NITROGEN CYCLING AND WEED DYNAMICS IN A

PEA-COVER CROP-SWEET CORN ROTATION

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ABSTRACT

NITROGEN CYCLING AND WEED DYNAMICS IN A
PEA-COVER CROP-SWEET CORN ROTATION

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The effect of cover crops on N and weed dynamics was assessed within a pea (*Pisum sativum* L.) – cover crop – sweet corn (*Zea mays* L.) rotation. Cover crops of oat (*Avena sativa* L.), perennial rye (rye) (*Secale cereale* L.), oilseed radish (OSR) (*Raphanus sativus* L. var. *oleoferus* Metzg Stokes), and OSR plus perennial rye (OSR+rye) increased plant available N (PAN) over the cover crop growing season compared to the no cover control at the Bothwell site only. However, at neither site did cover crops result in increased PAN for the sweet corn, indicating that these cover crops will not reduce required N fertilizer applications. Also, cover crops posed neither an increased or decreased need for weed management during sweet corn production. However, OSR may be useful in pesticide reduced programs due to its potential ability to reduce fall herbicide applications, provided it does not set viable seed.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1. LITERATURE REVIEW

1.1.1. Introduction

A cover crop can be defined as a vegetative ground cover, which is planted into or after a main crop and killed before the next main crop is planted (Hartwig and Ammon, 2002). Cover crops have been in use for centuries. Historically, main uses of cover crops were for green manures and animal feed; however, their role in agricultural systems has changed over time, with cover crops now being used for new management practices and to provide a wide array of environmental and production benefits (Hartwig and Ammon, 2002; Sarrantonio and Gallandt, 2003). Two important uses for which cover crops are currently being employed are improved N cycling and weed suppression. The effectiveness of cover crops for these uses, however, is not fully understood, especially in vegetable production in Ontario. Although some cover crops are capable of reducing NO_3^--N losses from the soil during fallow periods (Wyland et al., 1996) and providing additional N to subsequent crops (Sainju and Singh, 2008), these results have not been consistently observed. Similarly, cover crops may reduce agricultural weed populations under some circumstances (Ngouajio and Mennan, 2005; Ngouajio et al., 2003), while being ineffective in others (Malik et al., 2008; Peachey et al., 2004). It is therefore important to review the mechanisms involved in cover crop N cycling and weed dynamics to better understand the role of cover crops in N cycling and weed management and thereby improve best management practices for Ontario vegetable production.

1.1.2. Cover Crop Benefits and Limitations

One of the primary benefits of using cover crops is the associated reduction in runoff and soil erosion (Hartwig and Ammon, 2002). Erosion is most likely to occur when the soil is bare of vegetative cover. This lack of vegetation provides no protection from the erosive forces of falling raindrops, overland water flow and wind (Bruce et al., 1991). Cover crops shelter the soil, slow the velocity of water and wind on the soil surface and increase infiltration (Hartwig and Ammon, 2002). With an increase in infiltration and reduction in runoff, the use of cover crops may result in decreased surface water pollution, such as nutrients and agricultural chemicals (Hartwig and Ammon, 2002). In addition, cover crops improve the productivity of soils by increasing the amount of organic matter added to the field due to the increased biomass on the site (Hartwig and Ammon, 2002; Bruce et al., 1991). Organic matter bonds soil particles together creating soil aggregates. This improvement in soil structure increases soil permeability and aeration, easing crop emergence and promoting root growth (Hartwig and Ammon, 2002). Cover crops also have the ability to recycle plant nutrients (Lu et al., 2000). This is especially important for N as it can be easily lost from the soil system. Leaching of excess N can be minimized as cover crops sequester excess soil N before it can seep below root zones and into groundwater sources (Hartwig and Ammon, 2002; Meisinger et al., 1991). Denitrification losses may also decrease through this reduction of soil mineral N. In addition, the use of water by cover crops for transpiration may reduce NO_3^--N leaching and denitrification losses (Weinert et al., 2002). In some cases, cover crops may also be beneficial due to their ability to reduce weeds, disease and pests in a field (Lu et al., 2000; Snapp et al., 2005). Depending on the species, cover crops can reduce weed density and biomass through mechanisms such as resource competition and allelopathic and phytotoxic effects (Ngouajio and Mennan, 2005). As a result, total marketable yields can increase by as much as 154% (Ngouajio and Mennan, 2005).

Despite the various benefits of using cover crops, some limitations do exist. While cover crops can lead to a decrease in pests, they may also harbour and introduce new pests to the field, which may be damaging to the following crop (Lu et al., 2000; Viaene and Abawi, 1998). Also, a large portion of agricultural property is rented; growers who lease this land try to obtain maximum benefits from the property during their lease with the smallest investment. This type of arrangement is not conducive to the adoption of cover crops, as growers may not be concerned with long term benefits that cover crops may provide (Lu et al., 2000). Cover crops may also not be feasible in areas with a short growing season. There must be adequate time after main crop harvest for cover crop establishment to occur. As well, cover crops often reduce soil temperature and/or increase soil moisture in the spring, which may result in reduced main crop yields due to delayed planting dates in short growing season areas (Lu et al., 2000). Therefore, the benefits of cover crops will be dependent on the goals of the farmer and the system within which the cover crops are incorporated.

1.1.3. Cover Crop Options

When selecting a cover crop, it is important to first define the temporal and regional factors which may influence the viability of the selected species in the specified region. Additionally, economic and cultural management factors should also be considered. Therefore, when selecting a cover crop it is important to consider the following criteria (Kuo et al., 1997; Weinert et al., 2002):

- Availability and cost of seed
- Cost of planting and killing
- Winter hardiness
- Germination speed and growth potential
- Effect on pests
- Extensiveness of rooting system
- Early spring re-growth of overwintering cover crops
- Degradation of residues
- Residue effect on short and long term N availability in the soil

There are numerous species to choose from when selecting a cover crop for a production system; most typically used are cereals, legumes and Brassica species. Many species are more suited to supply certain benefits than others; therefore, cover crop choice depends largely on the goals of the farmer.

Perennial rye is a cereal cover crop that has an extensive root system with aboveground biomass that provides adequate soil cover, making it an effective scavenger of soil mineral N and excellent at preventing erosion (Snapp et al., 2005). However, depending on planting date and soil moisture levels, its shoot growth in the fall is often slower than some other cover crop species in southern Ontario. Herbicide applications are required to halt the rapid growth of rye in spring and may require mechanical incorporation of residues to enhance N mineralization (Snapp et al., 2005).

Oat is another cereal that grows quickly in the fall, but dies off in the winter (Lu et al., 2000). While this means spring killing is not required, overall biomass production may be less than rye and uptake of excess soil N by growing cover crops in the spring is not possible (Lu et al., 2000; Miller, 1985).

Legumes are dicotyledonous crops that have the potential to fix atmospheric N. Legume cover crops have been shown to sequester 16-98 kg N ha^{-1} and produce biomass yields ranging from 940-4400 kg ha^{-1} in Ontario (Miller et al., 1992; Vyn et al., 2000; Vyn et al., 1999). Legume cover crops have N contents of between 2.5-4% (Lu et al., 2000). Red clover (*Trifolium pratense* L.), alfalfa (*Medicago sativa* L.) and hairy vetch are some of the most commonly used legume winter cover crops in southern Ontario. One drawback of legumes is their high seed cost, which can limit their adoption by farmers.

Brassica species are non-leguminous dicotyledons that appear to be the most suited for the control of pests (Snapp et al., 2005), due to the high glucosinolate content in the foliage that decomposes to toxic isothiocyanates (Burket et al., 2003). Oilseed radish does not survive the winter in Ontario; in the fall, it can produce between 890-3700 kg ha^{-1} of biomass and sequester between 14-66 kg N ha^{-1}(Miller et al., 1992; Vyn et al., 2000; Vyn et al., 1999).

Relative to monocultures, cover crop mixtures that include more than one species can improve resource capture, both spatially and temporally, and increase biomass production (Fukai and Trenbath, 1993; Snapp et al., 2005; Teasdale and Abdul-Baki, 1998). For example, the erect habit of grasses and the vining nature of legumes are highly complementary. A hairy vetch/crimson clover/rye mixture was found to increase cover crop biomass by up to 60% over the individual cover crops (Teasdale and Abdul-Baki, 1998). Cover crop mixtures that contain a small grain, like rye, tend to produce the highest cover crop biomass (Creamer et al., 1997). Consequently, it is important to choose the appropriate cover crop species, in regards to both location and desired benefits, in order to maximize the effectiveness of their use.

1.1.4. Nitrogen and Cover Crop Dynamics

The nitrogen cycle is a complex system involving many inputs and several chemical and biological processes (Fig. 1.1). Although all of the processes in the N cycle play a role in agronomic systems, the most important processes regarding cover crop N dynamics are plant N uptake, mineralization and immobilization, nitrification, leaching and denitrification.

1.1.4.1. *Plant N Uptake and Use*

Plant nutrient uptake occurs primarily through two mechanisms: mass flow and diffusion. Mass flow involves the movement of nutrients to the root through the convective forces of water caused by the transpiration of plants (Foth and Ellis, 1996). If mass flow does not supply enough nutrients to the plant, nutrient concentration in soil solution at the root will decrease. This creates a concentration gradient, which causes nutrients to diffuse toward the root. The proportion of a nutrient taken up by each mechanism varies by nutrient. Nitrogen is predominantly taken up by mass flow (Foth and Ellis, 1996). This is because the majority of mineral N in the soil is in the form of NO_3^--N, almost all of which is in soil solution and easily transported in water. A rapidly growing and transpiring crop, such as corn, may acquire approximately 80% of its N through mass flow (Foth and Ellis, 1996). Nitrogen is required throughout plant development because it is a constituent of structural and non-structural cell components (Schrader, 1984). Nitrogen required for vegetative growth is assimilated from N absorbed from the soil or through biological fixation (Schrader, 1984).

Nitrogen sequestration by cover crops is dependent on several factors including cover crop establishment, biomass quantity and species selection. Cover crop establishment is the most important factor for cover crop growth success and is greatly affected by species selection. The yields of cereal cover crops, such as winter barley (*Hordeum vulgare* L.) and rye, are more predictable than non-cereals such as phacelia (*Phacelia tnacetifolia* Benth.), mustard (*Brassica sp.*), fodder radish (*Raphanus sativus* L.), and buckwheat (*Fagopyrum esculentum* Moench) (Allison et al., 1998). As well, large seeded cover crops have been found to have a 16% better establishment rate than small seeded cover crops (Keeling et al., 1996). Without successful establishment, cover crops cannot produce adequate biomass to take up significant quantities of N or perform other basic functions such as erosion control. Good cover crop establishment is dependent on sufficient heat for crop growth, moisture for seed germination and nutrients for biomass production. There is often a small window of opportunity for cover crop planting after main crop harvest, especially in cereal crop production. Cover crops should be planted as early as possible because adequate heat units during the fall and winter must be available to promote cover crop growth, root exploration and N uptake, especially in cooler climates (Weinert et al., 2002). Establishment is also highly dependent on soil moisture. Keeling et al. (1996) have found that establishment of small seeded legumes is governed by the timing of rainfall events after seeding, while large seeded covers, like rye, are less dependent on timely rainfall when interseeded into cotton (*Gossypium hirsutum* L.). Adequate available soil N is also important in successful cover crop establishment. Vyn et al. (2000) noted low oat and OSR biomass production when planted after wheat, due to low soil residual N levels. If the main crop limits available nutrients in the soil, cover crop growth could be negatively impacted.

Cover crop N uptake usually increases with biomass production. There is a positive linear relationship between increasing N uptake and cover crop biomass (Fig. 1.2) (Vyn et al., 2000) because as the plant grows there are more roots to take up N and more vegetative growth requiring N for assimilation. It appears that this relationship is the strongest for cover crop species that resume growth in the spring, such as rye and red clover ($R^2 = 0.9288$ to 0.9999) compared to species which are frost killed such as OSR ($R^2 = 0.8929$) and oat ($R^2 = 0.6642$). When greater than 3000 kg ha^{-1} of shoot biomass is produced, cover crops have been found to accumulate over 100 kg N ha^{-1} (Weinert et al., 2002).

Some species have physical and physiological characteristics which make them more suitable for use as N scavenging cover crops. Deep, densely rooted cover crops will be capable of intercepting more NO_3^- in the soil because they have access to a larger soil volume and thus can remove NO_3^- from areas in the soil which are inaccessible to shallow-rooted crops (Thorup-Kristensen, 2001). Research by Thorup-Kristensen (2001) showed that brassica cover crops, such as fodder radish, have higher root intensities and frequencies in the subsoil compared to cereal cover crops in November. Nitrogen uptake by fodder radish from the subsoil is thereby increased compared to cereals. This research also indicates that fodder radish can reduce NO_3^--N concentrations by 99% compared to a no cover control, while rye may result in only an 80% reduction (Thorup-Kristensen, 2001). Quickly growing cover crops will also be more capable of removing excess NO_3^--N from the soil. The reasons for this include i) there is a faster demand for N by growing vegetative parts, ii) plants with roots that begin to grow quickly will begin to take up N more rapidly, and iii) plants with faster growing roots generally have a larger soil volume to scavenge N from in the early season. Fodder radish has a rooting depth penetration rate of 2 mm d^{-1} $^{o}C^{-1}$ or more, while cereals have much lower rates of between 0.9-1.2 mm d^{-1} $^{o}C^{-1}$ (Thorup-Kristensen, 2001). In addition, non-legumes tend to sequester more soil N than legumes due to the ability of legumes to biologically fix N. Shipley et al. (1992) indicate that only 5-20% of N assimilated by hairy vetch and crimson clover is attributed to uptake of fertilizer N from the soil due to biological fixation, while 40-50% of N assimilated by rye and ryegrass (*Lolium multiflorum* Lam.) is attributable to soil fertilizer N.

1.1.4.2. ***Mineralization and Immobilization***

The rate of organic matter decomposition is influenced by many factors including: organic composition of the residue being mineralized, soil temperature and water content, soil drying and wetting events, and soil characteristics such as clay content and aeration; all of which influence soil microbial activity (Cabrera et al., 2005). Soil temperature and water content affect decomposition because of the effects that these factors have on the soil microorganism populations. Optimal soil temperatures for decomposition range from 25-40°C, as warmer temperature stimulates microbial processes (Foth and Ellis, 1996). Soil water content, affects the availability of substrates to the organisms, thereby influencing decomposition. Microbial processes tend to be more rapid at field capacity. As soil water content decreases, decomposition is limited due to any combination of the following mechanisms: limited access to substrates due to reduced microbe mobility, decreased diffusion of soluble substrates to microbial cells and the inhibition of enzyme activity due to low intracellular water potential (Zak et al., 1999). Decomposition is also limited in very wet conditions because the microbes responsible for decomposition are generally aerobic, requiring some oxygen for decomposition to take place. In relation to this, drying and rewetting of soils tends to have a negative effect on decomposition, as microbial populations may be sensitive to the drought conditions, thereby reducing the microbial population available to perform the required processes (Cabrera et al., 2005). Decomposition may also be influenced by soil type as different soils have diverse populations of microorganisms that vary in C:N ratio, different abundances of clay onto which organic N can be adsorbed and various levels of aeration (Cabrera et al., 2005).

