AN ABSTRACT OF THE THESIS OF

John Paul Gainer McQueen for the degree of Master of Science in Soil Science
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Title: Estimating the Dry Matter Production, Nitrogen Requirements, and Yield of Organic Farm-Grown Potatoes.

Abstract approved:

Dan M. Sullivan

As part of a participatory research project, where farmers and Oregon State University researchers collaborated, aspects of potato (*Solanum tuberosum* L.) growing systems were studied. It was determined through conversations with the farmers that quantification of certain growth parameters of potato was lacking, including dry matter accumulation, crop nitrogen (N) uptake, and yield. In order to better assist the farmers in making fertilization decisions a study of the systems was undertaken.

An important aspect in making fertilization recommendations is estimating the contribution of N by the soil in a growing season. This contribution was estimated in two ways. The first was through a laboratory aerobic incubation. Soil was collected in spring, summer, and post-harvest from the participating farms' potato fields in 2006. The N mineralization incubation was conducted for 63 d at 22˚C with subsampling to determine NO3-N every 21 d beginning with Day 0. The second method was by using a plant bioassay approach. Plant biomass, excluding roots, was harvested three to four times during tuber bulking from plots where no current season amendments were added to the soil (zero-N plots). The concentration of N was determined for the plant residues and N uptake estimated. Petiole samples were analyzed for NO_3-N to monitor the relative N status during the season and to determine if there were N deficiencies.

Growth measurements of potato were also conducted on “Intensive Farms” in plots where farmers conducted “typical” nutrient management. Weekly plant samples were removed beginning when tubers were 1 to 3 cm in diameter. From these samples dry matter accumulation, crop N uptake, and fresh tuber yield were estimated. Petiole samples were also taken to determine the relative N status of the plant. Yield was also measured for a second group of farm, “All-Farms”. This sampling used an “as-is” approach that consisted of hand-digging sections of row and calculating yield per hectare using row spacing found in the sampled field.

In the laboratory, net N mineralization rates were approximately 0.4 to 1.3 NO_3-N mg kg^{-1} d^{-1} during the 63-day incubation at 22°C for soils collected from 11 farms in the spring with a median of 0.7 NO_3-N mg kg^{-1} d^{-1}. The N-supplying capacity of the soils is estimated at 120 to 160 kg N ha-1 for 2000 degree days. The uptake of N by the potato in zero-N plots at harvest was 83 to 237 kg N ha^{-1} confirming the high amounts of N mineralization observed in the laboratory incubation. The soils on these farms mineralize an estimated 3% of total soil N in less than 1400 degree days (base 0˚C).

On Intensive Farms, total nitrogen uptake was an estimated 145, 190, and 245 kg N ha^{-1} for Farms 1, 2, and 3. Despite different levels of N uptake, fresh tuber yields on Intensive Farms were similar between farms with 53 Mg ha^{-1} on Farm 1, 45 Mg ha^{-1} on Farm 2, and 43 Mg ha^{-1} on Farm 3. Higher N levels on Farm 3 did not increase yields and total N in shoots at harvest was highest at 150 kg ha^{-1} verses Farm 1 with 40 kg ha^{-1}. Tuber bulking rates were 0.8, 0.7, and 1.0 Mg ha^{-1} d^{-1} for Farms 1, 2, and 3. Delaying harvest could have resulted in higher yields. For tuber yields of 50 Mg ha^{-1} farmers can expect a total N uptake of approximately 200 kg N ha^{-1} with 0.9 m between-row spacing. Fresh tuber yields on All-Farms varied by cultivar and location with a median of 19 Mg ha^{-1} that reflected in-field between-row spacing. At harvest, medium tubers 85 to 227 g (3 to 8 oz) averaged 50% of fresh tuber yield. To accomplish higher yields, row spacing near 1 m is recommended. Petiole N levels were variable during the season with starting values lower than common recommendations and decreasing rapidly as time progressed. We estimate that the soil at these farms supplies approximately 120 to 160 kg N ha^{-1} and applications of less than 100 kg of plant-available N should support current yields.

Estimating the Dry Matter Production, Nitrogen Requirements, and Yield of Organic Farm-Grown Potatoes

by

John Paul Gainer McQueen

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

John Paul Gainer McQueen, Author

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CONTRIBUTION OF AUTHORS

Dr. Dan Sullivan who assisted with study design and laboratory methods. Lane Selman who collaborated with data collection in the field and laboratory.

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GENERAL INTRODUCTION

Information was lacking concerning the growth of potato (*Solanum tuberosum* L.) on organic farms in Oregon and western Washington. Farmers and Oregon State University researchers collaborated in a participatory research project directed towards the growing of potatoes. Farmer directed research questions were explored to help the growers utilize their resources more wisely. A survey-type approach was used to help understand the participating farms as a group.

A concern for the small organic farm is the need to make fertilizer decisions for a range of crops in a system that relies on large amounts of organic matter contributions where fertilizer recommendations have not been calibrated. Fertilizer guides are typically made for certain crops in specific locations and extrapolating the results to fit different scenarios is not advised. However, knowing the soil N contribution to crop N uptake could improve recommendations by creating a baseline for applying additional fertilizer.

Organic farms generally supply large amounts of organic matter to their soils through composts and cover cropping. Over time, these additions increase the size of the active pool of soil organic matter (Marriott and Wander, 2006) and could change the amount of N from mineralization that should be budgeted for. Estimating the contribution of soil N to these systems could lead to more efficient use of N, minimizing risks to the environment and lowering production costs (Jarvis et al., 1996; Rice and Havlin, 1994). Increased information on the contribution of soil N to the crop could be useful to these growers since their nutrient management programs are driven by soil N mineralization. If soil N mineralization is high the amount of fertilizer that is recommended could be in excess.

Specific information relating N mineralization from soil to organic agriculture is not available. Extension bulletin PNW 513 Nitrogen Uptake and Utilization by Pacific Northwest Crops (Sullivan et al., 1999a) estimates that the soil N supply from mineralization in the Willamette Valley, OR commonly ranges from 50 to 130 kg N ha^{-1} depending on soil type and crop management practices. A common recommendation states that N mineralization estimates can be made by assuming that approximately 2% of the total organic N in the surface foot of soil is mineralized annually (Brady and Weil, 1999; Schepers and Mosier, 1991) and that the uncertainty associated with this estimate is 25 to 50% (Schepers and Mosier, 1991). This estimate could double with irrigation bringing favorable moisture conditions, or a history of adding crop residues that increase the soil organic matter content and enlarge the pool of readily decomposable plant material compared with the more recalcitrant pool of soil organic matter (Schepers and Mosier, 1991). A situation likely encountered on the study farms.

Many methods for estimating organic N mineralization in laboratory and field settings are used. Most of the laboratory procedures employ incubating a known quantity of soil for a specified period of time and measuring the increase in NH_4-N and NO_3-N. Incubations can be performed under anaerobic or aerobic conditions. Field indices include manipulations with the soil or using plants as an indicator of N mineralization. In situ soil methods include buried bag methods (Eno, 1960), cover-cylinders (Adams and Attiwill, 1986), and cylinders containing ion-exchange resin (DiStefano and Gholz, 1986). Sullivan et al. (1999b) found that for farms with a history of manure application their estimated rate of N mineralization was in the range of 0.015 to 0.035 NO_3-N mg kg^{-1} DD^{-1} (median 0.028 NO_3-N mg kg^{-1} DD^{-1}).

One of the best field-based approaches to estimating N mineralization is using a recently unfertilized crop as a bioassay of N mineralization (Schepers and Meisinger, 1994). Field methods capture the variability of field conditions including farming management practices, soil moisture and temperature, and the rooting depth of the crop. Potatoes have been used as a field bioassay of soil N supply (Zebarth, 2005b).

Fertilizer trials generally include a nutrient control plot were the contribution of N by the soil is estimated in absence of fertilizer N applications. Usually in these plots, P and K are added to assume no other plant growth limitations. In Canada, Zebarth (2005a) observed in ‘Russet Burbank’ potato a N uptake of 91, 60, and 73 kg

ha^{-1} in 2000, 2001, and 2002. Riley (2000) on sandy soils in Norway, observed N uptake values of 46 kg ha^{-1} by ‘Rutt’ potato, an early maturing cultivar. Trehan (2006), in India, observed a N uptake of 122 kg ha^{-1} as an average of 11 cultivars of potato following a green manure crop of *Sesbania sp.*, and 51 kg ha^{-1} without the green manure crop. Lorenz (1944 and 1947), in California, observed N uptake values of 71 and 67 kg ha^{-1} in 1942 and 1945 for ‘White Rose’ potato. Dyson and Watson (1971) at the Rothamsted experiment station in England found that ‘King Edward’ potato contained a total of 50 and 90 kg N ha^{-1} in 1963 and 1964. Millard and Marshall (1986) found that ‘Maris Piper’ potato contained 80 and 60 kg N ha^{-1} in 1983 and 1984 in 100 days after emergence. Vos (1997) growing ‘Prominent’ and ‘Vebeca’ potatoes in the Netherlands, found an average of 110, 55, 55, 75, and 55 kg N ha^{-1} in years 1988, 1989, 1990, 1992, and 1993. Overall, the amount of N taken up by the potato plant in N control plots is variable from year to year probably due to climatic and environmental conditions affecting N mineralization and losses of N from the system.

Understanding the growth of the potato can explain how N requirements fluctuate during plant development. ‘Russet Burbank’ potato has been described as having four stages of growth (Kleinkopf et al., 1981; Lang et al., 1999; Ojala et al., 1990). Stage 1 is vegetative growth and starts after planting when the seed piece produces stolons that later form the tubers. The underground stolons elongate during Stage 1 until the tips swell, signaling the start of Stage 2: tuberization or tuber initiation. During this 10 to 14 day period, tubers grow to approximately 3 cm. During Stage 3, tubers are in their maximum growth or bulking phase. It concludes with the start of leaf senescence. In growth Stage 4 tubers mature, set tougher skin, and any increase in tuber weight is generally from the translocation of nutrients from the leaves. Commonly farmers aid tuber maturation by killing the shoots through mowing, chemical sprays, or forgoing irrigation, an efficient method in the dry summers of the Pacific Northwest.

The pattern of N uptake and dry matter accumulation for potato from planting until shoot senescence has been described by a sigmoid curve function (Alva et al., 2002; Kleinkopf et al., 1981). During growth Stage 1, N uptake and dry matter accumulation are both relatively slow. But by the end of Stage 2, Kleinkopf et al. (1981) found that 60% of total seasonal N uptake had occurred while only 20% of the dry matter was produced, thus N uptake precedes dry matter accumulation. They also found that at end of Stage 3, the potato had accumulated 98% of its total N and 95% of its total dry matter, but only 80% of the tuber dry weight had been obtained. The remaining 20% of dry weight gain would occur during Stage 4 when reallocation from the shoots to the tubers is responsible for the increase.

Recommendations for fertilizer N rates to obtain optimal potato yields vary. The Extension Service publication Potato Nutrient Management for Central Washington (Lang et al., 1999) gives fertilizer N recommendations based on yield goals and residual soil test N which includes NO_3-N and NH_4-N. With a soil test N value of 0, they recommendation applying 220, 280, 340, and 390 kg N ha^{-1} to achieve yields of 45, 60, 70, and 80 Mg ha^{-1} respectively. For every 10 ppm increase in soil test N the N application rate decreases by 20 % from the 0 ppm value.

The Malheur County Oregon Experiment Station found during cultivar trials conducted in 1993 and 1994 that optimum fertilizer rates didn’t exceed 135 kg N ha^{-1} for ‘Shepody’ and ‘Russet Burbank’ potatoes grown under sprinkler irrigation with wheat grown as the previous crop (Shock, 2005). They found that optimum yield responses also occurred at rates of 0 to 120 kg N ha^{-1} depending on the year.

In a summary of mixed fertilizer potato trials from the past 40 years, the Florida Cooperative Extension Service recommends a maximum N application of 200 kg ha^{-1} for optimal potato yields and with only sporadic yield increases with up to 225 kg N ha^{-1} (Hochmuth and Cordasco, 2000). And from the Virginia Cooperative Extension for white potato production, a recommendation of 140 to 170 kg N ha^{-1} is given for a yield goal of 22 Mg ha^{-1} of fresh tubers (Phillips et al., 2004). For higher yield goals they recommend that growers add approximately 7 kg N per Mg of yield increase. Westermann (2005) reported in a review of the nutritional requirements of potatoes that for a 56 Mg ha^{-1} yield a total uptake 235 kg N ha^{-1} is used.

Petiole sampling can provide a grower with an in-season method to ascertain whether or not to supply addition N fertilizer to obtain desired yields, as top dressing with N fertilizer has been shown to maintain petiole nitrate (petiole N) during tuber bulking (Gardner and Jones, 1975). Petiole nitrate values generally start high at the beginning of the season and decline with growth (Gardner and Jones, 1975; Lewis and Love, 1994; Meyer and Marcum, 1998; Wescott et al., 1991), therefore sampling petioles more than once during the growing season is recommended (Gardner and Jones, 1975). A monitoring program is suggested due the variability in values from one site to the next and in order to measure the actual effects of soil N availability during growth (Wescott et al., 1991).

To assist organic farms in Oregon and western Washington with fertilization decisions, a study of potato growing systems was undertaken. Our objectives were to (i) estimate the N contribution from soil through laboratory and field methods, (ii) estimate dry matter accumulation, N uptake, and yield under normal growing conditions, (iii) monitor petiole N levels, and (iii) give a fertilizer recommendation based on research results.

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ESTIMATING THE NITROGEN SUPPLYING CAPACITY OF ORGANICALLY MANAGED SOILS FOR POTATO PRODUCTION

Abstract

As part of nutrient budgets in annual cropping systems, the amount of nitrogen (N) supplied by the soil is generally estimated for planning purposes. Inaccurately accounting for the amount of N the soil contributes to crop uptake can lead to over, or under, fertilization. This study was undertaken to provide an estimate of N contribution by the soil during a growing season for organic potato production. Nitrogen release by the soil was estimated for 12 small organic farms in Oregon and Washington using an aerobic laboratory incubation technique and zero-applied N plots located on the farms. Net mineralization rates were in the range of 0.4 to 1.3 NO_3-N mg kg^{-1} day^{-1} during the 63-day incubation at 22°C for soils collected in the spring with a median of 0.7 NO_3-N mg kg^{-1} day^{-1}. The N-supplying capacity of the soils is estimated at 120 to 160 kg N ha^{-1} for 2000 degree days (base 0°C) assuming a sample depth of 15 cm and bulk densities of 1.0 to 1.3 g cm^{-3}. The uptake of N by the potato in zero-N plots at harvest ranged from 83 to 237 kg N ha^{-1} with a median of 155 kg N ha^{-1} confirming high amounts of N mineralization. The soils on these farms mineralize an estimated 3% of total soil N in less than 1400 degree days.

Introduction

When determining the amount of nitrogen (N) a grower needs to supply as fertilizer, it is common to estimate the amount of N taken up by the crop and then subtract the N contribution from various sources (Eq. 1).

$$\text{fertilizer N} = \text{N requirement of crop} - \text{nonfertilizer N source} \qquad [1]$$

Nitrogen contributions that are non-fertilizer sources include recent incorporation of a cover crop, mineralization of N from past organic additions and the soil organic matter, and pre-plant soil nitrate-N levels. Guidelines for estimating cover crop N vary but are commonly based on the plant species, dry weight, %N, stand density, and the height when incorporated (Sattell and Dick, 1998). Guidelines on the estimated N contribution from soil mineralization vary depending on the source.

Typically, when fertilizer guides are created, the amount of N mineralized from the soil is included in the recommended fertilizer rate. This value is obtained from the crop response grown in the nutrient control plot. Fertilizer guides are typically made for crops in specific locations and extrapolating the results to fit different scenarios is not recommended.

Within the context of this study, on small organic farms (USDA, 2002), the diversity of crops grown in relatively small areas suggests that fertilization decisions are made to cater to a variety of crops and might not fit within the parameters of fertilizer guides. Herein lays a concern for the small organic farm, the need to make fertilizer decisions for a host of crops in a system that relies on large amounts of organic matter contributions where fertilizer recommendations have not been calibrated. Increased information, such as on a field or farm scale on the contribution of soil N mineralization to the amount of non-fertilizer N, could be useful to these growers since their nutrient management programs are driven by soil N mineralization.

Information on estimating the N contribution from mineralization is not readily available. Extension bulletin PNW 513 Nitrogen Uptake and Utilization by Pacific Northwest Crops (Sullivan et al., 1999a) estimates that the soil N supply from mineralization in the Willamette Valley, OR commonly ranges from 50 to 130 kg N ha^{-1} depending on soil type and crop management practices. A common recommendation states that N mineralization estimates can be made by assuming that approximately 2% of the total organic N in the surface foot of soil is mineralized annually (Brady and Weil, 1999; Schepers and Mosier, 1991) and that the uncertainty associated with this estimate is 25 to 50% (Schepers and Mosier, 1991). This estimate could double with irrigation bringing favorable moisture conditions, or a history of adding crop residues that increase the soil organic matter content and enlarge the pool of readily decomposable plant material compared with the more recalcitrant pool of soil organic matter (Schepers and Mosier, 1991).

Estimating the contribution of soil N to the system could lead to more efficient use of N on farms minimizing risks to the environment and lowering production costs (Jarvis et al., 1996; Rice and Havlin, 1994). Organic farms generally add large additions of organic matter to their soils through composts and cover cropping. This activity increases the size of the active pool of soil organic matter (Marriott and Wander, 2006). These additions change the amount of N from mineralization that should be budgeted.

Many methods exist for estimating organic N mineralization in laboratory and field settings. Most of the laboratory procedures employ incubating a known quantity of soil for a specified period of time and measuring the increase in NH_4-N and NO_3-N. This can be done under anaerobic or aerobic conditions.

Anaerobic incubations involve saturating a sample of soil and storing it at 40°C for a period of seven days and then measuring the amount of NH_4-N present. Most of the aerobic incubation methods are related to Stanford and Smith (1972) who employed a leaching method to determine soil accumulated NH_4 and NO_3-N.

Field indices include manipulations with the soil or using plants as an indicator of N mineralization. In situ soil methods include buried bag methods (Eno, 1960), cover-cylinders (Adams and Attiwill, 1986), and cylinders containing ion-exchange resin (DiStefano and Gholz, 1986).

A review of N mineralization results for soils that are similar to our study sites is given in Table 2.1. Kusonwiriyawong (2005) performed N mineralization experiments in microplots with exchange resin where separated dairy solids were applied in the current season and where they were applied the previous season. Estimates from the microplots were 0.004 and 0.009 mg N kg^{-1} DD^{-1} for current season application of screened dairy solids and 0.014 and 0.019 mg N kg^{-1} DD^{-1} where screened dairy solids were applied one year ago. Sullivan et al. (1999) found on dairy farms with high organic matter content soils a median of 0.026 mg N kg^{-1} DD^{-1} using microplots with exchange resin.

One of the best field-based approaches to estimating N mineralization is using a recently unfertilized crop as a bioassay of N mineralization (Schepers and Meisinger, 1994). This method captures the variability of field conditions including farming management practices, soil moisture and temperature, and the rooting depth of the crop. Potatoes (*Solanum tuberosum* L.) have been used as a field bioassay of soil N supply (Zebarth, 2005b).

The following potato research trials contained zero-N control plots (Table 2.2). All values reported here for N uptake were obtained from those plots and averaged across years. Within each study, fairly consistent N uptake values were obtained from the zero-N plots. In Canada, Zebarth (2005a) observed a N uptake of 91, 60, and 73 kg ha^{-1} in 2000, 2001, and 2002 by 'Russet Burbank' potato. Riley (2000) on sandy soils in Norway, observed N uptake values of 46 kg ha^{-1} by 'Rutt' potato, an early maturing cultivar. Trehan (2006), in India, observed a N uptake of 122 kg ha^{-1} as an average of 11 cultivars of potato following a green manure crop of *Sesbania sp.*, and 51 kg ha^{-1} without the green manure crop. Lorenz (1944 and 1947), in California, observed N uptake values of 71 and 67 kg ha^{-1} in 1942 and 1945 for 'White Rose' potato. Dyson and Watson (1971) at the Rothamsted experiment station in England, found that 'King Edward' potato contained a total of 50 and 90 kg N ha^{-1} in 1963 and 1964. Millard and Marshall (1986) found that 'Maris Piper' potato contained 80 and 60 kg N ha^{-1} in 1983 and 1984 in 100 days after emergence. Vos (1997) growing 'Prominent' and 'Vebeca' potatoes in the Netherlands, found an average of 110, 55, 55, 75, and 55 kg N ha^{-1} in years 1988, 1989, 1990, 1992, and 1993. Overall the amount of N taken up by the potato plant in N control plots is variable from year to year probably due to climatic and environmental conditions affecting N mineralization and losses of N from the system.

Jackson et al. (1974) conducted fertilizer trials in the Willamette Valley, OR on Experiment Stations and in collaborator's fields during the 1960s. The zero-N plots obtained yields of 25, 22, 13, 36, 22, and 27 Mg ha^{-1}. Likewise, many fertilizer studies have published values for yields from zero applied N to measure the N contribution of mineralizing soil organic matter. A review of published values (Table 2.3) had a median yield of 33 Mg ha^{-1} (standard error 2.0 Mg ha^{-1}).

This study was undertaken to provide organic farms an estimate of N availability to potato crops in the absence of current season N inputs. This information could be used for fertilization planning. Our methods included both an in-field measurement of soil N mineralization by measuring N uptake by potatoes and an aerobic laboratory incubation using soil collected from the participating farms. A review of the farms' nutrient management and soil tests was also conducted.

Materials and Methods

Farms 1-12 participated in the laboratory soil incubation experiment. Farm 12 joined the study later and therefore had no soil samples taken in the spring. The soil for the N mineralization incubation was sampled from the 2006 potato field that received typical farm management in spring, summer, and post-harvest. Field plots were used to monitor crop N uptake in absence of current season N inputs (zero-N plots), which Farms 1, 2, 3, 4, 6, and 10 participated in. A winter cover crop was planted on most of the farms and the incorporated residue may have contributed to N mineralization during the growing season. The zero-N plots were not replicated within the field. Petiole samples were taken from the zero-N plots and analyzed for NO_3-N during the sampling period (petiole-N). At harvest on most farms, the soil profile was sampled for NO_3-N to the 90 cm depth in 30 cm increments.

Nitrogen Mineralization Laboratory Incubation

The samples for the N mineralization incubation were collected three times during the year, in spring, summer, and post-harvest. Spring soil samples were taken before current season amendments were applied. Field preparation had not begun on the farms except Farms 8 and 9 which had already added amendments and tilled the soil. Since most of the spring samples were taken before amendments were applied, they represent past management activities, whereas the summer and post-harvest samples were possibly influenced by current season applications.

The summer sample was taken at a time that was appropriate for a sidedress N application from the potato hill. Hilling operations remove soil from between the rows, piling it around the potato plants. This action potentially impacts the soil profile sampled from the hills making the soil depth sampled the top 15 cm, not 30 cm.

In spring and summer, the soil was sampled with a stratified random method that resulted in three composite samples of 10-15 cores each. Each composite sample was incubated separately for a total of three samples per farm. The average sampled area was approximately 2000 m^2. Sampling was conducted with a 2.5 cm diameter probe to a depth of 30 cm. From the spring samples, a whole field sample (mixture of the 3 field composite samples) was submitted for nutrient analysis (Table 2.4).

After harvest, the samples were collected using a shovel with a blade approximately 15 cm wide by 45 cm tall, to a depth of 30 cm. A large volume was sampled, approximately 34 L for a concurrent greenhouse experiment. The shovel was pushed into the soil and then drawn back creating a hole that exposed the 30 cm profile. Slices of the profile were taken to the 30 cm depth. The sampling procedure was executed in such a manner as to attempt to collect equal volumes from the 30 cm profile. This procedure was repeated approximately 10 times randomly in the whole field. Many times the shoots of the potato plants were mowed prior to the post-harvest soil sampling and decomposition of the shoots might have influenced NO_3-N levels found in the soil. For the post-harvest collection, the entire field sample was mixed and three subsamples were removed for the laboratory incubation procedure.

For the incubation procedure, field-moist soil was added to 1 L polyethylene bags at a rate of 500 g on a dry weight basis. If gravimetric moisture content was below 20% distilled water was added with a hand spray bottle and the soil was mixed. The soil was not pulverized and screened unless clods or aggregates larger than 1 cm were present to preserve some of the soil structure. Aggregates of this size could interfere with subsampling for nitrate extraction. The bags were placed in plastic boxes with loose-fitting lids, then in an incubation closet in the dark at 22°C.

The bags were sealed to preserve moisture loss except for a drinking straw inserted to facilitate gas exchange and maintain aerobic conditions. Moisture was monitored by determining gravimetric moisture content at each extraction event. A 10 g subsample was removed from the bag, weighed, and dried at 105°C for 24 hours upon which time it was weighed again. Any moisture loss from the previous extraction event was corrected by adding distilled water by way of a spray bottle, followed by a thorough mixing. See Appendix 1 for moisture levels during the incubation process. Moisture level change during the incubation period averaged 3.5 g water 100 g dry soil^{-1} (± 0.4 g, 95% confidence interval).

Ten gram soil samples were removed from the incubation bags and extracted with 50 mL 2 *M* KCl at intervals of 0, 21, 42, and 63 days. Samples were analyzed for NO_3-N in spring, summer, and post-harvest. Additionally, spring samples were analyzed for NH_4-N. The extracts were analyzed by automated colorimetric analysis with the salicylate method for NH_4-N determination and cadmium reduction for NO_3-N (Horneck et al., 1989).

Net N mineralization was determined by subtracting the starting nitrate-N concentration of the soil from the concentration determined at the final sampling event (Eq.2).

$$\text{Net Nmin } (NO_3\text{-N mg kg}^{-1}) = NO_3\text{-N at sampling event (mg kg}^{-1}) - NO_3\text{-N at Day 0 (mg kg}^{-1}) \quad [2]$$

A rate of net N mineralization was calculated by dividing the final net N mineralization value by the number of days of the incubation or thermal units elapsed during the incubation (Eq. 3).

$$\text{Net Nmin rate } NO_3\text{-N mg kg}^{-1} (\text{d}^{-1} \text{ or DD}^{-1} \text{ base } 0°\text{C}) = (\text{net } NO_3\text{-N mg kg}^{-1}) / (\text{d or DD base } 0°\text{C}) \quad [3]$$

Incubation DD were calculated by subtracting the incubation temperature from 0°C. Temperature levels during the incubation were typically measured at 22°C (±

2°C) and a constant 22°C was used in calculations (Honeycutt, 1994) which equaled 1386 DD for the incubation period of 63 days.

Percent of soil N mineralized in relation to days of incubation or thermal units was calculated by dividing NO_3-N kg ha^{-1} measured at the end of the incubation by the total soil N kg ha^{-1} determined during the spring soil analysis (Eq. 4).

$$\text{\% soil N mineralized} = \text{incubation kg N ha}^{-1} / \text{field total soil N kg ha}^{-1} \qquad [4]$$

The incubation kg N ha^{-1} was calculated by multiplying the final NO_3-N mg kg^{-1} by the weight of a hectare of soil estimated to be 1 500 000 kg ha^{-1}. This weight was determined by assuming that the potato hills had a bulk density of 1.0 Mg m^{-3} and multiplying by the sampling depth of 15 cm to represent the potato hill. The field soil total N kg ha^{-1} was calculated by multiplying the N concentration of the soil determined in the spring soil sample analysis by weight of a hectare of soil 15 cm deep, again using 1 500 000 kg ha^{-1}.

