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Cover Crop and Nitrogen Fertilizer Management for Potato Production in the Northeast

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COVER CROP AND NITROGEN FERTILIZER MANAGEMENT FOR POTATO PRODUCTION IN THE NORTHEAST

A Dissertation Presented

by

EMAD JAHANZAD

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DEDICATION

To Maryam,

I could not have made it without your patience, encouragement, and love

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ABSTRACT

COVER CROP AND NITROGEN FERTILIZER MANAGEMENT FOR POTATO PRODUCTION IN THE NORTHEAST

SEPTEMBER 2015

EMAD JAHANZAD, B.A., AZAD UNIVERSITY OF ROUDHEN
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Potato (*Solanum tuberosum* L.) rates fourth among the world's agricultural products in terms of production volume and human consumption and worldwide demand for potatoes will exceed that of rice, wheat, or corn by 2020. Potato consumption has been a major part of the North American diet since early in the 17th century and as a dominant arable crop in the Northeastern United States. There are over 2700 potato fields in the Northeast United States and potato growers often over apply nitrogen (N) fertilizer to ensure against loss of yield. High mobility of nitrate form N fertilization in the soil profile makes it susceptible to leach to the lower soil levels leading to ground water nitrate contamination, other environmental concerns, and increased costs of production.

Rye (*Secale cereale* L.) is the most widely grown cover crop in the Northeast U.S, and its N-scavenging capacity and adaptability to the soils and climates in the region have been well documented. However, it might not be an adequate source of N for the early planted cash crops in the spring because it is not given the opportunity to grow in the spring and accumulate substantial amount of biomass. Therefore, we implemented field experiments to evaluate whether forage radish (*Raphanus sativus* L.) or winter peas (*Pisum sativum* L.) could be a more appropriate cover crop than rye in rotation with Dark Red Norland and Superior potatoes in Massachusetts. We also applied four levels of N fertilizer (0, 75, 150, and 225 kg ha^{-1}) in combination with cover crops to tailoring N rates as an external source of N in addition to the released N from cover crop residues.

Our study centered on three major topics: (i) Cover crop decomposition rate and trend of nutrient release in a conventional or no till system to evaluate whether there is a synchrony with potato nutrient demands (ii) Tuber yield and nutrient density of potatoes as influenced by cover crops and N fertilization and (iii) Nitrogen use efficiency (NUE) indices, tuber quality, and pest control in potatoes.

Our results indicated that a conventional tilling system accelerated the decomposition process and also increased the rate of nutrient loss in the soil compared with a no till system. Among the cover crops used in this study, forage radish or peas accumulated more N than rye. Also, forage radish or peas with narrower C:N ratio released their N content in a faster trend. Potato tuber yield in both varieties was improved, and peas or forage radish outperformed than rye or no cover crop plots in this regard. Also, forage radish was advantageous over winter peas or rye in terms of providing nutrients other than N as suggested by more nutrient dense potatoes.

Cover crops, especially peas or forage radish were efficient in reducing N fertilization requirements in both potato varieties as indicated by higher NUE parameters. Potatoes planted after cover crops were less efficient in utilization of the supplied N than potatoes following fallow. Application of high rates of N fertilizer decreased NUE parameters through enhanced vegetative growth or probably environmental losses. Forage radish or peas exhibited more synchrony with potato N demands at its critical growth stages in terms of N release from residues. Cover crops did not produce potato tubers of higher quality than no cover crop plots. Colorado potato beetle infestation was lower in potato plants after rye early in the spring than with the other cover crops; however, later in the season all of the treatments showed the same infestation. Weed

infestation tended to be lower in cover crop plots than in no cover crop plots, yet, rye and forage radish were advantageous over winter peas for suppressing weeds.

Overall, it is proposed that planting forage radish as early as possible in late August or early September could produce more potato yield and improve nutrient density than winter peas or winter rye. Also, to get the most out of the released nutrients, especially nitrogen, it is important to prepare the land and plant potatoes as early as possible in the spring.

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CHAPTER 1

INTRODCUTION

Agriculture in the 21st Century faces multiple challenges. It has to produce more food to feed a growing population and to contribute to overall development in the many agriculturally dependent developed and developing countries that need to adopt efficient production methods. For most of human history, the earth's population has increased at a slow, steady pace. However, in the past 100 years, the number of human beings who need to be fed by farms has increased from 1.5 billion to 7 billion, a trend that indicates the necessity of growing high-yielding crops to cope with emerging hunger and malnutrition that limit human productivity in modern times. On the other hand, decreasing arable lands and the need for more food has resulted in intensive cropping systems and extensive use of fertilizers to cope with soil fertility problems that are associated with nutrient depletion by crop production.

According to the Food and Agriculture Organization of the United Nations (FAO), maize (*Zea mays* L.), wheat (*Triticum aestivum* L.), rice (*Oryza sativa* L.), and potatoes (*Solanum tuberosum* L.) have been the most consumed food in world in 2012. It is predicted that by 2020, worldwide demand for potatoes will exceed that of wheat or rice in terms of human consumption and production volume.

Today potato is considered as one of the major staple foods in industrialized or developing countries in the world. In the United States, potato consumption has been a major part of people's diet since early in the 17th Century. There are up to 2700 potato fields in the Northeastern United States, and over 50,000 hectares of arable land are under potato cultivation in this area. However, increasing demand of potato for different purposes along with economic pressures have forced potato growers to move toward more intense potato production systems with extensive use of fertilizers and increased frequency of potato in crop rotations.

Nitrogen (N) is considered as one the most important key nutrients for growth and developments of plants, as well as high-yielding potatoes. Therefore, potato growers often over apply N to ensure against loss of potato yield and quality. Over application of N in potato fields along with a high risk of nitrate leaching by rainfall or irrigation and the shallow root system of potato have raised concerns about nitrate contamination of water resources and threatening of environmental health. According to the USDA, about one-third of United States assessed surface waters do not meet designated uses, and agriculture is the source of over 60 percent of this impairment, largely from N problems. Especially, this problem is observed mainly in agricultural fields of rural areas where nitrate runoff percolates into groundwater. Nitrogen as nitrate in drinking water is potentially dangerous to pregnant women and newborn infants. Thyroid disruption, pancreatitis, and cancers of the digestive system are also caused by nitrate contaminated water (Knobeloch et al., 2000; Weyer et al., 2000; Ward et al., 2005). Contamination of drinking water by nitrate has been documented as a serious problem in many areas in the United States. For instance, nitrite and nitrate contamination has been found in treated tap water of several states in the Northeastern USA including, New York, Delaware, Maine, Connecticut, Rhode Island, and Vermont, in some area, water tables have already passed the 10 ppm threshold of nitrate-N contaminated waters (Mueller et al., 1995; Driscoll et al., 2001; Aber et al., 2003).

In addition to the leaching, volatilization, to a large degree, and denitrification, to a lesser degree, can lead up to 50% loss of the applied N fertilizer, losses that increase costs of production and therefore economic viability of farming.

Obviously, N management practices, which adjust N fertilizer application and improve the efficiency use of fertilizer, seem to be necessary. Management practices such as tailoring N fertilizer rates and integrating appropriate cover crops into potato production can reduce nitrate leaching and enhance profitability by cutting fertilization costs. By scavenging such large quantities of nitrate-N, cover crops contribute to protecting water quality and decrease enormous costs caused by water nitrate contamination to human health. In addition, cover crops can provide nutrients for the following crop, increase soil organic matter, improve soil structure, reduce soil erosion and compaction, increase residue recycling, enhance moisture availability, suppress weeds, reduce soil salinity, increase crop and soil organism diversity, and enhance wildlife habitat. The use of deep- rooted cover crops in rotation with potato, can significantly recover the nitrate-N that was leached from the previous shallow-rooted potatoes as well as residue nutrients which otherwise will be lost through leaching. However, the full fertility benefit of cover crops will be dependent upon the synchrony between N mineralization from cover crops and N demand of cash crops and an accurate estimation of supplemental fertilizer N requirement of the subsequent crop.

Potato growers in Massachusetts frequently plant rye (*Secale cereale* L.) as a winter cover crop in rotation with potato to prevent nitrate losses and soil erosion during the winter. Although cereal cover crops have been reported to be more efficient in preventing nitrate leachate compared with legumes, higher carbon (C): N ratio in cereals does not provide a proper synchrony between cover crop nutrient release and N demand of the succeeding potatoes, and consequently, nutrients will be lost to the air or washed to lower soil levels. In addition, rye residues in spring may interfere with soil preparation and delay planting due to colder/wetter soils in New England condition. Therefore, it is important to look for alternative cover crops for potatoes cultivation that can serve better in terms of nutrient cycling and spring termination.

In addition to cereals, selected species of legumes and brassicas can be considered as proper cover crop for potato production. Most of the legumes, as N-fixing plants, can produce a substantial amount of N, which could be used by the succeeding crops. Among the widely used legume cover crops, winter peas (*Pisum sativum* L.) are top N producers that can yield up to 150 kg N ha^{-1} (SARE, 2007). Also, in recent years, there has been an interest in brassica plants in rotation with cash crops because of their nutrient recycling and pest suppression characteristics (White and Weil, 2004). For example, forage radish (*Raphanus sativus* L.), as a newcomer in Massachusetts, has unique nutrient-scavenging characteristics that make it an eligible cover crop to be used in rotation with spring, early-planted cash crops such as potatoes.

The current study evaluates the performance and efficiency of winter peas and forage radish cover crops in compression to rye, as the traditionally planted cover crop in Massachusetts and also aims on tailoring N fertilization in a potato production system in the Northeast United States. To have a better evaluation of the efficiency of cover crops and N fertilizer management in this experiment, the following measurements will be made as an assessment tool: Potato tuber yield, nutrient density, cover crop decomposition rate, possible synchrony between released nutrients from potatoes and cover crops, and nitrate leaching measurements.

CHAPTER 2

LITERATURE RIVEW

Importance of potato in agricultural products

Currently, potato rates third among the world's agricultural products in production volume and consumption (International Potato Center, 2009). The annual per capita consumption ranges from 55 kg in the most affluent to 11 kg in developing countries (Tian et al., 2003). According to World Potato Center's research, worldwide demand for potatoes will exceed that of rice, wheat, or corn by 2020. Potato consumption has been a major part of the North American diet since early in the 17th Century (Sieczka and Thornton, 1993) and as dominant arable crop in the northeastern USA. Potato (*Solanum tuberosum* L.) is carbohydrate-rich source with an important role in feeding people and is of interest because of its very high yields. Potato produces as much protein and about twice as much carbohydrate as grains (Aghighi et al., 2011). Its tuber is economically valuable and is extensively used in feeding people and livestock and in starch production (Aghighi et al., 2011).Potato tuber energy and protein production per unit area is greater than that of wheat or rice because of its high yield (Khajehpour, 2004).

Potatoes are important to industrialized and developing countries as a source of income and are a staple food for the world population. Potatoes are grown under a wide range of locations throughout the world, ranging from 70° latitude in northern Europe to the equator in the South American Andes Mountains (Cao and Tibbitts, 1991). No other crop can match the potato in its production of food energy and food value per unit area. It is also high in Vitamin C, niacin and Vitamin B_6 (Sieczka and Thornton, 1993). Limited availability of land and economic pressures have forced the potato industry to move toward intensive potato production systems with extensive use of mineral fertilizers and increased frequency of potato in crop rotations (Stark and Porter, 2005). In recent years, there has been interest in new methods for producing potatoes of high quality and yield in an environmentally sustainable manner using cover crops and nitrogen management (Delgado, 2002; Delgado et al., 2001).

Importance of nitrogen management in a potato production system

Nitrogen presence in soil organic matter can be an important source of soil fertility but is not always available at the right time and in sufficient quantity for crop growth (Sinick et al., 2008).Proper nitrogen management is one of the most important factors required to obtain high yields of excellent quality potatoes (Rosen and Bierman, 2008). An adequate early- season nitrogen supply is important to support vegetative growth of potato, but excessive soil nitrogen later in the season will suppress tuber initiation, limit yields, and suppress the specific gravity in some cultivars. Excessive soil nitrogen late in the season can delay maturity of the tubers and result in poor skin set, which harms the tuber quality and storage properties (Rosen and Bierman, 2008). Nitrogen management systems that use inorganic fertilizer and organic sources, such as cover crop residues, could combine the benefits of fertilizer nitrogen with soil organic matter maintenance and carbon sequestration derived from the organic source (Legg and Meisinger, 1982). Another alternative that has been tested on potatoes is to supply nitrogen in synchronization with potato nitrogen crop demand through the use of controlled- release fertilizers (Rosen and Vomuya, 1999; Shoji, et al., 2001) that permit a 50% potential reduction in N applied without reducing tuber yields (Collins, et al., 2007). Included in these new methods and changes in agricultural systems for higher nitrogen practices are sustainable crop rotations, use of cover crops, viable nitrogen rates, synchronization of inputs and nitrogen uptake sinks, fertilizer type, precision agriculture, precision conservation, nitrification inhibitors, nitrogen index, and management zones (Berry et al., 2003; Berry et al., 2005; shoji 1999).

Importance of cover crops in potato production

In recent years, there has been interest in new methods for producing crops of high quality and yield in an environmentally sustainable manner (Delgado 2002; Delgado et al. 2001). Cover crops are considered to be an appropriate tool to improve potato yield and quality while alleviating environmental concerns. A cover crop is grown mainly to take up available N in the soil after harvest of the main crop and thereby to reduce leaching losses of N already in a cropping system (Delgado and Follett, 2010). Cover crops can provide nutrients for the following crop, increase soil organic matter, improve soil structure, reduce soil erosion and soil compaction, increase residue recycling, enhance water availability, suppress weed, reduce soil salinity, increase crop and soil organism diversity, and enhance wildlife habitat. At the same time, they can reduce costs, increase profits and even create new sources of income (Delgado and Follett, 2010).

Cover crops have been promoted as a means of maximizing the efficient use of available N to subsequent crops in agricultural systems, thereby limiting risks of environmental problems associated with nitrate contamination of surface and ground water while potentially enhancing profitability through a reduced nitrogen fertilizer N requirement (Shipley et al., 1992; Decker et al., 1994). Cover crops can accumulate substantial amounts of biomass and potentially available organic nitrogen. However, the full benefit of using cover crops will be dependent on the synchrony between N mineralization from the cover crop and N demand of the subsequent crop as well as accurate estimation of supplemental fertilizer N requirement of the subsequent crop. The quantity of cover crop N available to a subsequent crop is species–dependent and usually associated with greater availability of N from legumes than from nonlegumes (Dekker et al., 1994; Torbert et al., 1996; Vyn et al., 1999). Cover crops can recover 150 to 300 kg N ha^{-1} from the soil profile and return this N to the surface soil (Ditsch et al., 1993; Bundy and Andraski, 2005). Cover crops have been reported to increase potato tuber yield and quality (Essah et al, 2012). Vyn et al. (1999) found that cover crops, such as annual ryegrass, oat, oilseed radish, or even red clover, could serve as scavenger crops that can recover residual soil nitrate and potentially cycle it to the following crop.

Winter peas

Legumes as rotation crops are an important component of sustainable cropping systems in potato production (Stark and Porter, 2005). Including legume green manure crops in potato rotations can increase N availability to subsequent potato crops, improve potato tuber yield and quality, improve soil physical properties, and suppress soil-borne potato diseases (Griffin and Hesterman, 1991; Sanderson et al., 1999). Legume crops can contain large quantities of N, up to 240 kg N ha^{-1} (Griffin and Hesterman, 1991), most of which is released during the first year after incorporation into soil (Fox and Piekielek, 1988; Vanotti and Bundy, 1995). Longer rotation systems including legumes can improve soil N mineralization capacity while maintaining desirable levels of soil organic matter required for natural fertility of the soils (Sanchez et al., 2001). The Austrian winter peas (*Pisum sativum* L.) is a low-growing, vining annual legume. It is sometimes called black pea or field pea. It has a hollow, slender, succulent stem that is 2-4 feet long. Winter peas are high nitrogen fixers and produce abundant vining forage and contribute to short-term soil conditioning. Their succulent stems break down easily and are a quick source of available N (Sarrantonio, 1994). Field peas grow rapidly in the cool, moist weather that encounter as winter annuals. Austrian winter peas, can withstand temperatures as low as 10° F with only minor injury, but they do not overwinter consistently in areas colder than moderate USDA Hardiness Zone 6. Under a long, cool, moist season during their vegetative stages, Austrian winter peas produce more than 5,000 kg dry matter ha^{-1}, even if planted in spring in cold climates. Austrian winter peas are top N producers, yielding from 90 to 150 kg N ha^{-1} and at times up to 300 kg N ha^{-1} (SARE, 2007).

Rye

Rye (*Secale cereale* L.) is the hardiest of cereals and outperforms all other cover crops on infertile, sandy, or acidic soil or on poorly prepared land. It is adapted widely, but grows best in cool, temperate zones. Compared to other cover crop seeds, rye is inexpensive and easy to establish. Rye can be seeded later in fall than other cover crops and still provide considerable dry matter. Rye can restrict nitrate leaching and has exceptional weed suppression. It is the best cool-season cereal cover for absorbing unused soil N. It has no taproot, but rye’s quick-growing, fibrous root system can take up and hold as much as 100 kg N ha^{-1} before subsequent crop is planted in spring (Hashemi et al, 2013).The root system promotes better drainage, whereas its quick maturity in spring compared with other cover crops can help conserve late-spring soil water (SARE, 2013). A Maryland study credited rye with holding 60 percent of the residual N that could have leached from a silt loam following intentionally over-fertilized corn (Shipley et al., 1992). Rye increases the concentration of exchangeable potassium (K) near the soil surface, by bringing it up from lower in the soil profile (Eckert, 1991). Along with conservation tillage practices, rye provides soil protection on sloping fields and holds soil loss to a tolerable level (Edwards, 1993). Rye is one of the best cool-season cover crops for outcompeting weeds, especially small-seeded, light-sensitive annuals such as lambsquarters, redroot pigweed, velvetleaf, chickweed, and foxtail. Rye also suppresses many weeds allelopathically (as a natural herbicide), including dandelions and Canada thistle, and has been shown to inhibit germination of some triazine-resistant weeds (Przepiorkowski and Gorski, 1994). Rye grows and matures rapidly in spring, but its maturity date varies depending on soil water and temperature. Tall rye immobilizes N as it decomposes following incorporation into soil. The N tie-up varies directly with the maturity of the rye.

Killing rye early, while it is still succulent, is one way to minimize N tie-up and conserve soil water. But spring rains can be problematic with rye, especially before an N-demanding crop, such as corn is planted. One way to offset yield limitations from immobilization of N by rye would be to increase N application (Decker et al., 1992). Another option is growing rye with a companion legume, a practice that allows farmers to delay killing the covers by a few weeks and sustain yields, especially if the legume is at least half of the mixed cover. This action gives the legume more time to fix N (in some cases doubling the N contribution) and rye more time to scavenge a little more leachable N (Decker et al., 1992).

Forage radish

Brassica cover crops are known for their rapid fall growth, great biomass production, and nutrient scavenging ability. Brassicas are used increasingly as winter or rotational cover crops in vegetable and specialty crop production, such as potatoes and tree fruits. There is also growing interest in their use in row-crop production, primarily for nutrient capture, nematode, trapping, and biotoxic activity. Some brassicas have a large taproot that can break through plow pans better than the fibrous roots of cereal cover crops or brassicas such as mustards. Some brassicas such as forage radish can provide greater than 80% soil coverage when used as a winter cover crop (Haramoto and Gallandt, 2004). Depending on location, planting date and soil fertility, they produce up to 8,000 kg biomass ha^{-1}. Because of their fast fall growth, brassicas are well suited to capture soil nitrogen (N) remaining after previous crop harvest (Kremen and Weil, 2006). The amount of nitrogen captured is related mainly to biomass accumulation and the amount of N available in the soil profile. Because they immobilize less nitrogen than some cereal cover crops after plowing under, much of the N taken up can become available for uptake by main crops in early to late spring.

Forage radish (*Raphanus sativus* L.) suppresses weeds in the fall with their rapid growth and canopy closure. In spring, its residues can inhibit small-seeded annual weeds (Munoz and Graves, 2013.

