Chapter 12
Nitrogen Management in Organic Potato Production

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Abstract There is increasing interest in organic potato production in Canada, within a context of continuing strong growth rates for organic products globally. Using data from on-farm and station based trials, key characteristics of organic potato production in the Atlantic Canada region, notably the use of extended rotations involving leguminous crop green manures combined with organic amendments, low intensity of nitrogen and residual soil mineral N (RSMN) post harvest, and enhanced soil quality and health, are shown as sustainable outcomes of these systems. Data presented confirm nitrogen as the primary factor limiting total and marketable yields. Without additional N supplementation but following legume green manures (GMr) of red clover, or hairy vetch, potato yields and N uptake are shown to range from 30 to 35 Mg ha^{-1} and 100–125 kg N ha^{-1}, respectively, while RSMN remains low. Combining N supplementation (with composts or dehydrated manures) with GMr consistently increased total and marketable yield. The effect of N supply and GMr type on pest (wireworm, Colorado potato beetle) population dynamics is also examined. Finally, synchronizing N supply in these systems with crop demand remains challenging and the potential to use novel soil tests and plant bioassays to improve N management in organic production systems is also discussed.

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12.1 Introduction

Organic potato (*Solanum tuberosum* L.) production is characterized by extended rotations involving leguminous crop green manure (GMr) crops often combined with organic amendments (Lynch et al. 2008a, b). These are key elements of a sustainable approach to soil and nutrient management (Stark and Porter 2005). Losses due to insects and pest damage and overall low quality, typically reduce organic potato yields to an average of 50–75% that of conventional production (Pimentel 1993; Varis et al. 1996; Mattsson and Wallen 2003; VanDelden et al. 2003; Maggio et al. 2008). In addition, inconsistent nutrient availability and the complexity of nutrient management in these systems combined with yield uncertainty increases economic risk and may even promote post-harvest N losses through leaching (Van Delden 2001; De Neve et al. 2003; Stark and Porter 2005). At the same time, strong annual growth rates have continued for retail sales of organic food products over the past 20 years and globally organic cropping acreage is estimated at 30.4 million hectares (Willer 2008). In Atlantic Canada, premiums for organic table stock potatoes have often exceeded 100–200% of conventional market prices (PEIDAF, 2000). Popularized literature and guide books for organic potato production have become more recently available (Bostock 2008).

On commercial organic farms producing field crops in Canada potatoes are typically included in rotation with small grains (wheat, barley) and leguminous forage crops or GMr. For organic vegetable producers potatoes are often included in even more complex and longer term rotations (Bostock 2008). Weeds and topkilling are managed through mechanical means. Organic potato production in Atlantic Canada currently is primarily for the tablestock rather than the processing market and varieties are typically early to mid-season in maturity (70–110 days) (PEIDAF 2000; Bostock 2008). Potato late blight (*Phytophthora infestans*) remains particularly difficult to control under organic management as synthetic fungicides, with the exception of copper products, are not allowed (Canadian General Standards Board 2009b). The reduced efficacy of copper products and concern over their continued use has led to research efforts, as yet unsuccessful, to identify either acceptable resistant varieties (Speiser et al. 2006) or fungicides (Sturz et al. 2006). However, losses due to late blight in organic potato production systems may be overestimated and the use of earlier season and earlier tuber set varieties, combined with other agronomic strategies such as chitting (or seed tuber pre-sprouting) can be effective late blight 'escape strategies' which minimize losses (Finckh et al. 2006; Möller and Reents 2007). Möller et al (2007) concluded, following a survey and data collection from 220 organic potato fields in Germany, that N availability explained 73% of the observed variability in yield, and remains the most important yield limiting factor in organic potato production. Through our on-farm and research station studies conducted in Atlantic Canada over the past 6 years, and discussed in further detail below, we have also found this to be the case (Lynch et al. 2008a, b; Liu et al. 2008, 2010)

Nitrogen is critically important for canopy development, tuber initiation and yield of potato (Porter and Sisson 1991; Belanger et al. 2001). Insufficient N supply results in lower tuber yields and tuber size, while excess N can promote abundant haulm growth, delays tuber initiation and crop maturation, and reduces tuber yield and quality (Van Delden 2001; Finckh et al. 2006). In short season humid areas such as Atlantic Canada lengthening of the vegetative period and delay of tuberization can negatively enhance risk of losses to late blight, and promote excessive post-harvest mineral N losses to the environment (Lynch et al. 2008a, b; Sharifi et al. 2009). The N requirement of high yielding potatoes ranges from 2.5 to 5.9 kg N per Mg of yield (Munoz et al. 2005), although interestingly there is some suggestion that N use efficiency can be improved under low input or organic systems (Finckh et al. 2006; Möller et al. 2007) perhaps linked to improved light use efficiency when N is limiting (Van Delden 2001). In Germany, Möller et al. (2007) reported organic potato yields of 30 Mg ha^{-1} requiring 3.5-3.7 kg N Mg^{-1} (or 100–120 kg N ha^{-1}) compared to ranges closer to 4.0-6.0 kg N required per Mg^{-1} in conventional systems. However, soil and fertility management in organic systems is built around managing the complex processes of organic matter deposition and decomposition, thus managing N and synchronizing N availability with crop demand in organic potato production systems is correspondingly a challenge. The supply of N from organic amendments, crop residues plus residual soil mineral N to the crop varies with climatic conditions and among years (Sharifi et al. 2009; Zebarth et al. 2009).

Nitrogen availability and intensity may also have significant impacts with respect to potato insect pest dynamics (Alyokhin et al. 2005; Boiteau et al. 2008). With respect to defoliating insects, Colorado potato beetle (CPB) (*Leptinotarsa decemlineata* (Say)) is the most destructive insect pest in Canada and North America (Boiteau et al. 2008). Boiteau et al. (2008) found excessive rates (300 kg N ha^{-1}) of fertilization with Nutriwave (Envirem Organics Inc., Fredericton, New Brunswick), a 4-1-2 commercial pelletized organic fertilizer derived from poultry manure, promoted more rapid CPB larval development and earlier peaks of abundance of beetle larvae. The authors concluded, however, that as the influence of fertilizer on overall potato beetle populations was limited, fertility management would only have a secondary role in control of CPB. In Maine, Alyokhin et al. (2005) found CPB densities were higher on plots receiving full rates of synthetic fertilizers compared to those receiving reduced fertilizer rates combined with manure inputs. In addition to various agronomic strategies varying in effectiveness, this pest is commonly controlled in recent years in organic potato production in Canada by targeted use of foliar applications of Entrust (spinosad 80% (Dow Agrosciences, Indianapolis, Indiana)). Given this product's relatively high cost and broad spectrum activity it is typically used selectively in combination with crop scouting for CPB, and as border or perimeter sprays only (Bostock 2008). Wireworm (*Agriotes spp.*) damage from long term forage leys or pastures prior to potato planting can also reduce plant stands and /or reduce marketable yields as found by Lynch et al. (2008a,b) and Liu et al. (2010).