Mineralization and immobilization are both functions of organic matter decomposition. Mineralization is the conversion of organic N into NH_4^+. Soil organic matter is formed from decaying animals, plants and microorganisms and manure inputs (Fig. 1.1). As organic N is assimilated by microorganisms within the soil, NH_4^+ is released. Mineralization is the result of enzymatic reactions, which require compounds such as proteins, cell wall constituents and nucleic acids (Sumner, 1999). Immobilization is the assimilation of inorganic N into organic forms. Ammonia and ammonium are the preferred inorganic N sources of microbes for immobilization, although NO_3^- is also used under some conditions. Similar to mineralization, immobilization is enzymatic (Sumner, 1999).

When soil organisms breakdown organic matter, they must assimilate both N and C; the quantity required of both N and C is determined by the respiration C requirement of the microorganisms themselves. If the quantity of N in the residue being decomposed is greater than the requirement of the organisms, mineralization will occur and inorganic

N will be released. If organic N is equal to the requirement of the organisms, no mineralization will take place and if less N is available in the residue than is needed, available mineral N from the soil will be immobilized in order to complete the decomposition process (Cabrera et al., 2005).

As a general guideline, residues with a C:N ratio of >25 result in immobilization and <25 result in mineralization (Wagger, 1989). However, this C:N mineralization/immobilization midpoint can range between 20-40 (Cabrera et al., 2005). The range of observed midpoints is related to the C:N ratio of the decomposers themselves, as well as the composition of the residues. Because the quantity of N required for mineralization is dependent on the C:N ratio of the decomposers, microbial biomasses with lower C:N ratios will lower the midpoint and vice versa. The lignin, polyphenol and carbohydrate content of residues influences the speed at which decomposers can breakdown residues (Sumner, 1999; Wagger, 1989). For example, lignin linkages are different between legumes and non-legumes, which generally results in a greater proportion of residue being resistant to decomposition in non-legumes (Wagger, 1989). In addition, different factors appear to be more influential for residue breakdown during different stages of decomposition. Available nutrients and C appear more important during early decomposition, while lignin content is more important during later decomposition stages (Sumner, 1999). Therefore, the speed at which material is decomposed is dependent on the stage of decomposition and the nature of the material being decomposed. Nitrogen, which may be initially immobilized during early stages of decomposition, can be re-mobilized in later stages when required C:N ratios have changed.

Due to these factors net mineralization differs between cover crops. Schomberg et al. (2006) found that N mineralized at approximately 110 d after cover crop incorporation was 1.3 to 2.2 times greater for oat, crimson clover and OSR compared to rye. Vyn et al. (1999) suggest that OSR releases N faster in the spring than red clover, as May soil NO_3^- -N levels were higher under the OSR. This is consistent with the notion that OSR is considered 'leaky' as it quickly takes up N in the fall, but decomposes rapidly after frost kill due to its relatively low C:N ratio and lignin content and its large surface area. Kuo et al. (1997) found that leguminous cover crops were more effective at increasing N availability in the soil after incorporation compared to non-leguminous crops as large amount of N was mineralized from the legumes by June. Rosecrance et al. (2000) found that the decomposition of vetch resulted in net mineralization, while rye resulted in net immobilization. After correcting for N mineralization from fallow treatments, net N mineralization for rye, vetch and vetch+rye was -0.34, 0.98 and 0.10 mg (NO_3^- + NH_4^+)-N d^{-1} over 55 days (Rosecrance et al., 2000). Cover crop kill date may also play a role in the timing of net mineralization of cover crops. Wagger (1989) found that 8 wk after desiccation, the percentage of N remaining in cover crop residues killed at early and late desiccation dates was 54% and 60% for rye, 25% and 44% for crimson clover and 5% and 16% for hairy vetch, respectively, even though there was no difference in C:N ratio between the desiccation dates for all three species. This indicates that earlier kill dates result in faster decomposition.

1.1.4.3. ***Nitrification***

Nitrification is the conversion of NH_4^+ to NO_3^- through biological oxidation. This is a two step process where: i) NH_3 / NH_4^+ is converted to NO_2^- by nitrosomonas, obligate autotrophic bacteria, and ii) NO_2^- is converted to NO_3^- by nitrobacter, a similar type of bacteria. The rate of nitrification is affected by factors which influence the nitrifying bacteria populations, including soil pH, temperature, oxygen, moisture and substrate concentration and availability (Sahrawat, 2008). Optimal soil pH for nitrification is approximately 8.5, although nitrification will take place between pH 5.5 and 10.0 (Sahrawat, 2008). Nitrification is also optimal between 30-35°C, following a normal temperature response curve (Sahrawat, 2008). However, the effect of temperature on nitrification is climate dependent and optimal temperatures may be lower in cooler climates (Sahrawat, 2008). Soil pH and temperatures outside of the aforementioned range affect the ability of nitrosomonas and nitrobacter to survive, thereby inhibiting nitrification. Molecular oxygen is required for nitrification to take place because nitrobacteria are autotrophs; therefore, the relationship between soil moisture and oxygen availability in the soil affects the nitrification process. Nitrification is maximized in well-aerated soils with approximately 20% oxygen, at near field capacity (Sahrawat, 2008). The availability of the substrate (NH_3/ NH_4^+) to the nitrobacteria is also a limiting factor in nitrification. Nitrobacteria may not be able to oxidize the substrate due to sorption or fixation of organic N and NH_4^+ ions by clay particles or by immobilization of NH_4^+ (Sahrawat, 2008).

1.1.4.4. *Nitrate Leaching*

Nitrate leaching is the downward movement of NO_3^- anions in soil solution through the soil profile to depths beyond which it is possible for plants to use, and may ultimately infiltrate into the groundwater. In the soil, NO_3^- anions are not readily adsorbed because negative colloids dominate the soil profile. Therefore, NO_3^- is very mobile and is subject to rapid uptake by roots or leaching with soil water (Sumner, 1999). Nitrate leaching is largely a function of i) the amount NO_3^- in the soil and ii) the amount of water available to leach through the soil. In turn, the amount of water is affected by the area's seasonal water budget and the hydraulic properties of the soil.

Examination of an average water budget in southwestern Ontario (Fig. 1.3) reveals that there is typically a water surplus, higher precipitation than evapo-transpiration, from fall to spring (October to May) (Fallow et al., 2003). During these times of surplus, demand for water from plants in the form of evapo-transpiration is not great enough to use all of the available water. Consequently water is able to move over the land surface in the form of runoff or through the soil in the form of deep drainage. On a Embro Silt Loam with a sand:silt:clay content of 20:67:13 mean annual deep drainage under this typical water budget would be approximately -27mm of water a year (Fallow et al., 2003). Consistent with time of water surplus, deep drainage is higher from late fall to spring compared to the summer when there is a water deficit (Fig. 1.3). Water flow through the soil matrix resulting in deep drainage and the rate at which this occurs is complex and may depend on water potential, texture and structure. In a simplified system, the quantity of water that can flow through a saturated soil column with a homogenous pore system can be defined by Darcy's Law:

$$Q = (K_s \, A \, \Delta P)/L$$

Where K_s is the saturated hydraulic conductivity, A is the area and L is the length of the column through which the water flows and ΔP is the change in pressure head within the column. Therefore, depending on the soil characteristics, during irrigation and precipitation events, water may move rapidly through the soil matrix, especially under conditions of partial or complete soil saturation. In addition, cover crop transpiration leads to a reduction in soil water potential. This results in less water available to percolate through the soil, which is an important means by which NO_3^- leaching potential can be reduced (Weinert et al., 2002).

Therefore, the ability of cover crops to grow and sequester N during the fall and spring may help to reduce the loss of NO_3^--N to leaching during these periods. Vyn et al. (2000) suggest that oat, OSR, rye and red clover (*Trifolium pretense* L.) may all significantly reduce soil NO_3^--N concentrations in the top 60 cm by early November after cover crop establishment. As well, Wyland et al. (1996) found that NO_3^--N leaching from November to March can be three to four times higher under no cover than rye or phacelia cover crops. In another study, ryegrass was shown to reduce NO_3^--N leaching during cover crop growth by 64% compared to bare fallow (Martinez and Guiraud, 1990). In the same study where fertilizer labeled with ^{15}-N was applied to winter wheat in the spring prior to ryegrass planting, ^{15}-N was first detected in leachate water in the fall, 5 months after the spring application. Under no cover, 18.7% of the labeled N was leached during the winter period while only 7.1% was leached under the cover crop (Martinez and Guiraud, 1990).

Despite the apparent ability of cover crops to reduce soil NO_3^--N leaching during the fall and winter due to N uptake, N may be lost from the system in the following spring or summer if N mineralization from the cover crop residues is not synchronous with N demand of the following crop. Although cover crops may reduce fall leaching and provide higher soil NO_3^--N levels in the spring compared to a no cover control, this may not result in increased N uptake or yield by a subsequent crop such as sweet corn

(Schomberg et al., 2006). Weinert et al. (2002) suggest that spring incorporation of living cover crops is more efficient, compared to fall incorporated cover crops, at minimizing N leaching and recycling N to the next crop due to extensive N mineralization within 5 weeks after incorporation of cover crop biomass with low C:N ratios. This N release is timed more closely with N demand of the following crop than the release from fall incorporated cover crops. Therefore, overwintering cover crops are generally more effective than frost-killed cover crops at reducing soil NO_3^--N concentrations over the winter even when shoot N accumulations are comparable.

However, when mineralization of cover crops is timed well with N demand of following crops, N fertilizer applications can be reduced. In sorghum [*Sorghum bicolor* (L.) Moench] and cotton production, hairy vetch and hairy vetch + rye are effective cover crops for not only reducing leaching, but also for supplying N for uptake by the following main crops, which can ultimately lead to a reduction in the quantity of applied fertilizer N (Sainju and Singh, 2008).

1.1.4.5. ***Denitrification***

Denitrification is the chemical reduction of NO_3^- and NO_2^- to NO, N_2O and N_2. The bacteria which perform denitrification are mainly heterotrophic and use NO_3^- as an electron acceptor when O_2 is unavailable; therefore, in soil environments, denitrification occurs when organic C and NO_3^- are available and O_2 availability is restricted (Sumner, 1999). The main factors that affect denitrification include soil structure and water content, pH and temperature (Foth and Ellis, 1996). The availability of O_2 is restricted in anaerobic environments, resulting in the increased potential for denitrification in increasingly wet soils if NO_3^- is present. Consequently, because NO_3^- is produced in aerobic environments denitrification is enhanced through periods of soil wetting and drying (Foth and Ellis, 1996). Denitrification can also occur in well-drained soils within soil aggregates where water is still present. Soil pH affects not only the rate of decomposition but also the end product of the reaction. Dinitrogen and N_2O tend to be the major gases produced above and below the pH of 6.0, respectively (Foth and Ellis, 1996). Similar to other microbial processes in the N cycle, denitrification increases with temperature; however high quantities of denitrification can occur when it is too cool for crop growth, such as in the late fall and early spring (Foth and Ellis, 1996).

Cover crops have the ability to decrease denitrification during these times of high denitrification potential by reducing the amount of NO_3^- in the soil by its sequestration in plant tissue. As well, transpiration of the cover crops reduces soil water, thereby reducing the available anaerobic environments in which denitrification can take place. Despite this, cover crops also have the potential to increase denitrification after spring kill when they supply large quantities of decomposable plant tissue, especially if it has a low C:N ratio, when rapid mineralization exceeds the rate of crop N uptake (Shelton et al., 1997).

1.1.5. Weed Dynamics

In cover crop selection, growers also consider impact of cover crops on weed populations and potential for cover crops to become a weed. Cover crops may become a weed during succeeding production seasons through cover crop volunteers produced either by setting viable seed or through germination of planted seeds in a later season. For example, OSR has the potential to set viable seed in the fall, which may result in large volunteer populations the following spring and summer.

Reductions in vegetable crop yields and profits due to weeds are mainly attributable to resource competition (Peachey et al., 2004) and in some cases allelopathic and phytotoxic effects from weeds (Obaid and Qasem, 2005). However, cover crops can suppress weed germination and growth through many mechanisms. Cover crops can compete for resources prior to main crop planting, physically obstruct weed emergence, lower soil temperatures and reduce diurnal temperature fluctuations. As well, they can increase weed seed consumption by providing habitat for seed foragers. Some cover crops also possess allelopathic and/or phytotoxic potentials, which reduce the ability of nearby plants to grow (Moore et al., 1994; Ngouajio and Mennan, 2005; Reader, 1991). Weed management costs, therefore, may be reduced if weed seed production is lessened during cover cropping and if weed emergence and growth is reduced during the subsequent vegetable crop (Brennan and Smith, 2005).

During cover crop growth, weed emergence may be unaffected by cover crops when the majority of the weeds emerge within the first 50 d after planting (Brennan and Smith, 2005), as cover crops have a larger effect on late emerging weeds (Huarte and Arnold, 2003). However, cover crops may affect weed biomass and weed seed production during cover crop growth. A mustard mix (*Brassica hirta and B. juncea*) was found to be more effective at this than oats and a legume/oats mix (*Vicia faba, Pisum sativum, V. sativa, V. villosa* spp. *dasycarpa* and oats) in lettuce production (Brennan and Smith, 2005). These effects may be explained by early season canopy development of the cover crops. The mustard mix in that study had the highest canopy development, while the legume/oat mix had the lowest. These rankings were consistent with each cover crop's ability to suppress early season weed biomass and weed seed production (Brennan and Smith, 2005). The mustard mix was also effective at reducing weed emergence after cover crop incorporation, likely due to the isothiocyanates produced from the residues (Brennan and Smith, 2005). In cucumber (*Cucumis sativus* L.) systems, cover crops such as sudangrass, rye and hairy vetch can also reduce weed densities both during spring cover crop growth and after cover crop incorporation by up to 85% compared to a bare ground control (Ngouajio and Mennan, 2005; Vasilakoglou et al., 2006).

Generally, weed suppression is positively correlated with cover crop biomass production and early cover crop biomass is positively correlated to cover crop density. This suggests that early ground cover development could be increased in low-density cover crops by increasing the seeding rate of either the whole mix or of the smaller seed component in the mix, which in turn may increase weed suppression (Brennan and Smith, 2005; Ngouajio and Mennan, 2005).Weed suppression may also be dependent on the type of weeds present because annual weeds have been found to be more sensitive to cover crop residues than biennial weeds (Mohler and Teasdale, 1993; Teasdale and Abdul-Baki, 1998) .

Cover crops that include a mixture of species can improve capture of resources such as nutrients, light and water, both temporally and spatially, relative to the respective monocultures (Fukai and Trenbath, 1993), which can result in an increase in cover crop biomass (Mohler and Teasdale, 1993). These mixtures are most productive when the growth duration of the component crops differ, resulting in different periods of maximum requirement for resources. Therefore, for maximum productivity, the mixture should contain early- and late-maturing cover crops. The early-maturing species usually have little competition from the other species. The late-maturing species may be more affected by the earlier crop, but an extended period of maximum growth later in the season allows these species to recover and utilize available resources (Fukai and Trenbath, 1993). In addition, physiological differences among mixture components may result in optimal resource capture. For example, in a pea–oat–vetch mixture, optimum biomass was achieved due to early radiation interception by the pea crop and high radiation use efficiency by all three mixture components in the middle of the season (Jannink et al., 1996). Cover crop mixtures that contain species with similar growth periods may also be productive, if resources can still be captured more efficiently than under the sole component crops; however, the less competitive component may suffer as a result of the strong resource competition (Fukai and Trenbath, 1993).