Nutrient leaching and environmental concerns

In many developed countries, the historic emphasis on plant nutrition has focused on crop production studies to minimizing nutrient losses to the environment (Westernmann, 2005). There is a need to continue developing new management practices to limit nitrogen losses that affect air, soil, and water quality. Nitrogen often is over applied in potato production, to ensure against loss of yield and tuber quality (Waddell et al., 1999). Relatively higher rates of N required for potato production combined with potato shallow root system and susceptibility of nitrate leaching by rainfall and irrigation have increased concerns about nitrate losses and groundwater pollution (Neumann et al., 2012; Errebhi et al., 1998; Millburn et al., 1990). The N loss can be as high as 50% of the applied N (Machado et al., 2010). Significant N losses due to leaching from potatoes have been reported in several studies (Shepherd and Lord, 1996; Gasser et al., 2002; Torstensson et al., 2006; Arriaga et al., 2009; Shrestha et al., 2010).

Reasons for nitrate loading of groundwater include the nature of land use, sandy permeable soils, irrigated systems and planting of shallow rooted crops with high N inputs (Collins et al, 2007). Contamination of water resources by agricultural production systems will not be tolerated by the public and could lead to laws regulating the use of N fertilizers if this contamination is not minimized (Rosen and Bierman, 2008). Since nitrate-N is a high mobile element that is susceptible to being transported below the root zone to underground water resources, by scavenging these large quantities of nitrate-nitrogen, these cover crops contribute to protecting water quality (Delgado, 1998; Delgado 2001). Cover crops have been defined as crops grown to protect the soil from losses of nutrients via leaching and runoff (Reeves, 1994). Several researchers have reported the benefits of cover crops to restrict off-site transport of sediment (Bilbro, 1991; Langdale et al., 1991; Decker et al., 1994; Dabney et al., 1998; Delgado, 1999). Cover crops can scavenge the residual soil nitrate-nitrogen that was leached from the previous crop, but also they can limit the nitrate leaching from the following crop (Delgado, 1998; Delgado et al., 2001).

Deep-rooted crops, such as winter cover crops scavenged nitrate that was leached from a previous shallow-rooted lettuce crop and by reduced and cleaned the soil profile of nitrate- that was available to leach, and also the losses of nitrate from the next year with the potato crops were lower (Delgado, 1998; Delgado 2001). Nonlegume cover crops catch residual N as well as N mineralized after harvest of the main crop thereby reducing the risk of nitrate leaching (Thorup-Kristensen et al., 2003; Moller et al., 2006). Neumann et al. (2012) reported that despite the high mineral soil nitrogen content after potato harvest in June, early potatoes with radish as catch crop showed the lowest N leaching losses of all potato cropping systems. They also stated that potatoes harvested in August and September/October followed by triticale sown in October had the highest losses to leaching.

Nitrogen-use efficiency and nutrient scavenging

Even with the continuing research in N management, average worldwide nitrogen use efficiencies (NUE) are reported to be around 50% of the applied nitrogen (Newbould, 1989) and as low as 33% for worldwide cereal production (Raun and Johnson, 1999). These low NUE are in part due to the unique dynamics and mobility of N in the system (Delgado and Follett, 2002). Three key components identified to increase nitrogen use efficiencies (NUE) are the use of N-efficient crop varieties, a carefully controlled N application rate, and better synchronization between applied N and N uptake by potato (Essah et al., 2012). Pre-plant N applications for potatoes, especially those in irrigated sandy soils tend to have lower NUE than applications at planting (Shoji et al., 2001). A viable management practice that can increase NUE after shallow-rooted crops, including potato, is the use of cover crops. Several studies have reported the impacts of cover crops on increasing NUE (Lal et al., 1991; Lal, 1997; Staver and Brinsfield, 1998; Groffman et al., 1987; Meisinger et al., 1991; Shipley et al., 1992). Green manures or catch crops grown in the autumn can be important tools to restrict N losses and increase N supply for the succeeding crops (Stute and Posner, 1995). These crops affect not only the amount of organic N available for the main crops but also the depth distribution of the available N in the soil. Earlier research reported that after plowing and burying grassland, net mineralization of N in sandy soils can reach 55 to 80 kg N ha^{-1} (Li et al., 1999; Gasser, 2000). Winter cover crops scavenge an average of 100 to 178 kg N ha^{-1} and up to 300 kg N ha^{-1} when they are grown in potato systems with high residual soil nitrate (Delgado et al., 2007).

Early fall planted cover crops can return a large amount of biomass that is beneficial for these soils that are mainly sandy, coarse soils with low soil organic matter. The amount of dry biomass returned to the surface can average 3.8 tons per hectare for the early planted winter cover crop (Delgado et al., 2007). Delgado (1998) showed that a winter cover rye could scavenge residual soil nitrate leached below the root zone of shallow-rooted crops and return it back to the surface. The use of cover crops to scavenge residual soil nitrate from the soil profile to minimize nitrate leaching has been demonstrated in different cropping systems (Holderbaum et al., 1990; Meisinger et al., 1991; Weinert et al., 2002). Cover crops can recover 150 to 300 kg N ha^{-1} from the soil profile and return this N to the surface soil (Ditsch et al., 1993; Bundy and Andraski, 2005, Hashemi et al, 2013). Studies conducted across the region have found that cover crops can contribute to maintaining high levels of soil organic matter levels, reducing losses of fine particles, and maintaining the nutrient levels for soils that are susceptible to wind erosion of particulate organic carbon (Al-Sheikh et al., 2005). These deep- rooted systems have the potential to contribute to precision conservation (Berry et al., 2005) and can be used to scavenge higher amounts of nitrogen from the areas of the field with higher residual soil nitrate (Delgado, 1998; 2001; Delgado et al. 2001).

Cover crop and nitrogen fertilizer influence on potato tuber yield

Nitrogen fertilizer is considered to be a major component in improving potato tuber yield. Studies on N uptake characteristics of potato roots have shown that N fertilizers are applied in excess of the optimal rate for maximum yield (Munoz et al., 2005). Potato is a crop that is highly responsive to cover crop treatments and N fertilizer. According to Essah et al (2012), tuber yield and quality can be affected by both low N availability and over-fertilization. It is important that site-specific nitrogen management practices are developed to consider cultivar physiological responses to total nitrogen application as well as to the physiological stage when the nitrogen is applied to maximize yields, tuber quality, and economic returns. There have been several studies on the optimum nitrogen fertilizer rate for potato tuber production. Li et al. (1999) obtained optimal potato production using only 70 kg N ha^{-1} following plowing under of grassland. Riley (2000) and found that the optimum N levels were 80 kg N ha^{-1} for a yield of 15 t

ha^{-1} up to 120 kg N ha^{-1} for a yield of 40 t ha^{-1}. Maximum tuber yield and quality for the Sangre cultivar was observed with N application rate of 90 kg N ha^{-1} at planting (Essah et al., 2012). On the other hand, optimum N application for maximum tuber yield and quality for 'Canela Russet' was 157 kg N ha^{-1} split as 90 kg N ha^{-1} applied at planting and three fertigations of 22 kg N ha^{-1} applied biweekly after initial tuberization (Essah et al., 2012). Neeteson (1988) found that at otherwise optimal N fertilizer rates, potato tuber yields were slightly lower following legumes. Griffin and Hesterman (1991) tested the effect of several legume cover crops on subsequent potato crops and found sweet clover [*Melilotus officinalis* (L.) Pall], as the highest N-yielding legume, which added 238 kg N ha^{-1} to the following potatoes. In that study, potato crops after all legume green manures showed a higher N accumulation and produced a higher plant dry matter than in non-legume treatments.

Results from studies conducted by Sincik et al. (2008) indicated that potato following legume cover crops produced 36% to 38% higher tuber yield than potato following winter wheat (*Triticum aestivum* L.) when no N was applied. Differences between tubers yields following cover crops and without cover crops decreased as N rates increased (Sincik et al., 2008). Research in Wisconsin on sandy soils (Kelling et al., 1993) found that maximum potato yield following sorghum sudangrass required 40 kg ha^{-1} more N than following red clover and 80 kg ha^{-1} more N than following alfalfa. Similar results from a 20-year study in the Netherlands found that N requirements for optimum potato yield following oats were 60 kg N ha^{-1} greater than following red clover and 90 kg N ha^{-1} greater than following alfalfa (Neeteson, 1989). Tuber quality from the use of excessive N fertilizer might be affected negatively. Several studies showed that N rates recommended in potato varied between 120 and 220 kg N ha^{-1} according to the regions in conventional agricultural systems (Kusman et al., 1988; Ozyurt, 1982; Isık and Alpturk, 1986).

Essah and Delgado (2009) found that excessive application of N fertilizer suppressed potato tuber yields and quality and that this response was dependent on potato cultivar. In other words, in cases where the amount of N is increased to higher levels than needed, a negative effect could then be observed (Essah and Delgado, 2009). Further, if N is applied in better synchronization with the N demands of a given potato cultivar (and the N that is cycled is accounted for when applying N), tuber yields could be increased. It is believed that effects of legumes or non-legume cover crops on tuber yield responses could have been in part due to responses of potato cultivars to the increased availability of N (Essah et al, 2012). On the other hand, methods of fertilizer application are considered to be influential on potato tuber yield. For instance, banding increases the availability of those nutrients that can be "fixed" by soil components or leached out of the active root zone. Westermann and Davis (1992) reported that banding nitrogen fertilizer at planting time was generally more efficient than broadcasting before planting under furrow irrigation.

CHAPTER 3

DECOMPOSITION RATE AND RELEASE OF NITROGEN FROM RYE, FORAGE RADISH, OR WINTER PEAS COVER CROPS UNDER CONVENTIONAL OR NO-TILLING SYSTEMS

Abstract

Increased frequency of continuous cropping and extensive use of synthetic fertilizers has threatened environment and human health and has increased the costs of crop production. Employing nitrogen management practices and using cover crops could be a possible alternative that may contribute to more sustainable environment and farming systems via more efficient nutrient cycling and less fertilization. To study the efficiency of three different cover crops from different plant families under no- till or conventional tillage conditions a 2-yr field experiment was conducted. Cover crops used in this study included annual winter rye, forage radish, and Austrian winter peas. Our results indicated that forage radish produced higher dry matter compared with rye and winter peas. All three cover crops species had a faster decomposition rate and release of nitrogen under conventional tilling system. During the decomposition process, forage radish and peas lost their initial biomass and nitrogen content at a faster trend than winter rye. Considering the decomposition rate and trend of nitrogen release in cover crops, forage radish and peas may be a more feasible option than rye to provide sufficient N for the early planted cash crops in the spring.

Key words: decomposition rate, forage radish, nitrogen, peas, rye

Introduction

Current agricultural practices have resulted in excessive use of synthetic fertilizers and increased environmental concerns (Brandi-Dohrn et al., 1997; Malpassi et al., 2000). Nitrogen (N) in particular is more prone to losses because of high mobility of nitrate in the soil, a property that makes N susceptible to leaching. Percolation of nitrate into the soil results in eutrophication of water resources and nitrate contamination of drinking water (Dean and Weil, 2009). In addition to leaching, volatilization and denitrification of N can lead to up to 50% loss of the applied N fertilizer (Weinert et al. 2002; O'Reilly et al., 2012). On the other hand, the relatively high cost of N fertilizer increases costs of production and threatens economic viability of farmers. Thus, to minimize pollution from nutrients alternative management practices should be employed to provide more sustainable farming systems by better utilization of N in cropping systems (Luna-Orea, et al., 1996).

Cover crops play an important role in efficient cycling of nutrients in cropping systems, especially in areas with high levels of precipitation with great potential of nitrogen leaching from the soil (Kowalenko, 1987; Odhiambo and Bomke 2001). In addition, cover crops are a feasible option to cover the ground and restrict soil erosion (Liu et al., 2002), increase soil organic matter (Fageria, 2007), alleviate subsoil compaction (Weil and Kremen, 2007), and suppress weeds and other pests (Fisk et al., 2001).

Annual winter grasses and legumes cover crops are important components of sustainable cropping systems, facilitating nutrient cycling and providing soil and water conservation (Ranells and Wagger, 1997). Small grain cover crops, such as rye, can use a significant amount of residual soil and fertilizer N in the fall during the period of their rapid establishment (Meisinger et al., 1991). Selection of appropriate cover crops for a given region requires an adequate knowledge of the growth potential and degradation rate of the residues incorporated into soil, as well as the residue effect on short- and long term N availability in the soil (Stivers-young, 1998).

Rye is the most widely grown cover crop in Massachusetts, and its N scavenging capacity and adaptability to the soils and climates in the region has been well documented (Staver and Brinsfi eld, 1998; Hashemi et al, 2013). It establishes rapidly and produces significant biomass, which can help limit soil erosion and contribute to increased soil carbon. Therefore, rye could be considered a logical benchmark to which other crops performance could be compared with in the Massachusetts.

However, rye cannot be a reliable source of N for the succeeding crops, especially for early-planted cash crops in the spring. Because of wide C:N ratios, rye can pose the risk of net immobilization of soil N, an action that often happens in early decomposition residues of rye as more N is needed by the developing microorganisms than is provided by the substrate (Ranells and Wagger, 1997). Rye residues also may interfere physically with planting of cash crops, thereby resulting in poor seed-soil contact and stand suppressions. In addition, soil water depletion and allelopathy effects of rye residues could be problematic for the establishment of the cash crops (Clark et al., 1997).

Unlike rye, legumes do not scavenge N effectively during fall and winter (Meisinger et al., 1991) because N may move below the rooting zone before fall-planted legumes such as winter peas begin active growth (Shipley et al., 1992). Yet, there has been a lot of research suggesting that winter annual legumes such as winter peas and hairy vetch can fix most or the entire N required for maximum yield of following crops (Clark et al., 1995). Austrian winter peas are considered as top N producers, yielding from 90 to 150 kg N ha^{-1}, and at times up t to 300 kg N ha^{-1}. Brassica cover crops, such as forage radish (*Raphanus sativus* L.), oilseed radish (*Raphanus sativus* L.), and rape (*Brassica napus* L.), have received renewed attention, as effective N- and phosphorus-capturing plants, in some cases out performing rye in taking up N and decreasing soil nitrate leaching (Armstrong et al. 1994; Vos and Van Der Putten, 2004).

Forage radish is relative newcomer to Massachusetts as a cover crop and is being used in many parts of the world as a winter cover crop to alleviate soil compaction, restrict nitrate leaching, suppress weeds, and control erosion (Weil and Kremen, 2007). Among many unique characteristics of forage radish are its relatively high tissue P concentration, rapid dry matter accumulation in the fall, and rapid residue decomposition (White and Weil, 2011). Forage radish grows rapidly in the fall and can scavenge significant quantities of N, and the residues decompose very rapidly due to their low C/N ratio. Yet, selection of appropriate cover crops for a given region requires an adequate knowledge of the growth potential and degradation rate of the residues incorporated into soil, as well as the residue effect on short- and long-term N availability in soil (Stivers-young, 1998).

In an integrated cropping system, cover crop residues are the main source of organic materials and nutrients; however, the effectiveness of released N and fertilizer value of cover crops to succeeding crops depends on their ability to decompose and release nutrients (Adediran et al. 2003; Murungu et al., 2011). In order to effectively manage residual N, it is necessary to understand the pattern of N release from cover crops residues. The rates at which the decomposing residues release N depends on the structural and chemical characteristics or ‘‘residue quality’’ of the plant species (Van Veen and Kuikman, 1990; Palm et al., 2001).

Several studies have determined that N, lignin (L), cellulose contents, as well as C/N, Lignin to N (L/N) ratios are useful indices of residue quality that control residue decomposition and N release (Palm et al., 1991; Vanlauweet et al., 1996; Baijukya et al., 2006). An analysis of these quality parameters aids in explaining any differences in decompositions rates of various organic materials (Murungu et al., 2011). In a field study conducted by Muller et al. (1988), N release from soil-incorporated plant residues of three clover species decreased with increasing concentrations of lignin and hemicellulose, whereas N release increased with increasing cellulose and N concentrations.

In addition to the chemical and structural characteristics of plant residues, tilling systems may alter the decomposition process and nutrient release from cover crops. Mechanical cultivation typically disintegrates macro aggregates to expose the protected, partially decomposed plant material for microbial degradation (Cambardella and Elliott, 1993) and increases air permeability, thereby accelerating organic carbon oxidation (Dalal and Mayer, 1988; Kou et al., 1997). Chemical alterations during decomposition therefore might be different from residues that are buried or left on soil surface

(Franzluebbers et al., 1996). Surface placement of crop residues, however, with conservation tillage can improve soil physical, chemical, and biological properties (Hatfield and Stewart, 1994). Wilson and Hargrove (1986) reported that crimson clover residue released N more rapidly in conventional tillage than in no-tillage systems during the initial 8 wk after field placement; however, by 16 wk after placement the percentage of N remaining was nearly equal (Ranells and Wagger, 1992).

During the past decade, agronomists have attempted to characterize patterns of N release from various cover crop residues. Few studies have compared mass and nutrient loss in the field from residues of crops, such as forage radish and pea, with rye, which is the conventionally grown cover crop in Massachusetts. Such data are required to understand the role of various crop residues in nutrient cycling in agro-ecosystems. Therefore, this study was conducted to evaluate the pattern of nutrient release of buried and surface residues of forage radish, winter peas, and rye.

Materials and methods

Experimental Site

The experiment was conducted at the Crops and Animal Research and Education Farm of the University of Massachusetts in South Deerfield (42°28′37″ N, 72°36′2″ W), in 2013 and 2014. The soil type was a Hadley fine sandy loam (coarse-silty, mixed, superactive, nonacid, mesic Typic Udifluvent) and the selected soil physical and chemical characteristics of the top 15 cm were as follows: 52% sand, 33% clay; ECEC 3 to 4 cmolc kg^{-1}, pH 5.9 (l:l, soil: water), organic matter content of 1.4%, extractable N, P, K, and Ca content of 3, 9, 73, and 868 mg kg^{-1}, respectively. The mean annual temperature and rainfall during the growing season are presented in Figure 1.

Experimental Design and Cultural Practices

An experiment was laid out on pre-existing cover crop plots in a randomized complete block design with three replications. Annual winter rye, forage radish, and winter peas were planted using a small grain drill (Kincaid Manufacturing, Haven, KS, USA) at the seeding rates of 100, 9, and 120 kg ha^{-1} respectively. Planting occurred on August 25 and August 28 in 2013 and 2014, respectively. No fertilizer was applied before cover crops were planted; however, winter pea was inoculated by *Rhizobium leguminosarum* just before planting. Prior to planting the cover crops in each fall, the experimental area was chisel-plowed and disked. To monitor soil temperature in the cover crop plots, soil temperature measurements were made using temperature probes permanently installed in selected treatment plots at 20 cm depth. Soil temperature measurements taken during the experiment is presented in figure 2.

Sampling and laboratory analyzes

Aboveground cover crop biomass was collected and determined by cutting at ground-level in each plot prior to winter frost (late November) and cover crop termination. A hedge clipper was used for harvesting cover crops from 1 m2 quadrats. Cover crop biomass was dried at 70°C in a forced air oven to constant weight. Cover crop dry matter accumulation was calculated on an ash-free weight basis by ashing plant tissue samples at 550°C and then subtracting the weight of ash from the dry sample weight to correct for possible soil contamination. A subsample of the initial plant materials was ground (1 mm) and analyzed for total N, as well as lignin and cellulose. Nitrogen content of plant tissue was determined using the Kjeldahl procedure (Bremner, 1996). Carbon was determined using Automated Pregl-Dumas Technique with a Perkin-Elmer 2400 CHN elemental analyzer (Norwalk, CT) (Patterson, 1973; Chatterjee et al., 2009). Lignin and cellulose was determined by an acid-detergent method (Van Soest, 1968).

To examine the decomposition of rye cover crops in soil or on the soil surface, a mesh bag technique was used. Mesh bag preparation and sampling followed the methods of Wilson and Hargrove (1986), Stute and Posner (1995), and Liu (1997). Before cover crop termination in the winter and just before frost, forage radish and peas tissue samples were harvested, and a portion of each sample was set aside for preparation of the mesh bags, and the remaining samples were dried for later analysis of Kjeldahl N. An approximately 100-g fresh sample from each species was weighed and placed in polyamide nylon mesh bags to ensure that sufficient material remained at the end of the decomposition period and after drying.