Crop N Uptake in Zero-N Plots

Farms 1, 2, 3, 4, 6, and 10 participated in the potato bioassay of N mineralization. Planting dates, row spacing, and sampling dates is in Table 2.5. Zero-N plots of at least four rows wide and 15 m long were marked and no current season amendments, such as composts or chicken litter, were added. The spacing between the rows was based on the current management practice of the farmer and ranged from 0.9 m to 1.8 m. All calculations to determine N uptake were based on 0.9 m row spacing and 0.3 m between plants, equating a plant population of 36 360. This calculation assumes that no additional growth response occurred as a result of wider spacing. We observed bare areas of ground between rows when the spacing was wider than 0.9 m. The inner two rows were sampled three or four times during the growing season at three-week intervals beginning at early tuber set when the tubers were approximately 1 to 3 cm diameter. At each sample event, three sections of three plants in a row were harvested and separated into shoots and tubers. The plants were weighed, dried at 55°C, ground in a stainless steel Wiley Mill through a 2mm screen, and analyzed for total C and N with a LECO Total CNS elemental analyzer (LECO Corp., Las Vegas, NV; Nelson and Sommers, 1996). Nitrogen uptake was determined by multiplying the dry biomass by its N concentration (Eq. 5).

$$\text{uptake N kg ha}^{-1} = \text{dry biomass kg ha}^{-1} \times \text{N\%} \qquad [5]$$

Petiole samples were taken at the time of bioassay plant sampling to help monitor the relative N status of the plants (Figure 2.1). Twenty of the first fully mature leaves were removed, one per plant, stripped of the blades and placed in a paper bag. The petioles were dried at 50°C and submitted for analysis to a commercial plant tissue testing laboratory for nitrate-N by a nitrate combination electrode (Hanna Instruments, Ann Arbon, MI).

Farm Descriptions

The farms in this study were 5 to 100 acres, certified organic farms in Oregon and western Washington that grow a diversity of vegetable crops. Many of them market their produce through regional farmers' markets, wholesalers, farm stands, restaurants, local natural food stores, and subscription programs such as community-supported agriculture. A majority of the group has been farming in their respective locations for 10 to 25 years on purchased or leased land. The size of potato fields in 2006 ranged from 0.2 to 1 ha for Farms 1 through 8, 10 and 11, and 2 through 5 ha for Farms 9 and 12. The farms grew between 5 and 15 potato cultivars.

The amendment application values reported were provided by the farmers or approximations derived from conversations with the growers (Table 2.6). Some of the farms had detailed records, others did not. Approximations were made when information was limited.

Farmers approached nutrient management differently (Table 2.6). Most of the farms grew winter cover crops, applied compost in spring prior to planting, and used chicken litter compost for N. Farms 2, 6, and 7 used concentrated organic fertilizers, such as feather meal or blood meal, instead of chicken litter compost to supply N.

Nutrient management at Farm 1 consisted of a cover crop and applied composts that were made on-site at their Willamette Valley, Oregon location (Table 2.6). The composts were combinations of horse, rabbit, and cow manures with leaves and yard waste compost and stacked broiler litter. The compost was made using a windrow system utilizing a tractor-drawn mixer that added water to the compost during the turning. Some of these composts, such as the composted rabbit manure, are extremely stable with decomposition rates of around 10% in 70 days at 22°C (Gale et al., 2006). Broiler litter from a nearby chicken operation was also allowed to heat without water additions. Application rates were approximately 45 Mg ha^{-1} on an "as-is" moisture basis for the stable compost. An estimate of the N application rate is 450 kg N ha^{-1} for the compost and 100 kg N ha^{-1} from broiler litter. Data was collected on Farm 1's soils and composts (Appendix 2).

The potato field in 2006 was newly leased land that had previously been grass hay for 20+ years receiving limited fertilization. In fall of 2005, it was tilled and a cover crop of sorghum sudangrass (*Sorghum bicolor* L.) and field peas (*Pisum sativum* L.) planted, but establishment was minimal and was probably not a large contributor of organic matter once tilled in spring of 2006. The N control plot was planted with 'Nicola' potato on 29 April.

Farm 2, near Portland, OR, is located on a publicly-owned historic farm site that also has community gardens. Its nutrient program utilized a winter cover crop and concentrated organic fertilizers (Table 2.6). The potato field in 2006 had a 1.75m tall stand of sorghum sudangrass (*Sorghum bicolor* L.) that was mowed and tilled in after being winter-killed. Feather meal with a N concentration of 12% was banded in the row at a rate of 4.5 kg for every 90 meters, supplying approximately 33 kg N ha^{-1} at a row spacing of 1.8 m. 'Island Sunshine' potato was planted in the zero-N plot on 12 May. For irrigation, a single drip line was utilized on top of the hills and the plants displayed signs of water stress during farm visits suggesting uneven water distribution in the hills. Irrigation also began relatively late in the season, approximately during the beginning of tuber bulking.

Farm 3, in the Willamette Valley, OR, utilized mixtures of winter cover crops, that included legumes, and composted chicken litter for its nutrient program (Table 2.6). Greenhouse and processing wastes, such as vegetable culls and potting soil, were also composted on-site for application. The 2006 potato field contained a cover crop mixture of hairy vetch and oats, but due to excessive rainfall did not grow well. Composted chicken manure with a N concentration of 3.1% (grower comm..) was applied by a manure spreader prior to planting at a rate of 9.6 Mg ha^{-1} on an “as-is” moisture basis, assuming a moisture content of 30% this is approximately 210 kg N ha^{-1}. ‘Yellow Finn’ potato was planted in the zero-N plot on 2 May.

Farm 4, near Portland, OR, employed the use of concentrated organic fertilizers, such as blood meal, with winter cover crops (Table 2.6). In 2006, on the potato field, a one-time application of blood meal with 12.5% N was broadcast at a rate of 470 kg ha^{-1} or 60 kg N ha^{-1}. In addition, kelp meal (1.2-0.2-2.5) was applied at 450 kg ha^{-1} and sulfate of potash (0-0-50) at 340 kg ha^{-1}. Irrigation water tested on 5 Sept 2007 contained levels of 14 mg L^{-1} NO_3-N. A 2.5 cm application of irrigation water supplies approximately 3.6 kg N ha^{-1}. This water was used throughout the growing season for irrigation. The concentration found in September was of the same magnitude as previous well-water samplings performed by other parties. ‘Yukon Gold’ potatoes were planted in the zero-N plot on 12 April.

Farm 5, located in southwest Oregon, is one of the newest farms with the 2006 growing season was their second year in crop production. In 2006, nutrient management at this site consisted of a rye/vetch winter cover crop and pelletized chicken manure with 4% N applied by a drop spreader at a rate of 110 kg N ha^{-1} (Table 2.6). Liquid fish fertilizer with a guaranteed fertilizer analysis of 4-3-3, and an unknown dilution, was also added with an application rate of 18.9 L for every 60 m of row.

Farm 6 is located near Bend, OR east of the Cascade mountain range. Compost was made at the farm from horse barn clean-out, a mixture of manure and straw, mixed with brewery wastes consisting of wet grain slurry. Spent hops were used as mulch and a soil amendment. In addition, concentrated organic fertilizers were applied at an unknown rate. French Fingerlings were planted on 18 April in the zero-N plot. A late freeze occurred and killed the tops of the potatoes after which they revegetated.

Farm 7, located in southwest Oregon, has recently concentrated a majority of their growing efforts to a few wholesale crops. The nutrient additions for 2006 was a plowed-down stand of crimson clover and additions of broadcasted pelletized chicken manure with 4% N at a rate of 1.3 Mg ha^{-1} or 52 kg N ha^{-1} and in-row banded pelletized fish fertilizer with 8% N at a rate of 0.7 kg m^{-2} or approximately 560 kg N ha^{-1} (Table 2.6). The total N addition by concentrated organic fertilizers was 610 kg N ha^{-1}.

Farm 8 is also located in southwest Oregon where crops are grown mainly for the wholesale market. The 2006 potato crop received composted chicken litter at a rate of 40 m^{-3} ha^{-1} on an “as-is” moisture basis, assuming a dry bulk density of 0.7 Mg m^{-3} and 50% moisture content, this is approximately 14 Mg ha^{-1} on a dry weight basis and at 3% N equals 420 kg N ha^{-1} (Table 2.6).

Farm 9 is in the Skagit Valley of Washington. It grows primarily root vegetables for the wholesale market.

Farm 10 is located in the Willamette Valley of Oregon close to Farms 1 and 3. The 2006 potato field was on rented land close to the Willamette River. Nutrient additions were chicken litter with 3% N at a rate of 4.5 to 6.7 Mg ha^{-1} which equals 135 to 200 kg N ha^{-1}, and yard waste compost with 1.8% N at a rate of 18 to 20 Mg ha^{-1} which is approximately 325 to 360 kg N ha^{-1} (Table 2.6). This is a total of 460 to 560 kg N ha^{-1} although 70% of this N, represented by the yard waste compost, is only 6 - 16% available in the first year after application (Gale et al., 2006). ‘Carola’ potato was grown in the zero N plot and was planted on 10 May.

Farm 11, growing crops for 15+ seasons, is in the southern Willamette Valley of Oregon. Nutrient management was based on 5-year rotations that include some years in pasture for grazing cattle. Compost was also made on-farm using biodynamic methods and broadcasted at a rate of 22 Mg ha^{-1}. Compost samples analyzed by the Central Analytical Laboratory at Oregon State University had 7.2% C and 0.7% N. At the reported application rate this is approximately 130 kg N ha^{-1} (Table 2.6).

Farm 12 is in the northeast Olympic Peninsula of Washington. They used legume and cereal cover crops, farm based manure composts, and reduced tillage. Compost was applied at the “as-is” rate of 22 Mg ha^{-1} supplying 220 to 440 kg N ha^{-1} for an estimated N concentration of 1 - 2% (Table 2.6).

Results and Discussion

To assist organic farms with their nutrient management programs, this study provided an estimate of the timing and amount of N available to potato crops in the absence of current season N inputs. A laboratory N mineralization test was performed for spring, summer, and post-harvest farm-collected soils. In addition, a zero-N plot was established utilizing potatoes for N uptake. Petiole-N values were also used to inform the relative N status of the crop.

The field N uptake experiment had the strength of representing the same environment that the farmer experiences. The zero-N plots were subject to the farmers’ decisions on cultural practices including cultivation and irrigation, and they reflect the farm management history. Using a crop as a N sink is considered one of the simplest methods to gather information on the amount of N released by the soil (Jarvis et al., 1996). However, unaccounted for N additions and losses were possible. Some possible losses include leaching and denitrification, and also nonharvested plant parts such as senesced leaves (Jarvis et al., 1996). Unaccounted N additions also can occur through pathways such as irrigation water, for example Farm 4. The laboratory incubation experiment has the advantage of potentially eliminating unaccounted N losses and additions from the environment. Since it is performed under controlled conditions, it might not reflect the farming environment and due to the handling and processing of the samples, e.g. mixing, sieving, wetting, drying, mineralization rates could be affected (Jarvis et al., 1996). In spite of these limitations and differences between the methods, both pointed to medium to high N supply on these farms.

The differences between farms, in terms of their approaches to soil management and history, warrant individual interpretation of the results. Farms that participated in both the laboratory incubation and the field bioassay will be addressed before an overall summary is given.

Farm 1 has been in operation for 20 years. In 2006, the location of the soil samples, zero-N plot, and potato field was on newly leased land that had a history of low inputs. This was reflected in the Bray P1 soil test value of 8 mg kg^{-1}. The organic matter level of 50 g kg^{-1} is reasonable given that perennial grasses were grown in this field for many years. The net N mineralization observed in the spring laboratory incubation, 62 NO_3-N mg kg^{-1} (SE = 1.4) in 63 days, was expected for a field that was previously in perennial grass and recently tilled (Table 2.7). However, this high rate of N release is likely not sustainable once the easily degradable organic matter from the incorporated grass has further decomposed. This could be the reason for the decrease in the amount of net N mineralization observed in the summer soil sample, 45 NO_3-N mg kg^{-1} (SE = 4.5) (Table 2.8), as it appeared lower than the spring value.

The ‘Nicola’ potato had N content at harvest of 116 kg N ha^{-1} (SE = 7.0). Assuming a linear N uptake this amounted to 1.2 kg ha^{-1} day^{-1} (Table 2.9). Of the farms in the study this was one of the lowest uptake values, but when compared to values from other potato studies with zero-N plots, it is high (Table 2.2). The petiole values suggest that the plants could have been N-limited (Figure 2.1). Recommended petiole-N levels for ‘Russet Burbank’ in the Colombia Basin in a similar growth stage are 15 to 26 g kg^{-1} (Lang et al., 1999) whereas the ‘Nicola’ tested around 8 g kg^{-1}.

The low result of the Bray P1 test, 8 mg kg^{-1}, suggests that animal manure composts can be applied for some time without building excess levels of P in the soil; a common result when using animal manures for N. The Bray P1 level should be monitored and the nutrient management program evaluated for the amount of P added in the composts. Compost analysis in 2006 revealed that the N to P ratio averages 2 to

1 (Appendix 2). With this ratio, total P applications are approximately 200 to 250 kg P ha^{-1} at the current rate of amendment application. When the Bray P1 level has reached adequate levels in the soil, 20-40 ppm, switching to a concentrated form of organic N fertilizer could help to prevent an excess of P in the soil.

Farm 2 has a unique situation in its location on a publicly owned historic dairy farm that has been converted to vegetable production, although soil test K indicates that the dairy has probably not been operational for many years. The net N mineralization in the laboratory incubation appeared high with 43 NO_3-N mg kg^{-1} (SE = 5.6) in 63 days for the spring sample. Nitrogen uptake in the field by 'Island Sunshine' potato was also high compared with other studies (Table 2.2) but ranked with the median in our study with 127 kg N ha^{-1} (SE = 23.0) at harvest (Table 2.9). The amount of N in the shoots of the potatoes appeared to be increasing throughout the sampling period indicating that after 107 DAP maturity was probably yet not reached and N-uptake values could have been higher. Petiole-N values were fairly high early in the season indicating ample N availability (Figure 2.1).

Currently, levels of N inputs on this farm are low, 33 kg N ha^{-1}. This field could be in a situation where continued cropping with low N additions could lead to a decline in yields. The concentrated organic N fertilizer currently in use should be supplemented with compost for adding organic matter.

Farm 3 has been in organic production for 10-15 years. The soil test values reflect the continuous use of animal manure composts with high levels of P and K (Table 2.4). The levels are high enough that monitoring is recommended and composts should be applied following best management practices for P fertilization to avoid continued build-up of P.

The results of the mineralization studies in the laboratory and crop N uptake suggest that low levels of inputs could sustain current production and that the contribution by the soil to plant-available N is high. The laboratory incubation resulted in a net increase of 45 NO_3-N mg kg^{-1} (SE = 4.0) for the 63 day incubation.

The amount of N mineralized was near the estimated median value for all of the farms at 41 NO_3-N mg kg^{-1} (SE = 5.0).

The 'Yellow Finn' potato bioassay resulted in a total uptake of 220 kg N ha^{-1} (SE = 22.1) at harvest, one of the highest in our study group. The petiole-N reflects a high level of N supply by the soil with close to 20 g kg^{-1} at tuber initiation. Since the shoots had appeared to stop accumulating N at the final sampling 106 DAP, the plants were nearing maturity. However, approximately 114 kg N ha^{-1} (SE = 16.3) remained in the shoots at the time of harvest. Shoots were mowed off one to two weeks prior to harvesting the tubers for market. This represents a significant NO_3-N source at the end of the season and it is recommended that steps to minimize losses to the environment should be taken, such as the planting of a trap crop in early fall.

A yearly application of stable compost with the discreet use of concentrated organic fertilizers during periods of maximum plant uptake should maintain the current productivity of this soil as the intensity of organic inputs have been high over the long term.

Levels of organic inputs as reported by Farm 4 are low (Table 2.6). At the level of current production the soil is possibly being depleted of organic N. The elevated levels of NO_3-N that have been found in the irrigation water could be supplying the N required for crops growth. The long history of agricultural production in the region is reflected in the excessive levels of the Bray P1 test at 117 mg kg^{-1}. However, the level of K in the soil, 127 mg kg^{-1}, suggests that a plant response might occur with the addition of K-containing materials. Increasing the inputs on this farm could deter any loss of yield in the future.

Farm 6 displayed the highest level of net mineralization in the laboratory for spring-collected soil, 79 NO_3-N mg kg^{-1} (SE = 19.6) in 63 days. The level of total N uptake at harvest was 237 kg N ha^{-1} (SE = 60.4), the highest observed in the study, along with highest levels of petiole-N at 32 g kg^{-1} at 85 DAP. This suggests that the past farming activities have provided readily mineralizable organic matter. A continuation of current compost application with a reduction in the use of readily available N sources should result in sustained production while minimizing the risks of nutrient losses to the environment.

Farm 10 has adequate levels of P, Bray P1 69 ppm, and K, 339 mg kg^{-1}. The percent of total N mineralized, 2.6 %, matched the median for the farms (Table 2.10); suggesting an ample level of microbial activity and readily mineralizable organic sources. However, relative to the other farms, the N mineralization was below the median at 34 NO_3-N mg kg^{-1} (SE = 2.1) in 63 days for the spring collected soil. The N uptake was also the lowest in the study with 83 kg N ha^{-1} (SE = 13.1) at harvest. A continuation of current nutrient management practices should result in increased organic matter levels and sustained production.

Laboratory N Mineralization Incubation

The laboratory incubation was conducted for 63 days at 22°C with NO_3-N determination conducted at 3-week intervals. We were trying to determine if the level of N mineralization was high or low compared to other studies and recommendations. A radical departure from linear NO_3-N release was not observed during the incubation (Figure 2.2). The need to separate the data into two or more pools of soil organic matter was not warranted since this study is a survey type, looking at values across farms, and not looking for a high degree of precision within each farm.

Net N mineralization values for the 12 Farms was approximately 25 to 79 NO_3-N mg kg^{-1} with a median of 41 NO_3-N mg kg^{-1} (SE = 5.0) for the spring collected soil during the 63-day incubation at 22°C (Table 2.7). The summer-collected samples were estimated at 20 to 144 NO_3-N mg kg^{-1} with a median of 43 NO_3-N mg kg^{-1} (SE = 2.9) for the same incubation period (Table 2.8), and the post-harvest-collected samples were approximately 13 to 96 NO_3-N mg kg^{-1} with a median of 24 NO_3-N mg kg^{-1} (SE = 1.9) (Table 2.11). These values are similar to soils collected in 2005 from the study farms and other organic farms in the region (Appendices 3 and 4).

The spring samples are likely more representative of potential soil N mineralization because generally they do not have current season amendments that can influence net N mineralization. However, winter cover crops could have affected N mineralization. Soil testing early in the season has the potential to influence current season management decisions.

The level of NO_3-N accumulating in the soil during the N mineralization incubations appeared steady. The median N mineralization rates for all spring samples were approximately 0.8 (SE = 0.06), 0.8 (SE = 0.06), and 0.7 (SE = 0.05) NO_3-N mg kg^{-1} day^{-1} for 0 to 21, 21 to 42, and 42 to 63 days after incubation respectively (Table 2.12). The summer samples median N mineralization rates were approximately 0.8 (SE = 0.08), 0.6 (SE = 0.05), and 0.6 (SE = 0.05) NO_3-N mg kg^{-1} day^{-1} for 21, 42, and 63 days after incubation respectively (Table 2.12). A few of the farms did not have such consistent rates between sampling events. Farm 6 received fall-applied manure which might account for the rapid period of N mineralization in the first 21 days of the spring incubation, a rate of 2.4 NO_3-N (SE = 0.76) mg kg^{-1} day^{-1}. Farms 8 and 9 had applied amendments to the fields prior to the spring soil collection. Farm 8 displayed a decreasing rate of mineralization during the spring incubation, starting at 1.3 (SE = 0.06) NO_3-N mg kg^{-1} day^{-1} for 0 to 21 days, and ending at 0.8 (SE = 0.08) NO_3-N mg kg^{-1} day^{-1} for 42 to 63 days. Farm 9 started with relatively high NO_3-N levels in the soil for the spring soil incubation at 23 (SE = 1.0) NO_3-N mg kg^{-1}, but had lower than the median rates of net N mineralization. Farm 7 had very high rates of N mineralization for the summer collected sample at 3.3 (SE = 0.53), 2.6 (SE = 0.44), and 2.3 (SE = 0.40) NO_3-N mg ka^{-1} day^{-1} for 0 to 21, 21 to 42, and 42 to 63 days respectively. Farm 7 also reported the highest application rates of concentrated organic fertilizers (Table 2.6).

The farms can be placed in four categories according to their N incubation mineralization rate: low, medium, high, or very high (Table 2.13). In comparison to a review of other N mineralization studies (Table 2.1), most of the farms in our group fall into the medium to high range of N mineralization rates. The high N mineralization rates observed is consistent with what is known about the nutrient management programs of the farms where large amounts of animal manure compost were added that have probably increased the size of the readily mineralizable pool of soil organic matter. Past additions of animal manures have been shown to increase the mineralization of N during soil incubations (Kusonwiriyawong, 2005; Sullivan et al., 1999b). Most farms had similar rankings of N mineralization rate between the spring and summer collected sample. An exception was Farm 7, with a ranking of low for the spring sample and high for the summer sample. The increase in the N mineralization rate for summer could be a result of the high rates of concentrated organic fertilizers applied to the soil.

The percent of total soil N mineralized during the 63-day incubation for the spring soil samples ranged from 1.2 to 4.7% with a median of 2.6% (Table 2.10). This is similar to a western Washington microplot incubation study with dairy farms where soils that had received a history of manure, an average of 2.9 % and 4.0 % for each of the two study years was observed (Sullivan et al., 1999b). It appears that assuming an annual mineralization rate of 2% of soil organic matter per year is too low for these farms where large amounts of organic materials are added. The 63-day incubation represents 1386 DD and a growing season for potatoes and other crops is typically longer.

Crop N Uptake

The amount of total N in the shoots and tubers of the potatoes grown in the zero-N plots at harvest was approximately 83 for farm 10, 116 for farm 1, 127 for farm 2, 184 for farm 4, 220 for farm 3, and 237 for farm 6 kg N ha^{-1} (Figure 2.3). On Farm 10 plants harvest did not occur until a week or two after the final sampling date and uptake might have continued resulting in a higher uptake value. The petiole-N values observed (Figure 2.1) suggests that the plants were N deficient (Lang et al., 1999; Wescott et al., 1991) on all farms except Farm 6 and it is likely that the amount of potato N uptake is an accurate reflection of the amount of soil N made available by mineralization. Soil NO_3-N levels were also low during the growing season except for Farm 6 (Table 2.9).

The amount of N uptake on Farms 3, 4, and 6 was comparable to other N uptake research studies in systems where manure is used (Table 2.14). Marx (1995) showed that N uptake values on dairy farms in the Pacific Northwest where manure, but no additional mineral N was applied to the current season of silage corn, N uptake values were generally in the range 175 to 210 kg N ha^{-1}. Other fertilizer trials in the Pacific Northwest report soil N contribution ranging from 50 to 125 kg N ha^{-1}.

All of the study farms had high levels of N uptake compared to other potato research studies reviewed that reported results for zero-N plots (Lorenz, 1944 and 1947; Riley, 2000; Trehan, 2006; Zebarth, 2005a) (Table 2.2). Assuming that the potatoes were efficient scavengers of N, this is indicative of high soil N mineralization rates or that N was entering the system from an unknown source. Petiole analysis during tuber growth also showed that the N status of the plants on Farms 3, 4, and 6 was higher than on Farms 1, 2, and 10 (Figure 2.1).

Farms that had high levels of laboratory mineralization (Table 2.13) also had high rates of N uptake in the field (Table 2.15). In the absence of current season fertilization, soil N mineralization supplied large amounts of plant-available N to these plants. However, the amount or rate of N mineralization in the laboratory incubations was not a good predictor of the amount of N uptake by the potato except in a general sense. This is probably due to the variability associated with field studies; particularly when conducted on-farm with non-replicated plots.

The soil NO_3-N levels reported for day 0 of the incubations are indicative of PAN levels present in the soil near the time of collection. These values provide a measure of PAN during the growing season (Figure 2.2). Rodrigues (2004) found that when comparing N indicators for the need of supplemental sidedress-N, soil NO_3-N was the most accurate. In general, the NO_3-N was low in the spring samples and higher at the summer and post-harvest sampling. For crops like corn (*Zea mays*), pre-sidedress soil nitrate test NO_3-N levels above 25 mg kg^{-1} do not typically respond to additional fertilization in western Oregon and western Washington (Marx et al., 1997). Farms 5, 6, 7, and 8 had summer values of 22, 41, 53, and 42 NO_3-N mg kg^{-1}

respectively, which indicate adequate to excess NO_3-N in the soil mid-season. The post-harvest soil sample incubation day 0 NO_3-N levels are relatively high, with only two Farms, 9 and 10, below 20 mg kg^{-1}. The post-harvest samples were stored for approximately 100 days at 4°C before the soil was extracted and this likely resulted in increased levels of NO_3-N in the samples at the time of extraction. Regardless, the NO_3-N levels were probably high at sampling, and high enough to cause some concern for the fate of this nutrient over winter. The 90 cm soil samples were collected in mid-August near the time of harvest and generally before the shoots of the potatoes were cut. The soil for the post-harvest mineralization incubation was collected at the end of August after the shoots were down. The relatively large difference of NO_3-N in the surface soil between these two sample events is likely due to the mineralization of potato shoot residue and continued N mineralization from soil organic matter that could accumulate without the presence of plant roots acting as a sink for uptake. Farms with the highest post-harvest NO_3-N levels, particularly 2, 7 and 8, are known to have used concentrated organic fertilizers or quickly degradable amendments like chicken litter that were applied at high rates.

The post-harvest soil NO_3-N levels to a depth of 90 cm are summarized in Table 2.16. Generally, the levels are low in the surface with the exceptions of Farm 3 and 7. Farm 7 had high application rates of easily mineralizable N sources. A high level of NO_3-N in the top 30 cm seemed to indicate high levels in the 0 to 90 cm profile. One high sample was found at the 30-60 cm depth on Farm 10 where irrigation could have leached the NO_3-N downward.

Conclusions

The N uptake by a crop in an unfertilized plot and the PAN measured in the laboratory were of the same approximate magnitude. This provides additional justification for using the laboratory incubation method to estimate the supply of N in the soil. Due to the linear appearance of the N release during the laboratory incubation, a shorter period of time, less than 63 days, might be warranted. To provide an estimate that is not influenced by current season activities, soil samples taken in the spring before field work has begun is recommended.