Due to optimization of biomass production and resource use, fewer weeds tend to emerge through polyculture cover crop residues than monoculture residues (Teasdale and Abdul-Baki, 1998). Cover crop mixtures that contain a small grain may produce the highest quantity of cover crop biomass (Creamer et al., 1997). Optimal seeding rates for cover crops are essential to the success of weed suppression. Optimal planting densities are well documented for cover crop monocultures; however, few studies have evaluated the optimal seeding rates of polycultures. Seeding rates in these polycultures are more complex as competition with weeds and among the component covers may be affected. An inappropriate planting density of cover crops may lead to a decrease in weed suppression (Brennan and Smith, 2005).

The allelopathic or phytotoxic effect of some cover crops on weeds may also result in weed reduction. Allelopathy involves the usually negative biochemical interaction between plants caused by secondary compounds, released either above or below ground from living plants (Hill et al., 2006). The breakdown of these compounds by microbial populations can lead to further allelopathic chemicals. Once released in the soil, allelopathic chemicals can affect seed germination and growth (Vasilakoglou et al., 2006). Phytotoxicity refers to the similar detrimental effects of chemicals released from decaying plant material. The magnitude of allelopathic or phytotoxic effects is dependent on quantity and persistence of the compound, which in turn are dependent on species, environmental conditions and chemical composition (Hill et al., 2006). Studies show that residues from cover crops such as barley, rye and triticale (*X Triticosecale* Wittm.), have the ability to reduce grassy weed seed germination in cotton, corn and sugar beet (*Beta vulgaris* subsp. *vulgaris*) production compared to no cover controls (Dhima et al., 2006; Vasilakoglou et al., 2006). This may be the result of high concentrations of phtyotoxic chemicals in soil immediately after cover crop residue incorporation (Vasilakoglou et al., 2006). However, these cover crops had no effect on the growth of surviving weeds. This may be because fewer of the phytotoxic chemicals are present in the soil at this time due to their decomposition or because the surviving weeds developed a tolerance to the chemicals (Vasilakoglou et al., 2006).

Weed seed consumption by herbivores such as carabid beetles and fire ants, may increase in production systems with cover crop mulch compared to systems without mulch (Pullaro et al., 2006). Susceptibility of weeds to seed consumption can vary and may depend on herbivore preference of weed seed size. Research in bell pepper and collard (*Brassica oleracea* L.) production indicates that fire ants prefer smaller seeds, such as redroot pigweed (*Amaranthus retroflexus* L.), to the larger morning glory

(*Ipomoea hederacea* L.) seeds (Pullaro et al., 2006). This increase in seed consumption may alter weed species richness.

Despite aforementioned examples, cover crops do not always result in weed suppression. Herbicide treatments reduce weed biomass compared to treatments with cover crops and no herbicides (Hoyt and Walgenbach, 1995; Pullaro et al., 2006). In addition, Peachey et al. (2004) indicate that weed emergence in irrigated vegetable row crops was more affected by planting system (no-till or conventionally planted) than cover crops. Conventional planting resulted in consistently lower weed emergence rates than no-till planting, while cover crops generally had no effect compared to a no cover crop control (Peachey et al., 2004). It is estimated that two to four times the natural biomass production (300 g m^{-2}) of these cover crops would be required to significantly lower weed emergence (Mohler and Teasdale, 1993).

1.2. PROJECT DESCRIPTION

Vegetable production is an important part of Ontario's agriculture and economy, with nearly 10% of all Ontario farm cash receipts coming from vegetable and greenhouse production in 2006 (OMAFRA, 2008). Vegetable production is often input intensive, typically with high N fertilization and pesticide application requirements. Many vegetable growers in southern Ontario currently incorporate cover crops into their production system for erosion control and soil quality purposes. However, there has been increased interest from growers regarding the effects of cover crops on N cycling, including their ability to decrease N losses and provide N credits to the following crop. In addition, growers are concerned about the potential negative effects that cover crops have on weeds in the subsequent crop.

Unfortunately, reliable information regarding the role of cover crops in these processes is limited, especially for vegetable production systems in southern Ontario. The majority of cover crop N and weed dynamic research focuses on field crops, even though cover crops may be more advantageous in vegetable production due to longer periods of fallow that increase the potential for cover crops to sequester N. In addition, the majority of cover crop studies occur in the United States. The lack of research in southern Ontario makes it difficult to provide growers with applicable information with which to make decisions because cover crop N uptake varies with climate and growing season. Weed populations are also affected by these factors and differ between geographic locations. Many growers are currently unwilling to incorporate cover crops into their production cycle due to a lack of information and the relatively high value of most vegetable crops in relation to fertilizer and herbicide costs. Therefore, the overall goal of this study was to investigate N and weed dynamics of vegetable cropping systems with different winter cover crops in a pea (*Pisum sativum* L.) – cover crop – sweet corn rotation in order to provide information to growers for the improvement of N use and weed control best management practices.

1.3. HYPOTHESES AND OBJECTIVES

This study involves three related investigations:

I. Assessing the effect of cover crops on N dynamics within a pea – cover crop – sweet corn rotation.

II. Assessing the effect of cover crops on weed dynamics during cover crop and sweet corn growth.

III. Assessing the interaction of N fertilization and weed populations on sweet corn growth.

The corresponding hypotheses for these investigations are as follows:

I. Cover crops will increase plant available N over the cover crop – sweet corn rotation

II. Cover crops will reduce weed biomass and density during the cover crop – sweet corn rotation

III. Weed control and N fertilization will lead to a discernable increase in plant available N at sweet corn harvest.

In order to investigate these hypotheses the following objectives were met:

a) Determine soil and plant (crop, cover crop and weed) N concentrations to develop an N budget for the production system
b) Assess the effects of cover crops, N fertilization and weeds on sweet corn yield
c) Determine if a synchrony exists between the timing of N release from cover crops and N demand from crops
d) Determine under which treatment N uptake and weed suppression are maximized

1.4. TREATMENTS

The experimental sites were arranged in split-split-plot arrangement in a randomized complete block design with 4 replications in a pea – cover crop – sweet corn rotation. The main plot factor was winter cover crop type, the split-plot factor was quantity of N fertilizer applied to the sweet corn crop and the split-split-plot factor was presence (weedy) or absence (non-weedy) of weeds in the sweet corn. The cover crop treatments included a no cover crop control, oat (cv. Manotick), perennial rye (cv.

Common #1), OSR (cv. Common #1) (Ridgetown only), and OSR plus perennial rye (OSR+rye). The N fertilizer treatments were 0 and 140 kg N ha^{-1}, applied preplant broadcast to the sweet corn. Non-weedy sections were hand hoed from the time of sweet corn emergence (Ridgetown) or 42 days after planting (Bothwell) to harvest; while weedy sections were not hoed. Each main plot was 6 m by 16 m, each N split-plot was 6 m by 8 m, each weedy split-plot was three sweet corn rows (2.3 m) wide by 8 m long, and each non-weedy split-plot was five sweet corn rows (3.8 m) wide by 8 m long (Fig. 1.4). There were a total of 16 and 20 treatment combinations at Bothwell and Ridgetown, respectively (Fig. 1.5 & 1.6).

1.5. WEATHER INFORMATION

Weather data is present from 2006-2008 for Ridgetown, ON (Table 1.1). Weather data from Bothwell was incomplete and unreliable and was therefore not presented. Annual precipitation and temperature trends at Ridgetown were similar to Bothwell. The 2006 growing season had relatively average temperatures compared to the 30-year mean, although average precipitation from April to August was was above average, with higher rainfall occurring especially in September and October. The 2007 growing season was a hot dry year in comparison. Mean temperatures were 3.3°C higher in 2007 than normal. As well, 68 mm less rainfall than average accumulated during this season. Rainfall was noticeably lower in June and July. The 2008 growing season was slightly warmer than normal; however, total precipitation over the season was very similar to the 30-year mean. Therefore, the experimental period encompassed a range of climatic conditions from hot and dry to near average.

Table 1.1. Monthly mean temperature and total precipitation at the University of Guelph Ridgetown Campus, Ridgetown, ON, Canada, in 2006-2008 as compared to the 30 year mean.

	Temperature			
Month	2006	2007	2008	30 yr mean
	---------- °C ----------			
Jan.	2.0	-1.4	-1.7	-3.7
Feb.	-1.2	-7.2	-3.7	-2.4
Mar.	3.1	4.2	0.5	2
Apr.	12.5	10.5	12.1	7.1
May	14.2	17.9	12.1	13.6
June	18.2	21.6	20.1	18.8
July	21.8	23.6	22.1	21.5
Aug.	19.8	23.4	19.8	20.6
Sept.	17.2	18.6	22.6	16.8
Oct.	12.6	16.9	12.8	10.6
Nov.	6.1	4.7	4.2	4.8
Dec.	3.1	-1.2	-2.4	-1.2
Mean	10.8	11.0	10.0	9.0
	Precipitation			
	---------- mm ----------			
Jan.	101	132	71	61
Feb.	72	21	107	54
Mar.	66	103	116	60
Apr.	67	72	45	73
May	84	79	64	77
June	55	64	170	82
July	98	83	83	93
Aug.	76	101	26	105
Sept.	110	42	140	93
Oct.	132	70	31	55
Nov.	56	56	88	75
Dec.	111	92	142	67
Total	1028	915	1083	895

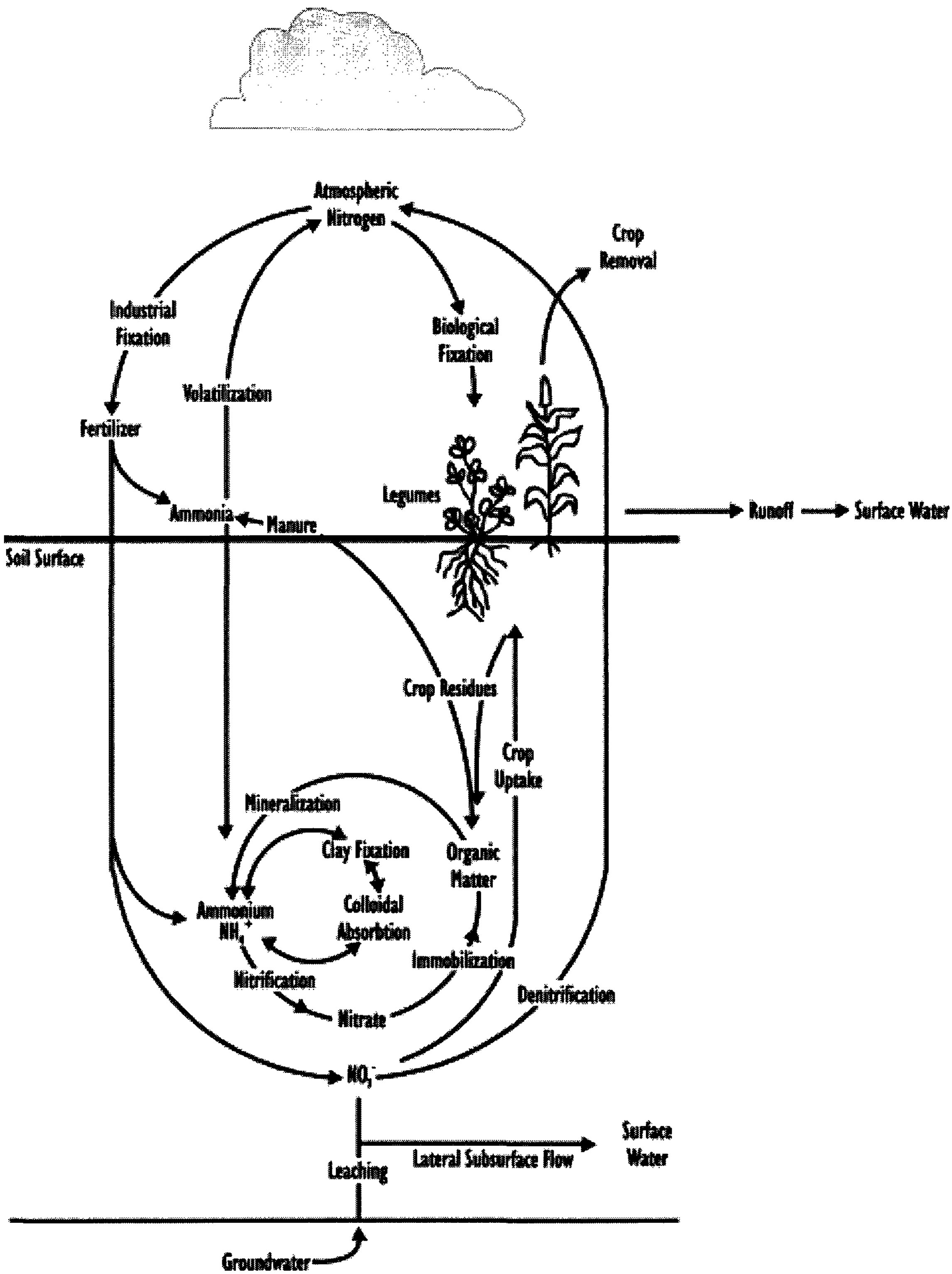


Fig. 1.1. The nitrogen cycle (Cross and Cooke, 2002).