Because of fleshy tap roots of forage radish, roots were also shoveled out in addition to the shoots. While a group of bags were only filled with forage radish shoots (for the no tillage treatments), another set of bags were filled with combined samples of forage radish shoots and roots according to their ratio after weighting them. We only harvested winter peas shoots in this study. Samples were put into the mesh bags made of polyamide nylon mesh with minimal detachment or breakage of plant parts and were in a condition similar to that represented in the field. Mesh size was 60 μm, and finished bag size was 20 cm x 9 cm. For each cover crop species, twenty six bags per replication were prepared in this manner, considering 13 retrieval dates for no-till and conventional tillage systems. Forage radish and winter peas samples were enclosed in the mesh bags and placed on the soil surface and to prevent bags of getting dragged through the winter, they were fixed with a metal wire on the soil surface.

Prior to killing rye early in the spring (rye was disked and plowed under); plant tissue samples were also harvested and put in the mesh bags using the method described above. Afterwards, mesh bags of all cover crops were buried 20cm deep in the soil at approximately the second week of April to mimic the tilling conditions. Another group of the mesh bags were placed on the soil surface to mimic no-till condition. Each block contained 13 mesh bags, and for each cover crop species, three replications were used. Mesh bags were recovered on a weekly basis (single bag was retrieved from each replication). At each retrieval time, the content of each bag was dried at 70°C, ground, and analyzed for Kjeldahl N according to Bremner (1996). The differences in dry weight, lignin, cellulose, and N content of cover crop residues in each retrieval time was compared with the very first sample and with each other to determine the trend of N release and decomposition rate. Soil samples were taken every two weeks from three different depths (20, 40, and 60 cm). Each soil sample was a composite of 4 cores taken with a 2.5-cm diameter soil auger. Soil samples were brought back to the laboratory and frozen until processed. Samples were then air dried (as recommended by Tan, 1996) for two days on greenhouse benches, sieved, and stored frozen until analyzed. Nitrate content of soil samples was determined by reduction of NO_3^- to NO_2^- using a Lachat Quick-Chem 8000 analyzer (Charette and Buesseler, 2004).

Statistical Analysis

The decomposition rate study was a randomized complete block design with three replications. The percentage of remaining mass in the mesh bags (%RM) was calculated from the remaining mass (RMt) at each sample period (t) and the initial mass (IM0) (Murungu et al., 2001):

$\%RM = 100RM_t = IM_0$

Data shown in figures are the arithmetic means of three replicates of each treatment, and error bars give the standard error. Cover crops and tilling system were considered as fixed effects, while year and block were considered random. All variables were a continuous array of treatments, so trends due to cover crop residue N, lignin, cellulose, and dry matter loss during the decomposition process were assessed by regression analysis using the SAS General Linear Model's procedure (SAS, v. 9.2, Cary, NC) (Steel and Torrie (1980). Effects were considered significant at $P \leq 0.05$ by the *F* test, and when the *F* test was significant, Least Significant Difference Test was used for mean separations.

Results and discussion

Cover crop biomass and N yield

Forage radish produced the highest biomass yield of 3460 kg ha^{-1} followed by peas and rye (3100 and 2425 kg ha^{-1}, respectively). In this study, we only used shoots of rye and peas; however, since forage radish produces large fleshy taproots, samples of forage radish roots also were used in addition to the shoots (Table 1).

Forage radish and winter peas have a rapid growth and establishment in the fall and can accumulate substantial amount of biomass if planted early in the fall (Kuo et al., 1997; Williams and Weil, 2004). The forage radish and peas yields in our study were similar to those reported by Holderbaum et al. (1990) and White and Weil (2010); however, rye dry matter yield was lower than expected and reported by Herbert et al. (1995) and Lui (1997) at the same planting date. Low dry matter yield of rye could partly be attributed to the rye variety which was distributed in Massachusetts in 2012 and 2013. Most growers experienced a poor crop growth especially in fall. Reports by Hashemi et al. (2013) and Herbert et al. (1995) indicated that rye dry matter yield prior to corn silage planting in early May at similar location were significantly higher than yield obtained in the current study. Another reason for unexpected lower yield of rye as cover crop is related to the earlier termination time which was mid-April as oppose to late April in above mentioned reports. In both years, rye cover crop was incorporated into soil in mid-April for early planting potatoes in late April. Therefore, winter rye cover crop could not probably provide sufficient N to the succeeding potatoes in our study (Table 1).

The highest tissue nitrogen content of 3.85% was in peas followed by forage radish and rye (Table 1). Austrian winter peas produce abundant vining forage, and as nitrogen fixing plants are considered as top N producers that can yield from 50 to 190 kg N ha^{-1} and at times up to 300 kg N ha^{-1} (SARE, 2007). However, forage radish yielded more N per hectare than peas considering both shoots and roots (Table 1). Relatively high nitrogen content of forage radish could be attributed to its roots ability in scavenging residual nitrogen from top soil and lower levels of soil (Kermen, 2006). Forage radish produces a large fleshy taproot, typically 3 to 6 cm in diameter and 15 to 30 cm in length

In addition, the long singular taproot of forage radish may penetrate as deep as 5 feet in the soil, making it able to scavenge the leached nitrate from lower levels of soil. While major part of N in peas, as a legume, was derived from N_2 fixation, N in forage radish and rye came from mineralized soil organic N or residual mineral N following the summer crop (Schomberg et al., 2006).

Table 1 also shows the C:N ratio of cover crops at the time of harvest. As expected with cereals, rye had a wider C:N ratio at the time of harvest than forage radish and winter peas. Greater C:N ratios than those obtained in this study have been reported for winter rye, mainly due to later termination. However values of C:N obtained in this study were comparable to those reported by several other researchers (Reeves 1994, Kelly, 2002).

Dry matter loss

Initial biomass of cover crops tissues was significantly affected by cover crop species and tilling systems at the time of each sampling ($P \leq 0.01$). In either conventional or no tilling system, a steady loss of dry matter over the decomposition period was observed (Figure 3). Cover crops lost a higher percentage of their initial biomass in tilling system compared with no till (Figure 3). Larger variations were observed by week 7, and dry matter losses showed smaller variations after week 7 (Figure 3).While forage radish and peas had lost almost 70 and 50% of their original dry matter by approximately week 6, rye had lost about 30% of its original dry matter by that time (Figure 3). The dry matter loss occurred at a slower rate in all of the cover crops in no till system; however, cover crops lost their initial biomass in a faster trend in conventional tilling system, and the decay stabilized 8 weeks after soil incorporation (Figure 3). For example, about 60% of initial biomass had been vanished in rye by week 6, whereas forage radish and peas had lost about 70% of their initial biomass at the same time. The numbers stabilized around 32% for rye and 13% and 10% for peas and forage radish, respectively (Figure 3). After weeks 7 and 9, the slope of the decomposition curve began to change and become more level in no till and conventional tilling system (Figure 3). These results contrast slightly with those of Liu (1997), who found that 50% of rye dry matter had been lost after 9 weeks. Several researchers have shown that conventional tilling systems may alter the decomposition process by breaking down the cover crop tissues into smaller parts and ultimately larger area is exposed to microbial activity as well as allowing for air to enter the soil (Wilson and Hargrove, 1986; Carrera et al., 2005). Also, wider C:N ratio of rye residues may contribute to the slower biomass loss in its tissue compared with forage radish and peas in conventional or no till system. Soon and Arshad (2006) also reported a slower decomposition rate and dry matter loss of wheat residues in comparison to pea and canola.

Nitrogen loss

The N content of cover crop residues tissues has been shown often to be an important determinant of decomposition patterns, especially during the early stages of decomposition. In order to manage residual N in the soil, it is important to understand the trend of N release in cover crop residues (Constantinides and Fownes, 1993; Quemada and Cabrera 1995, Kelly, 2002). Concentration of nitrogen in cover crops tissue samples and the patterns of N disappearance from residue under conventional and no-tillage conditions at the time of each sampling are shown in Figure 3. Our results showed that initial Kjeldahl N concentration of the cover crop samples followed the same trend as the dry weight, and the initial N samples started to decline as the interval of sampling increased in conventional and no till system. However, based on the regression lines for the two tillage methods, residue N disappearance occurred more rapidly under conventional tillage than no-tillage conditions.

In conventional tilling system, nitrogen decline was most rapid during the first few weeks after placement in forage radish and peas, and this trend leveled off in rye between weeks 2 to 7. Afterwards, N content continued to decline in rye residues (Figure 3). In both tilling systems, forage radish or peas showed a faster decline in nitrogen content compared with rye (Figure 3). For example, in no till system, rye, peas, and forage radish, had lost 69, 48, and 45%, respectively, of their initial N content by week 6, and these numbers dropped to 55, 30, and 25% at the same time in conventional tilling system. This more rapid disappearance of N is an expected result since the residue under conventional tillage is in a generally more favorable environment for microbial decomposition. According to Wilson and Hargrove (1986), cover crop residues in tillage systems lose a larger amount of their nitrogen content compared with conservative or no tilling systems. By week 12, percentage of N remaining in the residue had declined to 50 (forage radish), 32 (peas), and 24% (rye) for conventional and 32 (forage radish), 24 (peas), 14% (rye) in no-tillage conditions, respectively.

Cellulose

Cellulose level changes in the initial cover crop tissue were significantly affected by tilling systems and cover crops ($P \leq 0.01$). Forage radish lost a larger amount of its cellulose content compared with peas or rye and decreased from 28% of the plant tissue one week after incorporation to 12.5% of tissue by week 12. Peas also showed a 54% decrease in the cellulose content 12 weeks after incorporation (Figure 4). However, cellulose content in rye decreased at a slower trend compared with peas or rye (Figure 4). A similar trend was observed in conventional tilling system; however, the decomposition of cellulose occurred at a faster rate compared with no tilling system. For example, 12 weeks after incorporation, cellulose content was 26, 22, and 12% of the tissue sample in rye, peas, and forage radish, respectively, and these values declined to 16, 14, and 5% of the plant tissue in conventional tilling system. Several researchers have shown that legumes are generally lower in cellulose content than grasses, and also a faster decomposition rate is observed than with grasses. Also, the faster trend of cellulose loss in no till system compared with conventional tilling system might be associated with the more rapid changes in C to N in conventional tilling system (Magid et al., 2004).

Lignin

Contrary to the cellulose content, the percentage of lignin in cover crop tissue samples tended to increase following a linear trend through the decomposition process as the sampling interval increased (Figure 4). In no till system, the lignin content changes in all of the cover crops followed a similar trend by week 8; however, rye showed a faster increase in lignin percentage compared with peas and forage radish after week 8, which might be explained by higher concentration of lignin in rye compared with peas or forage radish (Figure 4) .

In no tilling system, lignin was 21, 17, and 16% of tissue sample in rye, peas, and forage radish, respectively, whereas tillage resulted in increased values of 26, 20, and 16% of the tissue As observed, conventional tilling system caused an increase in the lignin percentage in the cover crops tissue, which could be as a result of residue exposure to more light, heat, and microbial activity and ultimately faster degradation of readily decomposable biomass and consequently an increased ratio of the lignin. Lignin is a class of complex organic polymers and is one of the main classes of structural materials in the support tissues of vascular plants, and because they are resistant to decay, an increase in lignin to biomass ratio could be expected through the decomposition process (Franzluebbers et al, 1996). Increased ratio of lignin compared with the initial biomass through the decomposition process has been reported by other researchers (Magid et al., 2004; Kriauciuniene et al., 2008).

Changes in soil nitrate-N

Cover crops and tilling systems had a significant effect ($P \leq 0.01$) on the nitrate level changes in soil samples taken from the corresponding subplots at the time of each sampling. There was an increase in soil nitrate levels with increasing soil temperature after week 4. For example, soil nitrate-N in no-till rye plots decreased from 5 $\mu g\ N\ g^{-1}$ in week zero to 0.9 $\mu g\ N\ g^{-1}$ by week 4 and increased in a steady trend afterwards reaching its peak of 9 $\mu g\ N\ g^{-1}$ in week 12. Soil samples taken from forage radish and peas plots also showed decreases by week 4, and then an increase was observed through the decomposition process (Figure 5). Soil samples in forage radish and peas plots showed a relatively higher nitrate content than rye plots, probably because of higher N content and also faster release of N in residues as a result of narrower C:N ratio compared with rye. Soil incorporation resulted in increased soil nitrate levels at the top 20 cm of soil with the highest levels being recorded at forage radish plots (14 $\mu g\ N\ g^{-1}$ by week 6) followed by peas (11 $\mu g\ N\ g^{-1}$). The increasing trend of nitrate levels in rye plots occurred with the highest nitrate level of 11 μg N g^{-1} in week 12 (Figure 5). The increases of soil nitrate levels in conventional tilling systems could be attributed to increased microbial activity on plant residues as a result of tilling and also increased soil temperature in response to tilling. Also, tillage results in the oxidation and destruction of carbon in the soil by increasing the soil oxygen levels, thereby promoting bacteria populations to expand and consume plant residues in the soil.

Regardless of slight decreases in soil nitrate levels in cover crops 2 weeks after incorporation, overall nitrate levels tended to increase at the depth of 40 cm during the decomposition process in till or no till systems (Figure 5). However, a faster trend in nitrate release was observed in conventional tilling system (Figure 5). In no till system, the highest nitrate levels of 6.1, 4.9, and 4.1 μg N g^{-1} were recorded by week 12 (forage radish, peas, and rye, respectively), and these numbers reached their peak of 8 (forage radish, week 6), 7 (peas, week 7) and 6 μg N g^{-1} (rye, week 8) in conventional tilling system. According to our yield and nitrogen accumulation results, forage radish can take up a considerable substantial amount of nitrate through its roots and probably decomposition of root resides in the depth of 40 cm resulted in increased concentration of nitrate in the soil in the depth of 40 cm . Our results correspond to those reported by Dean and Weil (2009) who reported higher concentration of nitrate in lower levels of the soil in forage radish plots compared with rye plots. Regardless of the soil nitrate levels in the depth of 60 cm in no till plots, clear trends were evident in the growing pattern of changes in soil nitrate within each time of sampling (Figure 5). Figure 2 also shows the recorded data from soil temperature probes installed at a depth of 15 cm in the trenches on 6 subplots within the experimental plots. The temperature data indicate that a consistent and fairly sharp rise in soil temperature began at around the same time at the rise in soil nitrate in most of the occasions (Figure 5). The slopes of the temperature rise and the soil nitrate rise also appear similar. These data suggest that the simultaneous rise in soil nitrate seen in all three cover crops was the result of increasing soil temperature and consequent increased microbial activity and consequently, more mineralization of residues.

As in the case of the N concentration of the decomposing cover crop tissue samples, this pattern of rises in soil nitrate levels does not seem to support the idea that immobilization was occurring on the plots and that soil nitrate levels were not influenced by nitrate immobilization to any significant degree. The lack of definitive evidence for soil nitrate immobilization seen in this experiment was not expected, particularly given the higher C/N ratio of 20 seen in the rye tissue at the time of sampling. A likely explanation for the lack of an immobilization period apparently observed in this case may lie in the history of the cover cops plots or high organic matter content of soil. These two effects may have combined to create a soil environment in which plentiful N was available for microbial digestion of cover crop residues without the need for immobilization of nitrate in the surrounding soils.

Conclusion

Our results indicated that the effectiveness of released N and fertilizer value of cover crops depend on the rate at which the residues decompose. Conventional tilling system accelerated the decomposition process and also increased the rate of nutrient loss in the soil compared with no-till system. Among the cover crops used in this study, forage radish and peas accumulated more nitrogen content as well as yield per hectare than rye. Also, forage radish and peas with narrower C:N ratio released their N content in a faster trend than rye. Therefore, it is necessary to use cover crops with narrower C:N ratios for early planted cash crops in the spring to get the most out of the released nutrients from cover crops.

Table 1: Dry matter yield, nitrogen accumulation, and C:N ratio of rye, peas, and forage radish.

Cover crop		DM yield	N uptake	N content (tissue)	C:N
		……….kg ha^{-1}…….		%	
Rye	Shoot	2425	42	1.61	22
Peas	Shoot	3100	119	3.85	15
Forage Radish	Shoot	3460	96	2.79	12
	Root	2380	43	1.82	16
LSD (0.05)		124	18	0.89	5.8

Least significant difference at $P \leq 0.05$

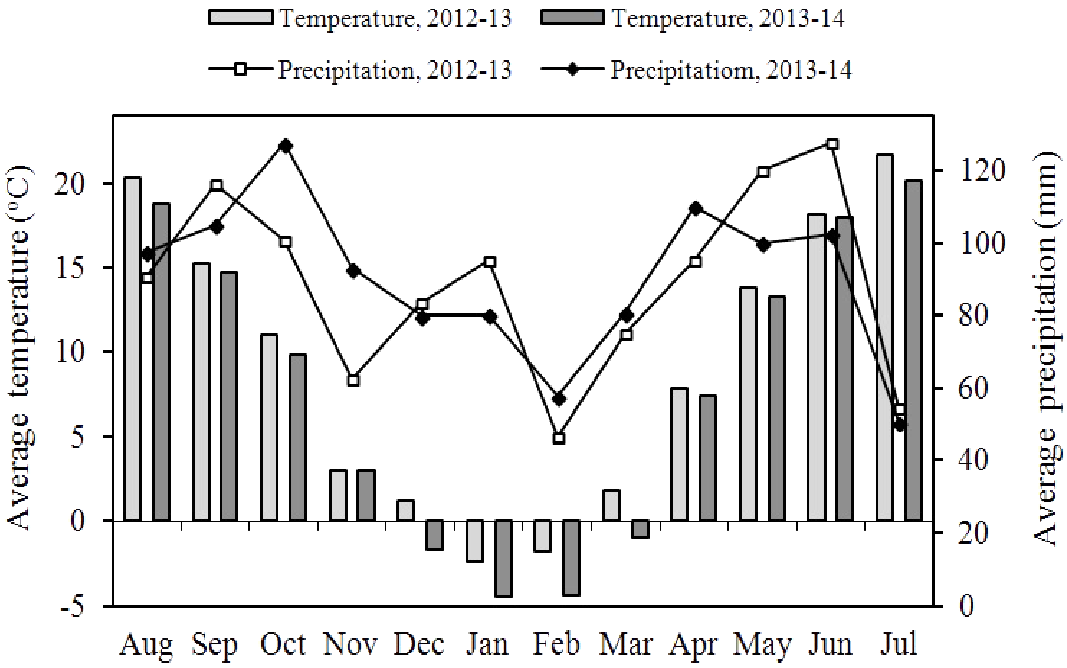

Figure 1: Monthly precipitation and average temperature during the first (August 2012- July 2013) and second (August 2013-July 2014) year of the experiment.

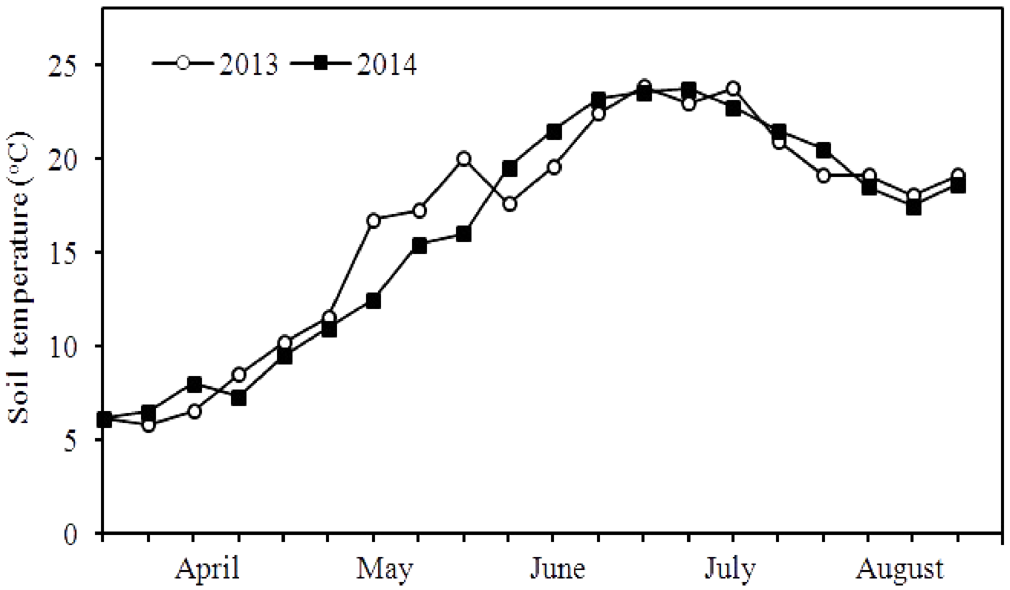

Figure 2: Soil temperatures during the first (April 2013- August 2013) and second (April 2014- August 2014) year of the experiment. Experiments were started at the second week of April after soil incorporation and placing/burying the decomposition bags on/ in the soil, respectively.