In the laboratory, we observed a typical N mineralization rate of 0.7 (SE = 0.06) NO_3-N mg kg^{-1} d^{-1} (Table 2.12). This is approximately 120 to 160 kg N ha^{-1} in the field for a growing season of 2000 degree days (base 0°C). This calculation assumes a soil sample depth of 15 cm from potato hills since hilling operations build up soil from the top 15 cm to create a 30 cm depth. It also assumes bulk densities of 1.0 to 1.3 g cm^{-3} and a soil N concentration of 0.2%. As a percent of total N mineralized, the median value observed for the spring collected samples was 2.6% in 63 days of incubation (Table 2.10) or approximately 3.7% in 2000 degree days assuming a continued linear increase of NO_3-N. Using 2% of organic N mineralized per year as a guideline appears to be too low for these farms. An estimated 3 to 4% of total soil N mineralized per year could be used for planning purposes.

Our results are similar to studies that incubated soils with a history of manure application (Table 2.1). Sullivan et al. (1999b) found that for farms with a history of manure application their estimated rate of N mineralization was in the range of 0.015 to 0.035 NO_3-N mg kg^{-1} DD^{-1} (median 0.028 NO_3-N mg kg^{-1} DD^{-1}). Our results ranged from an estimated 0.018 to 0.057 NO_3-N mg kg^{-1} DD^{-1} (median 0.031 NO_3-N mg kg^{-1} DD^{-1}) for spring-collected soil in the laboratory incubation.

The observed crop N uptake at harvest in the on-farm zero-N plots was an observed 83 to 237 kg N ha^{-1} (median 155 kg N ha^{-1}; SE = 25 kg N ha^{-1}). Nitrogen uptake from zero-N plots was approximately 70% of N uptake for potatoes under typical grower management (data in Chapter 3). If tuber yields of 50 Mg ha^{-1} require a crop N uptake of approximately 200 kg ha^{-1} (Chapter 3), and the soil supplies >100 kg N ha^{-1}, a fertilizer application of less than 100 kg of plant-available N from organic sources is recommended.

Most of the Farms had low amounts of NO_3-N in the soil profile at harvest (Table 2.16). Those with the highest reported values also have high rates of applying N in readily available forms (Table 2.6). These farms should be cautious about the possibility of N losses from their systems as the soil samples collected for the post-harvest N mineralization incubation, taken a few weeks after the harvest samples, revealed the highest levels of NO_3-N.

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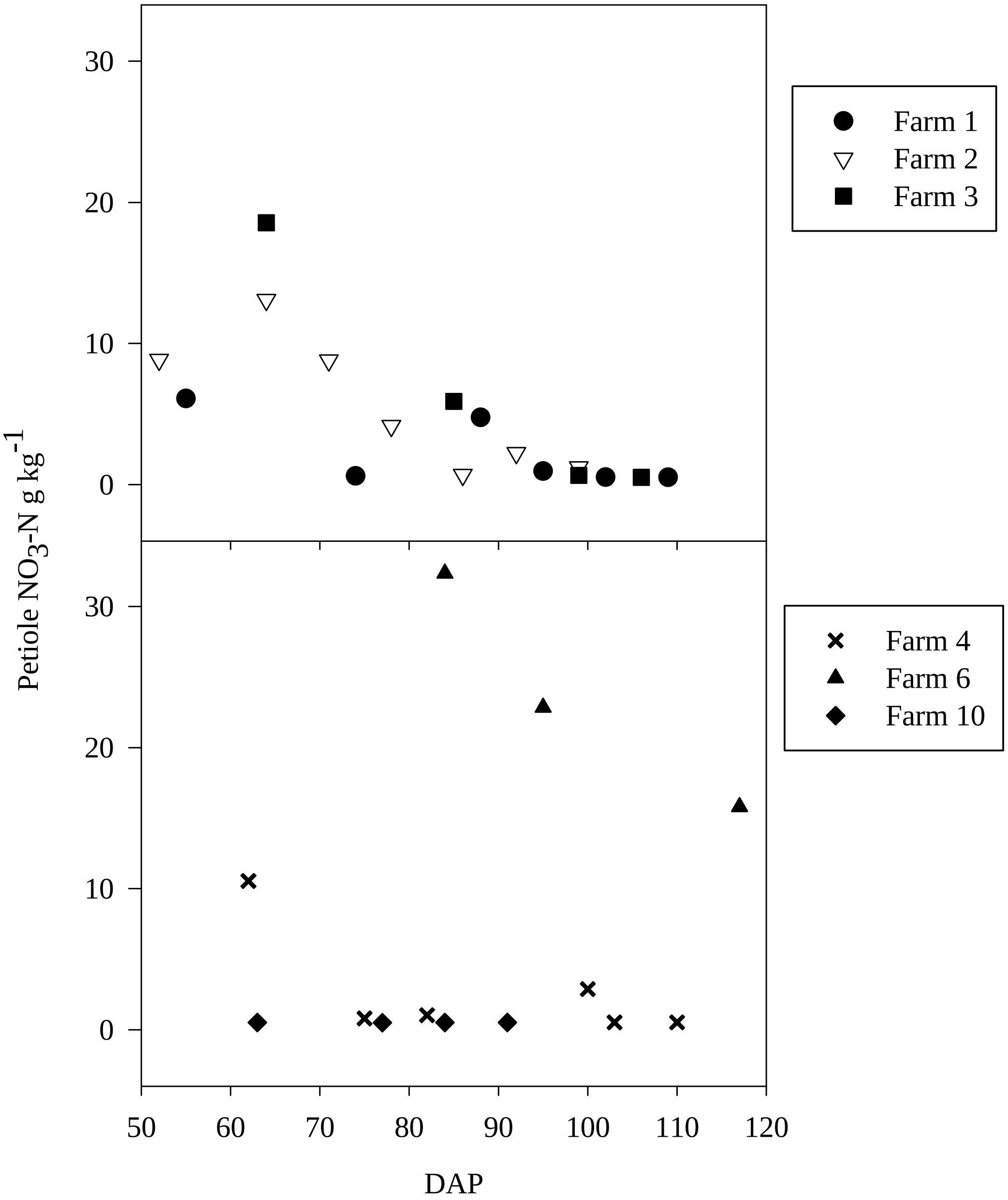

Figure 2.1. Petiole nitrate concentration of potato plants during N uptake in zero-N plots. Sampling began at tuber initiation. Farm 6 had delayed tuber initiation due to a freeze that caused die-back of the shoots early in the season.

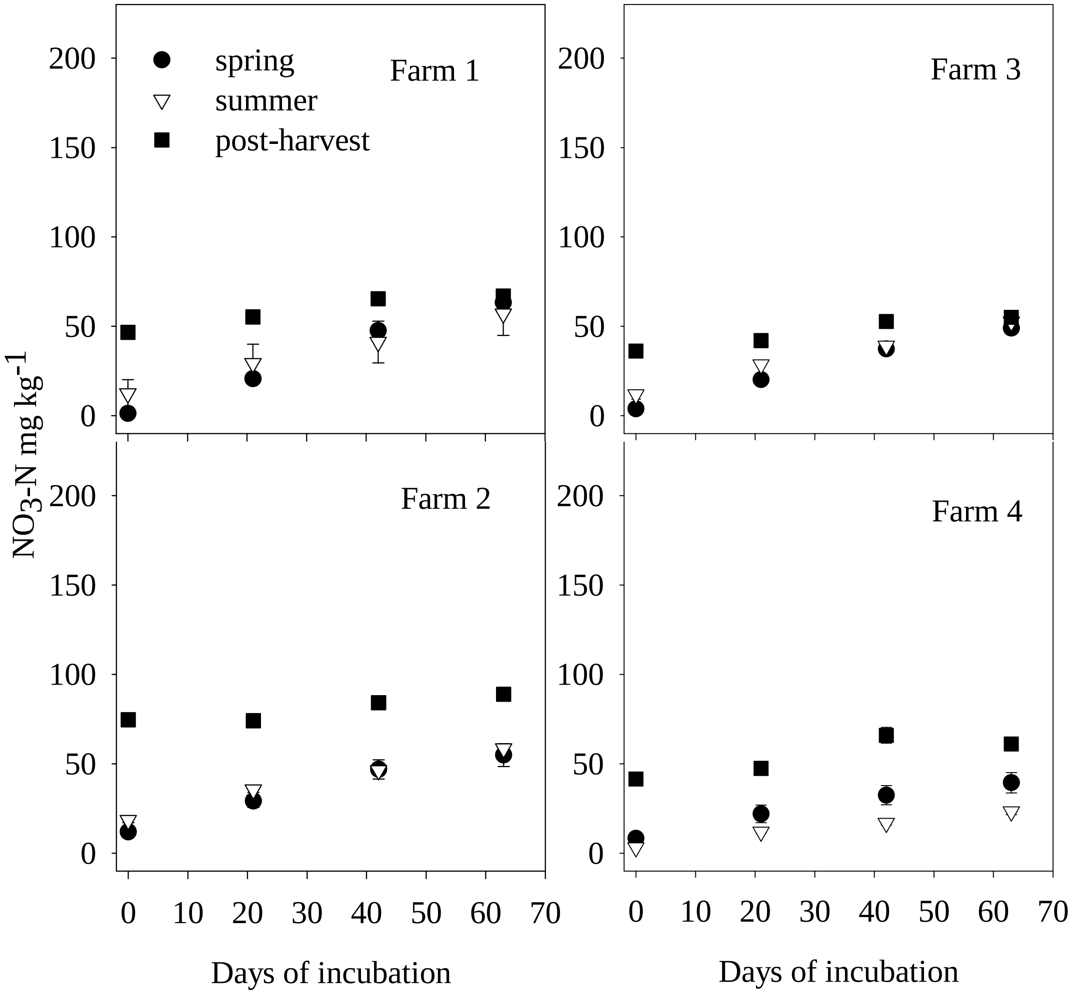

Figure 2.2. Nitrate-N accumulation as a result of incubation period in laboratory for 63 days at 22°C. Post-harvest samples were stored for 100 days at 4°C. Points are means of 3 samples and error bars are the SE.

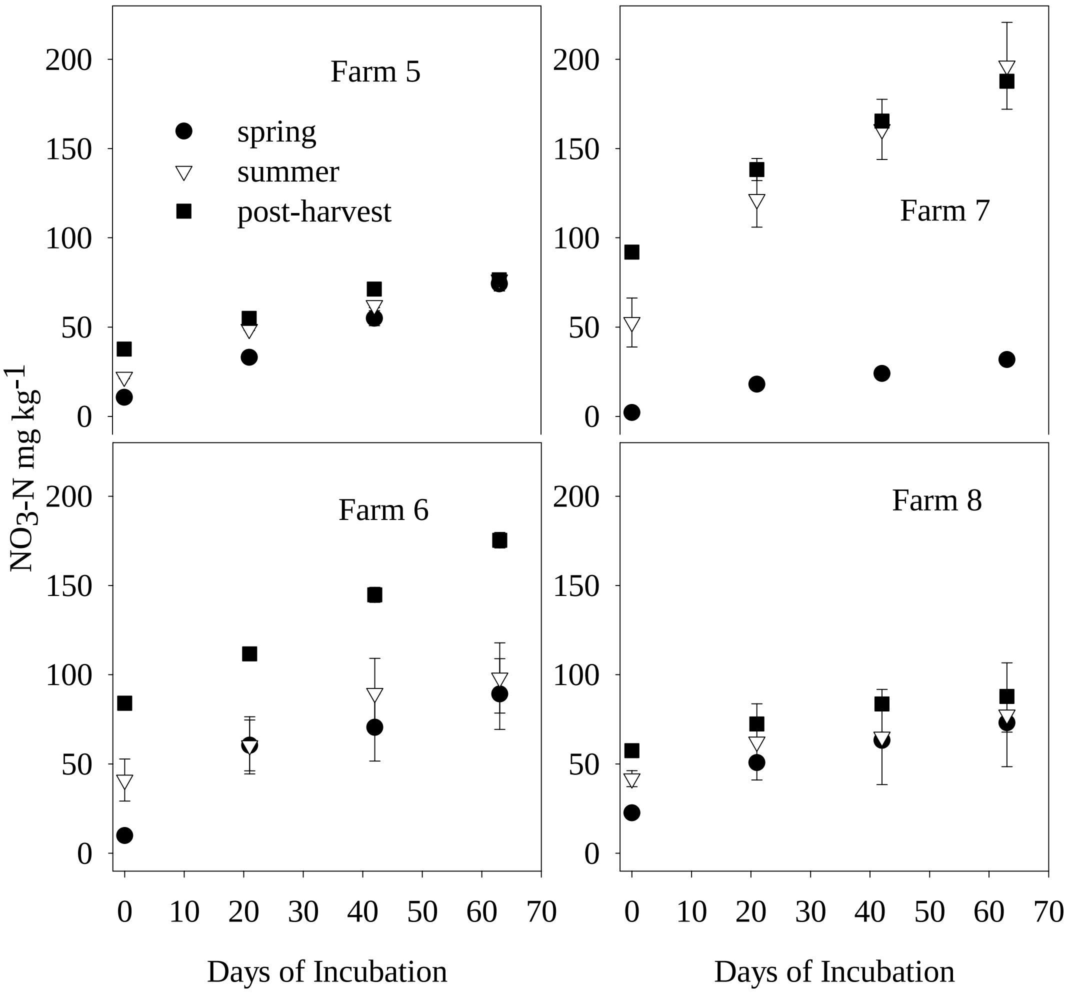

Figure 2.2. Nitrate-N accumulation as a result of incubation period in laboratory for 63 days at 22°C. Post-harvest samples were stored for 100 days at 4°C. Points are means of 3 samples and error bars are the SE (continued).

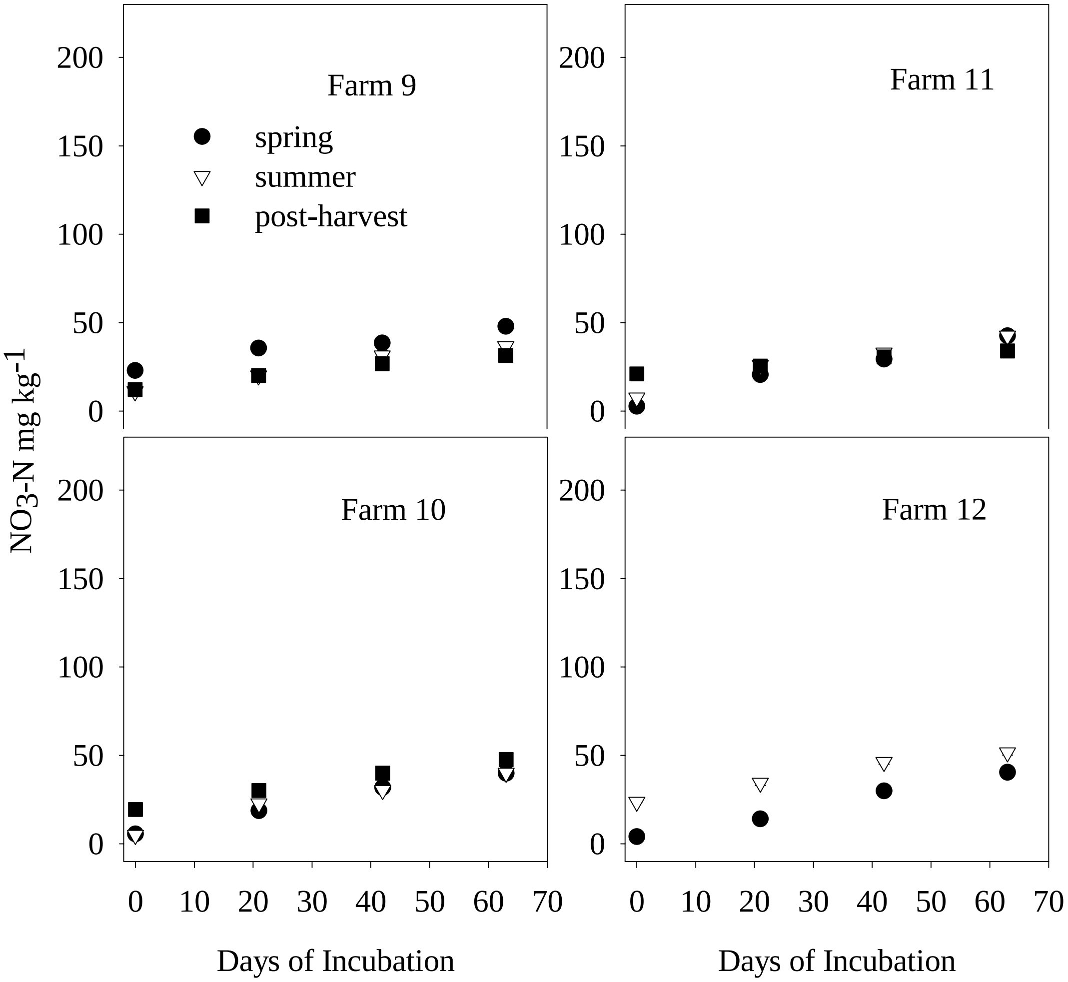

Figure 2.2. Nitrate-N accumulation as a result of incubation period in laboratory for 63 days at 22°C. Post-harvest samples were stored for 100 days at 4°C. Points are means of 3 samples and error bars are the SE (continued).

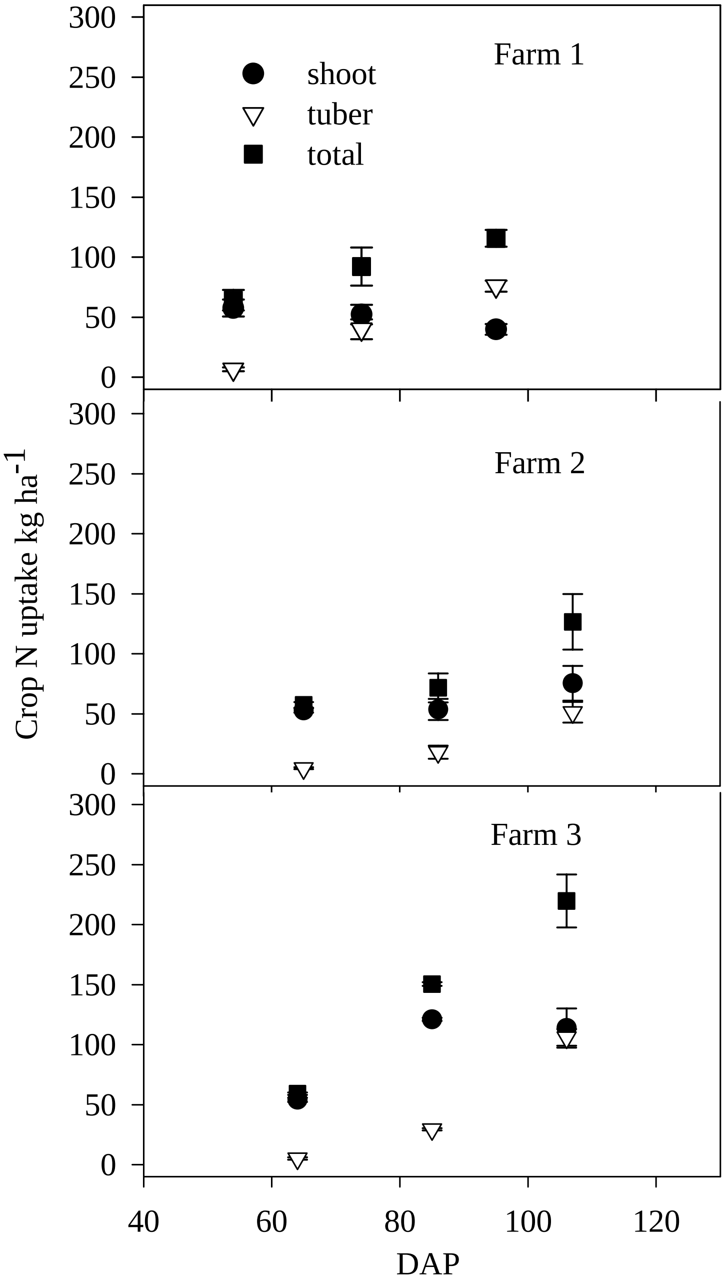

Figure 2.3. Total N uptake by potatoes grown in zero-N plots. Values shown reflect a between-row spacing of 0.9 m, in-row spacing of 0.3 m, and plant population of 36 360 ha^{-1}. Points are the mean of three samples and error bars are the SE.

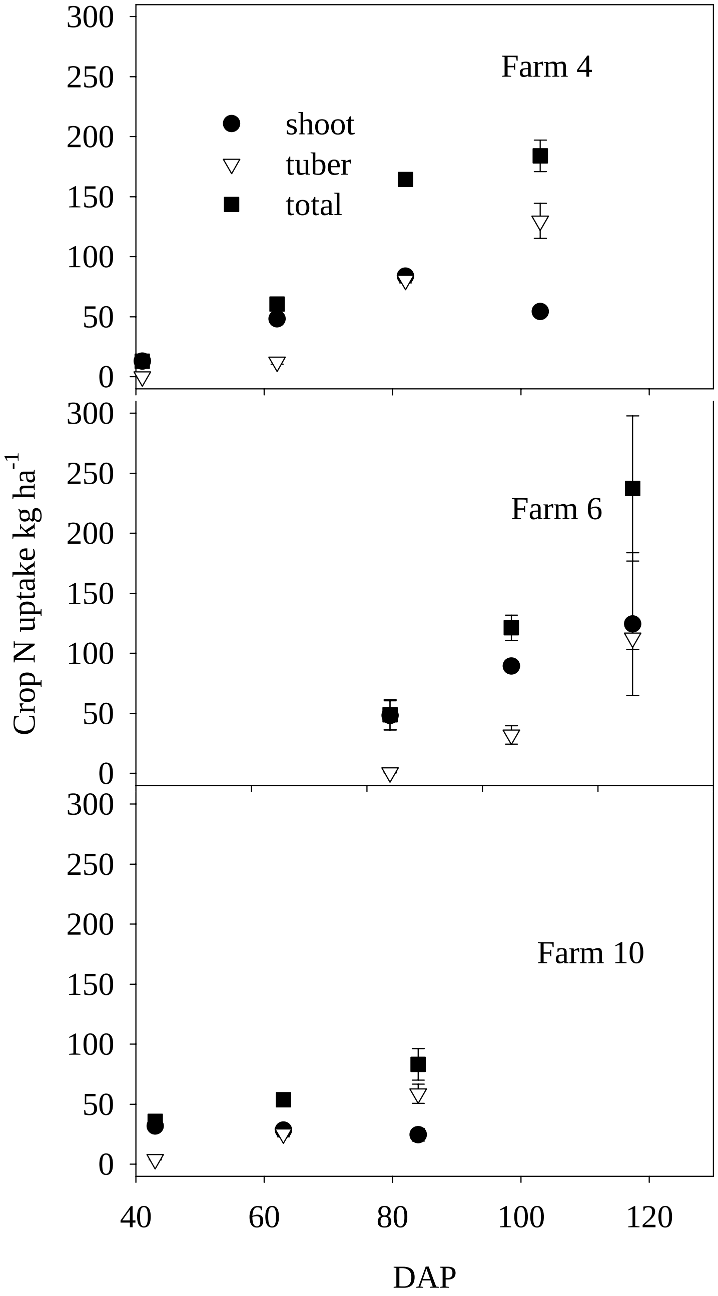

Figure 2.3. Total N uptake by potatoes grown in zero-N plots. Values were computed on a per plant basis and then changed to reflect a between-row spacing of 0.9 m, in-row spacing of 0.3 m, and plant population of 36 360 ha^{-1}. Points are the mean of three samples and error bars are the SE (continued).

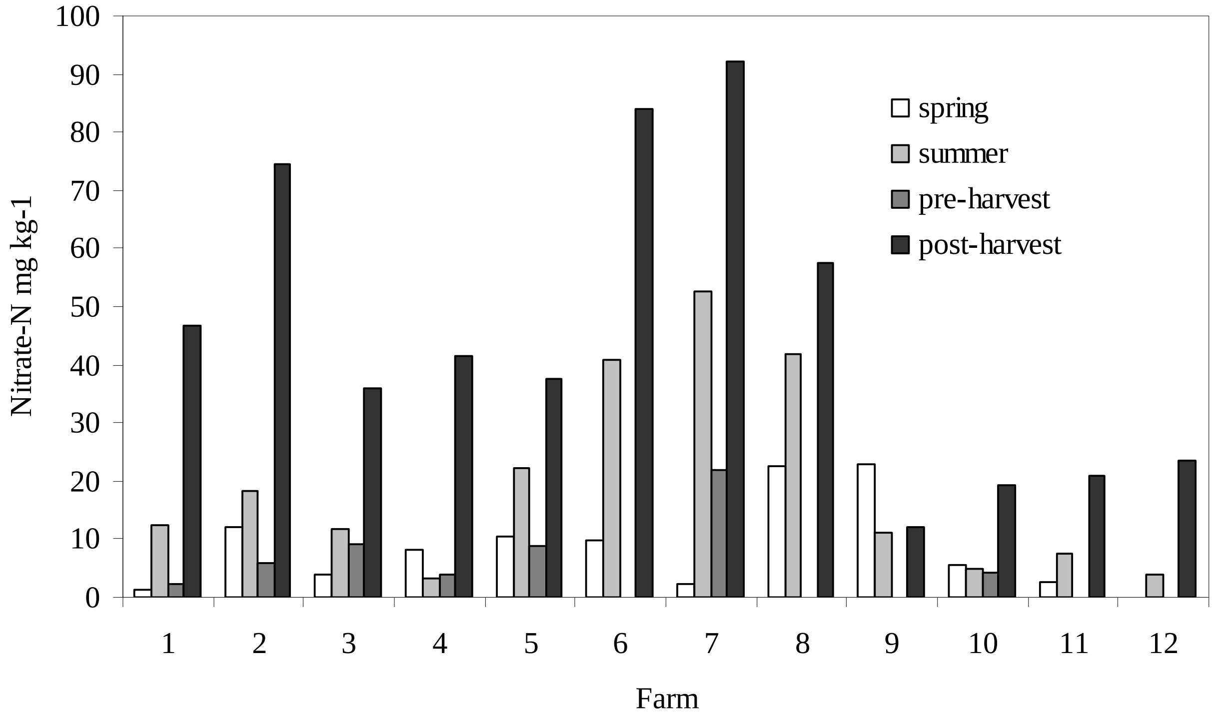

Figure 2.4. Levels of nitrate-nitrogen present during the growing season 2006. Soil samples, 0-30cm, were collected for N mineralization incubation procedure and are the values determined for day 0 of the incubations in spring, summer, and post-harvest. The pre-harvest samples were the 0-30 cm depth of the 0-90 cm soil samples. The post-harvest samples were stored for 100 days at 4°C before the incubation began and nitrate-nitrogen levels are likely elevated from what was present in the field at the time of collection.

Table 2.1. Review of N mineralization studies.

Source[a]	Type of incubation[b]	Soil[c]	Year	Length of incubation		Net N mineralized	Estimated rate of N mineralization[d]	Notes
				days	degree days base 0 C	mg N kg-1	mg N kg-1 DD-1	
1	field	Chehalis sil	2003		1486	28.5	0.019	365 d elapesed since screeded dariy solid application for 2 prior seasons
	field	Chehalis sil	2003		1486	12.9	0.009	current year screened dairy solids plus 2 seasons previous applications
	field	Chehalis sil	2004		1310	17.9	0.014	365 d elapesed since screeded dariy solid application for 3 prior seasons
	field	Chehalis sil	2004		1310	4.8	0.004	current year screened dairy solids plus 3 seasons previous applications
	field	Chehalis sil	2004		1310	-19.5	0	current season screened dairy solid application with no previous application
	lab	Puyallup sl	2004	90	1486	65.1	0.044	365 d since composted dairy solids application
	field	Puyallup sl	2004	90		33.1		365 d since composted dairy solids application
	lab	Willamette sil	2004	90	1486	56.0	0.038	365 d since composted dairy solids application
	field	Willamette sil	2004	30	535	31.4	0.059	365 d since composted dairy solids application

[a] 1 = Kusonwiriyawong, 2005, 2 = Sullivan et al., 1999

[b] field = in situ microplot with resin bags, lab = aerobic bags in laboratory at 22°C

[c] sil = silt loam, sl = sandy loam, l = loam

[d] rate assumed linear, N mineralized divided by degree days

Table 2.1. Selected N mineralization studies utilizing aerobic incubations (continued).