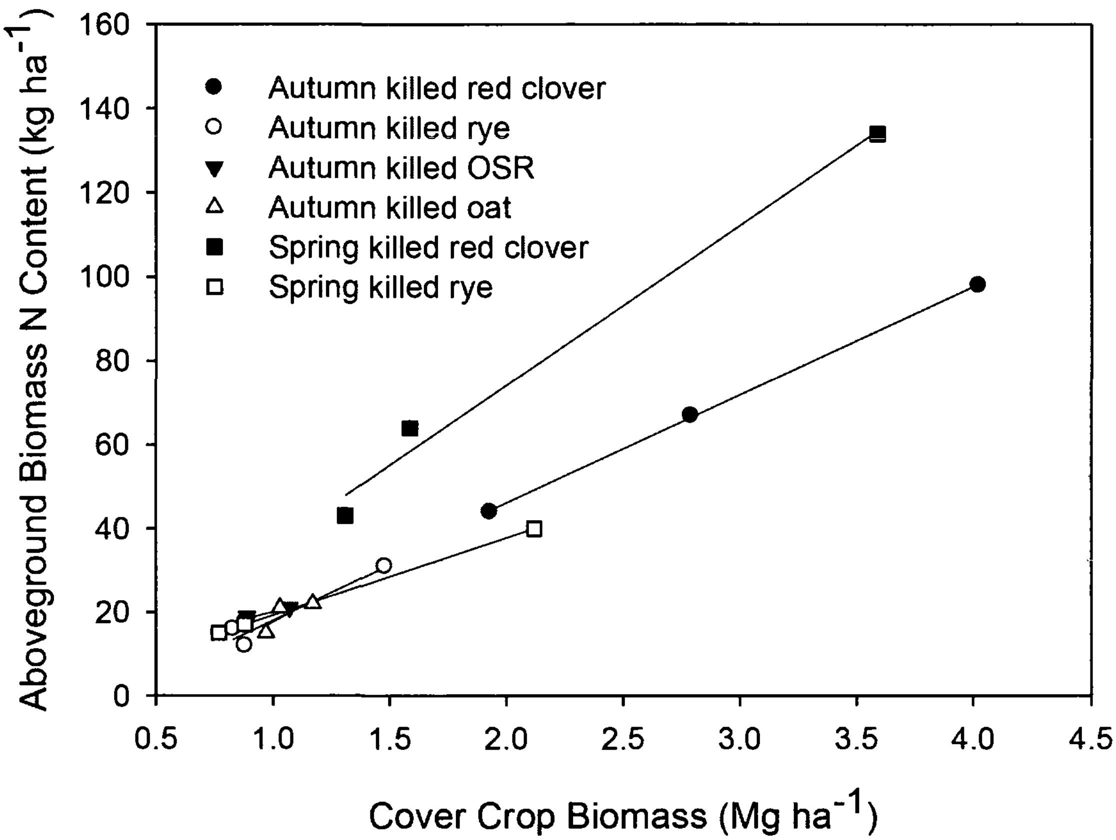


Fig. 1.2. Relationship between cover crop biomass production and N uptake (Adapted from Vyn et al., 2000). Autumn killed red clover: y=-5.48 + 25.79x, R^2=0.9997; Autumn killed rye: y=-8.71+ 26.69x, R^2=0.9288; Autumn killed OSR: y=6.14+ 13.89x, R^2=0.8929; Autumn killed oat: y=-12.43+ 30.06x, R^2=0.6642; Spring killed red clover: y=-2.07+ 38.09x, R^2=0.9881; Spring killed rye: y=0.7128+18.53x, R^2=0.9999.

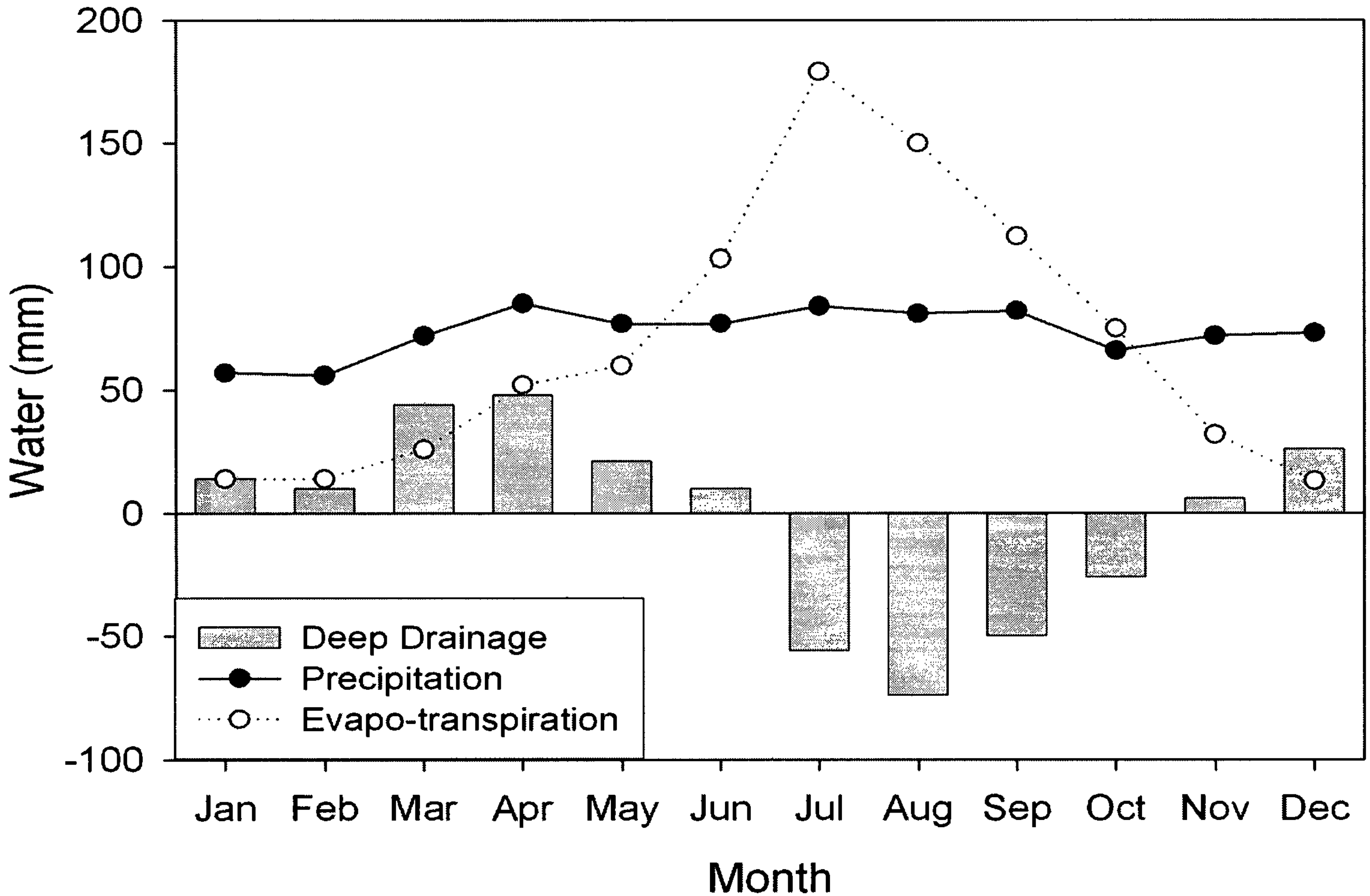
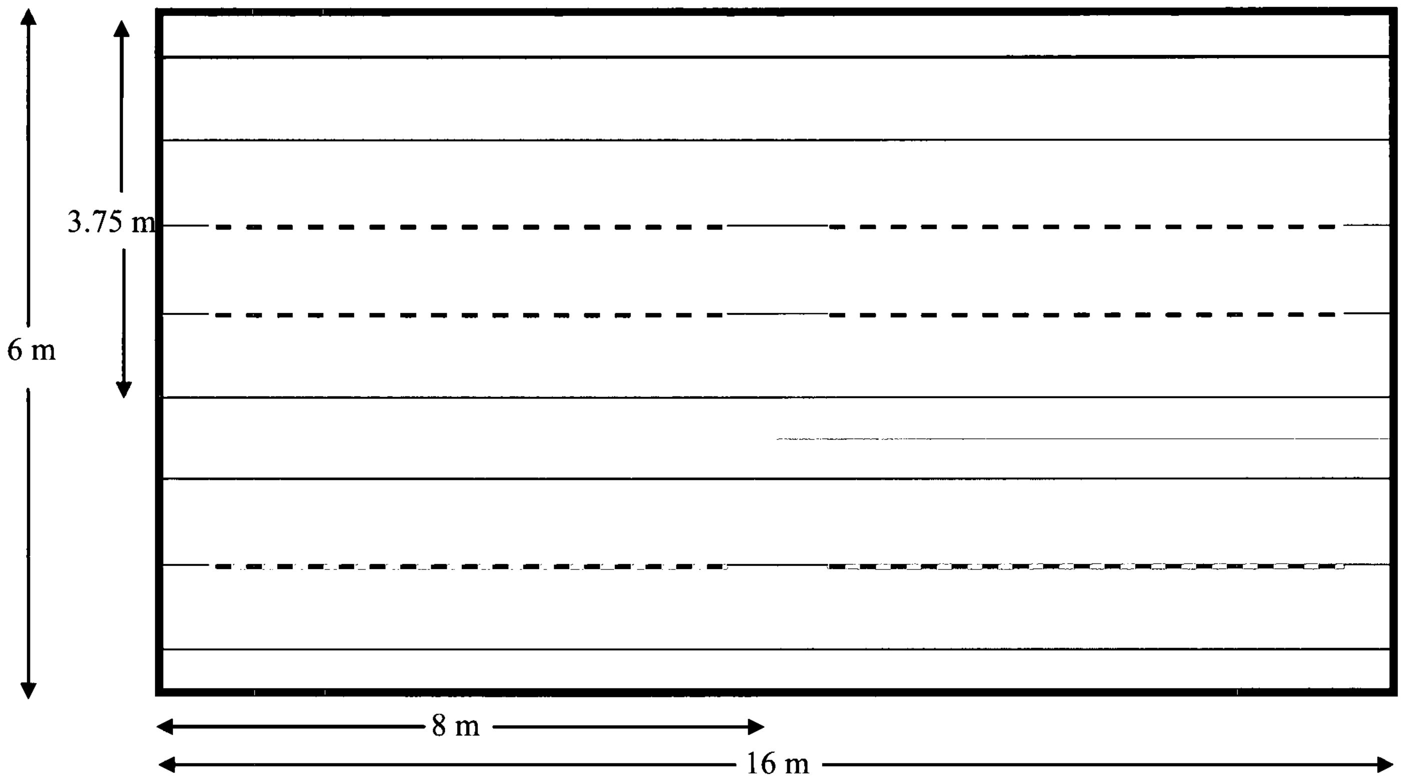


Fig. 1.3. Average water budget at Harrow, ON from 1954-2001 (Adapted from Fallow et al., 2003).



	Non-weedy unfertilized plot
	Weedy unfertilized plot
	Non- weedy fertilized plot
	Weedy fertilized plot
————————	Sweet corn rows
- - - - - - - -	Harvest rows

Fig. 1.4. Plot dimensions and example layout.

Treatment Combinations		
Cover Crop – N Treatment – Weed Treatment		
1 – No Cover	N – 0 kg N ha^{-1}	N – Non-weedy
2 – Oats	Y – 140 kg N ha^{-1}	W – Weedy
3 – OSR+rye		
4 – Rye		
5 – OSR		

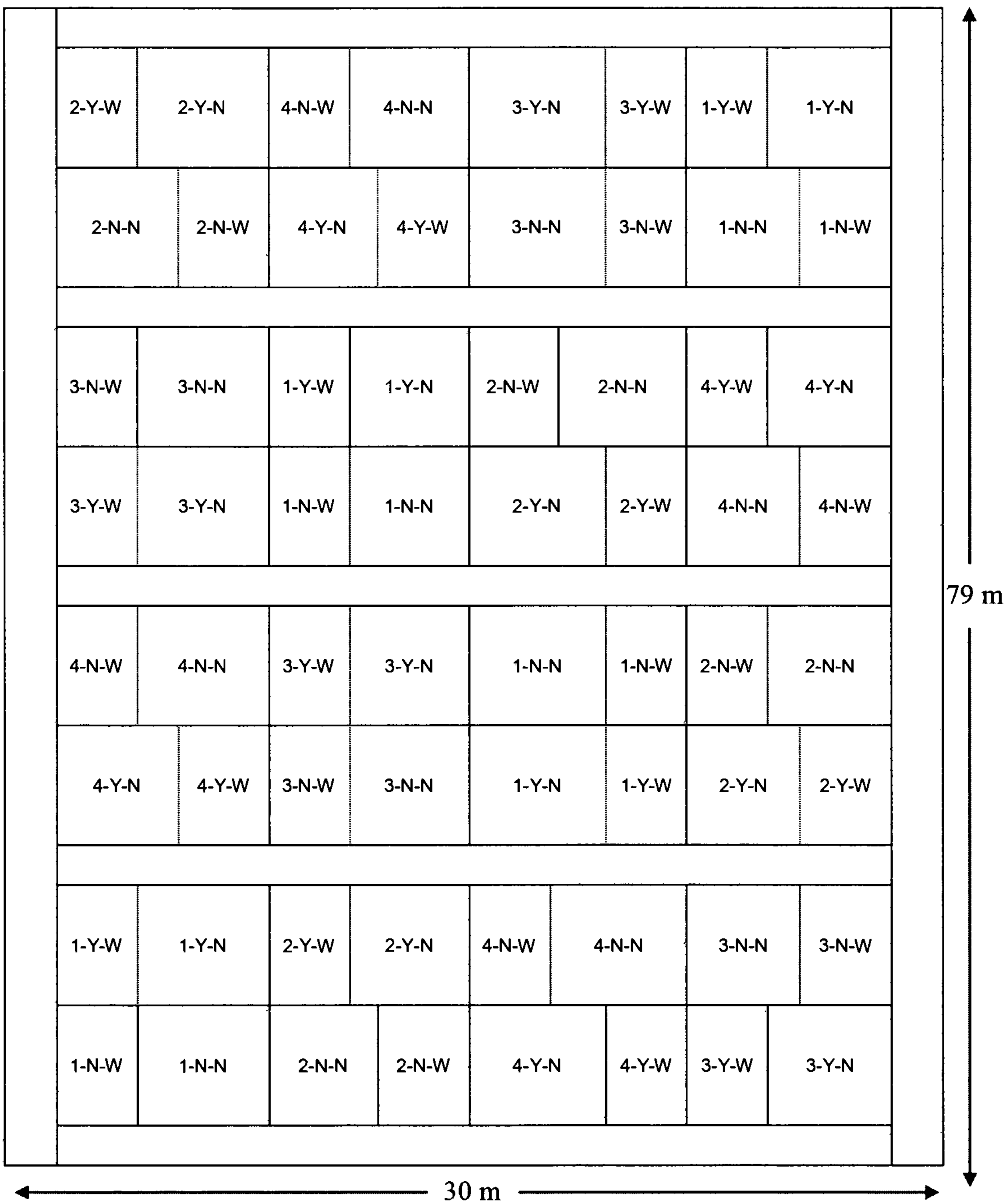


Fig. 1.5. Plot arrangement at Bothwell, 2006- 2007.

