WEED CONTROL WITH COVER CROPS IN POTATO (*SOLANUM TUBEROSUM* L.)

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MASTER OF SCIENCE

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ABSTRACT

Field experiments were conducted near Oakes and Fargo, North Dakota from 2009-2010, and repeated near Carrington, North Dakota from 2010-2011, to evaluate weed control in both irrigated and non-irrigated potato production as influenced by cover crops and cover crop termination methods. Cover crop treatments at Oakes and Fargo were no cover crop, triticale, rye, turnip/radish, and rye/canola. Cover crop treatments at Carrington were no cover crop, triticale, rye, hairy vetch, and rye/hairy vetch. Termination treatments for the cover crops were roller-crimp, disk-till, roto-till, and herbicide.

Cover crop residue was mostly sufficient for weed control at all locations. However, after two cultivations cover crops controlled weeds similar to no cover crop. Cover crop had no effect on potato marketable yield at the two locations. Results support the consideration of cover crops for potato production as a means of additional early-season weed control, especially when non-chemical weed control methods are desired.

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DEDICATION

The thesis is dedicated to my wife, Jenna. Without your love and support this would not have been possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDIX TABLES

GENERAL INTRODUCTION

Cover crops are crops that are grown for a management goal in between times of cash crop growth (Brady and Weil, 2008). Cover crop integration into conventional agriculture rarely occurs today due to growers' ability to easily overcome production problems with pesticides, fertilizer, and crop rotation. However, more growers are beginning to consider the use of cover crops to enhance soil retention, soil and environment quality, as well as to provide alternate methods for fertility management and pest control (Blevins et al, 1990).

Furthermore, cover crops are often used in organic and sustainable agriculture systems. In North Dakota these practices continue to increase in acreage each year, with North Dakota ranking second in the U.S. for organic crop production (Knopf, 2011). From 2008-2010, potato production in North Dakota ranked fifth in the U.S. for potato acreage, with an average of 34,000 hectares devoted to this crop. Weed control in organic potato production relies on the effectiveness of cultivation, harrowing, and weed suppressing cultivars (Beveridge and Naylor, 1999). Unfortunately, regular precipitation and slow soil drying due to the clay soil texture in the Red River Valley, make timely cultivation difficult and often impossible. Growing winter annual cover crop species provides a potential alternative early season weed suppression method. The short growing season found in the Upper Midwest, specifically North Dakota, will limit certain aspects of cover crops, such as the length needed for a cash crop to mature out of the possible growing days in a seasons, leaving little time for cover crops (Snapp et al, 2005; Teasdale, 1998).

This research evaluated the effects of cover crop, termination method, and potato cultivar on weed control in potato. The first objective was to determine if cover crops improved weed control in potato production where chemical control was not desired. The second objective was to determine how cover crops influenced potato yields. Results of this research will be relevant to potato producers who are considering adding cover crops to their potato production systems.

LITERATURE REVIEW

Production of potatoes in conventional agriculture is an intensive process, encompassing seed bed preparation, pest control, fertility management and hilling (Beukema and Van Der Zaag, 1990). Though not currently used in conventional management of potatoes, cover crops are being researched for benefits in many areas of production (Duval, 1997).

Weed Control in Potato

Without herbicides weeds would likely be the most serious threat to conventional agriculture. Millions of dollars are spent annually on weed problems under conventional practices (Bridges, 1992). Furthermore, weeds have been identified as the most serious threat facing organic and low-external input agriculture (Barberi, 2002).

Weed competition has been evaluated in non-irrigated potatoes. Nelson and Thoreson (1981) found that yields were reduced an average of 54% for cultivars 'Norchip' and 'Viking' if no weeds were controlled during the season. Previous research showed that 'Red Norland' and 'Red Pontiac' tuber yield was reduced 65 and 45%, respectively, in zero weed control plots (Nelson and Gilles, 1989). Nelson and Gilles (1989) found that when weeds were controlled for the first three weeks after potatoes emerged, only 16% yield loss occurred. If weeds were allowed to grow for the first eight weeks after potatoes emerged, then were controlled the remainder of the season, yield loss was only 19%. If weeds were allowed to grow until 10 weeks after potato emergence yield decrease ranged from 25 to 40%. Thus, weed control during the early part of potato development was most critical for high yielding and good quality potatoes. Weed competition later in the season has been shown to be less important for producing high quality potatoes due to potato row closure and plant competitiveness.

Eighty seven percent of the hectares planted to potatoes are treated with herbicides for weed control nationally, with the remaining land receiving mechanical weed control (United States Department of Agriculture, 1999). Yield loss for producers using mechanical management methods with no herbicide was approximately 32%.

Conventional agriculture is efficient and effective, feeding the world with ever increasing crop yields. However, concerns about the potential environmental impacts of pesticides and fertilizers, coupled with interest in greater price premiums for organic crops, have led to interest in reducing chemical use in cropping systems (Boydston and Vaughn, 2002).

Cover Crops

Cover crops are grown to protect soil and improve soil quality, primarily in periods between regular crop production cycles (Brady and Weil, 2008). Winter annual cover crops are primarily grown during the winter months when cash crops cannot be grown. Cover crops are typically planted during late summer or early fall, primarily during August and September in the Upper Midwest. This timing does not preclude growing a cash crop, but might limit production of crops with longer growing seasons (Snapp et al, 2005; Teasdale, 1998). In the fall, some cover crop seedling establishment and vegetative growth is necessary to ensure plant survival over the winter months. Once growing conditions are favorable in the spring, cover crops resume growth, accumulating most of their biomass just prior to senescence or termination and the subsequent planting of the summer cash crop.

Benefits. Cover crops have been used for a wide variety of reasons in the United States including erosion protection (Nyakatawa et al, 2001; Kessavalou and Walters, 1999); improving soil properties (Doran, 1987; Smith et al, 1998; McVay et al, 1989); snow trapping (Feyereisen et al, 2006); and disease prevention (Potter et al, 1998; Vargas-Ayala et al, 2000). Snow trapping is the ability of a growing crop to catch greater snow than fallow, improving moisture in the soil. Cover crops role in soil erosion reduction has been well documented. During typically fallow periods in the fall and winter, cover crops can support soil against rainfall and wind (Johnson et al, 1998; Kaspar et al, 2001). One survey of commercial vegetable producers in western New York reported that 20 producers were using cover crops during potato production (Stivers-Young and Tucker, 1999). Rye (*Secale cereal* L.), oat (*Avena sativa* L.), clovers species (*Trifolium* spp.), barley (*Hordeum vulgare* L.), and wheat (*Triticum aestivum* L.) were the cover crops utilized with 9, 4, 3, 2, and 2 producers, respectively, using each cover crop. However, whether weed control was the main reason a cover crop was used is unknown. Producers reported control of wind and water erosion, as well as adding organic matter as the most important benefits from cover crop use.

Improvements in soil organic matter are found when cover crops are returned to the soil as green manures (Dabney et al, 2001; Varco et al, 1999). If organic carbon inputs into the soil system are greater than organic matter loses from decomposition, erosion, and leaching soil organic matter increases (Huggins et al, 1998). Winter annual cover crops are an effective practice for maintaining or improving soil organic matter compared to fallowed fields (Hargrove, 1986; Kuo et al, 1997).

Cover crops positively affect soil health by improving physical conditions of the soil (Scott et al, 1990) and soil quality (Dabney et al, 2001). Reduction in soil bulk density (Latif et al, 1992), greater porosity of soil (Ess et al, 1998), increased soil water holding capacity (Smith et al, 1987), and improved water infiltration (McVay et al, 1989) have been found from cover crops. The ability of cover crop species to impact soil physical conditions is highly variable, and is dependent on mass of residue and root system of the species (Dexter, 1991; Powers et al, 1998).

Soil fertility and fertilization are important aspects of potato production. Potatoes require large amounts of nitrogen throughout the growing season. Excess nitrogen can be leached and made unavailable to the plant if nitrogen management and synchronization to the potato crop is not practiced (Waddel et al, 2000). Organic nitrogen sources are difficult to manage for synchronicity with potato crop demand (Pan and Letey, 2000). Cereal rye is an above average soil nitrogen scavenger (Isse et al, 1999). Cover crops are often used as catch crops because they can scavenge nutrients from the soil, thus, changing the fertility of the soil as they grow (Stute and Posner, 1995) Leguminous cover crops fix atmospheric nitrogen, adding nitrogen to the soil as the plant residue decomposes, to be used by the ensuing crop (Holderbaum et al, 1990). Research conducted by Varco et al. (1993) using N^{15} labeled hairy vetch concluded that nitrogen from the hairy vetch was released faster and more completely than N^{15} labeled fertilizer under identical conditions. Leaching of the nitrogen was also increased with N from the fertilizer as compared to N from the hairy vetch.

Cover crops also alter the temperature of the soil compared to bare ground. Teasdale and Mohler (1993) reported less soil temperature fluctuation when rye and hairy vetch were grown as a cover crop as compared to no cover crop being present. Similarly, another study reported that cover crops rye and hairy vetch reduced the maximum soil temperature in the production system (Creamer et al, 1996). Cover crops can conserve soil moisture when the residue acts as a mulch (Morse, 1993). Higher soil moisture content was found in a no-till cropping system when compared to conventional-till system when wheat straw was used as a cover crop residue.

Species. Rye and triticale (*Triticum durum* L.) are winter hardy when used as cover crops planted in the fall. Rye is a common cereal grain used in cover crop systems due to its winter hardiness, extensive root system, and quick accumulation of biomass (Rosecrance et al, 2000). It is also known to suppress weeds via allelopathic interactions with the weed seed bank (Putnam et al, 1983). Triticale is a cross of rye and wheat that is less commonly used as a cover crop, but is also planted for its root system and biomass accumulation. In a mulch experiment, triticale suppressed the weeds redroot pigweed and common lambsquarters approximately 50% less than rye (Moore et al, 1994).

Hairy vetch (*Vicia villosa* Roth) is a nitrogen fixing legume that vines extensively and provides excellent soil cover (Rosecrance et al, 2000). A combination of hairy vetch and rye is useful as the hairy vetch climbs and vines on the rye and the two in combination provide nitrogen fixing, prevent nitrogen leaching, and provide better cover and residue accumulation than either species in monoculture. Hairy vetch is planted in the fall as a winter-annual where winter temperatures are warm enough for winter survival, which varies between selections of the species.

Turnip (*Brassica rapa* L.), radish (*Raphanus sativus* L.), and canola (*Brassica napus* L.) are also used as cover crops. Turnip, as a cover crop, can decrease soil compaction, increase nutrient capture, and when decomposed in the soil has been shown to contain allelopathic chemicals that interact with the seed bank, especially affecting small sized weed seeds (Petersen et al, 2001). Radish, as a cover crop, can decrease soil compaction and increase nutrient capture (Justes et al, 1999). Canola has been shown to be less capable of scavenging soil nutrients than other cover crops such as rye or turnip, yet has been used as a cover crop (Kuo et al, 1997).

Weed Control. Cover crops are capable of suppressing weeds. To successfully control weeds cover crops must do four things: produce high biomass, be easily terminated by chemical or mechanical methods, suppress weed seed germination, grow long enough to minimize weed-crop competition, and not interfere directly with crop growth (Morse, 2006). Cover crops control weeds by competition, allelopathy, weed seed decay in the seed bank, and the proliferation of residue (Conklin et al, 2002).

The life cycle of weeds in the field can be traced linearly from the dormant seed bank to the active seed bank and from there to the germinated seeds, which finally result in emerged seedlings (Agricultural Research Service, 2009). Cover crop residue can control weeds in numerous ways at different steps in the weed emergence model. Residue can attenuate environmental germination cues such as light, temperature, rainfall, and oxygen, which are all activators for dormant seeds (Teasdale, 1998). Inhibitory plant phytotoxins from the residue can terminate germinating weed seeds. Residue can provide a physical interference to germinating seeds by limiting light levels and limiting emergence of weeds through cover crop residue.

A modified system of cover crop utilization with rye has been investigated in potato (Boydston and Vaughn, 2002). This research showed that cover crop residues along with cultivation and a banded herbicide application with a reduced spray width could provide potato yields identical to the conventionally grown potato crop. Potatoes planted into an herbicide terminated rye cover crop, with banded metribuzin, decreased the herbicide input for the entire season by 66%, and when cultivation was used, yields were almost identical to the conventional treatment. Reducing herbicide input beyond 66% may be possible if terminating the cover crop, could be accomplished without the use of an herbicide. Investigating mechanical methods to terminate the cover crop may lead to alternative methods that provide similar results as herbicides, yet effectively reduce herbicide input in the system even more.

The emergence of redroot pigweed (*Amaranthus retroflexus* L.), common lambsquarters (*Chenopodium album* L.), curly dock (*Rumex Crispus* L.), velvetleaf (*Abutilon theophrasti* Medik), witchgrass (*Panicum capillare* L.), common chickweed (*Stellaria media* L.), barnyard grass (*Echinochloa crus-galli* L.), and dandelion (*Taraxacum officinale* L.) all decreased under increased hairy vetch or rye residue (Teasdale and Mohler, 1993). Not all species reacted the same way to the cover crop. Redroot pigweed, common lambsquarters, witchgrass, and barnyard grass all showed a linear decline in emergence with increasing residues. Emergence of curly dock, common chickweed, and dandelion increased when small amounts of residue were present compared to no residue, but that trend was reversed as weeds were suppressed with increasing residue.

Weed control using winter annual cover crops is obtained via the cover crop residue left on the soil surface or incorporated into the soil (Teasdale, 1998). In one study the weed suppression effectiveness of desiccated hairy vetch residue was compared to live hairy vetch that was allowed to grow until it naturally senesced in late June in a no-till corn field (Teasdale and Daughtry, 1993). The live hairy vetch suppressed weeds more than the terminated hairy vetch, while both suppressed weeds more than no cover crop. If growers were able to have a thick stand of hairy vetch until approximately the end of June, or longer in the Upper Midwest, while still harvesting high yields in the chosen crop, a live hairy vetch system would be the ideal method to reduce herbicide use while still controlling weeds. The perfect system for live hairy vetch use would allow live hairy vetch to suppress weeds during the critical period of early weed competition, and then senesce at the onset of maximum crop growth and canopy development.

In potato production, this practice would be effective if the potatoes could be planted without disrupting the live growth of the cover crop and planted late enough for the potato vegetative growth to not be limited by living hairy vetch. The mechanical hilling with disk closure when potatoes are initially planted would be difficult with an approximately 0.5 meter high crop of hairy vetch. When the potato planter initially covers the potato seed at planting, only approximately ten cm between two planted rows is untouched by the disks, suggesting that hairy vetch would most likely clog the planter.

In organic production, three general weed control methods are used: land preparation, plant competition, and in-crop weed control (Beveridge and Naylor, 1999). Land preparation is the use of crop rotation and stale seed beds. Plant competition is the use of highly competitive cultivars or a higher seeding rate. Colquhoun et al. (2009) found no differences in weed control among 10 potato cultivars. However, yields for 5 of the 10 cultivars under weedy conditions, relative to yields under weed free conditions, were greater than the yields of the other cultivars under weedy conditions.

In-crop weed control is accomplished by the use of hand-weeding, cultivation, or harrowing. One survey of organic potato producers in the U.K. and Scotland showed that potato producers relied on land preparation and in-crop weed control far more than plant competition (Beveridge and Naylor, 1999). The main reason plant competition has not been used in potato production is that planting more tubers in the ground would simply decrease the size of harvested tubers resulting in fewer marketable tubers overall.

The most cost effective and widely used weed control method for potato production is cultivation (Chitsaz and Nelson, 1983). Cultivation can control weeds by disturbing the soil in between rows and disrupting weed growth in the rows by throwing soil on the hills to cover up germinating weeds. Cultivation is targeted for early in the potato growing season, to keep the soil surface weed free until the potatoes have grown large enough to begin shading the surrounding soil, thereby controlling weeds without mechanical or chemical inputs. In addition, cultivation reduces tuber greening from the exposure of potatoes to sunlight (Bellinder et al, 1996). A constraint to cultivation is the potential for decreased yield with additional cultivation, due either to lateral root pruning or soil compaction resulting in increased soil density (Nelson and Thoreson, 1981). A 1.7% decrease in yield was found with each additional cultivation after potato planting, compared to a weed free treatment where the only weed control was accomplished by hand weeding, and the only hill created was at planting. Another constraint to cultivation is weather conditions that prevent timely cultivation and result in increased weed infestations (Chitsaz and Nelson, 1983). Additional weed control in potato production would be beneficial due to these constraints.

Integrated weed management is practiced by growers not relying solely on one method for weed control. In potato production, integrated weed management has been practiced for years by combining preemergence and postemergence herbicides with cultivation for season-long weed control. However, in organic potato production, where herbicides are not used, mechanical methods are used for weed control, and integrated weed management is not practiced. With the addition of cover crops, organic potato producers have diversified options for weed control. Cover crops and cultivation function in different ways to achieve the goals of integrated weed management of weed populations through events that decrease fitness and increase mortality of the seed bank. Winter annual cover crops including rye, triticale, wheat, barley, and hairy vetch that were terminated with an herbicide application, lowered the infestation levels of *Setaria* spp. and *Amaranthus* spp. 3 to 5 weeks after planting a soybean crop compared to no cover crop (Williams II et al, 1998). This allowed for stand establishment of the soybean crop and resulted in a consistent yield without an herbicide input for the first 3-5 weeks. Mohler and Teasdale (1993) evaluated the use of hairy vetch and rye cover crops in a no-till corn system for weed control with paraquat termination. For most weed species the authors reported overall reduced weed biomass associated with both rye and hairy vetch residues in no-till corn.

