and 2014 at the Kimberly Agrimet weather station, which is located one mile from the site of the present study.

	mean	std dev	median	minimum	maximum
2013	20.6	6.3	22.9	5.0	28.5
2014	20.9	5.8	21.9	8.0	30.7

Whole season net N mineralization, following biennial amendments

Biennial treatments applied dairy manure at 0 (control), 17.3, 34.7 and 52.0 Mg ha^{-1} only in 2013, which added 0, 290, 584, and 874 kg ha^{-1} manure N. The zero-order models estimated season-long net N mineralization in 2014 to be 11, 11, 20 and 20 mg kg^{-1}, respectively (Table 2-15). Biennial manure applications of 17.3 Mg ha^{-1} resulted in N mineralization rates that were equal to or less than those in control soils. Therefore, biennial manure applications at or below 17.3 Mg ha^{-1} did not contribute appreciably to the growing season inorganic N pool 2 years after application. Lentz and Lehrsch (2012) found contradicting results that the relatively low biennial manure application of 21.7 Mg ha^{-1} with a manure N content of 307 kg ha^{-1} resulted in end of season inorganic N concentrations that were greater than those of control treatments. Additional research is warranted to determine the long term N mineralization potential of relatively low dairy manure application rates near 17.3 Mg ha^{-1}.

In a similar study to the present one researchers monitored N mineralization in a southern Idaho Portneuf silt loam soil that received 23.3 and 45.7 Mg ha^{-1} (dry wt.) dairy manure in the fall of 2002. This manure had a manure N content of 433 and 850 kg ha^{-1}, respectively. The investigators found that November 2002 through October 2003 soil cumulative net N mineralization values were 47.8 and 54.5 mg kg^{-1}. The researchers found that without additional manure applications November 2003 through October 2004 soil cumulative net N mineralization values were 27.7 and 34.2 mg kg^{-1} (Lentz et al., 2011). Direct comparisons with the present study are not appropriate in this case due to the difference in incubation time period, though the study results do confirm that fall applied dairy manure N is still being mineralized at significant rates two years after application. Therefore, crop producers should consider the contribution of fall applications of dairy manure to inorganic N pools 2 years after a dairy manure application.

Early and late growing season net N mineralization 2 years after manure applications (2014 biennial treatments)

(0-30 cm soil depth)

In 2014 after biennial manure applications, we used zero-order models to estimate net N mineralization for the early growing season (May 3 to July 18).Calculated values were 4, 5, 9 and 10 mg kg^{-1} for 0 (control), 17.3, 34.7 and 52.0 Mg ha^{-1} manure rates, respectively. Crops such as barley are harvested in July, these crops do not utilize the inorganic N mineralized over the full season. Therefore, early season mineralization of manure N is more important than mineral N released in the late season. Inorganic N concentrations monitored in this study 2 years after a fall application of dairy manure may have been substantial enough to credit when applying fertilizer at least at the application rate of 34.7 and 52.0 Mg ha^{-1} because concentrations were appreciably larger than those in control soils.

Crops that are harvested in September such as sugar beets do utilize the full season inorganic N release from fall applications of dairy manure. Sugar beets are sensitive to late season mineral N, too much mineral N between July and September can result in reduced quality and sugar extraction efficiency. The linear mineralization trend observed in this study indicates that manure N is still mineralizing at significant rates during the late growing season (Figure 2-9, Table 2-15). Dairy manure applications in 2012 of 0 (control), 17.3, 34.7 and 52.0 Mg ha^{-1} with a manure N content of 0, 292, 588, and 874 kg ha^{-1}, respectively were predicted to release mineral N between July 18, 2013 and October 10, 2013 at concentrations of 7, 6, 11, and 11 mg kg^{-1}, respectively (data not shown). These findings show that 52-56% of the full growing season mineral N released from dairy manure applied biennially occurs in the second half of the growing season (Table 2-15).

Whole season net N mineralization following annual amendments

The annual treatments applied manure at 17.3, 34.7, and 52.0 Mg ha^{-1} (dry wt.), which added 0 (control), 290, 584 and 874 kg ha^{-1} manure N in year one and 0 (control), 258, 518, and 776 kg ha^{-1} manure N in year two. The zero-order model estimated season-long net N mineralization in 2014 to be, in order of increasing manure applied, 11, 22, 29, and 32 mg kg^{-1} at the 0-30 cm depth (Table 2-16). The results of the present study have shown that one time biennial manure applications of 34.7 and 52.0 Mg ha^{-1} contributed significantly to inorganic N pools 2 years after application. When dairy manure was applied annually over 2 consecutive years, the end of season net inorganic N concentrations were greater than those of biennial manure treatments measured 2 years after application. Therefore it is likely that 2012-2013 and 2013-2014 annual manure applications both contributed to the full seasons inorganic N pools two years after application.

End-of-season inorganic N concentrations after annual manure treatments were greater than those of biennial manure treatments. This compounding effect of repeated manure applications should be taken into account when managing dairy manure N in soils that received manure in the previous year.

Early and late growing season net N mineralization, following annual amendments (0-30 cm soil depth)

Zero order model estimates for annual manure treatments applied at 17.3, 34.7 and 52.0 Mg ha^{-1} indicated that the percent of inorganic N that released from May 3, 2014 to July 18, 2014 that would mineralize over the entire growing season was 42, 48 and 53%, respectively (Table 2-16). These percentages show that more manure N was released from July 18 to October 10 than from May 3 to July 18.

Crops that are harvested in September such as sugar beets do utilize the full inorganic N release from fall applications of dairy manure. Sugar beets though are sensitive to late season mineral N. Too much mineral N between middle July and September can result in reduced quality and sugar extraction efficiency of the sugar beet. The linear mineralization trend observed in 2014 at the 0-30 cm soil depth indicates that manure N is still mineralizing during late growing season (Figure 2-9, Table 2-16). Dairy manure applications in 2012 of 0 (control), 17.3, 34.7 and 52.0 Mg ha^{-1} with a manure N content of 0, 290, 584, 874 kg ha^{-1} the first year and 0, 258, 518 and 776 kg ha^{-1} in 2013 between July 18, 2014 and October 10, 2014 were predicted to be 7, 13, 15 and 15 mg kg^{-1} (data not shown). Late season manure N mineralization should be taken into account when estimating dairy manure contribution to the late season inorganic N pool after two annual manure applications.

Biennial and annual dairy manure applications with similar cumulative rates, 2014 (0-30 cm soil depth)

To evaluate the impact of manure application frequency on net N mineralization rate in 2014, we compared results from the 34.7 Mg ha^{-1} biennial and 17.3 annual manure treatments. The analysis showed that net N mineralization rates (k values) for the two treatments did not differ, (Table 2-14) suggesting that the one-time, 34.7 Mg ha^{-1} manure application of fall 2012 was still mineralizing at an appreciable rate in the second growing season.

Growing season in-situ net nitrogen mineralization (30-60 cm soil depth)

Trend analysis of k values calculated from cumulative net N mineralization values in soils at the 30-60 cm depth indicated that there was not a linear or quadratic manure treatment effect for either annual or biennial application timings (Table 2-18). However, subsoil treatment effects were detected after manure was applied at 52.0 Mg ha^{-1} biennially. This finding suggests that there was sufficient manure-derived organic matter that had leached down into the subsoil by the second study year to significantly increase growing season N mineralization processes. Subsoil organic matter measured on March 18, 2014 was not found to be significantly influenced by manure treatments. While no significant effects of annual or biennial manure treatments were detected, the annual applications did appear to show an increase in OM with increased rate, particularly at the annual application of 52.0 Mg ha^{-1}. Mean organic matter was 0.9, 1.0, 1.0, and 1.6 % with standard deviations of 0.3, 0.3, 0.3, and 0.7 corresponding with annual manure applications of 0 (control), 17.3, 34.7 and 52.0 Mg ha^{-1}.