Source[a]	Type of incubation[b]	Soil[c]	Year	Length of incubation		Net N mineralized	Estimated rate of N mineralization[d]	Notes
				days	degree days base 0 C	mg N kg-1	mg N kg-1 DD-1	
2	field	Hale sil	1996		3000	97	0.032	9% OM, manure history
					3000	78	0.026	11.4% OM, no manure for 10 years
			1997		3000	105	0.035	10.2% OM, manure history
					3000	76	0.025	8.8% OM, no manure for 10 years
	field	Edmonds-Woodlyn l	1996		3000	44	0.015	5.8% OM, manure history
					3000	34	0.011	5.4% OM, no manure for 10 years
			1997		3000	85	0.028	4.6% OM, manure history
	field	Kickerville sil	1996		3000	83	0.028	5.6% OM, manure history
					3000	49	0.016	8% OM, no manure for 10 years
			1997		3000	93	0.031	5.8% OM, manure history
					3000	81	0.027	7% OM, no manure for 10 years
	field	Puyallup sl	1996		3000	35	0.012	3.6% OM, no manure for 10 years
					3000	53	0.018	3.6% OM, no manure for 10 years

[a] 1 = Kusonwiriyawong, 2005, 2 = Sullivan et al., 1999

[b] field = in situ microplot with resin bags, lab = aerobic bags in laboratory at 22°C

[c] sil = silt loam, sl = sandy loam, l = loam

[d] rate assumed linear, N mineralized divided by degree days

Table 2.2. Published N uptake data for potato grown in zero applied N plots.

Source	Soil	Potato cultivar	Year	Total N uptake[a]
				kg ha^{-1}
Zebarth, et al. 2005	loam	Russett Burbank	2000-2002	75
Riley, H., 2000	sand	Rutt	1993-1995	46
Trehan, S.P., 2006	loam	unknown	2003-2004	122[b]
			2003-2004	51[c]
Lorenz, O.A., 1944	sandy loam	White Rose	1942, 1945	69
Dyson and Watson, 1971	clay loam	King Edward	1963, 1964	70
Millard and Marshall, 1986		Maris Piper	1983, 1984	70
Vos, 1997		Prominent and Vebeca	1988-1993	70
Median				70
Standard error				4.2

[a] Uptake was averaged across years within each study

[b] average of 11 varieties with a green manure crop, *Sesbania spp.*

[c] average of 11 varieties without green manure

Table 2.3. A review of published potato tuber yields from zero applied N plots.

Source	Location	Soil	Cultivar	Year(s)	Yield Mg ha-1
Meyer and Marcum, 1998	Fall River Valley, CA	sandy loam	Russet Burbank	1992	43
				1993	29
Lewis and Love, 1994	Aberdeen, Idaho	silt loam	Frontier Russet	1986 to 1988	33
			Ranger Russet		40
			Butte		43
			Russet Burbank		40
			Gemchip		42
Jackson et al., 1974	Willamette Valley, OR	silt loam	Russet Burbank	1961	24
		silt loam	Russet Burbank	1962	22
		silt loam	Kennebec	1968	37
Zebarth et al. 2005	Fredericton, NB, Canada		Russet Burbank	2000	30
			Shepody		33
			Russet Burbank	2002	51
			Shepody		48
	Charlottetown, PE, Canada		Russet Burbank	2000	24
			Shepody		34
			Russet Burbank	2002	21
			Shepody		23

Table 2.3. A review of published potato tuber yields from zero applied N plots (continued).

Source	Location	Soil	Cultivar	Year(s)	Yield
					Mg ha-1
Curless, et al, 2004	Antigo, WI	silt loam	Snowden	2000	47
		silt loam	Snowden	2001	37
		silt loam	Snowden	2002	37
Millard and Marshall, 1986	Aberdeenshire, GB		Maris Piper	1983	32
			Maris Piper	1984	37
Lorenz, O.A., 1944	Shafter, CA		White Rose	1942	26
Doll, et al., 1971	Michigan	sandy loam	Sebago		15
			Russet Burbank		25
			Katahdin		65
Riley, Hugh, 2000	Hedmark, Norway	sand	Rutt (early maturing)	1993-1995	14
			Laila (semi early)		27
Median					32
Standard error					2.6

Table 2.4. Soil analysis in spring 2006[a].

Farm	pH	SMP buffer pH	Bray P1	K	Ca	Mg	C	N	Organic matter[b]	Location
			mg kg^{-1}	mg kg^{-1}	cmol(+) kg^{-1}	cmol(+) kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	
1	5.8	5.8	8	131	19.7	8.4	28.8	2.4	49.7	Philomath, OR
2	6.0	6.1	72	134	6.4	1.5	23.6	1.8	40.6	Lake Oswego, OR
3	6.7	6.4	111	688	22.2	5.9	21.2	1.7	36.5	Lebanon, OR
4	5.9	6.0	117	127	6.0	0.9	19.2	1.5	33.1	Portland, OR
5	6.7	6.8	49	183	11.9	3.2	20.7	2.0	35.8	Applegate, OR
6	6.5	6.8	35	424	5.4	2.5	18.4	1.7	31.8	Bend, OR
7	6.3	6.7	112	569	14.6	2.3	16.0	1.4	16.0	Day Springs, OR
8	6.8	6.9	56	159	15.1	4.4	12.2	1.1	21.0	Medford, OR
9	6.0	7.0	166	213	3.5	0.7	10.0	0.9	17.0	Mt. Vernon, OR
10	6.1	6.3	61	339	13.6	5.0	16.4	1.3	28.2	North Albany, OR
11	6.0	6.0	14	139	13.3	1.6	41.3	3.3	73.0	Noti, OR

[a] Samples taken from site of 2006 zero-N plots

[b] Organic matter assumed to be 58% total carbon

Table 2.5. Summary of farms participating in zero N plots 2006.

Farm	Potato cultivar	Maturity class[a]	Planting date	Between-row spacing	Sample event[b]	Grower vine kill	
				m	DAP	Date	DAP
1	Nicola	mid-season	29-Apr	1.07	54, 74, 95	23-Aug	116
2	Island Sunshine	late to very late	12-May	1.83	65, 86, 107	8-Sep	119
3	Yellow Finn	mid-season	2-May	1.22	64, 85, 106	16-Aug	106
4	Yukon Gold	early to mid-season	12-Apr	1.22	41, 62, 82, 103	24-Jul	103
6	French Fingerling	mid-season	18-Apr	1.22	84, 105, 126	22-Aug	126
10	Carola	mid-season	10-May	1.22	43, 63, 84	1-Sep	114

[a] Potato Association of America, the Canadian Food Inspection Agency, Plant De Pomme De Terre, Cornell University, and online seed distributors

[b] In some cases sampling did not continue until grower harvest.

Table 2.6. N application rates of organic amendments reported by growers in 2006.

Farm	Cover crop preceeding 2006 potato	contribution rating[a]	Organic amendment source	applied from amendment
				kg N ha^{-1}
1	sudangrass and pea mixture	+	compost	450
			chicken litter	100
2	sudangrass	+	feather meal	33
3	hairy vetch and oats	+	chicken litter	210
4		-	blood meal	60
5	rye and vetch mixture	+	pelletized chicken manure	110
6	rye and vetch mixture	+	brewery wastes	
7	crimson clover	++	pelletized chicken manure	52
			pelletized fish meal	560
8	barley	-	chicken litter	420
9		-	unreported	
10		-	chicken litter	135 - 200
			yard waste compost	325 - 360
11	vetch, oats, and annual rye mixture	-	compost	130
12	grass and legume mixture	-	compost	220 - 440

[a] cover crop N contribution estimated by author's observation when applicable, - = unknown, + = 0-40 kg N ha-1, ++ = >40 kg N ha-1

Table 2.7. Nitrogen mineralization of 2006 spring soil samples in laboratory incubation for 63 days at 22°C (mean and SE).

Farm[a]	Days				Net N mineralization[b]	Net N mineralization rate[c]	
	0	21	42	63	mg NO3-N kg^{-1}	mg NO3-N kg^{-1} day^{-1}	mg NO3-N kg^{-1} DD^{-1}
	NO3-N mg kg^{-1}						
1	1 (0.4)	21 (2.0)	48 (2.5)	63 (1.2)	62	1.0	0.045
2	12 (0.8)	29 (3.5)	47 (5.4)	55 (6.4)	43	0.7	0.031
3	4 (0.4)	20 (0.9)	37 (3.5)	49 (3.6)	45	0.7	0.033
4	8 (2.3)	22 (5.0)	32 (5.4)	39 (5.7)	31	0.5	0.022
5	11 (0.2)	33 (0.7)	55 (4.2)	74 (3.9)	64	1.0	0.046
6	10 (1.7)	60 (16.0)	70 (18.8)	89 (19.8)	79	1.3	0.057
7	2 (0.1)	18 (0.7)	24 (0.9)	32 (1.7)	30	0.5	0.021
8	23 (0.9)	51 (2.2)	63 (3.0)	73 (5.3)	50	0.8	0.036
9	23 (1.1)	36 (1.6)	38 (2.2)	48 (2.2)	25	0.4	0.018
10	6 (0.1)	19 (1.1)	32 (1.5)	40 (2.0)	34	0.5	0.025
11	3 (0.1)	21 (2.4)	29 (2.2)	43 (3.5)	40	0.6	0.029
median	8 (0.4)	22 (2.0)	38 (3.0)	49 (3.6)	41	0.6	0.031

[a] Samples collected between 28 March and 27 April 2006.

[b] Starting value was subtracted from 63 d value (Eq. 2)

[c] Rate was assumed to be linear, net mineralization at 63 d was divided by number of days or thermal units (degree days, base 0°C) during incubation (Eq. 3).

Table 2.8. Nitrogen mineralization of 2006 summer soil samples in laboratory incubation for 63 days at 22°C (mean and SE).

Farm[a]	Days				Net N mineralization[b]	Net N mineralization rate[c]	
	0	21	42	63	mg NO3-N kg^{-1}	mg NO3-N kg^{-1} day^{-1}	mg NO3-N kg^{-1} DD^{-1}
	NO3-N mg kg^{-1}						
1	12 (7.8)	29 (10.7)	41 (11.6)	57 (12.2)	45	0.7	0.032
2	18 (1.4)	35 (1.5)	46 (2.3)	59 (0.8)	40	0.6	0.029
3	12 (2.6)	29 (0.8)	39 (1.9)	53 (3.9)	41	0.6	0.029
4	3 (0.1)	12 (0.7)	17 (1.1)	23 (1.7)	20	0.3	0.014
5	22 (1.0)	49 (0.7)	62 (1.3)	77 (3.2)	55	0.9	0.039
6	41 (11.8)	60 (14.2)	90 (19.5)	98 (19.7)	57	0.9	0.041
7	53 (13.7)	122 (15.6)	161 (16.8)	196 (24.3)	144	2.3	0.104
8	42 (4.5)	62 (21.3)	65 (26.7)	78 (29.1)	36	0.6	0.026
9	11 (1.8)	20 (2.5)	31 (2.9)	37 (2.4)	26	0.4	0.018
10	5 (0.7)	23 (2.3)	30 (1.2)	40 (1.0)	35	0.6	0.025
11	8 (0.6)	26 (1.7)	33 (1.0)	42 (1.7)	35	0.6	0.025
12	4 (0.9)	14 (2.2)	30 (2.8)	40 (1.4)	36	0.6	0.026
median	12 (1.6)	29 (2.2)	40 (2.5)	55 (2.8)	43	0.7	0.028

[a] Samples collected between 19 July and 2 August 2006.

[b] Starting value was subtracted from 63 d value (Eq. 2)

[c] Rate was assumed to be linear, net mineralization at 63 d was divided by number of days or thermal units during incubation (Eq. 3).

Table 2.9. Nitrogen uptake and yield by potatoes in zero-N plots 2006 (means and SE).

Farm	DAP	Total N uptake			Total N uptake rate[a]	Yield
		shoot	tuber	total	kg ha^{-1} d^{-1}	Mg ha-1
		kg ha-1				
1	54	58 (7.0)	7 (1.6)	64 (8.5)	1.2	4 (1.0)
1	74	52 (8.2)	40 (8.3)	92 (15.8)	1.2	22 (3.5)
1	95	40 (4.4)	76 (4.7)	116 (7.0)	1.2	39 (4.1)
2	65	53 (1.9)	5 (0.7)	57 (2.3)	0.9	2 (0.3)
2	86	54 (8.8)	18 (5.5)	72 (12.1)	0.8	7 (2.0)
2	107	75 (14.5)	51 (8.6)	127 (23.0)	1.2	19 (1.5)
3	64	54 (1.6)	5 (1.0)	59 (1.0)	0.9	2 (0.4)
3	85	121 (1.3)	29 (0.9)	150 (1.6)	1.8	14 (0.7)
3	106	114 (16.3)	106 (6.9)	220 (22.1)	2.1	48 (6.9)
4	41	13 (1.0)	0 (0.0)	13 (1.0)	0.3	0
4	62	48 (1.7)	12 (1.9)	61 (3.4)	1.0	6 (1.1)
4	82	84 (3.3)	81 (2.3)	164 (5.0)	2.0	40 (2.2)
4	103	54 (2.2)	130 (14.6)	184 (13.1)	1.8	69 (7.5)
6	84	48 (12.2)	1 (0.2)	49 (12.5)	0.6	1 (0.4)
6	105	89 (3.1)	32 (7.7)	121 (10.6)	1.2	11 (2.6)
6	126	124 (59.5)	113 (9.7)	237 (60.4)	1.9	34 (2.7)
10	43	32 (2.6)	4 (0.4)	36 (2.4)	0.8	3 (0.2)
10	63	28 (2.3)	25 (2.6)	54 (4.6)	0.9	14 (2.1)
10	84	24 (5.3)	59 (8.0)	83 (13.1)	1.0	31 (4.7)

[a] Total N uptake rate is the concentration of total N at harvest divided by the number of days elapsed since planting. Rate is assumed to be linear for comparative purposes.

Table 2.10. Percent N mineralized from 2006 spring soil samples in 63-day incubation at 22°C.

Farm	Net NO3-N after 63 day incubation[a]	Total soil N[b]	Total N mineralized[c]
	mg kg-1	g kg-1	%
1	62.0	2.4	2.6
2	43.0	1.8	2.4
3	45.1	1.7	2.6
4	31.2	1.5	2.1
5	63.6	2.0	3.2
6	79.3	1.7	4.7
7	29.6	1.4	2.2
8	50.5	1.1	4.4
9	25.0	0.9	2.8
10	34.3	1.3	2.6
11	39.8	3.3	1.2
median	43.0	1.7	2.6

[a] Net NO_3-N calculated by subtracting the starting nitrate level from the 63 d nitrate level (Table 2.7 and Eq. 2).

[b] Concentration determined by combustion analysis of 2006 spring soil sample.

[c] Determined by dividing the estimated NO_3-N kg ha^{-1} from the incubation by the total soil N kg ha^{-1} (Eq. 4).

Table 2.11. Nitrogen mineralization of 2006 post-harvest soil samples in laboratory incubation for 63 days at 22°C (mean and SE).

Farm[a]	Days				Net N mineralization[b]	Net N mineralization rate[c]	
	0	21	42	63	mg NO3-N kg^{-1}	mg NO3-N kg^{-1} day^{-1}	mg NO3-N kg^{-1} DD^{-1}
	NO3-N mg kg^{-1}						
1	47 (0.3)	55 (0.9)	65 (1.3)	67 (3.7)	20	0.3	0.015
2	75 (3.5)	74 (1.5)	84 (0.2)	89 (2.3)	14	0.2	0.010
3	36 (0.4)	42 (0.4)	53 (0.2)	55 (0.5)	19	0.3	0.014
4	41 (0.8)	47 (0.9)	66 (4.4)	61 (1.4)	20	0.3	0.014
5	38 (0.5)	55 (1.2)	71 (0.9)	76 (1.4)	39	0.6	0.028
6	84 (1.9)	112 (0.5)	145 (4.2)	175 (4.4)	91	1.4	0.066
7	92 (1.6)	138 (6.2)	165 (1.1)	188 (3.1)	96	1.5	0.069
8	58 (2.6)	72 (1.2)	84 (2.1)	88 (1.4)	30	0.5	0.022
9	12 (0.0)	20 (0.5)	27 (0.4)	31 (0.3)	19	0.3	0.014
10	19 (0.2)	30 (0.9)	40 (0.3)	48 (0.5)	28	0.4	0.020
11	21 (0.5)	25 (0.0)	31 (0.5)	34 (0.6)	13	0.2	0.009
12	24 (0.2)	34 (1.5)	46 (1.2)	52 (1.4)	28	0.4	0.020
median	40 (0.5)	51 (0.9)	66 (1.0)	64 (1.4)	24	0.4	0.017

[a] Samples collected between 28 August and 20 September 2006.

[b] Starting value was subtracted from 63 d value (Eq. 2)

[c] Rate was assumed to be linear, net mineralization at 63 d was divided by number of days or thermal units during incubation (Eq. 3).

Table 2.12. Net mineralization rates at sampling intervals of 2006 spring and summer soil samples during 63 day laboratory incubation at 22°C (mean and SE).

Farm	Sample event					
	21 days		42 days		63 days	
	spring	summer	spring	summer	spring	summer
	NO3-N mg kg^{-1} day^{-1d}					
1	0.9 (0.09)	0.8 (0.14)	1.1 (0.06)	0.7 (0.10)	1.0 (0.02)	0.7 (0.07)
2	0.8 (0.13)	0.8 (0.04)	0.8 (0.11)	0.7 (0.05)	0.7 (0.09)	0.6 (0.01)
3	0.8 (0.05)	0.8 (0.12)	0.8 (0.09)	0.6 (0.11)	0.7 (0.06)	0.6 (0.10)
4	0.7 (0.13)	0.4 (0.04)	0.6 (0.07)	0.3 (0.03)	0.5 (0.06)	0.3 (0.03)
5	1.1 (0.04)	1.3 (0.05)	1.1 (0.10)	1.0 (0.02)	1.0 (0.06)	0.9 (0.06)
6	2.4 (0.76)	0.9 (0.25)	1.4 (0.44)	1.2 (0.25)	1.3 (0.31)	0.9 (0.22)
7	0.8 (0.03)	3.3 (0.53)	0.5 (0.02)	2.6 (0.44)	0.5 (0.03)	2.3 (0.40)
8	1.3 (0.06)	1.0 (0.85)	1.0 (0.05)	0.6 (0.54)	0.8 (0.08)	0.6 (0.40)
9	0.6 (0.03)	0.4 (0.06)	0.4 (0.04)	0.5 (0.03)	0.4 (0.02)	0.4 (0.02)
10	0.6 (0.05)	0.8 (0.09)	0.6 (0.04)	0.6 (0.01)	0.5 (0.03)	0.6 (0.02)
11	0.9 (0.11)	0.9 (0.07)	0.6 (0.05)	0.6 (0.02)	0.6 (0.05)	0.6 (0.03)
12		0.5 (0.06)		0.6 (0.05)		0.6 (0.01)
median	0.8 (0.06)	0.8 (0.08)	0.8 (0.06)	0.6 (0.05)	0.7 (0.06)	0.6 (0.05)

[a] Rates calculated by subtracting the nitrate level at the previous sample event from the nitrate level at the subsequent sample and dividing by the number of days elapsed, in each case 21 d. Rates were assumed to be linear.

Table 2.13. Ranking of nitrogen mineralization rates from spring 2006 soil samples and from other studies as a basis for comparison.

Farm	Sample time	N mineralization rate ranking			
		low	med	high	very high
		<0.02	0.02-0.03	0.03-0.05	>0.05
		NO_3-N mg kg^{-1} DD^{-1}[a]			
1	spring			x	
	summer			x	
2	spring			x	
	summer		x		
3	spring			x	
	summer			x	
4	spring		x		
	summer	x			
5	spring			x	
	summer			x	
6	spring				x
	summer			x	
7	spring		x		
	summer				x
8	spring			x	
	summer		x		
9	spring	x			
	summer	x			
10	spring		x		
	summer		x		
11	spring			x	
	summer		x		
12	summer		x		
Count of observations within N mineralization rate ranking[b]					
Kusonwiriyawong, 2005		5	0	2	1
Sullivan, 1999		5	5	3	0

[a] Rate calculated from spring 2006 soil samples assuming a linear rate of N mineralization (Eq. 3).

[b] See Table 2.1 for details about incubation results.

Table 2.14. Crop N uptake in zero-N plots from fertilizer studies.

Source	Soil	OM	Crop	Year	Length of N uptake	N uptake	notes
		%			days	kg ha^{-1}	
Sullivan et. al, 2002	Puyallup fine	3	Forage-type tall fescue	1993	66	88	
	sandy loam		(*Festuca arundinacea* L.)	1994	140	82	
			'A.U. Triumph'	1995	138	52	
Cogger et al., 2001	Puyallup fine	3	Tall fescue	1993	200	60	
	sandy loam		(*Festuca arundinacea* L.)	1994	200	112	
				1995	200	90	
				1996	200	90	
				1997	200	125	
				1998	200	96	
				1999	200	75	
Sullivan et. al, 2000	Buckley loam	10	Orchardgrass	Sept 1993-	200	171	
	Greenwater loamy sand	2	(*Dactylis glomerata* L.)	Aug-95	200	100	
Sullivan et. al, 1997	Buckley loam	10	Prairiegrass	1991		62	
			(*Bromus unioloides* L.)	1992		154	
				1993		70	

Table 2.14. Crop N uptake in zero-N plots from fertilizer studies (continued).

Source	Soil	OM	Crop	Year	Length of N uptake	N uptake	notes
		%			days	kg ha^{-1}	
Christensen and Mellbye, 2006	silty loam to silty clay loam		Soft white winter wheat (*Triticum aestivum* L.) 'Foote' or 'Madsen'	sown fall 2002 or 2003		40-240	10 out of 15 sites had uptake in the range of 75 to 125 kg N ha-1
Salisbury, 1999	Woodburn		Soft white winter wheat (*Triticum aestivum* L.) 'Stephens'	1996		44	following oats
				1997		20	
				1998		44	
Gale, 2004	Puyallup fine sandy loam		Sweet corn (*Zea mays* L.) 'Jubilee'	2002		45	
				2003		70	
	Willamette silt loam			2002		48	
				2003		50	
Kusonwiriyawong, 2005	Puyallup fine sandy loam		Sweet corn (*Zea mays* L.) 'Jubilee'	2004		47	
	Willamette silt loam			2004		44	

Table 2.14. Crop N uptake in zero-N plots from fertilizer studies (continued).

Source	Soil	OM	Crop	Year	Length of N uptake	N uptake	notes
		%			days	kg ha^{-1}	
Marx, 1995	silt loam		Silage corn (Zea mays L.)	1993-	approx.	122	3 cooperator sites receiving no
				1994	100 days	173	current season manure or fertilizer
						234	
	silt loam		Silage corn (*Zea mays* L.)	1993-		238	14 cooperator sites receiving manure
				1994		92	in the current growing season at a
						213	farmer determined rate
						174	
						177	
						195	
						202	
						202	
						100	
						187	
						141	
						212	
						209	
						220	

Table 2.15. Categories of crop N uptake from zero-N plots on Farms 1-6 and 10 compared to other fertilizer trials with zero-N plots.

Farm	Crop N uptake rate ranking[a]			
	low	med	high	very high
	<0.02	0.02-0.03	0.03-0.05	>0.05
	NO_3-N mg kg^{-1} DD^{-1}[b]			
1			**x**	
2		**x**		
3				**x**
4			**x**	
6			**x**	
10		**x**		
Study[c]	Number of results in each category			
Sullivan et al., 2002		2	1	
Cogger et al., 2001		6		
Sullivan et al., 2000		1		
Sullivan et al., 1997		1		
Marx, 1995			10	6

[a] Rankings determined by J.P.G. McQueen and D.M. Sullivan

[b] Rate calculated by dividing the crop N uptake at harvest by the number of days elapsed since planting assuming a linear rate of uptake. Crop N uptake is a combination of shoots plus tubers, excluding roots.

[c] Details on reported studies are in Table 2.14.

Table 2.16. Pre-harvest nitrate-N levels in 2006 potato fields, 0-90 cm sample in 30 cm increments.

Farm	Sample date	Sample depth (cm)			
		0-30	30-60	60-90	total
		NO3-N mg kg^{-1}			
1	2-Aug	2.0	1.2	1.3	4.5
1	2-Aug	2.5	1.6	1.5	5.6
2	14-Aug	7.0	5.6	9.1	21.8
2	14-Aug	5.0	4.5	4.0	13.5
3	2-Aug	14.0	9.7	8.4	32.1
3	2-Aug	4.2	2.5	4.0	10.7
4	31-Jul	4.3	2.2	2.6	9.1
4	31-Jul	3.7	1.8	1.8	7.3
5	15-Aug	9.4	3.0	3.3	15.8
5	15-Aug	8.0	6.5	9.0	23.6
7	15-Aug	28.2	13.1	11.1	52.4
7	15-Aug	15.5	5.6	10.7	31.8
10	2-Aug	2.2	2.0	1.9	6.0
10	2-Aug	6.3	37.6	8.9	52.8

GROWTH, NITROGEN UPTAKE, AND YIELD OF POTATO ON ORGANICALLY MANAGED FARMS

Abstract

Information about the growth of potato (*Solanum tuberosum* L.) on organic farms is limited. Farmers in this study group needed data to help support fertilization decisions for growing medium-sized tubers. The objectives of this study were to determine dry matter uptake, nitrogen (N) uptake, and fresh tuber yields on participating organic farms. Petiole nitrate-nitrogen levels were also monitored. Single plots were established on three “Intensive Farms” where weekly biomass samples were taken. A larger group, “All-Farms” had in-field yields measured at harvest. Total nitrogen uptake was an estimated 145, 190, and 245 kg N ha^{-1} (130, 170, and 220 lb acre^{-1}) for Farms 1, 2, and 3. Despite different levels of N uptake, fresh tuber yields on Intensive Farms were similar between farms with 53 Mg ha^{-1} (24 ton acre^{-1}) on Farm 1, 45 Mg ha^{-1} (20 ton acre^{-1}) on Farm 2, and 43 Mg ha^{-1} (19 ton acre^{-1}) on Farm 3. Higher N levels on Farm 3 did not increase yields and total N in shoots at harvest was highest at 150 kg ha^{-1} (134 lb acre^{-1}) verses Farm 1 with 40 kg ha^{-1} (36 lb acre^{-1}). Tuber bulking rates were 0.8, 0.7, and 1.0 Mg ha^{-1} d^{-1} (714, 625, and 893 lb acre^{-1} d^{-1}) for Farms 1, 2, and 3. Delaying harvest could have resulted in higher yields. For tuber yields of 50 Mg ha^{-1} (23 ton acre^{-1}) farmers can expect a total N uptake of approximately 200 kg N ha^{-1} (180 lb acre^{-1}) with 0.9 m (34 inch) between-row spacing. Fresh tuber yields on All-Farms varied by cultivar and location with a median of 19 Mg ha^{-1} (8.5 ton acre^{-1}) that reflected in-field between-row spacing. At harvest, medium tubers 85 to 227 g (3 to 8 oz) averaged 50% of fresh tuber yield. To accomplish higher yields, row spacing near 1 m is recommended. Petiole N levels were variable during the season with starting values lower than some recommendations and decreased rapidly as time progressed.