Weed control when using a cover crop is dependent upon the amount of biomass on the surface of or incorporated into the soil. Mohler and Teasdale (1993) reported that weed seedling emergence decreased with increasing cover crop residue biomass. Cover crop residues have not been shown to control weeds the entire growing season, nor have they been shown to control every weed in the field (Snapp et al, 2005). Almost perfect weed control has been shown in the greenhouse and in the field when artificially high cover crop residue, two to four times more than what occurs naturally, was placed on the soil surface (Lanfranconi et al, 1993). Natural field biomass levels of hairy vetch and rye at optimal growing locations are approximately 3,500 kg/ha and 11,000 kg/ha, respectively (Mohler and Teasdale, 1993; Carrera et al, 2005). In a study at two locations in SE Minnesota, maximum biomass accumulation was 6,500 kg/ha when rye was allowed to mature until 8 June (De Bruin et al, 2005). Cover crops like hairy vetch and rye require extra time in the spring to reach their maximum growth and biomass accumulation in order to provide maximum weed control, thus delaying potato planting by several weeks from the earliest possible planting date (Mundy et al, 1999). A decision must be made by the producer as to whether they would rather plant a longer maturing and higher yielding potato cultivar sacrificing biomass of the cover crop, or plant a shorter maturing, possibly lower yielding potato cultivar so that maximum winter annual cover crop biomass accumulation can be obtained. In Maryland, growers accumulate enough biomass from immature cover crops that planting date is not an issue (Carrera et al, 2005). Biomass of rye in Maryland reached 4,000 kg/ha and still had least a month more growing before reaching maturity and maximum biomass.

Soil Preparation

Conventional potato production involves highly intensive tillage practices for land preparation. Multiple tillage procedures before planting help provide a uniform seedbed with adequate air movement throughout the soil (Bishop and Grimes, 1971). Using cover crops in potato production involves a different set of land preparation practices. For winter annual cover crops, the last tillage practice can occur in the fall just before the cover crop is planted. Mechanical and chemical control methods are commonly used to terminate winter annual cover crops (Moore et al, 1994; Teasdale and Daughtry, 1993).

Little research about no-till potato production has been documented. A no-till system was evaluated in North Carolina using a modified tiller-transplanter to cut through terminated sorghum-sudangrass cover crop and potato planting followed (Mundy et al, 1999). In this experiment, hills were formed after potato seed pieces were laid in the furrow by manual raking. No-till potato yields were 24.3 Mg/ha compared to 32.7 Mg/ha under conventional tillage at a site with sandy soil and low organic matter. At a second location with finer sandy soil and greater organic matter, yields were 31.1 Mg/ha in no-till and 32.3 Mg/ha in conventional till. Researchers concluded that success with no-till potato production was site specific and primarily influenced by soil type, thus soil type should be the first factor considered when looking to produce potato in no-till systems.

Another no-till potato experiment in Virginia used raised beds instead of traditional soil preparation methods of single row hills (Morse, 2006). Mechanically formed raised beds, measuring 20.23 cm high, 1.22 m wide, and 16.76 m long had combinations of rye, clover, and hairy vetch planted with a grain drill modified to plant at the same depth along the contour of the bed. A modified 2-row subsurface tiller-transplanter was used to cut through the living cover crop and bury the potato seed piece. The live cover crop was terminated with a flail mower just before potato emergence, leaving a thick and even layer of cover crop residue. Plots did not require cultivation, hilling, or additional weed control measures. Marketable tuber yields varied during the three years of the experiment, resulting in no yield difference between the cover crop and no cover crop treatments with an average yield of 20 Mg/ha. Researchers determined that tuber yield was not impacted as long as the weed biomass approximately two months after planting was at or below 1,120 kg/ha. Since the raised bed system cannot be cultivated, there are concerns about weed control when climatic conditions do not allow for high biomass production such as in the Midwest compared to the Eastern U.S.

Morse (2006) reported that when planting no-till potatoes into a winter annual cover crop, mowing was a necessity, as the cover crop residue was too great for the traditional planter disks to slice through with any planter other than a highly modified planter. Without mowing, the cover crop residue will clog and disrupt the potato planter. The style of mower may influence weed control with cover crops (Dabney et al, 1991). A rotary mower may not distribute cover crop residue evenly, and may leave a windrow of residue. A rotary mower does not cut as close to the soil surface as needed with cover crops, and may result in regrowth of the cover crop and undesirable competition with the crop. Another study found regrowth of rye after mowing was high when the rye was mowed early in its development, but decreased with advanced rye growth stages up to maturity, where almost no regrowth was seen (De Bruin et al, 2005). Flail mowers are preferred over all other mower types as they cut closest to the soil surface and distribute a uniform layer of cover crop residue (Creamer et al, 1995). Sickle-bar mowers were less effective, with performance especially poor when vine-type cover crops were grown.

When tillage is used to terminate a cover crop it is known as a green manure, incorporated into the soil to benefit the soil and crop. Green manure cover crops are an important part of an organic system due to their ability to enhance fertility, increase organic matter, and improve nutrient retention (Augustin et al, 1999; Malpassi et al, 2000). An experiment using common vetch (*Vicia sativa* L.) and winter wheat as green manures for potato production concluded that potato was an ideal crop for common vetch as it required high nitrogen (Sincik et al, 2008). Green manures have the potential to reduce the amount of nitrogen fertilizer applied to the crop. If an effective tillage treatment is not performed, cover crop regrowth becomes a major concern.

The roller-crimper has provided an additional tool for no-till crop production (Ashford and Reeves, 2003). The roller-crimper is an implement that snaps the stem of a plant to lay it parallel with the soil surface. The implement is made from a cylindrical steel well casing filled with water to add weight, with slats added on the outside to snap a plant stem. The roller-crimping does not always provide 100% termination with plant maturity and time of day being two factors affecting termination with roller-crimping. It has been shown that rye is most effectively terminated when roller-crimping is done at or after anthesis (Mirsky et al, 2009). It has also been suggested that rye terminated with a roller-crimper will be more effective in the morning than afternoon as the plant stem is more turgid due to decreased transpiration rates during the night and early morning (Steve Zwinger, personal communication, 2010).

Herbicide is an effective method for terminating a cover crop (Boydston and Vaughn, 2002). Every cover crop has a different family of herbicides that provide 100% termination, though certain products are equally effective on all cover crops not containing any weed resistance, like glyphosate or paraquat. Chemical termination is ideal for no-till systems as no soil disturbance is involved with an herbicide application.

Literature Cited

Agricultural Research Service. Understanding the complexities of cover crop residue on weed emergence [Online]. Available at http://www.ars.usda.gov/SP2UserFiles/Place/12650400/WebsiteWeedSuppressionbyCoverCropResidue.pdf (posted 21 Feb. 2007; verified 20 May 2012). United States Department of Agriculture.

Ashford, D.L. and D.W. Reeves. 2003. Use of a mechanical roller-crimper as an alternative kill method for cover crops. Amer. J. Alt. Agr. 18:37-45.

Augustin, E.O., C.I. Ortal, S.R. Pascua Jr., P.C. Santa Cruz, A.T. Padre, W.B. Ventura, S.R. Obien, and J.K. Ladha. 1999. Role of indigo in improving the productivity of rainfed lowland rice-based cropping systems. Experimental Agr. 35:201-210.

Barberi, P. 2002. Weed management in organic agriculture: are we addressing the right issues? Weed Res. 42:177-193.

Bellinder, R.R., R.W. Wallace, and E.D. Wilkins. 1996. Reduced rates of herbicides following hilling controlled weeds in conventional and reduced tillage potatoes. Weed Technol. 10:311-316.

Beukema, H.P. and D.E. van der Zaag. 1990. Introduction to potato production. Backhuys Publishers, Kerkwerve, Netherlands.

Beveridge, L.E and R.E.L. Naylor. 1999. Options for organic weed control-what farmers do. P. 939-944. *In* The 1999 Brighton conference-Weeds, Brighton, UK. 15-18 Nov. 1999. Department of Agriculture, Scotland, UK.

Bishop, J.C and D.W. Grimes. 1971. The influence of some soil physical properties on potato yields and grade distribution. Amer. J. Pot. Res. 48:414-422.

Blevins, R.L., J.H. Herbek, and W.W. Frye. 1990. Legume cover crops as a nitrogen-source for no-till corn and grain-sorghum. Agron. J. 82:769-772.

Boydston, R.A. and S.F. Vaughn. 2002. Alternative weed management systems control weeds in potato (*Solanum tuberosum*). Weed Technol. 16:23-28.

Brady, N.C. and R.R. Weil. 2008. The nature and properties of soils. 14th ed. Pearson Education, Upper Saddle River, NJ.

Bridges, D.C. 1992. Crop losses due to weeds in the United States, 1992. Weed Sci. Soc. Amer., Champaign, IL.

Colquhoun, J.B., C.M. Konieczka, and R.A. Rittmeyer. 2009. Ability of potato cultivars to tolerate and suppress weeds. Weed Technol. 23:287-291.

Chitsaz, M. and D.C. Nelson. 1983. Comparison of various weed control programs for potatoes. Amer. Pot. J. 60:271-280.

Carrera, L.M., R.D. Morse, B.L. Hima, A.A. Abdul-Baki, K.G. Hanes, and J.R. Teasdale. 2005. A conservation-tillage, cover-cropping strategy and economic analysis for creamer potato production. Amer. J. Pot. Res. 82:471-479.

Conklin, A.E., M.S. Erich, M. Liebman, D. Lambert, E.R. Gallandt, and W.A. Halterman. 2002. Effects of red clover (*Trifolium pretense*) green manure and compost soil amendments on wild mustard (*Brassica Kaber*) growth and incidence of disease. Plant and Soil. 238:245-256.

Creamer, N.G., B. Plassman, M.A. Bennett, R.K. Wood, B.R. Stinner, and J. Cardina. 1995. A method for mechanically terminating cover crops to optimize weed suppression. Amer. J. Alt. Agr. 10:157-162.

Creamer, N.G., M.A. Bennett, B.R. Stinner, and J. Cardina. 1996. A comparison of four processing tomato production systems differing in cover crop and chemical inputs. J. Amer. Soc. Hort. Sci. 121:559-568.

Dabney, S.M., M.W. Buehring, and D.B. Reginelli. 1991. Mechanical control of legume cover crops. P. 146-147. *In* W.L. Hargrove (ed.) Cover Crops for Clean Water. Soil and Water Conservation Society, Ankeny, IA.

Dabney, S.M., J.A. Delgado, and D.W. Reeves. 2001. Using winter cover crops to improve soil and water quality. Commun. Soil Sci. Plant Anal. 32:1221–1250.

De Bruin, J.L., P.M. Porter, and N.R. Jordan. 2005. Use of rye cover crop following corn in rotation with soybean in the Upper Midwest. Agron. J. 97:587-598.

Dexter, A.R. 1991. Amelioration of soil by natural processes. Soil Tillage Res. 20:87–100.

Doran, J.W. 1987. Microbial biomass and mineralizable nitrogen distributions in no tillage and plowed soils. Biol. Fertil. Soils. 5:68–78.

Duval, J. 1997. Cover cropping in potato production. Ecological Agriculture Projects. Publication 71.

Ess, D.R., D.H. Vaughan, and J.V. Perumpral. 1998. Crop residue and root effects on soil compaction. Trans ASAE. 41:1271–1275.

Feyereisen, G.W., B.N. Wilson, G.R. Sands, J.S. Strock, and P.M. Porter. 2006. Potential for a rye cover crop to reduce nitrate loss in southwestern Minnesota. Agron. J. 98:1416–1426.

Hargrove, W.L. 1986. Winter legumes as a nitrogen source for no-till grain sorghum. Agron. J. 78:70–74.

Holderbaum, J.F., A.M. Decker, J.J. Meisinger, F.R. Mulford, and L.R. Vough. 1990. Fall seeded legume cover crops for no-tillage corn in the humid East. Agron. J. 82:117-124.

Huggins, D.R., G.A. Buyanovsky, G.H. Wagner, J.R. Brown, R.G. Darmody, T.R. Peck, G.W. Lesoing, M.B. Vanotti, and L.G. Bundy. 1998. Soil organic C in the tallgrass prairie-derived region of the corn belt: Effects of long-term crop management. Soil Tillage Res. 47:219–234.

Isse, A.A., A.F. MacKenzie, K. Stewart, D.C. Cloutier, and D.L. Smith. 1999. Cover crop and nutrient retention for subsequent sweet corn production. Agron. J. 91:934-939.

Johnson, T.J., T.C. Kaspar, K.A. Kohler, S.J. Corak, and S.D. Logsdon. 1998. Oat and rye overseeded into soybean as fall cover crops in the upper Midwest. J. Soil Water Conserv. 53:276–279.

Justes, E., B. Mary, and B. Nicolardot. 1999. Comparing the effectiveness of radish cover crop, oilseed rape volunteers and oilseed rape residues incorporation for reducing nitrate leaching. Nutrient Cycling in Agroecosystems. 55:207–220.

Kaspar, T.C., J.K. Radke, and J.M. Laflen. 2001. Small grain cover crops and wheel traffic effects on infiltration, runoff, and erosion. J. Soil Water Conserv. 56:160–164.

Kessavalou, A., and D.T. Walters. 1999. Winter rye cover crop following soybean under conservation tillage: Residual soil nitrate. Agron. J. 91:643–649.

Knopf, D. 2011. North Dakota Agriculture. USDA, National Agricultural Statistics Service. North Dakota Field Office. 80:65-69.

Kuo, S., U.M. Sainju, and E.J. Jellum. 1997. Winter cover cropping influence on nitrogen in Soil. Soil Sci. Soc. Amer. J. 61:1392-1399.

Lanfranconi, L.E., R.R. Bellinder, and R.W. Wallace. 1993. Grain rye residues and weed control strategies in reduced tillage potatoes. Weed Technol. 7:23-28.

Latif, M.A., G.R. Mehuys, A.F. Mackenzie, I. Alli, and M.A. Faris. 1992. Effects of legumes on soil physical quality in a maize crop. Plant Soil. 140:15–23.

Malpassi, R.N., T.C. Kaspar, T.B. Parkin, C.A. Cambardella, and N.A. Nubel. 2000. Oat and rye root decomposition effects on nitrogen mineralization. Soil Sci. Soc. Amer. J. 64:208-215.

McVay, K.A., D.E. Radcliffe, and W.L. Hargrove. 1989. Winter legume effects on soil properties and N fertilizer requirements. Soil Sci. Soc. Am. J. 53:1856–1862.

Mirsky, S.B., W.S. Curran, D.A. Mortensen, M.R. Ryan, and D.L. Shumway. 2009. Control of cereal rye with a roller/crimper as influenced by cover crop phenology. Agron. J. 101:1589-1596.

Mohler, C.L. and J.R. Teasdale. 1993. Response of weed emergence to rate of *Vicia villosa* Roth and *Secale cereal* L. residue. Weed Res. 33:487-499.

Moore, M.J., T.J. Gillespie, and C.J. Swanton. 1994. Effect of cover crop mulches on weed emergence, weed biomass, and soybean (Glycine max) development. Weed Technol. 8:512-518.

Morse, R.D. 1993. Components of sustainable production systems for vegetables-conserving soil moisture. HortTechnol. 3:211-214.

Morse, R.D. 2006. Using high-residue cover crop mulch for weed management in organic no-till potato production systems. Organic Farming Research Foundation.

Available at: http://ofrf.org/funded/reports/morse_03s18.pdf (posted 6 Jan. 2006; verified 20 May 2012).

Mundy, C., N.G. Creamer, C.R. Crozier, L.G. Wilson, and R.D. Morse. 1999. Soil physical properties and potato yield in no-till, subsurface-till, and conventional-till systems. HortTechnol. 9:240-247.

Nelson, D.C. and J.F. Giles. 1989. Weed management in two potato (*Solanum tuberosum* L.) cultivars using tillage and pendimethalin. Weed Sci. 37:229-232.

Nelson, D.C. and M.C. Thoreson. 1981. Competition between potatoes (*Solanum tuberosum*) and weeds. Weed Sci. 29:672-677.

Nyakatawa, E.Z., K.C. Reddy, and K.R. Sistani. 2001. Tillage, cover cropping, and poultry litter effects on selected soil chemical properties. Soil Tillage Res. 58:69–79.

Pan, X.P. and J. Letey. 2000. Organic farming: challenge of timing nitrogen availability to crop nitrogen requirements. Soil Sci. Soc. Amer. J. 64:247-253.

Potter, M. J., K. Davies, and A. J. Rathjen. 1998. Suppressive impact of glucosinolates in Brassica vegetative tissues on root lesion nematode Pratylenchus neglectus. J. of Chem. Eco. 24:67-80.

Power, J.F., P.T. Koerner, J.W. Doran, and W.W. Wilhelm. 1998. Residual effects of crop residues on grain production and selected soil properties. Soil Sci. Soc. Am. J. 62:1393–1397.

Petersen, J., R. Belz, F. Walker, and K. Hurle. 2001. Weed suppression by release of isothiocyanates from turnip-rape mulch. Agron. J. 93:37-43.

Putnam, A.R., J. Defrank, and J.P. Barnes. 1983. Exploitation of allelopathy for weed control in annual and perennial cropping systems. J. Chem. Ecol. 9:1001-1010.