While the focus of the current study is on nitrogen supply in organic potato production, the importance of adequate P and K supply is often underestimated (Hagman et al. 2009). Srek et al. (2010) in the Czech Republic found that over a 53 year study soil available P (Mehlich III) concentrations below 30 mg kg^{-1} reduced tuber production. Indeed, across all organic production systems in Canada there is increasing evidence (Martin et al. 2007; Roberts et al. 2008; Knight et al. 2010) that soil phosphorus levels in particular may be becoming a critically important limitation to crop growth. Constraints with respect to P release efficacy of mined rock phosphates (Arcand et al. 2010) permitted under organic standards make this issue a further challenge. Livestock-based manure and compost sources, can in some cases, be in limited supply, and more novel organic amendments such as source separated municipal solid waste (MSW) (or 'green waste') composts may be an effective source of soil P (and N) supply to a range of crops including potatoes (Hargreaves et al. 2008; Passoni and Borin, 2009) and are discussed below. In contrast to phosphorus, potassium is much more easily supplied to meet organic potato crops needs through, in addition to manure, commercial inorganic amendments such as sulpomag, potassium sulphate or other soluble commercial sources (Lynch et al. 2008a, b, 2011; Bostock 2008; Canadian General Standards Board 2009b).

Finally, any study of productivity and nutrient dynamics in specific organic farming systems cannot be delinked from consideration of that system's sustainability, or ability to minimize environmental impacts while maintaining an economically viable production level (Hansen et al. 2001). In some jurisdictions, most notably Europe, product premiums, and consumer and government support for organic farming and its products partially reflect support for these perceived environmental benefits of organic farming systems (Lynch 2009). In Canada, as in other countries (Hansen et al. 2001), many of the key principals outlined in Canadian national standards for organic production (Canadian General Standards Board 2009a) and now enshrined in federal regulations, relate to goals associated with environmental benefits from these production systems. Environmental benefits with respect to energy use, soil quality, biodiversity and reduced off-farm nutrient impacts are closely linked to reliance on legume biological nitrogen fixation and organic matter inputs, reduced overall nutrient intensity, and increased spatial and temporal diversity associated with more complex rotations found on organic arable cropping farms (Lynch 2009, Griffiths et al. 2010; Lynch et al. 2011). In turn, these extended rotations within organic systems can enhance soil health and soil biological pools, which may contribute to soil N dynamics in these systems in ways not fully yet appreciated (Nelson et al. 2009).

While research on the topic is advancing, management of N within organic production systems remains challenging. This chapter will evaluate, primarily within the context of Atlantic Canada, how tuber yield, crop N recovery and residual soil nitrate within organic production systems are influenced by crop rotation, timing and type of green manures, and amendment with supplemental N sources (including manures, composts, and processed manure products). The potential to use soil tests to improve N management in organic production systems will also be evaluated. The effects of extended rotations and organic amendments on soil quality and soil health will also be discussed briefly.

12.2 Tuber Yield, Crop Apparent N Recovery and Residual Soil Mineral N as Affected by Rotation Design and Green Manure Type

In Atlantic Canada recommended base N requirements for conventional fertility management (i.e. from all sources) of tablestock varieties popular with organic producers such as 'Goldrush' are in the range of 190 kg N ha^{-1} (NBSCIA 2007). Earlier harvests reduce this requirement and yields by 10% or more. In general, organic potato yields in the range of 25–30 Mg ha^{-1} (or approximately 25% less than conventional) can be expected where N supplied to the crop from soil and GMr alone averages 100–130 kg N ha^{-1} from short or longer organic rotations (Sullivan et al. 2007; Liu et al. 2008; Lynch et al. 2008a, b; Maggio et al. 2008) and when pests such as wireworm (Lynch et al. 2008a, b) and late blight (Möller et al 2007) and other factors are not limiting or yield reducing. In Germany, Finckh et al. (2006) reported finding a supply of 110–130 kg N ha^{-1} supported a potential yield, under organic management, in the order of 35 Mg ha^{-1} while in Sweden, Hagman et al. (2009) reported yields of 35 Mg ha^{-1} obtained for some varieties as being high for Swedish organic production. On individual farms potential yields are affected by many factors, including environmental conditions or pest problems limiting GMr productivity (Schmidt et al. 1999) and decomposition, which may prevent farms from achieving these yield goals. Case studies of commercial organic potato farms in Ontario cited in Bostock (2008) indicated a wide range in farmer reported average yields where potatoes follow forage (typically alfalfa) of between 15 and 35 Mg ha^{-1}.

Choice of rotation design and GMr frequency and type are critical considerations for successful organic potato production. This is especially true for 'stockless' organic farming systems that are common (Bostock 2008; Schmidt et al. 1999). Total N content of a legume GMr precrop can be as high as 240 kg N ha^{-1} and GMr contribute to soil inorganic N and soil labile N pools. It must be noted also that benefits due to legume breaks in a rotation are partially due also to non-N effects such as reduction in pest incidence (Schmidt et al. 1999; Stark and Porter 2005). Schmidt et al. (1999) describes three 4-year organic potato rotations in Europe where red clover comprised 25% of the rotation phases. On commercial organic potato farms in Atlantic Canada rotations of 4–5 years duration including 2 years leguminous forage or GMr are not uncommon (Lynch et al. 2008a, b; Nelson et al. 2009). This is in contrast to much more frequent cropping of potatoes under conventional cropping practices (Angers et al. 1999). Few studies have examined mineralization of N from remaining GMr residues 2 years after incorporation, i.e. following the potato crop. While this will vary with environmental conditions and quality of GMr residue, Schmidt et al. (1999) reported utilization of GMr N by the crop following potato was small and in keeping with reported ranges of 3–15%. The effect of GMr length on potato productivity has received little attention also. In Sweden, Bath et al. 2006 found a 2-year grass-clover GMr (biomass of 107 kg N ha^{-1}), but not a 1-year GMr (biomass of only 36–44 kg N ha^{-1}) as the pre-crop increased organic potato yields. There is a need for more research to examine the net benefits to soil labile N pools of GMr of varying type and duration (1–2 years), within lengthened rotations where potatoes (and associated frequent soil disturbance) occurs less frequently, as found on organic farms (Stark and Porter 2005) . We report below in section 12.4 selected interim results from one such ongoing study at the Nova Scotia Agricultural College (NSAC) in Truro, Nova Scotia.

Practical handbooks and guides available to organic producers in Canada differ in expected N supplied from perennial forage or GMr incorporation prior to potatoes. An Ontario provincial guideline (Baute et al. 2002) suggests that plowdown of forage grass/legume stands containing 50% or more of legume content supplies 100 kg N/ha to the succeeding potato crop. In 6 years (2005–2011) of research trials on organic potato fertility in Atlantic Canada, we have typically obtained potato whole crop N recovery at topkilling (i.e. PNU_{0N}) of over 100 kg N ha^{-1} following fall plowing of a red clover (*Trifolium pratense*) GMr crop. Exceptions were during unseasonably dry conditions. In a study to examine productivity and N dynamics under extended rotation characteristic of production practices on commercial organic potato farms in Atlantic Canada, conducted in Prince Edward Island (PEI) and at an experimental site at NSAC, relatively high tuber yields (~30 Mg ha^{-1}) were achieved without supplemental N application, in 2 of 3 years when seasonal moisture levels were non-limiting. PNU_{0N} in un-amended soils, but following a red clover GMr, averaged 112 kg N ha^{-1} (Lynch et al. 2008a). In contrast, Sharifi et al. (2008), reporting on data from a 13 year University of Maine research trial in Presque Isle, Maine, found for PNU_{0N} a 1-year mixed alfalfa/timothy crop (within a 4 year potato-soybean-barley-alfalfa/timothy sequence) supplied only 99 kg N ha^{-1}. Background soil fertility undoubtedly also influences the degree of response to a leguminous GMr. Liu et al. (2008, 2010) conducted a four organic rotation study in Truro, Nova Scotia, where various farming systems (stockless, ruminant and monogastric) were reflected in choice of crop sequence (including 0, 1 or 2 years red clover forage) and amendment. While soil N supply in the potato year (year 4) increased by 15–22% with increasing forage frequency, limited PNU_{0N} differences (average 103 kg N ha^{-1}) among rotation treatments was attributed to the high soil fertility from a previous long term pasture at the experimental site. In PEI, Sanderson and MacLeod (1994) report a N replacement value (determined from tubers alone) of 53 kg N ha^{-1} following a late fall incorporated lupin (*Lupinus albus*) whole plant GMr and no other N source applied. That study was not managed organically, however.

