AN ABSTRACT OF THE THESIS OF

John Paul Gainer McQueen for the degree of Master of Science in Soil Science presented on July 24, 2007.
Title: Estimating the Dry Matter Production, Nitrogen Requirements, and Yield of Organic Farm-Grown Potatoes.

Abstract approved:

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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

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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

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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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