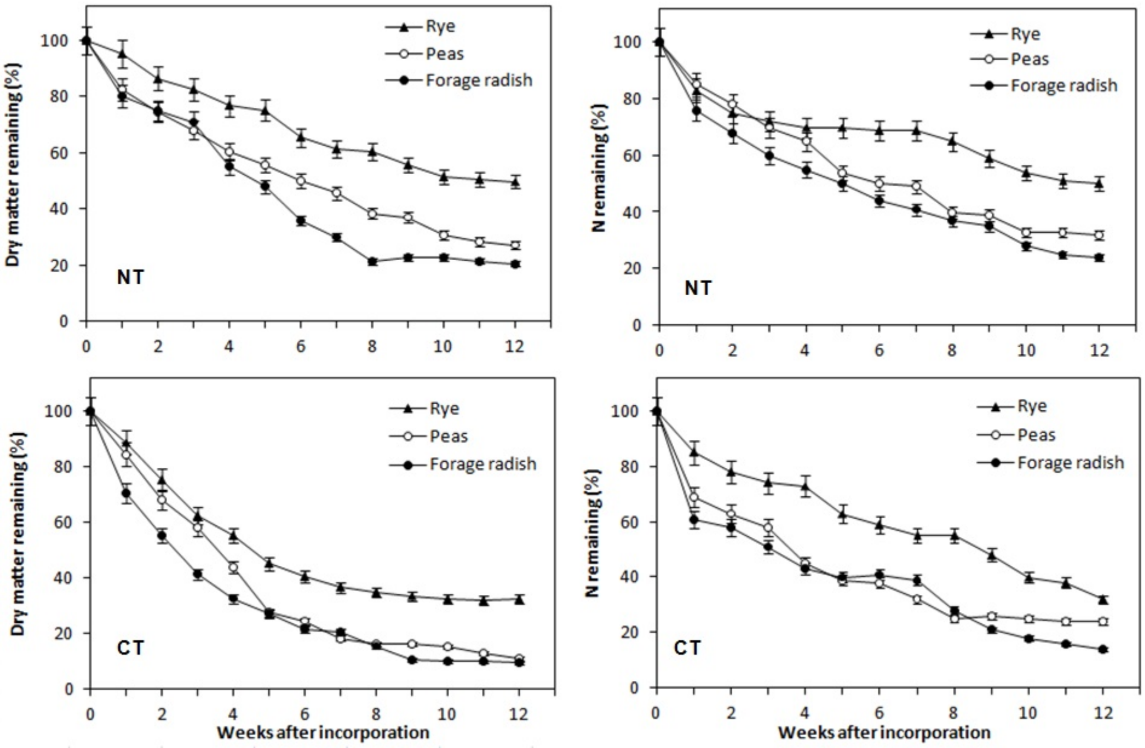

Figure 3: Dry matter and nitrogen remaining during the decomposition process as affected by cover crops and tilling system. NT and CT represent no-till and conventional tillage system, respectively.

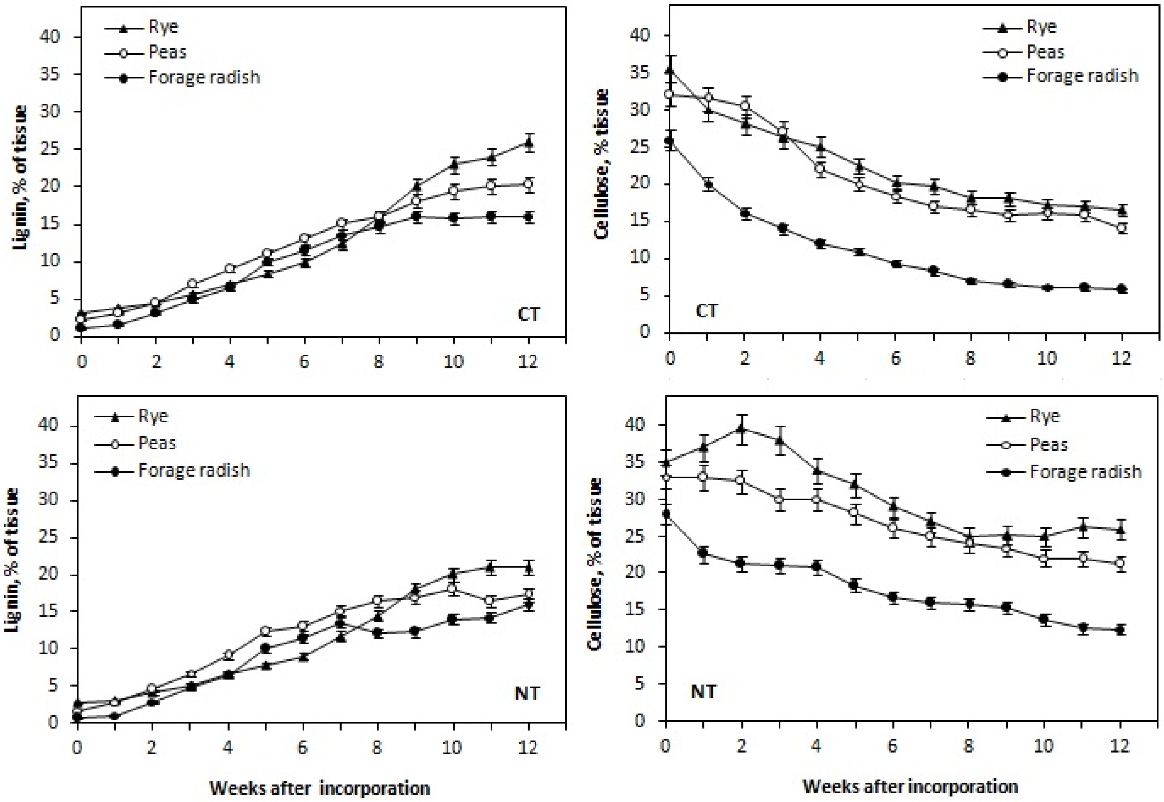

Figure 4: Lignin and cellulose changes during the decomposition process as affected by cover crops and tilling system. NT and CT represent no-till and conventional tillage system, respectively.

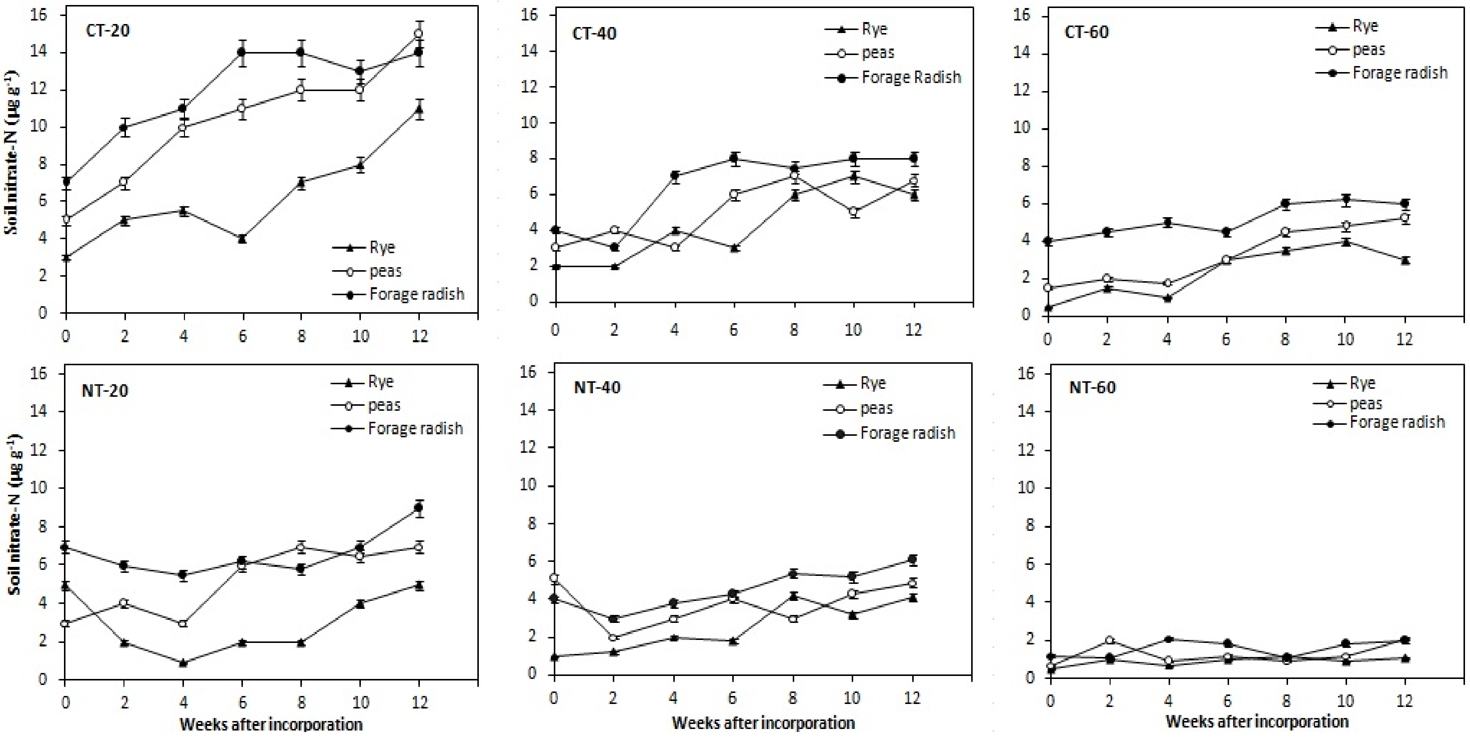

Figure 5: Soil nitrate changes with time after incorporation and at three depths and as influenced by cover crops and tilling system. NT and CT represent no-till and conventional tillage system, respectively. 20, 40, and 60 are depths of sampling in cm.

CHAPTER 4

EFFECT OF NITROGEN FERTILIZATION OF COVER CROPS ON TUBER YIELD AND NUTRIENT DENSITY OF DARK RED NORLAND AND SUPERIOR POTATOES

Abstract

The need for more food and environmental concerns have raised the necessity of alternative cropping systems that can alleviate environmental concerns and at the same time sustain crop production. Potato (*Solanum tuberosum* L.), as a staple food crop, relies on extensive fertilization to maintain high-yielding crops. This study evaluated the efficiency of three different cover crops including rye (*Secale cereale* L.), forage radish (*Raphanus sativus* L.), and winter peas (*Pisum sativum* L.), to supply nitrogen (N) to potatoes. We also studied tuber yield changes as affected by four N rates (0, 75, 150, and 225 kg N ha^{-1}) and two potato varieties, Dark Red Norland (DRN) and Superior (SUP). Our results indicated that potatoes planted after cover crops needed less N to produce the same yield as the potatoes grown in no cover crop plots and fertilized at the highest N rate (225 kg N ha^{-1}). Potatoes planted after forage radish produced the highest potato yield (31.5 Mg ha^{-1}) with 75 kg N ha^{-1} without any significant difference from 150 kg N Ha^{-1}. Potatoes planted after winter peas produced the highest yield (31.7 Mg ha^{-1}) with 150 kg Nha^{-1}. Potato yield was suppressed in cover crop plots where the highest N rate was applied (225 kg N ha^{-1}). The performance of rye was weaker than forage radish or peas; yet, yields following rye were the same with 150 kg N ha^{-1} or 225 kg N ha-^{1}. Potatoes planted after cover crops accumulated more nutrients in the tubers such as N, Sulfur (S), Boron (B) and Calcium (Ca) in both varieties. However, DRN tended to accumulate more nutrients than SUP. Overall, forage radish could be a better option than peas or rye in providing nutrients for an early planted cash crop in the spring such as potatoes.

Key words: Cover crop, forage radish, nutrient density, peas, potato, rye, tuber yield

Introduction

In recent decades, soil fertility issues associated with nutrient depletion by crop production has resulted in decreased arable lands and malnutrition in humans' diet, and in addition, increasing world population indicates the necessity of growing high-yielding crops to cope with emerging hunger and malnutrition that limit human productivity (Kataki and Babu, 2002; Welch, 2002; Welch and Graham, 1999; Tan et al., 2005). Potato is considered as one of the most important staple foods in industrialized and developing countries, and according to the International Potato Center, the worldwide demand for potatoes will exceed that of wheat or rice by 2020 in terms of human consumption and production volume (IPC, 2009). However, increasing demand for potatoes along with economic pressures have forced potato growers to move toward more intense production systems with extensive use of fertilizers and increased frequency of potato in crop rotations, actions that raise environmental concerns and costs of production (Munoz et al., 2005; Torstensson et al., 2006). An alternative fertility management practices to reduce synthetic fertilizer application seems crucial. Management practices such as tailoring N fertilizer rates and selecting appropriate type of cover crops in rotation with potato can reduce nutrient losses and can enhance farmers' profitability by cutting fertilizer costs (Delgado et al., 2004; Essah et al., 2012).

Cover crops play an important role in efficient nutrient cycling in cropping systems, (Kowalenko, 1987; Odhiambo and Bomke 2001), are a feasible option to cover the ground and restrict soil erosion (Liu et al., 2002), increase soil organic matter (Fageria, et al., 2005), alleviate subsoil compaction (Weil and Kremen, 2007), and suppress weeds and other pests (Fisk et al., 2001). Several studies have reported that continuous potato production without proper crop rotation and/or use of cover crops requires higher fertilizer rates to achieve high yielding potatoes (Fan and Mylavarapu, 2010; Rosen et al., 1999). However, Essah and Delgado (2009) found that excessive application of N fertilizer in a cover crop-potato rotation system reduced potato tuber yield and quality and that this response was dependent on the type of potato cultivar. In other words, in cases where the amount of N is increased to higher levels than needed, a negative effect could then be observed (Essah and Delgado, 2009).

Grass and legume winter annual cover crops are important components of sustainable cropping systems, facilitating nutrient cycling and providing soil and water conservation (Ranells and Wagger, 1997). Small grain cover crops, such as rye, can use a significant amount of residual soil and fertilizer N in the fall during the period of their rapid establishment (Meisinger et al., 1991). However, Neeteson (1988) reported low yields for potato following oat (*Avena sativa* L.), which is a cover crop with higher C:N ratio and low potential to release N. He found that, potato yields were slightly lower following legumes with otherwise optimal N fertilizer rates. On the other hand, Neeteson (1988) reported higher potato yields with low N fertilizer rates and following leguminous crops, such as red clover (*Trifolium pretense* L.) and alfalfa (*Medicago sativa* L.). Results from studies conducted by Sincik et al. (2008) indicated that potato following legume cover crops produced 36 to 38% higher tuber yields than potato following winter wheat (*Triticum aestivum* L.) when no N was applied. Vyn et al. (2000) in Canada found that cover crops, such as oilseed radish (*Raphanus sativus* L.), could serve as nutrient scavenger crops to recover residual soil nitrate and release it to the following crop. Essah et al (2012) and Delgado et al. (2007) also reported other benefits from cover crops and observed a 12 to 30% increase in total yield and marketable tubers when potato followed cover crops, with a greater increase in large tubers.

In addition to N, cover crops can scavenge and recycle other nutrients in soils and make them available for the succeeding crops once they are decomposed. White and Weil (2011) reported that shoots of both forage radish and rye cover crops have the potential to take up significant quantities of P when these cover crops are managed for maximum dry matter production. They also found that after 3 years of forage radish cover crops in a no-till system, soil

P in top soil moderately increased since forage radish cycled large quantities of P. They concluded that in the vicinity of forage radish root holes soil test P increased dramatically even when the total P cycled by the forage radish cover crops was small. Wang et al. (2008) studied nutrient recycling in brown mustard (*Brassica juncea*), oilseed radish, oriental mustard (*Brassica juncea*), and yellow mustard (*Sinapis alba*) and reported that brassica cover crop biomass accumulate a considerable amount of Calcium (Ca), Sulfur (S), and Boron (B), which can be released after they decompose. He reported that there was higher concentration of Magnesium (Mg), Iron (Fe), Cupper (Cu), and Zinc (Zn) in Sorghum Sudangrass [*Sorghum bicolor* (L.) Moench] compared with brassica cover crops. Eckert (1991) reported that winter rye cover crop increased the concentration of exchangeable K near soil surface by removing it from lower levels in the soil profile.

Rye is the most widely grown cover crop in the Northeast U.S due to its N-scavenging capacity and adaptability to the soils and climates of the region (Staver and Brinsfield, 1998; Hashemi et al, 2013). However, rye might not be a suitable source of N for the early planted cash crops in spring because of its relatively high C:N and therefore possibility of N tie up. Moreover, most of winter rye growth takes place in early spring which may interfere with early planting cash crops. Forage radish as a new cover crop in the region has shown strong nutrient recycling capacity. However its impact on potatoes production has not been investigated. There remains a need for studies on the effect of different cover crops on potato total tuber yield and also on tuber nutrient density. This study investigates whether adopting winter peas and forage radish, which are winter killed, can be a better cover crop option for growing potatoes compared with rye. Therefore, the main goal of this study was to evaluate potato tuber yield and nutrient density as affected by different N application rates and cover crops.

Materials and Methods

Experimental site

This experiment was conducted at the Crops and Animal Research and Education Farm of the University of Massachusetts in South Deerfield (42°28′37″ N, 72°36′2″ W), in 2011-2012 and 2012-2013 growing seasons. The soil type was a Hadley fine sandy loam (coarse-silty, mixed, superactive, nonacid, mesic Typic Udifluvent). The measured physical and chemical characteristics of the top 15 cm of soil are presented in table 2. Also, the mean annual precipitation during the growing seasons is presented in Figure 6.

Experimental Design and Cultural Practices

The experimental design was a randomized complete block replicated four times. Treatments included three types of cover crops (rye, forage radish, and winter peas) along with no cover crop plots, four N fertilizer rates (0, 75, 150, and 225 kg N ha^{-1}) supplied as urea, and two early-maturing potato varieties (Dark Red Norland and Superior). Cover crops were assigned to main plots and varieties and N fertilizer were in sub plots and sub-subplots, respectively. Prior to planting the experimental plots were plowed, disked, and leveled for planting. Rye, forage radish, and winter peas were planted using a small grain drill (Kincaid Manufacturing, Haven, KS, USA) at the seeding rates of 100, 9, and 120 kg ha^{-1} respectively. Planting occurred on September 2 in 2011 and August 25 in 2012. Winter peas was inoculated by *Rhizobium leguminosarum* just before planting. Winter peas and forage radish were winter killed in early December, while rye survived the winter. Early in the spring, cover crop residues along with rye were plowed under and seed potatoes were planted using a small potato planter on May 3 and April 29 in 2012 and 2013, respectively. Prior to planting, whole potatoes were cut into smaller seed pieces with each having at least two eyes. To prevent soil fungi infection, cut seeds were stored at room temperature for 4 days to heal. Plots were 7-m long, and rows were 0.9 apart. Also, potato plants were 0.2 m apart on the rows. Each subplot consisted of three rows of potatoes in which, the middle row was for the harvest, and two rows on the sides were guard rows. Urea was applied with band placement alongside the hills and covered with soil when potatoes were in their vegetative growth stage (Growth stage II). Potatoes were hand harvested on August 7 and 10 in 2012 and 2013, respectively. Excluding guard rows, 5 meters of potato tubers were harvested from the middle row and used for yield calculation. A subsample of potato tubers was selected randomly from the middle row to be analyzed for plant nutrients. Potato tubers were washed once in tap water and twice in de-ionized water and oven dried at 70°C. Dried samples were then ground using a Wiley Mill, 0.5 g of ground samples was burnt at 500°C for 8 h in a furnace, and the ash was dissolved in 10% HCl (v/v) prepared with distilled H_2O and concentrated HCl. Afterwards, the solutions were filtered and analyzed for mineral element concentration by inductively coupled plasma spectrophotometry (Jones Jr. et al., 1991; Kalra, 1998).