Though there is some evidence that manure-derived organic N moved into the subsoil after annual and biennial manure applications of 52.0 Mg ha^{-1}, it is likely that the dominant form of manure N that leached into the subsoil was as nitrate. As previously discussed there was a strong linear relationship detected of increasing May 3, 2014 subsoil inorganic N concentrations corresponding with increasing annual ($P< 0.0001$) and biennial ($P=0.0010$) manure treatments as well as on October 9, 2014 buried bag sampling dates for annual ($P=0.0137$) and biennial ($P=0.0202$) treatments (Table 2-13). When time=0 preplant inorganic N concentrations were subtracted from the values used for these calculations, the strong linear relationship was no longer detected for either application interval. Therefore the preplant subsoil manure treatment response was likely caused by manure-derived nitrate leaching into the subsoil sometime after the first years 2012 fall manure application and the installment of the buried bags in the spring of 2014. In other words, if organic manure N had caused the strong preplant linear increase of inorganic N corresponding with increasing manure applications, one would expect that the subsoil organic manure N would continue to mineralize, significantly influencing cumulative net N mineralization values.

Table 2-18 Statistical significance and trend analysis of dairy manure fall applied at rates of 0 (control), 17.3, 34.7 and 52.0 Mg ha^{-1} on growing season net N mineralization in a Portneuf silt loam (30-60 cm depth) incubated in the field at the same soil depth in polyethylene bags near Kimberly, Idaho. In addition, control vs. fertilizer, 52.0 annual vs. control, and 52.0 biennial vs. control k values are tested for equivalence. Similarly all annual then biennial (17.3, 34.7 and 52.0 Mg ha^{-1}) manure applications as a group vs. control and fertilizer as a group is tested for equivalence. Dairy manure was applied two times on October 18, 2012 and November 7, 2013 to annual plots and one time on October 18, 2012 to biennial plots. Experimental design is a RCBD with four replications.

	Application interval	Pr > F	Significance
Control vs. fertilizer	-	0.9511	NS
Linear trend	annual	0.3426	NS
Quadratic trend	annual	0.8329	NS
Linear trend	biennial	0.0762	NS
Quadratic trend	biennial	0.2006	NS
52.0 vs. control	annual	0.5046	NS
52.0 vs. control	biennial	0.0799	*
17.3+34.7+52.0 vs. control + fertilizer	annual	0.6256	NS
17.3+34.7+52.0 vs. control + fertilizer	biennial	0.4041	NS

* significant at alpha=0.10

NS not significant

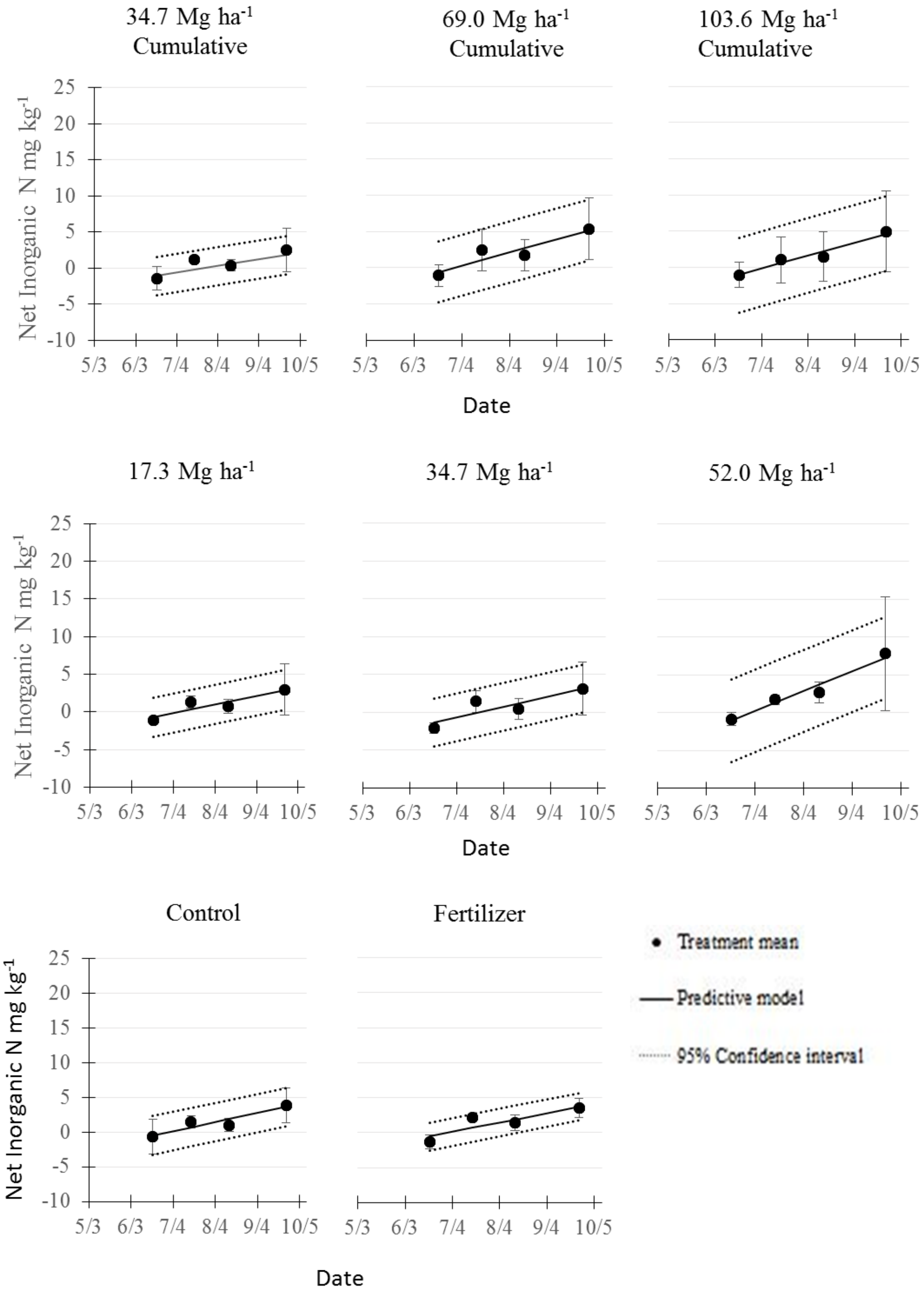

Figure 2-13 Cumulative net mean N mineralization values in a Portneuf silt loam (30-60 cm depth) incubated in the field at the same soil depth in polyethylene bags near Kimberly, Idaho. Dairy manure was applied on October 16, 2012 to annual and biennial plots and again on November 7, 2013 to annual plots. Experimental design is a RCBD with four replications.

Cumulative net N mineralization variability

Sample standard deviations for 0-to-30-cm, cumulative net-N-mineralization responses were calculated for each biennial manure treatment rate and bag-extraction date in 2013, and presented in Fig. 2-14. The mean standard deviation for each treatment manure rate was 3, 3, 4 and 9 mg kg^{-1} (given in order of increasing manure rates, 0 to 52.0 Mg ha^{-1}). As soil temperatures and cumulative net N mineralization increased over the 2013 study year (April 12- September 9, 2013), mean standard deviations for all treatments appeared to follow an increasing trend (Fig. 2-14). This standard deviation trend may be caused by an interaction between time, soil temperature, and soil microorganism activity. In addition, variability in N mineralization rates appeared to plateau or decline in response to a decreasing trend in soil temperatures.

Treatment effects on standard deviation of cumulative net N mineralization from each buried bag sampling date for the 2014 0-30 cm soil depth after annual manure applications are shown in figures 2-15. The mean standard deviation for each annual treatment manure rate was 2, 5, 4 and 13 mg kg^{-1} (given in order of increasing manure rates, 0 to 52.0 Mg ha^{-1}). The mean standard deviation for each biennial treatment manure rate was 2, 5, 5, and 7 mg kg^{-1}. Net inorganic N concentrations for the 103.6 cumulative manure treatment effect on standard deviations exceeded control, 17.3, 34.7, and 69.0 kg ha^{-1} at all 11 buried bag sampling events over the growing season (Fig. 2-15).

In addition to an apparent increase in net N mineralization variability in response to increasing manure application rates, there also may be an interaction between net N mineralization variability and fluctuating soil temperatures. Soil temperatures gradually increased from the start of the study in early May peaking in the middle of July then gradually declining through the last sampling date in the middle of October. Nitrogen mineralization rates followed this growing season soil temperature arc, with what appeared to be a 4-week delay in it N release response (Fig. 2-15) Nitrogen mineralization variability followed the same trend as N mineralization, where the peak in response occurred 4 weeks after the middle of July peak in soil temperature. As dairy manure application rates increased, N mineralization rates increased as well as N mineralization variability. Therefore, cumulative annual manure rates of 103.6 Mg ha^{-1} resulted in the most pronounced variability of N mineralization concentrations (Fig. 2-15).