Green manure options for organic producers are not limited to perennial leguminous forage crops (Munoz et al. 2005) and variability in PNU_{0N} response to a legume precrop may also be attributed to type and productivity of a GMr and timing (discussed below) of it's incorporation. In Italy, Campiglia et al. (2009) grew a range of overwintering cover crops before organic potatoes and produced remarkably high marketable yields of 48.5 Mg ha^{-1}matching that from N-P-K fertilizer following GMrs of subclover (*Trifolium subterraneum L.*) or hairy vetch (*Vicia villosa Roth.*), which produced 169 and 147 kg N ha^{-1} in aboveground biomass alone. Vetch as GMr is popular as an annual GMr for organic vegetable production in the eastern seaboard of the US and has been part of an organic systems trial comparing GMrs at NSAC over the past 5 years, and discussed below in section 12.4. Provincial guides to cover crops for organic production in Eastern Canada (OMAFA 2011a, b) and general organic potato production guides (Bostock 2008) suggest, in addition to perennials red clover or alfalfa (*Medicago sativa* L.), GMr such as hairy vetch, sweetclover (*Melilotus* spp.) and field peas (*Pisum sativum* L.).

Timing of N release from GMrs may not always synchronize with crop demand. In Maine USA, Porter et al. (1999) found that while a leguminous green manure (oats-pea-vetch mixture), compared to oats, increased soil nitrate levels throughout the season and late season haulm growth, this was not reflected in a yield benefit, as treatments in that study also received N fertilizer (at 134–202 kg N ha^{-1}). In Michigan, USA, Griffin and Hesterman (1991) reported on use of GMrs of alfalfa, clover, sweetclover, hairy vetch or birdsfoot trefoil in short (2-year) rotations with potatoes conventionally grown and fertilized with N at 0–225 kg N ha^{-1}. PNU_{0N} was increased by 75–145% by these GMrs which contained as much as 165–230 kg biomass N ha^{-1}. The lack of total and marketable yields response, however, was attributed to a poor synchrony of GMr-N release and potato N demand. In PEI, Sanderson and MacLeod (1994) attributed their finding that N from lupin GMr contributed more to late season N uptake , but not yield, and was partly due to their use of an indeterminate variety, Russet Burbank, compared to the determinate varieties ('Shepody' and 'Atlantic') used by Griffin and Hesterman (1991). As noted by Möller and Reents (2007) selection of an appropriate potato variety is a key agronomic strategy to take advantage of N status and avoid late blight under organic production.

In eastern Canada an increasing acreage of agricultural soils over the past 20 yr has been classified as at high risk of being a source of nitrate losses to water (de Jong et al. 2007). In humid regions of Atlantic Canada, most leaching losses of nitrates from agricultural soil occur between growing seasons and in major conventional potato growing areas such as PEI, losses of nitrates to groundwater is currently a major concern (Lynch 2009). Residual soil mineral N (RSMN) after harvest of conventionally managed potatoes of up to 110 kg NO_3-N ha^{-1} are not unknown globally (VanDelden et al. 2003) but regionally have averaged closer to 60 kg NO_3-N ha^{-1} under conventional management. In organic systems, optimizing management of GMr to synchronize with crop demand and prevent excessive N release and loss from the systems is a continuing challenge for organic systems, particularly in humid regions (Pimentel et al. 2005; Lynch 2009). In studies conducted on commercial organic potato farms in PEI and New Brunswick (Lynch et al. 2008a,b), much lower RSMN (<25 kg NO_3-N ha^{-1}) in the soil following organic potato harvest was found than for more intensive conventional potato systems in the region (Zebarth et al. 2003; de Jong et al. 2008). While some of these organic farms are mixed livestock and cropping operations, it should be noted that manure is often in limited supply.

Hansen et al. (2001) in Europe attributed the reduced nitrate leaching from organic farming systems in general, (in the range of 8 to 34 kg N ha^{-1} yr^{-1}), including arable cropping systems, to be partially due to the greater use of catch crops in fall and winter under organic management. In the short, cool, humid growing season of Atlantic Canada, there is a limited post-harvest window after a potato crop in which a catch crop can rapidly produce the extensive root system required to reduce RSMN and prevent leaching.

Finally, GMrs and extended rotations used in organic production can contribute not only to maintenance of soil organic matter and turnover of labile pools of crop residue, but also promote soil health and associated biological activity in soil. In a study conducted on four commercial potato farms in Atlantic Canada over 2 years, Nelson et al. (2009) found microbial quotient (microbial biomass as a fraction of total organic carbon (TOC)) and earthworm abundance and biomass increased continuously during the 5 year forage legume green manure-grain-potato rotation at

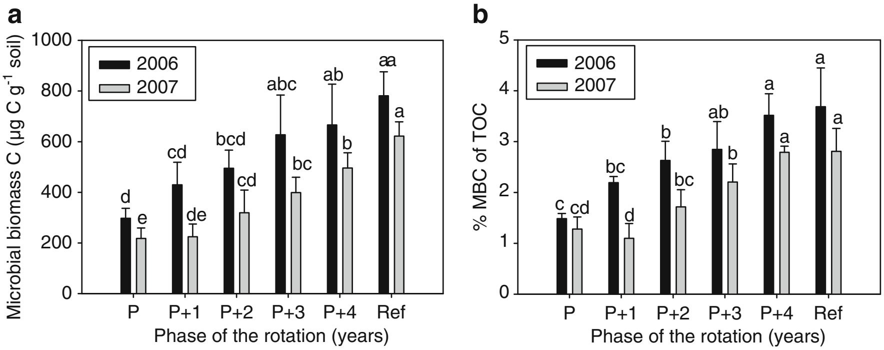

Fig. 12.1 Microbial biomass C amount (**a**) and microbial quotient (**b**) for each phase of 5-year organic potato rotations and adjacent undisturbed reference fields for years 2006 and 2007. Values are means of n = 4 sites. Error bars represent standard error of the means and treatments sharing the same letter are not significantly different according to Fisher's LSD at $p < 0.05$. P, P + 1, P + 2, P + 3, P + 4 and ref refer to potato phase, 1 year after potato, 2 years after potato, 3 years after potato, 4 years after potato and reference field. Reprinted from Agriculture, Ecosystems and Environment, 131, Nelson, KL, Lynch, DH and Boiteau, G, Assessment of changes in soil health throughout organic potato rotation sequences, 220–228, 2009, with permission from Elsevier