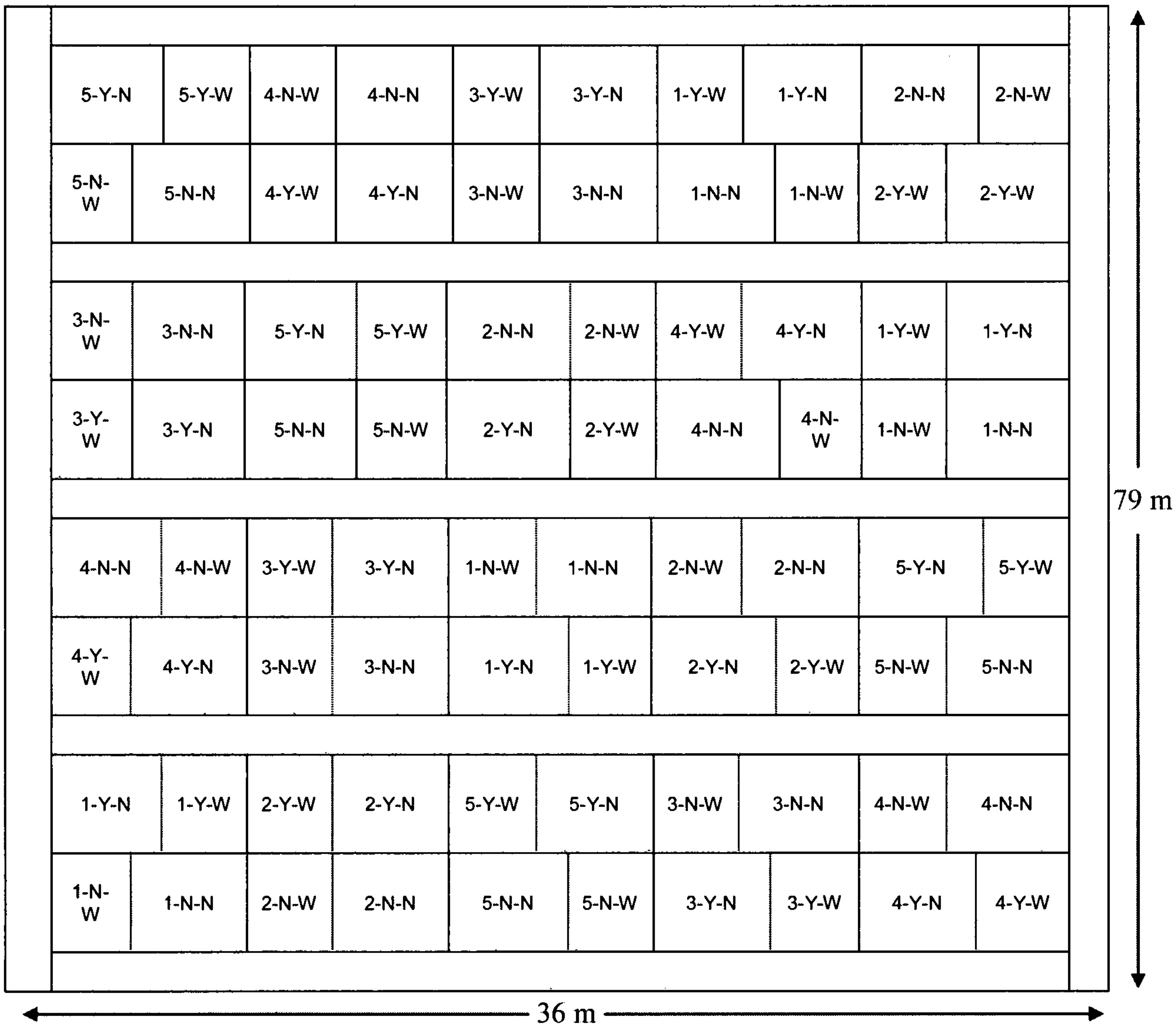


Fig. 1.6. Plot arrangement at Ridgetown, 2007-2008 (Refer to Fig. 1.1 for treatment combinations).

CHAPTER 2

RECOVERY AND RELEASE OF NITROGEN FROM WINTER COVER CROPS IN SWEET CORN PRODUCTION

2.1. INTRODUCTION

Nitrate, a highly soluble form of N, easily leaches through the soil profile. Nitrate leaching can be considerable, especially under temperate vegetable crop production (Bacon, 1995; McCracken et al., 1994). Worldwide, in areas of intensive agriculture, NO_3^- leaching has lead to groundwater pollution (Agriculture and Agri-Food Canada, 2000). In Ontario, approximately 30% of the province's drinking water is supplied from groundwater sources (Goss et al., 1998). Up to 20% of tested private rural wells contain NO_3^- levels above the maximum acceptable value for drinking water (10 mg N l^{-1}) (Goss et al., 1998). High NO_3^- levels in drinking water are linked to methaemoglobinaemia (blue baby syndrome) and possible increased risks of cancer (Weyer et al., 2001).

Leaching often occurs post-harvest when NO_3^- is present in the soil and/or when crop residues mineralize during long periods of fallow (Weinert et al., 2002) and when downward fluxes of water are common in Ontario (Fallow et al., 2003). Several vegetable crops, such as pea, can leave fields fallow for up to nine months of the year, resulting in a long time period for N losses to occur. Nitrate leaching beyond crop roots may not only result in the pollution of groundwater resources, but a valuable nutrient in crop production is lost from the agricultural system (López-Cantarero et al., 1997). This may result in decreased yields in subsequent seasons or the need for increased N fertilizer applications. Post-harvest planted cover crops can potentially absorb and store N over the winter, thereby possibly reducing soil N leaching potential (Huntington et al., 1985).

Cover crops have been suggested to assist in the efficient use of N in agricultural systems (Decker et al., 1994). Cover crops may reduce environmental problems, such as drinking water contamination and surface water eutrophication, by decreasing N leaching, erosion and/or runoff. As well, cover crops may supply N to next season's crops, thereby potentially reducing fertilizer N requirements of the crop. Cover crop N accumulation and its availability to succeeding crops can be affected by cover crop species, precipitation, temperature, length of growing season and soil fertility (Decker et al., 1994; Miller, 1985; Stute and Posner, 1993). Thus, there is a need to evaluate cover crops N dynamics under conditions in southwestern Ontario.

Over the fall, cover crops such as rye, oat and oilseed radish (OSR) may accumulate between 12- 66 kg N ha^{-1} in Ontario (Vyn et al., 2000; Vyn et al., 1999). By sequestering N in plant biomass, cover crops may reduce the quantity of mineral N available for loss from the soil. From a review of past research, Meisinger et al. (1991) found that cereal cover crops can reduce leachate NO_3^--N concentrations by an average of 50% compared to a no cover control, while Brassica covers, on average, can result in a 60% to 75% reduction. Legumes were less effective at reducing leachate NO_3^--N concentration, with only a 6% average decrease (Meisinger et al., 1991). McCracken et al. (1994) found that although both rye and hairy vetch may reduce leachate NO_3^--N concentrations compared to a no cover control, rye was superior to vetch, effectively reducing NO_3^--N in the fall, winter and early spring when discharge volumes were the greatest; vetch reduced NO_3^--N concentrations only after resuming growth in the spring.

In one study, cover crops were found to supply 20-55% of recovered N to subsequent crops after incorporation (Malpassi et al., 2000). However, the limiting factor in the ability of cover crops to supply N to succeeding crops is the synchrony of cover crop N mineralization and N demand by the successive crop (Vyn et al., 2000; Weinert et al., 2002). Cover crop C:N ratio is one of the major factors that affects this synchronization. Plants with high C:N ratios, such as rye (38.6 - 44.7) (Quemada and Cabrera, 1995; Schomberg et al., 2006), may lead to little or no N mineralization (Allison et al., 1998) or even net immobilization (Miller et al., 1992) when incorporated into the soil. However, plants with low C:N ratios such as OSR (20.4) (Schomberg et al., 2006), may mineralize rapidly after incorporation. Depending on the time of incorporation and stage of crop development, this may result in N being available to the following crop.

Although evidence exists in the literature that cover crops are effective at N uptake from the soil, most of these studies have been completed in field crop situations, with limited research in vegetable production. Despite this, cover crops may be more advantageous in vegetable production due to longer periods of fallow which increases the potential for cover crops to sequester N. As well, there is limited research on cover crop mineralization in the following season, which is crucial to ensure proper synchronization with vegetable crop N demand. Added to this, the majority of cover crop studies occur in the United States. Because cover crop biomass, and subsequently N uptake, varies with climate, it is imperative that research be conducted in Ontario to provide transferable information to local vegetable growers. Many growers are currently unwilling to modify N rates based on cover crops due to a lack of solid information coupled with the relatively high value of most vegetable crops in relation to fertilizer costs. Therefore, to improve N best management practices in southwestern Ontario, the objectives of this study are to determine: 1) the impact of cover crops on soil and plant N contents over the rotation, 2) if cover crops affect plant available N for sweet corn, and 3) if cover crops affect sweet corn biomass and/or yield.

2.2. MATERIALS AND METHODS

2.2.1. Experimental Design

Research was conducted from 2006 to 2007 in a production field near Bothwell, ON (42°66'N latitude, 81°95'W, longitude) and from 2007 to 2008 at the University of Guelph Ridgetown Campus, Ridgetown, ON (42°46'N latitude, 81°89'W, longitude). Soil types were a Brady Loamy Sand (Canada Experimental Farms Services, 1957) and a Brookston Sandy Loam (Anonymous, 1936) (Typic Hapludalfs) at Bothwell and Ridgetown, respectively. Crops grown in the previous season were corn and soybeans at Bothwell and Ridgetown, respectively. The experiment was a split-plot arrangement in a randomized complete block design with four replications in a pea – cover crop – sweet corn rotation. The main plot factor was winter cover crop type and the split-plot factor was N fertilization of the sweet corn crop. The cover crop treatments included a no cover crop control, oat (cv. Manotick), perennial rye (cv. Common #1), OSR (cv. Common #1) (Ridgetown only), and OSR+ perennial rye (OSR+rye). The N fertilizer treatments were 0 (0N) and 140 (140N) kg N ha^{-1} applied preplant broadcast incorporated to the sweet corn. Each split-plot was five 76 cm rows (3.8 m) wide by 8 m long.

Pea (cv. Encore) seed was planted at 1,482,000 plants ha^{-1}. Plant row and within row spacing was 17.8 and 3.8 cm, respectively. Peas were fertilized with 56 kg N ha^{-1}, 78 kg P ha^{-1}, 90 kg K ha^{-1}at Bodkin and 67 kg N ha^{-1}, 78 kg P ha^{-1}, 90 kg K ha^{-1} at Ridgetown. Typical Ontario production practices for peas were followed for fertilizer, pest and other field management (Table 2.1). To estimate pea biomass, N content and yield, three 1 m^2 quadrats per replicate were hand harvested. The remainder of the field was not harvested and was considered a bypass field. After pea hand harvest estimates, the entire trial was sprayed with glyphosate [isopropylamine salt of N-(phosphono-methyl)glycine] at 810 g a.i. ha^{-1} and was disked and cultivated prior to cover crop planting. Oat, rye, OSR and ORS+rye were planted with a drill at rates of 81, 67, 16 and 9+34 kg ha^{-1}, respectively. No fertilizer was applied to the cover crops. At Ridgetown, the no cover plots were sprayed with diquat [6,7-dihydrodipyrido (1,2-a:2',1'-c) pyrazinediium dibromide] at 300 g a.i. ha^{-1} and glyphosate at 810 g a.i. ha^{-1} to keep the no cover treatment weed free (Table 2.1). The following spring, to kill the rye cover crops, the entire trial was sprayed with glyphosate at 810 g a.i. ha^{-1}. The entire trial was disked and cultivated before sweet corn planting. Sweet corn (cv. Temptation) was planted at 59,300 plants ha^{-1}. Plant row and within row spacing was 76.2 and 21.6 cm, respectively. Calcium ammonium nitrate (27-0-0) was hand broadcast applied to appropriate plots at 140 kg N ha^{-1} and incorporated. Typical Ontario production practices were followed for pest management, fertilization for all nutrients other than N, and other field management (Table 2.1).

2.2.2. Soil Measurements

The following preplant soil characteristics were evaluated according to Gregorich and Carter (2008) on one composite sample taken from 10-12, 15 cm depth soil cores sampled from each entire trial area: soil pH (1:1 v/v method), organic matter (modified Walkley Black method), P (Olson bicarbonate extraction method), Ca, K, Mg, Na (atomic absorption via ammonium acetate extraction), Zn, Fe, Cu, (DTPA extraction for atomic adsorption), Mn (phosphoric acid extraction with atomic adsorption), percentage sand/silt/clay (hydrometer method), and CEC (estimated based ammonium acetate extraction and pH).

Mineral N concentration (NO_3^--N and NH_4^+-N) was determined on composite soil samples taken from five cores to 90 cm depths. In the field, soil cores were divided into 30 cm increments, homogenized by depth, sealed in plastic bags and put into a cooler for transport. Samples were immediately stored frozen (-20 °C) and sent frozen to an Ontario accredited laboratory for analysis. Under the pea crop, composite samples were taken from each block prior to planting (Table 2.2 and 2.3) and at harvest. Under the cover crops, composite samples were taken from each main plot 5-9 times over the fall and spring growing season. During sweet corn, composite samples were taken from each split-plot at planting and again every three weeks until harvest. Soil NO_3^--N and NH_4^+-N were quantified using the Maynard et al. (2008) method, which consisted of a 2 M KCl extraction with cadmium reduction and the phenate method, respectively, using an autoanalyzer (Technicon Auto Analyzer II; Tarrytown; New York; USA). Soil N was calculated as kg N ha^{-1} based on soil bulk density for the 0-60 and 60-90 cm depths.

2.2.3. Crop Measurements

At pea harvest, aboveground biomass from three 1 m^2 quadrats was collected from each replicate. Biomass was threshed to separate peas from aboveground biomass and determine yield. Aboveground biomass of cover crops was collected 2-4 times in the fall (one 0.5 m^2 quadrat main $plot^{-1}$) and 2-3 times in the spring (two 0.5 m^2 quadrats main $plot^{-1}$). Cover crop biomass samples were taken from a different randomly selected quadrat within the main plot at each sample date. Five sweet corn plants from each split-plot were collected every three weeks up to and at harvest. At sweet corn harvest, 6 m of the centre two rows of each split-plot were hand harvested. Harvested ears were separated into marketable and non-marketable categories based on a stringent examination of each ear. This involved opening the husk of each ear and examining ear size, kernel development and insect damage. If any insect damage or poor kernel development was found, the ear was considered non-marketable. This was completed due to additional insect research being completed at the sites. Weight and the number of marketable and non-marketable ears were recorded. A representative sample of five cobs split-plot^{-1} was selected for further analysis. All plant tissue, including yields, was weighed fresh, dried at 60°C, weighed dry, and a representative sample ground to pass through a 2 mm screen using a Wiley mill. Total N and C content in plant tissue were determined by dry combustion (McGill and Figueiredo, 2008) using a LECO N determinator and a LECO C determinator (Leco Corporation, St. Joseph, MI, USA), respectively. Carbon to nitrogen ratios for the OSR+rye treatments were determined by calculating the C:N ratio of the component cover crops and averaging these according to their relative proportion by biomass. Plant available N (PAN) was quantified as the sum of soil mineral N in the top 60 cm and the total N content of the aboveground plant tissue. Pea and corn shoot N was defined as total N content within the aboveground shoots of the plant. Pea seed N was defined as total N content within the shelled pea seed, while cob N was defined as total N content within the cob, grain and the husk. Total N in the crop at harvest was the sum of shoot N and seed or cob N.

2.2.4. Statistical Analyses

Data were analyzed using the MIXED procedure of SAS Version 9.1 after testing for normality and homogeneity of variance (SAS Institute, Cary, NC). Data were subjected to ANOVA and means were separated using the Tukey-Kramer adjustment test at the 0.05 probability level. A split-plot analysis was used in the sweet corn biomass, soil N, plant N and PAN analyses, where the split-plot factor was N rate (Bowley, 1999). A split-plot analysis was not required for the pea or cover crop analyses because N rate was not a factor in those analyses. In all analyses, comparisons were made between treatments at each date. Outliers were determined using the boxplot method (Tukey, 1977). When outliers were present, they were removed from the analysis only if the results were significantly affected by their removal. All data from each site were analyzed separately due to the differences in treatments, sampling dates, and physical and environmental factors between the two site-years.