Introduction

During conversations with organic farmers (USDA, 2002) in Oregon and Washington, they expressed interested in information concerning the growth of potato (*Solanum tuberosum* L.). Common questions they shared dealt with the yield of their crop, whether or not the crop was nitrogen (N) limited, and what kind of crop nutrient monitoring they could perform. Although the area dedicated to potato on a typical diversified small farm is usually minor compared to conventional potato growing operations, any information learned could carry over into other aspects of their farms, optimizing production systems.

Most fertilizer recommendations are based on mineral fertilizer studies performed on conventional farms or experiment stations. This information may not be directly applicable to the organic farmer since relying on organic amendments makes the timing and amount of nutrients released by the amendments harder to predict (Stark and Porter, 2005). In addition, organic amendments, such as composts or concentrated organic fertilizers like feather meal, behave differently when applied to the soil (Gale et al., 2006). The amount and rate of plant-available N (PAN) in organic amendments is dependent upon microbial action to degrade the material and release excess mineral N into the soil solution where it is available for plant uptake. This is a biological process dependent upon environmental factors, such as moisture and temperature; that control the rate and timing of N availability.

Current fertilizer recommendations might not be applicable on organic farms due to the amount of organic matter applied. As a result of organic farming techniques, soil organic carbon and nitrogen accumulate (Drinkwater et al., 1998; Marriott and Wander, 2006). This leads to higher amounts of N released by the soil (Mikha et al., 2006) decreasing the amount of N additions required to meet crop N demand.

Nitrogen management on organic farms in western Oregon is usually a combination of applying composted animal manures, and/or high N specialty amendments, growing N-fixing cover crops, and relying on N mineralization from soil organic matter (author's observations). A common concern is that N release from the mineralization of organic materials does not match periods of maximum crop demand of N and yields will be affected. For instance, the type and quality of the organic material applied to a soil controls the rate of its decomposition and in turn, its PAN (Gale et al., 2006). If N is added in the form of concentrated organic fertilizers, such as the feather meal, the availability of N is closer to that of mineral fertilizers providing nearly 100 % availability in the first growing season following application (Gale et al., 2006). Compost, due to its stability from a decomposition process prior to application, might have a PAN of only 0 to 10% of the total N applied in the first year after application (Gale et al., 2006).

A review by Berry et al. (2002) indicated that the sources of N in organically managed systems will restrict crop productivity during periods of maximum N uptake. But potatoes that have a longer period of N uptake than other crops can make better use of slow but sustained N release, and through management, the timing of N availability from amendments and soil with the N demand of crops can be improved. In addition, Van Delden et al. (2001) through simulations found that crop yields would be higher and residual soil mineral N after harvest lower if organic growers planted mid- to late-maturing potatoes instead of early types, except in cases of premature harvest when tuber quality could be decreased.

Understanding the growth of the potato can explain how N requirements fluctuate during plant development. 'Russet Burbank' potato has been described as having four stages of growth (Kleinkopf et al., 1981; Lang et al., 1999; Ojala et al., 1990). Stage 1 is vegetative growth and starts after planting when the seed piece produces stolons that later form the tubers. The underground stolons elongate during Stage 1 until the tips swell, signaling the start of Stage 2: tuberization or tuber initiation. During this 10 to 14 day period, tubers grow to approximately 3 cm. During Stage 3, tubers are in their maximum growth or bulking phase. It concludes with the start of leaf senescence. In growth Stage 4 tubers mature, set tougher skin, and any increase in tuber weight is generally from the translocation of nutrients from the leaves. It is common for farmers to aid in tuber maturation by killing the shoots through mowing, chemical sprays, or forgoing irrigation, an efficient method in the dry summers of the Pacific Northwest.

The pattern of N uptake and dry matter accumulation for potato from planting until shoot senescence has been described by a sigmoid curve function (Alva et al., 2002; Kleinkopf et al., 1981). During growth Stage 1, N uptake and dry matter accumulation are both relatively slow. But by the end of Stage 2, Kleinkopf et al. (1981) found that 60% of total seasonal N uptake had occurred while only 20% of the dry matter was produced, thus N uptake precedes dry matter accumulation. They also found that at end of Stage 3, the potato had accumulated 98% of its total N and 95% of its total dry matter, but only 80% of the tuber dry weight had been obtained. The remaining 20% of dry weight gain would occur during Stage 4 when reallocation from the shoots to the tubers is responsible for the increase. Rates of maximum N uptake reported are 2.8 to 5.5 kg N ha^{-1} day^{-1} (Kleinkopf et al., 1981; Lang et al., 1999; Roberts et al., 1991).

During conversations with organic farmers, it was realized that many of the potatoes they grow do not reach maturation, but are harvested early for fresh market. In this situation, growth Stage 4 might not be reached and the N uptake and dry matter accumulation could be described as a linear function starting with the beginning of tuber bulking. It is possible that translocation of N to the tubers from the shoots in growth Stage 4 would not be complete, leaving a larger proportion of N in the shoots then a mature plant would have. This could impact post-harvest soil management as the fate of the N released from decomposing shoots is questionable, whereas at full plant maturity, the N component in the plant residue is minimal (Alva et al., 2002).

The proportion of N in the shoots versus the tubers varies under excess, adequate, or deficient N fertilization as determined by Lauer (1984). In that experiment, an application of 610 kg N ha^{-1}, the excessive N treatment, recorded an estimated maximum uptake of 574 kg N ha^{-1} which occurred at 94 days after emergence with a total tuber yield of 60 Mg ha^{-1}. The adequate treatment with 210 kg N ha^{-1} yielded an estimated total N uptake of 210 kg N ha^{-1} and a yield of 63 Mg ha^{-1}, a slightly higher yield than the excessive N treatment. Interestingly, in the adequate treatment the tubers contained 63% of the total N, where as in the excessive treatment the tubers contained 40%. Also, the tubers in the excessive treatment took up 250 kg N ha^{-1}, 70 kg N ha^{-1} more than the adequate treatment at 180 kg N ha^{-1}, even though the yield was slightly lower in the excessive treatment, indicating that the potato will consume and store excess N in the tubers. The deficient N rate of 150 kg N ha^{-1} resulted in a tuber yield of 55 Mg ha^{-1}, and a tuber N uptake of 115 kg N ha^{-1} that contained 65% of the total N, similar to the adequate N rate. At this deficient rate maximum yield was not obtained, but the use of N was efficient.

Maturity class of potatoes affects the dry matter accumulation and N uptake rates. Early maturing types tend to have increased rates of both (Kleinkopf et al., 1981), even thought the overall amounts are similar to later maturing types. This is consistent with the fact that the life cycle of early types is shorter than later types. Ojala et al. (1990) recommends that due to the greater N uptake rates of early types, N availability needs to be greater than for later types during tuber bulking and nitrogen management can be adapted for this.

When using organic amendments to supply plant nutrients, Van Delden (2001) found at final harvest higher N application rates increased tuber dry weight and tuber N uptake independent of year and cultivar. The study, in the Netherlands, used three levels of organic N. In 1998, the lowest level (N1) used 57 kg N ha^{-1} from compost, the middle level (N2) used the same compost rate with an additional 270 kg N ha^{-1} from cattle slurry, and the high level (N3) used the same compost rate with an additional 480 kg N ha^{-1} from cattle slurry and 120 kg N ha^{-1} from calcium ammonium nitrate. The organic sources were fall applied and the mineral N in N3 was spring applied. The total tuber N uptake in for N1, N2, and N3 in 1998 was, respectively, 50.3, 57.2, and 92.5 kg N ha^{-1} for ‘Junior’ potato, an early season type, and 73.6, 78.9, and 141.8 kg N ha^{-1} for ‘Agria’, a mid- to late-season type.

In another organic amendment potato trial, Rodrigues (2004) in Portugal, used cultivar 'Desiree' and a total N application rate of 100 kg N ha^{-1} from poultry manure, cow manure, and municipal solid waste in separate treatments. Included in this trial also were treatments of 0, 50, 100, 200, and 300 kg N ha^{-1} from urea. In the first year, 1996, all treatments were significantly similar, including the zero-N control plot, with tuber yields close to 50 Mg ha^{-1}. In the second year, the organic treatment yields were near 30 Mg ha^{-1}, while the maximum was again close to 50 Mg ha^{-1} for the 100-300 kg N ha^{-1} urea treatments. Similarly, in the third year, yields were lower in the organic treatments close to 35 Mg ha^{-1}, not statistically different from the zero-N plot, where the 100-300 kg N ha^{-1} treatments were approximately 45 Mg ha^{-1}.

Published yields from conventional potato trials are summarized in Table 3.1. In comparing the yields from N application rates, the largest increase in yield is generally found in the first rate above the zero-N plot. As fertilizer N rates increase, a diminishing return becomes apparent toward a maximum yield plateau. Overall, in the trials reviewed the median yield and N application rate were 39 Mg ha^{-1} and 140 kg N ha^{-1}.

Recommendations for fertilizer N rates to obtain optimal potato yields vary. The Extension Service publication Potato Nutrient Management for Central Washington (Lang et al., 1999) gives fertilizer N recommendations based on yield goals and residual soil test N which includes NO_3-N and NH_4-N. With a soil test N value of 0, they recommendation applying 220, 280, 340, and 390 kg N ha^{-1} to achieve yields of 45, 60, 70, and 80 Mg ha^{-1} respectively. For every 10 ppm increase in soil test N the N application rate decreases by 20 % from the 0 ppm value.

The Malheur County Oregon Experiment Station found during cultivar trials conducted in 1993 and 1994 that optimum fertilizer rates didn't exceed 135 kg N ha^{-1} for 'Shepody' and 'Russet Burbank' potatoes grown under sprinkler irrigation with wheat grown as the previous crop (Shock, 2005). They found that optimum yield responses also occurred at rates of 0 to 120 kg N ha^{-1} depending on the year.

In a summary of mixed fertilizer potato trials from the past 40 years, the Florida Cooperative Extension Service recommends a maximum N application of 200 kg ha^{-1} for optimal potato yields and with only sporadic yield increases with up to 225 kg N ha^{-1} (Hochmuth and Cordasco, 2000). And from the Virginia Cooperative Extension for white potato production, a recommendation of 140 to 170 kg N ha^{-1} is given for a yield goal of 22 Mg ha^{-1} of fresh tubers (Phillips et al., 2004). For higher yield goals they recommend that growers add approximately 7 kg N per Mg of yield increase. Westermann (2005) reported in a review of the nutritional requirements of potatoes that for a 56 Mg ha^{-1} yield a total uptake 235 kg N ha^{-1} is required.

If inadequately fertilized, the potato plant responds to N stress in several ways. Van Delden (2001) found that potato under N limitations may reduce its light interception with less leaf area but maximizes its light use efficiency by maintaining the concentration of N in its leaves. Gardner and Jones (1975) found that lower rates of N fertilizer produced plants with a larger proportion of tubers that were less than 114 g. Vos (1997) found that as the N supply for potatoes decreases total N uptake also decreases, and in turn so does total dry matter yield.

Petiole sampling can provide a grower with an in-season method to ascertain whether or not to supply addition N fertilizer to obtain desired yields, as top dressing with N fertilizer has been shown to maintain petiole nitrate (petiole N) during tuber bulking (Gardner and Jones, 1975). Petiole nitrate values generally start high at the beginning of the season and decline with growth (Gardner and Jones, 1975; Lewis and Love, 1994; Meyer and Marcum, 1998; Wescott et al., 1991), therefore it is recommended to sample petioles more than once during the growing season (Gardner and Jones, 1975). A monitoring program is suggested due the variability in values from one site to the next and in order to measure the actual effects of soil N availability during growth (Wescott et al., 1991).

Research has established guidelines for petiole N levels during the growing season as petiole N values have been shown to be a reliable guide to more efficient use of N fertilizer in potato production (Gardner and Jones, 1975). Wescott et al. (1991), in Montana, determined that a critical nutrient concentration for petiole N in ‘Russet Burbank’ at tuber initiation is 25 g kg^{-1}, 14 g kg^{-1} for tuber initiation plus 21 days, and 10 g kg^{-1} for tuber initiation plus 42 days. Porter and Sisson (1991) working with ‘Russet Burbank’ in Maine concluded that critical petiole N at 57-62 DAP was 13 g kg^{-1}, 67-73 DAP was 9 g kg^{-1}, and for 79-83 DAP 8 g kg^{-1}. Meyer and Marcum (1998) found that to reach near maximum yields for ‘Russet Burbank’ in Northern California that petiole N in the 15 to 25 g kg^{-1} range for 48 DAP was necessary, 5 to 15 g kg^{-1} at 63 and 76 DAP, but less than 5 g kg^{-1} at 90 and 104 DAP. Gardner and Jones (1975) give deficient levels of petiole N for potatoes when stolons are forming at 16 g kg^{-1}, when tubers are 1 to 3 cm 10 g kg^{-1}, and when tubers are 4 to 5 cm 8 g kg^{-1}.

In petiole sampling, the first fully mature leaf is selected, usually the fourth or fifth leaf from the growing tip. The blades are stripped from the leaf and the remaining petiole is either dried or refrigerated, then ground prior to analysis for NO_3-N. A collection of around 20 petioles, each from separate plants, is recommended for an accurate representation of NO_3-N status in the crop (Wescott et al., 1991). Environmental conditions and sampling methods can influence the concentration of NO_3-N in petioles. Soil N mineralization, N fertilization rate, sampling date, and cultivar can influence the petiole N level (Vitosh and Silva, 1996). Insufficient water for plant growth can result in the accumulation of NO_3-N in petioles (Meyer and Marcum, 1998). Potatoes that have not received current season nitrogen fertilization generally have lower petiole N values earlier in the season and that these values decline rapidly after tuber set (Gardner and Jones, 1975; Porter and Sisson, 1991; Wescott et al., 1991). A maximum petiole N can be reached at levels of 25 to 30 g kg^{-1} in response to high rates of applied N (Wescott et al., 1991).

It has been suggested that since the rate of petiole N change during the season is so rapid that establishing critical petiole N is difficult unless the precise age of the plant is known and that since the NO_3-N status of the soil fluctuates less it might be a better indicator of the N status of the crop (Doll et al., 1971; Rodrigues, 2004).

Other implications for petiole sampling include cultivar and timing. Research by Lewis and Love (1994) in Idaho indicate that cultivar petiole N levels differ when grown under the same conditions. One of the cultivars they grew, ‘Gemchip’, did not show differences in petiole N to difference rates of N fertilizer. At sampling dates later than 50 DAP, petiole N has been shown to be a sensitive indicator of the N status of potatoes receiving different levels of N fertilization, while sampling prior to 50 DAP can identify extremely N deficient potatoes (Porter and Sisson, 1991).

Petiole nitrate has been shown to indicate the amount of N supplied by previously applied organic amendments or incorporated cover crops (Porter and Sisson, 1991). Thus, petiole N testing has potential value for the organic grower of potato.

This study was performed in cooperation with organic farmers in Oregon and western Washington to supply information about their potato growing system to help with nutrient management decisions. The objectives were to provide the participating farms with estimates of potato dry matter production, N uptake, and fresh tuber yield. In addition, petiole sampling was performed to compare values to petiole N recommendations.

Materials and Methods

The farms in this study were part of a participatory research project that was farmer directed. The farmers had questions pertaining to N fertilization and how it related to potato production on their farms (see Chapter 2) which this study aimed to answer. The farms were placed into two groups, Intensive Farms, where dry matter, N uptake, and yield were followed through weekly samplings of potato plants, and All-Farms, where yield was measured with simpler methodology explained below.

Intensive Farms

A summary of sampling details for the Intensive Farms is found in Table 3.2. Plots were established within the larger potato field where typical cultural and fertilization practices were not altered. The on-farm plots, not replicated, were approximately 30 m long and a minimum of 4 rows wide. Sampling took place inside the outer 2 rows of the plots. At each sampling event, 3 adjacent plants were removed from 3 locations within the plot, totaling 9 plants. The plants were separated into tubers and shoots which were weighed and then dried at 55°C, the roots were discarded. Following drying, the plants were ground in a stainless steel Wiley Mill through a 2mm screen and analyzed for total C and N with a LECO Total CNS elemental analyzer (LECO Corp., Las Vegas, NV; (Nelson and Sommers, 1996). Biomass, N uptake, and tuber yield were averaged at each sampling date and the means of the three samples were used for calculations with the standard error of the mean used for an estimate of variability. The results determined per plant were multiplied by a constant plant per hectare basis for comparative purposes. The in-row spacing was similar at most locations, 20 to 30 cm between plants, and although row spacing varied from approximately 1 to 2 m, vines did not generally cover the inter-row area wider than 1 m, therefore, a plant population of 36 360 was used to estimate a between-row spacing of 0.9 m and an in-row spacing of 0.3 m. Equation 1 is an example of converting the N uptake on a per plant basis to a per hectare basis.

$$\text{kg N plant}^{-1} \text{ x } 36\,360 \text{ plants ha}^{-1} = \text{kg N ha}^{-1} \qquad [1]$$

Due to the observational nature of this study, statistical analyses were not performed. Samples were not taken from a random population and plots on farms were not replicated; in addition, samples taken within a farm are not considered independent of one another. Linear and non-linear regression was used only for a general description of the data and not to test hypotheses. The fit of linear and non-linear regression models, generated by least-squares fitting, were compared using R^2 values and the simplest model was chosen to represent the data when possible (Sigmaplot, version 10, Systat Software, Inc). In several instances, quadratic functions provided a similar R^2 value as sigmoid functions, but the sigmoid was chosen since the quadratic function resulted in negative values for which there is no biological basis. The regression was performed on the mean value for each of the three samples removed from plots on each sampling event. For shoot accumulation of dry matter and N uptake, a data point was added to the data set at 0 DAP with a value of 0 for dry matter and N uptake. This aided in forcing the regression through the origin to represent the biological significance of dry matter and N accumulation beginning shortly after planting. This procedure was also conducted for total dry matter and N uptake but not for tubers since tubers are not developed until weeks after planting.

Petioles were sampled for the Intensive Farms. The fourth or fifth leaf from the growing tip was removed, the blades stripped off, then placed in a paper bag. Twenty petioles at each sample date were collected. The petioles were dried at 50°C and submitted for analysis to a commercial plant tissue testing laboratory for NO_3-N by a nitrate combination electrode (Hanna Instruments, Ann Arbon, MI). Nitrate-N levels in the potato hills were also monitored during the season (Chapter 2).

All-Farms

The second group of farms in the study included the Intensive Farms plus 7 others (see Chapter 2 for farm descriptions). Only yield was measured in this group. Yield was determined at harvest using an “as-is” approach. Three sections, 3 m long each, of each cultivar was hand dug and weighed, from which the mean and the standard error of the mean was determined (Table 3.6). The tubers were separated into three groups, small, medium, and large based on masses of <85 g, 85-227 g, and >227 g, respectively. Yield was calculated using the field row spacing, and an in-row spacing of 0.3 m between plants, which was generally the case. Areas were avoided that showed signs of plant distress.

Soil was sampled to a 30 cm depth using a soil probe with a diameter of 2.5 cm. An agronomic soil test was performed from a whole-field composite sample made up of 3 separate samples, each containing 15 to 20 cores (See Chapter 2 for soil analysis). Soil nitrate-N to a depth of 0.9 m was also determined for some of the farms (data in Chapter 2).

Intensive Farm Descriptions

Farm 1 has been in operation for approximately 20 years in the Willamette Valley of Oregon. In 2006, the potato field was newly leased land that had previously been pasture for 20+ years receiving limited fertilization. In the fall of 2005, it was tilled and a cover crop of sorghum sudangrass (*Sorghum bicolor* L.) and field peas (*Pisum sativum* L.) planted, but establishment was minimal and was probably not a large contributor of nutrients when incorporated. Compost, produced on-farm from a mixture of manures and plant wastes, was applied in the spring prior to planting at a rate of 45 Mg ha^{-1} on a “as-is” moisture basis with an estimated of the total N application rate of 450 kg N ha^{-1} (see Chapter 2, Table 2.6). Other composts from this Farm have been studied and shown to have a low decomposition rate indicating stability when soil applied (Gale et al., 2006). Compost samples were analyzed in 2006 for nutrient content (Appendix 2) and ranged in total N from 9 to 30 g kg^{-1}. Chicken litter was also spring applied at an approximate N rate of 100 kg ha^{-1}. This was ‘composted’ chicken manure that was minimally turned. ‘Nicola’ potato, a medium-maturity type (Plant De Pomme De Terre, 2007), was planted on 29 April 2006 with 1 m between rows and 0.3 between plants in the row.

Sampling began at tuber initiation 54 days after planting (DAP) and continued weekly until 116 DAP when the potatoes were harvested for market, for a total of 10 sampling events. Petiole sampling was conducted 6 times during the growing season beginning at 55 DAP. Irrigation was supplied by overhead sprinklers and at no time during the season did the plants appear to be water stressed.

Farm 2 was located south of Portland, OR. It was located on a city-owned historic dairy farm where community gardens are also located. The 1 ha potato field was planted in sorghum sudangrass (*Sorghum bicolor* L.) the previous fall. It grew to a height of 1.5 m before being winter-killed. In spring it was mowed and then later roto-tilled in preparation for planting. Soil testing results (See Chapter 2) revealed high levels of Bray P1 and low to medium levels of cations (Marx et al., 1996). The soil organic matter levels were 41 g kg^{-1} reflecting the long history of pasture at the site. Spring added nutrients, in the form of 12 % N feather meal, was banded in the row at a rate of 4.5 kg for every 90 m supplying approximately 33 kg N ha^{-1} at the between row spacing of 1.8 m.

'Yukon Gold' potato, a medium-early maturity type (Potato Association of America, 2007), was planted with 1.8 m between-row spacing and 0.3 m in-row spacing on 12 May 2006. Two rows, 30 m long were sampled randomly during the season for biomass. A single irrigation drip line was placed on top of the hill after plant emergence. It was noticed that plants were suffering water stress at during the season. Biomass sampling began 45 DAP and concluded 108 DAP, eight days before final grower harvesting. Petiole samples were taken 7 times during the growing season beginning 52 DAP.

Farm 3 is located in east-central Willamette Valley, OR near the foothills of the Cascade mountain range. The 2006 potato crop was planted in a field that received organic management for 15 years. The 0.5 ha potato field was planted in fall 2005 with a cover crop mixture of hairy vetch and oats. However, it was planted late and the stand was poor. Soil test results revealed excess levels of Bray P1 at 111 mg kg^{-1} and high levels of K at 688 mg kg^{-1}. Calcium and Mg levels were also in the high range at 22 and 6 cmol(+) kg^{-1} respectively. The high levels of plant nutrients found probably indicate a history of compost application in excess of plant uptake. The nutrient addition in spring 2006 was of 'composted' chicken manure at a rate of 9.6 Mg ha^{-1} on an as-is moisture basis. At a nitrogen concentration of 3.1 % (grower communication) and assumed moisture content of 30%, the application supplied approximately 210 kg N ha^{-1}.

The 'Yellow Finn' potato, another medium maturity type (Cornell Cooperative Extension, 2007), was planted on 2 May 2006. Plant spacing between the rows was 1.2 m with in-row spacing of 0.3 m. Due to a compromised stand, samples were taken from all four rows beginning 57 DAP and concluding 106 DAP one day before shoot kill. Petioles were sampled four times beginning 64 DAP.

Results and Discussion

From weekly biomass sampling on Intensive Farms, potato dry matter, N uptake, and fresh tuber yield was measured. Fresh tuber yields were also estimated for the other farm group in the study, All-Farms, using an “as-is” approach to field sampling. Petioles on Intensive Farms were also sampled and NO_3-N concentration measured.

Intensive Farm Dry Matter

Dry matter accumulation was best described by a sigmoid curve for shoots and total (shoots and tubers combined, roots were excluded), while tubers followed a linear pattern on Intensive Farms (Figure 3.1). Values for the y-intercept in Tables 3.3 and 3.4 are not significantly different than 0 indicated by the p-values over 0.05. (Sigmaplot, version 10, Systat Software, Inc). Maximum total dry matter occurred on the final sampling date for all farms with similar estimates of 15, 14 and 16 Mg ha^{-1} on Farms 1, 2, and 3. Tuber dry matter increased at similar rates at an estimated 0.20, 0.15, and 0.18 Mg ha^{-1} d^{-1} for Farms 1, 2, and 3 with a maximum estimated production of 12, 9, and 8 Mg ha^{-1}. Tuber dry matter exceed shoot dry matter after approximately 65 and 60 DAP for Farms 1 and 2, but this did not occur on Farm 3 until 85 DAP. At final sampling, tuber weight accounted for 83, 69, and 53% of total accumulation for Farms 1, 2, and 3. Alva et al (2002) found for ‘Russet Burbank’ and ‘Hilite Russet’ that dry tuber weight was 76 to 87% of total dry weight at full maturity. This suggests that perhaps the plants were not mature when harvested on Farms 2 and 3 and that dry matter partitioning from the shoots to the tubers might have continued unless the plants were restricted by disease or insect pressure. Biedmond and Vos (1992) found however, potatoes under increasing N rates will allocate more dry matter to the shoots instead of the tubers, suggesting higher N availability on Farms 2 and 3 since all three cultivars grown were of a similar reported maturity class. Insufficient N on Farm 1 could have increased biomass partitioning to the tubers (Belanger et al., 2001).

Intensive Farm N Uptake

The pattern of N uptake on Farms 1 and 2 were similar with linear trends for total and tubers and a decreasing quadratic function for the shoots (Figure 3.2). Nitrogen uptake on Farm 3 was best described with linear trends for shoots, tubers, and total, with no observed decrease in the amount of shoot N. Others have described N uptake patterns with sigmoid functions (Alva et al., 2002; Kleinkopf et al., 1981), or cubic and quadratic (Lauer, 1984). These functions did not fit our data. Possible reasons for this include not beginning the sampling early enough in the season and not continuing the sampling until the plants were mature. Sampling until plant maturity was not an option due to farmers' decision to harvest and to keep with the participatory nature of this project attempts were not made to prolong sampling.

The linear functions representative of tuber N uptake described maximum N uptake and uptake rates during crop development. Estimated maximum amounts of N uptake for tubers were 110, 100, and 90 kg N ha^{-1} for Farms 1, 2, and 3. Tuber N uptake rates for Farms 1, 2, and 3 were 1.8 (SE = 0.18), 1.6 (SE = 0.16), and 2.0 (SE = 0.34) kg N ha^{-1} d^{-1}. These rate values are lower than some literature estimates of 2.6 kg N ha^{-1} d^{-1} (Lauer, 1985), 2.8 - 4.0 kg N ha^{-1} d^{-1} (Kleinkopf et al., 1981), and 3 - 4.5 kg N ha^{-1} d^{-1} (Lang et al., 1999). Tuber uptake values reported in the literature are generally created using non-linear functions that result in higher peak bulking rates than using linear functions. Carpenter (1957), at the Maine Agricultural Experiment Station, found lower rates at 0.5 kg N ha^{-1} d^{-1} by simply dividing maximum tuber N found at harvest by the number of days since tuber initiation. In total N uptake, differences were greater than for tuber N uptake with values of 1.4 (SE = 0.21) for Farm 1, 1.8 (SE = 0.25) for Farm 2, and 3.0 (SE = 0.50) for Farm 3, resulting in an estimated maximum N uptake of 145, 190, and 245 kg N ha^{-1}, respectively, with shoot uptake being responsible for the differences.