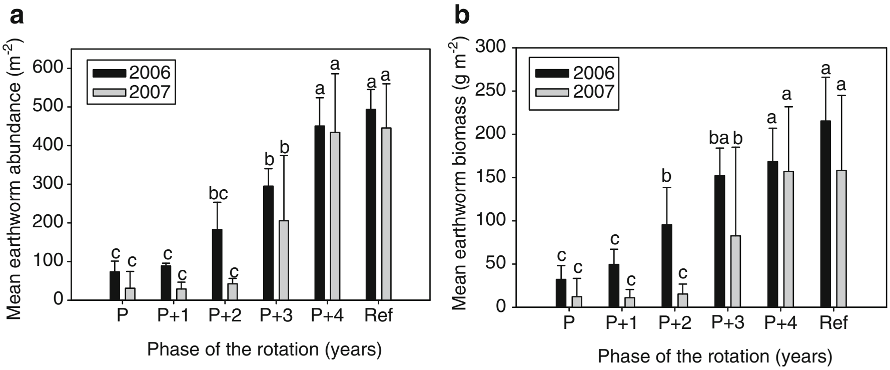

Fig. 12.2 Earthworm abundance (**a**) and biomass (**b**) for each phase of 5-year organic potato rotations and adjacent undisturbed reference fields for 2006 and 2007. Values are means of n = 4 sites. Error bars represent standard error of the means and treatments sharing the same letter are not significantly different according to Fisher's LSD at $p < 0.05$. P, P + 1, P + 2, P + 3, P + 4 and ref refer to potato phase, 1 year after potato, 2 years after potato, 3 years after potato, 4 years after potato and reference field. Reprinted from Agriculture, Ecosystems and Environment, 131, Nelson, KL, Lynch, DH and Boiteau, G, Assessment of changes in soil health throughout organic potato rotation sequences, 220–228, 2009, with permission from Elsevier

each site (Figs. 12.1a,b and 12.2a,b). Microbial quotient and earthworm abundance recovered to levels (3–4% of TOC and 400–500 m^2, respectively) found in adjacent undisturbed (pasture) fields and was greatest immediately prior to potato planting at all sites. How this enhanced biological activity and turnover specifically contributes to N (and P) dynamics in these rotations remains largely unexplored.

12.3 Tuber Yield, Crop Apparent N Recovery and Soil Mineral N as Affected by Timing of Green Manure Incorporation

With some exceptions, fall incorporation of legumes is standard practice in conventional and organic potato rotations in Atlantic Canada, in order to prepare an adequate seed bed for subsequent potato planting (Sanderson et al. 1999). Soil conditions on some organic farms, however, or type of GMr, can allow for spring rather than fall tillage. In Maine, Porter et al. (1999) found a GMr of oats-peas-hairy vetch could be left to overwinter before tillage prior to potatoes. As part of a larger study on N dynamics and GHG emissions in organic potato production at NSAC (Lynch et al. 2008b), we compared the effect of timing of tillage (spring vs fall) of a timothy or red clover (2 year stand) GMr, and potato N fertility regime (with or without added ammonium nitrate fertilizer N at 90 and 140 kg N ha^{-1} following red clover and timothy respectively, banded in the potato hill at planting) on yield and PNU_{0N}. Weed and pest management followed required organic certification protocols. Clover GMr dry matter production averaged 4.4 Mg ha^{-1}, while timothy forage DM yields increased with timothy N fertilization (120 kg N ha^{-1}) from 3.8 to 6.1 Mg ha^{-1}. Tuber yield and average size, and PNU_{0N} was greatest when forages were spring rather than fall plowed, and when supplemented with N fertilizer (Table 12.1). Total yields following clover consistently averaged in the 30–35 T ha^{-1} range and benefited less from added N supplementation. In unfertilized potato plots, PNU_{0N} increased from an average of 77.7 kg N ha^{-1} following timothy plowed in fall or spring to an average of 113.1 kg N ha^{-1} following clover and was highest (145.4 kg N ha^{-1}) for spring incorporated clover + N fertilizer. For both GMr, spring plowing increased PNU_{0N} by 20–30 kg N ha^{-1} suggesting overwinter losses of nitrate N occurred following fall plowing. However, Sanderson et al. (1999) in PEI, found spring incorporation of a 2 year red clover stand (with no additional N fertilization but otherwise under conventional management) only produced greater potato yields (47 Mg ha^{-1} compared

Table 12.1 Potato tuber dry matter yield plus tuber and whole plant N uptake as affected by type of green manure precrop, timing (fall vs spring) of green manure tillage, and supplemental fertilizer N applied to potato. Values are means (n = 4). Adapted from Lynch et al. 2008b

Potato fertilizer rate (kg N ha^{-1})	Previous crop	Forage tillage date	Tuber dry matter yield (Mg ha^{-1})	Tuber N uptake (kg N ha^{-1})	Whole plant N uptake (kg N ha^{-1})
0	Timothy	Spring	5.67[1]	69.2[1]	94.3[1]
140	Timothy	Spring	6.10	80.0	112.9
0	Timothy	Fall	4.70	47.0	61.1
140	Timothy	Fall	6.04	70.8	93.6
0	Clover	Spring	7.19	89.9	127.5
90	Clover	Spring	6.91	101.9	145.4
0	Clover	Fall	6.69	72.7	98.7
90	Clover	Fall	7.13	92.0	127.3

to 42–43 Mg ha^{-1}) than fall incorporation in one out of 3 years. Where fall incorporation of GMr is a necessity, delaying incorporation can reduce overwinter N losses. Sanderson and MacLeod (1994) in PEI, found late fall (October 1st) compared to early fall (September 1st) incorporation of a lupin GMr benefited subsequent potato tuber yield (35.1 vs 32.4 Mg ha^{-1}). This was due to greater N (190–265 kg N ha^{-1}) in lupin GMr biomass in late compared to early fall (160–250 kg N ha^{-1}) and that, as evidenced by enhanced fall and lower spring soil nitrate levels, earlier incorporation in the fall provided more opportunity for mineralization of GMr residue and subsequent overwinter losses. Sanderson et al. (1999) similarly found late fall (mid-October) compared to early fall (mid-September) tillage of red clover increased subsequent potato yields and reduced nitrate N in soil in late November following GMr incorporation. Petiole sampling was used as the index of potato crop N status and petiole nitrate-N generally increased as tillage of red clover was delayed.

12.4 Tuber Yield and Quality, Crop Apparent N Recovery and Soil Mineral N as Affected by Rotation Design and Use of Supplemental Organic Amendments

Organic potato production relies on well designed, extended rotations, ideally including 25% or more of leguminous GMr typically combined with some additions of manures and other organic amendments (Finckh et al. 2006; Lynch et al. 2008a). Möller et al. (2007) in Germany characterized, from among 220 organic potato fields, broad N fertility groupings of 'low' (precrop of cereals with manure applied at a maximum of 40 kg N ha^{-1}), 'intermediate' (precrop of pea or cereals with manure 40–100 kg N ha^{-1}) and 'high' (precrop of grass-clover or cereals and manure at or above 100 kg N ha^{-1}). Yield potential ranges from 20–25 Mg ha^{-1} ('low') to 30–40 Mg ha^{-1} ('high') compared with a range of 50–60 Mg ha^{-1} for conventional production. While laboratory analyses can provide some indication of the average potential nutrient contributions from manures and composts, the availability and timing of nutrient release from these materials in the field is highly variable and remains hard to predict (Stark and Porter 2005; Lynch et al. 2004; Zebarth et al. 2009). Routine use of manures for N supply in organic potato production also runs the risk of oversupply of P if manure is relied on as the primary N source (Lynch et al. 2004; Stark and Porter 2005). In an effort to improve potato yields and reduce P accumulation in organic farming systems, VanDelden et al. (2003) modeled N uptake, tuber yield and RSMN over 30 years as affected by (i) N:P ratio of the manure (pig (4.0) vs cattle (6.2)), (ii) time of manure (slurry) application, (iii) historical N use, and (iv) cultivar maturity. Manure application rates varied from 0 to 490 kg N ha^{-1}. The model indicated that when slurry is spring applied at the maximum rate (128 kg slurry N ha^{-1}) to avoid soil P accumulation (based on estimated crop export of 21 kg P ha^{-1}) potato yields would average 77% of that obtainable at the maximum slurry application rate (PNU_{0N} for unamended controls were estimated at 95 kg N ha^{-1}). As choosing a manure with a lower N:P reduced allowable application rates by a further one third, it was concluded leguminous crops would be needed in the rotation to avoid N limitations. While regional validation would be required, such studies provide useful tools for balancing N and P inputs in organic potato production systems using manure resources.