This variability indicates that N mineralization potential of dairy manure becomes increasingly challenging to predict with certainty as dairy manure application rates increase and also as soil temperatures increase over the growing season. Nutrient managers may need to take this trend into account when determining N mineralization potential of different rates of dairy manure over the growing season. Future research is needed to validate these observations.

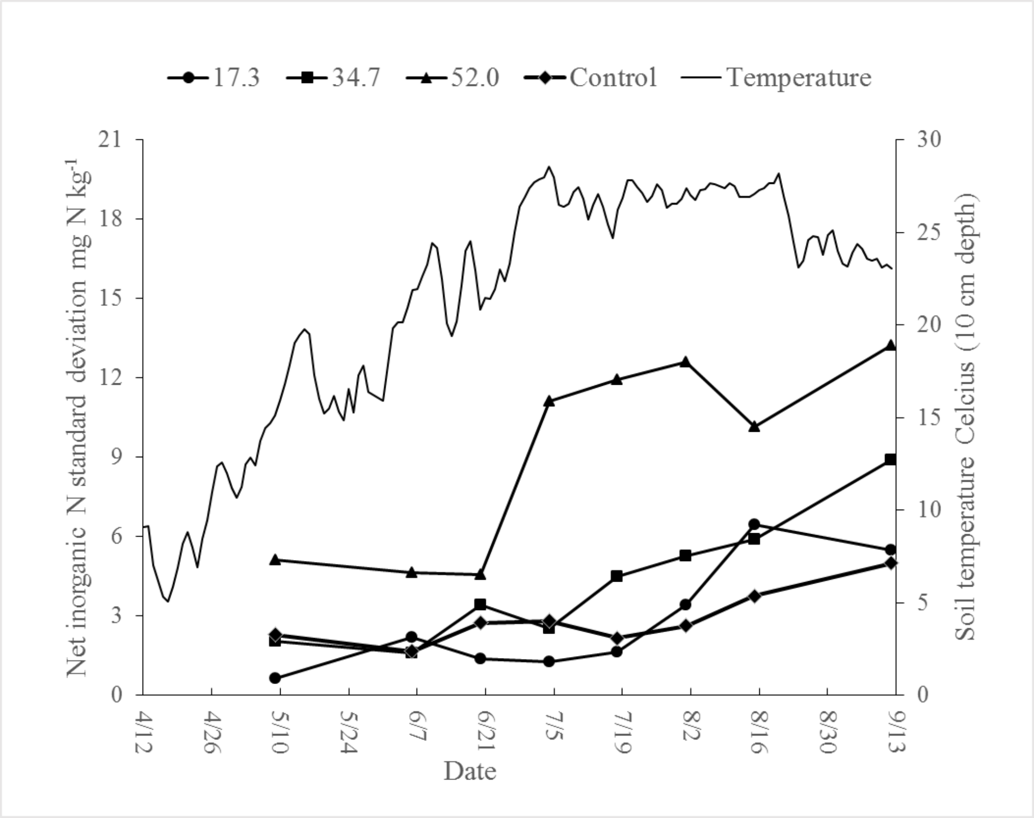

Figure 2-14 Variation in measured net N mineralization for biennial treatments relative to soil temperature (10 cm depth) at different dates during the 2013 growing season. Net N mineralization was measured in a Portneuf silt loam (0-30 cm depth) incubated in the field at the same soil depth in polyethylene bags near Kimberly, Idaho. (n=4). Standard deviations are calculated from sample measurements.

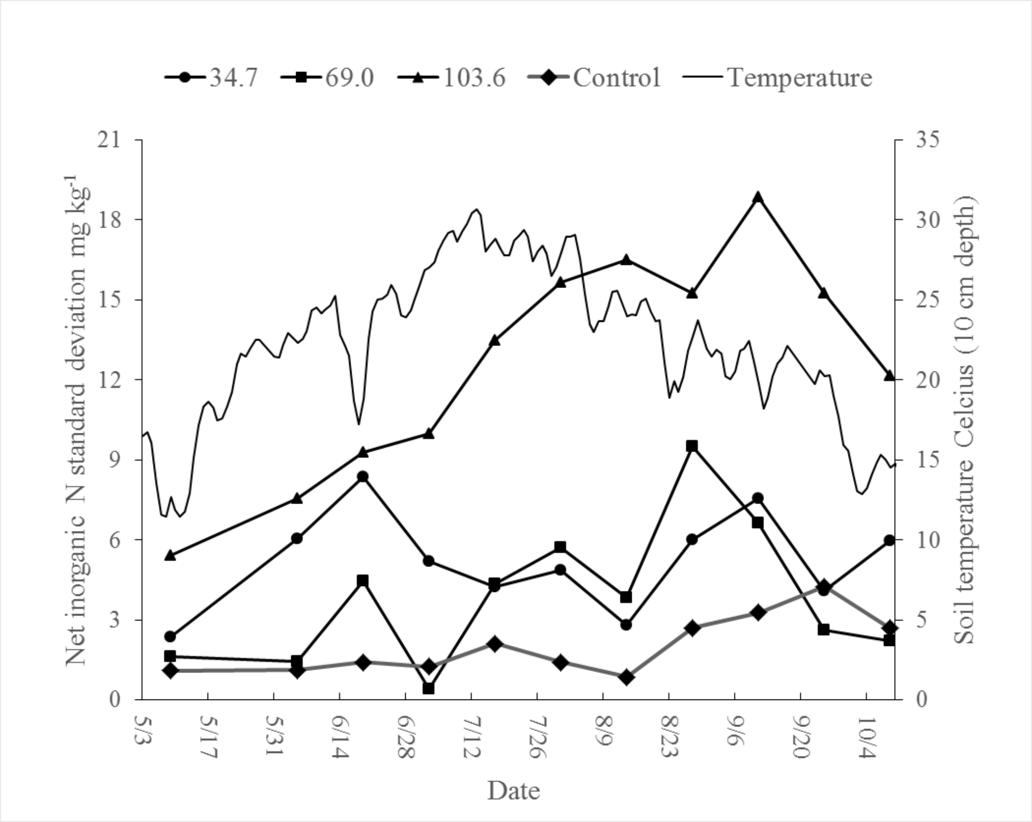

Figure 2-15 Variation in measured net N mineralization for annual treatments, relative to soil temperature (10 cm-depth) at different dates during the 2014 growing season, Net N mineralization was measured in a Portneuf silt loam (0-30 cm depth) incubated in the field at the same soil depth in polyethylene bags near Kimberly, Idaho. Dairy manure was applied on October 16, 2012 and again on November 7, 2013. (n=4) Standard deviations are calculated from sample measurements.

Buried bag N mineralization versus plant N uptake

Inorganic N concentrations in the buried bags at harvest (0-60 cm soil depth) were compared to N plant uptake in barley (2013) and sugar beets (2014) using correlation analysis to gauge the strength of the relationship between the Cumulative net N mineralized and the amount of N taken up by the plant. Barley N uptake was poorly correlated to soil inorganic N at harvest, with a Pearson correlation coefficient of 0.34 and a Spearman correlation coefficient of 0.30. Linear regression analysis produced an r-square of 0.08 (Fig. 2-16). It was determined that barley N uptake did not correlate well with inorganic N concentrations monitored in the field. Physiological limitations of barley may cause the crop to be a poor proxy for estimating inorganic N release from organic N compounds in the soil. Barley crops typically take up between 157 and 270 kg N ha^{-1} (Robertson and Starke, 1993). Excessive soil N often results in lodging (Robertson et al. 1993). Once lodging occurs, barley growth slows, resulting in the barley plant not being able to utilize additional nutrients. A crop that is a luxury consumer of N would likely work better to estimate inorganic N concentrations in the field.