Statistical analysis

Analysis of variance was by PROC ANOVA procedure of SAS (SAS, v. 9.2, Cary, NC). Nitrogen fertilizer levels, potato varieties, and cover crops were considered as fixed effects, and year and block were considered random. Effects were considered significant at $P \leq 0.05$ by the F test, and when the F test was significant, Least Significant Difference Test was used for mean separations. Trends due to N application were assessed by regression analysis.

Results and discussion

Potato tuber yield

The results of ANOVA showed that potato tuber yield was affected significantly by N fertilization, cover crops, and N by cover crop interaction effect (Table 3). Regression analysis of potato tuber yield showed that total yield increased with higher N rates; however, the yield response was quadratic in the ranges between 0 to 225 kg N ha^{-1} (Figure 7). Increasing N rate from 0 to 75 and 150 kg ha^{-1} resulted in 23 and 37% tuber yield increase, respectively. There was a 2% decline in tuber yield when plants were fertilized at 225 kg N ha^{-1} (Figure 7).

Nitrogen is one of the most important key nutrients for plant growth, and an adequate early season N supply is important to support vegetative growth of potato and high tuber production. The positive yield response to N fertilizer is well documented (Jenkins and Nelson, 1992; Errebhi et al., 1998; Atkinson et al., 2003). (Jenkins and Nelson, 1992; Errebhi et al., 1998; Atkinson et al., 2003). However, excessive soil N later in the season can delay maturity of tubers and suppress tuber initiation, limit yields, and decrease the specific gravity in some cultivars (Rosen and Bierman, 2008).

Tuber yield was influenced significantly by cover crops (Figure 8). Potatoes planted after forage radish or winter peas produced higher tuber yield (24.9 and 25.3 Mg ha^{-1}, respectively) than rye or no cover crops plots (Figure 8). Cover crops can accumulate substantial biomass and potentially available organic N; therefore, they have been have been promoted as a means of maximizing the efficient use of available N to subsequent crops in agricultural systems (Shipley et al., 1992; Decker et al., 1994). The quantity of cover crop N is available to a subsequent crop is species–dependent and usually associated with greater availability of N from legumes than from nonlegume cover crops (Dekker et al., 1994; Torbert et al., 1996; Vyn et al.s, 1999). Forage radish has a rapid fall growth and has the potential to capture N in large amounts and from deep in the soil profile and release it to the succeeding crops (Kremen and Weil (2006). Vyn et al. (1999) also found that cover crops, such as radish, could serve as scavenger crop that can recover residual soil nitrate and potentially cycle it to the following crop. Winter peas as a legume is a N fixer cover crop and produces significant amount of aerial tissue with relatively high N percentage which can readily be available to the following crop (Sarrantonio, 1994). In our study winter rye, did not provide sufficient N to the potatoes. This was partly due to the fact that rye was killed early in the spring so experimental plots were prepared for planting potatoes. This resulted in unsatisfactory biomass accumulation which could explain less tuber yield in rye plots compared with forage radish and peas. However, potatoes grown in winter rye plots out yielded those with no cover crops about 5 Mg ha^{-1}.

The significant interaction between cover crops and N fertilization may further clarify the efficiency of cover crops in providing N to the proceeding potatoes (Figure 9). In plots with no cover crop tuber yield showed an increasing trend as fertilizer application rate increased thus highest yield resulted from application of the highest fertilizer rate (225 kg N ha^{-1}) (Figure 9). Potatoes planted after cover crops, regardless of the species, reached their yield peak at lower N rates when compared with no cover crops plots (Figure 9). For example, potatoes planted after forage radish produced highest yield with application of only 75 kg ha^{-1} whereas peas reached their peak yield of 31.7 Mg ha^{-1} when plants were fertilized at 150 kg N ha^{-1} (Figure 9). Similarly, potatoes after winter rye required 150 kg N ha^{-1} to reach its maximum yield. The overall results of this study indicates that potatoes planted after cover crops were less dependent on synthetic fertilizer and significant savings in fertilizer purchase and lower risk of environmental pollution enhance sustainability of potatoes cultivation in Northeast region . The significant interaction between N application and potato varieties indicates that varieties responded differently to the N rates (Figure 10). Increasing N rates from 0 to 150 kg ha^{-1} boosted tuber yield in both verities, however, increasing N rate to 225 kg ha^{-1} resulted in 7% yield decline in DRN (Figure 10). In contrast, SUP showed a positive yield response when plants were fertilized at 225 kg N ha^{-1}, which resulted in 2.7 Mg ha^{-1} yield increase compared with 150 kg N ha^{-1}.

Tuber nutrient density

Nutrient analysis of potato tubers showed that with exception of Calcium (Ca), DRN accumulated more macronutrients in its tubers than SUP variety (Table 4). For example N and K accumulation in DRN were 9% and 6% higher than SUP, respectively. Superior, however, accumulated more Ca compared with DRN (Table 4). Among micronutrients DRN had a higher Fe and Zn concentrations compared with SUP. The two varieties were not different significantly in terms of Boron (B), Cupper (Cu), Manganese (Mn), and Nickel (Ni) concentration (Table 4). In general, potatoes planted after cover crops accumulated more nutrients than those grown in no cover crop plots (Table 5).

Nitrogen concentration in potato tubers planted after forage radish and peas were similar (1.90%) followed by rye and plots without cover crops (NCC) (1.69 and 1.44%, respectively). Potatoes planted after cover crops were similar in terms of phosphorus (P) concentration and showed 41% increase in P content on average compared with NCC (Table 5). Grasses in general require and uptake more K from soil than legumes. Among cover crops and NCC plots, potato tubers tended to accumulate more K after rye (2.81%) whereas the difference between forage radish and peas was not significant (Table 5). According to Eckert (1991), rye can increase the concentration of exchangeable potassium (K) near the soil surface, by bringing it up from lower in the soil profile, an action that may be the reason for higher concentration of K in potatoes planted following rye in this study.

Magnesium (Mg) and Ca concentrations in potato tubers followed the same trend in no-cover crop plots and cover crop plots with the NCC treatment having the lower concentrations (Table 5). While concentration of Sulfur (S) was not affected by peas, rye, or NCC, potatoes planted after forage radish accumulated a significant higher percentage of S in their tubers (Table 5). Also, potato tubers accumulated more B compared to the other treatments in forage radish plots whereas peas, rye, and no cover crop plots were similar with this regard (Table 5). Forage radishes can take up large amounts of nutrients, especially N, P, S, Ca, and B because of its specific root characteristics (SARE, 2007, and 2013), results that may explain higher concentrations of some macro or micronutrients in potatoes planted after forage radish. Potatoes also accumulated more Zn or Mn in cover crop plots compared with no cover crop plots;

however, the Zn and Mn changes in tubers were not significantly different among cover crops (Table 5).

Nitrogen concentration in potato tubers followed a quadratic trend in response to N fertilization (Table 6), and increasing N rate from 0 to 75 and to 150 kg ha^{-1} resulted in 0.63 and 1.7% increase in N concentration, respectively. However, application of 225 kg N ha^{-1} did not further increase N content of tubers (Table 6). Increased N concentration as a result of N fertilization has been reported in other studies (Alva, et al., 2002; Haase et al., 2007; Van Delden, 2001). While P and K concentrations were not influenced by N application, Mg concentration increased linearly in respond to the N application (Table 6). Unfertilized potatoes along with plants fertilized at 75 kg N ha^{-1} did not show a significant difference in terms of Mg concentration; however, 150 or 225 kg N ha^{-1} increased Mg concentration to 1.67 and 1.92%, respectively. Calcium concentration also followed the same trend and ranged from 0.66% in un-fertilized plants to 1.66% where 225 kg N ha^{-1} was applied (Table 6). Our results were in accordance to those reported by Chase and Henry (1997) who found a slight increase in Mg and Ca concentration in response to N application and in contrast to Barunawati (2013) who found no difference in concentration of the nutrients affected by N fertilization. Also Ciampitti et al. (2013) reported that P, K, and S levels were not influenced by N application. In contrast, Heidari et al. (2012) reported a positive relationship between P and K concentration and N treatments.

In addition to the main effects of treatments, S and Fe concentration of potato tubers were affected by a significant interaction between cover crop and N fertilization and variety by N fertilization (Table 7). However, because of the small effect of these interactions they are not further discussed.

Conclusion

According to the results of our study, forage radish or winter peas could be used instead of rye in potato production system in Massachusetts, because of higher available N for potatoes in forage radish and peas plots compared with rye. However, forage radish was advantageous over winter peas in terms of providing nutrients other than N as suggested by more nutrient dense potatoes.

Table 2: Selected properties of the top soil (0-15 cm) at the site of the experiment showing soil pH, organic matter, mechanical analysis, and Morgan Solution extractable nutrients.

Soil parameters	2011-2012	2012-2013
Soil pH	5.6	5.9
Organic matter (%)	1.2	1.4
Clay (%)	30	33
Silt (%)	12	15
Sand (%)	58	52
Soil texture	Sandy loam	Sandy loam
N (mg kg^{-1})	3	4
P (mg kg^{-1})	18	9
K (mg kg^{-1})	86	73
Ca (mg kg^{-1})	657	868
Mg (mg kg^{-1})	81	72
Zn (mg kg^{-1})	2.4	1.8
Cu (mg kg^{-1})	1.3	1.2
Mn (mg kg^{-1})	7.1	1.6
Fe (mg kg^{-1})	4.1	6.1
S (mg kg^{-1})	10.2	7.6

Table 3: ANOVA for influence of nitrogen, cover crop, and potato variety on tuber yield, macronutrients, and micronutrients concentrations.

SOV[†]	Tuber yield	Macronutrients						Micronutrients					
		N	P	K	Mg	Ca	S	B	Cu	Fe	Mn	Ni	Zn
Nitrogen (N)	**	**	NS	NS	*	*	NS	NS	NS	NS	*	NS	NS
Cover crop (C)	**	**	*	**	**	*	*	**	NS	*	NS	NS	*
Variety (V)	*	**	NS	*	NS	*	NS	NS	*	**	NS	NS	**
N × C	**	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N × V	*	*	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS
C × V	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS
N×V×C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[†] SOV, source of variation.

NS, non-significant; *, significant at $P \leq 0.05$; **, significant at $P \leq 0.01$.

Table 4: Macronutrient and micronutrient concentration in the tubers of Dark Red Norland (DRN) and Superior (SUP) potatoes.

Variety	Macronutrient concentration					
	N	P	K	Mg	Ca	S
	……………………………………………%…………………………………………………………………					
DRN	1.81	0.58	2.76	2.08	0.87	0.25
SUP	1.65	0.50	2.59	1.86	1.41	0.28
LSD (0.05)	0.08	0.12	0.16	0.46	0.38	0.04
	Micronutrient concentration					
	B	Cu	Fe	Mn	Ni	Zn
	………………………………………… $mgkg^{-1}$ …………………………………………………					
DRN	16	19	121	26	1.06	43
SUP	13	14	100	22	1.12	34
LSD (0.05)	5	6	17	9	0.07	8

Table 5: Influence of cover crops and no cover cropping (NCC) on the concentration of macronutrients and micronutrients in potato tubers.

Cover crop	Macronutrient concentration					
	N	P	K	Mg	ca	S
	………………………………	………	…%, dry wt…	………	………	………
Peas	1.91	0.48	2.45	1.96	0.97	0.21
Rye	1.69	0.51	2.81	1.84	1.18	0.25
Forage radish	1.90	0.55	2.52	1.97	1.71	0.35
NCC	1.44	0.36	1.50	1.81	0.86	0.24
LSD (0.05)	0.18	0.11	0.25	0.09	0.43	0.10
	Micronutrient concentration					
	B	Cu	Fe	Mn	Ni	Zn
	………………………………	………	…mg kg^{-1}, dry wt…	………	………	………
Peas	15	19	122	21	1.06	33
Rye	18	16	134	25	1.12	34
Forage radish	25	18	131	23	1.08	38
NCC	15	16	114	19	1.21	28
LSD (0.05)	6	4	14	7	0.07	8

Table 6: Effect of nitrogen fertilization on the concentration of macro and micronutrients in potato tubers.

Fertilizer (kg N ha^{-1})	Macronutrient concentration					
	N	P	K	Mg	ca	s
	………………………..…………%...					
0	0.72	0.53	2.65	1.22	0.66	0.19
75	1.35	0.54	2.76	1.27	1.05	0.18
150	2.42	0.55	2.64	1.67	1.56	0.24
225	2.12	0.54	2.18	1.92	1.66	0.21
Trend‡	Q**	NS	NS	L*	L*	NS

Fertilizer (kg N ha^{-1})	Micronutrient concentration					
	B	Cu	Fe	Mn	Ni	zn
	…………………….………………mg kg^{-1}..					
0	19	15	101	17.3	1.15	32
75	20	16	103	18.9	1.05	30
150	20	16	119	19.1	1.21	32
225	19	16.	117	19.4	1.18	33
Trend‡	NS	NS	NS	L*	NS	NS

NS, non-significant; *, significant regression at *P*≤ 0.05; **, significant at *P*≤ 0.01. ‡ Quadratic (Q) and linear (L) regression.

Table 7: Interaction of cover crop x N application on sulfur concentrations and interaction of potato cultivar x N application on iron concentrations in potato tubers.

Fertilizer (kg N ha^{-1})	Cover crop				Variety	
	Peas	Rye	Forage radish	NCC	DRN	Sup
	S (%)				Fe (mg kg^{-1})	
0	0.191	0.210	0.261	0.181	108	89
75	0.204	0.221	0.286	0.192	108	94
150	0.204	0.220	0.312	0.210	112	96
225	0.207	0.225	0.325	0.208	114	105

LSD (0.05) sulfur = 0.02; LSD (0.05) iron = 6

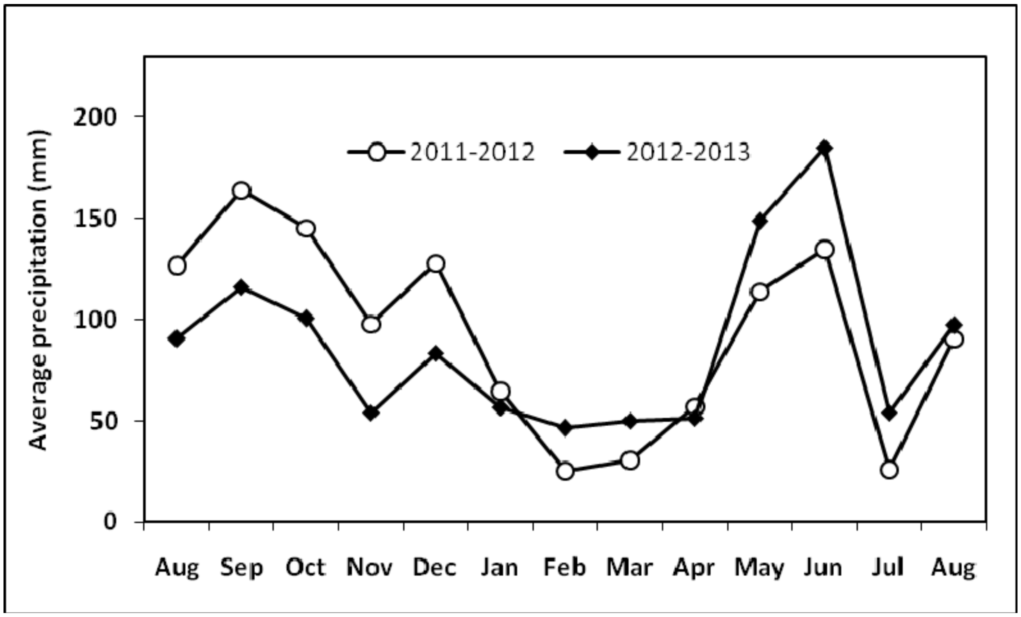

Figure 6: Average precipitation during the growing seasons in 2011-2012 and 2012-2013.

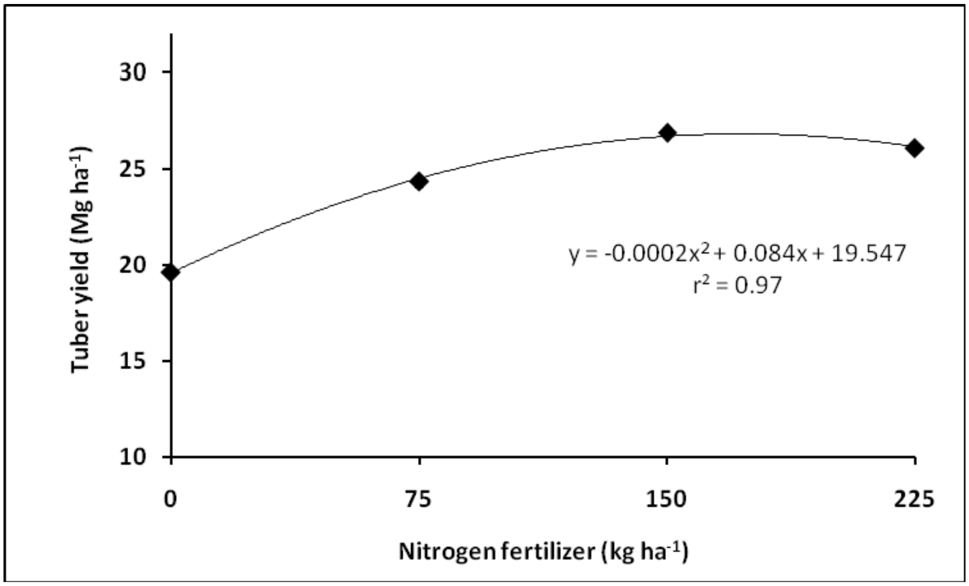

Figure 7: Potato tuber yield as influenced by nitrogen application.

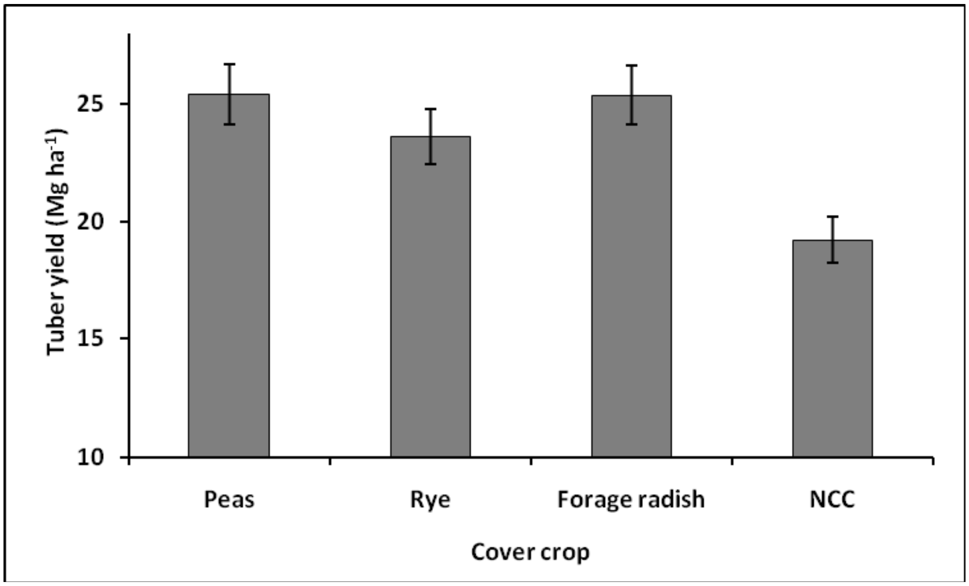

Figure 8: Potato tuber yield as affected by cover crops and no covering (NCC) system (LSD 0.05=1.58). Bars are standard error.