In Maine, USA, Porter et al. (1999) compared the effect of two GMrs (oats or oats-pea-vetch (OPV)) precrops, with or without amendment (beef or dairy manure vs. potato waste compost), or irrigation, on soil properties and yield and quality of 'Superior' potatoes. No interaction of amendments with GMr occurred but amendments increased yields by 4.0 to 8.6 Mg ha^{-1} across all rotations, although supplemental N fertilizer (at 134 to 202 kg N ha^{-1}) was also applied to all treatments. Similarly to GMr in rotation, organic amendments, through their effect on soil structure and organic matter, water holding capacity and root development have also been found to benefit potato yields and yield stability though 'non-nutrient' benefits as well as through direct nutrient effects. These benefits can persist for many years after a single amendment application (Opena and Porter 1999; Carter 2007; Mallory and Porter 2007). In contrast to GMr, organic amendments can also produce a substantial residual nutrient effect with substantial continued N mineralization after harvest (Mallory et al. 2010) and beyond the succeeding potato year, and these effects may mask rotation effects.

There is an increasing availability of commercially produced organic amendments approved for use in organic production, such as composts and dehydrated pelletized manures, which are changing options for producers and possibly the intensity of N use in organic potato production systems (Lynch et al. 2008a). Under certain strict quality control criteria with respect to potential contaminants, composts and byproducts from municipalities and industry may also be permitted within Canadian organic systems (Canadian General Standards Board 2009b). In Nova Scotia all municipalities are required to produce compost from food and yard waste source separated and collected from residences. The efficient use of all such sources of N in organic potato production is required to minimize negative impacts on water and air quality and increase the economic return on the crop.

Supplemental organic N sources with a substantial proportion of mineral or readily mineralizable N applied at planting or shortly after emergence can improve organic potato yields (VanDelden et al. 2003). Given current premiums for certified organic potatoes in Canada, improving yields through application of amendments supplying moderate rates of N or organic matter appears warranted. However, excessive N fertilization with organic amendments can result in excessive N supply, haulm growth and RSMN levels, delay tuber initiation and crop maturation, and reduces tuber yield and quality (Van Delden 2001; Neuhoff and Kopke 2002; Finckh et al. 2006; Möller et al. 2007; Lynch et al. 2008a). Delayed crop maturation also favours increased risk of infection with late blight (Finckh et al. 2006). Lynch et al. (2008a) examined, at two sites in Atlantic Canada (a commercial farm in Winslow, PEI, and a research site at NSAC in Nova Scotia), the impacts of contrasting organic amendments (compost and dehydrated poultry manure) on Shepody potato yield, quality and soil mineral nitrogen dynamics under organic management. Application of a commercial pelletized poultry manure product (NW; analyses 4-1-2; C:N ~9:1) at 300 kg total N ha^{-1} (broadcast applied at planting to supply an estimated 112 kg plant available N (PAN) ha^{-1}) promoted gains in yields (+ 5.8 Mg ha^{-1} average above ~30 Mg ha^{-1} for plots relying on GMr-N alone) and marketable yields (+ 7.0 Mg ha^{-1} average) of Shepody, but RSMN levels rose to 61 kg N ha^{-1} from 25 kg NO_3-N ha^{-1} for unamended and compost amended plots. At very higher rates of NW application (600 kg total N ha^{-1}), no yield response was obtained and excessive haulm growth and delayed senescence was clearly visible. While tuber number differed little between NW treatments average tuber size for the highest NW rate was much smaller than the unamended control as a result of delayed plant maturity and tuber fill (Möller et al. 2007). Tuber N uptake as a proportion of total plant at harvest also dropped from an average of 62% for the unamended treatments to 49%, and RSMN values rose to 141 kg NO_3-N ha^{-1} for the highest rate of NW. In Atlantic Canada, most leaching losses of NO_3-N occur between planting seasons, and such excessive levels of RSMN must be avoided. The moderate rates of manure N applied here falls within the range (0 to 350 kg manure N ha^{-1}) reported from a survey of 115 farms across seven European countries (Finckh et al. 2006). Similar data on on-farm manure availability on organic farms is not currently available in Eastern Canada.

Compost (hog manure and sawdust; C:N ~18:1) resulted in higher total yields than unamended treatments in one of three site-years. Apparent mineralized N and crop recovery of N from compost was negligible and yield benefits were attributed to factors other than N availability. The in-season dynamics of soil (0-30 cm) mineral N (NH_4 and NO_3), averaged across three site years and as affected by amendments, are shown in Fig. 12.3 (Sharifi et al. 2009). In the unamended control, apparent soil N mineralization over the growing season averaged 141 kg N ha^{-1} while NW treatments added an extra 115 and 195 kg N ha^{-1}. Much of the readily mineralizable N from NW was released within the first 10 days of application, with nitrification of the majority of this mineral N present as NH_4 by 31 days after planting. As discussed below, improved use of plant bioassays and soil tests to generate site specific information for organic producers on the N supplying ability of their rotations sequences and GMr management strategies will help refine the targeted use of supplementary organic N sources.

As noted above for the compost treatment, organic amendments, particularly when applied at moderate supplementary rates, do not always contribute to RSMN. Liu et al. (2010), in Nova Scotia, found N supply from two manure based composts (from beef or poultry) in the field was much lower than could be predicted from controlled environment mineralization studies and suggests this limits the effectiveness of composts as a means of addressing short term N deficiencies in potato based rotations. Lynch et al. (2004) suggests using the legume component of the rotation as a 'N buffer' to accommodate, through biological nitrogen fixation, this variability and low N supplying ability of composts when building a labile N pool for a succeeding crop such as potatoes of high N demand. Hargreaves et al. (2008) provides a review on use of MSW composts in agriculture. To provide a high input of inorganic N, studies have shown application rates have to be very high, i.e. 40–50 Mg compost ha^{-1}. In contrast significant increases in plant available P have been more consistently achieved with these composts. Fahmy et al. (2010) in New Brunswick

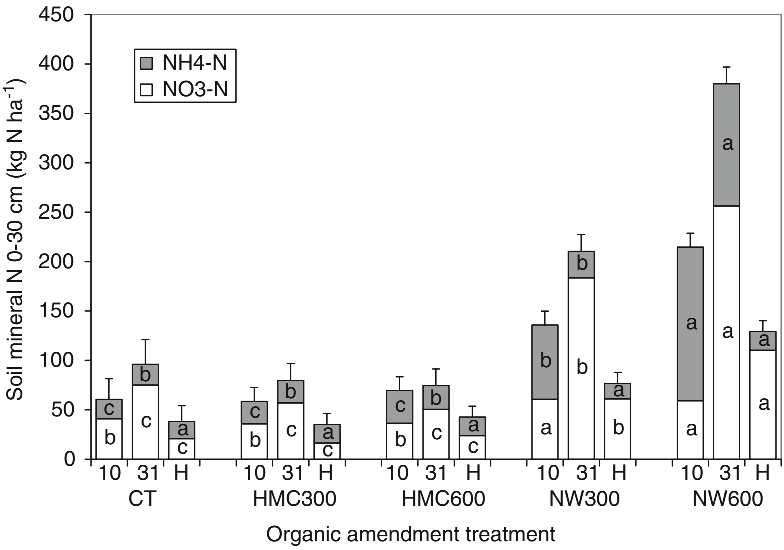

Fig. 12.3 Soil NH_4-N and NO_3-N at 10 days after planting (DAP), 31 DAP and harvest (H) as affected by organic amendment source (non-amended control (CT), hog manure-sawdust compost (HMC) and pelletized dehydrated poultry manure (NW)) and application rate (300 and 600 kg N ha^{-1}). The means comparison was done separately for each sampling date and for NO_3-N and NH_4-N. Values with the same letter are not significantly different at 0.05 probability level using Fisher's protected least significant difference test. Bars represent standard error for soil mineral N. Reprinted with permission from American Journal of Potato Research, 86, Sharifi et al., Evaluation of nitrogen supply rate measured by in situ placement of Plant Root Simulator™ probes as a predictor of nitrogen supply from soil and organic amendments in potato crop, 356–366, 2009

reported that composted pulp fibre residues was a good source of plant available P and K to potatoes.