When considering the results for dry matter accumulation, the total N uptake suggests a difference in the amount of N available in the soil on each farm. Although similar total dry matter was found on each farm, the amount of N uptake varied.

Millard and Marshall (1986) reported that the potato crop can take up more N than is needed to satisfy immediate requirements. Although this increased N uptake on Farm 3 didn't result in increased biomass production, it did appear to alter the partitioning of the biomass by producing more shoots with relatively similar amounts of tubers as the other farms. The patterns of N uptake for the three farms are similar to a study by Lauer (1984) where 'Russet Burbank' was grown with excess, adequate, and deficient rates of N fertilization. Lauer observed in the excessive treatment a much higher proportion of N in the vines (60%) than in the adequate treatment (37%) at 94 days after emergence, and an even lower proportion in the deficient treatment (35%). Lauer also observed a similar pattern of shoot N uptake with the adequate and deficient treatment obtaining maximum N halfway through the season around 50 days after emergence, where the excess treatment was around 84 days after emergence ten days before the end of the season. Farms 1 and 2 had maximum shoot N at approximately 65 and 80 DAP; in contrast, Farm 3 reached a maximum shoot N on the final day of sampling indicating excess N in the system.

Intensive Farm Fresh Tuber Yields

Fresh tuber yields followed tuber dry matter production, accumulating in a linear fashion (Figure 3.3). Farms had similar estimated rates of yield increase with 0.8 (SE = 0.06), 0.7 (SE = 0.07) and 1.0 (SE = 0.09) Mg ha^{-1} d^{-1}. Farm 1 had the longest growing season and also the highest yield of the three farms at an estimated 53 Mg ha^{-1} at 116 DAP, followed by Farm 2 with 45 Mg ha^{-1} at 108 DAP and Farm 3 with 43 Mg ha^{-1} at 106 DAP. It is likely that Farm 3 would have produced larger yields as the shoot dry matter was increasing at the final sampling date and translocation of dry matter to the tubers was not complete. The yield values are similar to other potato research studies reported in Table 3.1 whose overall median yield was 39 Mg ha^{-1} with a median applied N fertilizer rate of 140 kg ha^{-1}.

The yield results reveal another consideration for the growers: timing of harvest. Evidence points to the plants not being mature on Farm 3, particularly the linear uptake of N in the shoots and the partitioning of dry matter. Although size of tubers, especially the tubers being too large, is a concern for these growers early harvesting can mean a sacrifice in yields. Early harvesting can also result in more N left in easily degradable vines from incomplete translocation of nutrients. This N is available for uptake by a fall-planted cover crop which in turn can supply N to the next crop following incorporation.

All-Farms Tuber Yields

The fresh tuber yield for the All-Farms group were variable by farm and cultivar (Figure 3.4 and Table 3.6). As a group, the median was close to 20 Mg ha^{-1}, with over 60% of yields between 15 and 25 Mg ha^{-1}. Very few 'cull' potatoes were sampled and the total yield represents all potatoes removed from the hills. These yields are about 50% lower than the fresh weight tuber yield for the Intensive Farms 1-3 (Figure 3.3). This is expected as the between-row spacing was often wider than the 0.9 m spacing used to calculate yields for the uptake study. Also, yields for Intensive Farms were calculated on a per plant basis and represent an optimized yield with a full stand. With the exception of a few farms (9, 10, 12) most of the yield was medium-size tubers (85-227 g). Farm 10 was intentionally managing for small-sized (<85 g) tubers, and Farm 12 saw an unexpected increase in the amount of large (>227 g) tubers by 'Iona'.

Intensive Farm Petiole Nitrate

The petiole N followed a typical pattern during the sampling, starting at some elevated point and declining as the season progressed (Porter and Sisson, 1991) (Figure 3.5). Farm 1 exhibited the lowest starting petiole N at 6.1 NO_3-N g kg^{-1}, followed by Farm 2 with 8.9 NO_3-N g kg^{-1}, while Farm 3 had the highest starting petiole N at 18.6 NO_3-N g kg^{-1}. Petiole nitrate levels were quite variable during the season with some increases in value as time progressed. Sampling at closer intervals more often and starting earlier in the season might have facilitated a more detailed interpretation of petiole N trends.

Since petiole N is a good index of the current N status of the crop (Wescott et al., 1991), it appears that Farm 1 had lowest N availability followed by Farm 2. In spite of petiole N being related to relative yield (Porter and Sisson, 1991), the yield on Farms 1, 2, and 3 was similar. Elevated petiole N levels early in the season are possible if the potato crop follows a recent incorporation of high N fresh residues (Porter and Sisson, 1991; Wescott et al., 1991), and although Farm 1 and 3 had similar estimated amounts of cover crop biomass (author's observation), petiole N values differed between these farms by over 10 NO_3-N g kg^{-1} at the first sampling. It has been found that petiole N is related to the rate of N application (Doll et al., 1971; Lewis and Love, 1994; Porter and Sisson, 1991), therefore the differences we see between farms was likely the result of nutrient management in the current season combined with soil supplied N.

Westcott et al. (1991) determined in a study in Montana with 'Russet Burbank' potato that a petiole N value of 13 g kg^{-1} should be maintained throughout tuber growth. On all three Farms this was not the case, indicating that perhaps the N requirements of the potato were not met during the growing season, or N uptake occurred as NH_4 from soil N mineralization.

Conclusions

The objectives in this study were to provide the participating farms with estimates of potato dry matter production, N uptake, and fresh tuber yield. In addition, petiole sampling was performed to compare values to petiole N recommendations.

Dry matter production on the Intensive Farms was estimated at 15 Mg ha^{-1} for Farm 1, 14 Mg ha^{-1} for Farm 2, and 16 Mg ha^{-1} for Farm 3. Although these results are similar between the farms, the partitioning of the dry matter appeared different. At harvest, Farm 1 tubers accounted for 83% of the dry matter, on Farm 2 69%, and on

Farm 3 tubers were only 53% of dry matter. The different partitioning on each farm is likely due to differing N availability as indicated by the N uptake and petiole N levels. At these farms higher N availability resulted in increased shoot production.

The results of N uptake are explained well when the field histories at each Intensive Farm are considered. Farm 1 planted into a field that for the first season was under their management. This field had reportedly received low inputs for 20+ years. Farm 2 had managed the potato field for 2-3 years. The location of the plot on Farm 3 was in a field that had received animal manure compost for 10+ years. Although Farm 3 did report using the highest rates of easily degradable N sources (210 kg N ha^{-1} as chicken litter) we believe the N uptake results are more indicative of how past management activities influence the current season. Results of N uptake in zero-N plots in Chapter 2 confirm this. However, our results could be confounded by location, cultivar, and of limited scope with only one year's data.

Fresh tuber yields at grower harvest time for the All-Farms group were approximately 20 Mg ha^{-1}. Intensive Farm results show that higher yields, approximately 40 to 50 Mg ha^{-1} are possible with smaller between-row spacing and an optimal stand. These yields were produced with a tuber N uptake rate near 1.0 kg N ha^{-1} d^{-1} during tuber bulking. Yields were produced in similar amounts on all three of the Intensive Farms even though indicators like petiole N and total N uptake point to higher N availability on Farm 3, suggesting a high amount of N efficiency on Farms 1 and 2. Crop N uptake (tubers and shoots) was 145, 190 and 245 kg N ha^{-1} at Farms 1, 2, and 3. If the soils on these farms supply 120-160 kg N ha^{-1} (data in Chapter 2) an application of less than 100 kg of plant-available N per hectare should result in yields of approximately 50 Mg ha^{-1} provided a between-row spacing of less than 1 m.

Conventional petiole N standards might not be a good indicator of N limitations on these farms if yield expectations and goals are being met with current practices. Lowering petiole N recommendations could be warranted after further study.

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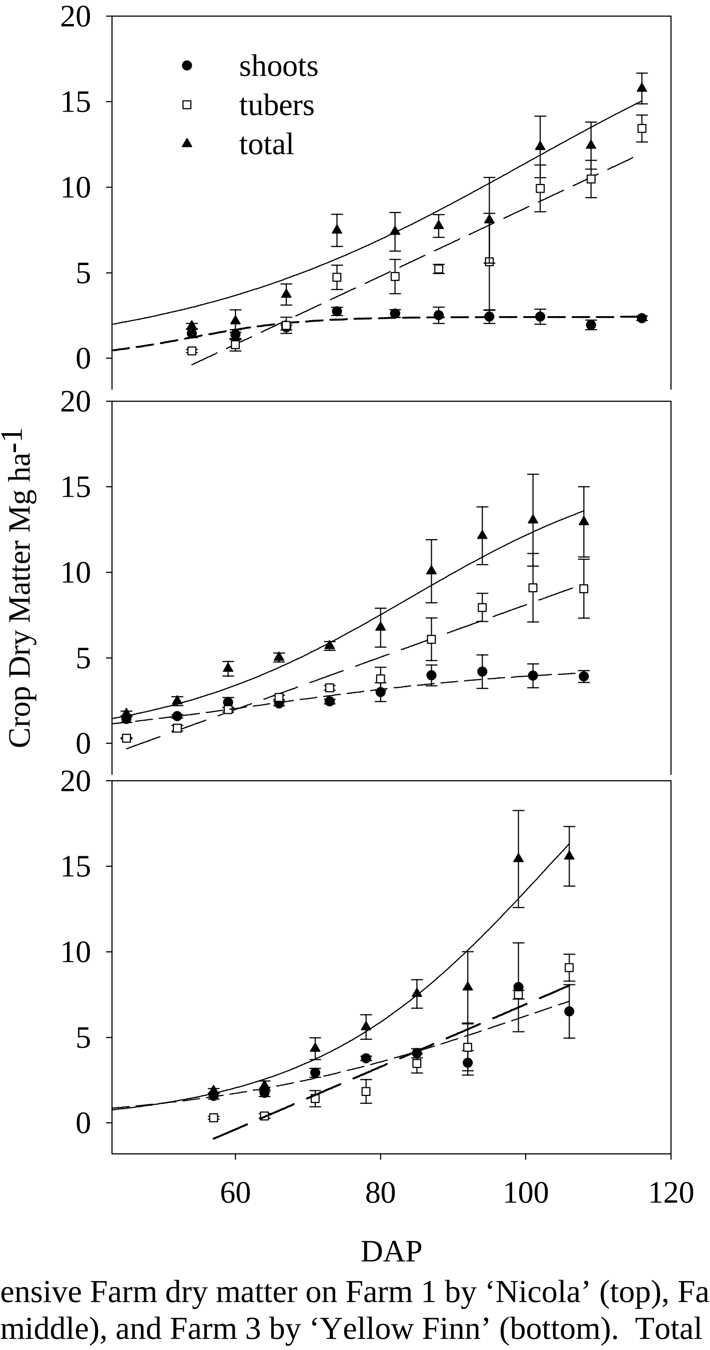

Figure 3.1. Intensive Farm dry matter on Farm 1 by 'Nicola' (top), Farm 2 by 'Yukon Gold' (middle), and Farm 3 by 'Yellow Finn' (bottom). Total is the tuber plus the shoot dry matter. Values were calculated on a per plant basis and then multiplied by a constant (36 360 plants ha^{-1}) for comparative purposes. Tuber dry matter increased in a linear fashion, while total and shoot dry matter were best described with a sigmoid function forced through the origin. See Table 3.3 for coefficients of regressions.

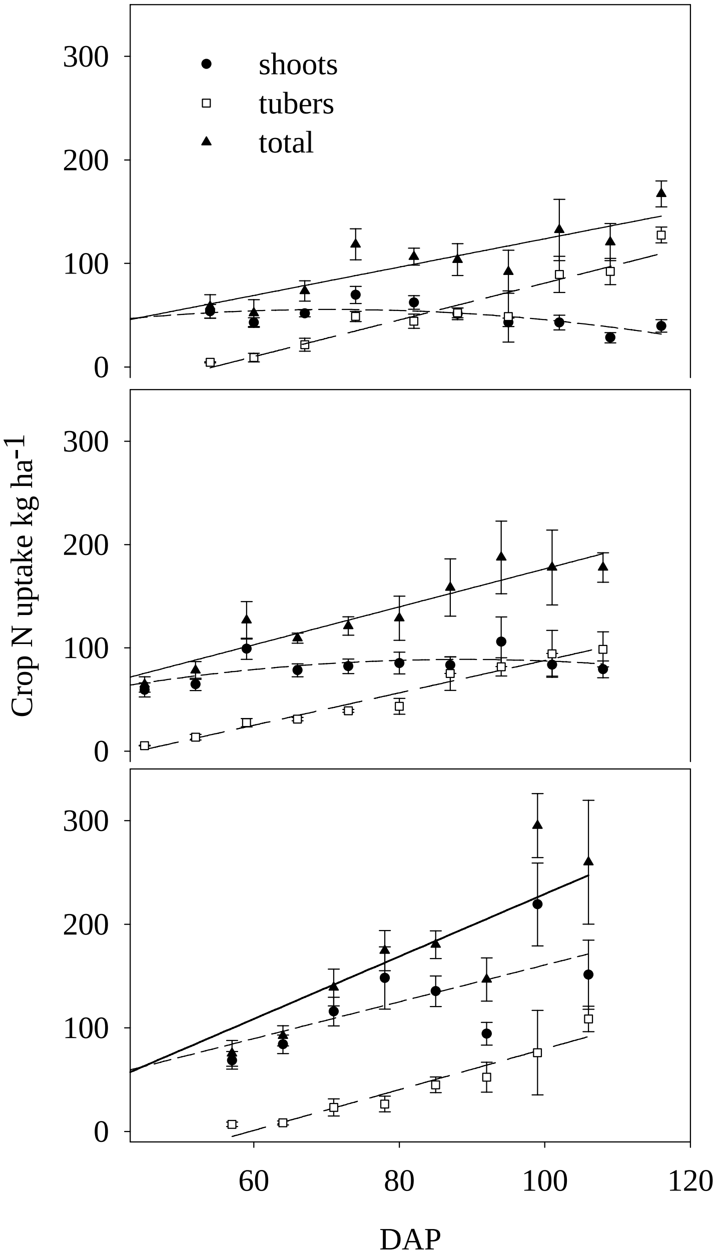

Figure 3.2. Intensive Farm N uptake verses days after planting on Farm 1 by 'Nicola' (top), Farm 2 by 'Yukon Gold' (middle), and Farm 3 by 'Yellow Finn' (bottom). Values were calculated on a per plant basis and then multiplied by a constant (36 360 plants ha^{-1}) for comparative purposes. Uptake was described by linear functions except Farm 1 and 3 shoot uptake where a quadratic equation was used. See Table 3.4 for coefficients of regressions.

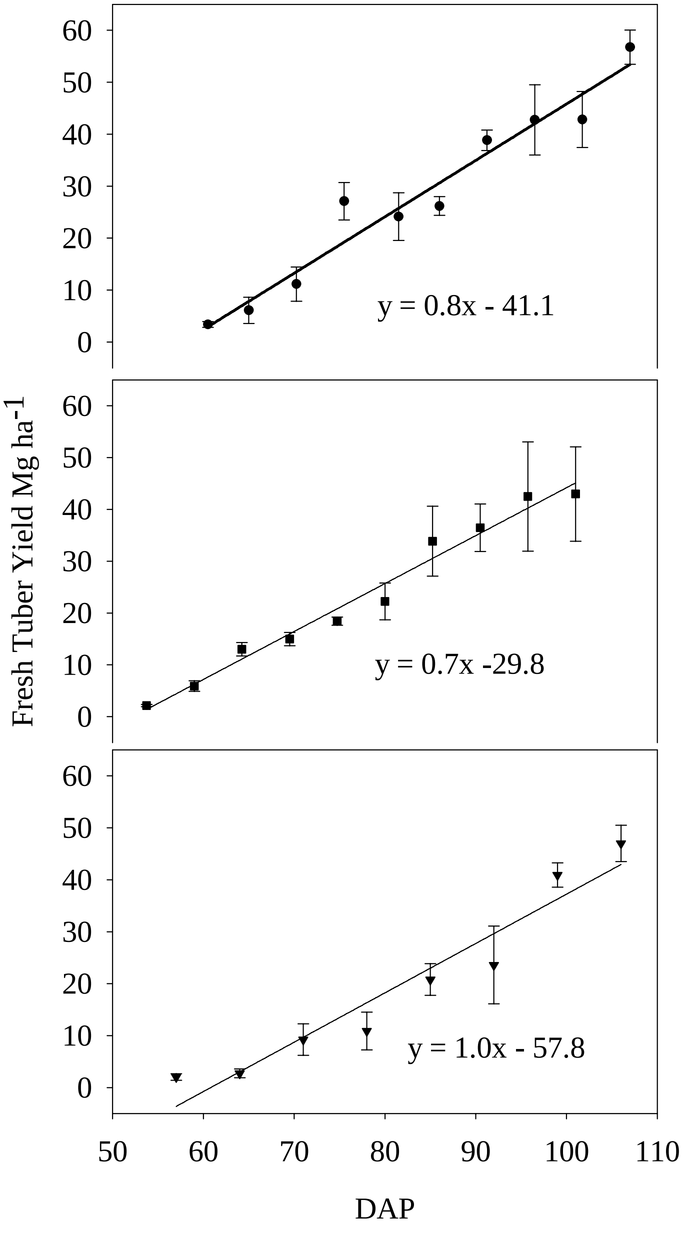

Figure 3.3. Intensive Farm tuber yields increased in a linear fashion on Farms 1, 2, and 3. Cultivars were ‘Nicola’ on Farm 1, ‘Yukon Gold’ on Farm 2, and ‘Yellow Finn’ on Farm 3. Values were calculated on a per plant basis and then multiplied by a constant (36 360 plants ha^{-1}) for comparative purposes. Regression equations in Table 3.5.

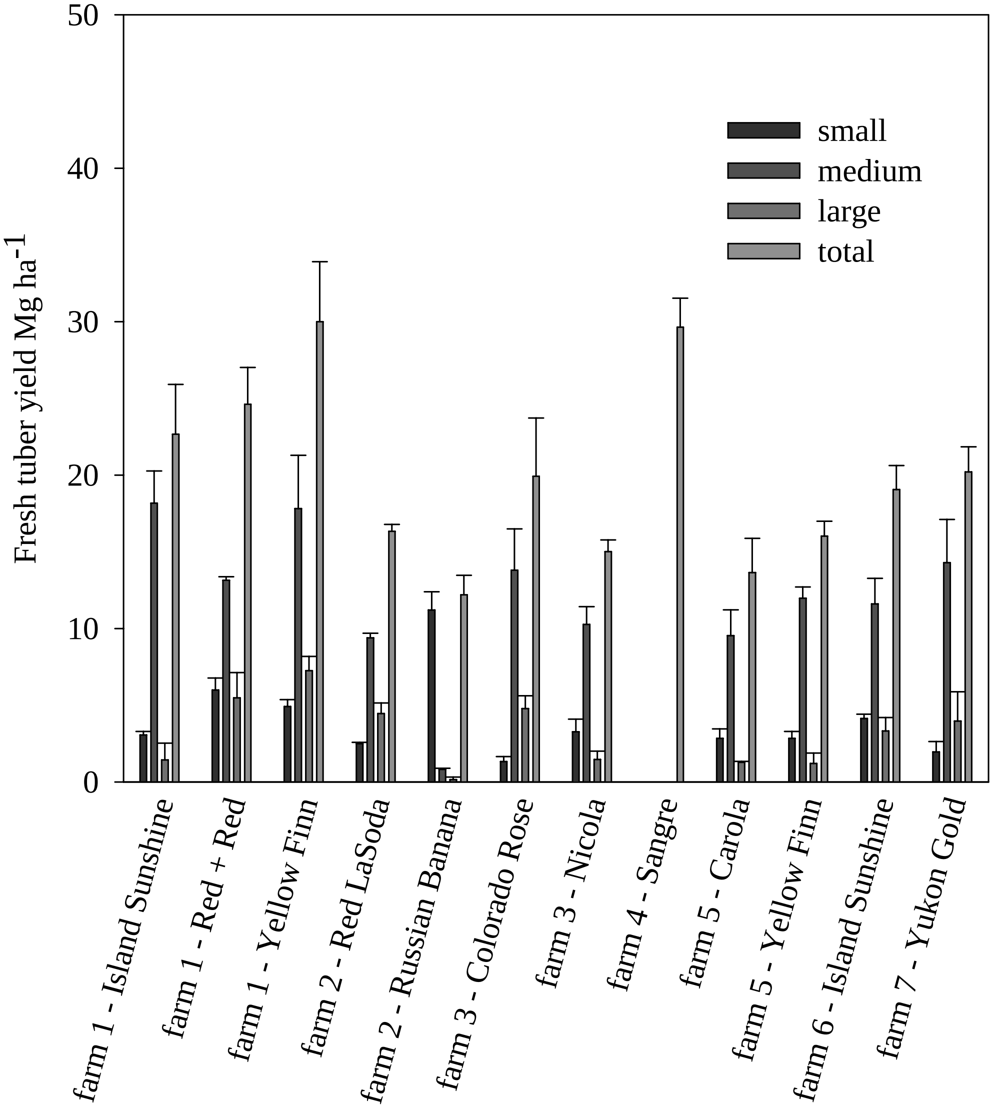

Figure 3.4. All-Farms yields of tubers "as-is" separated by weight class. Yield is an average of 3 sections of 0.3 m of row hand dug and weighed in the field. Small corresponds to 0-85 g, medium 85-227 g, and large >227 g. The yield per hectare was calculated using the row spacing found in the field at the time of sampling.

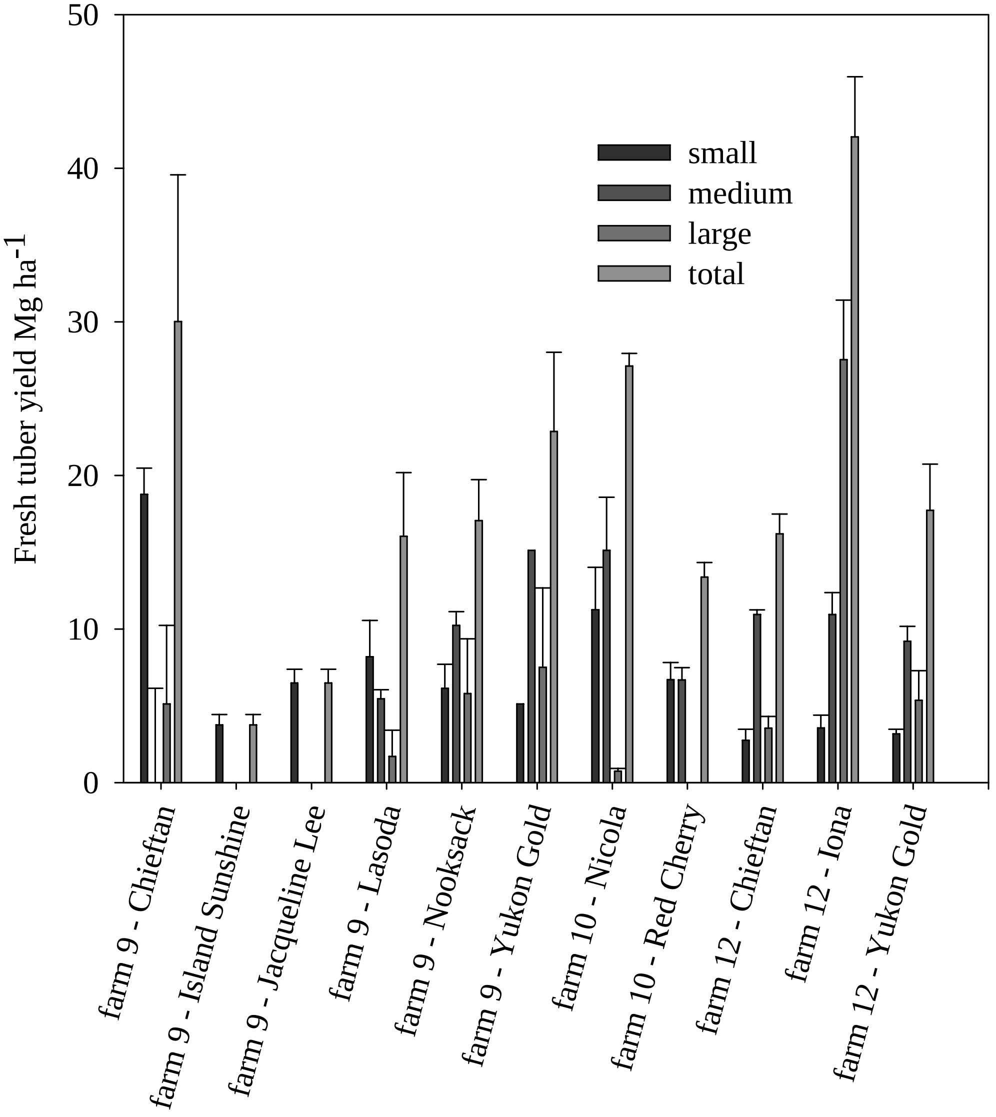

Figure 3.4. All-Farms yields of tubers “as-is” separated by weight class. Yield is an average of 3 sections of 0.3 m of row hand dug and weighed in the field. Small corresponds to 0-85 g, medium 85-227 g, and large >227 g. The yield per hectare was calculated using the row spacing found in the field at the time of sampling (continued).