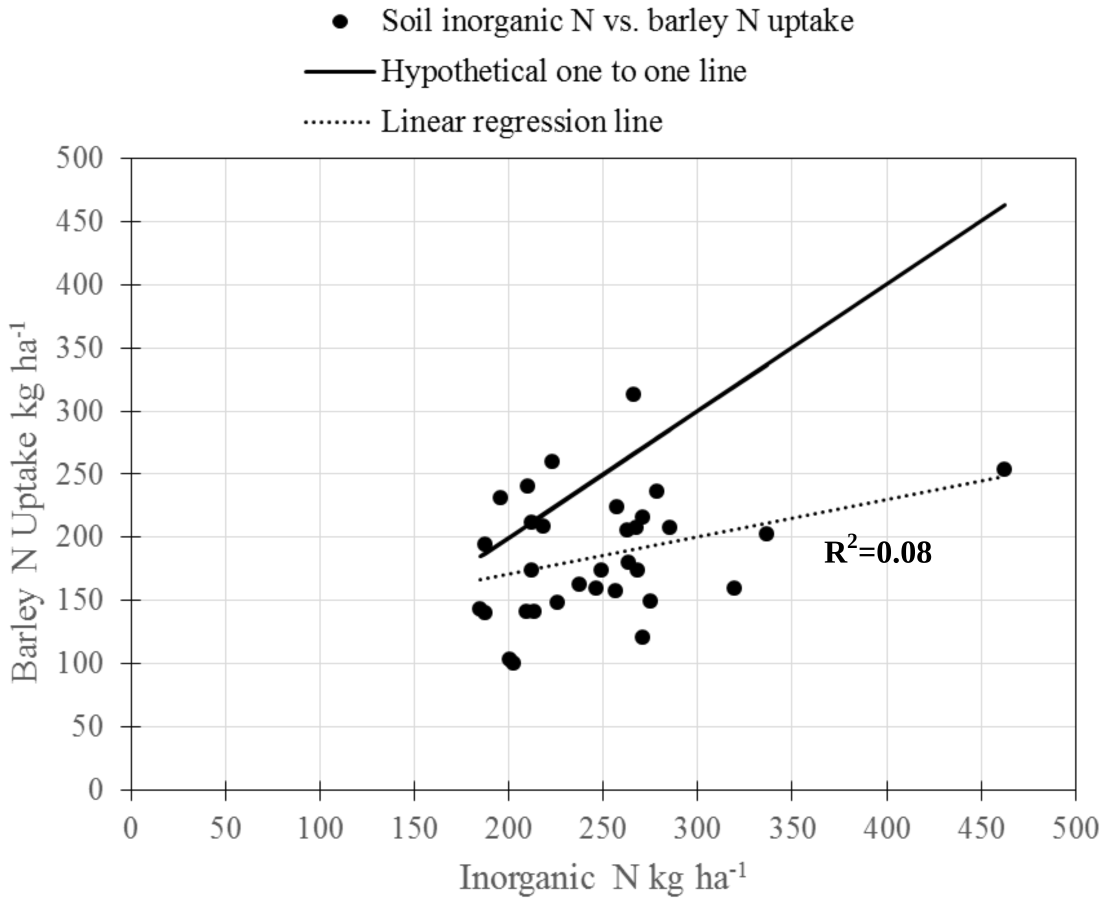

Figure 2-16 Barley N uptake in above ground tissue as a function of inorganic N accumulated in buried bags (0-60 cm) during the growing season (Apr 12 to18 July, 2013). All treatments are included along with linear regression and hypothetical one-to-one line.Portneuf silt loam soil (0-60 cm depth) was incubated in a field cropped to spring barley at the same soil depth in polyethylene bags near Kimberly, Idaho. Dairy manure was applied on October 16, 2012. Experimental design is a RCBD with four replications.

As mentioned above, inorganic N concentrations from the buried bags at harvest (both depths) were compared against sugar beet N uptake in 2014. A Pearson correlation coefficent of 0.86 and a Spearman correlation coefficient of 0.84 were determined. A linear regression resulted in an r-square value of 0.74 (Fig. 2-17). The significant correlation between N uptake in sugar beets and inorganic N observed in the buried bags may be interpreted as an encouraging indicator that the buried bag method has the potential to accurately estimate N mineralization rates in a field environment, assuming that soil moisture is maintained at an adequate level for plant and microbial growth. Sugar beets are efficient N scavengers and will consume N past the N requirement of the plant. According to the southern Idaho fertilizer guide, sugar beets require between 146 and 370 kg ha^{-1} inorganic N for optimum yield and quality (Moore et al., 2009).

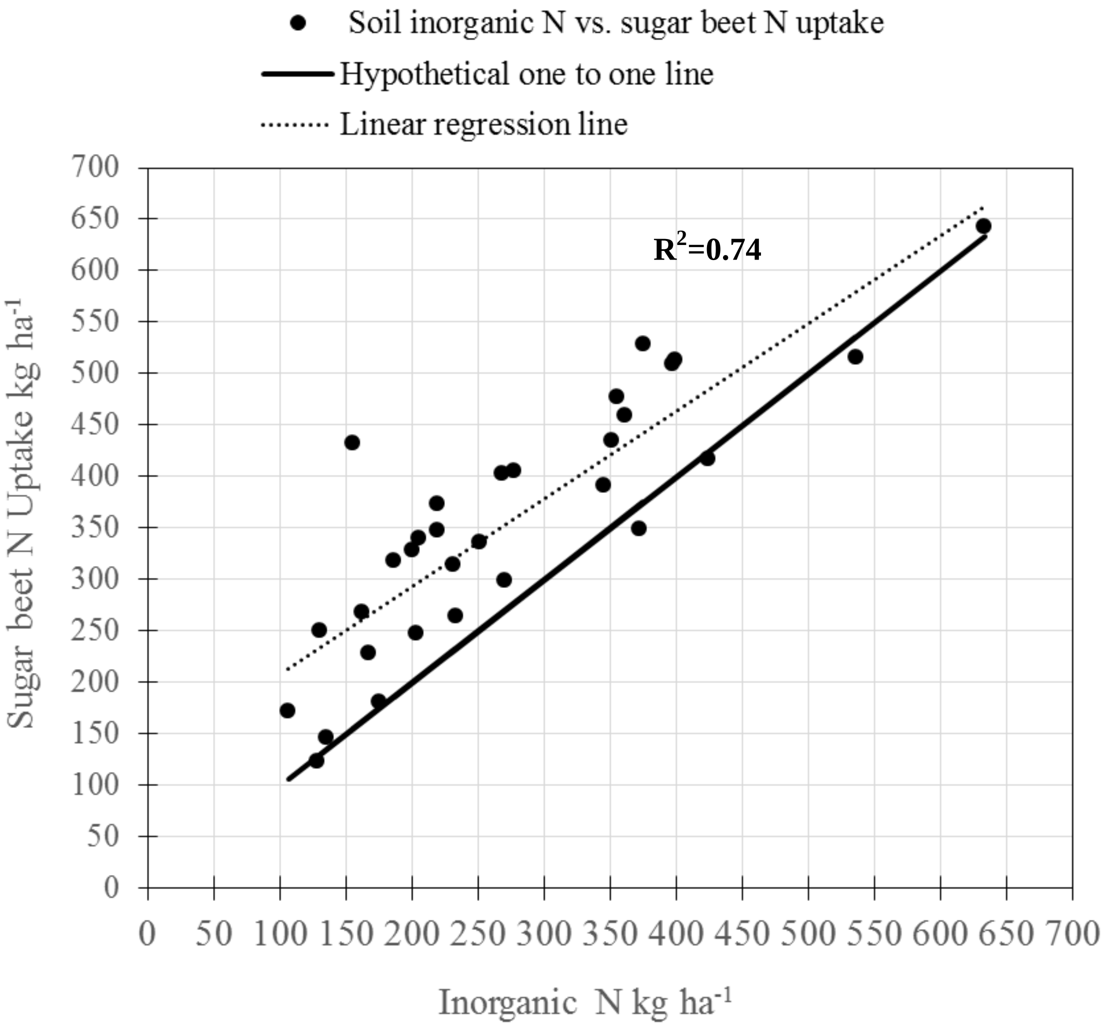

Figure 2-17 Linear regression and hypothetical one to one line of inorganic N vs. barley N uptake. Inorganic N was monitored over the 2014 growing season in a Portneuf silt loam (0-60 cm depth) incubated in a field cropped to sugar beets at the same soil depth in polyethylene bags near Kimberly, Idaho. Dairy manure was applied on October 16, 2012 to annual and biennial plots and on November 7, 2013 to annual plots. Experimental design is a RCBD with four replications.