In an organic cropping systems study commenced in 2006 at NSAC in Truro, the impact of GMr type and frequency in rotation, and with or without organic amendment or N fertilizer supplement, on potato yield and marketable yield, soil quality, soil N dynamics, greenhouse gas emissions and overwinter N losses are being evaluated. Interim (first 3 years until the first potato phase) data on crop and soil mineral N dynamics are presented here. The soil at the site is a Pugwash sandy loam classified as Orthic Humo-Ferric Podzols in Canadian soil classification (Webb et al. 1991). The experiment consists of a split-plot arrangement of treatments in a randomized complete block design with three replications. Main plots (i.e. rotation sequences) differed in green manure type (red clover vs. oats/pea/vetch mixture) and frequency (Table 12.2). Data is presented here for three sequences; (C1) ORC-RC (oats (*Avena sativa* L.) underseeded with red clover-red clover) (C3) carrots-OPV (carrots (*Daucus carota* subsp. sativus)- oats/pea /hairy vetch mixture); and (C4) BBu-OPV (beans (*Phaseolus lunatus* L.) followed by buckwheat (*Polygonum convolvulus* L.)- Oats/pea/vetch mixture). The experiment is partially phased such that three phases of each 5 year rotation sequence are present in each year.

Table 12.2 Five-year organic crop rotation sequences in the organic cropping systems study at NSAC, Truro, Nova Scotia. RC, solid stand (2nd year) of red clover as green manure; ORC, oats underseeded with red clover; OPV, oats/pea/vetch mixture as an annual green manure; BBu, yellow beans followed by buckwheat as green manure. Data from the potato crop phase produced after the first 3 years (2006–2008) of rotations C1, C3 and C4 are presented. (Lynch et al. unpublished)

	Year				
Rotation	1	2	3	4	5
C1	ORC	RC	Potato	ORC	Carrots
C2	ORC	RC	Potato	BBu	Carrots
C3	Carrots	OPV	Potato	ORC	BBu
C4	BBu	OPV	Potato	ORC	Carrots

Seeding rates for the rotation crops are 70 kg ha^{-1} for oats (variety(var.) AC Francis), 12 kg ha^{-1} for Red Clover (var. AC Christie), 3.20 kg ha^{-1} for carrots (var. Maverick), 60, 60, and 34 kg ha^{-1} for oats, pea (var. Mozart), and common vetch, respectively in oats/pea/vetch mixture, and 108.4 kg ha^{-1} for beans (var. Goldrush). The RC plots that were going to potatoes were moldboard plowed late in the previous fall. The OPV GMr was incorporated by mowing and discing late in the fall. Beans residues were disced and plowed in late July to early August, and buckwheat was seeded and allowed to grow until mid-October then incorporated.

Fertility treatments (applied in potato years only) comprise the subplots and include (i) a control (unamended), (ii) fertilized with mineral N and P at recommended rates based on soil test for P and regional N credits for leguminous green manures (FERT), (iii) source separated MSW compost (12 Mg ha^{-1} wet weight; dry weight = 60%) and (iv) composted paper mill biosolids (PMB) (30 Mg ha^{-1} wet weight; dry weight = 39%). Compost application rates were designed to provide the potato crop with a current-season average of 60 kg ha^{-1} of plant available P_2O_5 based on compost analyses and assuming 50% of total P is plant available in the year of application. The MSW compost is of higher quality, i.e. higher N content (2.1% vs 1.6%) and lower C:N (7.0 vs 14.3), than that of the PMB compost (Lynch et al. unpublished data). Composts thus also provided 82 kg total N ha^{-1} (MSW) and 121 kg total N ha^{-1} (PMB), respectively. Potato N and P needs in FERT subplots were met with 80 kg N ha^{-1} as ammonium nitrate and 60 kg P_2O_5 ha^{-1} as triple super phosphate fertilizer. The N rate was adjusted for a regional estimated N credit of 50 kg N ha^{-1} from legumes (Zebarth and Rosen 2007). Composts were broadcasted on subplots mid-May and hills and furrows were formed approximately 4 weeks after planting using a tool carrier. Nitrogen and P fertilizers were banded 5 cm below and 5 cm to the side of the seed pieces at planting in fertilized subplots. Potassium (K) was broadcasted each year on all experiment plots as Sulpomag (0-0-22) as required by soil test. Potatoes (cv. Goldrush) were planted by hand on June 6–9 using hand-cut seed pieces (≈50 ± 3 g each) in rows 83 cm apart, at 31 cm within-row spacing and at a depth of 5–10 cm. Weeds were controlled by cultivation and hand. Late blight and Colorado potato beetle were controlled with the application of copper hydroxide (Parasol) and Entrust®, respectively, as required. Potatoes were harvested on 25th September 2008. No supplemental irrigation was applied.

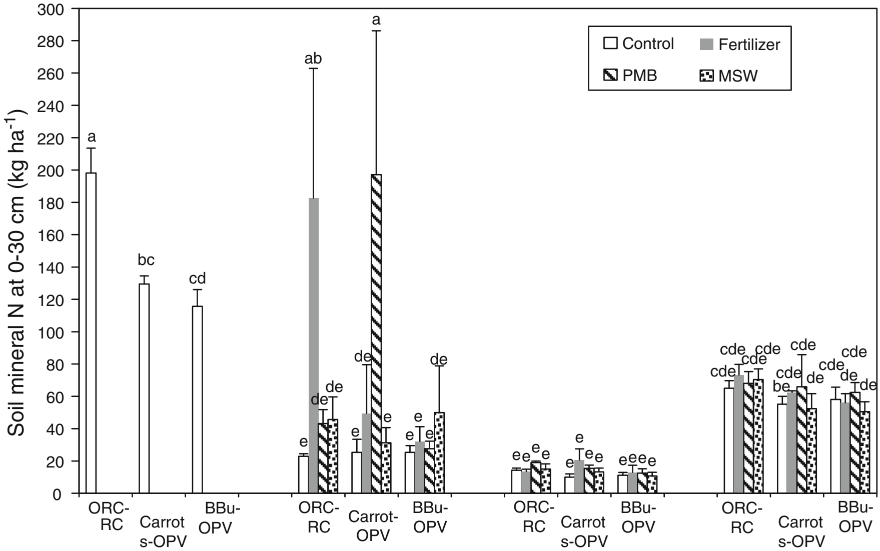

Fig. 12.4 Seasonal changes in soil mineral N as influenced by rotation sequences and fertility treatments (composts or inorganic N fertilizer) in 2008 (potato phase) of the organic cropping systems study at NSAC. Soil mineral N was measured at pre-plant, tuber initiation stage, tuber bulking stage and post-harvest in 2008. Error bars represent standard error of the means and treatments sharing the same letter are not significantly different according to Fisher's LSD at 0.05 probability level. MSW, source separated municipal food waste compost; PMB, paper mill biosolids compost; BBu, yellow beans followed by buckwheat as green manure; ORC, oats underseeded with red clover; OPV, oats/pea/vetch mixture as an annual green manure; RC, solid stand of red clover as green manure. (Lynch et al. unpublished)

Soil sampling was carried out prior to planting up to 45 cm (0–15 cm, 15–30 cm and 30–45 cm), at tuber initiation stage (~35 days after planting (DAP)) up to 15 cm, at tuber bulking stage (~80 DAP) up to 30 cm (0–15 cm and 15–30 cm) and at post-harvest up to 60 cm (0–15 cm, 15–30 cm and 30–60 cm).