Rosecrance, R.C., G.W. McCarty, D.R. Shelton, and J.R. Teasdale. 2000. Denitrification and N mineralization from hairy vetch (*Vicia villosa* Roth) and rye (*Secale cereal* L.) cover crop monocultures and bicultures. Plant and Soil. 227:283-290.

Scott, H.D., T.C. Keisling, B.A. Waddle, R.W. Williams, and R.E. Frans. 1990. Effects of winter cover crops on yield of cotton and soil properties. Bull. 924. Arkansas Agric. Exp. Stn., Fayetteville, AR.

Sincik, M., Z.M. Turan, and A.T. Goksoy. 2008. Responses of potato (*Solanum tuberosum* L.) to green manure cover crops and nitrogen fertilization rates. Amer. J. Pot. Res. 85:150-158.

Smith, M.S., W.W. Frye, and J.J. Varco. 1987. Legume winter cover crops, p. 95–139. Adv. Soil Sci., Vol. 7. Springer-Verlag, New York Inc.

Smith, K.A., A.G. Chalmers, B.J. Chambers, and P. Christie. 1998. Organic manure phosphorus accumulation, mobility and management. Soil Use Manage. 14:154–159.

Snapp, S.S., S.M. Swinton, R. Labarta, D. Mutch, J.R. Black, R. Leep, J. Nyiraneza, and K. O'Neil. 2005. Evaluating cover crops for benefits, costs, and performance within cropping system niches. Agron. J. 97:322-332.

Stivers-Young, L.J. and F.A. Tucker. 1999. Cover-cropping Practices of Vegetable Producers in Western New York. HortTechnol. 9:459-465.

Stute, J.K. and J.L. Posner. 1995. Synchrony between legume nitrogen release and corn demand in the upper Midwest. Agron. J. 87:1063-1069.

Teasdale, J.R. 1998. Cover crops, smother plants, and weed management. p. 247-270. *In* J.L. Hatfield, D.D. Buhler, and B.A. Stewart (ed.) Integrated weed and soil management. Sleeping Bear Press, Chelsea, MI.

Teasdale, J.R. and C.S.T. Daughtry. 1993. Weed suppression by live and desiccated hairy vetch (*Vicia villosa*). Weed Sci. 41:207-212.

Teasdale, J.R. and C.L. Mohler. 1993. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. Agron. J. 85:673-680.

United States Department of Agriculture. 1999. Pest management in U.S. agriculture. USDA Publication Agricultural Handbook No. 17.

Varco, J.J., W.W. Frye, M.S. Smith, and C.T. MacKown. 1993. Tillage effects on legume decomposition and transformation of legume and fertilizer nitrogen -15. Soil Sci. Soc. Amer. J. 57:750-756.

Varco, J.J., S.R. Spurlock, and O.R. Sanabria-Garro. 1999. Profitability and nitrogen rate optimization associated with winter cover management in no-tillage cotton. J. Prod. Agric. 12:91–95.

Vargas-Ayala, R., R. Rodriguez-Kabana, G. Morgan-Jones, J. A. McInroy, and J. W. Kloepper. 2000. Shifts in soil microflora induced by velvetbean (Mucuna deeringiana) in cropping systems to control root-knot nematodes. Biological Control. 17:11-22.

Waddel, J.T., S.C. Gupta, J.F. Moncrief, C.J. Rosen, and D.D. Steele. 2000. Irrigation and nitrogen management impacts on nitrate leaching under potato. Agron. J. 91:991-997.

Williams II, M.M., D.A. Mortenson, and J.W. Doran. 1998. Assessment of weed and crop fitness in cover crop residues for integrated weed management. Weed Sci. 46:595-603.

CHAPTER 1. WEED CONTROL WITH COVER CROPS IN IRRIGATED POTATO (*SOLANUM TUBERSOSUM* L.)

Abstract

A research experiment was conducted near Oakes, North Dakota in 2009 and 2010, and repeated at Carrington, North Dakota, in 2010 and 2011 to evaluate the potential of using cover crops for weed control and potato yields in irrigated potato production. Cover crop treatments included no cover crop, triticale, rye, hairy vetch, and rye/hairy vetch. The hairy vetch winter killed at Oakes and was replaced with turnip/radish and rye/canola cover crop treatments. Cover crop termination methods for both locations were disk-till, roto-till, and herbicide. The results were analyzed as a RCBD with a factorial arrangement and as a RCBD with a check. Locations were not combined due to winter-kill of hairy vetch in 2009-2010 and replacement with turnip/radish and canola. At Oakes, compared to the no cover crop treatment, cover crop treatments had 5% greater weed control 14 DAP, 14% greater 29 DAP, and 2% greater 51 DAP. At Carrington, compared to the no cover crop treatment, cover crops had 1% greater weed control 13 DAP, 1% greater 26 DAP, and 1% lower 42 DAP. Cover crops did not affect potato yield at Oakes, but negatively impacted yields at Carrington, with 18% greater marketable yield without a cover crop. The results of this experiment support the consideration of cover crops in an irrigated potato system as a means of additional weed control. However,, longer maturing potato cultivars present a problem as they require resources during the same part of the season that is critical for cover crop biomass accumulation.

Introduction

Irrigated potato production in North Dakota occurs in locations throughout eastern North Dakota which do not receive the high rainfall of the Red River Valley. Long season potato cultivars such as russet skinned, white, and yellow types are generally produced on irrigated land for processing into fries, chips, dehydrated products, and table stock, to ensure profitability. In 2010, North Dakota Agricultural Statistics reported that irrigated production occurred on approximately one-third of the potato hectares in ND, but provided over 50% of the potato yields (Knopf, 2011). No research has been conducted in North Dakota to evaluate the potential of integrating cover crops into irrigated potato production systems. Cover crop research could benefit producers aiming at high value, niche parts of the potato market, including the organic and specialty cultivar markets. The smaller land area farmed by producers in these markets provides the opportunity for diversified agronomic practices to improve their operation, which includes the use of cover crops.

Materials and Methods

General Procedures. Field experiments were conducted from 2009-2011 to evaluate weed control with cover crops in irrigated potato. Field experiments were conducted at the Oakes Research Extension Center (OREC), near Oakes, North Dakota (46.07N, -98.09W; elevation 392 m) in 2010 and repeated in 2011 at the Carrington Research Extension Center (CREC), near Carrington, North Dakota (47.51N, -99.13W; elevation 475 m). The experimental design was a randomized complete block with a two factor arrangement and four replicates. Cover crop termination treatments were herbicide, disk-till, and roto-till. Cover crop treatments were triticale, rye, hairy vetch, rye/hairy vetch, and no cover crop. Hairy vetch winter-kill during 2009-2010 resulted in the spring planting of turnip/radish and canola. The factorial combination of no cover crop and roto-till was not included, and substituted for a check treatment of no cover crop and no termination treatment. Certified seed potatoes were cut into 57 g ± 14 g seed pieces that were stored at 16 C with approximately 90% relative humidity for 2-7 days to allow for suberization before planting. Potatoes were grown using standard recommended grower practices for soil fertility, irrigation, and insect and disease management practices unless specifically described in the following Oakes or Carrington sections. Individual cover crop treatment plots were 3.66 m wide by 7.62 m long while individual treatment plots were 1.83 m wide by 7.62 m long and contained two potato rows.

Early-season weed control was estimated by weed species counts, weed above – ground fresh weights, and visual evaluations. Weed evaluations (weed counts, weights, and visual control ratings) were taken three times, approximately 14, 28, and 42 days after planting (DAP). Cultivation was conducted with a two-row disk cultivator (Harriston Industries; Minto, ND, USA) immediately after the first two weed evaluations. Weed counts were taken within a 0.09 m^2 quadrat placed on top of a potato row. Visual weed control evaluations were taken using a rating scale of 0 to 100%, where 0=no control and 100=complete weed control, referenced to the alleyways of the research where no weed control existed.

Harvested tubers were graded in Fargo with a single six station slide ejection photo sizer (Hagen Electronics; Reno, NV, USA). Tubers were separated into non-marketable (<113 g) and marketable (>113 g) yields, the table stock standard for potato. Ten tubers from each plot were randomly selected for hollow heart and sun scald evaluation. Hollow heart was detected by slicing each potato in half and identifying the presence of a hollow center, while sun scald was measured by analyzing the halved potatoes for greening between the skin and inner flesh. Data from each location (Oakes and Carrington) were analyzed individually using PC SAS 9.2 (SAS Institute Inc.; Cary, NC, USA). Proc ANOVA and Proc GLM procedures were used with an alpha value of 0.05 for all agronomic data. Means were separated, where appropriate, using Fisher's Protected least significant differences (LSD) test at $P \leq 0.05$.

Oakes, 2010. The experiment was conducted on an Embden loam (coarse-loamy, mixed, superactive, frigid Pachic Hapludolls) and Gardena loam (coarse-silty, mixed, superactive, frigid Pachic Hapludolls). The previous crop in 2009 for half of the trial was spring wheat and the other half dry edible bean. The plots received overhead irrigation using a linear system. Winter annual cover crops (triticale, rye, and hairy vetch) were planted on 28 Sept. 2009 with a grain drill (Case International Harvester; Racine, WI, USA). Triticale, rye, and hairy vetch were planted at 151.3 kg/ha, 132.4 kg/ha, and 33.6 kg/ha, respectively. In the combined planting, rye was planted at 65.4 kg/ha and hairy vetch was planted at 33.6 kg/ha. A spring granular fertilizer of 31.1 kg N/ha, 20.9 kg P/ha, and 47.4 kg K/ha was applied 6 Apr. 2010 to replications 1 and 2 where the spring wheat was grown the previous year to compensate for soil testing differences in replications 3 and 4. Due to the hairy vetch winter-kill a turnip/radish combination and canola were planted on 16 Apr. 2010. Turnip/radish took the place of the hairy vetch treatment and were planted by manual spreading and subsequent raking seed at 5.6 kg/ha turnip and 5.6 kg/ha radish into the soil. Canola was manually over seeded at 12.4 kg/ha into the rye/hairy vetch treatment to become the rye/canola cover crop treatment. A burn-down herbicide application of glyphosate at 861.8 g ae/ha was applied 24 May 2010. Cover crop biomass was harvested on 1 June 2010 inside a 0.09 m^2 quadrat and dried at 40 C for a dry weight measurement. Each whole plot was mowed with a 1.5 m rotary mower (John Deere; Moline, IL, USA) prior to either tillage treatment on 1 June. The roto-till treatment was performed with a 1.8 m roto-tiller (Woods; Oregon, IL, USA) while the disk-till treatment was performed with a 2.13 m disk (John Deere; Moline, IL, USA). Potato seed pieces were planted on 2 June with a two-row potato planter (Iron Age Co. (defunct); Glenoch, NJ, USA). A granular fertilizer, 32-10-10 (N, P, K) was banded in-furrow during potato planting at 160 kg N/ha, 50 kg P/ha, and 50 kg K/ha. Six soil samples (0-15 cm) were taken within each plot and composited into one, before planting on 12 May and 14 DAP on 16 June, and analyzed for NO_3-N content at the North Dakota State University Soil Testing Laboratory. Weed evaluations were taken on 16 June, 1 July, and 23 July. Potato stand counts were taken on 3 Aug., to evaluate if cover crop influenced seed piece survival. Potato tubers were harvested on 13 Oct. with a single-row potato digger (US Small Farms; Torrington, WY, USA).

Carrington, 2011. The experiment was carried out on a Heimdal loam soil (coarse-loamy, mixed, superactive, frigid Calcic Hapludolls), and the previous crop was barley. The plots received overhead irrigation using a center pivot system. Winter annual cover crops (triticale, rye, and hairy vetch) were planted on 26 Aug. 2010 with a grain drill (Case International Harvester; Racine, WI, USA). Triticale, rye, and hairy vetch were planted at 151.3 kg/ha, 132.4 kg/ha, and 33.6 kg/ha, respectively. In the combined planting, rye was planted at 65.4 kg/ha and hairy vetch was planted at 33.6 kg/ha. A burn-down herbicide application of glyphosate at 861.8 g ae/ha was applied 3 June 2011. Cover crop biomass was harvested on 15 June inside a 0.09 m^2 quadrat and dried at 40 C for dry weight measurements. Each whole plot was mowed with a rotary mower (John Deere; Moline, IL, USA) prior to either tillage treatment on 16 June. The roto-till treatment was performed with a 1.8 m roto-tiller (Woods; Oregon, IL, USA) while the disk-till treatment was performed with a 3.05 m disk (John Deere; Moline, IL, USA). Potato pieces were planted on 16 June with a two-row potato planter (Iron Age Co. (defunct); Glenoch, NJ, USA). A granular fertilizer, 32-10-10 (N, P, K) was banded in-furrow during potato planting at 160 kg N/ha, 50 kg P/, and 50 kg K/ha. Six soil samples (0-15 cm) were taken within each plot and composited into one before planting on 2 June and 13 DAP on 29 June, and analyzed for NO_3-N content at the North Dakota State University Soil Testing Laboratory. Weed evaluations were taken on 29 June, 12 July, and 28 July. Potato stand counts were taken on 28 July, to evaluate if cover crop influenced seed piece survival. Potato tubers were harvested on 13 Oct. with a single-row potato digger (US Small Farms; Torrington, WY, USA).

Results and Discussion

Irrigated

Cover crop biomass. Cover crop treatment had a significant effect on total dry weight biomass accumulation of the cover crop at Oakes in 2010 (Table A1). Cover crop biomass accumulation was greater for rye/canola and triticale compared to no cover crop or the turnip/radish cover crop (Table 1). Biomass for the no cover crop treatment was from a combination of weed species. The rye and triticale treatments accumulated far less than reported in the Eastern U.S., but above the level reported to suppress weeds in greenhouse studies (Mohler and Teasdale, 1993). Cover crops were terminated prior to anthesis of the cereal crops due to foreseen irrigation needs by other crops under the linear system. De Bruin et al. (2005) found significant rye regrowth when mowed at growth stages before anthesis. Rye and triticale terminated 1 June did not exhibit regrowth in treatments where mowing was followed by a termination treatment of roto-till or disk-till.

Table 1. Average dry weight biomass for cover crop treatments, Oakes, ND, 2010.

Cover crop	Dry weight
	-----------------kg/ha-----------------
Rye/canola	5892 a[z]
Triticale	5551 a
Rye	4954 ab
No cover crop	2186 b
Turnip/radish	2115 b

[z] Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Cover crops had an effect on total dry weight biomass accumulation at Carrington (Table A11). Hairy vetch and hairy vetch/rye accumulated greater biomass than when no cover crop was planted (Table 2). Hairy vetch in monoculture accumulated biomass equal to what has been reported in the Eastern U.S. (Mohler and Teasdale, 1993). Rye and triticale accumulated similar biomass to no cover crop and both hairy vetch treatments. Biomass for the no cover crop treatment was from a combination of weed species and was low at 54 kg/ha, harvested on 15 June. In Oakes during the 2010 growing season, there was an average of 2,186 kg/ha of weed biomass harvested on 1 June, illustrating the difference in weed pressure between the two locations (Table 1). Rye and triticale biomass accumulations were lower than expected when allowed to mature until 15 June. Environmental conditions in the spring included cool temperatures and wet soil, which may have contributed to the low accumulations. Cover crops terminated 15 June did not exhibit regrowth in treatments where mowing was followed by a termination treatment of roto-till or disk-till.

Hairy vetch is only moderately hardy in northern climates (Maul et al, 2011). Hairy vetch did not winter-kill during 2010-2011, though it did winter-kill during 2009-2010. Hairy vetch seed planted in 2009 was labeled as a product from Oregon. The hairy vetch seeded in 2010 was a genotype selected by the Carrington Research and Extension Center specifically for its winter hardiness. This seed source resulted in a dense stand of hairy vetch in 2011 (Table 2).

Table 2. Average dry weight biomass for cover crop treatments, Carrington, ND, 2011.

Cover crop	Dry weight
	-----------------kg/ha-----------------
Hairy vetch	3996 a[z]
Rye/hairy vetch	3580 a
Triticale	1850 ab
Rye	1671 ab
No cover crop	54 b

[z] Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Soil analysis. Cover crop treatment had no significant effect on soil NO_3-N level 21 days before planting at Oakes (DBP) (Table A2). There was no legume in the cover crop treatments to significantly affect soil NO_3-N 14 DAP (Table 3).

At Carrington, cover crop treatment had a significant effect on soil NO_3-N level 14 DBP (Table A12). Triticale cover crop plots had higher nitrogen than any other cover crop treatment with 39.6 kg/ha (Table 4). Results suggest that as nitrogen was being mineralized in the spring, less was immobilized by triticale or less leached below the collection depth due to the triticale root architecture, or a combination of these two events resulting in higher nitrogen levels in triticale plots.

Table 3. Effect of cover crop on average soil NO_3-N level 21 days before planting averaged over termination method, Oakes, ND, 2010.

Cover crop	21 DBP
	---------------------kg/ha---------------------
Triticale	110.5 a[z]
Rye	91.8 a
Turnip/radish	104.0 a
Rye/canola	90.8 a
No cover crop	106.5 a

[z] Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD (P≤0.05).

Table 4. Effect of cover crop on average soil NO_3-N level 14 days before planting averaged over termination method, Carrington, ND, 2011.

Cover crop	14 DBP
	-----------------kg/ha-----------------
Triticale	39.6 a[z]
Rye	32.2 b
Hairy vetch	28.4 bc
Rye/hairy vetch	26.6 c
No cover crop	25.6 c

[z] Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD (P≤0.05).