2.3. RESULTS AND DISCUSSION

2.3.1. Pea Crop

2.3.1.1. Yield

At Bothwell, the fresh pea crop yield in 2006 was approximately 4.7 t ha^{-1}, which is similar to that year's provincial average of 5.1 t ha^{-1}. The pea crop had an average tenderometer reading of 96 psi, which was within the optimal range of 90 to 120 psi for processing peas. At pea harvest, shoot dry biomass was 955 kg ha^{-1}. At Ridgetown, the fresh pea crop yield in 2007 was approximately 3.2 t ha^{-1}, which is similar to that year's provincial average of 3.9 t ha^{-1}. The pea crop had an average tenderometer reading of 91.25 psi and at pea harvest shoot dry biomass was 2458 kg ha^{-1}. Shoot dry biomass may have been much larger at Ridgetown due to the initial high soil NO_3^--N levels at this site (Table 2.4) and the additional 11 kg N ha^{-1} applied to the peas, which may have led to more vegetative growth.

2.3.1.2. N Dynamics

At Bothwell, in the top 60 cm of soil, total mineral N and NH_4^+-N were higher at pea planting than at pea harvest (Table 2.4). Soil NO_3^--N was numerically higher at pea planting than harvest (Table 2.4). This is similar to other research where soil NO_3^--N in the top 40 cm decreased from pea planting to harvest (Voisin et al., 2002). From 60-90 cm, total mineral N and NO_3^--N did not change over the pea growing season (Table 2.4). Pea shoot, seed and total aboveground plant N at harvest were 22.9, 37.7 and 60.6 kg N ha^{-1}, respectively (Fig. 2.1). Plant available N increased from 51.0 at pea planting to 93.8 at harvest (Table 2.4).

At Ridgetown, from 0-60 cm, total mineral N and NO_3^--N were higher at pea planting than at pea harvest, while NH_4^+-N did not change (Table 2.4). This is similar to Bothwell and Voisin et al. (2002). From 60-90 cm, total mineral N and NO_3^--N increased from planting to harvest while NH_4^+-N did not change (Table 2.4). Pea shoot, seed and total aboveground plant N at harvest were 48.5, 26.4 and 74.9 kg N ha^{-1}, respectively (Fig. 2.1). Plant available N did not change between planting and harvest (Table 2.4).

Differences in PAN between the two sites are likely due to initial soil mineral N levels. Soil NO_3^--N levels in the top 60 cm at planting were 51 and 213 kg N ha^{-1} at Bothwell and Ridgetown, respectively (Table 2.4). Lower levels at Bothwell explain the much lower PAN levels compared to Ridgetown, as less soil mineral N was available for the plants. In addition to this, 11 kg N ha^{-1} more N was applied to the pea crop at Ridgetown than at Bothwell, organic matter was nearly 1% higher at Ridgetown (Table 2.2) and in the previous season soybeans were planted at Ridgetown which may have provided additional soil N, opposed to the corn planted previously at Bothwell. Although changes were seen in soil mineral N over the pea growing season, it is difficult to effectively link these changes to any one process due to the dynamic nature of N in the soil, the various time scales over which these processes occur and the natural mineralization of N over the summer season.

2.3.2. Cover Crops

2.3.2.1. Biomass Production

At Bothwell, cover crop biomass production was affected by cover crop species at all sample dates (Oct. 6 & May 3, $P = 0.001$; Dec 12 & May 15, $P = <0.001$) (Fig. 2.2). In October, the OSR+rye treatment had higher biomass than the cereals. However, by December, oat and OSR+rye had produced more biomass than rye, which is consistent with the typical slow shoot growth of rye in the fall. On 3 May, all of the cover crops had more biomass than the no cover control and oats had higher biomass than the rye treatment (Fig. 2.2). However, by 15 May rye more than doubled in biomass, resulting in higher biomass in the rye than the OSR+rye treatment. This was due to rye over-wintering and growing in the spring, while oat and OSR were killed by frost in the fall. The rye component of the OSR+rye treatment, however, produced less biomass than the rye only treatment and may be the result of the phytotoxic effects of the OSR (Fahey et al., 2001). Other Brassica species have been shown to reduce germination and growth rates of monocots such as barley and oat (Tawaha and Turk, 2003; Turk and Tawaha, 2003). Lower spring rye biomass in the OSR+rye may also be due to lower rye biomass in the fall in the OSR+rye treatments, leading to less rye available for regrowth in the spring.

At Ridgetown, cover crop biomass production was also affected by cover crop species at all sample dates ($P \leq 0.022$) (Fig. 2.3). Over the fall, the OSR+rye and OSR treatments consistently produced more biomass than either oat or rye. The relatively low biomass production for oat and rye in comparison to the OSR treatments, especially in the later sampling dates, may have been due to the high weed pressure at this site in the fall (Fig. 2.3). The high biomass production of the OSR and OSR+rye treatments was likely due to high soil N levels. At the time of cover crop planting, total mineral soil N from the 0-30 cm depth was 22.21 and 106.41 kg N ha^{-1} at Bothwell and Ridgetown, respectively. In a separate trial, fertilized OSR produced nearly twice as much biomass as unfertilized plants (Schomberg et al., 2006). Over the fall, biomass in the no cover treatment biomass was no different than the cereal treatments regardless of the fact that the no cover plots were sprayed with diquat on 25 September and glyphosate on 17 October. In April, there was no difference in biomass between the no cover and the cover crop treatments (Fig. 2.3). In May, the OSR+rye and OSR cover crops had higher biomass than the oat and rye treatments, with the exception of rye and OSR in late May. Higher biomass in the OSR treatment was likely attributable to its production of larger quantities of fall biomass, which remained on the soil surface in the spring. Throughout May, the cover crop treatments had higher biomass than the no cover control.

Biomass production was generally higher at Ridgetown than at Bothwell. This may be because of the earlier planting date at Ridgetown, which in turn influenced the accumulated growing degree days (GDD, base 4.4°C) at each site (Charles et al., 2006; Stivers-Young, 1998). Accumulation of GDD between cover crop planting and the last fall sampling date at Ridgetown (1631 GDD) was more favourable than at Bothwell

(1081 GDD) (Fig. 2.4). Between cover crop planting and the first fall sample date, Ridgetown accumulated 318 more GDD than Bothwell. This, combined with early season rainfall at Ridgetown (Table 1.1), led to good establishment and quick growth of the cover crops and weeds (Fig. 2.3); whereas at Bothwell, growth was more limited in the early season due to less rain in the month following planting and fewer GDD. It is not uncommon for cover crops to produce varying quantities of biomass between years due to differences in weather and planting and kill dates (Barberi and Mazzoncini, 2001; Clark et al., 1995).

2.3.2.2. N Dynamics

2.3.2.2.1. *Plant N Content*

At Bothwell, cover crop treatment affected plant N content in December (P = <0.001) and early May (P = 0.001) (Fig. 2.5). The no cover control was only sampled on May 3 and on this date had lower aboveground plant N than the cover crop treatments (Fig. 2.5), due to the relative absence of weed biomass production in the control plots (Fig. 2.2). At all dates except December, none of the cover crop treatments differed significantly in plant N content (Fig. 2.5). This may be attributed to similarities of some of the treatments in biomass production at each date (Fig. 2.2) and variability in plant %N (data not shown). The differences seen in December are likely due to the large differences in biomass production between the treatments at this date (Fig. 2.2).

At Ridgetown, plant N content was affected by cover crop treatment at all dates except April (Sept. 19, P = 0.007; Oct. 9, P = 0.015; Oct. 30, Nov.23 & May 5, P = <0.001; Apr., P = 0.065; May 26, P = 0.001) (Fig. 2.6). In September, the no cover treatment had lower plant N content than the OSR treatment. However, for the remainder of the fall, the no cover treatment had lower plant N content than all of the cover crop treatments with the exception of oat in early October (Fig. 2.6). Plant N content followed similar patterns as biomass production at Ridgetown, although differences between the no cover and cereal treatments were more pronounced in plant N content. Higher plant N content of the cereals is likely due to their higher plant %N (Appendix B, Table B.2). In April, there was no difference in plant N content between any of the treatments, due to weeds in the no cover treatment. By May, the cover crop treatments had higher plant N than the no cover due to a decrease in biomass in the no cover treatment; however, there was no difference in plant N between the cover crops (Fig. 2.6). It was unclear why weed biomass decreased between 21 April and 5 May; however, this decrease was consistent across all cover crop treatments including the no cover control. Differences were seen in biomass production between the cover crop treatments in May; however, the lower plant %N of the OSR (1.1%) compared to the cereals (Oats, 2.0%; rye, 2.5%) was likely the cause of similar plant N contents between the treatments.

Vyn et al. (2000) also found no difference in cover crop N content between rye, oats and OSR in late fall in three separate years in southern Ontario. Plant N content was much higher in this study compared to Vyn et al. (2000), which was due to higher biomass in this study. Vyn et al. (2000) suggested that low soil NO_3^--N after wheat harvest restricted the growth of the non-leguminous cover crops in their study. Differences in cover crop biomass and N content between the two studies may also be the result of the different agronomic systems used. Vyn et al. (2000) studied a soft winter wheat – cover crop – corn rotation. In comparison, peas are a shorter season crop that was hand-harvested at full maturity, leaving plant material with a relatively low C:N ratio on the field. Therefore, in this study there was more available N to the cover crops to improve biomass production and N uptake. The early harvest of the peas also allowed for earlier planting of the cover crops, increasing the GDD available for the cover crops to grow compared to the wheat rotation studied by Vyn et al. (2000). Similarities in cover crop N content in the spring are consistent with other research completed in the USA (Schomberg et al., 2006).

Cover crop plant N content levels differed between the sites; plant N content tended to be higher in the fall at Ridgetown than at Bothwell (Fig. 2.5 & 2.6). This may be due to earlier planting date resulting in greater plant biomass and higher soil mineral N levels. Earlier sown cover crops tend to have higher N content in the fall than later sown covers (Allison et al., 1998). However, in the spring, plant N content at Ridgetown was lower than at Bothwell (Fig. 2.5). This may be due to mineralization of some of the covers, as high soil N levels were seen at Ridgetown in the spring. In addition, mineralization may have been slower at Bothwell, due to the high sand content of the soil which results in a decrease in biological activity.

2.3.2.2.2. *Soil N*

At Bothwell, soil mineral N in the no cover control numerically increased from October to December in both the 0-60 and 60-90 cm depth (Table 2.5); this possibly indicates mineralization of the pea crop and movement of NO_3^--N through the soil profile over the fall season. Incorporation of pea residue often results in initial N immobilization; however, depending on climate and C:N ratio, quantities of N can be mineralized by 60 days after pea incorporation (Jensen, 1997). The increase was likely only seen in the no cover treatment because the mineralized N was taken up by the growing cover crops in the other treatments.

By October, all of the cover crop treatments had lower total mineral N and NO_3^--N than the no cover control in the top 60 cm (Table 2.5). However, by December only rye had lower NO_3^--N than the no cover. Also by December, rye had the lowest total mineral N of all of the treatments, although oat and OSR+rye also had lower total mineral N than the no cover control. This decrease in soil mineral N under the rye treatment may be due to a combination of factors. First, rye was not frost killed; therefore, it may still have been growing and taking up N in December. Second, a numerical decline in both total mineral N and NO_3^--N between October and December was observed under the no cover treatment (Table 2.5). Because total mineral N and NO_3^--N levels numerically dropped between these two dates in the 60-90 cm zone as well, it may be assumed that N leached or denitrified out of the soil system. The difference in soil mineral N levels between the control and the oat and OSR+rye treatments decreased between October and December due to this large loss from the no cover system. Therefore, rye was more effective at reducing total mineral N and NO_3^--N levels due to its ability to withstand frost kill and to continue to grow and take up N, not due to the release of N from cover crops. Weinert et al. (2002), also found that after a killing frost for winterkill species, rye had lower total mineral N and NO_3^--N levels than both a no cover control and a Brassica cover crop species.

At Bothwell, by October, all of the cover crops had lower total mineral N and NO_3^--N levels compared to the no cover control, with the exception of NO_3^--N in the oat treatment, in the 60-90 cm depth (Table 2.5). By December, total mineral N was lower than the control only under oat and NO_3^--N was lower under the oat and OSR+rye treatments. This is generally consistent with cover crop N content levels, where plant N content was similar between the three cover crops in October, but was higher under the oat by December (Fig. 2.5).

During the spring at Bothwell, none of the cover crops differed from the no cover control in total soil mineral N levels in the top 60 cm of soil (Table 2.5). However, rye had lower total mineral N than both oat and OSR+rye in May. Nitrate-N followed a similar trend, with the exception that rye was lower than the no cover control in late May (Table 2.5). In late May, rye reduced soil NO_3^--N levels by 16.0 kg N ha^{-1}, while oat and OSR+rye did not result in any reduction (Table 2.5). Differences between cover crops may be attributed to plant N uptake, as rye plant N content at this time was 110.2 kg N ha^{-1}, while oat and OSR+rye N content was 88.8 and 71.6 kg N ha^{-1}, respectively (Fig. 2.5). This is consistent with the resumed growth of rye in the spring and the subsequent uptake of NO_3^--N from the soil, as the plant N content of the oat and OSR+rye treatments is contained in crop residue, not growing plant material in the spring. Vyn et al. (1999) also found that ryegrass also tended to lower soil NO_3^--N levels more than OSR and no cover crop treatments in May. In the 60-90 cm zone, rye was the only cover crop to have lower total mineral N or NO_3^--N levels than the no cover treatment (Table 2.5).

In the top 60 cm at Bothwell, NH_4^+-N was higher in the OSR+rye and rye treatments compared to the no cover and oat treatments in October (Table 2.5). By December, only rye had higher NH_4^+-N levels than the control. From 60-90 cm, OSR+rye had higher NH_4^+-N levels than the no cover treatment in October; however, by December, none of the cover crops differed from the no cover treatment (Table 2.5).

There was no difference in NH_4^+-N levels between all treatments in the spring at both soil depths (Table 2.5).

At Ridgetown, in the top 60 cm, oat was lower than the no cover control in total mineral N and NO_3^--N in the fall (Table 2.6). The OSR and OSR+rye treatments were lower than the control in both total mineral N and NO_3^--N levels at all fall sample dates (Table 2.6). Total mineral N and NO_3^--N levels under the rye were not different from the no cover treatment in August and September; however, from October to November, the rye cover crop resulted in lower soil mineral N levels compared to the no cover control (Table 2.6). The differences in the abilities of the cover crops to lower soil mineral N levels through the fall are reflected in plant N content of the cover crops. The oat treatment had similar plant N content values as the no cover treatment in September and early October (Fig. 2.6). Although plant N content values in the oat in late October and November were higher than the no cover control, they were numerically the lowest of the four cover crop treatments. The OSR and OSR+rye treatments consistently had the highest plant N content values over the fall and were typically higher than the no cover control treatment (Figure 2.6). By October, rye had higher plant N content than the no cover control. Vyn et al. (2000) found that OSR, oat and rye cover crops reduced soil NO_3^--N compared to a no cover control in November. Oat did not reduce NO_3^--N levels, in this study, which is likely due to lower biomass production and subsequent N uptake than the other covers, whereas Vyn et al. (2000) found very similar biomass and N levels between all three covers in their study. A decrease in soil mineral N over the fall similar to Bothwell was not observed at Ridgetown. This is likely because of the higher sand content and precipitation at Bothwell, which led to more water moving through the soil profile to depth, thereby possibly increasing NO_3^--N leaching in the process.