Implications for crop producers

Supplemental N fertilizer estimates after both annual and biennial dairy manure applications are based on N requirements as determined by Idaho crop yield averages in 2012 (NASS, 2014) and N requirements by crop outlined in University of Idaho (UI) fertilizer guides (Robertson and Stark, 1993; Brown et al., 2001; Stark et al., 2004; Brown et al., 2010;

Brown et al., 2012) assuming an initial soil inorganic N concentration of 10 mg kg^{-1} and negligible crop residues in the soil from previous cropping. Calculations for spring barley are based on May 3, 2014 to July 18, 2014 mineral N releases from dairy manure. All other calculations are based on full season N release. Soil temperatures and N content of manure that vary from those in the present study may result in dairy manure treatment effects that are different from those reported here.

Assuming that soil N concentrations are at or below 10 ppm in the first and second foot soil depths the results of this study show that supplemental N fertilizer may be needed for high and moderate N consumers at annual repeated application rates of 17.3 Mg ha^{-1} or less. Only very high N consumers, like potatoes, may need additional N fertilizer at rates up to 52.0 Mg ha^{-1}.

Conclusion

Manure that was fall-applied in 2012 at rates from 17.3 to 52.0 Mg ha^{-1} (dry wt.) resulted in significant increases in preplant soil inorganic N concentrations in 2013, in comparison to the fertilizer-only and control treatments. In addition, treatments that either did or did not receive additional fall-applied manure in 2013 resulted in significant increases in preplant soil inorganic N concentrations in 2014, again in comparison to the fertilizer-only and control treatments. Accurate crediting of overwinter release of manure N though can be achieved with routine preplant soil tests. Growing season net N mineralization showed a closer fit to linear than quadratic models for all manure and non-manure treatments in both 2013 and 2014 at the 0-30 cm soil depth. For this reason, the zero-order linear model was selected for estimating net N mineralization rate (k), N mineralization amount, the y-intercept, and data variability (r-square). The linear net N mineralization rate consistently increases from April to September at 1 and 2 years after application and after 2 years of repeated fall applications. This finding confirms those of past studies that dairy manure is an effective slow release N fertilizer mineralizing manure N years after application. The results of this study though did show that the relatively low manure rate of 17.3 Mg ha^{-1} (dry wt.) did not appear to contribute appreciably to the inorganic N pool 2 years after application.

Increasing manure application rates also resulted in a linear increase in net N mineralization rates (k values) 1 and 2 years after a fall application, and after 2 years of repeated fall applications at the 0-30 cm soil depth. These results show that the activity of ammonifying and nitrifying soil organisms is limited by mineralizable N and C containing substrates in Portneuf silt loam soils at manure C and N rates at least up to 14,822 and 874 kg ha^{-1} (52.0 Mg ha^{-1} dry wt.) in the first year and at least up to a cumulative manure C and N rate of 19,214 and 1,650 kg ha^{-1} (103.6 Mg ha^{-1} dry wt.) in 2014 at the 0-30 cm soil depth. Years where soil temperatures vary from those of the present study may result in N mineralization potential that differ from those reported here.

Distinct preplant (May 3, 2014) subsoil (30-60 cm) manure treatment effects were detected 2 years after a fall manure application and after 2 years of repeated fall manure applications. Growing season cumulative net N mineralization rates were found to be greater two years after a fall manure application of 52.0 Mg ha^{-1}, indicating organic manure N had leached into the subsoil two years after a single application of 52.0 Mg ha^{-1}. The dominant form of manure-derived N that leached into the subsoil is likely in the form of nitrate as the distinct preplant linear increase of inorganic N corresponding with increasing manure applications was not similarly detected when growing season cumulative net N mineralization was calculated. Therefore preplant subsoil treatment effects were likely caused by nitrate leaching into the subsoil between fall manure applications in 2012 and the placement of the in-situ incubation bags in the spring of 2014.

Nitrogen mineralization data collected from in-situ buried bag studies, like this one, may help growers improve in-season N crediting estimates for fields in south central Idaho or fields in other semiarid regions also under irrigation with dairy manure application histories. Increased precision in plant available N crediting from dairy manure N can result in increased profits due to reduced fertilizer inputs while still providing a high quality product that is competitive in current markets. In addition, improved plant available N estimates may also reduce environmental damage by assisting crop producers in supplying plants with N at a rate that does not exceed the plant’s capacity to utilize the nutrient, thus reducing its offsite transport. Further investigation is warranted to determine if accounting for unique soil temperatures will result in improved estimates of N mineralization potential of dairy manure, as well as possibly improving modeling efforts resulting in increased predictive accuracy across growing seasons with varying soil temperatures.

Works Cited

Adams, M.A., and P.M. Attiwill. 1986. Nutrient cycling and nitrogen mineralization in eucalypt forests of south-eastern Australia. Plant Soil 92:341-62.

AgriMet. "AgriMet Weather Station Equipment and Sensors."Agrimet Pacific Northwest Region. The Pacific Northwest Cooperative, 2016 Web. 21 Aug. 2016.

Beegle, D. B., K. A. Kelling, and M. A. Schmitt. "Nitrogen from Animal Manures." Nitrogen in Agricultural Systems. Ed. J. S. Schepers and W. R. Raun. Madison: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, 2008. 823-27. Print. Agronomy Monograph No. 49.

Binkley, D., and S. Hart, 1989. The components of nitrogen availability assessments in forest soils. Adv. Soil Sci. 10: 57-112.

Binkley, D., R. Bell, and P. Sollins. 1992. Comparison of methods for estimating soil nitrogen transformations in adjacent conifer and alder–conifer forests. Can. J. For. Res. 22.6:858-63.

Bossio D.A., K.M. Scow, N. Gunapala, and K.J., Graham. 1998. Determinants of soil microbial communities: effects of agricultural management, season, and soil type on phsopholipid fatty acid profiles. Microb. Ecol. 36:1-12

Brady, N.C.1990. Organisms of the soil. In The nature and properties of Soil. 10th ed. Macmillan, New York, NY. 254-76

Burford, J. R., and D. J. Greenland. 1970. Denitrification under an annual pasture. In: Proc. of International Grassland Conference, Surfers Paradise Queensland University, St. Lucia, Australia.

Burnell, B., and M. Thomas. 1990. Integrated Database: Idaho. Idaho Department of Health and Welfare DEQ. http://www.nesc.wvu.edu/septic_idb/idaho.htm#septicstats (accessed 19 Sept. 2016).

Cabrera, M.L., and D.E. Kissel. 1988. Evaluation of a method to predict nitrogen mineralized from soil organic matter under field conditions. Soil Sci. Soc. Am. J. 52:1027-031.

Cabrera, M.L., J.A. Molina, and M. Vigil. 2008. Modeling the nitrogen cycle. Agr. Monograph. 49: 695:730.

Cameron, D.R., C.G. Kowalenko, and K. C. Ivarson. 1978. Nitrogen and chloride distribution and balance in a clay loam soil. Can. J. Soil. Sci. 58.1:77-88.

Campbell, C. A. "Influence of Fluctuating Temperature and Constant Soil Moisture on Nitrogen Changes in Amended and Unamended Soil." Canadian Journal of Soil Science 52 (1972): 323-36. Web. 21 May 2015.

Carreiro, M.M., and R.E. Koske. 1992. Room temperature isolations can bias against selection of low temperature microfungi in temperate soils. Mycologia 84.6: 886-900.

Cassman KG, Munns DN (1980) Nitrogen mineralization as affected by soil moisture, temperature, and depth. Soil Sci Soc Am J 44:1233–1237.

Chae, Y.M., and M.A. Tabatabai. 1986. Mineralization of nitrogen amended with organic wastes. J. Environ. Qual. 15.2:193-98.

Cheever BM, Webster JR, Bilger EE, Thomas SA (2013) The relative importance of exogenous and substrate-derived nitrogen for microbial growth during leaf decomposition. Ecology 94:1614–1625

U.S. Department of Energy. Pacific Northwest National Laboratory. Value-added chemicals from animal manure, by S. Chen, J.H. Harrison, W. Liao, D. C. Elliott, C. Liu, M. D. Brown, Z. Wen, A. E. Solana, R. L. Kincaid, and D. J. Stevens. National Technical Information Service. Springfield, VA, 2003.

DiStefano, J.F., and H.L. Gholz. 1986. A proposed use of ion exchange resins to measure nitro-gen mineralization and nitrification in intact soil cores. Commun. Soil. Sci. Plant Anal. 17:989–998.