Weed control Oakes, 2010. Weed species present at Oakes included common lambsquarters (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), hairy nightshade (*Solanum sarrachoides* Sendtner), yellow foxtail (*Setaria glauca* L. Beauv.), Pennsylvania smartweed (*Polygonum pensylvanicum*), and common purslane (*Portulaca oleracea* L.). No differential control of any specific weed species was observed among any factors in this study either year (data not shown). Since so few grass species were present and broadleaf weed species responded similarly, the weed analysis was combined over species and analyzed as total weeds and average weed control.

Cover crop and termination method affected average weed control 14 and 29 DAP (Table A3). At 14 DAP, roto-till and herbicide termination methods had greater weed control than disk-till across all cover crop treatments besides rye/canola (Table 5). Herbicide termination when no cover crop was planted had 10% greater weed control than disk-till termination. Similarly, roto-till and herbicide termination treatments had 10% greater weed control in turnip/radish cover crop than disk-till termination. Cover crop treatments of rye and rye/canola had greater than or equal to 93% weed control across all termination methods. At 29 DAP, no termination method had greatest weed control across all cover crop treatments. Both disk-till and roto-till termination treatments had greater weed control than herbicide termination on a rye cover crop. Herbicide termination when no cover crop was present had 13% greater weed control than disk-tilling no cover crop. The importance of weed control early in the season has been demonstrated previously, with only 16% potato yield loss when weeds were controlled up until three weeks after potato emergence compared to 45-65% yield loss when weeds were not controlled (Nelson and Thoreson, 1981). At both 14 and 29 DAP the cover crops of triticale, rye, and rye/canola across all termination methods demonstrated early season weed control with 85% or greater weed control, compared to slightly lower weed control in turnip/radish and no cover crop plots with certain termination treatments. Moore et al. (1994) reported significantly lower redroot pigweed control when glyphosate terminated a triticale cover crop in no-till soybean compared to a glyphosate terminated rye cover crop. The authors did not mention an explanation for this particular finding, though rye allelopathic effects on redroot pigweed were discussed throughout the article. Moore et al. (1994) results were somewhat contrary to those at Oakes as herbicide terminated rye and triticale cover crops had similar weed control at 14 DAP. The reverse effect was seen at 29 DAP with triticale terminated by an herbicide having 4% greater weed control than herbicide terminated rye. However, average weed control with no cover crop at Oakes was relatively high at 86% 14 DAP, and the additional cultivation further improved the weed control.

Table 5. Effect of cover crop and termination method on average weed control 14 and 29 days after planting averaged, Oakes, ND, 2010.

	Cover crop				
Termination method	Triticale	Rye	Turnip/radish	Rye/canola	No cover crop
	--------------------------------% control--------------------------------				
<u>14 DAP</u>					
Disk-till	88 d[z]	93 b	79 f	93 b	81 e
Roto-till	93 b	95 a	89 d	94 ab	-[y]
Herbicide	95 a	95 a	89 d	95 a	91 c
<u>29 DAP</u>					
Disk-till	86 cd[z]	95 a	84 de	88 bc	70 f
Roto-till	94 a	93 a	88 bc	93 a	-[y]
Herbicide	89 b	85 de	89 b	90 b	83 e

[z] Means followed by the same letter within each timing are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

[y] The factorial treatment combination of no cover crop and roto-till was substituted for a no cover crop check.

Termination method affected average weed control 51 DAP (Table A3). Cover crop plots killed with an herbicide application or roto-till had greater weed control at 51 DAP compared to cover crop plots terminated with disk-tilling (Table 6). To decrease the potential for clogging during tillage, potato planting, or cultivation, the entire plot was mowed with a rotary mower just before roto-tilling, disk-tilling, and potato planting. The rotary mower that was used visibly distributed the mowed cover crop residue unevenly; leaving a swath of residue running parallel with a swath of very little residue in the direction the mower was operated, potentially lowering weed control overall. Dabney et al. (1991) recognized that a rotary type mower could not mow as close to the ground as other mower types. Creamer and Dabney (2002) identified that a flail mower provided the most uniform distribution of cover crop residue over the soil surface resulting in more uniform weed control.

Table 6. Effect of termination method on average weed control 51 days after planting averaged over cover crop, Oakes, ND, 2010.

Termination method	51 DAP
	---------------------% control---------------------
Disk-till	89 b[z]
Roto-till	94 a
Herbicide	93 a

[z] Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Cover crop and termination method affected weed density (Table A4). More weeds emerged per unit area when disk-till was used to terminate the triticale cover crop (Table 7). Termination method did not influence weed density when rye was the cover crop or when no cover crop was grown. Allelopathy has been demonstrated for some weed species, namely redroot pigweed, from both rye and turnip cover crop residues, although no evidence for allelopathy was found in this study for any of the weed species present (Petersen et al, 2001; Putnam et al, 1983).

Table 7. Effect of cover crop and termination method on average weed density pooled over three weed evaluation periods, Oakes, ND, 2010.

	Cover crop				
Termination method	Triticale	Rye	Turnip/radish	Rye/canola	No cover crop
	------------------------------density/m^2------------------------------				
Disk-till	108 g[z]	43 ab	65 cd	75 de	65 cd
Roto-till	54 bc	32 a	97 fg	43 ab	-[y]
Herbicide	43 ab	32 a	86 ef	54 bc	75 de

[z] Means followed by the same letter are not significantly different according to Fisher's Protected LSD (P≤0.05).

[y] The factorial treatment combination of no cover crop and roto-till was substituted for a no cover crop check.

Analysis with check. Cover crop and termination method were considered treatments and compared to the check which consisted of no cover crop, no termination method, and thus was considered a no-till conventional treatment. Cover crop type and termination method together had an effect on weed control averaged over all three weed evaluations (Table A5). The check treatment averaged 63% weed control, while the no cover crop treatment with an herbicide applied to control any vegetation prior to planting, also treated as no-till, averaged 88% weed control (Table 8). Results suggest that some form of weed control is needed at the start of the growing season to allow for cultivation to remain effective two and four weeks after potato planting. Without the herbicide application, weeds had nine more days to emerge and grow before potatoes were planted and the soil was disturbed for the first time in the check.

Table 8. Effect of cover crop and termination method on average weed control pooled over three weed evaluation timings, Oakes, ND, 2010.

Cover crop	Termination method	Weed control
		--% control--
Triticale	Roto-till	94 a[z]
Triticale	Herbicide	93 ab
Rye	Roto-till	93 ab
Rye/canola	Roto-till	93 ab
Rye	Disk-till	92 b
Rye/canola	Herbicide	92 b
Rye	Herbicide	92 b
Turnip/radish	Herbicide	90 c
Rye/canola	Disk-till	90 c
Triticale	Disk-till	89 cd
Turnip/radish	Roto-till	89 cd
No cover crop	Herbicide	88 d
Turnip/radish	Disk-till	83 e
No cover crop	Disk-till	81 f
No cover crop	No termination	63 g

[z] Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Treatment had a significant effect on weed density and fresh weight averaged over all three weed evaluations (Table A6). Weed density averaged over the three weed evaluation periods was similar in the check treatment to many other treatment combinations (Table 9). However, weed fresh weights for the check treatment were greater than any other treatment combination, suggesting that the weeds had grown without any early disturbance and were much larger. The presence of small germinating weeds weighing almost nothing accounted for weed densities greater than 27 plants/m^2 paired with fresh weed weights of zero.

Table 9. Effect of cover crop and termination method treatments on average weed density and weed fresh weight pooled over three weed evaluation timings, Oakes, ND, 2010.

Cover crop	Termination method	Weed density	Weed weight
		---density/m^2---	------g/m^2------
Triticale	Disk-till	102 h	24.7 a
Triticale	Roto-till	54 cd	3.2 a
Triticale	Herbicide	43 bc	0.0 a
Rye	Disk-till	54 cd	0.5 a
Rye	Roto-till	27 a	0.0 a
Rye	Herbicide	32 ab	1.6 a
Turnip/radish	Disk-till	65 def	2.2 a
Turnip/radish	Roto-till	86 g	8.1 a
Turnip/radish	Herbicide	86 g	0.0 a
Rye/canola	Disk-till	70 ef	7.0 a
Rye/canola	Roto-till	38 ab	2.2 a
Rye/canola	Herbicide	59 de	18.3 a
No cover crop	Disk-till	59 de	87.1 b
No cover crop	No termination	65 def	524.2 c
No cover crop	Herbicide	75 fg	4.3 a

[z] Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD (P≤0.05).

Weed control Carrington, 2011. Weed species present at Carrington included common lambsquarters, redroot pigweed, yellow foxtail, wild buckwheat (*Polygonum convolvulus* L.), and Eastern black nightshade (*Solanum ptycanthum* Dun.).

Cover crop and termination method had a significant effect on average weed control 13, 26, and 42 DAP (Table A13). At 13 DAP all treatment combinations had 95% or greater average weed control (Table 10). At 26 DAP all treatment combinations had 94% or greater average weed control. The absence of termination was associated with consistently high weed control across all cover crop treatments. At 42 DAP, all of the treatment combinations were associated with at least 90% weed control. The presence of a cover crop did not affect weed control compared to no cover crop. Weed control decreased slightly at 42 DAP, but potato row closure occurred shortly after this evaluation and provided weed control for the remainder of the growing season.

Table 10. Effect of cover crop and termination method on average weed control 13, 26, and 42 days after planting, Carrington, ND, 2011.

	Cover crop				
Termination method	Triticale	Rye	Hairy vetch	Rye/hairy vetch	No cover crop
	---------------------------------% control---------------------------------				
13 DAP					
Disk-till	98 ab[z]	96 c	97 bc	98 ab	95 d
Roto-till	98 ab	98 ab	98 ab	98 ab	-[y]
Herbicide	99 a	99 a	97 bc	97 bc	99 a
26 DAP					
Disk-till	95 de[z]	99 a	96 cd	95 de	94 e
Roto-till	96 cd	99 a	97 bc	98 ab	-[y]
Herbicide	98 ab	98 ab	94 e	94 e	99 a
42 DAP					
Disk-till	90 c[z]	93 b	95 a	91 c	95 a
Roto-till	95 a	95 a	95 a	93 b	-[y]
Herbicide	95 a	95 a	90 c	93 b	94 ab

[z] Means followed by the same letter within each timing are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

[y] The factorial treatment combination of no cover crop and roto-till was substituted for a no cover crop check.

Weed density and fresh weight were not significantly affected by cover crop or termination method (data not shown). The lack of differences is attributed to generally low weed pressure at Carrington in 2011.

Analysis with check. Cover crop and termination method were considered treatments and compared to the check which consisted of no cover crop, no termination method, and thus was considered a no-till conventional treatment. Treatment had a significant effect on weed control pooled over all three weed evaluations (Table A15). The check treatment averaged 80% weed control, while the no cover crop treatment with an herbicide applied to control any vegetation prior to planting, also treated as no-till, had 97% weed control (Table 11).

Treatment did not affect weed density or weed fresh weight pooled over all three weed evaluations (Table A16). Low weed pressure probably caused the lack of differences between treatments (Table 12). The majority of treatments did not record a single weed when averaged over the three weed evaluations.

Table 11. Effect of cover crop and termination method on average weed control pooled over three weed evaluation timings, Carrington, ND, 2011.

Cover crop	Termination method	Weed control
		--% control--
Triticale	Herbicide	97 a[z]
No cover crop	Herbicide	97 a
Rye	Roto-till	97 a
Rye	Herbicide	97 a
Hairy vetch	Roto-till	97 a
Triticale	Roto-till	96 ab
Rye	Disk-till	96 ab
Hairy vetch	Disk-till	96 ab
Rye/hairy vetch	Roto-till	96 ab
Rye/hairy vetch	Disk-till	95 bc
Triticale	Disk-till	94 c
Hairy vetch	Herbicide	94 c
Rye/hairy vetch	Herbicide	94 c
No cover crop	Disk-till	94 c
No cover crop	No termination	80 d

[z] Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Table 12. Effect of cover crop and termination method on average weed density and weed fresh weight pooled over three weed evaluation timings, Carrington, ND, 2011.

Cover crop	Termination method	Weed density	Weed weight
		---density/m^2---	------g/m^2------
Triticale	Disk-till	0 a[z]	0.0 a[z]
Triticale	Roto-till	0 a	0.0 a
Triticale	Herbicide	6 a	0.0 a
Rye	Disk-till	0 a	0.0 a
Rye	Roto-till	0 a	0.0 a
Rye	Herbicide	0 a	0.0 a
Hairy vetch	Disk-till	0 a	0.0 a
Hairy vetch	Roto-till	6 a	4.3 a
Hairy vetch	Herbicide	6 a	1.6 a
Rye/hairy vetch	Disk-till	0 a	0.0 a
Rye/hairy vetch	Roto-till	0 a	0.0 a
Rye/hairy vetch	Herbicide	0 a	0.0 a
No cover crop	Disk-till	0 a	2.2 a
No cover crop	No termination	6 a	2.2 a
No cover crop	Herbicide	0 a	0.6 a

[z] Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Yield Oakes, 2010. Cover crop termination method did not have a significant effect on plant stand count (Table A7). Stand count averaged 85% over all termination treatments (data not shown). Stand counts less than 100% was in part due to difficulties when planting into cover crop residue greater than 5,000 kg/ha for many cover crop treatments.

Total tuber yield paralleled marketable yield, thus discussion will focus on marketable yield. There were no significant interactions or main effects for marketable yield (Table A8). Yields exceeded 21 Mg/ha for all cover crop and termination method combinations except when a rye cover crop was killed with the glyphosate application (Table 13).

Table 13. Effect of cover crop and termination method on average marketable yield, Oakes, ND, 2010.

	Cover crop				
Termination method	Triticale	Rye	Turnip/radish	Rye/canola	No cover crop
	----------Mg/ha----------				
Disk-till	22.6 a[z]	21.3 a	22.2 a	24.0 a	22.8 a
Roto-till	24.3 a	21.8 a	25.1 a	27.4 a	-[y]
Herbicide	22.7 a	19.9 a	21.3 a	23.3 a	23.2 a

[z] Means followed by the same letter are not significantly different according to Fisher's Protected LSD (P≤0.05).

[y] The factorial treatment combination of no cover crop and roto-till was substituted for a no cover crop check.

Hollow heart is a physiological tuber defect that can lead to lower marketable yields at harvest. No treatment had any significant effect on hollow heart susceptibility, averaging 20% across all cover crop treatments (Table A9) (data not shown). Certain cultivars have been recognized to have greater susceptibility to hollow heart (Pavlista, 2011).

Analysis with check. Cover crop and termination method were considered treatments and compared to the check which consisted of no cover crop, no termination, and thus was considered a no-till conventional treatment (Table 14). Treatment had a significant effect on marketable yield (Table A10). The check treatment had significantly lower marketable yield compared to all other treatments. Marketable yields in the check treatment was 12.5 Mg/ha. Marketable yield from the second lowest yielding treatment was 59% greater when compared to the check. Results suggest that without weed control prior to planting, dramatic marketable yield losses will occur from weed competition.

Table 14. Effect of cover crop and termination method on average marketable potato yield, Oakes, ND, 2010.

Cover crop	Termination method	Marketable yield
		-----Mg/ha-----
Rye/canola	Roto-till	27.4 a
Turnip/radish	Roto-till	25.1 a
Triticale	Roto-till	24.3 bc
Rye/canola	Disk-till	24.0 bcd
Rye/canola	Herbicide	23.3 cde
No cover crop	Herbicide	23.2 cde
No cover crop	Disk-till	22.8 def
Triticale	Herbicide	22.7 ef
Triticale	Disk-till	22.6 efg[z]
Turnip/radish	Disk-till	22.2 efgh
Rye	Roto-till	21.8 fgh
Rye	Disk-till	21.4 gh
Turnip/radish	Herbicide	21.3 h
Rye	Herbicide	19.9 i
No cover crop	No termination	12.5 j

[z] Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Yield Carrington, 2011. Cover crop did not have a significant effect on potato stand count (Table A17). Stand count averaged 83% over all cover crop treatments (data not shown). Stand counts less than 100% may be due to difficulties when planting into any cover crop residue.

Total tuber yield paralleled marketable yield, thus discussion will focus on marketable yield. There were no significant interactions between cover crop and termination method on potato marketable yield (Table A18). Cover crop had no effect on marketable potato yield (Table A18). Yields were greater than 19 Mg/ha for all cover crop treatments (Table 15).

Table 15. Effect of cover crop on average marketable yield averaged over termination method, Carrington, ND, 2011.

Cover crop	Marketable yield
	-------Mg/ha-------
Triticale	22.2 a[z]
Rye	19.6 a
Hairy vetch	20.9 a
Rye/hairy vetch	22.6 a
No cover crop	25.1 a

[z] Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD (P≤0.05).

Termination method had a significant effect on marketable yield (Table A18). When roto-till was used to terminate the cover crops a 2 Mg/ha yield advantage was found over either disk-till or herbicide (Table 16). Roto-tilling of the soil before potato planting produced the most uniform soil seed bed, potentially leading to improved potato yield.

Table 16. Effect of termination method on average marketable yield averaged over cover crop, Carrington, ND, 2011.

Termination method	13 DAP
	----------------------Mg/ha----------------------
Disk-till	22.6 b[z]
Roto-till	24.6 a
Herbicide	22.1 b

[z] Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD (P≤0.05).