Soil mineral N (SMN) dynamics are presented in Fig. 12.4. At planting, SMN for rotation C1 (198 kg NO_3-N ha^{-1}) was 62% ($P<0.05$) greater than C3 and C4 rotations, but SMN did not significantly differ between C3 and C4 (130 and 116 kg NO_3-N ha^{-1}, respectively). Ammonium N comprised less than 1 kg N ha^{-1}. Spring soil N supply rate measured *in-situ* by plant root simulator probes (PRS™) (Western Ag. Innovations Inc., Sakatoon, SK) ion exchange membranes was also 58% greater in C1 compared with C3 (data not shown). Rotation did not influence soil total organic C and N but a substantial proportion of total organic N (41%) was in the form of particulate (>53 µm) organic N of high quality (C:N of 6.0 to 8.3) which is highly sensitive to mineralization. The high SMN values at planting support the importance of GMrs as a source of N for organic potato crops in this region (Lynch 2009). At the tuber initiation stage, higher SMN was measured under FERT/C1 and under PMB/C4 in comparison with other treatments (Fig. 12.4). Overall, greater than a nine-fold decrease in SMN was measured for all amendments and fertility

Table 12.3 Potato total tuber yield, dry matter accumulation, specific gravity, and tuber size distribution as affected by amendment application and rotation crop during the first 3 years of a organic potato rotation study at NSAC, Truro, Nova Scotia. RC, solid stand (2nd year) of red clover as green manure; ORC, oats underseeded with red clover; OPV, oats/pea/vetch mixture as an annual green manure; BBu, yellow beans followed by buckwheat as green manure. PMB = paper mill biolsolids compost; MSW = source separated municipal food waste compost; Fertilizer = inorganic N and P fertilizer. Data from the potato crop phase produced after the first 3 years (2006–2008) of rotations C1, C3 and C4 are presented. (Lynch et al. unpublished)

		Tuber yield	Dry matter	Culls	Small	Canada #1	Jumbo	Wireworm
		Mg ha^{-1}				%		
Amendment ($n = 9$)								
Control		32.3b	24.9	4.8	24.1a	57.4	0.23	26.6
Fertilizer		39.8a	24.4	3.4	17.5b	64.3	0.66	20.6
PMB		33.2b	24.7	4.7	23.1a	56.0	0.00	28.8
MSW		34.9ab	25.2	3.7	19.8ab	60.9	0.16	26.3
Proceeding crop ($n = 12$)								
Oats/RCl-RCl		35.6	24.7	3.8	21.7	61.8	0.45	50.3a
Carrots-OPV		34.3	24.4	4.8	21.3	58.8	0.27	9.7b
Bean/Buckwheat-OPV		35.3	25.2	3.8	20.5	58.3	0.07	16.7b
Source of variation	df							
Block	2	NS	NS	NS	NS	***	NS	***
Proceeding crop (PC)	2	NS	NS	NS	NS	NS	NS	***
Amendment (A)	3	*	NS	NS	*	NS	NS	NS
A × PC	6	NS	NS	NS	NS	NS	NS	NS
EMS	22	NS	NS	NS	NS	NS	NS	NS
CV %	–	15	3	38	20	17	321	38

treatments from planting to tuber bulking. More than 80% of the decrease in SMN from planting to harvest (average 133 kg N ha^{-1}) can be attributed to plant N uptake (average 109 kg N ha^{-1}). Rotation affected PNU_{0N} and was greatest for C1 (124.4 kg N ha^{-1}) compared to C3 and C4 (106.2 and 99.7 kg N ha^{-1}, respectively). These values are within the range of PNU, of 100–120 kg N ha^{-1} obtained for fields of 'high' N input status among 220 commercial organic fields in Germany by Möller et al (2007). PNU increased to 149 kg N ha^{-1} under the FERT treatment (data not shown).

Yields did not differ by rotation (range 34.3 – 35.6 Mg ha^{-1}) but were influenced by amendment treatments (Table 12.3). Yields for the unamended control and PMB treatment were similar (average 32.5 Mg ha^{-1}) but were significantly lower than those obtained for MSW (34.9 Mg ha^{-1}) and FERT (39.8 Mg ha^{-1}) treatments. Tuber size distribution also benefited from these latter treatments, with % small sized tubers decreasing from an average of 23.5% (Cont and PMB) to 19.8% (MSW) and 17.5% (FERT). Nitrogen use efficiency decreased, however, from approximately 30 kg N uptake required per 10 Mg of yield for C3 and C4, to 35 kg N per 10 Mg for C1 and 37 kg N per 10 Mg for the FERT treatment (data not shown), in general agreement with Möller et al (2007). Much greater incidence of wireworm damage for rotation C1(~50% of tubers) compared to C3 and C4 (average 11.7%) was the major factor influencing loss of marketable yield. These results suggest a GMr of hairy vetch can be an effective substitute for red clover for organic potato production in the Eastern Canada region, especially when combined with supplemental organic N sources. Once elaborated, effective and productive rotations such as these can be combined with further agronomic strategies to take full advantage of fertility status. Möller and Reents (2007) found, particularly under conditions of high N availability for organic systems, selection of varieties with mid-early tuber initiation and tuber pre-sprouting further increased yields by 18-23%.

The measured RSMN values to 30 cm depth post harvest of ~60 kg NO_3-N ha^{-1} (Fig. 12.4), while above those found on commercial organic potato farms in the region noted above, were similar to the level (61 kg N ha^{-1}) reported above following 300 kg N ha^{-1} pelletized poultry manure application to organic potatoes (Lynch et al. 2008a, b). The RSMN values are in the lower end of the range reported by Zebarth et al. (2003) for 228 commercial conventionally managed potato fields in New Brunswick Canada (3 to 250 kg N ha^{-1}) and by Cambouris et al. (2008) in 2 sites for 3 years in Quebec, Canada (52–114 kg N ha^{-1}).

In Italy, Canali et al. (2010) assessed the contribution of contrasting organic amendments (farmyard manure or municipal 'green waste' compost) in combination with a subterranean clover cover crop on organic potato (var. Monna Lisa) N nutrition. Amendments were applied at 0, 50 and 100 kg total N ha^{-1} to cultivated or uncultivated GMr main plots. Incorporation of GMr or farmyard manure alone increased tuber yields by 22–25%. When GMr and amendments were combined yields increased by 43%, but RSMN did not increase significantly as found in our cropping systems study discussed above. In Sweden, Bath et al. (2006) found the combination of a clover-grass GMr precrop and fermented manure slurry (containing between 37 and 94 kg NH_4-N ha^{-1}) increased organic potato N uptake by approximately 50% and yields by approximately 40%, on a site with poorer soil but not on a site with more fertile soil. In late fall (November), RSMN (0–0.9 m depth) was lower at the poor soil site (25–60 kg N ha^{-1}) than under more fertile soil conditions (50–90 kg N ha^{-1}). The results of these studies suggest effective combinations of GMrs and supplementary organic amendments can be developed, adapted to regional conditions and production systems, which enhance organic potato productivity without compromising on maintaining a low environmental footprint of these systems.