Eberbach Corporation, 505 South Maple Rd, Ann Arbor, MI 48103

Eghball, B., B.J. Wienhold, J. E. Gelley, and R. A. Eigenberg. 2002 Mineralization of manure nutrients. J. Soil Water Conserv. 57.6:470-73.

Eno, C.F. 1960. Nitrate production in the field by incubating the soil in polyethylene bags. Soil Sci. Soc. Amer. J. 24.4:277-99.

Gavlak, R., D. Horneck, and R. Miller. 2005. Soil, plant and water reference methods for the western region. WREP 125.

Gavlak,R., D. Horneck, and R. Miller. 1997. Western States Laboratory Proficiency Testing Program Soil and Plant Analytical Methods, version 4.0, pp. 37-38. From: Plant, Soil, and Water Reference Methods for the Western Region. WREP 125. 1994.

Gale, E.R., M. Dan, C. G. Cogger, and A.I. Bary. 2006. Estimating plant available nitrogen re-lease from manures, composts, and specialty products. J. Environ. Qual. 35:2321-332.

Griffin, T.S., and C.W. Honeycutt. 2000. Using the growing degree days to predict nitrogen availability from livestock manures. Soil Sci. Soc. Am. J. 64:1876-882.

Griffin T.S, Honeycutt C.W, and Z. He. 2002. Effects of temperature, soil water status, and soil type on swine slurry nitrogen transformations. Biol. Fertil. Soils 36, 442–446.

Griffin, T.S., Z. He, and C.W. Honeycutt. 2005. Manure composition affects net transformation of nitrogen from dairy manures. Plant Soil 273:29–38. doi:10.1007/s11104-004-6473-5

Griffiths, B.S, K. Ritz, N. Ebblewhite, and G. Dobson. 1998. Soil Microbial Community Structure: Effects of Substrate Loading Rates. Soil Biol. and Biochem. 31.1:145-53.

Hanselman, T.A., D.A. Graetz, and T.A. Obreza. 2004. A comparison of in-situ methods for measuring net nitrogen mineralization rates of organic amendments. J. Environ. Qual. 33:1098-105.

Honeycutt, C.W., T.S. Griffin, B.J. Wienhold, B. Eghball, S. L. Albrecht, J. M. Powell, B.L. Woodbury, K. R. Sistani, R. K. Hubbard, and H. A. Torbert. 2005b. Protocols for nationally coordinated laboratory and field research on manure nitrogen mineralization. Commun. Soil. Sci. Plant Anal. 36:2807-822.

Honeycutt C.W., T.S. Griffin, and Z. He. 2005a. Manure nitrogen availability: dairy manure in northeast and central U.S. soils. Biol. Agric. Hortic. 23:199–214.

Honeycutt, C.W. 1999. Nitrogen mineralization from soil organic matter and crop residues: field validation of laboratory predictions. Soil Sci. Soc. Am. J. 63:134-141.

Hopkins D.W., R.S. Shiel. 1996. Size and activity of soil microbial communities in long-term experimental grassland plots treated with manure and inorganic fertilizers. Biol. Fertil. Soils 22: 66-70

Idaho 2015 Census tables. 2015. Census: Idaho Department of Labor. https://lmi.idaho.gov/census (accessed 07 Oct. 2016).

IDEQ. 2014. Water Quality Division. Nitrate priority area delineation and ranking process. IDEQ (Boise). https://www.deq.idaho.gov/media/1117845/nitrate-priority-area-delineation-ranking-2014.pdf (accessed 05 Sept. 2016).

Katterer, T., M. Reichstein, O. Andren, and A. Lomander. 1998. Temperature dependence of or-ganic matter decomposition: a critical review using literature data analyzed with different models. Biol. Fertil. Soils 27:258-62.

Khanna P.K., Raison R.J. 2013. In-situ core methods for estimating soil mineral-N fluxes: re-evaluation based on 25 years of application and experience. Soil Biol. Biochem. 64:203–210.

Killham, K. 1994. The ecology of soil nutrient cycling. In Soil Ecology. Cambridge University Press, New York. pp. 107.

Kjonaas, O.J. 1999a. Factors affecting stability and efficiency of ion exchange resins in studies of soil nitrogen transformation. Commun. Soil. Sci. Plant Anal. 30:2377-397.

Kjonaas, O.J. 1999b. In-situ efficiency of ion exchange resins in studies of nitrogen transformation. Soil Sci. Soc. Am. J. 63:399-409.

Kusonwiriyawong, C., Dan Sullivan, C. G. Cogger, A. J. Bary, and L. Myhre. "Predicting Plant-Available Nitrogen from Organic Amendments in the Second Year after Application." Organic Matter Management and Compost in Horticulture (2014): no. page. Web.

LECO® Corporation, 1998. CNS-2000 Instrumentation for Characterization of Organic/Inorganic Materials and Microstructural Analysis. CNS-2000 Instructional Manual. LECO® Corporation, 3000 Lakeview Ave. St., Joseph, Michigan 49085.

Lehrsch, G.A., B. Brown, R.D. Lentz, J.L. Johnson-Maynard, and A.B. Leytem. 2016. Winter and growing season nitrogen mineralization from fall applied composted or stockpiled solid dairy manure. Nutr. Cycl. Agroecosyst. 104:125.

Lentz, R.D., and G.A. Lehrsch. 2012. Net nitrogen mineralization from past years' manure and fertilizer applications. Soil Sci. Soc. Am. J. 76.3:1005-015.

Lentz, R.D., G.A. Lehrsch, B. Brown, J. Johnson-Maynard, and A.B. Leytem. 2011. Dairy manure nitrogen availability in eroded and noneroded soil for sugarbeet followed by small grains. Agron. J. 103.3:628-43.

Lentz, R.D., J.A. Ippolito, and K.A. Spokas. 2014. Biochar and manure effects on net nitrogen mineralization and greenhouse gas emissions from calcareous soil under corn. Soil Sci. Soc. Am. J. 78.5:1641-655.

Liao, W., Y. Liu, C. Liu, and S. Chen. 2004. Optimizing dilute acid hydrolysis of hemicellulose in a nitrogen-rich cellulosic material--dairy manure. Bioresour. Technol. 94:33-41.

Lutzow, M. V., and I. Kogel-Knabner. "Temperature Sensitivity of Soil Organic Matter Decomposition- What Do We Know?" Biology and Fertility of Soils 46 (2009): 1-15. Lyrasis Springer Link Journals. Web. 4 June 2015.

Meek, B.D., D.L. Carter, and D.T. Westermann. 1994. Root-zone mineral nitrogen changes as affected by crop sequence and tillage. Soil Sci. Soc. Am. J. 58.5:1464-469.

Milton Roy Co. 201 Ivyland Road Warminster, PA 18974

Moore, A.D, J. Stark, B. Brown, and B. Hopkins. 2009. Southern Idaho fertilizer guide sugar beets. Idaho Nutrient Management. University of Idaho Extension.

Moorhead D., and R.L. Sinsabaugh. 2006. A theoretical model of litter decay and microbial interaction. Ecol Monogr 76:151-174

Mulvaney, R.L. 1996. Nitrogen-Inorganic forms. Pp 1123-1184. In D.L. Sparks et al. (Ed.) Methods of soil analysis. Part 3. Chemical Methods. SSSA, ASA, Madison, WI.

Nahar, M.s., P.s. Grewal, S.a. Miller, D. Stinner, B.r. Stinner, M.d. Kleinhenz, A. Wszelaki, and D. Doohan. "Differential Effects of Raw and Composted Manure on Nematode Community, and Its Indicative Value for Soil Microbial, Physical and Chemical Properties." Applied Soil Ecology 34.2-3 (2006): 140-51. Web. 15 Aug. 2016.

NASS (2015). 2014. State agriculture overview: Idaho. USDA NASS, Washington, DC. http://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=IDAHO. Accessed 21 Aug 2016

Nennich T.D., J.H. Harrison, L.M. VanWieringen, D. Meyer, A.J. Heinrichs, W.P. Weiss, N.R. St-Pierre, R.L. Kincaid, D.L. Davidson, and E. Block. 2005. Prediction of manure and nutrient excretion from dairy cattle. J. Dairy Sci. 88:3721–3733.

Norton, J.M. 2008. Nitrification in agricultural soils. In: J.S. Schepers and W.R. Raun, editors, Nitrogen in agricultural systems. Agron. Monogr. 49. ASA, Madi-son, WI. p. 173-99.