No significant interactions or main effects were significant for tuber sun scald (Table A19). Sun scald was prevalent in Carrington, affecting 37% of tubers on average. Tuber sun scald generally results from a poor hill structure that causes tubers to be exposed to the sun (Bellinder et al, 1996). The entire trial had uniform sun scald. Sun scald would lead to additional sorting of marketable tubers and perhaps rejection of the entire shipment decreasing profit for producers. Bellinder et al. (1996) identified increased cultivation as the primary solution for tuber greening. If an additional cultivation had been added by moving the first two cultivations up a few days, the sun scald problem may have been mitigated. Chitsaz and Nelson (1983) recognized the importance of cultivation for successful potato production, but they also realized one key detriment to cultivation: the dependence on favorable weather conditions. Weather in this study was favorable, but may have been a problem for weed control if additional cultivation was needed for adequate weed control.

Cultivar differences exist in the depth of tuber set within the hill, with certain cultivars setting tubers deeper than others (Pavek and Thornton, 2009). Shallower set tubers require larger hills to ensure no tuber greening, while providing room to maximize yield potential. Variation in depth of tuber set was not a factor considered when selecting cultivars for this research. The knowledge gained through two field seasons of cover crop potato production provides evidence for recommendation of cultivars with a deeper tuber set when hills may be less well-formed.

There were no significant differences in hollow heart from cover crop or termination treatments (Table A20). Average hollow heart was 25% over all termination treatments (data not shown).

Analysis with check. Cover crop and termination method were considered treatments and compared to the check which consisted of no cover crop, no termination, and thus was considered a no-till conventional treatment (Table 17). Treatment had a significant effect on marketable yield (Table A21). When no cover crop was combined with no termination method, marketable yield was the greatest among all treatment combinations besides three.

Table 17. Effect of cover crop and termination method on average marketable potato yield, Carrington, ND, 2011.

Cover crop	Termination method	Marketable yield
		-----Mg/ha-----
No cover crop	No termination	26.7 a[z]
No cover crop	Disk-till	26.4 ab
Rye/hairy vetch	Roto-till	25.9 ab
Triticale	Roto-till	24.3 abc
Rye/hairy vetch	Herbicide	23.9 bc
No cover crop	Herbicide	23.9 bc
Hairy vetch	Disk-till	23.2 cd
Triticale	Herbicide	22.2 cde
Rye	Herbicide	20.9 def
Triticale	Disk-till	20.4 efg
Hairy vetch	Herbicide	20.2 efg
Rye	Roto-till	19.5 fg
Hairy vetch	Roto-till	19.4 fg
Rye	Disk-till	18.5 fg
Rye/hairy vetch	Disk-till	18.0 g

[z] Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Summary

Field experiments were conducted at Oakes and Carrington to determine 1) if cover crops could be used in a mechanical weed management system in irrigated potato and 2) if cover crops affect potato yield. More specifically, the field trials evaluated the influence of cover crop and cover crop termination method on weed control, potato yield, and potato quality. Since potato production is a tillage intense system and the field trials consisted of a reduced tillage system, all difficulties with field operations were reported.

In general, cover crops presented difficulties during almost all phases of potato production. Cover crops terminated with herbicide were planted into a no-till field without customized no-till machinery. Lack of rigorous tillage before planting and the presence of cover crop residue made hill formation difficult throughout the season. Problems indicative of poor potato hill structure such as high rate of potato sun scald were prevalent. Hairy vetch was the cover crop considered most difficult to plant potatoes into due to its high biomass, slow dry down of vegetative tissue, and vine growth form.

Plots containing triticale, rye, and rye/canola had greater weed control with all termination methods (85-94%) up to one month after potato planting compared to turnip/radish and no cover crop treatments (76-94%) with all termination methods at Oakes. The high biomass of triticale, rye, and rye/canola compared to turnip/radish and no cover crop resulted in this difference. When each treatment combination was compared individually, average weed density over all three weed evaluations was 61 weeds/m^2 and 65 weeds/m^2 for all treatments combined and the checks alone, respectively. However, total weed fresh weight averaged over all three weed evaluations for the check was 524.9 g/m^2, but only 11.4 g/m^2 for all other treatment combinations combined. Cover crops had no effect on potato yield at Oakes. Treatments in this experiment lowered stand counts an average of 20%.

When a cover crop was present, average weed control was not improved above the no cover crop treatments at Carrington. All cover crop and termination treatments provided at least 90% average weed control averaged over all three evaluations periods. Evaluating each treatment combination separately showed minimal weed pressure, with most treatment combinations averaging 0-11 plants/m^2 and 0-15 g/m^2 weed fresh weight.

The checks did not have greater average weed density or weed fresh weight than any other combination of treatments. Cover crops did not have an effect on yield at Carrington. Treatments in this experiment lowered stand counts an average of 20%.

The results of this experiment point to further research being needed to better understand how to improve yields in this system. Mechanical difficulties encountered during planting must be overcome in order to understand the direct effects of cover crops on potato yield and quality. Results support the consideration for the use of a winter annual cover crop system in irrigated potato. However, additional research should examine soil physical and chemical changes as weed suppression only suggests a short-term benefit from the inclusion of a cover crop.

Literature Cited

Bellinder, R.R., R.W. Wallace, and E.D. Wilkins. 1996. Reduced rates of herbicides following hilling controlled weeds in conventional and reduced tillage potatoes. Weed Technol. 10:311-316.

Chitsaz, M. and D.C. Nelson. 1983. Comparison of various weed control programs for potatoes. Amer. Pot. J. 60:271-280.

Creamer, N.G. and S.M. Dabney. 2002. Terminating cover crops mechanically: Review of recent literature and assessment of new research results. Amer. J. Alt. Agr. 17:32-40.

Dabney, S.M., M.W. Buehring, and D.B. Reginelli. 1991. Mechanical control of legume cover crops. P. 146-147. *In* W.L. Hargrove (ed.) Cover Crops for Clean Water. Soil and Water Conservation Society, Ankeny, IA.

De Bruin, J.L., P.M. Porter, and N.R. Jordan. 2005. Use of rye cover crop following corn in rotation with soybean in the Upper Midwest. Agron. J. 97:587-598.

Knopf, D. 2011. North Dakota Agriculture. USDA, National Agricultural Statistics Service. North Dakota Field Office. 80:65-69.

Maul, J., S. Mirsky, S. Emche, and T. Devine. 2011. Evaluating a germplasm collection of the cover crop hairy vetch for use in sustainable farming systems. Crop Sci. 51: 2615-2625.

Mohler, C.L. and J.R. Teasdale. 1993. Response of weed emergence to rate of *Vicia villosa* Roth and *Secale cereal* L. residue. Weed Res. 33:487-499.

Moore, M.J., T.J. Gillespie, and C.J. Swanton. 1994. Effect of cover crop mulches on weed emergence, weed biomass, and soybean (Glycine max) development. Weed Technol. 8:512-518.

Morse, R.D. 1993. Components of sustainable production systems for vegetables-conserving soil moisture. HortTechnol. 3:211-214.

Nelson, D.C. and M.C. Thoreson. 1981. Competition between potatoes (*Solanum tuberosum*) and weeds. Weed Sci. 29:672-677.

Pavek, M and R. Thornton. Planting depth influences potato plant morphology and economic value. Amer. J. Pot. Res. 86:56-67.

Pavlista, A.D. 2001. G1437 Green potatoes: the problems and the solution. Historical Materials from University of Nebraska-Lincoln Extension. Paper 88.

Pavlista, A.D. 2011. CropWatch: potato education guide. Available at: http://cropwatch.unl.edu/web/potato/yukongold_tables (posted 2011; verified 12 March 2012).

Petersen, J., R. Belz, F. Walker, and K. Hurle. 2001. Weed suppression by release of isothiocyanates from turnip-rape mulch. Agron. J. 93:37-43.

Putnam, A.R., J. Defrank, and J.P. Barnes. 1983. Exploitation of allelopathy for weed control in annual and perennial cropping systems. J. Chem. Ecol. 9:1001-1010.

Teasdale, J.R. 1998. Cover crops, smother plants, and weed management. p. 247-270. *In* J.L. Hatfield, D.D. Buhler, and B.A. Stewart (ed.) Integrated weed and soil management. Sleeping Bear Press, Chelsea, MI.

Varco, J.J., W.W. Frye, M.S. Smith, and C.T. MacKown. 1993. Tillage effects on legume decomposition and transformation of legume and fertilizer nitrogen -15. Soil Sci. Soc. Amer. J. 57:750-756.

CHAPTER 2. WEED CONTROL WITH COVER CROPS IN NON-IRRIGATED POTATO (*SOLANUM TUBERSOSUM* L.)

Abstract

A field experiment was conducted at Fargo, North Dakota, from 2009-2010 and repeated near Carrington from 2010-2011 to evaluate the potential for weed control and potato yields using cover crops in non-irrigated potato production. Cover crop treatments included no cover crop, triticale, rye, hairy vetch and rye/hairy vetch. The hairy vetch winter killed at Fargo and was replaced with turnip/radish and canola cover crop treatments. Cover crop termination treatments for both locations were disk-till, roller-crimp, and herbicide. The results were analyzed as a RCBD with a factorial arrangement and as a RCBD with a check. Locations were not combined due to winter-kill of hairy vetch in 2009-2010 and replacement with turnip/radish and canola. At Fargo compared to the no cover crop treatment, plots with a cover crop had 17% greater weed control 17 DAP, 15% greater at 34 DAP, and 5% greater 49 DAP. At Carrington, plots with a cover crop had equal weed control to plots without a cover crop planted at 12 and 28 DAP, though plots with a cover crop had 5% greater weed control at 47 DAP than those without a cover crop. Yield in Fargo was low on average due to cover crop treatment and soil conditions. In Carrington, average marketable yield from the no cover crop plots was 35% greater than cover crop treatments. The results of this experiment support the consideration of cover crops in a non-irrigated potato system as a means of additional weed control. Further investigation into the yields under cover crops would improve the certainty of this recommendation.

Introduction

Two-thirds of the area planted to potatoes in North Dakota is under non-irrigated production and account for 49% of all potato production (Knopf, 2011). Non-irrigated potato production in ND is primarily located in the Red River Valley. Shorter season cultivars such as red-skinned potatoes are primarily grown for table stock and are suited to non-irrigated production. Cover crop research could benefit producers aiming at high value, niche parts of the market, including the organic and specialty cultivar market. The smaller land area farmed by producers in these markets opens the door for diversified agronomic practices to improve their operation, and cover crops could assist with diversification practices. Land in the Red River Valley has recently been inaccessible until later in the growing season due to wet soils resulting from wet falls and heavy snowfall during winter. Cover crops look enticing in this situation because the majority of their growth occurs during the early spring. Cover crops utilize much of the excess water in the spring before it drains from the soil.

Materials and Methods

General Procedures. Field experiments were conducted from 2009-2011 to evaluate weed control with cover crops in non-irrigated potato. Field experiments were conducted in Fargo, North Dakota (46.90N, -96.81W; elevation 293 m) in 2010 and repeated in 2011 at the Carrington Research Extension Center (CREC), near Carrington, North Dakota (47.51N, -99.13W; elevation 475 m). The experimental design was a randomized complete block with a two factor arrangement and four replicates. Cover crop termination treatments were herbicide, disk-till, and roller-crimp. Cover crop treatments were triticale, rye, hairy vetch, rye/hairy vetch, and no cover crop. Hairy vetch winter-kill during 2009-2010 resulted in the spring planting of turnip/radish and canola. The factorial combination of no cover crop and roto-till was not included, and substituted for a check treatment of no cover crop and no termination treatment. Certified seed potatoes were cut into 57 g ± 14 g seed pieces that were stored at 16 C with approximately 90% relative humidity for 2-7 days to allow for suberization before planting. Potatoes were grown using standard recommended grower practices for soil fertility, and insect and disease management practices unless specifically described in the following Fargo or Carrington sections. Individual cover crop treatment plots were 3.66 m wide by 7.62 m long while individual potato treatment plots were 1.83 m wide by 7.62 m long and contained two potato rows.

Early season weed control was estimated by weed species counts, weed above–ground fresh weights, and visual evaluations. Weed evaluations (weed counts, weights, and visual control ratings) were taken three times, approximately 14, 28, and 42 days after potato planting (DAP). Cultivation was conducted with a two-row disk cultivator (Harriston Industries; Minto, ND, USA) immediately after the first two weed evaluations. Weed counts were taken within a 0.09 m^2 quadrat placed on top of a potato row. Visual weed control evaluations were taken using a rating scale of 0 to 100%, where 0=no control and 100=complete weed control, referenced to the alleyways of the research where no weed control existed.

Harvested tubers were graded in Fargo with a single six station slide ejection photo sizer (Hagen Electronics; Reno, NV, USA). Tubers were separated into non-marketable (<113 g) and marketable (>113 g) yields, the table stock standard for red potato cultivars. Data from each location (Fargo and Carrington) were analyzed individually using PC SAS

9.2 (SAS Institute Inc.; Cary, NC, USA). Proc ANOVA and Proc GLM procedures were used with an alpha value of 0.05 for all agronomic data. Means were separated, where appropriate, using Fisher's Protected least significant differences (LSD) test at $P \leq 0.05$.

Fargo, 2010. The experiment was conducted on Fargo silty clay (fine, montmorillonitic, frigid Vertic Haplaquolls). The field was left fallow during 2009. Winter annual cover crops (triticale, rye, and hairy vetch) were planted on 24 Sept. 2009 with a grain drill (Case International Harvester; Racine, WI, USA). Triticale, rye, and hairy vetch were planted at 151.3 kg/ha, 132.4 kg/ha, and 33.6 kg/ha, respectively. In the combined planting, rye was planted at 65.4 kg/ha and hairy vetch was planted at 33.6 kg/ha. Due to the hairy vetch winter-kill a turnip/radish combination and canola were planted on 20 Apr. 2010. Turnip/radish took the place of the hairy vetch treatment and was planted by manual spreading and subsequent raking seed at 5.6 kg/ha turnip and 5.6 kg/ha radish into the soil. Canola was manually over seeded at 12.4 kg/ha into the rye/hairy vetch treatment to become the rye/canola cover crop treatment. A burn-down herbicide application of glyphosate at 861.8 g ae/ha was applied 14 June. Cover crop biomass was harvested on 23 June 2010 inside a 0.09 m^2 quadrat and dried at 40 C for dry weight measurements. All plots, except the roller-crimp treatment plots, were mowed with a 1.5 m rotary mower (John Deere; Moline, IL, USA) prior to the tillage treatment on 24 June. The roller-crimp treatment was performed with a 3.1 m roller-crimper (I & J Manufacturing; Gap, PA, USA) while the disk-till treatment was performed with a 2.1 m disk (John Deere; Moline, IL, USA) on 25 June. Potato seed pieces were planted on 25 June with a two-row potato planter (Iron Age Co. (defunct); Glenoch, NJ, USA). A granular fertilizer, 32-10-10 (N, P, K) was banded in-furrow during potato planting at 160 kg N/ha, 50 kg P/ha, and 50 kg K/ha. Six soil samples (0-15 cm) were taken within each plot and composited into one, before planting on 3 June and 16 DAP on 9 July, and analyzed for NO_3-N content at the North Dakota State University Soil Testing Laboratory. Weed evaluations were taken on 12 July, 29 July, and 13 Aug. Potato stand counts were taken on 29 July to evaluate cover crop influence on seed piece survival. Potato tubers were harvested on 22 Oct. with a single-row potato digger (US Small Farms; Torrington, WY, USA).

Carrington, 2011. The experiment was carried out on a Heimdal loam soil (coarse-loamy, mixed, superactive, frigid Calcic Hapludolls). Previous crop was barley in 2010. Winter annual cover crops (triticale, rye, and hairy vetch) were planted on 27 Aug. 2010, with a grain drill (International Harvester; Racine, WI, USA). Triticale, rye, and hairy vetch were planted at 151.3 kg/ha, 132.4 kg/ha, and 33.6 kg/ha, respectively. In the combined planting, rye was planted at 65.4 kg/ha and hairy vetch was planted at 33.6 kg/ha. A burn-down herbicide application of glyphosate at 861.8 g ae/ha was applied 6 June. Cover crop biomass was harvested on 29 June inside a 0.09 m^2 quadrat and dried at 40 C for dry weight measurements. All plots, except the roller-crimp treatment plots, were mowed with a 1.5 m rotary mower (John Deere; Moline, IL, USA) prior to the tillage treatment on 29 June. The roller-crimp treatment was performed with a 3.1 m roller-crimper (I & J Manufacturing; Gap, PA, USA) while the disk-till treatment was performed with a 2.1 m disk (John Deere; Moline, IL, USA). Potato seed pieces were planted on 30 June with a two-row potato planter (Iron Age Co. (defunct); Glenoch, NJ, USA). A granular fertilizer, 32-10-10 (N, P, K) was banded in-furrow during potato planting at 160 kg N/ha, 50 kg P/ha, and 50 kg K/ha. Six soil samples (0-15 cm) were taken within each plot and composited into one, before planting on 2 June and 14 DAP on 12 July, and analyzed for NO_3-N content at the North Dakota State University Soil Testing Laboratory. Weed evaluations were taken on 12 July, 28 July, and 16 Aug. Plots were hilled using a two-row cultivator (Harriston Industries; Minto, ND, USA) immediately after the first weed evaluation, but the intended second hilling could not be performed due to wet field conditions and potato row closure. Potato stand counts were taken on 28 July to evaluate if cover crop influenced seed piece survival. Potato tubers were harvested on 18 Oct. and 20 Oct., with a single-row potato digger (US Small Farms; Torrington, WY, USA).