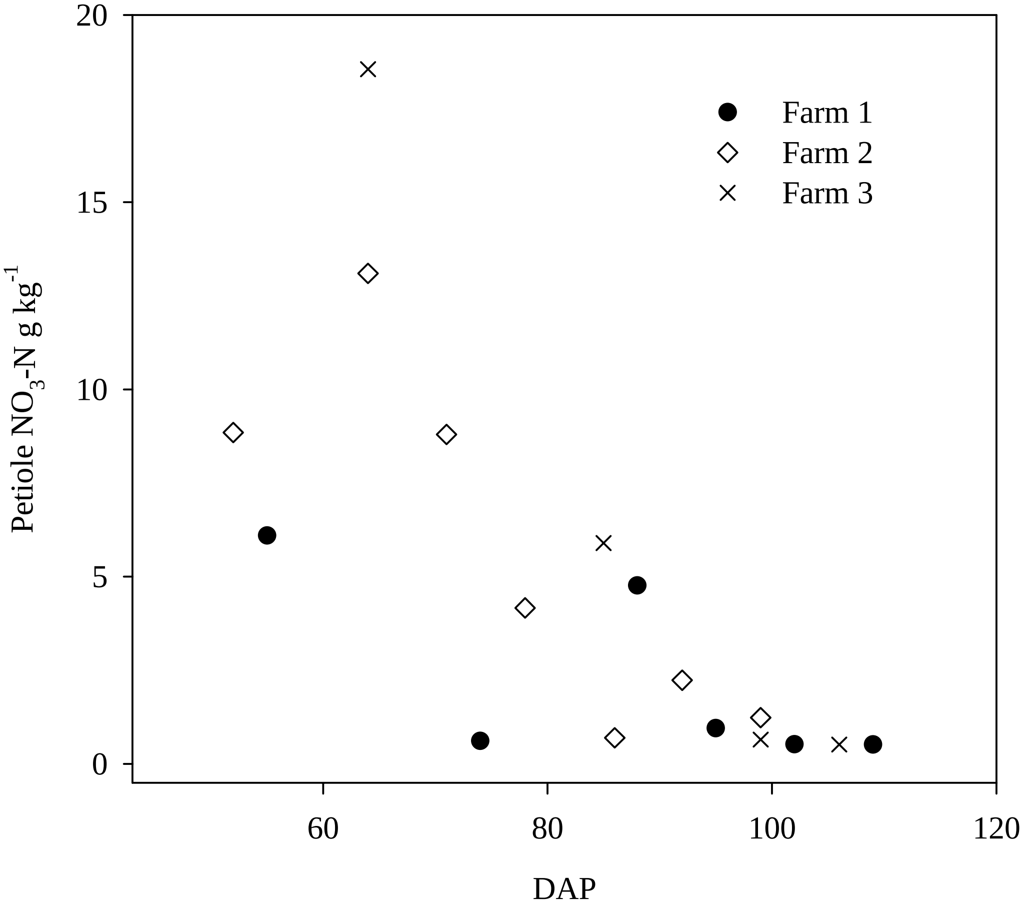

Figure 3.5. Intensive Farms 1, 2, and 3 petiole nitrate-nitrogen levels. Twenty petioles, each one from a different plant within the plot, were removed on or near the time of biomass sampling.

Table 3.1 Review of tuber yield and potato crop N uptake in selected N fertilizer trials.

Source	Location	Year(s)	Soil textural class	Cultivar	Fertilizer N	Fresh tuber yield	Total N uptake	N in tubers	Additional kg of yield per kg of fertilizer added[a]
					kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	kg ha^{-1}	
Li, H. et al., 2006	Laval University, Canada	1993-1995	silt loam	Superior	140	40	200	158	
	Mistassini	1994-1996	loamy sand	Superior	168	32	143	93	
	Saint-Damase, Quebec, Cananda	1985-1986	loamy sand	Norland	140	39	205	142	
	Soulanges, Quebec, Cananda	1985-1986	loamy sand	Norland	140	38	195	134	
Meyer and Marcum, 1998	Fall River Valley, Northern CA	1992	sandy loam	Russet Burbank	0	43		159	
					112	54		197	95
					168	55			74
					224	44		158	5
					448	47		188	10
		1993			0	29		62	
					56	41			205
					112	43		108	123
					168	45			93
					224	49		144	87
					448	38		140	20

[a] Additional yield was calculated by dividing the yield increase by the additional N fertilizer added. Table numbers were rounded after calculations were made from author’s data.

Table 3.1 Review of tuber yield and potato crop N uptake in selected N fertilizer trials (continued).

Source	Location	Year(s)	Soil textural class	Cultivar	Fertilizer N	Fresh tuber yield	Total N uptake	N in tubers	Additional kg of yield per kg of fertilizer added[a]
					kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	kg ha^{-1}	
Lewis and Love, 1994	Aberdeen, Idaho	1986-1988	silt loam	Frontier Russet	0	33			
					140	35			9
					280	37			11
					420	32			0
				Ranger Russet	0	40			
					140	45			37
					280	46			21
					420	47			16
				Butte	0	43			
					140	46			21
					280	47			16
					420	48			12
				Russet Burbank	0	40			
					140	44			27
					280	43			13
					420	43			8
				Gemchip	0	42			
					140	47			32
					280	44			8
					420	47			12

[a] Additional yield was calculated by dividing the yield increase by the additional N fertilizer added. Table numbers were rounded after calculations were made from author's data.

Table 3.1 Review of tuber yield and potato crop N uptake in selected N fertilizer trials (continued).

Source	Location	Year(s)	Soil textural class	Cultivar	Fertilizer N	Fresh tuber yield	Total N uptake	N in tubers	Additional kg of yield per kg of fertilizer added[a]
					kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	kg ha^{-1}	
Jackson et al., 1974	Willamette Valley, OR	1961	silt loam	Russet Burbank	0	24			
					45	31			156
					90	32			89
					180	34			56
		1962	silt loam	Russet Burbank	0	22			
					45	23			22
					90	26			44
					180	24			11
		1968	silt loam	Kennebec	0	37			
					110	36			0
					220	37			0
Zebarth et al., 2005	Fredericton, NB, Canada	2000		Russet Burbank	0	34			
					200	39			25
		2001		Russet Burbank	0	19			
					200	27			40
		2002		Russet Burbank	0	30			
					200	46			80

[a] Additional yield was calculated by dividing the yield increase by the additional N fertilizer added. Table numbers were rounded after calculations were made from author’s data.

Table 3.1 Review of tuber yield and potato crop N uptake in selected N fertilizer trials (continued).

Source	Location	Year(s)	Soil textural class	Cultivar	Fertilizer N	Fresh tuber yield	Total N uptake	N in tubers	Additional kg of yield per kg of fertilizer added[a]
					kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	kg ha^{-1}	
Curless et al, 2004	Antigo, WI	2000		Snowden	0	47		127	
					67	59		180	175
					134	63		192	117
					202	65		199	88
					269	59		217	43
		2001		Snowden	0	37		101	
					67	37		117	3
					134	37		102	1
					202	36		111	0
					269	37		102	1
		2002		Snowden	0	37		97	
					67	41		144	54
					134	39		149	12
					202	39		158	8
					269	39		158	6

[a] Additional yield was calculated by dividing the yield increase by the additional N fertilizer added. Table numbers were rounded after calculations were made from author’s data.

Table 3.1 Review of tuber yield and potato crop N uptake in selected N fertilizer trials (continued).

Source	Location	Year(s)	Soil textural class	Cultivar	Fertilizer N	Fresh tuber yield	Total N uptake	N in tubers	Additional kg of yield per kg of fertilizer added[a]
					kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	kg ha^{-1}	
Millard and Marshall, 1986	Aberdeenshire, GB	1983		Maris Piper	0	32	80	60	
					50	36	100	75	82
					100	44			123
					150	46	150	110	93
					200	46			69
					250	44	175	125	48
		1984		Maris Piper	0	37	60	50	
					50	47	110	100	198
					100	52			147
					150	56	160	145	129
					200	55			89
					250	55	190	150	71

[a] Additional yield was calculated by dividing the yield increase by the additional N fertilizer added. Table numbers were rounded after calculations were made from author's data.

Table 3.1 Review of tuber yield and potato crop N uptake in selected N fertilizer trials (continued).

Source	Location	Year(s)	Soil textural class	Cultivar	Fertilizer N	Fresh tuber yield	Total N uptake	N in tubers	Additional kg of yield per kg of fertilizer added[a]
					kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	kg ha^{-1}	
Lorenz, O.A., 1944	Kern County, CA	1942	"very light texture"	White Rose	0	26			
					210	45			90
Doll, et al., 1971	Michigan	1970	Karlin loamy sand	Sebago	0	15			
					50	16			20
					100	21			60
					150	20			33
					200	19			20
			Montcalm loamy sand	Russet Burbank	0	25			
					100	26			10
					150	28			20
				Sebago	0	34			
					100	39			50
					150	36			13
median					140	39			

[a] Additional yield was calculated by dividing the yield increase by the additional N fertilizer added. Table numbers were rounded after calculations were made from author’s data.

Table 3.2. Sampling summary for Intensive Farms.

Farm	Potato cultivar	Planting date	Between-row spacing	In-row spacing	Biomass harvesting	Petiole sampling	Grower shoot-kill^{a}	
			m		DAP	DAP	Date	DAP
1	Nicola	29-Apr	1.07	0.3	54, 60, 67, 74, 82, 88, 95, 102, 109, 116	55, 74, 88, 95, 102, 109	23-Aug	116
2	Yukon Gold	12-May	1.83	0.3	45, 52, 59, 66, 73, 80, 87, 94, 101, 108	52, 64, 71, 78, 86, 92, 99	8-Sep	119
3	Yellow Finn	2-May	1.22	0.3	57, 64, 71, 78, 85, 92, 99, 106	64, 85, 99, 106	16-Aug	106

[a] Some sampling concluded before the vine kill date, in these cases N uptake could occur after final sample date.

Table 3.3. Regression equations for dry matter production (Mg ha^{-1}) vs. days after planting on Intensive Farms 2006[a].

Farm	Dry matter				
	shoots				
	sigmoid function[b]		SE	p	R^2
	f = a/(1+exp(-(x-x0)/b))				
1	a =	2.4	0.142	<0.0001	0.52
	b =	7.6	4.317	0.09	
	x0 =	53.9	3.507	<0.0001	
2	a =	4.5	0.96	<0.0001	0.63
	b =	19.3	9.241	0.05	
	x0 =	64.0	10.10	<0.0001	
3	a =	12.7	18.20	0.49	0.55
	b =	22.0	18.40	0.24	
	x0 =	100.7	62.99	0.12	
	tubers				
	linear function		SE	p	R^2
	f = y0+a*x				
1	y0 =	-11.1	1.613	<0.0001	0.80
	a =	0.2	0.019	<0.0001	
2	y0 =	-7.2	1.137	<0.0001	0.80
	a =	0.2	0.014	<0.0001	
3	y0 =	-11.3	1.417	<0.0001	0.84
	a =	0.2	0.017	<0.0001	
	total (shoots + tubers)				
	sigmoid function[b]		SE	p	R^2
	f = a/(1+exp(-(x-x0)/b))				
1	a =	22.8673	13.63	0.105	0.73
	b =	24.2807	10.69	0.0313	
	x0 =	100.1151	30.62	0.0029	
2	a =	16.9435	4.955	0.002	0.77
	b =	17.2531	6.009	0.0079	
	x0 =	83.8904	12.29	<0.0001	
3	a =	30.5898	24.32	0.2217	0.82
	b =	16.5987	6.576	0.0193	
	x0 =	103.7705	25.75	0.0006	

[a] See Figure 3.1 for graphs of functions.

[b] Sigmoid function was forced through origin by adding an artificial data point at (0,0).

Table 3.4. Regression analysis values for crop N uptake (kg ha^{-1}) vs. days after planting on Intensive Farms 2006[a].

Farm	Crop N uptake				
	shoots				
	quadratic function[b]		SE	p	R^2
	f=y0+a*x+b*x^2				
1	y0 =	-1.7	14.71	0.91	0.39
	a =	1.6	0.39	0.0003	
	b =	-0.01	0.003	0.0002	
2	y0 =	-4.3	21.03	0.84	0.39
	a =	2.1	0.62	0.002	
	b =	-0.01	0.005	0.02	
	linear function				
	f = y0+a*x				
3	y0 =	-17.0	41.78	0.69	0.34
	a =	1.8	0.51	0.002	
	tubers				
	linear function		SE	p	R^2
	f = y0+a*x				
1	y0 =	-96.6	16.05	<0.0001	0.77
	a =	1.8	0.18	<0.0001	
2	y0 =	-69.0	12.49	<0.0001	0.78
	a =	1.6	0.16	<0.0001	
3	y0 =	-117.2	27.90	0.0004	0.61
	a =	2.0	0.34	<0.0001	
	total (shoots + tubers)				
	linear function		SE	p	R^2
	f = y0+a*x				
1	y0 =	-12.9	18.08	0.48	0.59
	a =	1.4	0.21	<0.0001	
2	y0 =	-7.3	19.55	0.7111	0.65
	a =	1.8	0.25	<0.0001	
3	y0 =	-72.4	40.48	0.087	0.62
	a =	3.0	0.50	<0.0001	

[a] See Figure 3.2 for graphs of functions.

[b] Quadratic function was forced through origin by adding an artificial data point at (0,0).

Table 3.5. Regression analysis values for fresh tuber yield (Mg ha^{-1}) versus days after planting on Intensive Farms 2006[a].

Farm	Wet tuber yield				
	function		SE	p	R^2
	f = y0+a*x				
1	y0 =	-41.1	5.37	<0.0001	0.86
	a =	0.8	0.06	<0.0001	
2	y0 =	-29.8	5.76	<0.0001	0.76
	a =	0.7	0.07	<0.0001	
3	y0 =	-57.8	7.35	<0.0001	0.84
	a =	1.0	0.09	<0.0001	

[a] See Figure 3.3 for graphs of functions.

Table 3.6. Yields for All-Farms group by tuber size and total estimated with field between-row spacing and 0.3m in-row spacing (means and SE).

Farm	Potato culitvar	Planting date	Sample date	Between-row spacing[a]	Tuber size			
				m	Small	Medium	Large	Total
					< 85 g	85-227 g	>227 g	Mg ha-1
					Mg ha-1	Mg ha-1	Mg ha-1	
1	Island sunshine	29-Apr	30-Aug	0.9	3 (0.2)	18 (2.1)	1 (1.1)	23 (3.2)
1	Red + red	29-Apr	30-Aug	0.9	6 (0.8)	13 (0.2)	5 (1.7)	25 (2.4)
1	Yellow finn	29-Apr	30-Aug	0.9	5 (0.5)	18 (3.5)	7 (0.9)	30 (3.9)
2	Red LaSoda	11-May	8-Sep	1.8	2 (0.1)	9 (0.3)	4 (0.7)	16 (0.5)
2	Russian Banana	11-May	8-Sep	1.8	11 (1.2)	1 (0.1)	0 (0.2)	12 (1.3)
3	Colorado rose	2-May	16-Aug	1.2	1 (0.3)	14 (2.7)	5 (0.8)	20 (3.8)
3	Nicola	2-May	16-Aug	1.2	3 (0.8)	10 (1.1)	1 (0.5)	15 (0.8)
4	Sangre	27-Mar	31-Jul	1.2				30 (1.9)
5	Carola	19-Apr	15-Aug	1.8	3 (0.6)	10 (1.7)	1 (0.1)	14 (2.2)
5	Yellow finn	19-Apr	15-Aug	1.8	3 (0.5)	12 (0.7)	1 (0.7)	16 (1.0)
6	Island sunshine	18-Apr	22-Aug	1.1	4 (0.3)	12 (1.7)	3 (0.9)	19 (1.6)
7	Yukon gold		15-Aug	1.4	2 (0.7)	14 (2.8)	4 (1.9)	20 (1.6)
9	Chieftan	29-Mar	22-Jul	0.9	19 (1.7)	6 (6.1)	5 (5.1)	30 (9.6)
9	Lasoda	29-Mar	31-Aug	0.9	8 (2.4)	6 (0.6)	2 (1.7)	16 (4.2)
9	Nooksack	18-Apr	31-Aug	0.9	6 (1.6)	5 (0.9)	6 (3.6)	17 (2.7)
9	Yukon gold	18-Apr	22-Jul	0.9	5 (0.0)	10 (0.0)	8 (5.2)	23 (5.2)
10	Nicola	10-May	1-Sep	1.2	11 (2.8)	15 (3.5)	1 (0.2)	27 (0.8)
10	Red cherry	10-May	1-Sep	1.2	7 (1.1)	7 (0.8)	0 (0.0)	13 (1.0)
12	Chieftan	25-Apr	21-Sep	1.0	3 (0.7)	10 (0.3)	4 (0.8)	16 (1.3)
12	Iona	25-Apr	21-Sep	1.0	4 (0.8)	11 (1.4)	28 (3.9)	42 (3.9)
12	Yukon gold	25-Apr	21-Sep	1.0	3 (0.3)	9 (1.0)	5 (1.9)	18 (3.0)
median					4 (0.7)	10 (1.1)	4 (0.9)	19 (2.2)

[a] Between-row spacing is the spacing that was observed in the field at the time of sampling and was used to calculate yields.

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APPENDICES

Appendix 1. Moisture levels during laboratory N mineralization incubations 2006.

Farm	Master ID	Season of soil collection	Time frame of experiment	Total solids	Gravimetric moisture content[a]	Estimated dry soil + water content[b]
			days		%	g
1	JM156	spring	0	0.72	38.2	690.8
			21	0.74	35.3	676.6
			42	0.75	33.5	667.6
			63	0.74	35.3	676.7
	JM157		0	0.73	37.3	686.4
			21	0.74	36.0	680.0
			42	0.75	32.6	662.9
			63	0.74	35.4	677.1
	JM158		0	0.74	35.9	679.4
			21	0.73	37.3	686.5
			42	0.75	32.5	662.3
			63	0.74	36.0	680.2
	JM344	summer	0	0.78	28.0	640.2
			21	0.77	30.5	652.3
			42	0.81	23.7	618.7
			63	0.77	29.6	648.1
	JM345		0	0.77	30.5	652.6
			21	0.77	30.5	652.4
			42	0.79	26.0	629.8
			63	0.77	30.7	653.5
	JM346		0	0.82	22.7	613.3
			21	0.81	24.2	620.8
			42	0.84	18.9	594.3
			63	0.80	24.3	621.6
	JM551a	fall	0	0.77	29.3	646.5
			21	0.78	27.8	638.9
			42	0.79	27.0	635.1
			63	0.78	27.9	639.7
	JM551b		0	0.78	28.2	640.8
			21	0.78	27.4	637.2
			42	0.79	26.8	633.8
			63	0.79	26.9	634.3
	JM551c		0	0.78	27.9	639.5
			21	0.78	27.7	638.3
			42	0.79	26.1	630.6
			63	0.79	27.2	636.0

[a] Gravimetric moisture content calculated by dividing the water mass by the dry soil,mass, in this case 500 g of dry soil.

[b] A large increase in moisture levels between 0 and 21 days indicates water was added immediately after the moisture at 0 days was determined.

Appendix 1. Moisture levels during laboratory N mineralization incubations 2006 (continued).

Farm	Master ID	Season of soil collection	Time frame of experiment	Total solids	Gravimetric moisture content[a]	Estimated dry soil + water content[b]
			days		%	g
2	JM150	spring	0	0.76	32.3	661.4
			21	0.76	31.2	655.9
			42	0.78	28.6	642.8
			63	0.76	31.1	655.7
	JM151		0	0.76	31.4	657.1
			21	0.77	30.1	650.5
			42	0.78	28.1	640.5
			63	0.77	30.4	652.1
	JM152		0	0.77	30.3	651.5
			21	0.77	29.2	645.9
			42	0.79	27.0	635.2
			63	0.77	30.3	651.6
	JM311	summer	0	0.78	28.9	644.4
			21	0.78	29.0	645.1
			42	0.79	26.0	630.1
			63	0.78	27.9	639.5
	JM312		0	0.76	31.6	658.2
			21	0.77	30.7	653.4
			42	0.77	29.2	645.9
			63	0.77	30.2	651.0
	JM313		0	0.77	30.5	652.3
			21	0.77	29.8	649.1
			42	0.78	28.9	644.4
			63	0.77	30.3	651.7
	JM552a	fall	0	0.84	19.5	597.7
			21	0.82	21.2	606.2
			42	0.82	21.3	606.5
			63	0.83	20.6	603.2
	JM552b		0	0.83	19.9	599.5
			21	0.82	21.3	606.7
			42	0.83	20.5	602.7
			63	0.83	21.2	605.9
	JM552c		0	0.84	19.1	595.6
			21	0.83	21.1	605.5
			42	0.83	20.4	602.1
			63	0.83	20.4	601.9

[a] Gravimetric moisture content calculated by dividing the water mass by the dry soil,mass, in this case 500 g of dry soil.

[b] A large increase in moisture levels between 0 and 21 days indicates water was added immediately after the moisture at 0 days was determined.

Appendix 1. Moisture levels during laboratory N mineralization incubations 2006 (continued).

Farm	Master ID	Season of soil collection	Time frame of experiment	Total solids	Gravimetric moisture content[a]	Estimated dry soil + water content[b]
			days		%	g
3	JM162	spring	0	0.75	34.2	670.9
			21	0.75	33.2	666.2
			42	0.77	30.7	653.3
			63	0.75	33.9	669.5
	JM163		0	0.73	36.6	683.2
			21	0.74	34.9	674.4
			42	0.76	31.2	656.2
			63	0.73	36.1	680.6
	JM164		0	0.72	39.4	696.9
			21	0.74	34.4	672.0
			42	0.76	31.8	658.8
			63	0.74	35.4	676.9
	JM341	summer	0	0.79	25.9	629.7
			21	0.79	27.3	636.4
			42	0.82	22.2	610.8
			63	0.79	26.1	630.5
	JM342		0	0.81	23.2	615.9
			21	0.79	26.4	632.1
			42	0.83	21.2	606.0
			63	0.80	25.1	625.5
	JM343		0	0.83	20.0	600.2
			21	0.78	27.8	639.1
			42	0.81	22.9	614.3
			63	0.79	27.0	634.8
	JM553a	fall	0	0.81	23.6	618.2
			21	0.81	23.3	616.7
			42	0.81	22.8	614.0
			63	0.81	23.0	615.1
	JM553b		0	0.66	52.1	760.6
			21	0.81	23.3	616.5
			42	0.82	22.7	613.4
			63	0.81	23.2	616.2
	JM553c		0	0.81	23.6	617.8
			21	0.81	23.3	616.3
			42	0.82	22.4	611.8
			63	0.81	23.1	615.3

[a] Gravimetric moisture content calculated by dividing the water mass by the dry soil,mass, in this case 500 g of dry soil.

[b] A large increase in moisture levels between 0 and 21 days indicates water was added immediately after the moisture at 0 days was determined.

Appendix 1. Moisture levels during laboratory N mineralization incubations 2006 (continued).

Farm	Master ID	Season of soil collection	Time frame of experiment	Total solids	Gravimetric moisture content[a]	Estimated dry soil + water content[b]
			days		%	g
4	JM153	spring	0	0.77	29.7	648.6
			21	0.78	28.7	643.4
			42	0.79	27.2	636.2
			63	0.78	28.7	643.6
	JM154		0	0.78	27.8	639.0
			21	0.79	26.7	633.7
			42	0.80	24.5	622.4
			63	0.79	26.7	633.6
	JM155		0	0.78	27.9	639.7
			21	0.79	27.1	635.6
			42	0.80	24.9	624.5
			63	0.78	27.9	639.4
	JM318	summer	0	0.81	22.8	614.0
			21	0.81	23.1	615.6
			42	0.82	21.4	606.8
			63	0.82	22.2	611.0
	JM319		0	0.82	22.1	610.6
			21	0.82	22.5	612.7
			42	0.83	20.4	602.2
			63	0.82	21.8	608.9
	JM320		0	0.82	21.4	606.9
			21	0.82	22.4	612.2
			42	0.83	20.1	600.7
			63	0.82	21.6	607.9
	JM554a	fall	0	0.84	19.2	595.9
			21	0.83	21.0	604.8
			42	0.84	19.2	596.1
			63	0.83	20.4	602.0
	JM554b		0	0.84	19.1	595.7
			21	0.83	20.3	601.4
			42	0.83	20.6	602.8
			63	0.83	20.5	602.5
	JM554c		0	0.84	19.2	596.1
			21	0.83	20.8	603.8
			42	0.69	44.3	721.5
			63	0.83	20.9	604.4

[a] Gravimetric moisture content calculated by dividing the water mass by the dry soil,mass, in this case 500 g of dry soil.

[b] A large increase in moisture levels between 0 and 21 days indicates water was added immediately after the moisture at 0 days was determined.

Appendix 1. Moisture levels during laboratory N mineralization incubations 2006 (continued).

Farm	Master ID	Season of soil collection	Time frame of experiment	Total solids	Gravimetric moisture content[a]	Estimated dry soil + water content[b]
			days		%	g
5	JM165	spring	0	0.82	21.6	608.0
			21	0.82	21.5	607.3
			42	0.84	19.6	598.0
			63	0.82	21.5	607.6
	JM166		0	0.79	27.4	636.9
			21	0.79	26.3	631.4
			42	0.82	21.9	609.5
			63	0.80	25.6	627.9
	JM167		0	0.80	24.9	624.3
			21	0.81	23.1	615.5
			42	0.84	19.6	598.1
			63	0.81	24.1	620.4
	JM347	summer	0	0.88	13.8	569.1
			21	0.80	24.8	623.8
			42	0.82	15.9	609.8
			63	0.81	24.0	620.1
	JM348		0	0.87	14.6	572.8
			21	0.80	24.9	624.4
			42	0.82	22.3	611.7
			63	0.80	24.4	621.9
	JM349		0	0.87	15.1	575.3
			21	0.79	27.1	635.5
			42	0.82	22.7	613.3
			63	0.80	25.4	626.9
	JM555a	fall	0	0.84	18.8	594.2
			21	0.83	20.6	603.0
			42	0.83	20.2	601.2
			63	0.83	20.4	602.2
	JM555b		0	0.84	19.3	596.5
			21	0.83	20.7	603.6
			42	0.83	20.3	601.6
			63	0.83	20.6	603.1
	JM555c		0	0.84	19.6	597.9
			21	0.83	20.8	604.0
			42	0.83	20.7	603.5
			63	0.83	21.0	605.1

[a] Gravimetric moisture content calculated by dividing the water mass by the dry soil,mass, in this case 500 g of dry soil.

[b] A large increase in moisture levels between 0 and 21 days indicates water was added immediately after the moisture at 0 days was determined.

Appendix 1. Moisture levels during laboratory N mineralization incubations 2006 (continued).

Farm	Master ID	Season of soil collection	Time frame of experiment	Total solids	Gravimetric moisture content[a]	Estimated dry soil + water content[b]
			days		%	g
6	JM180	spring	0	0.79	26.2	631.1
			28	0.80	24.3	621.3
			42	0.80	24.3	621.3
			63	0.82	22.7	613.3
	JM181		0	0.79	26.4	632.1
			28	0.80	24.2	621.2
			42	0.81	23.2	616.0
			63	0.82	22.0	610.1
	JM182		0	0.82	22.3	611.4
			28	0.83	21.0	605.1
			42	0.84	19.3	596.6
			63	0.84	19.0	595.2
	JM407	summer	0	0.82	22.2	611.0
			21	0.81	24.2	621.0
			42	0.81	23.1	615.3
			63	0.82	21.8	609.2
	JM408		0	0.81	22.8	614.1
			21	0.79	26.8	634.2
			42	0.80	25.3	626.4
			63	0.80	24.2	621.2
	JM409		0	0.83	19.8	599.1
			21	0.81	23.9	619.7
			42	0.81	22.8	614.2
			63	0.82	22.2	611.0
	JM556a	fall	0	0.72	38.0	689.8
			21	0.72	38.5	692.4
			42	0.73	36.9	684.6
			63	0.72	38.0	694.4
	JM556b		0	0.72	38.0	689.9
			21	0.73	37.2	685.9
			42	0.73	36.8	684.1
			63	0.72	38.1	690.5
	JM556c		0	0.73	37.7	688.6
			21	0.72	38.2	691.0
			42	0.73	36.9	684.5
			63	0.72	38.0	690.1

[a] Gravimetric moisture content calculated by dividing the water mass by the dry soil,mass, in this case 500 g of dry soil.

[b] A large increase in moisture levels between 0 and 21 days indicates water was added immediately after the moisture at 0 days was determined.

Appendix 1. Moisture levels during laboratory N mineralization incubations 2006 (continued).