Ohaus Corporation. 310 Campus Drive, Parsippany, NJ 07054

Parham J.A., S.P. Deng, H.N. Da, H.Y. Sun, W.R. Raun 2003. Long-term cattle manure application in soil. II. Effect on soil microbial populations and community structure. Biol. Fertil. Soils 38:209-215

Patterson P.E., and K.M. Painter. Idaho Crop Input Price Survey for 2014. 2014. Agricultural Economics Extension Series No. 14-04. Department of Agricultural Economics and Rural Sociology. https://www.uidaho.edu/~/media/UIdaho-Responsive/Files/cals/Programs/ID-Agbiz/crop-budgets/crop-input-price-summary/Crop-Input-Price-Survey-2014.ashx. (accessed 16 Sept. 2016).

Pettygrove, G.S., A. L. Heinrich, and A. J. Eagle. 2010. Dairy Manure Nutrient Content and Forms. University of California Cooperative Extension Manure Technical Bulletin Series. http://manuremanagement.ucdavis.edu/files/134366.pdf. (accessed 05 Oct. 2016).

Pratt, P.F., F.E. Broadbent, and J.P. Martin. 1973. Using organic wastes as nitrogen fertilizers. Calif. Agr. 27:10–13.

Raison, R., M. Connell and P. Khanna 1987. Methodology for studying fluxes of soil mineral-N in-situ. Soil. Biol. Biochem. 19:521-530.

Richards, B.N., J.E. Smith, G. J. White, and J. L. Charlie. 1985. Mineralization of soil nitrogen in three forest communities from the New England region of New South Wales. Aust. J. Ecol. 10:429-41.

Ritz K., R.E. Wheatley, B.S. Griffiths. 1997. Effects of animal manure application and crop plants upon size and activity of soil microbial biomass under organically grown spring barley. Biol. Fertil. Soils 24:372-377

Robertson, L.D., and J.C. Starke. 1993. Idaho Spring Barley Production Guide. Idaho Nutrient Management. University of Idaho Extension, Bul 742. 42 pp.

SAS Institute. 2013. SAS/CONNECT user’s guide. Version 9.3. SAS Inst. Cary, NC.

Schnabel, R.R., S.R. Messier, and R.F. Purnell. 1993. An evaluation of anion exchange resin used to measure nitrate movement through soil. Commun. Soil. Sci. Plant Anal. 24:863-79.

Schnabel, R.R., 1983. Measuring nitrogen leaching with ion exchange resin: a laboratory assessment. Soil Sci. Soc. Am. J. 47:1041-042.

Schnabel, R.R., 1995. Nitrate and phosphate recovery from anion exchange resins. Commun. Soil Sci. Plant Anal. 26:531-40.

Sierra, J. 1997. Temperature and soil moisture dependence of N mineralization in intact soil cores. Soil Biol. Biochem. 29.9-10:1557-563.

Simek M., D.W. Hopkins, J. Kalcik, T. Picek, H. Santruckova, J. Stana, K. Travnik 1999. Biological and chemical properties of arable soils affected by long-term organic and inorganic fertilizer applications. Biol Fertil Soils 29:300–308

Sims, J.R. and V.A. Haby. 1971. The colorimetric determination of soil organic matter. Soil Sci. 112:137-141.

Sistani, K.R., A. Adeli, S.L. Mcgowen, H. Towolde, and G.E. Brink. 2008. Laboratory and field evaluation of broiler litter nitrogen mineralization. Bioresour. Technol. 99.7:2603-611.

Soil Survey Staff. 2014. Soil Survey Field and Laboratory Methods Manual. Soil Survey Investigations Report No. 51, Version 2.0. R. Burt and Soil Survey Staff (ed.). U.S. Department of Agriculture, Natural Resources Conservation Service.

Sorensen, H. 1962. Decomposition of lignin by soil bacteria and complex formation between autoxidized lignin and organic nitrogen compounds. J. Gen. Microbiol. 27:21-34.

Stanford, G., M.H. Frere, and D.H. Schwaninger. 1973. Temperature coefficient of nitrogen mineralization in soils. Soil Sci. 119:222-226

Stanford G., J.N. Carter, D.T. Westermann , and J.J. Meisinger. 1977. Residual nitrate and mineralizable soil nitrate in relation to nitrogen uptake by irrigated sugar beets. Agron. J. 69:303–308

Stark, J. C., D.T. Westermann, and B.G. Hopkins. 2004. Nutrient management guidelines for Russet Burbank potatoes. Bull. 840. Univ. of Idaho, Moscow.

Stenger, R.E., E. Priesack, and F. Beese. 1996. In situ studies of soil mineral N fluxes: some comments on the applicability of the sequential soil coring method in arable soils. Plant Soil 183:199-211.

Subler, S., R.W. Parmelee, and M.F. Allen. 1995. Comparison of buried bag and PVC core methods for *in situ* measurements of nitrogen mineralization rates in an agricultural soil. Com-mun. Soil. Sci. Plant Anal. 26.15-16:2369-381.

Tarkalson, D.D. 2012. Nitrogen requirement for sugar beets: A summary of past and present research findings. Proceedings of the Idaho Nutrient Management Conference. p. 15-19. March 6, 2012. Jerome, ID.

Thermo Scientific. 168 Third Avenue, Waltham, MA 02451

Van Kessel, J.S., J.B. Reeves, and J.J. Meisinger. 2000. Nitrogen and carbon mineralization of potential manure components. J. Environ. Qual. 29:1669-677.

Van Kessel, J.S, and J.B. Reeves. 2002. Nitrogen mineralization potential of dairy manures and its relationship to composition. Biol. Fertil. Soils 36:118-23.

Wagner Packaging Solutions 2850A S 900 W, Salt Lake City, UT 84119

Weier, K.L., J.W. Doran, J.F. Power, and D.T. Walters. 1993 Denitrification and the dinitrogen/nitrous oxide ratio as effected by soil water, available carbon, and nitrate. Soil Sci. Soc. Am. J 57:66-72.

Westermann, D.T., and S.E. Crothers. 1980. Measuring soil nitrogen mineralization under field conditions. J. Am. Soc. Agron. 72:1009-012.

Willrich T.L., D.O. Turner, and V.V. Volk. 1974. Manure application guidelines for Pacific Northwest. ASAE Paper No. 74-4601, Am. Soc. Agric. Eng. St. Joseph, MI

Vitamix Corporation 6134 Kruse Drive, Solon, OH 44139

Wolf, D.C., and G.H. Wagner. 2005. Carbon transformations and soil organic matter formation. In: D.M. Sylvia, J.J. Fuhrmann, P.G. Hartel, and D.B. Zuberer, editors, Principles and Applications of Soil Microbiology. Pearson Education Inc. Upper Saddle River, NJ. p. 285-332.

Wyland, L.J., and L.E. Jackson. 1993. Evaluating nitrate recovery by ion exchange resin bags. Soil Sci. Soc. Am. J. 57:1208-211.

YSI Inc., 1700/1725 Brannum Ln, Yellow Springs, OH 45387

Zaccheo, P., Cabassi, G., Ricca, G., & Crippa, L. (2002). Decomposition of organic residues in soil: Experimental technique and spectroscopic approach. Organic Geochemistry, 33, 327–345.

Zhengxia, D., J.D. Toth, J.D. Jabro, R.H. Fox, and D.D. Fritton. 1996. Soil nitrogen mineralization during laboratory incubation: Dynamics and model fitting. Soil Biol. Biochem. 28.4:625-32.

Zogg, G.P., D.R. Zak, D.B. Ringelberg, D.C. White, N.W. Macdonald, and K.S. Pregitzer. 1997. Compositional and functional shifts in microbial communities due to warming. Soil Sci. Soc. Am. J. 61:475-81.

Appendix A: Nitrogen mineralization model selection

The zero order model worked well for all treatments to fit cumulative net N mineralization from fall applied dairy cow manure to a calcareous soil in southern Idaho conditions. Rate coefficients of mineralization were determined from zero order model fit and cumulative net N mineralization data as a function of time. Assessing model efficacy was based on the criteria of how well the model predicted net N mineralization for two growing season dates, July 18, 2013 and September 12, 2013. By the middle of July barley growth is at or near harvest maturity. Other crops such as sugar beets and potatoes are at or near harvest maturity in the middle of September. The more accurate the model predicts inorganic N concentrations for those two dates, the more utility the model provides to southern Idaho crop producers. Model efficacy was assessed by calculating Pearson, Spearman and linear regression correlation coefficients for measured inorganic N vs. predicted inorganic N for July 18, 2013 and September 12, 2013 (Table 2-19).