Results and Discussion

Non-irrigated

Cover crop biomass. Cover crop treatment had a significant effect on total dry weight biomass accumulation at Fargo in 2010 (Table A22). Plots containing triticale, rye/canola, and rye accumulated greater biomass than plots with no cover crop (Table 18). Biomass for the no cover crop treatment was a combination of weed species. Though statistically similar to turnip/radish, cover crop treatments including triticale or rye produced over 10,000 kg/ha biomass, compared to 3,436 kg/ha from turnip/radish. The rye and triticale treatments accumulated similar to what was reported when grown in the North Eastern U.S. (Mohler and Teasdale, 1993). De Bruin et al. (2005) found significant rye regrowth when mowed at growth stages before anthesis. Rye and triticale cover crops terminated by rotary mowing and disk-till 24 June did not exhibit regrowth.

Table 18. Average dry weight biomass for cover crop treatments, Fargo, ND, 2010.

Cover crop	Dry weight
	-----------------kg/ha-----------------
Triticale	11470 a[z]
Rye/canola	10426 a
Rye	10233 a
Turnip/radish	3436 ab
No cover crop	2818 b

[z] Means followed by the same letter within each treatment are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Termination method did not have an effect on turnip survival, which was assessed by measuring turnip density, but did influence turnip fresh weight (Table A23). Plant density varied greatly within the plots receiving roller-crimping termination, which led to the lack of difference between termination methods. The roller-crimper did not terminate turnip as effectively as triticale or rye, thus the difference in turnip weight with the roller-crimper termination methods compared to disk-till or the herbicide application (Table 19). The function of a roller-crimper is to apply a large force on a plant stem while simultaneously snapping the stem, resulting in a dead plant (Mirsky et al, 2009). Triticale and rye have a pronounced stem tall enough to be effectively snapped by force from the roller-crimper. In contrast, turnip has a stem low to the ground, flaccid, and not easily snapped, resulting in a turnip plant that can survive roller-crimping and persist into the cash crop season.

Though not different than disk-till or herbicide, an average of 22 turnips/m^2 in the roller-crimped plots presented a problem during planting and cultivation of the potato crop. The turnip/radish treatment was planted as a 50% mix of each species, but during the weed evaluations only turnip was present, while radish did not persist into the potato season. It remains unclear why the radish did not persist when the roller-crimper was used to terminate the cover crop. Radish may have been more succulent than turnip, resulting in pulverization of the aboveground plant portion. Dabney et al. (1991) recognized that a rotary type mower, as was used in this research, could not mow as close to the ground as other mower types, and thus suggests why some of the low to the ground turnip escaped termination in the disk-till treatment. Creamer and Dabney (2002) indicated that a flail mower provided a far more even distribution of cover crop residue along the soil surface, making for more even and accurate weed control.

Table 19. Effect of termination method on average turnip density and fresh weight pooled over three weed evaluations and cover crop, Fargo, ND, 2010.

Termination method	Turnip density	Turnip weight
	-------density/m^2-------	-------g/m^2-------
Disk-till	0 a[z]	0.0 a[z]
Roller-crimp	22 a	2.2 b
Herbicide	0 a	0.0 a

[z] Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Cover crop treatment had a significant effect on total dry weight biomass accumulation at Carrington in 2011 (Table A34). Cover crop biomass accumulation was greater for triticale, rye, and rye/hairy vetch than no cover crop (Table 20). Biomass for the no cover crop treatment was a combination of weed species. Rye/hairy vetch averaged 7,603 kg/ha dry weight while hairy vetch alone averaged 4,539 kg/ha. Cover crop accumulation was high in part due to a key factor recognized by Teasdale (1998) that winter annual cover crops take advantage of the cold winter and long wet spring. Cover crops in this study were allowed to grow until 29 June. Cover crops terminated 29 June did not exhibit regrowth in treatments when mowing was followed by a termination treatment of disk-till. The biomass accumulation in this study is in direct contrast to what was found in the irrigated study at Carrington in 2011, which was located approximately 400 meters from this site (Table 2). The only difference was that the cover crops in the Carrington non-irrigated site were allowed to mature 15 days longer, which resulted in over twice the biomass accumulations (Table 20). The non-irrigated rye accumulated 7,661 kg/ha while the irrigated rye accumulated 1,671 kg/ha, harvested just 15 days earlier than the non-irrigated.

Hairy vetch is only moderately hardy in northern climates (Maul et al, 2011). Hairy vetch did not winter-kill during 2010-2011, though it did winter-kill during 2009-2010. Hairy vetch seed planted in 2009 was labeled as a product from Oregon. The hairy vetch seeded in 2010 was a genotype selected by the Carrington Research and Extension Center specifically for its winter hardiness. This seed source resulted in a dense stand of hairy vetch in 2011 in addition to different climatic conditions (Table 20).

Table 20. Average dry weight biomass for cover crop treatments, Carrington, ND, 2011.

Cover crop	Dry weight
	-----------------kg/ha-----------------
Rye	7661 a[z]
Rye/hairy vetch	7603 a
Triticale	7415 a
Hairy vetch	4539 ab
No cover crop	1286 b

[z] Means followed by the same letter within each treatment are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Soil analysis. Cover crop treatment had a significant effect on soil NO_3-N 22 DBP at Fargo (Table A24). At 22 DBP, the greatest nitrogen was found when no cover crop was planted (Table 22). The NO_3-N level was greater in plots with the turnip/radish cover crop compared to triticale, rye, and rye/canola. Results suggest that the cereal cover crops were better than turnip/radish for nitrogen immobilization and uptake.

Table 21. Effect of cover crop on average soil NO_3-N level 22 days before planting averaged over termination method, Fargo, ND, 2010.

Cover crop	22 DBP
	----------------------kg/ha----------------------
Triticale	19.8 c[z]
Rye	20.5 c
Turnip/radish	24.2 b
Rye/canola	19.4 c
No cover crop	29.5 a

[z] Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Cover crop had an effect on soil NO_3-N 28 DBP at Carrington (Table A35). At 28 DBP hairy vetch and no cover crop had the greatest soil nitrogen possibly due to increased nitrogen scavenging and uptake from the robust root system of triticale and rye cover crops (Table 22).

Table 22. Effect of cover crop on average soil NO_3-N level 28 days before planting averaged over termination method, Carrington, ND, 2011.

Cover crop	28 DBP
	-----------------------kg/ha-----------------------
Triticale	32.1 b[z]
Rye	29.5 b
Hairy vetch	42.9 a
Rye/hairy vetch	34.0 b
No cover crop	45.2 a

[z] Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Weed control Fargo, 2010. Weed species present at Fargo were yellow foxtail (*Setaria glauca* L. Beauv.), common mallow (*Malva neglecta* Wallr.), venice mallow (*Hibiscus trionum* L.), wild buckwheat (*Polygonum convolvulus* L.), common lambsquarters (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), and common ragweed (*Ambrosia artemisiifolia* L.). No differential control of any specific weed species was observed between any factors in this study (data not shown). Since few grass species were present and broadleaf weed species responded similarly, the weed analysis was combined and analyzed as total weeds and average weed control.

Cover crop and termination method affected average weed control 17 DAP (Table A25). Triticale, rye, and rye/canola cover crop treatments had greater average weed control across all termination methods than turnip/radish and no cover crop (Table 23). This result is attributed to the biomass from the cereal cover crops.

Table 23. Effect of cover crop and termination method on average weed control 17 days after planting, Fargo, ND, 2010.

	Cover crop				
Termination method	Triticale	Rye	Turnip/radish	Rye/canola	No cover crop
	--------------------------------% control----------------------------------				
Disk-till	88 a[z]	88 a	70 b	83 a	64 bc
Roller-crimp	89 a	89 a	36 c	83 a	-[y]
Herbicide	83 a	83 a	61 c	83 a	58 c

[z] Means followed by the same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

[y] The factorial treatment combination of no cover crop and roller-crimp was substituted for a no cover crop check.

Cover crop had a significant effect on average weed control 34 DAP (Table A25). At 34 DAP, triticale and rye cover crop plots had greater weed control, while rye/canola had greater weed control than plots with no cover crop (Table 24). Given the similar biomass production from rye and rye/canola, the difference in weed control was unexpected. The importance of weed control early in the season has been demonstrated, with only 16% potato yield loss when weeds were controlled up until three weeks after potato emergence compared to 45-65% yield loss when weeds were not controlled (Nelson and Thoreson, 1981). Triticale and rye demonstrated better early season weed control compared to turnip/radish and no cover crop up until approximately four weeks after potato planting. At 60 and 66% weed control for rye and triticale cover crops at 34 DAP, this is below the industry accepted standard of 85% weed control. These results indicate that with a triticale or rye cover crop, the weed control timing between 17 DAP and 34 DAP is critical. There was cultivation at 17 DAP that was intended to cover weeds on the hills with soil and destroy weeds growing between the rows. The clay soil texture limited the success of this cultivation. For weed control purposes, cultivation should have been repeated at least once to better control weeds while they were small and controllable. Typically a single cultivation pass will cover the hills, but instead, large soil clods formed that were detrimental to potato growth and hill formation. If weeds were controlled at a similar level as they were at 17 DAP for the second and third weed evaluation timings potato yields may have improved.

Table 24. Effect of cover crop on average weed control 34 days after planting averaged over termination method, Fargo, ND, 2010.

Cover crop	34 DAP
	------------------------------% control-------------------------------
Triticale	66 a[z]
Rye	60 a
Turnip/radish	40 bc
Rye/canola	47 b
No cover crop	38 c

[z] Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD (P≤0.05).

Termination method had a significant effect on average weed control 34 DAP (Table A25). Disk-till termination had greater weed control than herbicide terminated plots 34 DAP (Table 25). All termination methods had less than 60% average weed control.

Table 25. Effect of termination method on average weed control 34 days after planting averaged over cover crop, Fargo, ND, 2010.

Termination method	34 DAP
	------------------------------% control-------------------------------
Disk-till	59 a[z]
Roller-crimp	51 ab
Herbicide	44 b

[z] Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD (P≤0.05).

Termination method affected weed density at weed evaluation timings 34 and 49 DAP (Table A27). The greatest weed density at 34 and 49 DAP occurred when disk-till was the termination method for the cover crops (Table 26). Disk-till cover crop termination resulted in greater soil disturbance at potato planting and may have led to greater weed seedling emergence due to more intensive soil disturbance than roller-crimping or the herbicide application.

Table 26. Effect of termination method and time on average weed density 17, 34, and 49 days after planting averaged over cover crop, Fargo, ND, 2010.

	Days after planting		
Termination method	17	34	49
	density/m^2		
Disk-till	54 a[z]	204 b[z]	97 b[z]
Roller-crimp	54 a	97 a	54 a
Herbicide	65 a	129 a	65 a

[z] Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$)

Termination method had a significant effect on average weed fresh weight 17, 34, and 49 DAP (Table A28). Cover crop plots that were terminated with glyphosate had greater total fresh weed weight at all three weed evaluation timings compared to the disk-till or roller-crimp termination methods (Table 27). Similar to the herbicide treatment, plots that were roller-crimped did not have an initial tillage, though it did provide a mat of cover crop residue, which may have decreased the weed weight. The extra soil disturbance with disk-till disrupted the weed seed bank, potentially leading to greater weed density 34 and 49 DAP (Table 26). The greater weed density may have caused greater competition for resources which resulted in lower weed fresh weight. Cultivation of plots that were roller-crimped was extremely difficult due to mats of biomass flattened to the soil surface. Plots were terminated with glyphosate 12 days prior to roller-crimping. This interval allowed weed germination and seedlings growth 12 days earlier in herbicide plots, possibly contributing to greater average weed fresh weights than the roller-crimping or disk-tilling.

Table 27. Effect of termination method and time on average weed fresh weight 17, 34, and 49 days after planting averaged over cover crop, Fargo, ND, 2010.

	Days after planting		
Termination method	17	34	49
	---------------------------------g/m^2---------------------------------		
Disk-till	50.5 a[z]	219.4 a[z]	100.0 a[z]
Roller-crimp	155.9 a	272.0 a	523.7 a
Herbicide	782.8 b	1120.4 b	1848.4 b

[z] Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD (P≤0.05).

Analysis with check. Cover crop and termination method were considered treatments and compared to the check, which consisted of no cover crop, and no termination method, and thus was considered a no-till conventional treatment. Treatment had a significant effect on weed control averaged over all three weed evaluations (Table A29). The check treatment had the lowest average weed control with 24% (Table 28). Roller-crimp terminated turnip/radish had the next lowest weed control with 35%. Roller-crimping the turnip/radish cover crop was problematic due to the inability to terminate turnip plants effectively, as well as limited biomass production to create a mat of residue to shade the soil. The check treatment had 22% lower average weed control than the herbicide terminated no cover crop treatment, which presented nearly identical no-till conditions, except that glyphosate was applied 12 days before planting. Weed control was greater than 60% in all triticale and rye cover crop plots under all treatment combinations, but never reached the industry standard of 85% weed control.

Table 28. Effect of cover crop and termination method on average weed control pooled over three weed evaluation timings, Fargo, ND, 2010.

Cover crop	Termination method	Weed control
		---% control---
Triticale	Disk-till	72 a[z]
Triticale	Roller-crimp	72 a
Rye	Roller-crimp	71 ab
Rye	Disk-till	69 b
Rye/canola	Disk-till	66 c
Triticale	Herbicide	63 d
Rye	Herbicide	62 de
Rye/canola	Roller-crimp	60 ef
Turnip/radish	Disk-till	59 f
Rye/canola	Herbicide	56 g
Turnip/radish	Herbicide	54 gh
No cover crop	Disk-till	53 h
No cover crop	Herbicide	46 i
Turnip/radish	Roller-crimp	35 j
No cover crop	No termination	24 k

[z] Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Treatment also had a significant effect on weed density and fresh weight averaged over all three weed evaluations (Table A30). The check treatment did not produce the greatest average weed weight or weed density. There were no pronounced trends between treatment combinations and weed density or weed weight (Table 29).

Table 29. Effect of cover crop and termination method on average weed density and weed fresh weight pooled over three weed evaluation timings, Fargo, ND, 2010.

Cover crop	Termination method	Weed density	Weed weight
		---density/m^2---	----g/m^2----
Triticale	Disk-till	134 f[z]	307.0 b[z]
Triticale	Roller-crimp	91 cd	442.5 cd
Triticale	Herbicide	81 bc	498.9 d
Rye	Disk-till	124 f	348.9 bc
Rye	Roller-crimp	65 a	362.9 bcd
Rye	Herbicide	97 de	821.0 fg
Turnip/radish	Disk-till	108 e	168.3 a
Turnip/radish	Roller-crimp	81 bc	900.5 g
Turnip/radish	Herbicide	75 ab	763.4 ef
Rye/canola	Disk-till	124 f	467.2 cd
Rye/canola	Roller-crimp	75 ab	441.4 bcd
Rye/canola	Herbicide	102 de	665.6 f
No cover crop	Disk-till	97 de	356.5 bc
No cover crop	No termination	108 e	800.5 efg
No cover crop	Herbicide	91 cd	1372.0 h

[z] Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Weed control Carrington, 2011. Weed species present at Carrington were common lambsquarters, redroot pigweed, common purslane (*Portulaca oleracea* L.), wild buckwheat, and Eastern black nightshade (*Solanum ptycanthum* Dun.).

Cover crop and termination method had a significant effect on average weed control 12, 28, and 47 DAP (Table A36). All combinations of cover crop and termination method had 91% or greater weed control 12 DAP (Table 30). Herbicide termination consistently had average weed control above 98% across all cover crop treatments. Roller-crimped hairy vetch cover crop had lower weed control than disk-till and herbicide termination methods for hairy vetch. When no cover crop was planted, weed control was identical to most treatment combinations with a cover crop, evidence that cover crop residue did not improve weed control over the no cover crop treatment at 12 DAP.

Herbicide termination consistently had average weed control at or above 94% across all cover crop treatments 28 DAP. Roller-crimped hairy vetch and rye/hairy vetch cover crops had significantly lower weed control than disk-till or herbicide termination treatments for the cover crops. At 47 DAP roller-crimp termination had the lowest weed control among the three termination methods across all cover crops at around 80%. Results suggest that roller-crimping is not a viable cover crop termination method for weed control in non-irrigated potato production. The difficulty of planting and cultivating into roller-crimped cover crops reinforces this result, as a mat of over 7,000 kg/ha cover crop residue on the soil surface created mechanically difficulties (Table 20). Mechanical improvements for potato planting such as the subsurface tiller-transplanter would improve success with roller-crimping (Morse, 1993).

Chitsaz and Nelson (1983) recognized how important cultivation was to successful potato production, but they also realized that the key downfall to cultivation was its dependence on favorable weather conditions. Carrington received heavy rains over a span of several weeks, allowing no cultivation of the plots from 28 DAP through row closure. Therefore, the plot had just a single cultivation at 12 DAP, in part explaining the decreased weed control seen from 28 to 47 DAP.

Weed density and fresh weight were not significantly affected by cover crop or termination method (data not shown). The lack of differences is attributed to generally low weed pressure at Carrington in 2011.

Table 30. Effect of cover crop and termination method on average weed control 12, 28, and 47 days after planting, Carrington, ND, 2011.