At Ridgetown, from 60-90 cm, total mineral N and NO_3^--N levels followed similar trends to the 0-60 cm depth over the fall. Soil mineral N levels under oat did not differ from the no cover treatment; total mineral N was lower under rye in October, but NO_3^--N was lower under rye only in November; the OSR treatment had lower soil mineral N levels than the control from September to November; the OSR+rye treatment had lower soil mineral N levels than the no cover control throughout the fall with the exception of total mineral N in September and NO_3^--N in November (Table 2.7). Allison et al. (1998) also found that some covers were effective at reducing soil mineral N levels between 30 and 90 cm. The reduction of soil mineral N below 60 cm in the OSR and OSR+rye treatments may be due to the growth of large quantities of biomass and deep roots. With high biomass production the OSR cover crops sequestered more N from the 0-60 cm depth, leaving less N in the soil to move down into the 60-90 cm depth. As well, dicotyledonous cover crops, such as fodder radish (*Raphanus sativus* L.) and winter rape (*Raphanus napus* L.), have faster and deeper growing roots than monocots (Thorup-Kristensen, 1993). Research has shown that fodder radish roots may reach 112cm after only 50 days after planting, while rye took approximately 120 days to reach the same depth (Thorup-Kristensen, 1993). Therefore, the potential of OSR to quickly produce high biomass and deep roots may have resulted in the uptake of N in lower soil depths.

In April at Ridgetown, OSR had higher soil mineral N levels than the other treatments from 0-60cm, although none of the other cover crops were different from the no cover treatment (Table 2.6). However, by May, there were no differences in soil mineral N levels between any of the cover crops. From 60-90 cm, none of the cover crops were different from the no cover control throughout spring (Table 2.7). Higher soil mineral N levels in the top 60cm under the OSR and OSR+rye treatments in the spring is consistent with work completed by Miller et al. (1992) in Ontario, which found that OSR had higher NO_3^--N levels than ryegrass, red clover and the no cover control. This indicated that OSR resulted in an earlier release of N than the other cover crops. Although not significantly different, soil NO_3^--N levels under the OSR and OSR+rye treatment were higher in the spring than in the fall, possibly indicating a release of N from plant tissues due to mineralization and subsequent nitrification.

At Ridgetown, NH_4^+-N was unaffected by cover crop treatment with the following exceptions: OSR+rye was higher than the no cover control in September in the 0-60 cm depth and oat was higher than OSR+rye in late October in the 60-90 cm depth (Table 2.6 & 2.7). The lack of effect of cover crops on NH_4^+-N throughout the soil profile was in the spring similar to at Bothwell.

2.3.2.2.3. *PAN*

At Bothwell, no difference in PAN was seen between cover crop treatments in August, after planting (Table 2.8). In October, PAN did not differ between the cover crop treatments and the no cover control, although OSR+rye had higher PAN than oat. The lack of difference in PAN between the cover crops and the control was likely because cover crop treatments had higher plant N than the no cover (Fig. 2.5), but the no cover treatment had significantly higher total soil mineral N (Table 2.5). This indicates that N loss through leaching or denitrification may not have been substantial prior to October, which may be due to 12 mm less rainfall from August to October in 2006 compared to the 30 yr mean (Table 1.1). In December, all of the covers had higher PAN than the no cover (Table 2.8). December PAN levels followed oat>OSR+rye>rye>no cover, with plant N being more influential than soil mineral N levels (Table 2.8). This indicates that by December, the cover crops were more effective at reducing NO_3^--N loss in the fall than the no cover control.

Over the winter cover crop season, total PAN in early May was higher for the cover crop treatments than the no cover control; however, there were no differences between the cover crop treatments (Table 2.8). Higher PAN in May for the cover crops was a result of higher plant N than the no cover, as soil mineral N did not vary between the treatments. Results were similar in late May (Table 2.8). These PAN values provide a rough estimate of the ability of cover crops to reduce N loss over the winter growing season. Therefore, oat, OSR+rye and rye cover crops prevented the loss of approximately 96.3, 76.3, 97.5 kg N ha^{-1}, respectively, in comparison to the no cover control (Table 2.8).

At Ridgetown, by the end of fall none of the cover crops resulted in higher PAN than the no cover (Table 2.9). November PAN levels followed the order of OSR $\geq$ OSR+rye = oat = no cover $\geq$ rye. This pattern was influenced by higher plant N values in the cover crops being balanced by their lower soil mineral N values compared to the control. This may indicate that there was little N lost over the fall growing season, as precipitation was 46 mm lower in September and October in 2007 compared to the 30-yr mean (Table 1.1). Differences may have been seen between the cover crop and control treatments if sampling had continued later into the season; however, this was not practical due to frozen soil conditions. Similar to Bothwell, low PAN levels in the rye may be due to slow fall rye development and leaf senescence during rye growth (Kristensen and Thorup-Kristensen, 2004).

At Ridgetown, over the winter cover crop season, PAN was unaffected by cover crops (Table 2.9). Cover crops may not have been as effective as increasing PAN over the cover crop growing season at Ridgetown than at Bothwell because i) Ridgetown soil was composed of less sand compared to Bothwell (Table 2.2), reducing the amount of water available to drain to depth and ii) less precipitation was received at Ridgetown that at Bothwell over the cover crop growing season (Table 1.1), resulting is less water available to facilitate N leaching. Therefore, at Ridgetown, the cover crops were less effective at preventing N loss than the no cover control compared to at Bothwell, possibly due to lower levels of precipitation and soil sand content.

2.3.3. Sweet Corn Crop

2.3.3.1. Biomass and Yields

Cover crop treatment did not affect sweet corn shoot biomass production at either site over the sweet corn growing season (Table 2.10 and 2.11). Sweet corn aboveground shoot biomass was sampled approximately every three weeks from planting. Values represent the average dry weight for each cover crop or N treatment at each sample date. At Bothwell, N treatment affected sweet corn biomass only in early July ($P = 0.006$) (Table 2.10), although, from June to harvest the 140N treatment had numerically higher biomass production than the 0N treatment. At Ridgetown, N treatment had no effect on sweet corn biomass production (Table 2.11).

At Bothwell, there was a cover crop x N treatment interaction for total yield ($P = 0.038$); there were no interactions for marketable yield ($P = 0.207$). Mean total yields at

Bothwell in the 140N treatment were 4.8 t ha^{-1} higher than in the 0N treatment (Table 2.12). For all treatments, the 140N treatment produced higher total yields than the 0N treatment with the exception of the OSR+rye. While both the oat and OSR+rye treatments produced higher total yields than the no cover control under the 0N treatment, there were no differences between cover crop treatments in the 140N treatment. At Bothwell, the 140N treatment produced 4.1 t ha^{-1} more marketable yield than the 0N treatment. Cover crops had no effect on marketable yields. The 2007 growing season was a comparably hot and dry year (Table 1.1), which contributed to the low yields observed at this site. Average marketable sweet corn yield in 2007 in Ontario was 12.1 t ha^{-1}. Low marketable yields in this study may have been a result of stringent criteria used to classify marketable and non-marketable ears.

At Ridgetown, there were no crop x N treatment interactions (total, $P = 0.327$; marketable, $P = 0.220$). The 140N treatment produced higher total yields than the 0N treatment; however, no differences were seen in marketable yield between the two N treatments (Table 2.13). Cover crop had no effect on total or marketable yields at this site. Total yields at this site were high due to a large number of plants having small non-marketable second cobs. Adequate summer rainfall (Table 1.1) may also have contributed to high yields.

There is little research regarding the effects of cover crops on sweet corn biomass over the growing season. Teasdale et al. (2008) found that by 9 wks after sweet corn planting hairy vetch and hairy vetch+rye cover crops killed prior to sweet corn planting did not result in higher sweet corn biomass than a no cover control. Effects of cover crops on sweet corn height and yields showed mixed and often contrasting results depending on the cover crop and site-year (Burgos and Talbert, 1996; Galloway and Weston, 1996; Malik et al., 2008). Some research indicates that yield is generally unaffected by cover crops (Burket et al., 1997), that yield is either positively or negatively affected depending on the cover crop (Burgos and Talbert, 1996; Galloway and Weston, 1996), or that cover crop effects on yield differ between site-years (Carrera et al., 2004; Malik et al., 2008). As well, Burgos and Talbert (1996) found that wheat (*Triticum aestivum* L.), rye and hairy vetch+rye all had detrimental effects on sweet corn height in the first year of the rotation; however, in the second year, these covers had no effect on corn heights. It was suspected that the lack of effect in the second year may have been due to later sweet corn planting dates after cover crop desiccation, thereby avoiding the negative phytotoxic effects of the cover crops (Burgos and Talbert, 1996). This may explain the lack of effect seen in the current study. At harvest, Isse et al. (1999) found that neither cover crops nor N treatment had an effect on sweet corn biomass.

It is difficult to explain why cover crops affected yield in the 0N treatment and not in the 140N treatment at Bothwell. It may be the result of increased available N resulting in the mineralization of the cover crops as seen in higher PAN in the cover crop treatments (Table 2.8) and numerically higher sweet corn plant N content (Table 2.14). This effect was probably only seen in the 0N treatment because sufficient N was available in the 140N treatment for maximum yields. In general, the positive effect of N rate on yields seen in Bothwell, and in total yields in Ridgetown is consistent with other research where increasing N application resulted in yield increases, often linearly (Burket et al., 1997; Cline and Silvernail, 2002; Griffin et al., 2000; Mullins et al., 1999; Teasdale et al., 2008). Marketable yield may not have been affected by N treatment due to the stringent processes used to determine marketable and non-marketable cobs.

The contrasting effects of N rate on sweet corn biomass between sites were somewhat unexpected. Soil mineral N levels prior to sweet corn planting and fertilization were 43 kg N ha^{-1} higher at Ridgetown than at Bothwell. This may be due to differences in organic matter, crop rotations, tillage and inherent soil fertility between the two sites. It is likely that soil mineral N at Ridgetown in unfertilized plots were sufficient for maximum plant growth (Table 2.6), thus additional fertilizer N did not increase sweet corn biomass; however, because of lower soil mineral N at Bothwell, unfertilized plots likely did not have enough N for maximum growth. Other research has also shown that fertilization does not necessarily lead to increased sweet corn biomass or plant populations (Teasdale et al., 2008; Mullins et al., 1999; Dyck and Liebman, 1994).

2.3.3.2. N Dynamics

2.3.3.2.1. Plant N

Cover crop had no effect on sweet corn plant N content over the growing season on at either site (Table 2.14, 2.15 & 2.16). Sweet corn total plant N at harvest ranged from 88.4 – 116.1 and 170.4 – 204.8 kg N ha^{-1} among the cover crop treatments at Bothwell and Ridgetown, respectively (Table 2.14). Variable effects of cover crops on sweet and field corn plant N have been noted in the literature (Isse et al., 1999; Teasdale and Abdul-Baki, 1998; Bundy and Andraski, 2005; Vyn et al., 1999). Isse et al. (1999) found that forage radish, ryegrass and red clover (*Trifolium pratense* L.) also did not affect sweet corn shoot or cob N content at yield. Teasdale and Abdul-Baki (1998) reported that at 9 wks after planting, effects of leguminous cover crops on sweet corn plant N can be variable. Inconsistent effects of cover crops on field corn N content were also found at harvest where N content under rye did not differ from the control (Bundy and Andraski, 2005) and at antithesis where cover crops had higher plant N than the control (Vyn et al., 1999).

At Bothwell, sweet corn plant N content was higher in the 140N treatment than the 0N treatment (Table 2.14 & 2.15) from July through to harvest. Cob and total N were unaffected by N treatment (Table 2.14). At Ridgetown, sweet corn plant N content was numerically higher in the 140N treatment than the 0N treatment; however this difference was significant only at harvest (Table 2.16). At harvest, shoot, cob and total sweet corn N was higher under the fertilized treatment (Table 2.14). This is consistent with other literature as Mullins et al. (1999) also found that fertilization increased sweet corn plant N content at harvest and Teasdale et al. (2008) reported increased sweet corn plant N contents with fertilization in most cover crop treatments at 9 wk after sweet corn planting.

2.3.3.2.2. Soil N

At Bothwell, in the top 60 cm, throughout the sweet corn growing season oat and OSR+rye did not affect soil total mineral N or NO_3^--N levels compared to the no cover treatment (Table 2.17). Rye, however, consistently had the numerically lowest total mineral N and NO_3^--N levels and in June and late July had significantly lower levels than the control (Table 2.17). Results were similar in the 60-90 cm depth (Table 2.17). Vyn et al. (1999) also found that cereal cover crops, such as ryegrass, tended to have lower soil NO_3^--N levels in June compared to a no cover control, while no difference was seen between the no cover and OSR treatment. Low soil NO_3^--N levels under the rye treatment may be due to N immobilization because of its higher C:N ratio. By late May, C:N ratios were 21:1, 21:1, and 24:1 for oats, OSR+rye and rye, respectively. A C:N ratio of 25:1 is the theoretical value at which net N immobilization tends to occur (Wagger, 1989). Thus, immobilization of rye may be the cause for the low soil N levels. The lower ratio of 21:1 for the oat and OSR+rye treatments may have resulted in quicker N mineralization. In addition to this, variation in lignin content between the cover crops may also have affected the speed of mineralization. In May, just a few days after incorporation, both the oat and OSR+rye treatment had numerically higher NO_3^--N levels than the no cover and the rye, possibly indicating increased mineralization due to incorporation (Table 2.17). However after this time, the no cover treatment tended to have numerically higher NO_3^--N levels. Mineralization response of cover crops can be within 5 days of incorporation; however, this is highly dependent on climate and environmental conditions (Jackson et al., 1993). In addition to C:N ratio, differences in mineralization between the cover crops may also have been affected by lignin content and stage of decomposition due to kill date (Wagger, 1989).

At Bothwell, cover crop treatments had no effect on NH_4^+-N at either soil depth (Table 2.17). This is similar to results found in this study during the pea and cover crop growing seasons and in another study during the potato growing season (Weinert et al., 2002).

At Bothwell, throughout the sweet corn growing season, the fertilized plots had higher soil mineral N than the unfertilized plots in both soil depths with the exception of NH_4^+- N at a few dates from 60-90 cm (Table 2.18). Soil NO_3^--N levels were also found by others to increase with increasing fertilizer rate at wheat (Ayoub et al., 1995) and corn harvest (Mooleki et al., 2004). This may be due to a decrease in nitrogen use efficiency at higher rates of applied N (Ayoub et al., 1995; Barbieri et al., 2008).