Table 2-19. Pearson, Spearman and linear regression correlation coefficients of measured inorganic N compared to predicted inorganic N on July 18, 2013 and September 12, 2013.

	Pearson correlation	Spearman correlation
July 18, 2013 measured vs. predicted	0.72	0.59
September 12, 2013 measured vs. predicted	0.99	0.92

Zero order models have been determined to be the best modeling approach for this N mineralization study, although their use is not without some limitations. Zero order models fail to account for multiple N pools. Many organic amendments are comprised of appreciable fractions of both labile and recalcitrant components (Van Kessel et al., 2000; Van Kessel and Reeves., 2002). First order kinetics are employed to model the rapidly mineralizable fractions while still describing the slow release portions with a single rate coefficient as the N mineralization rate plateaus from dairy cow manure additions to soils (Griffin and Honeycutt, 2002; Griffin and Honeycutt, 2005). Researchers have used sequential linear models to describe this same phenomenon of rapid and slow rate change. The researchers accomplished this not by describing N mineralization directly rather measuring decomposition rates of dairy cow manure solids added to soils then incubated in the laboratory (Gale et al., 2006).

Sequential linear modeling may have provided some utility in this N mineralization study, though not to model a slowing down or plateau effect rather to model an apparent increase in mineralization rates as soil temperatures peaked during the study period (Fig. 2-5).

Researchers found that after an aerobic incubation study where repeated dairy manure solids were applied to two different soils and reported on N mineralization data obtained the stwo years after application that N mineralized was successfully estimated with zero order kinetics (Kusonwiriyawong et al., 2014). Researchers monitoring N mineralization from biosolids also found that data best fit zero order kinetics when the C:N ratio was between 5 and 10 (Gilmore et al., 1985; Gilmore et al., 1999; Gilmore et al., 2003). Researchers evaluating N mineralization from soil organic fractions have also found that the monitored N mineralization data trends did not justify seeking out more complex models and that zero order kinetics adequately predicted the monitored N mineralization rates (Addiscott, 1983; Houot et al. 1989; Mary et al., 1999; Tabatabai and Al-Khafaji, 1980).

Another limitation of employing zero order kinetics to model N mineralization as a function of time is that the model does not account for fluctuating temperatures between growing seasons. Numerous studies have shown the effect of temperature on N mineralization in soils with varying soil textures (Campbell et al., 1981; Dessureault-Romper et al., 2010). In addition other workers have used cumulative heat units or growing degree days (GDD) to predict N mineralization from manures (Davenport et al., 2012; Griffin and Honeycutt, 2000; Griffin et al. 2002; Honeycutt et al., 1988). Modeling N mineralization as a function of GDD involves calculating the average of each days maximum and minimum temperatures minus a base temperature. GDD then cumulate by adding each days growing degree contribution. The GDD approach was not used in this N mineralization study in an effort to provide crop producers with a simple means to estimate N contributions from dairy cow manure additions to the soil. In addition, another limitation of the modeling approach in this N mineralization study is that the models can only predict changes during the growing season time period. Crop producers that want to plant spring or fall crops in manured soils are not encouraged to rely on the predictions from the work described here.

The simple zero order model was selected partially due to the ease of use that is possible with a single rate coefficient. Also the zero order model predicted well compared to measure inorganic N for the two growing season time periods of interest.

The zero order model worked well for all treatments, application intervals, and soil depths to fit net N mineralization from fall applied dairy cattle manure to a Portneuf silt loam soil in southern Idaho conditions. Rate coefficients of mineralization were determined from zero order model fit and net N mineralization data as a function of time. Assessing model efficacy was based on the criteria of how well the model predicted net N mineralization for two growing season dates of July 18, 2014 and October 10, 2014. By the middle of July, barley growth is at or near harvest maturity. Other crops such as sugar beets and potatoes are at or near harvest maturity near the end of September. The more accurate the model predicts cumulative net N mineralization values for those two dates, the more utility the model provides to southern Idaho crop producers. Model efficacy was assessed by calculating Pearson, Spearman, and linear regression correlation coefficients for measured inorganic N vs. predicted inorganic N for July 18, 2014 and October 10, 2014 (Table 2-20). The simple zero order model was selected partially due to the ease of use that is possible with a single rate coefficient. Also as noted previously, the zero order model predicted well compared to measure inorganic N for the two growing season time periods of interest (Table 2-20).

Table 2-20. Pearson, Spearman and linear regression correlation coefficients of measured inorganic N compared to predicted inorganic at July 18, 2014 and Oct 10, 2014

	Pearson correlation	Spearman correlation
July 18 measured vs. predicted	0.87	0.71
October 10 measured vs. predicted	0.98	0.95

Appendix B: Field activities by date

Table 2-21**.** Study seasons of 2012-2013 and 2013-2014 field activities by date.

Date	Field activity
September 20, 2012	Initial pre dairy manure soil samples were collected from the field.
October 14, 2012	Dairy manure was delivered to the study field.
October 18, 2012	Composite manure samples were collected and stored in a refrigerator.
October 18, 2012	Manure was applied and incorporated into the soil with disking.
October 30, 2012	Composite manure samples were shipped to an analytical laboratory.
April 2, 2013	Fertilizer was applied and the field was planted to spring barley.
April 12, 2013	Installed soil filled field incubation bags (buried bags).
April 12, 2013	Collected samples from composite soil used in bags to provide time=0 inorganic N.
May 3, 2013	Soils were collected from both the 0-30 cm depth and the 30-60 cm depth.
May 9, 2013	Buried bags were removed from the 0-30 cm soil depth from each plot.
June 6, 2013	Buried bags were removed from the 0-30 cm soil depth from each plot.
June 20, 2013	Buried bags were removed from the 0-30 and 30-60 cm soil depths from each plot.
July 7, 2013	Buried bags were removed from the 0-30 cm soil depth from each plot.
July 18, 2013	Buried bags were removed from the 0-30 and 30-60 cm soil depths from each plot.
July 24, 2013	Barley samples were collected.
August 8, 2013	Buried bags were removed from the 0-30 cm soil depth from each plot.
August 6, 2013	The remaining barley field in the study field was harvested.
August 15, 2013	Buried bags were removed from the 0-30 and 30-60 cm soil depths from each plot.
August 22, 2013	Swathed and bailed barley residue.
September 12, 2013	Buried bags were removed from the 0-30 cm soil depth from each plot.
October 25, 2013	Manure samples were collected for moisture analysis.
November 6, 2013	Collected composite samples of manure for analyses.
November 7, 2013	Dairy cow manure was applied to the study field and incorporated with disking.
April 17, 2014	Urea fertilizer was applied to the study field.
May 3, 2014	Installed soil filled field incubation bags.
May 3, 2014	Collected samples from composite soil used in bags to provide time=0 inorganic N.
	Soils were collected from both the 0-30 cm depth and the 30-60 cm depth.
May 5, 2014	Planted the study field to sugar beets (STS-21RR25).
May 9, 2014	Buried bags were removed from the 0-30 cm soil depth from each plot.
June 5, 2014	Buried bags were removed from the 0-30 cm soil depth from each plot.
June 19, 2014	Buried bags were sampled at the 0-30 and 30-60 cm soil depths from each plot.
July 3, 2014	Buried bags were removed from the 0-30 cm soil depth from each plot.
July 17, 2014	Buried bags were removed from the 0-30 and 30-60 cm soil depths from each plot.
July 31, 2014	Buried bags were removed from the 0-30 cm soil depth from each plot.

August 14, 2014	Buried bags were removed from the 0-30 and 30-60 cm soil depths from each plot
August 28, 2014	Buried bags were removed from the 0-30 cm soil depth from each plot.
September 11, 2014	Buried bags were removed from the 0-30 cm soil depth from each plot.
September 25, 2014	Buried bags were removed from the 0-30 and 30-60 cm soil depths from each plot.
September 30, 2014	Sugar beets at harvest maturity were sampled.
October 9, 2014	Buried bags were removed from the 0-30 cm soil depth from each plot.