	Cover crop				
Termination method	Triticale	Rye	Hairy vetch	Rye/hairy vetch	No cover crop
	---------------------------------% control---------------------------------				
<u>12 DAP</u>					
Disk-till	97 bc[z]	98 ab	99 a	95 d	97 bc
Roller-crimp	95 d	97 bc	91 e	96 cd	-[y]
Herbicide	99 a	99 a	98 ab	98 ab	98 ab
<u>28 DAP</u>					
Disk-till	91 c[z]	95 a	95 a	94 ab	93 b
Roller-crimp	93 b	94 ab	86 e	89 d	-[y]
Herbicide	95 a	95 a	94 ab	94 ab	94 ab
<u>47 DAP</u>					
Disk-till	83 de[z]	85 cd	94 a	89 b	76 g
Roller-crimp	80 e	80 e	79 e	81 ef	-[y]
Herbicide	89 b	91 b	91 b	90 b	86 c

[z] Means followed by the same letter within each timing are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

[y] The factorial treatment combination of no cover crop and roller-crimp was substituted for a no cover crop check.

Analysis with check. Cover crop and termination method were considered treatments and compared to the check which consisted of no cover crop, no termination method, and thus was considered a no-till conventional treatment. Treatment had a significant effect on weed control averaged over all three weed evaluations (Table A38). The check treatment averaged 54% weed control (Table 31). Herbicide applied to the no cover crop treatment was also treated as no-till and had approximately 40% greater weed control than the check. Results suggest that some form of weed control is needed at the start of the growing season to allow for cultivation to remain effective two and four weeks after planting. Without an herbicide application, weeds had 24 more days to germinate and grow before seed pieces were planted and the soil disturbed for the first time in the check.

Table 31. Effect of cover crop and termination method on average weed control pooled over three weed evaluation timings, Carrington, ND, 2011.

Cover crop	Termination method	Weed control
		---% control---
Hairy vetch	Disk-till	96 a[z]
Rye	Herbicide	95 ab
Triticale	Herbicide	94 bc
Hairy vetch	Herbicide	94 bc
Rye/hairy vetch	Herbicide	94 bc
Rye	Disk-till	93 cd
No cover crop	Herbicide	93 cd
Rye/hairy vetch	Disk-till	92 d
Rye	Roller-crimp	90 e
Triticale	Disk-till	90 e
Triticale	Roller-crimp	89 e
Rye/hairy vetch	Roller-crimp	89 e
No cover crop	Disk-till	89 e
Hairy vetch	Roller-crimp	85 f
No cover crop	No termination	54 g

[z] Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Treatment did not have a significant effect on weed density or fresh weight averaged over all three weed evaluations (Table A39). The check did not have greater weed density or weed fresh weight than any other treatment combination (Table 32). There was minimal weed pressure in Carrington. The greatest average weed density was 22 plants/m^2 and the greatest average weed fresh weight was 402.2 g/m^2, while most treatment combinations averaged less than one plant/m^2 weed density and less than 10 g/m^2 for fresh weed weight. The checks had an average of 54% weed control over three weed evaluations (Table 31), yet averaged less than one plant/m^2 (Table 32). When visually evaluating the check plots, there were a few large escaped weeds throughout the plot, which resulted in a low visual evaluation, but when a quadrat was used to record weed density, the randomly selected location often did not contain one of the large escapes. With an average weed fresh weight for the no cover crop check treatment of 201.7 g/m^2, at least one escaped large weed was found. The weed density for that treatment combination for all four replications and three weed evaluation timings was zero when rounded with significant figures, showing that it was likely just one or two total plots where an escaped weed was included.

Table 32. Effect of cover crop and termination method on average weed density and weed fresh weight pooled over three weed evaluations, Carrington, ND, 2011.

Cover crop	Termination method	Weed density	Weed weight
		---density/m^2---	----g/m^2----
Triticale	Disk-till	17 b^z	10.7 a^z
Triticale	Roller-crimp	0 a	0.0 a
Triticale	Herbicide	0 a	6.5 a
Rye	Disk-till	0 a	3.2 a
Rye	Roller-crimp	0 a	1.6 a
Rye	Herbicide	0 a	6.5 a
Hairy vetch	Disk-till	0 a	5.4 a
Hairy vetch	Roller-crimp	0 a	6.7 a
Hairy vetch	Herbicide	0 a	3.8 a
Rye/hairy vetch	Disk-till	0 a	6.5 a
Rye/hairy vetch	Roller-crimp	0 a	24.7 a
Rye/hairy vetch	Herbicide	11 b	5.4 a
No cover crop	Disk-till	0 a	100.6 a
No cover crop	No termination	0 a	201.7 a
No cover crop	Herbicide	0 a	1.1 a

^{z} Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Yield Fargo, 2010. Total tuber yield paralleled marketable yield, thus discussion will focus on marketable yield. Termination method had a significant effect on potato stand count (Table A31). The clay soil and cover crop residue proved difficult for potato seed emergence across all termination treatments. However, the disk-till and herbicide termination treatments averaged 12% greater seed piece emergence than the roller-crimp treatment (Table 33). Roller-crimping had the lowest stand counts due to compacted soil, mats of cover crop residue, and planting problems because the potato planter was not specialized to plant into no-till or high residue environments. The entire trial was tilled just before cover crop planting on 24 Sept. 2009 and left un-tilled until 25 June 2010, when one-third of the plots were disk-tilled, while the other two-thirds were left to either be roller-crimped or sprayed for the herbicide treatment. The entire plot was then disturbed on 25 June when potatoes were planted. The potato planter has a V-shaped shovel just before where the potato seed drops, creating a furrow for the seed piece to land. Two closing disks behind the seed piece tube should throw soil over the furrow to create a hill, covering the seed piece. These closing disks can only move as much soil into a hill as is loose enough to be moved. Often very little soil was moved due the undisturbed clay soil and varying concentrations of cover crop residue. The cereal cover crops that were roller-crimped appeared to have the greatest problem covering the seed pieces with soil from the closing disks. To carry out successful research each seed piece was hand-planted to ensure soil contact. However, even when hand-planting, plant stand was less with the roller-crimp termination method. A producer would need to make major mechanical adjustments for a successful potato crop in these conditions for higher stand counts.

Table 33. Effect of termination method on average stand count averaged over cover crop, Fargo, ND, 2010.

Termination method	Stand count
	---------% emergence---------
Disk-till	72 a[z]
Roller-crimp	60 b
Herbicide	72 a

[z] Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD (P≤0.05).

Cover crop treatment significantly affected marketable yields (Table A32). Triticale plots had greater marketable yields than plots with rye, rye/canola, or no cover crop (Table 34). When rye was included in the cover crop treatment, marketable yields were lower than any cover crop treatment. This negative potato response to a rye cover crop may have resulted from the allelochemical properties of rye and does not appear to be a response to cover crop biomass as triticale, rye, and rye/canola had similarly high biomass exceeding 10,000 kg/ha (Table 18). Rye and triticale had greater weed control at 17 and 34 DAP (Table 23; Table 24), which Nelson and Thoreson (1981) reported would lead to higher yields. The marketable yield for triticale reinforced conclusions from Nelson and Thoreson (1981), as it had significantly higher average yields than any other cover crop treatment with 6.7 Mg/ha. In contrast, rye cover crop plots had the lowest marketable yields despite high weed control at the first two evaluation timings.

Table 34. Effect of cover crop on average marketable yield averaged over termination method, Fargo, ND, 2010.

Cover crop	Marketable yield
	---------------------Mg/ha---------------------
Triticale	6.7 a[z]
Rye	3.5 c
Turnip/radish	5.6 ab
Rye/canola	3.1 c
No cover crop	5.1 b

[z] Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD (P≤0.05).

Termination method had a significant effect on marketable yield (Table A32). Plots that were disk-tilled had greater marketable yield than plots that were roller-crimped (Table 35). Results suggest the use of tillage over the roller-crimper to terminate cover crops grown in clay textured soils for non-irrigated potato production.

Table 35. Effect of termination method on average marketable yield averaged over cover crop, Fargo, ND, 2010.

Termination method	Marketable yield
	---------------------Mg/ha---------------------
Disk-till	5.9 a[z]
Roller-crimp	3.0 b
Herbicide	5.0 ab

[z] Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD (P≤0.05).

Analysis with check. Cover crop and termination method were considered treatments and compared to the check which consisted of no cover crop, no termination method, and thus was considered a no-till conventional treatment (Table A33). The check treatment had poor yields; though not statistically lower than several other treatment combinations (Table 36). However, in general, no pronounced trends in marketable yields were observed.

Table 36. Effect of cover crop and termination method on average marketable potato yield, Fargo, ND, 2010.

Cover crop	Termination method	Marketable yield
		-----Mg/ha-----
Triticale	Disk-till	10.6 a [z]
Turnip/radish	Disk-till	7.1 b
Turnip/radish	Herbicide	6.6 bc
No cover crop	Disk-till	6.3 bc
Triticale	Herbicide	5.7 c
Rye	Herbicide	5.5 c
No cover crop	Herbicide	3.9 d
Triticale	Roller-crimp	3.8 d
Rye/canola	Herbicide	3.6 de
No cover crop	No termination	3.6 de
Rye/canola	Disk-till	3.3 de
Turnip/radish	Roller-crimp	3.2 de
Rye	Roller-crimp	2.7 de
Rye/canola	Roller-crimp	2.5 e
Rye	Disk-till	2.4 e

[z] Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Yield Carrington, 2011. Total tuber yield paralleled marketable yield, thus discussion will focus on marketable yield. Cover crop and termination method had a significant effect on potato stand count (Table A40). Roller-crimp terminated hairy vetch and rye/hairy vetch had the lowest potato stand counts with 52% emergence, followed by roller-crimp terminated rye and herbicide terminated triticale with 60% emergence (Table 37). Hairy vetch terminated with the roller-crimper resulted in vegetative bedding for the seed piece rather than soil and decreased plant emergence. Disk-tilled plots with no cover crop grown and herbicide terminated rye plots had the greatest stand counts with 80%

emergence. Stand counts less than 100% may be due to difficulties when planting into any cover crop residue. In an attempt to build hills and improve potato stand counts by covering seed pieces missed at planting the entire plot was cultivated immediately after the potatoes were planted. For a larger scale producer mechanical adjustments would be needed for sufficient stand counts in a roller-crimped cover crop.

Table 37. Effect of cover crop and termination method on average stand count, Carrington, ND, 2011.

	Cover crop				
Termination method	Triticale	Rye	Hairy vetch	Rye/hairy vetch	No cover crop
	-----------------------------% Emergence------------------------------				
Disk-till	64 de[z]	68 cd	76 ab	72 bc	80 a
Roller-crimp	68 cd	60 e	52 f	52 f	-[y]
Herbicide	60 e	80 a	76 ab	72 bc	72 bc

[z] Means followed by the same letter are not significantly different according to Fisher's Protected LSD (P≤0.05)

[y] The factorial treatment combination of no cover crop and roller-crimp was substituted for a no cover crop check.

Cover crop had a significant effect on marketable yield (Table A41). The no cover crop treatment had greater marketable yield than any other cover crop treatment (Table 38). Results suggest there is a negative yield response from cover crops due to the difficulty in forming adequate hills with high biomass accumulating cover crops terminated by roller-crimping, herbicide, or disk-tilling.

Table 38. Effect of cover crop on average marketable yield averaged over termination method, Carrington, ND, 2011.

Cover crop	Marketable yield
	---------------------Mg/ha---------------------
Triticale	11.6 bc[z]
Rye	9.6 d
Hairy vetch	12.8 b
Rye/hairy vetch	10.9 cd
No cover crop	17.4 a

[z] Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Termination method affected marketable yield (Table A41). Lowest marketable yield was from the roller-crimp termination treatment (Table 39). Marketable tuber yields were 153% greater for disk-till and 117% greater for herbicide termination compared to average marketable yield for roller-crimp termination. A grower dedicated to chemical free practices would select disk-till or comparable tillage over the roller-crimp cover crop termination method.

Table 39. Effect of termination method on average marketable yield averaged over cover crop, Carrington, ND, 2011.

Termination method	Marketable yield
	---------------------Mg/ha---------------------
Disk-till	15.7 a[z]
Roller-crimp	6.2 b
Herbicide	13.5 a

[z] Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Analysis with check. Cover crop and termination method were considered treatments and compared to the check which consisted of no cover crop, no termination method, and thus was considered a no-till conventional treatment (Table 40). Treatment had a significant effect on marketable yield (Table A42). The check yielded in the middle of the range of all treatment combinations. When roller-crimping was used to terminate all four cover crops the marketable yield was significantly lower than any treatment combination not containing roller-crimping. A two-site-year study in Grand Forks, ND, found average marketable yields of 18.7 and 17.7 Mg/ha for 'Red Norland' and 'Red Pontiac', respectively (Nelson and Giles, 1989).

Table 40. Effect of cover crop and termination method on average marketable potato yield, Carrington, ND, 2011.

Cover crop	Termination method	Marketable yield
		-----Mg/ha-----
Turnip/radish	Herbicide	18.1 a
No cover crop	Disk-till	17.6 ab
No cover crop	Herbicide	17.2 abc
Turnip/radish	Disk-till	16.9 abc
Triticale	Disk-till	16.4 bc
Rye/canola	Disk-till	15.8 c
No cover crop	No termination	12.8 d
Triticale	Herbicide	11.6 de
Rye	Herbicide	11.4 def
Rye	Disk-till	10.7 ef
Rye/canola	Herbicide	9.9 f
Triticale	Roller-crimp	7.3 g
Rye/canola	Roller-crimp	7.0 g
Rye	Roller-crimp	6.7 g
Turnip/radish	Roller-crimp	3.7 h

[z] Means followed by the same letter within each column are not significantly different according to Fisher's Protected LSD (P≤0.05).

Summary

Field experiments were conducted to determine 1) if cover crops could be used in a mechanical weed management system in non-irrigated potato and 2) if cover crops affect potato yield and quality. More specifically, the field trials evaluated the influence of cover crop and cover crop termination method on weed control, potato yield, and potato quality. Since potato production is a tillage intense system and the field trials consisted of a reduced tillage system, any difficulties with field operations were reported.

In general, cover crops presented difficulties at almost all phases of potato production. Cover crops terminated with herbicide were planted into a no-till field without customized no-till machinery. Cover crops terminated with roller-crimping caused nearly impossible potato planting conditions with the conventional potato planter. Lack of rigorous tillage before planting and the presence of cover crop residue made forming proper hills difficult. Hairy vetch residue was difficult to plant potatoes through due to high biomass, slow dry down of vegetative tissue, and vine growth form. Turnip was not completely terminated with disk-till or roller-crimp, resulting in cover crop competition with the potato cash crop.

Triticale and rye provided significantly greater weed control up to one month after potato planting compared to turnip/radish and no cover crop at Fargo in 2010. Absence of a termination method resulted in the lowest consistent weed control, though glyphosate had lower weed control than disk-till or roller-crimp in three of five cover crop treatments. Weed density and fresh weight was high, with poor weed control throughout the entire season. The glyphosate termination had significantly greater weed fresh weight at the final two weed evaluations. Average potato marketable yields for cover crop treatments were 8% below average marketable yields without a cover crop planted. The cover crop and termination treatment conditions in this experiment lowered stand counts. Roller-crimp had the lowest overall average stand count at 40% below a full stand.

Cover crops provided similar average weed control 12 and 28 DAP to the no cover crop treatment at Carrington in 2011. At 47 DAP, cover crop treatments averaged 5% greater average weed control than the no cover crop treatment. Roller-crimped plots had the lowest season-long weed control compared to disk-tilled and herbicide treated plots. Weed pressure was low with most treatment combinations averaging less than one weed/m^2 and weed fresh weights less than 10 g/m^2. Cover crops had a detrimental effect on yield at Carrington. The no cover crop treatment had 35% greater average marketable yield than cover crop treatments. The cover crop and termination treatment conditions in this experiment lowered stand counts.

The results of this experiment point to further research being needed to better understand the causes for potato yield differences between the two locations when similar cover crops were used. Mechanical difficulties encountered during planting must be overcome in order to understand the direct effects of cover crops on potato yield. These results support the consideration for use of cover crops in non-irrigated potato, though not exclusively for weed control.

Literature Cited

Chitsaz, M. and D.C. Nelson. 1983. Comparison of various weed control programs for potatoes. Amer. Pot. J. 60:271-280.

Creamer, N.G. and S.M. Dabney. 2002. Terminating cover crops mechanically: Review of recent literature and assessment of new research results. Amer. J. Alt. Agr. 17:32-40.

Dabney, S.M., M.W. Buehring, and D.B. Reginelli. 1991. Mechanical control of legume cover crops. P. 146-147. *In* W.L. Hargrove (ed.) Cover Crops for Clean Water. Soil and Water Conservation Society, Ankeny, IA.

De Bruin, J.L., P.M. Porter, and N.R. Jordan. 2005. Use of rye cover crop following corn in rotation with soybean in the Upper Midwest. Agron. J. 97:587-598.

Knopf, D. 2011. North Dakota Agriculture. USDA, National Agricultural Statistics Service. North Dakota Field Office. 80:65-69.

Maul, J., S. Mirsky, S. Emche, and T. Devine. 2011. Evaluating a germplasm collection of the cover crop hairy vetch for use in sustainable farming systems. Crop Sci. 51: 2615-2625.

Mohler, C.L. and J.R. Teasdale. 1993. Response of weed emergence to rate of *Vicia villosa* Roth and *Secale cereal* L. residue. Weed Res. 33:487-499.

Morse, R.D. 1993. Components of sustainable production systems for vegetables-conserving soil moisture. HortTechnol. 3:211-214.

Mirsky, S.B., W.S. Curran, D.A. Mortensen, M.R. Ryan, and D.L. Shumway. 2009. Control of cereal rye with a roller/crimper as influenced by cover crop phenology. Agron. J. 101:1589-1596.

Nelson, D.C. and J.F. Giles. 1989. Weed management in two potato (*Solanum tuberosum* L.) cultivars using tillage and pendimethalin. Weed Sci. 37:229-232.