12.5 Use of Plant Bioassays and Soil Tests to Improve N Management in Organic Potato Production

Unlike phosphorus and potassium, there is currently no standard soil test for N to use in making N recommendations in humid environments such as Atlantic Canada. In this region, the loss of soil residual mineral N over late fall and winter results in N supply being dominated by in-season organic N mineralization (Sharifi et al. 2007; Zebarth et al. 2009). Advances in, and potential of, soil and plant tests to improve N use in potato production systems are reviewed in this text and elsewhere by Zebarth et al. (2009), Sharifi et al. (2007) and Sharifi et al. (2008). Many of these approaches, particularly with respect to a reliable lab test for potentially mineralizable soil N, would be important tools to help refine organic production systems. A few additional approaches of note are summarized below.

Sullivan et al. (2007), using a whole crop bioassay approach sampled just before vine kill from a zero supplemental N plot (PNU_{0N}) reports on plant-available N on six organic farms in Oregon, in the northeastern USA. This approach has the advantage of being conducted under field conditions where temperature, moisture, and aeration are representative of that experienced by the crop. It also incorporates the root interactions of the specific crop species, and is therefore expected to provide a better estimate of the crop specific soil N supply (Zebarth et al. 2005). Soil N supply also can be estimated as the sum of PNU_{0N} plus RSMN after crop harvest. Most organic producers in Atlantic Canada have not attempted to gauge the N supply from soil and GMr residues as affected by their management system, and this simple approach could be more widely promoted as suggested by Sullivan et al. (2007). The relative recovery of N in tubers compared to haulms can also be used to gauge N oversupply.

The *in situ* use of ion-exchange resins and membranes has been explored as a means to assess plant available N and as an alternative to a static measurement of SMN for timothy (Ziadi et al. 1999) and canola (Qian and Schoenau 2005). When buried *in situ*, nutrient adsorption to the ion-exchange membrane is influenced by the same edaphic factors that affect nutrient uptake by plant roots and the membrane thus measures the actual N flux over time in soils. The measured N flux can be influenced by duration of burial in the soil, soil temperature, soil moisture, competing sinks (microbial and roots), and crop N uptake pattern (Ziadi et al. 1999). Johnson et al. (2005) reported that PRS-N results are more sensitive to soil moisture, but less sensitive to temperature, compared with SMN. As part of the study described above and in Lynch et al. (2008a), Sharifi et al. (2009) examined the relationship between spring PRS-N flux and PNU_{0N} or PNU_{0N} and residual soil mineral N left at harvest (SMN_h) (Fig. 12.5a,b). The cumulative PRS-N flux for a burial period of 31 days after planting (DAP), soil mineral N at 10 days DAP and soil NO_3-N at 31 DAP successfully ($r = 0.71$-0.81) predicted N supply from soil and organic amendments to the potato crop. The PRS-N data was less variable (i.e. lower CV) compared with in-season soil mineral N data, but use of the sequential multi-burial approach can make it more costly and labour intensive. In our rotation trial described in section 4 above, we are continuing to test the effectiveness of *in situ* PRS as a measure of N availability for organic potato production systems in Atlantic Canada.

12.6 Conclusion

On farm and station based trials in Atlantic Canada, suggest effective combinations of GMrs and supplementary organic amendments can be developed, adapted to regional conditions and production systems, which enhance organic potato pro-

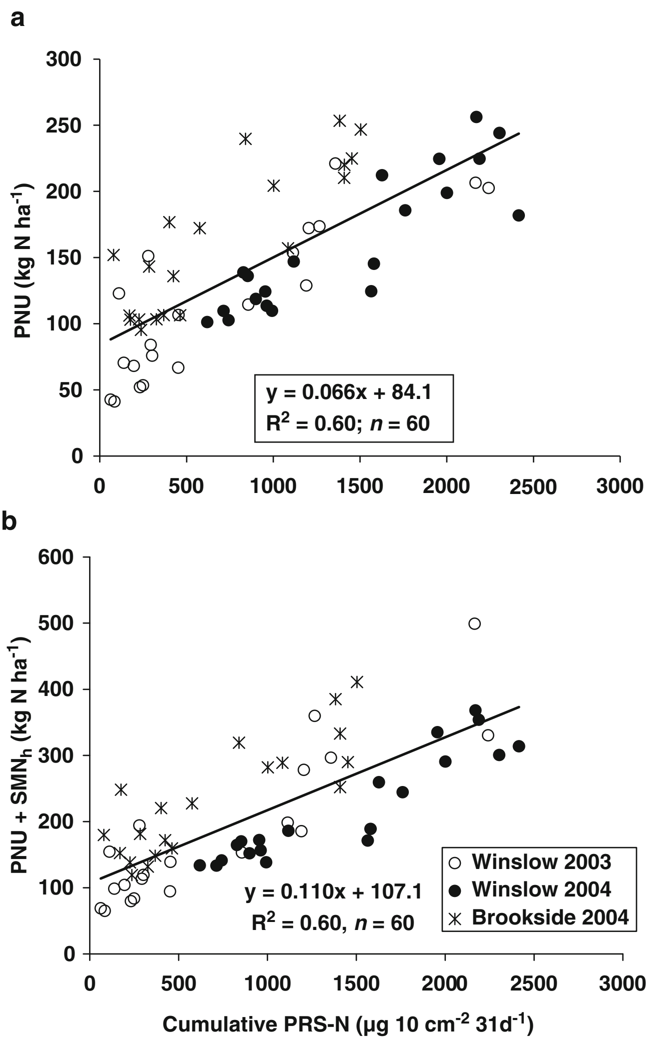

Fig. 12.5 Relationship between N supply rate measured by in situ burial of Plant Root SimulatorTM probes (PRS-N) for a cumulative burial period of 31 days after planting and N supply from soil and organic amendments as estimated by total plant uptake taken at potato vine topkilling (mechanical removal) (PNU) (**a**) or PNU plus soil (0-30 cm depth) mineral N at harvest (PNU + SMN_h) (**b**). All regression coefficients are significant at 0.001 probability level. Reprinted with permission from American Journal of Potato Research, 86, Sharifi et al., Evaluation of nitrogen supply rate measured by in situ placement of Plant Root Simulator™ probes as a predictor of nitrogen supply from soil and organic amendments in potato crop, 356–366, 2009

ductivity without compromising on maintaining a low environmental footprint of these systems. There is a need for more research to examine the net benefits to soil labile N pools of GMr of varying type and duration (1–2 years), within lengthened rotations where potatoes (and associated frequent soil disturbance) occur less frequently, as found on organic farms. Practical tools to gauge soil N supply within these production systems are also needed. Innovative approaches to management of green manures that reduce reliance on tillage, such as strip cropping systems, would also be an important advance. In the broader context a greater understanding of the ecological versus economic risks associated with different organic potato cropping system designs would be beneficial to both producers and policy makers. Finally, and as also noted by Griffiths et al. (2010), greater understanding of the potential environmental tradeoffs at play in these systems associated with improved soil quality on the one hand but possibly greater N losses to leaching and GHG is needed.

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