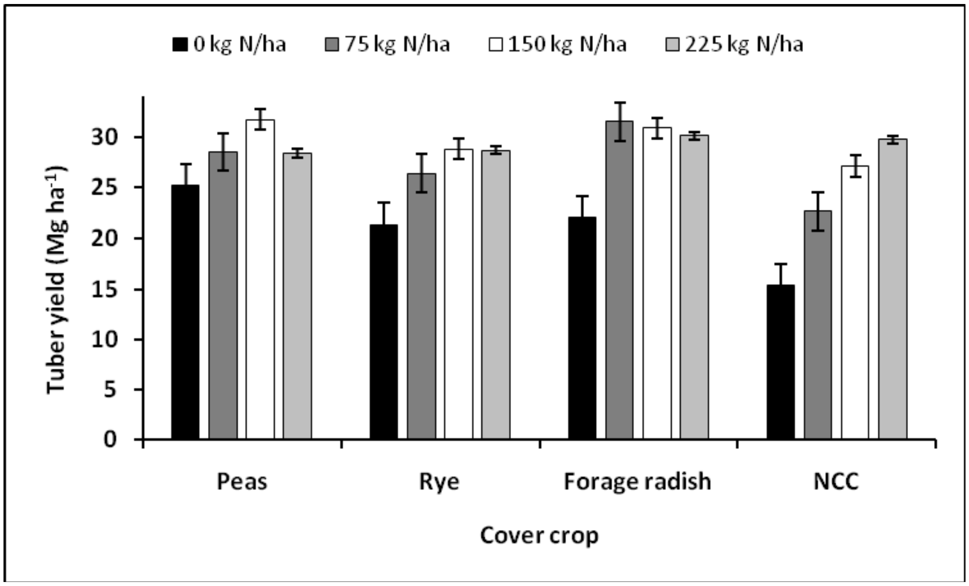

Figure 9: Interaction of nitrogen fertilizer × cover crop on potato tuber yield. LSD (0.05) = 1.48. Bars are standard error.

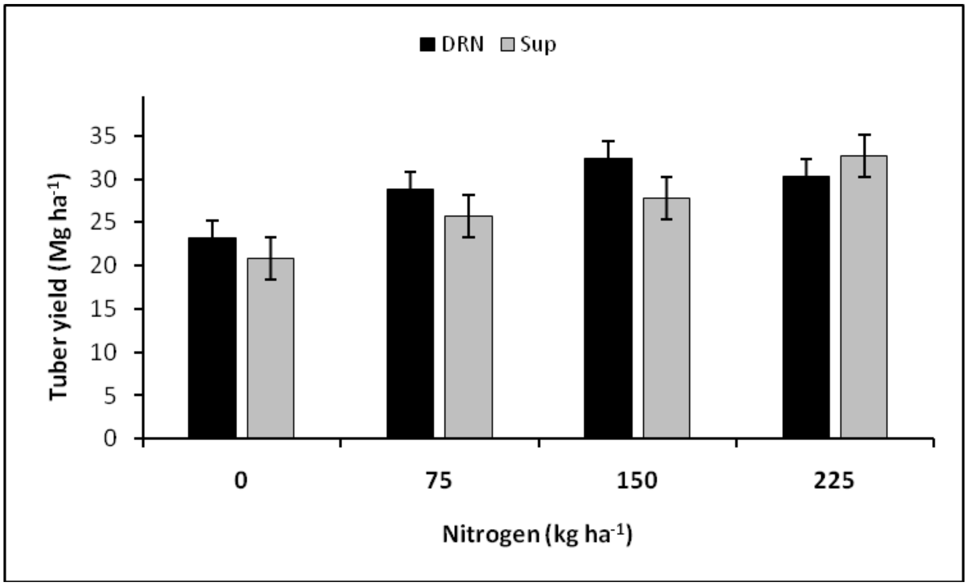

Figure 10: Interaction of nitrogen fertilizer × variety on potato tuber yield. LSD (0.05)= 2.08. DRN and SUP represent Dark Red Norland and Superior, respectively. Bars are standard error.

CHAPTER 5

TUBER YIELD AND NITROGEN USE EFFICIENCY INDICES OF DARK RED NORLAND AND SUPERIOR POTATOES AS INFLUENCED BY COVER CROPS AND NITROGEN FERTILIZATION

Abstract

Potato (*Solanum tuberosum* L.) is grown in many developing and industrialized countries as a staple food crop and relies on adequate nitrogen (N) fertilization to produce high-yielding tubers. Because farmers traditionally over-apply N fertilizer in potato production to guard against yield limitations, there is a need to continue developing new management practices to reduce N losses that affect air, soil, and water quality. Therefore, the effects of three N fertilizer rates (75, 150, and 225 kg N ha^{-1}) and cover crops [forage radish (*Raphanus sativus* L.), rye (*Secale cereale* L.), and winter peas (*Pisum sativum* L.)] on N-use efficiency (NUE) indices of Dark Red Norland (DRN) and Superior (SUP) potatoes were studied. Our results indicated that tuber yield and NUE indices can be restricted by very low or high levels of N fertilizer. Potato plants grown in no cover crop plots needed to be fertilized at a higher rate to produce the highest yield whereas potatoes after peas or forage radish produced the same or higher yields at lower N rates. Potatoes planted after cover crops showed more efficient use of N supply compared with no cover crop plots. Also, potato plants receiving N rates more than 150 kg N ha-^{1} exhibited lower NUE compared with lower N rates. Dark Red Norland tended to have higher yield and NUE regardless of the treatments than SUP.

Key words: Cover crop, nitrogen use efficiency, potato yield.

Introduction

Nitrogen (N) is generally the most limiting nutrient in crop production, but is also one of the most difficult to manage (Van Delden, 2001). Nitrogen is highly mobile in the soil, and there is generally a need for fertilization to meet N demands of crops, also, there is always a possibility for the fertilizer N will be lost from cropping systems, with consequent economic and environmental costs (Westermann and Kleinkopf, 1985). Potato, as a high-N demanding crop, is grown in many developing economies, and with proper selection of varieties and nutrient management practices, this crop can be cultivated and harvested during most parts of the year to feed the local population (Essah and Delgado, 2009). However, often farmers over apply N to ensure against yield suppressions. Therefore, there is a need to continue developing best management practices to increase N-use efficiency (NUE) while maximizing agricultural production, economic returns, and environmental sustainability (Essah and Delgado, 2009).

Included in these new methods and changes in agricultural systems for higher NUE practices are crop rotations, use of cover crops, viable N rates, and synchronization of inputs and N uptake sinks (Meisinger and Delgado 2002; Essah and Delgado, 2009). Several studies report that continues potato production without use of cover crops requires higher fertilizer rates to achieve high-yielding potatoes (Rosen et al., 1999; Fan and Mylavarapu, 2010). On the other hand, there have been reports of cover crops increasing the yield of the following crops (Dabney et al., 2001; Clark, 2007; Delgado et al., 2007). Grass and legume winter annual cover crops are important components of cropping systems, facilitating nutrient cycling and providing soil and water conservation (Ranells and Wagger, 1997). Small grain cover crops, such as rye, can use a significant amount of residual soil and fertilizer N in the fall during the period of their rapid establishment (Meisinger et al., 1991). However, Neeteson (1988) reported that lower yields were observed for potatoes following oat (*Avena sativa* L.) than with legumes. Oat a cover crop with a high C:N ratio and low potential for mineralization to release N. Therefore, there is a need for additional research on the potential benefits that cover crops may have on the yields of the following potato crop (Essah et al., 2012).

In a cover crop rotation system, crop residues are the main source of organic materials and nutrients in unfertilized plots. Release of organic N occurs during the process of decomposition of organic matter unless the C/N ratio is too wide. Much of the N in soil organic matter is bound in relatively stable organic compounds and therefore not readily available for crop growth (Sincik et al., 2008). Nitrogen present in soil organic matter can be an important source of soil fertility but is not always available at the right time and in sufficient quantity for crop growth. Availability of organic N sources is difficult to synchronize with crop demand (Pang and Letey, 2000), and the effectiveness of released N and fertilizer value of cover crops will depend on their ability to decompose and release nutrients in a synchrony with the cash crop N demands. Slow release of N from decomposing green manure residues may be well timed with plant uptake, possibility increasing N uptake efficiency and crop yield (Bath, 2000; Sinick et al., 2008; Wivstad, 1997). Therefore it is important to manage residue N effectively by knowing the pattern of N release from cover crop residue.

Rye is the most widely grown cover crop in the Northeast U.S.A., and its N-scavenging capacity and adaptability to the soils and climates in the region have been well documented (Staver and Brinsfield, 1998). However, it might not be an adequate source of N for the early-planted cash crops in the spring because it is not given the opportunity to re-grow in the spring and accumulate substantial amount of biomass and nitrogen. This study investigates whether including winter peas or forage radish can decrease N fertilization requirements and improve NUE and tuber production. The objectives of this study were to evaluate: (i) potato tuber yield and yield components and (ii) trend of N release from cover crops and NUE parameters in different cover crop species and N fertilizer rates.

Materials and Methods

Experimental Site

The experiment was conducted at the Crops and Animal Research and Education Farm of the University of Massachusetts in South Deerfield (42°28′37″ N, 72°36′2″ W), in 2012 and 2013. The soil type was a Hadley fine sandy loam (coarse-silty, mixed, superactive, nonacid, mesic Typic Udifluvent), and the selected soil physical and chemical characteristics of the surface 15 cm were as follows: 52% sand, 33% clay; ECEC 3 to 4 cmol kg^{-1}, pH 5.9 (l:l, soil: water), organic matter content of 1.4%, extractable N, P, K, and Ca content of 3, 9, 73, and 868 mg kg^{-1}, respectively.

Experimental Design and Cultural Practices

The experimental design was a randomized complete block replicated four times. Treatments included three types of cover crops (rye, forage radish, and winter peas) along with no cover crop plots, four N fertilizer rates (0, 75, 150, and 225 kg N ha^{-1}) supplied as urea, and two early-maturing potato varieties (DRN and SUP). Cover crops were assigned to main plots, and varieties and N fertilizer were in sub and sub-subplots, respectively. Prior to planting, the experimental plots were plowed, disked, and leveled for planting. Rye, forage radish, and winter peas were planted using a small grain drill (Kincaid Manufacturing, Haven, KS, USA) at the seeding rates of 100, 9, and 120 kg ha^{-1}, respectively. Planting occurred on September 2, 2011, and August 25, 2012. Winter peas was inoculated by *Rhizobium leguminosarum* just before planting. Winter peas and forage radish were terminated during the winter by frost killing, whereas rye over wintered. Early in the spring, cover crop residues along with rye were plowed under, and seed potatoes were planted using a small potato planter on May 3 and April 29 in 2012 and 2013, respectively. Prior to planting, whole potatoes were cut into smaller seed pieces with each having at least two eyes. To prevent soil fungi infection, cut seeds were stored at room temperature for 4 days to heal. Plots were 7-m long, and rows were 90-cm apart. Also, potato plants were 20-cm apart on the rows. Each subplot consisted of three rows of potatoes in which, the middle row was for the harvest, and two rows on the sides were guard rows. When potatoes were in their vegetative growth stage (Growth stage II), urea was applied with band placement alongside the hills and covered with soil. Potatoes were hand harvested on August 7 and 10 in 2012 and 2013, respectively. Excluding guard rows, 5 meters of potato tubers were harvested from the middle row for yield calculation. A subsample of potato tubers was selected randomly from the middle row to be analyzed for nitrogen content. Potato tubers were washed once in tap water and twice in de-ionized water and oven dried at 70°C. Dried samples were then ground using a Wiley Mill. A 0.5-g portion of ground samples was burnt at 500°C for 8 h in a furnace, and nitrogen content of plant tissue was determined using the Kjeldahl procedure (Bremner, 1996).

To examine the trend of N release in cover crop residues in the soil, we used a mesh-bag technique. Mesh bag preparation and sampling followed the methods of Wilson and Hargrove (1986), Stute and Posner (1995), and Liu (1997). Before cover crop termination in the winter and just before frost, forage radish and peas samples were harvested, and a portion of each sample was set aside for preparation of the mesh bags, and the remaining samples were dried for later analysis of Kjeldahl N. An approximately 100-g fresh sample from each species was weighed and placed in polyamide nylon mesh bags. Forage radish and winter peas samples were enclosed in the mesh bags and were placed on the soil surface and to prevent bags of getting dragged through the winter, they were fixed with a metal wire on the soil surface. Early in the spring, rye tissue samples were also harvested and put in the mesh bags using the method described above. Afterwards, mesh bags of all cover crops were buried 20cm deep in the soil at approximately the second week of April. Each block contained 13 mesh bags, and for each cover crop species, three replications were used. Mesh bags were recovered on a weekly basis (single bag was retrieved from each replication). At each retrieval time, the content of each bag was dried at 70°C, ground, and analyzed for Kjeldahl N according to Bremner (1996). The differences in N content of cover crop residues in each retrieval time was compared with the very first sample and with each other to determine the trend of N release from cover crop tissues.

Nitrogen use metrics

Nitrogen -use efficiency indices were calculated as described by Moll et al. (1982), Baligar et al. (2001) and Ball-Coelho et al. (2006):

N harvest index (NHI) = (shoot + root, or tuber N, accumulation/total N accumulation) × 100

N utilization efficiency (NUtE) = (shoot + root, or tuber, dry weight/total N accumulation) × 100

N use efficiency (NUE) = (kg tubers in N treated plots–kg tubers in unfertilized plots)/kg of applied N

Agronomic efficiency (AE) = kg biomass ha^{-1}/kg total applied N ha^{-1}.

Statistical analysis

Analysis of variance was conducted by PROC ANOVA procedure of SAS (SAS, v. 9.2, Cary, NC). Nitrogen fertilizer levels, potato varieties, and cover crops were considered as fixed effects, while year and block were considered random. Effects were considered significant at $P \leq 0.05$ by the *F* test, and when the *F* test was significant, Least Significant Difference Test was used for mean separations. Trends due to N application and cover crop residue N loss during the decomposition process were assessed by regression analysis (Steel and Torrie, 1980).

Results and discussion

Yield and yield components

Potato tuber yield and yield components were affected significantly by variety, cover crop, and nitrogen fertilization (Table 8). In general, most of the parameters had significantly higher means in potato plants that were planted after forage radish or winter peas than with rye or no cover crop plots (Table 8). Superior potatoes had taller plants and larger number of main stems per plant than DRN, whereas number of tubers per plant and mean tuber weight were higher in DRN (Table 8). Some potato varieties may exhibit different competition levels between source leaves and tuber sinks relative to other varieties in terms of partitioning assimilates (Mack and Schioerring, 2002).

Overall, plant height was higher in potatoes planted after cover crops, perhaps as a result of more available nitrogen in the soil for potatoes following cover crops. Also, potatoes planted after forage radish or peas had higher tuber weight than following rye or no cover crop (Table 8). As expected, N fertilization increased plant height and number of main stems per plant linearly (Table 8). These results agreed with previous studies which showed shoot growth is preferentially stimulated under high N supply (Goins et al., 2004; Mack and Schjoerring, 2002).

However, the number of tubers per plant and mean tuber weight responded to the N fertilization in a quadratic trend (Table 8). The number of tubers per plant increased from 7.12 in unfertilized plots to 9.55 and 9.67 if 75 and 150 kg N ha^{-1} were applied, respectively. However, further fertilization to 225 kg ha^{-1} resulted in 17% decrease in number of tubers per plant (Table 8). In a similar trend, tuber weight increased with fertilization, reaching its peak (89 g/tuber) at 150 kg N ha^{-1} whereas 225 kg N ha^{-1} limited the tuber weight to 73 g. Our results are in accordance with Sinick et al. (2008) who found similar responses to N fertilization with Marfona or Agria potato varieties.

Dark Red Norland produced higher tuber yield than Superior (Table 8). Also, potatoes planted after cover crops produced more yield than with no cover crop plots (Table 8). Tuber yield was the highest after peas or forage radish (26.1 and 26.7 Mg ha^{-1}) (Table 8). Presumably, higher tuber yield in potatoes planted after forage radish or peas could be explained by more synchrony with potato nitrogen demands and nitrogen release from these cover crop residues than with rye (Figures 11 and 12). Several studies have reported that potato yield after legumes and non-grass cover crops were higher than following cereal cover crops (Sarrantonio, 1994; Vyn et al., 1999; Kremen and Weil, 2006, Delgado et al., 2007).

The regression analysis of potato yield showed that increasing N rates increased potato yield in a quadratic trend (Table 8). Fertilized plants at 75 or 150 kg N ha^{-1} produced 34% more yield than unfertilized plots (Table 8). Nitrogen is one of the most important key nutrients for plant growth, and an adequate early season N supply is important to support vegetative growth of potato and high tuber production. Several studies have reported a potato yield increase as a result of N fertilization (Jenkins and Nelson, 1992; Errebhi et al., 1998; Atkinson et al., 2003). However, increasing N rate from 150 to 225 kg N ha^{-1} caused a 10% decrease in total yield in our study. Probably, higher N rates in addition to the released N from cover crop residues delayed tuber maturation by increasing the vegetative growth, resulting in a significant yield penalty in potato tubers. According to Rosen and Bierman (2008), excessive soil N can delay maturity of tubers and suppress tuber initiation, limit yields, and decrease the specific gravity in some cultivars. In addition, Sweetlove and Hill (2000) claimed that there is an apparent tradeoff between allocation of N to maintain photosynthesis activity of existing leaves and storage organ weight gain at high N rates. In contrast, Sinick et al. (2008) reported a linear increase in potato tuber yield with increasing N supply up to 225 kg ha^{-1}. Dark Red Norland, produced more marketable yield than Superior, also, more undersized and cull tubers were recorded in DRN (Table 8), a result that could be explained by overall higher tuber yield in DRN. In general, cover crops were similar in terms of marketable yield and produced more marketable yield than no cover crops plots (Table 8). Likewise, potatoes planted after forage radish or peas produced more undersized tubers and culls than with rye (Table 8). Nitrogen fertilization increased tuber marketability, fertilized plants at 75 and 150 kg N ha^{-1} produced 23 and 43% more marketable tubers than unfertilized plots (Table 8). However, application of 225 kg N ha^{-1} resulted in 740 kg less marketable tuber yield ha^{-1} than 150 kg N ha^{-1}.

Synchrony of nitrogen supply and crop demand

Figures 11 and 12 show the trend of released N from cover crop residues during the decomposition process and also dry matter accumulation in shoots and tubers of potatoes. Potato has its maximum N requirements during its tuber-bulking period (Stage III), which usually occurs 45-50 days after planting in early maturing potato varieties such as DRN or SUP. This growth stage usually lasts for about 4 weeks before the tubers enter the tuber maturation phase (Stage IV) (Sieczka et al., 1992). More available N in the soil during this period enhances tuber production (Westennann, 2005). Our results from the mesh bags indicated that peas and forage radish had lost 52 and 78% of their N content between weeks 6 to 10 whereas rye had lost 47 % of its N content compared with their N content at week 5 (Figures 11 and 12). Considering the higher N concentration of peas or forage radish than rye, and their release a large amount of their N content during the time potato had its highest N demands (between weeks 6 to 10), it could be concluded that a higher synchrony existed between forage radish or peas cover crops and potato plants in terms of timely N release by cover crop residues and potato N demands. However, Figures 11 and 12 also indicate a period of time in which, the released N from cover crops likely is lost because of an existing gap between planting and plant emergence and nutrient uptake. This result suggests the importance of earlier planting so that potato plants can get the most out of the released N from decomposing cover crops. According to Soon and Arshad (2006), cereal cover crops release their N content at a slower rate than legumes or brassicas.