Nelson, D.C. and M.C. Thoreson. 1981. Competition between potatoes (*Solanum tuberosum*) and weeds. Weed Sci. 29:672-677.

Teasdale, J.R. 1998. Cover crops, smother plants, and weed management. p. 247-270. *In* J.L. Hatfield, D.D. Buhler, and B.A. Stewart (ed.) Integrated weed and soil management. Sleeping Bear Press, Chelsea, MI.

Varco, J.J., W.W. Frye, M.S. Smith, and C.T. MacKown. 1993. Tillage effects on legume decomposition and transformation of legume and fertilizer nitrogen -15. Soil Sci. Soc. Amer. J. 57:750-756.

GENERAL SUMMARY

Cover crops present many difficulties to successful potato production. It was demonstrated that cover crops created an environment far different than what potato producers in this region are accustomed to. Furthermore, this environment is not one that potato production has been adapted to due to difficulties planting, cultivating, and harvesting. It was demonstrated that producing a quality potato without tuber greening in a system of high cover crop biomass is a problem that needs further investigation. It was also concluded that improvements in machinery would improve success in this high cover crop biomass system.

The problem of weed control in potato production was addressed in this research and results proved that weed control could be high up to 6 weeks after potato planting with a system using cover crop residue. Soil texture was one important element in this research, as clay dominant soils in Fargo, ND, proved to be difficult when combined with high cover crop biomass.

The ability of potatoes to yield in a cover crop system was tested. Besides the location at Fargo, ND, yield was sufficient to move forward with considering cover crops in a potato system.

We concluded that cover crops provided an alternative method for weed control if constraints of a producer are such that they would be beneficial for production. However, careful consideration to the difficulties with this system of potato production would be necessary to mitigate the problems that arose in this research.

APPENDIX

Table A1. ANOVA for average cover crop dry weight biomass, Oakes, ND, 2010.

SOV	df	MS	F
Replication	3	156.8	0.8
Treatment	4	3539.4	18.8**
Error	42	188.0	-

** Significant at the 0.01 probability level.

Table A2. ANOVA for average soil NO_3-N level 21 DBP, Oakes, ND, 2010.

SOV	df	MS	F
Rep	3	16738.3	43.1**
Cover crop (CC)	4	758.9	2.0
Termination (T)	2	98.8	0.8
CC X T	8	460.0	1.4
Error	42	388.5	-

** Significant at the 0.01 probability level.

Table A3. ANOVA for average weed control 14, 29, and 51 DAP, Oakes, ND, 2010.

		14		29		51	
SOV	df	MS	F	MS	F	MS	F
Rep	3	22.6	1.7	159.5	5.5**	96.1	3.9*
Cover crop (CC)	4	379.5	28.5**	658.3	22.8**	46.1	1.9
Termination (T)	2	446.8	33.5**	396.7	13.7**	240.3	9.9**
CC X T	7	45.9	3.4**	107.5	3.72**	25.8	1.1
Error	95	13.3	-	28.9	-	24.4	-

** Significant at the 0.01 probability level.

* Significant at the 0.05 probability level.

Table A4. ANOVA for average weed density averaged over all three weed evaluations, Oakes, ND, 2010.

		Weed density		Weed weight	
SOV	df	MS	F	MS	F
Rep	3	168.1	7.8**	45.5	0.7
Cover crop (CC)	4	156.1	7.2**	150.2	2.4
Termination (T)	2	41.9	1.9	119.1	1.9
CC X T	7	101.3	4.7**	82.0	1.3
Error	285	21.6	-	64.0	-

** Significant at the 0.01 probability level.

Table A5. ANOVA for average weed control averaged over all three weed evaluations by treatment, Oakes, ND, 2010.

SOV	df	MS	F
Rep	3	336.4	15.0**
Trt	14	1480.9	66.2**
Error	264	22.4	-

** Significant at the 0.01 probability level.

Table A6. ANOVA for average weed density and weed fresh weight averaged over all three weed evaluations by treatment, Oakes, ND, 2010.

		Weed density		Weed weight	
SOV	df	MS	F	MS	F
Rep	3	203.8	11.4**	799.7	7.0**
Trt	14	104.3	5.8**	3737.7	32.6**
Error	264	17.9	-	114.6	-

** Significant at the 0.01 probability level.

Table A7. ANOVA for average potato stand count, Oakes, ND, 2010.

SOV	df	MS	F
Rep	3	1.7	0.2
Cover crop (CC)	4	5.9	0.7
Termination (T)	2	4.1	0.5
CC X T	7	14.8	1.8
Error	95	5.2	-

Table A8. ANOVA for average marketable yield, Oakes, ND, 2010.

SOV	df	MS	F
Rep	3	76.7	3.7*
Cover crop (CC)	4	45.3	2.2
Termination (T)	2	68.8	3.3*
CC X T	7	4.9	0.2
Error	95	21.0	-

* Significant at the 0.05 probability level.

Table A9. ANOVA for average hollow heart, Oakes, ND, 2010.

SOV	df	MS	F
Rep	3	1.9	0.9
Cover crop (CC)	4	2.1	1.0
Termination (T)	2	0.6	0.3
CC X T	7	1.9	0.8
Error	95	2.2	-

Table A10. ANOVA for average marketable yield by treatment, Oakes, ND, 2010.

SOV	df	MS	F
Rep	3	69.1	3.6*
Trt	14	84.8	4.4**
Error	60	26.1	-

** Significant at the 0.01 probability level.
* Significant at the 0.05 probability level.

Table A11. ANOVA for average cover crop dry weight biomass, Carrington, ND, 2011.

SOV	df	MS	F
Rep	3	262.4	2.2
Trt	4	2629.6	21.8**
Error	42	120.5	-

** Significant at the 0.01 probability level.

Table A12. ANOVA for average soil NO_3-N level 14 DBP, Carrington, ND, 2011.

SOV	df	MS	F
Rep	3	396.7	2.7
Cover crop (CC)	4	1252.4	6.4**
Termination (T)	2	39.3	0.8
CC X T	8	29.2	0.6
Error	42	48.8	-

** Significant at the 0.01 probability level.

Table A13. ANOVA for average weed control 13, 26, and 42 DAP, Carrington, ND, 2011.

		13		26		42	
SOV	df	MS	F	MS	F	MS	F
Rep	3	19.3	4.0*	15.6	2.7*	22.6	4.7**
Cover crop (CC)	4	6.1	1.3	40.0	7.0**	17.8	3.7**
Termination (T)	2	24.8	5.1**	30.1	5.3**	24.1	5.0**
CC X T	7	12.1	2.5*	33.4	5.9**	38.1	7.9**
Error	95	4.9	-	5.7	-	4.8	-

** Significant at the 0.01 probability level.
* Significant at the 0.05 probability level.

Table A14. ANOVA for average weed control averaged over all three weed evaluations, Carrington, ND, 2011.

SOV	df	MS	F
Rep	3	44.0	8.6**
Cover crop (CC)	4	30.9	6.0**
Termination (T)	2	69.5	16.5**
CC X T	7	41.7	8.1**
Error	285	5.1	-

** Significant at the 0.01 probability level.

Table A15. ANOVA for average weed control averaged over all three weed evaluations by treatment, Carrington, ND, 2011.

SOV	df	MS	F
Rep	3	198.8	14.1**
Trt	14	465.2	33.0**
Error	306	14.1	-

** Significant at the 0.01 probability level.

Table A16. ANOVA for average weed density and weed fresh weight averaged over all three weed evaluations by treatment, Carrington, ND, 2011.

		Weed density		Weed weight	
SOV	df	MS	F	MS	F
Rep	3	5.8	7.1**	0.9	1.9
Trt	14	0.7	0.8	0.4	0.8
Error	306	0.8	-	0.5	-

** Significant at the 0.01 probability level.

Table A17. ANOVA for average potato stand count, Carrington, ND, 2011.

SOV	df	MS	F
Rep	3	4.2	0.5
Cover crop (CC)	4	11.1	1.3
Termination (T)	2	7.3	0.8
CC X T	7	4.0	0.5
Error	95	8.7	-

Table A18. ANOVA for average marketable yield, Carrington, ND, 2011.

SOV	df	MS	F
Rep	3	73.2	1.1
Cover crop (CC)	4	82.2	1.2
Termination (T)	2	27.9	0.4
CC X T	7	55.7	0.8
Error	95	68.1	-

** Significant at the 0.01 probability level.
* Significant at the 0.05 probability level.

Table A19. ANOVA for average potato sun scald, Carrington, ND, 2011.

SOV	df	MS	F
Rep	3	31.9	8.6**
Cover crop (CC)	4	8.3	2.2
Termination (T)	2	0.7	0.2
CC X T	7	3.0	0.8
Error	95	3.7	-

** Significant at the 0.01 probability level.

Table A20. ANOVA for average potato hollow heart, Carrington, ND, 2011.

SOV	df	MS	F
Rep	3	0.7	0.3
Cover crop (CC)	4	0.8	0.3
Termination (T)	2	1.5	0.6
CC X T	7	2.5	1.1
Error	95	2.4	-

Table A21. ANOVA for average marketable yield by treatment, Carrington, ND, 2011.

SOV	df	MS	F
Rep	3	70.8	0.8
Trt	14	67.4	0.8
Error	60	84.0	-

Table A22. ANOVA for average cover crop dry weight biomass, Fargo, ND, 2010.

SOV	df	MS	F
Rep	3	280.7	0.4
Trt	4	18179.3	28.2**
Error	42	645.4	-

** Significant at the 0.01 probability level.

Table A23. ANOVA for average turnip density and fresh weight averaged over all three weed evaluations, Fargo, ND, 2010.

		Turnip density		Turnip weight	
SOV	df	MS	F	MS	F
Rep	3	0.6	1.2	34.5	0.8
Trt	2	1.5	2.8	62.1	3.5*
Error	243	0.5	-	43.0	-

* Significant at the 0.05 probability level.

Table A24. ANOVA for average soil NO_3-N level 22 DBP, Fargo, ND, 2010.

SOV	df	MS	F
Rep	3	119.6	4.2*
Cover crop (CC)	4	169.9	6.0**
Termination (T)	2	56.9	2.0
CC X T	8	47.4	1.7
Error	42	28.2	-

** Significant at the 0.01 probability level.

* Significant at the 0.05 probability level.

Table A25. ANOVA for average weed control 17, 34, and 49 DAP, Fargo, ND, 2010.

		17		34		49	
SOV	df	MS	F	MS	F	MS	F
Rep	3	796.1	10.2**	1537.5	4.0*	160.4	1.5
Cover crop (CC)	4	4885.0	62.7**	3381.5	8.7**	153.4	1.4
Termination (T)	2	282.6	3.6*	2214.5	5.7**	57.1	0.5
CC X T	7	692.8	8.9**	800.5	2.1	251.3	2.4*
Error	81	77.9	-	388.4	-	106.6	-

** Significant at the 0.01 probability level.
* Significant at the 0.05 probability level.

Table A26. ANOVA for average weed control averaged over all three weed evaluations, Fargo, ND, 2010.

SOV	df	MS	F
Rep	3	1214.9	6.4**
Cover crop (CC)	4	5841.4	30.6**
Termination (T)	2	1638.6	8.6**
CC X T	7	1216.3	6.4**
Error	285	191.0	-

** Significant at the 0.01 probability level.

Table A27. ANOVA for average weed density 17, 34, and 49 DAP, Fargo, ND, 2010.

		17		34		49	
SOV	df	MS	F	MS	F	MS	F
Rep	3	38.4	2.4	186.2	2.4	74.2	2.8*
Cover crop (CC)	4	4.5	0.3	24.1	0.3	5.1	0.2
Termination (T)	2	11.9	0.7	847.3	10.9**	169.2	6.3*
CC X T	7	23.0	1.4	53.6	0.7	26.3	1.0
Error	81	16.0	-	77.4	-	26.8	-

** Significant at the 0.01 probability level.
* Significant at the 0.05 probability level.

Table A28. ANOVA for average weed fresh weight 17, 34, and 49 DAP, Fargo, ND, 2010.

		17		34		49	
SOV	df	MS	F	MS	F	MS	F
Rep	3	1775.7	2.7	3101.2	1.2	60238.8	3.7*
Cover crop (CC)	4	2777.5	4.2**	6718.5	2.6*	11998.6	0.7
Termination (T)	2	2256.0	3.4*	12199.1	4.8*	101872.8	6.2**
CC X T	7	969.7	1.5	2609.0	1.0	14717.0	0.9
Error	81	669.1	-	2558.2	-	16352.3	-

** Significant at the 0.01 probability level.
* Significant at the 0.05 probability level.

Table A29. ANOVA for average weed control averaged over all three weed evaluations by treatment, Fargo, ND, 2010.

SOV	df	MS	F
Rep	3	1258.6	11.5**
Trt	14	4574.0	41.8**
Error	264	109.3	-

** Significant at the 0.01 probability level.

Table A30. ANOVA for average weed density and weed fresh weight averaged over all three weed evaluations by treatment, Fargo, ND, 2010.

		Weed density		Weed weight	
SOV	df	MS	F	MS	F
Rep	3	118.3	2.6	17293.2	2.8*
Trt	14	111.4	2.5*	19711.9	3.2**
Error	264	45.4	-	6145.9	-

** Significant at the 0.01 probability level.
* Significant at the 0.05 probability level.

Table A31. ANOVA for average potato stand count, Fargo, ND, 2010.

SOV	df	MS	F
Rep	3	34.2	1.3
Cover crop (CC)	4	12.4	0.5
Termination (T)	2	99.3	3.8*
CC X T	7	17.6	0.2
Error	81	26.1	-

* Significant at the 0.05 probability level.

Table A32. ANOVA for average marketable yield, Fargo, ND, 2010.

SOV	df	MS	F
Rep	3	83.0	4.0*
Cover crop (CC)	4	51.7	2.5*
Termination (T)	2	76.1	3.7*
CC X T	7	27.4	1.3
Error	81	20.8	-

* Significant at the 0.05 probability level.

Table A33. ANOVA for average marketable yield by treatment, Fargo, ND, 2010.

SOV	df	MS	F
Rep	3	62.6	3.2*
Trt	29	40.1	2.1*
Error	87	19.4	-

* Significant at the 0.05 probability level.

Table A34. ANOVA for average cover crop dry weight biomass, Carrington, ND, 2011.

SOV	df	MS	F
Rep	3	281.0	1.2
Trt	4	8106.6	34.0**
Error	42	238.3	-

** Significant at the 0.01 probability level.

Table A35. ANOVA for average soil NO_3-N level 28 DBP, Carrington, ND, 2011.

SOV	df	MS	F
Rep	3	169.8	2.7
Cover crop (CC)	4	457.1	7.3**
Termination (T)	2	24.3	0.4
CC X T	8	41.2	0.7
Error	42	62.6	-

** Significant at the 0.01 probability level.

Table A36. ANOVA for average weed control 12, 28, and 47 DAP, Carrington, ND, 2011.

		12		28		47	
SOV	df	MS	F	MS	F	MS	F
Rep	3	2.9	0.3	35.7	4.3**	134.2	2.3
Cover crop (CC)	4	14.8	1.6	30.3	3.6**	132.4	2.3
Termination (T)	2	123.7	13.6**	150.7	18.1**	802.2	13.7**
CC X T	7	26.2	2.9**	37.6	4.5**	2.5	2.5*
Error	95	9.1	-	8.3	-		-

** Significant at the 0.01 probability level.
* Significant at the 0.05 probability level.

Table A37. ANOVA for average weed control averaged over all three weed evaluations, Carrington, ND, 2011.

SOV	df	MS	F
Rep	3	99.2	3.9**
Cover crop (CC)	4	38.0	1.5
Termination (T)	2	878.4	34.6**
CC X T	7	140.8	5.5**
Error	243	25.4	-

** Significant at the 0.01 probability level.

Table A38. ANOVA for average weed control averaged over all three weed evaluations by treatment, Carrington, ND, 2011.

SOV	df	MS	F
Rep	3	260.8	7.2**
Trt	14	2506.3	69.5**
Error	306	36.0	-

** Significant at the 0.01 probability level.

Table A39. ANOVA for average weed density and weed fresh weight averaged over all three weed evaluations by treatment, Carrington, ND, 2011.

		Weed density		Weed weight	
SOV	df	MS	F	MS	F
Rep	3	7.1	9.8**	2250.3	4.8**
Trt	14	2.1	3.0**	639.0	1.4
Error	306	0.7	-	467.0	-

** Significant at the 0.01 probability level.

Table A40. ANOVA for average potato stand count, Carrington, ND, 2011.

SOV	df	MS	F
Rep	3	11.8	0.7
Cover crop (CC)	4	30.1	1.8
Termination (T)	2	109.8	6.4**
CC X T	7	34.8	2.0*
Error	95	17.1	-

** Significant at the 0.01 probability level.

Table A41. ANOVA for average marketable yield, Carrington, ND, 2011.

SOV	Df	MS	F
Rep	3	82.3	3.1*
Cover crop (CC)	4	160.9	6.1**
Termination (T)	2	577.7	27.9**
CC X T	7	53.1	2.0
Error	85	26.4	-

** Significant at the 0.01 probability level.

* Significant at the 0.05 probability level.

Table A42. ANOVA for average marketable yield by treatment, Carrington, ND, 2011.

SOV	df	MS	F
Rep	3	90.4	3.6*
Trt	14	155.1	6.2**
Error	92	25.2	-

** Significant at the 0.01 probability level.

* Significant at the 0.05 probability level.