Farm	Master ID	Season of soil collection	Time frame of experiment	Total solids	Gravimetric moisture content[a]	Estimated dry soil + water content[b]
			days		%	g
7	JM174	spring	0	0.82	21.6	607.9
			28	0.84	19.5	597.6
			42	0.84	18.5	592.3
			63	0.85	17.6	588.0
	JM175		0	0.81	23.5	617.5
			28	0.84	19.3	596.4
			42	0.85	18.2	590.9
			63	0.85	17.1	585.4
	JM176		0	0.82	22.5	612.5
			28	0.83	19.8	598.9
			42	0.84	18.9	594.6
			63	0.86	16.9	584.4
	JM350	summer	0	0.83	21.2	605.9
			21	0.82	22.0	610.2
			42	0.84	19.7	598.7
			63	0.82	21.2	606.2
	JM351		0	0.81	23.9	619.6
			21	0.80	24.9	624.7
			42	0.82	22.1	610.6
			63	0.80	24.3	621.6
	JM352		0	0.83	20.4	602.2
			21	0.80	25.1	625.6
			42	0.81	23.3	616.5
			63	0.80	25.0	624.8
	JM557a	fall	0	0.84	19.6	598.0
			21	0.83	20.9	604.7
			42	0.83	20.4	602.1
			63	0.83	20.7	603.5
	JM557b		0	0.82	21.6	608.0
			21	0.82	22.0	609.9
			42	0.82	21.7	608.4
			63	0.82	21.9	609.4
	JM557c		0	0.84	19.3	596.6
			21	0.83	20.5	602.4
			42	0.83	20.2	600.8
			63	0.83	20.8	603.8

[a] Gravimetric moisture content calculated by dividing the water mass by the dry soil,mass, in this case 500 g of dry soil.

[b] A large increase in moisture levels between 0 and 21 days indicates water was added immediately after the moisture at 0 days was determined.

Appendix 1. Moisture levels during laboratory N mineralization incubations 2006 (continued).

Farm	Master ID	Season of soil collection	Time frame of experiment	Total solids	Gravimetric moisture content[a]	Estimated dry soil + water content[b]
			days		%	g
8	JM168	spring	0	0.83	19.9	599.5
			21	0.84	19.2	595.9
			42	0.85	17.3	586.5
			63	0.83	21.0	605.2
	JM169		0	0.83	20.9	604.3
			21	0.83	20.6	603.1
			42	0.85	17.6	587.8
			63	0.83	20.4	601.9
	JM170		0	0.80	24.4	622.1
			21	0.82	21.4	606.9
			42	0.84	19.2	596.1
			63	0.82	21.5	607.4
	JM353	summer	0	0.88	13.4	567.2
			21	0.81	23.7	618.5
			42	0.82	21.3	606.7
			63	0.81	23.2	616.1
	JM354		0	0.89	12.4	561.9
			21	0.81	24.2	621.0
			42	0.82	21.5	607.4
			63	0.80	24.3	621.4
	JM355		0	0.89	11.8	559.2
			21	0.80	24.3	621.7
			42	0.82	21.2	606.1
			63	0.81	23.5	617.4
	JM558a	fall	0	0.86	16.2	581.2
			21	0.84	19.6	598.0
			42	0.84	19.4	596.8
			63	0.84	19.7	598.7
	JM558b		0	0.86	15.7	578.6
			21	0.83	20.0	599.9
			42	0.84	19.7	598.6
			63	0.84	19.5	597.6
	JM558c		0	0.85	18.1	590.5
			21	0.83	20.5	602.5
			42	0.83	19.8	598.9
			63	0.83	20.5	602.3

[a] Gravimetric moisture content calculated by dividing the water mass by the dry soil,mass, in this case 500 g of dry soil.

[b] A large increase in moisture levels between 0 and 21 days indicates water was added immediately after the moisture at 0 days was determined.

Appendix 1. Moisture levels during laboratory N mineralization incubations 2006 (continued).

Farm	Master ID	Season of soil collection	Time frame of experiment	Total solids	Gravimetric moisture content[a]	Estimated dry soil + water content[b]
			days		%	g
9	JM171	spring	0	0.83	20.3	601.5
			28	0.84	19.0	595.2
			42	0.85	18.1	590.6
			63	0.85	17.8	589.1
	JM172		0	0.84	18.9	594.4
			28	0.86	16.9	584.7
			42	0.85	17.0	584.9
			63	0.86	16.3	581.4
	JM173		0	0.83	20.8	603.9
			28	0.84	18.8	594.1
			42	0.84	18.7	593.5
			63	0.84	18.5	592.3
	JM445	summer	0	0.92	9.2	545.8
			21	0.81	23.3	616.5
			42	0.82	22.2	610.9
			63	0.82	21.8	608.9
	JM446		0	0.93	7.4	537.0
			21	0.82	21.7	608.5
			42	0.83	20.7	603.6
			63	0.83	20.2	600.9
	JM447		0	0.93	7.9	539.3
			21	0.80	24.7	623.5
			42	0.81	23.4	616.9
			63	0.81	23.4	616.9
	JM559a	fall	0	0.83	20.3	601.5
			21	0.83	20.7	603.3
			42	0.83	20.9	604.3
			63	0.83	20.6	602.8
	JM559b		0	0.84	19.3	596.3
			21	0.83	20.3	601.6
			42	0.83	20.9	604.7
			63	0.83	20.6	602.9
	JM559c		0	0.84	19.4	596.9
			21	0.83	20.9	604.3
			42	0.83	20.4	601.8
			63	0.83	20.5	602.4

[a] Gravimetric moisture content calculated by dividing the water mass by the dry soil,mass, in this case 500 g of dry soil.

[b] A large increase in moisture levels between 0 and 21 days indicates water was added immediately after the moisture at 0 days was determined.

Appendix 1. Moisture levels during laboratory N mineralization incubations 2006 (continued).

Farm	Master ID	Season of soil collection	Time frame of experiment	Total solids	Gravimetric moisture content[a]	Estimated dry soil + water content[b]
			days		%	g
10	JM159	spring	0	0.78	27.8	639.2
			21	0.79	26.9	634.5
			42	0.80	25.2	625.9
			63	0.79	27.4	636.8
	JM160		0	0.77	29.5	647.5
			21	0.78	28.3	641.4
			42	0.80	25.5	627.5
			63	0.78	28.3	641.5
	JM161		0	0.78	28.6	643.0
			21	0.78	27.6	637.8
			42	0.80	25.5	627.4
			63	0.81	24.1	620.5
	JM359	summer	0	0.83	20.6	602.8
			21	0.80	25.1	625.6
			42	0.82	22.2	610.8
			63	0.80	24.8	623.9
	JM360		0	0.84	18.5	592.7
			21	0.80	25.7	628.6
			42	0.82	22.6	612.9
			63	0.80	24.9	624.5
	JM361		0	0.84	19.6	597.9
			21	0.75	32.9	664.7
			42	0.82	22.5	612.4
			63	0.80	24.9	624.4
	JM560a	fall	0	0.85	18.1	590.6
			21	0.82	21.6	608.2
			42	0.83	20.3	601.3
			63	0.83	21.1	605.3
	JM560b		0	0.85	17.9	589.7
			21	0.83	20.3	601.4
			42	0.83	20.6	602.9
			63	0.83	20.4	601.9
	JM560c		0	0.85	17.8	589.1
			21	0.82	21.4	607.0
			42	0.83	20.6	602.8
			63	0.83	20.8	603.9

[a] Gravimetric moisture content calculated by dividing the water mass by the dry soil,mass, in this case 500 g of dry soil.

[b] A large increase in moisture levels between 0 and 21 days indicates water was added immediately after the moisture at 0 days was determined.

Appendix 1. Moisture levels during laboratory N mineralization incubations 2006 (continued).

Farm	Master ID	Season of soil collection	Time frame of experiment	Total solids	Gravimetric moisture content[a]	Estimated dry soil + water content[b]
			days		%	g
11	JM177	spring	0	0.73	36.5	682.7
			28	0.75	32.7	663.6
			42	0.76	31.8	659.2
			63	0.77	30.3	651.4
	JM178		0	0.69	44.3	721.7
			28	0.71	41.5	707.5
			42	0.71	40.4	701.8
			63	0.72	39.2	696.1
	JM179		0	0.68	46.3	731.3
			28	0.70	43.6	717.9
			42	0.71	41.7	708.6
			63	0.71	40.1	700.4
	JM356	summer	0	0.78	29.0	644.8
			21	0.77	30.2	650.8
			42	0.79	26.5	632.6
			63	0.77	29.3	646.6
	JM357		0	0.75	32.5	662.7
			21	0.79	26.0	629.8
			42	0.77	29.7	648.5
			63	0.75	32.7	663.4
	JM358		0	0.74	35.9	679.6
			21	0.73	37.5	687.3
			42	0.76	32.3	661.6
			63	0.73	36.1	680.7
	JM561a	fall	0	0.80	24.3	621.3
			21	0.80	24.5	622.7
			42	0.81	24.2	620.9
			63	0.80	24.4	622.2
	JM561b		0	0.80	24.8	623.8
			21	0.80	24.7	623.5
			42	0.80	24.2	621.2
			63	0.80	24.3	621.7
	JM561c		0	0.80	25.6	628.1
			21	0.80	24.9	624.5
			42	0.81	24.1	620.4
			63	0.80	24.2	621.1

[a] Gravimetric moisture content calculated by dividing the water mass by the dry soil,mass, in this case 500 g of dry soil.

[b] A large increase in moisture levels between 0 and 21 days indicates water was added immediately after the moisture at 0 days was determined.

Appendix 1. Moisture levels during laboratory N mineralization incubations 2006 (continued).

Farm	Master ID	Season of soil collection	Time frame of experiment	Total solids	Gravimetric moisture content[a]	Estimated dry soil + water content[b]
			days		%	g
12	JM448	summer	0	0.94	6.5	532.3
			21	0.83	20.4	602.0
			42	0.83	20.0	600.1
			63	0.84	19.2	596.0
	JM449		0	0.92	8.3	541.6
			21	0.82	21.7	608.3
			42	0.84	19.7	598.4
			63	0.83	20.0	600.0
	JM450		0	0.92	9.0	544.9
			21	0.82	22.5	612.5
			42	0.83	19.9	599.6
			63	0.84	19.1	595.6
	JM562a	fall	0	0.85	17.4	586.9
			21	0.85	18.3	591.6
			42	0.84	18.6	593.1
			63	0.85	18.3	591.7
	JM562b		0	0.86	16.7	583.6
			21	0.84	18.4	591.8
			42	0.85	17.3	586.4
			63	0.85	17.5	587.5
	JM562c		0	0.86	16.7	583.5
			21	0.84	18.9	594.4
			42	0.85	18.1	590.3
			63	0.85	17.7	588.5

[a] Gravimetric moisture content calculated by dividing the water mass by the dry soil,mass, in this case 500 g of dry soil.

[b] A large increase in moisture levels between 0 and 21 days indicates water was added immediately after the moisture at 0 days was determined.

Appendix 2. Farm 1 compost analysis from 2006 collected samples.

Measurement	Units	Horse manure and broiler litter	Rabbit manure	Horse manure	Broiler litter
C	%	23.6	20.5	16.8	26.1
N	%	0.90	2.07	1.53	3.00
C:N ratio		26	10	11	9
P	%	0.35	1.26	0.57	2.07
K	%	0.74	2.59	1.25	2.76
S	%	0.12	0.45	0.21	0.59
Ca	%	0.73	2.55	2.02	3.51
Mg	%	0.50	1.36	0.78	0.74
Mn	ppm	618	862	1042	950
Cu	ppm	94	792	188	1004
B	ppm	12	57	25	51
Zn	ppm	127	383	199	622
Fe	ppm	22138	18690	21952	6393
Soluble salts	ms/cm	2.7	36.4	17.9	30.1

Appendix 3. Nitrate-N accumulation in laboratory incubation for 63 days at 22°C, 2005 summer soil samples.

Farm[a]			Days				Net N mineralization[b]	Net N mineralization rate[c]	
			0	21	42	63			
			mg kg^{-1}				mg kg^{-1}	mg kg^{-1} day^{-1}	mg kg^{-1} DD^{-1}
1	GTF	JM08	17	31	60	54	37	0.6	0.027
	First year on this soil for crops, previously in hay for about 40 years or so.								
1	GTF	JM09	3	3	8	13	10	0.2	0.007
	From hay field that has not yet been put into veggie production								
1	GTF	JM10	29	54	92	93	63	1.0	0.046
	Denny’s field, rented plot about an acre, described as one of their oldest growing spots and most productive								
10	SH	JM13	5	20	32	29	23	0.4	0.017
	Already harvested potato field, this was the second season of growing on this field, city compost and chicken manure added, limed as well								
10	SH	JM14	38	62	71	64	26	0.4	0.019
	Sample from a main field that has been in organic production for 16 years, freshly tilled following crop harvest								
11	WG	JM19	8	28	46	41	33	0.5	0.024
	Potato field in its 3rd year of 5 year rotation, next year it will return to pasture for two years to finish the rotation								
11	WG	JM20	6	18	42	38	32	0.5	0.023
	Pasture field currently in the pasture management of vegetable rotation, which is 3 years of veggies then 2 years of pasture								

[a] Samples collected between 21 July and 25 July 2005.

[b] Starting value was subtracted from 63 d value (Eq. 2)

[c] Rate was assumed to be linear, net mineralization at 63 d was divided by number of days or thermal units during incubation (Eq. 3).

Appendix 3. Nitrate-N accumulation in laboratory incubation for 63 days at 22°C, 2005 summer soil samples (continued).

Farm[a]			Days				Net N mineralization[b]	Net N mineralization rate[c]	
			0	21	42	63			
			mg kg^{-1}				mg kg^{-1}	mg kg^{-1} day^{-1}	mg kg^{-1} DD^{-1}
13	Den	JM11	31	53	76	66	35	0.6	0.025
	Potatoes field, old farmland, about 100 years of continuous production, organic for the last 15 years, sampled after the harvest								
13	Den	JM12	24	34	52	39	16	0.3	0.011
	Potato field on rented land right next to Springhill Farm rented land, potatoes on drip, a late planting, no flowering yet								
14	GWO	JM15	16	26	40	40	24	0.4	0.017
	First year in crops, previously in grass seed or hay, potatoes in ground on drip irrigation, "horse ranch field 3"								
14	GWO	JM16	18	27	51	38	20	0.3	0.014
	First year field on rented land, in sweet potatoes and winter squash now, potatoes maybe next year, "basketball ridge"								
14	GWO	JM17	8	16	39	33	26	0.4	0.019
	Longest field in production 5 or 6 years, currently in potatoes, many potatoes dead of some disease								
15	CG	JM18	40	72	122	88	49	0.8	0.035
	Older, typical field, many various veggies growing								
15	CG	JM21	9	19	57	46	37	0.6	0.027
	Rented field off Allison road just past Wintergreen Farm, currently in squash but part of a rotation including pastured poultry								
median			18	27	52	40	26	0.4	0.019

[a] Samples collected between 21 July and 25 July 2005.

[b] Starting value was subtracted from 63 d value (Eq. 2)

[c] Rate was assumed to be linear, net mineralization at 63 d was divided by number of days or thermal units during incubation (Eq. 3).

Appendix 4. Nitrate-N accumulation in laboratory incubation for 63 days at 22°C, 2005 fall soil samples.

Farm[a]			Days				Net N mineralization[b]	Net N mineralization rate[c]	
			0	21	42	63			
			mg kg^{-1}				mg kg^{-1}	mg kg^{-1} day^{-1}	mg kg^{-1} DD^{-1}
1	GTF	JM83	9	40	58	75	66	1.0	0.047
	Lettuce bed approx. 50 days after planting being harvested, compost added at planting								
1	GTF	JM84	15	40	57	77	61	1.0	0.044
	Swiss chard approx. 50-60 days old								
1	GTF	JM85	4	27	52	75	71	1.1	0.051
	Delicata squash bed, near end of production, compost added at time of sping planting only, 90-100 days old								
1	GTF	JM86	7	26	39	60	53	0.8	0.038
	Delicata squash bed, near end of production, compost added at time of sping planting only, 90-100 days old								
11	WG	JM79	11	45	68	94	83	1.3	0.060
	Potato field being harvested at time of collection								
11	WG	JM80	9	31	55	76	67	1.1	0.048
	Potato field being harvested at time of collection								

[a] Samples collected between 21 September and 22 September 2005.

[b] Starting value was subtracted from 63 d value (Eq. 2)

[c] Rate was assumed to be linear, net mineralization at 63 d was divided by number of days or thermal units during incubation (Eq. 3).

Appendix 4. Nitrate-N accumulation in laboratory incubation for 63 days at 22°C, 2005 fall soil samples (continued).

Farm[a]			Days				Net N mineralization[b]	Net N mineralization rate[c]	
			0	21	42	63			
			mg kg^{-1}				mg kg^{-1}	mg kg^{-1} day^{-1}	mg kg^{-1} DD^{-1}
13	Den	JM87	1	22	40	57	55	0.9	0.040
	Broccoli beds, at end of production, on west end of field, fertilizer consisted of 9000 lbs/ac. wet chicken manure, 750 lbs/ac. lime, 1500 lbs/ac. gypsum								
13	Den	JM88	1	20	39	52	51	0.8	0.037
	Broccoli beds, at end of production, on west end of field, fertilizer consisted of 9000 lbs/ac. wet chicken manure, 750 lbs/ac. lime, 1500 lbs/ac. gypsum								
13	Den	JM89	5	31	53	72	67	1.1	0.048
	Lettuce field, at end of production, some heads setting seed								
13	Den	JM90	4	25	41	55	52	0.8	0.037
	Lettuce field, at end of production, some heads setting seed								
13	Den	JM91	7	23	18	19	12	0.2	0.009
	Same potato field as previous sampling date, harvesting completed 2 days prior to sampling								
13	Den	JM92	4	19	32	38	34	0.5	0.024
	Same potato field as previous sampling date, will be harvested within the week								

[a] Samples collected between 21 September and 22 September 2005.

[b] Starting value was subtracted from 63 d value (Eq. 2)

[c] Rate was assumed to be linear, net mineralization at 63 d was divided by number of days or thermal units during incubation (Eq. 3).

Appendix 4. Nitrate-N accumulation in laboratory incubation for 63 days at 22°C, 2005 fall soil samples (continued).

Farm[a]			Days				Net N mineralization[b]	Net N mineralization rate[c]	
			0	21	42	63			
			mg kg^{-1}				mg kg^{-1}	mg kg^{-1} day^{-1}	mg kg^{-1} DD^{-1}
14	GWO	JM71	17	45	61	69	52	0.8	0.037
	Potato field in the process of being harvested, same site as sampled before								
14	GWO	JM72	5	22	34	44	39	0.6	0.028
	Potato field in the process of being harvested, same site as sampled before								
14	GWO	JM73	16	49	75	87	71	1.1	0.051
	Mixed veggie field, brassica spp, 18" high, no curds visable (if cauliflower)								
14	GWO	JM74	21	51	80	97	75	1.2	0.054
	Mixed veggie field, dinosaur kale 18" high								
14	GWO	JM75	9	36	65	86	78	1.2	0.056
	Raddichio bed, near the end of its production								
14	GWO	JM76	148	176	215	237	88	1.4	0.064
	Mature spinach bed								

[a] Samples collected between 21 September and 22 September 2005.

[b] Starting value was subtracted from 63 d value (Eq. 2)

[c] Rate was assumed to be linear, net mineralization at 63 d was divided by number of days or thermal units during incubation (Eq. 3).

Appendix 4. Nitrate-N accumulation in laboratory incubation for 63 days at 22°C, 2005 fall soil samples (continued).

Farm[a]			Days				Net N mineralization[b]	Net N mineralization rate[c]	
			0	21	42	63			
				mg kg^{-1}			mg kg^{-1}	$\text{mg kg}^{-1}\ \text{day}^{-1}$	$\text{mg kg}^{-1}\ \text{DD}^{-1}$
15	CG	JM77	65	114	120	150	86	1.4	0.062
	Beans near the end of production								
15	CG	JM78	25	63	82	107	81	1.3	0.059
	Beans near the end of production								
15	CG	JM81	2	27	45	63	61	1.0	0.044
	Allison Rd., same field as previous sampling date, arugula-like leaf plant, turnip maybe?								
15	CG	JM82	4	27	44	64	60	1.0	0.043
	Allison Rd., same field as previous sampling date, a large celery-like plant?								
median			15	45	63	85	71	1.1	0.051

[a] Samples collected between 21 September and 22 September 2005.

[b] Starting value was subtracted from 63 d value (Eq. 2)

[c] Rate was assumed to be linear, net mineralization at 63 d was divided by number of days or thermal units during incubation (Eq. 3).

Appendix 5. Levels of nitrate-N in stored post-harvest soil samples (depth = 30 cm). Samples stored at 4°C.

Farm	Sample Date	Extraction 1			Extraction 2	
		Date	NH_4	NO_3	Date	NO_3
1	30-Aug-2007	19-Oct-2006	1.3	36.4	16-Jan-2007	46.6
2	28-Aug-2007	19-Oct-2006	1.8	58.0	16-Jan-2007	74.6
3	30-Aug-2007	19-Oct-2006	0.9	26.1	16-Jan-2007	36.1
4	28-Aug-2007	19-Oct-2006	0.8	31.4	16-Jan-2007	41.5
5	31-Aug-2007	19-Oct-2006	3.5	19.0	16-Jan-2007	37.7
6		19-Oct-2006	1.0	51.1	16-Jan-2007	84.1
7	31-Aug-2007	19-Oct-2006	11.3	65.2	16-Jan-2007	92.1
8	31-Aug-2007	19-Oct-2006	0.8	39.4	16-Jan-2007	57.5
9		19-Oct-2006	1.6	6.6	16-Jan-2007	12.1
10	30-Aug-2007	19-Oct-2006	1.1	11.9	16-Jan-2007	19.4
11	31-Aug-2007	19-Oct-2006	0.6	14.9	16-Jan-2007	21.0
12		19-Oct-2006	0.4	13.3	16-Jan-2007	23.7

Appendix 6. Total solids and total N for shoots and tubers in zero-N plots 2006, means and SE.

Farm	DAP	Total solids shoots		Total solids tubers		Total N shoot		Total N tubers	
		%		%		%		%	
1	54	0.09	(0.004)	0.14	(0.004)	3.4	(0.11)	1.1	(0.03)
1	74	0.11	(0.006)	0.18	(0.005)	2.3	(0.08)	1.0	(0.07)
1	95	0.13	(0.004)	0.22	(0.002)	1.8	(0.12)	0.9	(0.05)
2	65	0.13	(0.003)	0.16	(0.004)	4.2	(0.18)	1.8	(0.02)
2	86	0.13	(0.000)	0.20	(0.018)	3.5	(0.27)	1.2	(0.13)
2	107	0.17	(0.002)	0.25	(0.009)	2.7	(0.12)	1.1	(0.13)
3	64	0.15	(0.003)	0.21	(0.005)	2.0	(0.22)	1.1	(0.05)
3	85	0.12	(0.003)	0.15	(0.003)	4.7	(0.07)	1.8	(0.07)
3	106	0.12	(0.002)	0.17	(0.007)	3.2	(0.14)	1.2	(0.09)
4	41	0.06	(0.004)	0.00	(0.000)	0.0	(0.00)	0.0	(0.00)
4	62	0.08	(0.002)	0.14	(0.001)	3.6	(0.06)	1.5	(0.04)
4	82	0.12	(0.002)	0.20	(0.006)	2.5	(0.17)	1.0	(0.03)
4	103	0.10	(0.007)	0.22	(0.003)	2.0	(0.06)	0.9	(0.03)
6	84	0.10	(0.008)	0.13	(0.018)	5.2	(0.15)	2.3	(0.70)
6	105	0.13	(0.006)	0.15	(0.001)	4.1	(0.26)	1.9	(0.02)
6	126	0.14	(0.006)	0.17	(0.007)	3.9	(0.26)	1.9	(0.08)
10	43	0.10	(0.004)	0.10	(0.005)	2.7	(0.16)	1.6	(0.03)
10	63	0.12	(0.001)	0.18	(0.004)	2.5	(0.17)	1.0	(0.05)
10	84	0.13	(0.003)	0.20	(0.011)	1.9	(0.19)	1.0	(0.10)

Appendix 7. Total solids and total N for shoots and tubers from intensive farm plots 2006, means and SE.

Farm	DAP	Total solids shoots		Total solids tubers		Total N shoot		Total N tubers	
		%		%		%		%	
1	60	0.10	(0.003)	0.14	(0.024)	3.1	(0.19)	1.2	(0.06)
1	67	0.12	(0.002)	0.18	(0.011)	2.9	(0.03)	1.1	(0.04)
1	74	0.10	(0.003)	0.17	(0.006)	2.5	(0.17)	1.0	(0.06)
1	82	0.12	(0.002)	0.20	(0.005)	2.4	(0.17)	1.0	(0.06)
1	88	0.12	(0.006)	0.20	(0.010)	2.0	(0.20)	1.0	(0.06)
1	95	0.12	(0.005)	0.21	(0.005)	1.8	(0.07)	0.9	(0.05)
1	102	0.13	(0.004)	0.23	(0.007)	1.7	(0.19)	0.9	(0.05)
1	109	0.13	(0.002)	0.24	(0.013)	1.4	(0.07)	0.9	(0.04)
1	116	0.12	(0.001)	0.23	(0.002)	1.7	(0.33)	1.0	(0.03)
2	45	0.11	(0.003)	0.14	(0.007)	4.2	(0.15)	1.8	(0.14)
2	52	0.12	(0.002)	0.15	(0.004)	4.1	(0.13)	1.5	(0.03)
2	59	0.11	(0.001)	0.15	(0.005)	4.1	(0.09)	1.4	(0.11)
2	66	0.14	(0.005)	0.18	(0.007)	3.4	(0.33)	1.2	(0.01)
2	73	0.12	(0.003)	0.17	(0.002)	3.4	(0.52)	1.2	(0.08)
2	80	0.13	(0.002)	0.17	(0.004)	2.8	(0.13)	1.2	(0.03)
2	87	0.15	(0.005)	0.18	(0.005)	2.1	(0.19)	1.2	(0.02)
2	94	0.16	(0.002)	0.22	(0.006)	2.5	(0.18)	1.0	(0.02)
2	101	0.15	(0.004)	0.22	(0.012)	2.1	(0.07)	1.0	(0.02)
2	108	0.15	(0.000)	0.21	(0.004)	2.1	(0.29)	1.1	(0.03)
3	57	0.13	(0.011)	0.19	(0.006)	2.2	(0.20)	1.2	(0.11)
3	64	0.11	(0.002)	0.15	(0.008)	4.3	(0.36)	2.3	(0.16)
3	71	0.09	(0.003)	0.15	(0.003)	4.0	(0.05)	1.6	(0.09)
3	78	0.10	(0.003)	0.15	(0.003)	4.8	(0.52)	2.2	(0.35)
3	85	0.11	(0.007)	0.16	(0.016)	4.0	(0.76)	1.7	(0.38)
3	92	0.10	(0.001)	0.17	(0.005)	3.3	(0.13)	1.3	(0.08)
3	99	0.11	(0.005)	0.19	(0.007)	2.9	(0.52)	1.3	(0.17)
3	106	0.12	(0.002)	0.18	(0.004)	2.8	(0.06)	1.6	(0.33)