Dry matter yield and nitrogen accumulation

Dark Red Norland accumulated more DM and N in its tubers than Superior (Table 9). In contrast, Superior accumulated more N in its vines, an action that could be as a result of differences in varieties or lower mobilization rate of N before vine desiccation in Superior compared to DRN. Also, potatoes after cover crops accumulated more DM and N in tubers and vines than with no cover crops plots (Table 9). Among cover crops, forage radish or peas produced more DM (4443 and 4400 kg ha^{-1}, respectively) whereas potatoes planted after rye or no cover crop plots produced 132 and 292 kg less DM ha^{-1} compared with the former ones. Probably, potato roots had access to more available N in the soil after forage radish or peas, resulting in higher N accumulation in vines or tubers. Nitrogen fertilization increased tuber DM from 3375 kg ha^{-1} in unfertilized plots to 4487 and 4863 kg ha^{-1} in fertilized plots (75 and 150 kg N ha^{-1}, respectively). However, higher N rate (225 kg ha^{-1}) resulted in 170 kg DM decrease ha^{-1} than 150 kg N ha^{-1}. Since the potato varieties used in this study were early maturing ones, they may have had a shortened tuber-bulking phase as a result of high N supply. Delayed tuber initiation can decrease DM yield when the time interval between planting and harvesting is not expended to accommodate the bulking phase (Goins et al, 2004).

The linear regression analysis of N accumulation indicated an increase in tuber and vine N accumulation with increasing N rates (Table 9). Turning to tuber N accumulation, however, the increasing trend continued up to 150 kg N ha^{-1} and further fertilization declined N accumulation in tubers (Table 9). Our results are in contrast to Zebarth et al. (2004) who reported a consistent growing amount of nitrogen in potato tubers with increasing N rates.

Nitrogen use metrics

Harvest index (HI), which is defined as the ratio of the total tuber yield to whole biomass production, may give a quantitative analysis of the partitioned assimilates to the tubers. In this study, HI was higher in DRN than Superior (Table 9). As mentioned earlier, potato varieties may differ in terms of partitioning assimilates to shoots or tubers (Mack and Schioerring, 2002).

Also, the proportion of N partitioned to tubers relative to the total N in the whole plant known as N harvest index (NHI) was higher in DRN than in Superior (Table 9). Nitrogen utilization efficiency (NUtE) shows the ability of plants to transform N acquired from fertilizer into economic yield (potato tubers). Our results did not show a significant difference between varieties with this regard (Table 9).

The highest HI value among cover crop treatments was observed in potato after peas (61%); however, the difference between cover crops was not significant (Table 9). Nitrogen harvest index also showed the same general trend as HI, and the differences among cover crops were not significant. Averaged over cover crops, there was an 11% significant increase in NHI compared with no cover crop plots (Table 9). Potatoes after forage radish had the highest NUtE; however, rye and peas were similar in this case (Table 9). Potato plants in no cover crop plots exhibited the lowest NUtE values with a significant difference from cover crop plots (Table 9).

The regression analysis of HI indicated a quadratic trend in response to N application (Table 9). Harvest index showed an 18% increase in fertilized plots on average compared to unfertilized plots; however, increasing N rate from 75 kg N ha^{-1} to 150 and 225 kg N ha^{-1} resulted in 6 and 7.3% decrease in HI, respectively (Table 9). Probably, plants fertilized at the highest N level produced significant quantities of shoot biomass. This possibility is important in that accumulation of N in the shoots has been shown to act as a signal to regulate shoot—root photosynthate in plants (Goins, et al, 2004). In other words, under ample N availability, a large proportion of N is stored as proteins in short or –long term pools in shoots (Djennane et al., 2002; Lawlor, 2002). According to the data presented in literature, potato HI decreases with the increase of N dose (Vos 1997, Mazurczyk and Lis 2000, Belanger et al., 2001). Nitrogen-utilization efficiency also showed the same trend as HI to the N application, whereas application of 75 kg N ha^{-1} increased NUtE from 61.27 to 64.85 kg kg^{-1}; further fertilization declined NUtE (Table 9).

Figure 13 shows the NUE of potatoes in different N rates and cover crops. A higher NUE suggests that most of the N applied was used in crop production, lowering potential of N losses to the environment, whereas a lower NUE suggests a higher probability that N is lost to the environment (Baligar et al. 2001). Overall, increasing N rates resulted in a significant decrease in NUE (Figure 13). Nitrogen-use efficiency in potato crops after forage radish or peas followed similar trend at all N levels; however, rye showed a different response to N rates, and no significant difference was observed between 75 and 150 kg N ha^{-1} (Figure 13). In contrast to cover crop plots, there was a 20% increase in NUE in no-cover crops plots as N rate increased to 150 kg N ha^{-1}, yet further fertilization led to a 7% less NUE (Figure 13). Presumably, as more N was taken up by plants under high N availability, less N was proportionately partitioned to tubers, and more N was directed into inedible biomass mostly represented by shoot tissue. It has been reported that NUE often is higher at lower N rates and decreases with increased N rate. According to Essah and Delgado (2009), NUE increased from 132 to 179 kg kg^{-1} as N rate increased from 67 to 90 kg ha^{-1}. They reported that application of 112 kg N ha^{-1} resulted in lower NUE.

Agronomic efficiency (AE), which reflects the proportion of total yield production to the N applied, showed the same general trends as NUE across treatments (Figure 14). In other words, as more N was applied and mainly accumulated in the shoot tissue, AE decreased as well. Perhaps this result can be attributed to an earlier tuber initiation observed in plants that received lower N supply. These findings agreed with a common notion that high N supply promotes new leaf tissue growth (Gastal and Lemaire, 2002), often at the expense of storage organs (Westernman et al., 1988).

Conclusion

In conclusion, cover crops, especially peas or forage radish were efficient in reducing nitrogen fertilization requirements in both potato varieties as indicated by higher nitrogen-use efficiency parameters. Potatoes planted after cover crops were less efficient in utilization of the supplied N than potatoes following cover crops. Application of high rates of N fertilizer decreased nitrogen-use efficiency parameters through enhanced vegetative growth or probably environmental losses. Forage radish or peas exhibited more synchrony with potato N demands at its critical growth stages in terms of N release from residues; however, to have better utilization of released nutrients from cover crops, it is important to plant them as early as possible considering climatic conditions.

Table 8: Effect of potato varieties, cover crops, and nitrogen fertilization on tuber yield, yield components, and tuber size of Dark Red Norland (DRN) and Superior (SUP) potatoes.

variety	Plant height (cm)	Stem No. plant^{-1}	Tuber No. plant^{-1}	Mean Tuber weight, g tuber^{-1}	Total yield Mg ha^{-1}	Tuber size[#]					
						Marketable yield		Undersize		Culls	
						Mg ha^{-1}	%[¥]	kg ha^{-1}	%	kg ha^{-1}	%
DRN	65	4.2	11.2	83.3	26.7	21.3	83	824	3.3	2351	9.2
SUP	76	5.1	9.8	79.4	23.6	18.1	80	770	3.4	1492	6.4
LSD (0.05)	8	0.6	1.0	3.1	2.4	3.1	4.1	98	0.4	214	2.4
Cover crop											
Peas	74.6	4.5	9.5	85.2	26.1	21.0	83	818	3.1	2173	9.1
Rye	63.1	4.1	9.0	81.4	24.6	20.0	85	826	3.6	1809	7.8
Forage radish	72.2	4.4	9.4	84.0	26.3	21.5	84	862	3.4	2102	8.6
No cover crop	55.0	3.1	7.8	68.6	20.2	15.6	82	691	3.6	1304	6.5
LSD(0.05)	5.8	0.8	0.5	5.1	1.2	5.1	3.9	141	0.5	115	2.9
N (kg ha^{-1})											
0	53.2	3.0	7.1	62.4	20.6	15.8	77	666	3.6	1255	6.4
75	63.3	4.2	9.5	83.1	27.0	20.6	82	913	3.2	2521	9.8
150	69.1	4.8	9.6	88.6	27.8	22.7	82	930	3.4	2681	10.1
225	75.1	5.2	8.2	73.1	25.3	21.9	81	770	3.5	2064	8.8
Trend§	L	L	Q	Q	Q	L	NS	Q	0.4	Q	1.8
Cover Crop	**	*	*	**	**	*	-	*	-	**	-
Nitrogen	**	**	*	*	*	*	-	**	-	*	-
Variety	**	*	*	*	**	*	-	*	-	**	-

[¥] % of total yield; [#] Undersize indicates potatoes < 4.50 cm in diameter; Marketable indicates potatoes 4.5 cm < >10 cm in diameter; Culls indicate damaged, bruised, deformed, rotted, or oversized tubers; [§] Quadratic (Q) and linear (L) regression; *, significantly different at $P \leq 0.05$; **, significantly different at $P \leq 0.01$; NS, non-significant.

Table 9: Tuber dry matter yield (DMY), nitrogen accumulation, harvest index (HI), nitrogen harvest index (NHI), and nitrogen utilization efficiency (NUtE) of Dark Red Norland (DRN) and Superior (SUP) potatoes as influenced by varieties, cover crops, and nitrogen fertilization

Variety	Tuber DMY	N accumulation			HI	NHI	NUtE
		Tuber	Vine	Total			
	………………….kg ha^{1}…………………				……………….%…………….		kg kg^{-1}
DRN	4511	112	18	130	56.5	6.2	62
SUP	3807	93	19	111	52.1	5.0	66
LSD(0.05)	58	21	1	29	3.1	0.8	4.5
Cover crop							
Peas	4443	115	20	134	61.2	5.8	62
Rye	4268	104	17	120	57.1	6.2	60
Forage radish	4400	114	19	132	58.6	6.0	64
No cover crop	4108	89	14	104	56.1	5.4	58
LSD(0.05)	45	12.4	1.2	1.8	6.2	0.4	2.5
N (kg ha^{-1})							
0	3357	64	13	78	56.1	4.7	60
75	4487	91	15	106	65.3	5.1	65
150	4863	138	23	161	61.4	5.8	55
225	4693	130	28	157	58.0	6.5	49
Trend[§]	Q	Q	L	Q	Q	L	Q
SOV[†]							
Cover crop (C)	**	*	*	**	*	**	*
Nitrogen (N)	*	**	*	**	*	*	**
Variety (V)	**	*	NS	*	*	*	**

[§] Quadratic (Q) and linear (L) regression; [†] SOV, source of variation; *, significantly different at $P \leq 0.05$; **, significantly different at $P \leq 0.01$, NS, non-significant.

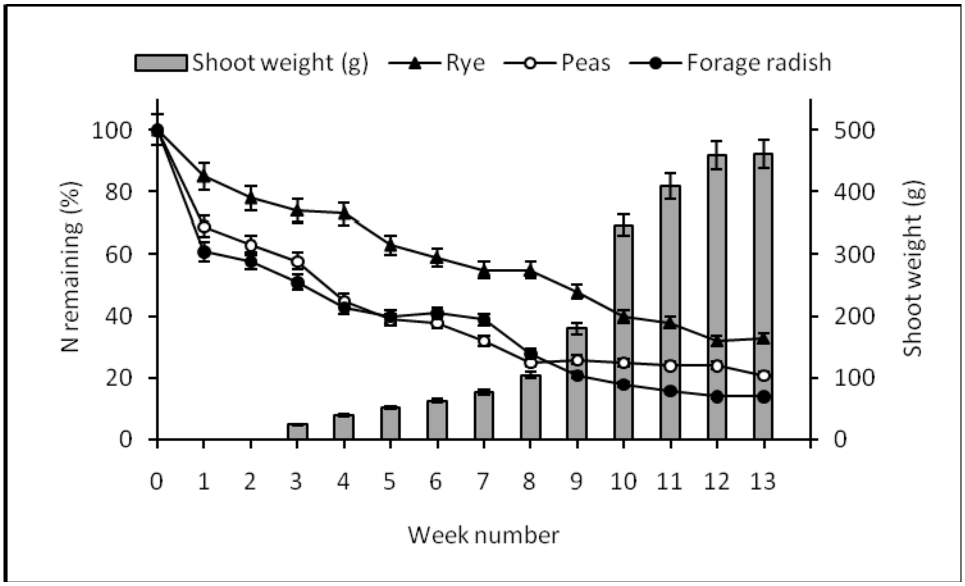

Figure 11: Nitrogen remaining from cover crops residues and potato shoot growth during the growing season in the mesh bag experiment. Vertical bars are standard errors. The horizontal axis represent weeks after planting potatoes.

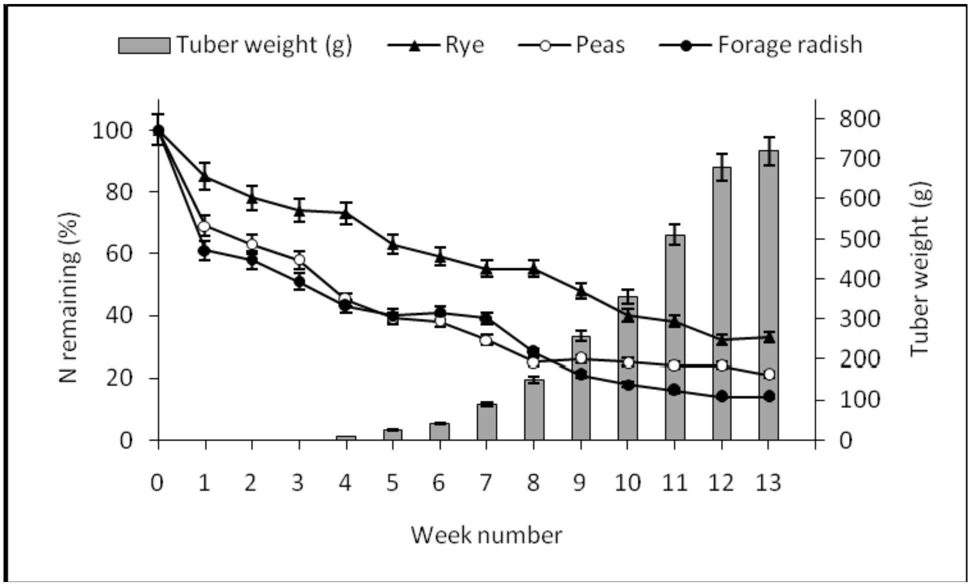

Figure12- Trend of released nitrogen from cover crops residues and potato tuber weight changes during the growing season. Vertical bars are standard error. The horizontal axis represent weeks after planting potatoes.

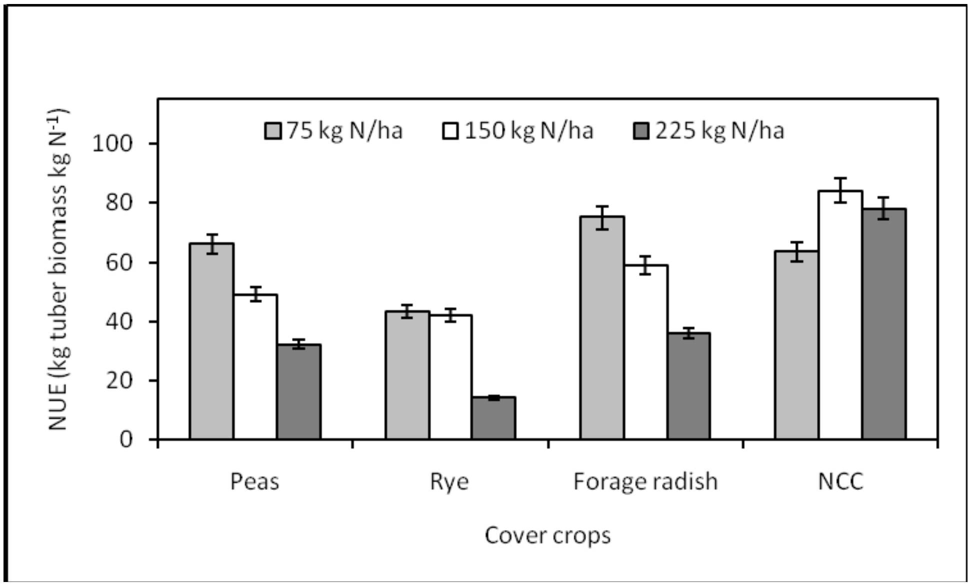

Figure 13: Interaction of cover crops and nitrogen fertilization on nitrogen- use efficiency (NUE) (LSD 0.05= 6.86). Vertical bars are standard error. NCC is no cover crop.

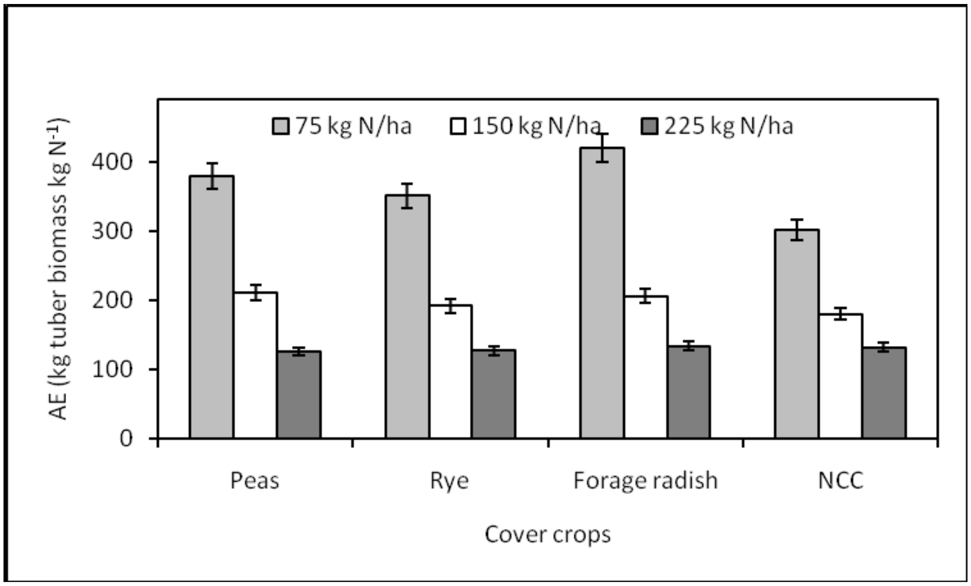

Figure 14: Interaction of cover crops and nitrogen fertilization on agronomic efficiency (AE) of potatoes (LSD 0.05= 41). Vertical bars are standard error. NCC is no cover crop.

CHAPTER 6

IMPROVEMENT OF TUBER QUALITY AND PEST MANAGEMENT IN DARK RED NORLAND AND SUPERIOR POTATOES WITH COVER CROPS

Abstract

Potato yield and quality can be affected by weed and pest pressure; therefore, growers employ intensive pest control methods that rely heavily on the use of pesticides and herbicides. Therefore, it is important to emphasize maximizing the beneficial, desirable ecological processes within farming systems that can maintain weed and pest populations at low, manageable levels and at the same time improve potato production and environmental conservation. This study evaluated tuber quality, Colorado potato beetle (CPB) and weed infestation in Dark Red Norland (DRN) and Superior (SUP) potatoes as affected by forage radish, peas, rye, and nitrogen (N) fertilization. Our results indicated that cover crops could not improve potato quality significantly and also could not suppress CPB population effectively. Weed infestation was lower in cover crops, especially forage radish and rye than with peas or fallow. Dark Red Norland and SUP were the same in terms of weed infestation; however, SUP had more resilience to CPB infestation than DRN. Overall, cove crops were efficient in terms of weed control than fallow, whereas no significant effect of cover crops on controlling CPB and improving potato tuber quality was observed in this study.

Key words: Colorado potato beetle, cover crop, nitrogen fertilizer, tuber quality, weeds

Introduction

Potato (*Solanum tuberosum* L.) is one of the most important staple food crops in the world. The annual per capita consumption ranges from 55 kg in the most affluent to 11 kg in developing countries (Tian et al., 2003). Fertilization, pest, and weed control are considered as crucial production issues in potato production system (Liebman and Davis, 2000). In conventional pest management strategies, pesticides and herbicides have been the major tactic used against the pests and weeds (Gauthier et al., 1981; Wright, 1984). The Colorado potato beetle (CPB) (*Leptinotarsa decemlineata* Say), is the most important insect defoliator of potatoes in much of the northeast region of North America (Wright, 1984; Weber and Ferro, 1994; Alyokhin et al., 2005a). Therefore, potato growers rely mostly on synthetic chemicals to control the CPB. However, overreliance on insecticides has raised input costs, environmental pollution, and insecticide resistance as a continuing problem in CPB management, especially in the eastern United States (Hare, 1980; Wright, 1984; Forgash, 1981; Alyokhin et al., 2005b).

Weed control, on the other hand, requires a complex approach to integrate the effect of different direct and indirect partially suppressive means (Barberi, 2002; Locke et al., 2002; Campiglia et al., 2009). Fertilization and weed control are related closely, as good crop nutrition and effective weed control enhance each other (Paolini and Campiglia, 2004; Campiglia et al., 2009). Therefore, alternate weed and pest control means are needed to provide a more diverse strategy for weed and pest management in an environmentally sound fashion (Wright, 1984).

In contrast, to conventional pest control systems, an ecological-based approach focuses on preventive practices and natural processes of population regulation with pesticides used only as therapeutic tools when needed. Emphasis is placed on maximizing the beneficial, desirable ecological processes within farming systems that can maintain weed and pest populations at low, manageable levels (Wright, 1984). Crop rotation is one cultural practice that can contribute significantly in weed and pest management. Cover crops are considered as an important component of crop rotation systems and increasingly are gaining attention in cropping systems worldwide. Diversification of the agroecosystem with cover crops can provide significant reductions in pest populations. A complex of inter-related processes accounts for pest and weed reductions in diversified systems (Trenbath 1993; Altieri 1994; Teasdale et al., 2002).

Winter annual cover crops typically are killed before summer crops are planted and leave residue on the surface of soils during the cropping season in no-till agriculture. This layer of cover crop residue can influence many factors that, in turn, influence the biological activity of weeds and pests in soils (Teasdale et al., 2002). Residue on the surface of soil can interfere with the establishment of weeds or any pest that emerges from soil by either physically impeding their emergence or dispersal, creating an unfavorable soil meteorological environment or releasing allelopathic substances (Teasdale et al., 2002). However, Ruppel and Sharpe (1985) reported that cover crop residues may encourage both pests and beneficial predators.

The live or dead plant material associated with use of cover crops is particularly suited to natural suppression of weeds and pests. Generally, a more diverse biological and physical environment at the surface of soils such as that associated with cover crops offers opportunities for regulating and minimizing pest populations (Teasdale et al., 2002). The formation of a physical barrier by cover crop residue is an important factor that can prevent emergence of weed seedlings or insect pests such as CPB, which over winters in the soils as adults (Weber and. Ferro, 1994). The cover also can hinder dispersal of pathogen spores. Residue physical properties have been shown to influence weed emergence by Teasdale and Mohler (2000) and would be expected to influence activity of most soil borne pest species. Once pests are established in a field, cover crops can interfere with pest populations by limiting dispersal, disrupting feeding, inhibiting reproduction, and enhancing mortality from predators and parasitoids (Teasdale et al., 2002). Management systems for cover crops can be designed to limit pest populations by either disrupting pest colonization of hosts or attracting natural enemies (Wright, 1984).

Chemical compounds released from cover crop residue have potential to stimulate or inhibit weed germination and growth (Liebman and Mohler 2001). Research has demonstrated the presence of allelochemicals that inhibit germination and growth of many weed species. On the other hand, nitrates released by legume residues can stimulate germination of selected weed species. In natural environments it is difficult to separate allelopathic effects from the physical effects. The degree of weed control provided by cover crops can vary according to cover crop species, residue biomass, and weed species (Liebman and Mohler 2001). Annual weed emergence is reduced by the biomass of residue on the soil surface (Teasdale and Mohler 2000). Generally, cover crop residue can be expected to provide early-season weed suppression but not full-season weed control. As a result, cover crops can contribute to weed control, but herbicides or other weed control tactics are required for achieving optimum weed control and crop yield.

However, cover crops can permit a reduction of herbicide inputs and a shift toward total post-emergence herbicide programs. Early weed suppression provided by cover crop residue should permit crops to become established before weeds (Teasdale et al., 2002). Cover cropping also has long and short-term weed control effects (Barberi, 2002), as a result of competition or allelopathy exerted by the crop (Randall et al., 1989; Boydston and Hang, 1995; Campiglia et al., 2009). These effects can enhance the effectiveness of other nonchemical weed control means in view of an effective integrated approach (Bond and Grundy, 2001; Campiglia et al., 2009; Creamer et al., 1996). Long-term weed control effects are due to the prevention of emergence and seedling suppression of species of different seasonality compared to the following crop, whereas short-term effects take place when emergence prevention and seedling suppression occur in species presenting the same seasonality of the following crop. However, timing of nutrient release from the organic residues may favor either the weeds or the crop depending on their relative growth rate and earliness of competitors (Davis and Liebman, 2001; Dyck et al., 1995; Paolini et al., 1999; Rasmussen, 1996). So, the absolute and relative importance of long and short-term weed control effects essentially depends on the type of weed infestation in the cover crop and on the type of weed infestation and the growing cycle of the following crop (Campiglia et al., 2009).

There is still need is a need for additional research on the potential benefits that cover crops may have on weed and CPB infestation in potato production system. The goal of this study was to evaluate the CPB and weed infestation in Dark Red Norland and Superior potatoes as influenced by forage radish, peas, rye cover crops, and nitrogen fertilization.

Materials and Methods

Experimental Site

The experiment was conducted at the Crops and Animal Research and Education Farm of the University of Massachusetts in South Deerfield (42°28′37″ N, 72°36′2″ W), in 2012 and 2013. The soil type was a Hadley fine sandy loam (coarse-silty, mixed, superactive, nonacid, mesic Typic Udifluvent), and the selected soil physical and chemical characteristics of the surface 15 cm were as follows: 52% sand, , 15% silt, and 33% clay; EC 3 to 4 cmol kg^{-1}, pH 5.9 (l:l, soil: water), organic matter content of 1.4%; and extractable N, P, K, and Ca content of 3, 9, 73, and 868 mg kg^{-1}, respectively.

Experimental Design and Cultural Practices

The experimental design was a randomized complete block replicated four times. Treatments included three types of cover crops (rye, forage radish, and winter peas) and no cover crop plots, four N fertilizer rates (0, 75, 150, and 225 kg N ha^{-1}) supplied as urea, and two early-maturing potato varieties (DRN and SUP). Cover crops were assigned to main plots, and varieties and N fertilizer were in sub and sub-subplots, respectively. Prior to planting, the experimental plots were plowed, disked, and leveled for planting. Rye, forage radish, and winter peas were planted using a small grain drill (Kincaid Manufacturing, Haven, KS, USA) at seeding rates of 100, 9, and 120 kg ha^{-1}, respectively. Planting occurred on September 2, 2011, and August 25, 2012. Winter peas was inoculated by *Rhizobium leguminosarum* just before planting. Winter peas and forage radish were terminated during the winter by frost killing, whereas rye over wintered. Early in the spring, cover crop residues along with rye were plowed under. Prior to planting, whole potatoes were cut into smaller seed pieces with each having at least two eyes. To prevent soil fungi infection, cut seeds were stored at room temperature for 4 days to heal. Seed potatoes were planted using a small potato planter on May 3 and April 29 in 2012 and 2013, respectively.

Plots were 7-m long, and rows were 90-cm apart. Also, potato plants were 20-cm apart on the rows. When potatoes were in their vegetative growth stage (Growth stage II), urea was applied with band placement alongside the hills and covered with soil.

Sampling and Data Collection

Weed biomass was collected using 0.1 m^2 quadrats from center rows of each plot with a hand mower and dried in a forced air oven at 55°C for 72 h and weighed. Weeds were separated based on the most dominant species in field, which were crabgrass (*Digitaria sanguinalis* L. Scop), common lambsquarters (*Chenopodium album* L.) and yellow nutsedge (*Cyperus esculentus* L.) in descending order and the other weed species were separated , weighed, and classified as other species. Since there are two generations of CPB in Massachusetts, insects were counted at two different times. Overwintering adults emerge in early May, locate a host, and begin to feed, mate, and lay eggs. Eggs hatch in about a week depending on temperature. The larvae go through 4 instars (growth stages) in the span of about two weeks. Fourth instar larvae drop from the plant and burrow into the ground to pupate. The pupal stage lasts about a week and marks the end of the first reproductive generation. Emergence of adults from these pupae -- the "summer adults" - marks the beginning of the 2nd generation. Insects were counted at weekly intervals in flagged area within each plot in May (overwintering adults) and July (summer adults). The summer adults count continued until the beetles reached the damaging population (threshold) and then plants were sprayed with Entrust (Naturalyte, Dow AgroSciences, Indianapolis, IN) to prevent excessive foliage damage and keeping CPB population below the damaging population. To determine the threshold we used the method recommended by (Howell and Hazzard, 2012). We walked in the field in a V-shaped pattern selected 50 plants in intervals and counted adults. Fifteen adults or fewer per 50 plants were considered below threshold, and 25 or more adults per 50 plants were considered above threshold. To determine internal browning and hollow heart of potatoes, 20 tubers were selected randomly within each plot and were cut lengthwise through the center to evaluate hollow heart and internal browning (Stevenson et al., 1999).

Statistical analysis

Analysis of variance was conducted by PROC ANOVA procedure of SAS (SAS, v. 9.2, Cary, NC). Nitrogen fertilizer levels, potato varieties, and cover crops were considered as fixed effects, while year and block were considered random. Effects were considered significant at $P \leq 0.05$ by the F test, and when the F test was significant, Least Significant Difference Test was used for mean separations. Trends due to N application were assessed by regression analysis (Steel and Torrie, 1980).

Results and discussion

Tuber quality

The results of our study showed that SUP was more susceptible to hollow heart and internal browning than DRN; however, varieties were the same in terms of external defects (Table 10). Potatoes with hollow heart ranged from 1.1% of tubers in no cover crop plots to 1.8% of tubers in potatoes planted after peas. Cover crops did not vary significantly in this regard (Table 10). Also, the frequency of internal browning in potato tubers was more prevalent in potatoes in cover crop plots than fallow. However, the difference between cover crops was not significant (Table 10). No cover crop plots produced 35% fewer tubers infested with internal browning than the average of cover crop plots (Table 10). Contrary to tuber hollow heart and internal browning, potato tubers with external defects were different significantly among cover crops and ranged from 0.66% of tubers in peas to 0.81% of tubers in rye. Yet, plots with no cover crop produced fewer external defects than cover crop plots. The higher frequency of tuber hollow heart, internal browning, and external defects in cover crops could be explained by higher potato yield in cover crops as a result of provided N by cover crop residues to potato plants and, therefore, more potatoes with lower tuber quality. Our results are in contrast to Essah et al. (2012) who found tubers of higher quality in cover crop plots than in fallow.

The percentage of tubers with hollow heart increased from 1.4% of tubers in unfertilized plots to 1.6 and 2.2% of tubers in 75 and 150 kg N ha^{-1}, respectively (Table 10). Although tuber internal browning was not affected by N fertilization, increasing N levels resulted in more frequency of tubers with external defects (Table 10), and unfertilized plots had the lowest percentage of defects (0.4% of tubers). Application of 150 and 225 kg N ha^{-1} resulted in the highest amount of tubers with external defects (Table 10). Rosen et al. (2011) also reported that higher N treatments tended to have higher incidences of hollow heart and brown center, probably due to their larger percentages of large tubers. Also, Essah and Delgado (2009) found that excessive application of N fertilizer reduced potato tuber quality compared to optimum application and that this response was dependent on the potato cultivar.

Colorado potato beetle population

Our results indicated that SUP was more susceptible to CPB than DRN. This result was true for overwintering adults or summer adults (Table 10). Among cover crops, overwintering adults affected potato plants less after rye early in the season than forage radish, peas, or no cover crop plots (Table 10). It has been reported that cover crop residues or mulches as a physical barrier can prevent, delay, or reduce CPB emergence and infestation (Teasdale and Mohler 2000). The first generation of CPB (overwintering adults) search for food plant by walking from the field edges and if beetles do not find host plant by walking they will fly in search of food (Howell and Hazzard, 2012). Since winters peas and forage radish residues provided less cover on the ground because of being winter killed, beetles could have easier access to potato plants by walking. Probably, rye residues acted as a barrier, which resulted in less infestation compared with forage radish, peas, or no cover crop. In contrast, the population of summer adults did not vary significantly between cover crops and no cover crop plots, and all of the treatments showed a similar population of CPB. The second generation of CPB (summer adults) could easily fly and find their host plants and could explain the results in our experiment later in growing season (Table 10). The highest population of overwintering adults was in unfertilized plants, and the differences among cover crops were not significant with this regard (Table 10). Nitrogen fertilization did not affect the population of summer adults.

Weed infestation

The dominant weed species in potato plots were crabgrass, common lambsquarters, and yellow nutsedge in descending order (Table 11). Dark Red Norland and SUP did not vary significantly in terms of weed biomass (Table 11). Weed biomass was lower in cover crops than no cover crops in all of the weed species and also cover crops were significantly different in terms of weed biomass production (Table 11). For example, the highest crabgrass biomass (1148 kg ha-^{1}) was in no-cover crop plots. Among cover crop lots, crabgrass biomass was the highest in peas (1007 kg ha^{-1}) followed by forage radish and rye (814 and 690 kg ha^{-1}, respectively). Overall, cover crop plots were less affected with weed infestation than in no-cover crops plots (Table 11). Also, forage radish and rye suppressed more weeds than peas (Table 11). Higher weed biomass in fallow and peas suggested that winter peas is not a suitable cover crop for controlling weeds, especially infested with crabgrass. Also, relatively high weed pressure in this study could be due to the soil disturbance before planting, an action that may encourage weed emergence from the soil seed bank. Campiglia et al. (2009) reported that rapeseed (*Brassica napus* L.) and ryegrass (*Lolium perenne* L.) were the most efficient weed suppressors and had the least proportion of weed biomass (<1%) of the total produced by the cover, and they also suppressed weed emergence in the following potato crops. Chemical compounds released from cover crop residue have potential to stimulate or inhibit weed germination and growth (Liebman and Mohler 2001).

There was a linear increase in weed biomass in response to N fertilization in our study (Table 11). Weed biomass was consistently higher in fertilized plots than in unfertilized plots for all three species as well as other weed species (Table 11). The lowest (982 kg ha^{-1}) and the highest (1289 kg ha^{-1}) weed biomass were from 0 and 225 kg N ha^{-1} treatments, respectively. Weeds are strong competitors with agronomic crops for the growth resources, and, therefore, higher N rates resulted in increased weed biomass.

Conclusion

Despite several reports on the improving effects of cover crops on potato tuber quality, we did not find proof to support this idea. However, increased frequency of low-order potato tubers in cover crops plots in our study might be as a result of higher tuber yield in potatoes after cover crops and ultimately more inferior tubers. Although CPB infestation was lower in potato plants after rye early in the spring, there was not a difference between cover crop treatments and fallow in terms of CPB infestation, a result that suggests the need to spraying insecticide if an above-threshold population of CPB is observed. Weed infestation tended to be lower in cover crop plots than in no-cover crop plots, and, rye and forage radish were advantageous over winter peas for suppressing weeds.

Table 10: Effects of variety, cover crops, and N fertilization on tuber quality and Colorado potato beetle population in Dark Red Norland (DRN) and Superior (SUP).

Treatments	Tuber quality			Colorado potato beetle	
	Hollow heart	Internal browning	External defects[#]	Overwintering adults	Summer adults
Variety	………. % of tubers ………..			Mean number of beetles/plant	
DRN	1.51	0.21	0.63	0.36	0.54
SUP	2.15	0.42	0.57	0.15	0.21
LSD[§]	1.08	0.08	0.33	0.11	0.24
Cover crop					
Peas	1.82	0.38	0.66	0.29	0.54
Rye	1.63	0.36	0.81	0.15	0.42
Forage radish	1.60	0.40	0.72	0.32	0.53
No cover crop	1.10	0.28	0.51	0.33	0.51
LSD	0.85	0.03	0.12	0.12	1.09
N (kg ha^{-1})					
0	1.41	0.45	0.44	0.38	0.50
75	1.66	0.43	0.58	0.25	0.46
150	2.26	0.53	0.74	0.27	0.48
225	1.92	0.54	0.79	0.26	0.42
Trend[¥]	L*	NS	L*	L**	NS

[#] Includes growth cracks, knobs, and misshapes.

[§] Least significant difference at $P \leq 0.05$.

[¥] Linear (L) regression; *, significantly different at $P \leq 0.05$; **, significantly different at $P \leq 0.01$, NS, non-significant

Table 11- Weed biomass as influenced by varieties, cover crops, and nitrogen fertilizer for Dark Red Norland (DRN) and Superior (SUP) potatoes.

Weed species	Crabgrass	Lambsquarters	Yellow nutsedge	Other species	Total
Variety	………………………………………	………………………………………	kg ha^{-1}	………………………………………	………………………………..
DRN	780	126	145	34	1085
SUP	830	118	194	38	1180
LSD[§]	114	86	53	10	116
Cover crops					
Peas	1007	101	86	29	1223
Rye	690	345	116	31	1182
Forage radish	814	206	67	34	1121
No cover crop	1148	111	136	42	1437
LSD	113	98	17	11	124
N (kg ha^{-1})					
0	782	114	86	28	1010
75	897	128	96	34	1155
150	908	223	114	42	1287
225	952	208	129	48	1337
Trend[¥]	L*	L*	L**	NS	L**

[§] Least significant difference at $P \leq 0.05$.

[¥] Linear (L) regression; *, significantly different at $P \leq 0.05$; **, significantly different at $P \leq 0.01$, NS, non-significant.

CHAPTER 7

OVERALL SUMMARY AND CONCLUSION

During the past decade, agronomists have attempted to adapt environmentally friendly cropping systems by using cover crops to limit fertilization and to lessen environmental concerns. Potato production relies on nitrogen (N) fertilization to maintaining high yielding tubers yields. Cover cropping in rotation with potato and tailoring N fertilizer rates may alleviate environmental impacts and reduce costs associated with over fertilization in potato fields. Thus, we conducted field trials to address these issues and to suggest an efficient cover crop and N fertilizer rate than can be used in potato fields in the Northeast, and particularly Massachusetts. The experiments investigated the following topics:

1) Decomposition rate and trend of nutrient release in forage radish (*Raphanus sativus* L.), rye (*Secale cereale* L.), and winter peas (*Pisum sativum* L.) residues as affected by conventional and no-tilling systems and also synchronization of released nutrients from cover crop resides and potato N demands.

2) Tuber nutrient density of Dark Red Norland (DRN) and Superior (SUP) varieties in response to cover crops and N fertilization.

3) Tuber yield and yield components of DRN and SUP potatoes after cover crops, fallow, and N fertilization.

4) Nitrogen-use efficiency indices of potato plants in different N levels and cover crop treatments.

5) Colorado potato beetle and weed infestation and quality of potato tubers as influenced by cover crops and N fertilizer.

According to our results, the effectiveness of released N and fertilizer value of cover crops depended on the rate at which the residues decompose. Conventional tilling system resulted in increased rate of nutrient release and decomposition process in the soil compared with no-till system. Forage radish and peas with narrower C:N ratio released their N content in a faster trend than rye. These results indicated the necessity of planting cash crops as soon as possible in the spring to get the most out of the released nutrients from cover crop with narrow C:N ratios such as forage radish or peas.

Potato tubers after forage radish, rye, and winter peas accumulated nutrients in their tubers in deceasing order; however, some accumulation of nutrients did not show a significant different between cover crop treatments and fallow.

Cover crops boosted potato tuber yield compared to fallow and reduced N fertilization in potatoes. For example, while no cover crop plots had to be fertilized at 225 kg N ha^{-1} to produce the highest yield, potato plants after peas or forage radish needed to be fertilized at only 75 kg N ha^{-1} to produce the same yield.

Potatoes planted after fallow were less efficient in utilization of the supplied N than potatoes following cover crops. Application of high amounts of N fertilizer (225 kg ha^{-1}) limited tuber yield and N-use efficiency through enhanced vegetative growth or environmental losses.

Although it has been reported that cover crops can improve potato tuber quality, we did not find proof to support this concept among our treatments. Despite the lower CPB infestation in potato plants after rye early in the spring, there was not a difference between cover crop treatments and fallow in terms of CPB infestation, which suggests the need to spraying insecticide if infestation above the threshold is observed in the field. Weed infestation tended to be lower in cover crop plots than fallow and rye and forage radish were advantageous over winter peas for suppressing weeds.

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