At Ridgetown, cover crops generally had no effect on soil mineral N in the top 60 cm (Table 2.19). From 60-90 cm, soil mineral N was unaffected by cover crops with the exception of total soil N being lower under rye than the no cover in May (Table 2.20), although, at times, some differences existed between the individual cover crop treatments. Cover crop C:N ratios in late May were 20:1, 38:1, 40:1 and 21:1 for oat, OSR, OSR+rye and rye, respectively. The higher C:N ratios of the OSR and OSR+rye treatments may have been due to the mineralization of select tissues over the winter or biomass leaching from rainfall events. Both OSR treatments had higher soil N levels and lower plant N levels in the spring compared to the fall, suggesting mineralization. The N mineralization may explain the higher C:N ratios observed in the spring. By late May, OSR residue averaged around 1% N but was around 3% in September, which indicates mineralization over the winter. A decrease in %N results in higher C:N ratios and immobilization of any additional N from the plants (Janssen, 1996). Nitrate can also be leached from cover crop residue during rainfall events (Miller et al., 1994). In a laboratory study, OSR was found to leach more NO_3^--N than ryegrass or red clover, with between 4.4-13.3% of N in the OSR biomass removed through leaching (Miller et al., 1994).

The ineffectiveness of the cereal covers to reduce soil N levels may be due to timing of N mineralization after their incorporation. Covers were incorporated a few days prior to sweet corn planting on 4 June. With low C:N ratios, a large quantity of N is often released immediately; up to 40% of plant N can be released within the first week if environmental conditions are appropriate (Wagger, 1989). As this possible N release would have occurred at a time of very low N demand from the sweet corn (Mills and McElhannon, 1982), leaching losses to depths of greater than 90 cm may have occurred. This leaching would have been enhanced by the 170 mm of rainfall that fell in June 2008, over double the 30 year mean for that month (Table 1.1).

In Ridgetown, the fertilized treatment had higher soil total mineral N and NO_3^--N levels than the 0N treatment in the top 60 cm (Table 2.21). From 60-90 cm, mineral N and NO_3^--N were affected by N treatment only in July (Table 2.21). With the exception of July in the 0-60 cm depth, NH_4^+-N was unaffected by N treatment (Table 2.21). Effect of fertilization on soil N levels is, for the most part, similar to results found at Bothwell.

2.3.3.2.3. PAN

At Bothwell, as expected, the 140N treatment had higher PAN than the 0N control (Table 2.22), which is also consistent with higher soil and plant N levels. In late July, the rye treatment resulted in lower PAN than the no cover control (Table 2.22). Although there were no differences between cover crop treatments from May to early July, rye was also numerically lower than the no cover at these dates (Table 2.22). It is likely that significant differences between treatments were not observed at these dates due to high variability within the samples. Low PAN in the rye is due to lower soil N levels in this treatment (Table 2.17). This indicates that rye has the potential to reduce PAN compared to the control during the sweet corn growing season, regardless of N fertilization rate. This suggests net N immobilization in the rye treatment. In addition, although oats and OSR+rye did not increase PAN compared to the control, they also did not result in a reduction. Therefore, although the cover crop treatments produced more

PAN than the no cover control before sweet corn planting, this did not translate into higher PAN levels during sweet corn growth.

Similar to Bothwell, PAN was higher for the fertilized than unfertilized treatments (Table 2.23), which is attributable to soil and plant N effects. Plant available N was higher in the OSR treatment than the no cover, oat and rye treatments in May (Table 2.23), which is likely attributable to the numerically higher PAN in the OSR treatment in the spring. However, for the remainder of the sweet corn growing season, cover crops had no effect on PAN, which is consistent with the fact that cover crops had no effect on total soil N or sweet corn plant N content. The general lack of effect of cover crops on PAN during sweet corn growth indicates that although cover crops did not reduce available N to the sweet corn, they did not provide additional N compared to the control. No relevant literature was found on the effects of cover crops on sweet corn PAN.

2.4. SUMMARY AND CONCLUSIONS

Although timing of N uptake and mineralization varied among the cover crops, they were all more effective at increasing PAN prior to sweet corn planting at Bothwell, while none of the cover crops were effective at Ridgetown. Despite this, there was little evidence that this translated into increased PAN for the sweet corn crop. The lack of effect of cover crops on sweet corn PAN is likely due to a lack of synchrony between release of N from the cover crops and N demand in the sweet corn. At times, especially under the OSR treatments, it appears that N was released over the winter; while rye plants with a high C:N ratio may result in N immobilization. Therefore, although the cover crops tested may be effective at conserving N over the fall and winter periods, they do not appear to provide any N credit to the following sweet corn crop. Rye may even result in lower PAN. Cover crop effects on sweet corn N may also have been subtle due to the high amount of N present in the soil during sweet corn growth. These cover crops do not increase or decrease N fertilizer applications to the sweet corn. However, sweet corn biomass and yield was largely unaffected by the cover crop treatments at both sites, even under the rye, indicating that, regardless of the purpose of cover crop implementation, the cover crops tested are unlikely to result in decreased sweet corn yields.

Table 2.1. Chronology of field operations and sampling.

Crop Activity	Bothwell	Ridgetown
Pea Crop		
Fertilization	10 May 2006	20 April 2007
Planting	10 May 2006	24 April 2007
Basagran, Assist and Excel Super Application	2 June 2006	28 May 2007
Harvest	12 July 2006	29 June 2007
Cover Crop		
Planting	4 Aug. 2006	19 July 2007
Diquat application to no cover plots	--	25 Sept. 2007
Glyphosate application to no cover plots	--	17 Oct. 2007
Fall soil and plant sampling	31 Aug. 2006 6 Oct. 2006 12 Dec. 2006	24 July 2007† 28 Aug. 2007† 19 Sept. 2007 9 Oct. 2007 30 Oct. 2007 23 Nov. 2007
Spring soil and plant sampling	3 May 2007 15 May 207	21 Apr. 2008 5 May 2008 26 May 2008
Glyphosate application (entire trial)	10 May 2007	8 May 2008
Sweet Corn Crop		
S-metolachlor application	--	29 May 2008
Fertilization	25 May 2007	4 June 2008
Planting	28 May 2007	4 June 2008
Nicosulfuron application	19 June 2007	13 June 2008
Sodium bentazon application	26 June 2007	--
Soil and plant sampling	29 May 2007 19 June 2007 10 July 2007 26 July 2007	26 May 2008 16 June 2008 14 July 2008 6 Aug. 2008
Sweet corn harvest	13 Aug. 2007	5 Aug. 2008

† Soil samples only

Table 2.2. Selected soil characteristics at pea planting.†

Location	sand:silt:clay	Texture	OM	pH	CEC	P	K	Ca	Mg
	%		%		MEQ/100g	------------	ppm	------------	
Bothwell	82:12:6	Loamy Sand	2.7	6.3	5.9	21	123	697	107
Ridgetown	68:21:11	Sandy Loam	3.8	5.9	8.5	20	106	1085	83

†Soil sample depth 15 cm for all parameters

Table 2.3. Soil mineral N levels at pea planting.

	NO_3^--N			NH_4^+-N		
Location	0-30 cm	30-60 cm	60-90 cm	0-30 cm	30-60 cm	60-90 cm
	---------- kg N ha^{-1} ----------					
Bothwell†	16.2	16.3	7.9	10.6	7.9	6.1
Ridgetown	163.0	23.8	11.3	19.8	8.6	6.3

†Samples taken on 5 May 2006 (before fertilization) at Bothwell and 31 May 2007 (after fertilization) at Ridgetown.

Table 2.4. Soil mineral N during the pea growing season.

	Bothwell				Ridgetown			
Date	Total mineral N	NO_3^--N	NH_4^+-N	PAN‡	Total mineral N	NO_3^--N	NH_4^+-N	PAN
	kg N ha^{-1}				kg N ha^{-1}			
					0-60 cm			
Pea planting	51.0 b†	32.4	18.5 b	51.0 a	213.4 b	184.1 b	27.5	213.4
Pea harvest	32.8 a	24.8	8.0 a	93.8 b	134.3 a	105.2 a	27.8	210.4
P value	0.039	0.138	0.004	0.001	0.048	0.044	0.958	0.913
					60-90 cm			
Pea planting	14.0	7.9	6.1 b	--§	17.3 a	11.0 a	6.2	--
Pea harvest	14.3	12.3	1.6 a	--	30.6 b	23.6 b	6.7	--
P value	0.885	0.094	0.011	--	0.047	0.037	0.697	--

† Within a column, for a given soil depth, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

‡ PAN, plant available nitrogen.

§ PAN calculated for 0-60 cm depth only.

Table 2.5. Soil mineral N during the cover crop growing season at Bothwell.

	0-60 cm					60-90 cm				
Date	No cover	Oat	OSR+rye†	Rye	*P* value	No cover	Oat	OSR+rye	Rye	*P* value
	kg N ha^{-1}					kg N ha^{-1}				
	Total mineral N					Total mineral N				
31 Aug. 2006	58.1‡	47.0	35.1	44.7	0.066	14.5	16.5	11.4	12.4	0.415
6 Oct. 2006	61.9 b	27.7 a	31.9 a	30.6 a	<0.001	25.6 c	11.5 b	7.1 ab	5.4 a	<0.001
12 Dec. 2006	30.3 c	24.3 b	31.6 b	14.4 a	<0.001	8.0 b	3.3 a	7.2 b	7.4 b	0.002
3 May 2007	46.3 ab	51.2 b	53.5 b	33.3 a	0.015	13.3 bc	15.0 c	11.3 b	8.0 a	<0.001
15 May 2007	47.8 ab	56.1 b	51.0 b	34.7 a	0.010	--	--	--	--	--
	NO_3^--N					NO_3^--N				
31 Aug. 2006	48.7 b	35.9 ab	20.8 a	33.5 ab	0.010	12.6	12.7	8.3	9.8	0.270
6 Oct. 2006	52.9 b	18.5 a	18.5 a	18.3 a	<0.001	23.3 c	9.3 bc	2.3 ab	2.1 a	0.001
12 Dec. 2006	21.1 b	16.3 b	16.8 b	5.2 a	<0.001	5.5 c	2.0 a	2.9 ab	4.7 bc	0.001
3 May 2007	25.6 ab	28.0 b	25.9 b	13.3 a	0.028	7.8 b	8.9 b	5.9 b	1.6 a	<0.001
15 May 2007	28.4 b	33.8 b	25.7 b	12.4 a	0.002	--	--	--	--	--
	NH_4^+-N					NH_4^+-N				
31 Aug. 2006	8.8	10.9	9.7	10.7	0.686	1.8	2.9	3.0	3.9	0.284
6 Oct. 2006	8.9 a	9.0 a	12.3 b	13.2 b	0.001	2.3 a	2.0 a	4.2 b	2.8 ab	0.006
12 Dec. 2006	7.9 a	9.0 a	9.2 a	14.7 b	<0.001	2.5 ab	1.3 a	3.9 b	2.5 ab	0.015
3 May 2007	20.4	22.4	25.2	19.1	0.421	5.0	5.5	6.3	6.6	0.579
15 May 2007	19.2	22.2	24.5	22.2	0.117	--	--	--	--	--

†OSR+rye, oilseed radish plus rye.

‡Within rows, for a given soil depth, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

Table 2.6. Soil mineral N during the cover crop growing season from 0-60 cm at Ridgetown.

Date	No cover	Oat	OSR†	OSR+rye	Rye	*P* value
			---------------------kg N ha^{-1} ----------------			
			Total mineral N			
24 July 2007	151.0	151.0	151.0	151.0	151.0	--
28 Aug. 2007	203.8 b‡	141.2 b	76.4 a	81.0 a	178.0 b	<0.001
19 Sept. 2007	122.6 b	134.2 b	47.8 a	48.4 a	84.5 ab	0.001
9 Oct. 2007	147.6 c	102.4 bc	47.7 a	35.8 a	61.9 ab	<0.001
30 Oct. 2007	154.7 b	112.1 b	36.6 a	32.5 a	46.5 a	<0.001
23 Nov. 2007	172.0 b	134.0 b	56.2 a	38.2 a	48.6 a	<0.001
21 Apr. 2008	77.1 ab	65.4 a	157.2 c	105.1 b	85.1 ab	0.001
5 May 2008	91.8	69.0	105.1	98.1	62.4	0.183
26 May 2008	89.1	73.9	123.2	93.8	72.5	0.187
			NO_3^--N			
24 July 2007	120.8	120.8	120.8	120.8	120.8	--
28 Aug. 2007	187.6 b	125.1 b	55.4 a	61.5 a	160.3 b	<0.001
19 Sept. 2007	113.8 b	123.9 b	33.9 a	33.7 a	73.0 b	0.001
9 Oct. 2007	130.5 b	84.3 b	25.5 a	17.3 a	41.3 a	<0.001
30 Oct. 2007	142.2 b	100.2 b	24.6 a	21.2 a	33.3 a	<0.001
23 Nov. 2007	155.9 b	118.7 b	30.1 a	21.6 a	29.1 a	<0.001
21 Apr. 2008	57.2 a	49.1 a	125.4 c	85.2 b	64.5 ab	<0.001
5 May 2008	74.4	55.2	82.6	82.0	48.4	0.221
26 May 2008	72.6	57.5	107.0	79.0	57.4	0.155
			NH_4^+-N			
24 July 2007	29.9	29.9	29.9	29.9	29.9	--
28 Aug. 2007	15.7	15.6	19.4	19.1	16.0	0.424
19 Sept. 2007	8.7 a	9.7 ab	13.2 ab	14.0 b	11.0 ab	0.019
9 Oct. 2007	16.7	16.8	21.9	17.6	19.2	0.131
30 Oct. 2007	12.4	11.7	11.6	10.6	13.1	0.496
23 Nov. 2007	15.8	14.7	21.7	15.2	18.1	0.090
21 Apr. 2008	16.9	14.3	30.5	19.6	19.5	0.072
5 May 2008	14.9	12.3	20.2	15.1	13.4	0.260
26 May 2008	13.7	14.5	16.1	14.5	14.9	0.769

† OSR, oilseed radish; OSR+rye, oilseed radish plus rye.

‡ Within rows, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

Table 2.7. Soil mineral N during the cover crop growing season from 60-90 cm at Ridgetown.

Date	No cover	Oat	OSR†	OSR+rye	Rye	*P* value
	--------------------------kg N ha^{-1} ---------------------					
			Total mineral N			
24 July 2007	24.3	24.3	24.3	24.3	24.3	--
28 Aug. 2007	35.4 b‡	26.8 ab	21.4 ab	15.8 a	31.4 b	0.011
19 Sept. 2007	14.8 b	9.4 ab	6.1 a	7.1 ab	7.7 ab	0.021
9 Oct. 2007	17.7 b	12.1 ab	8.3 a	8.5 a	8.1 a	0.005
30 Oct. 2007	24.1 c	13.4 bc	5.7 a	5.6 a	10.0 ab	0.001
23 Nov. 2007	19.5 b	15.4 ab	10.5 a	10.1 a	12.1 ab	0.011
21 Apr. 2008	12.7	12.9	14.6	12.3	12.0	0.803
5 May 2008	21.8	15.9	20.4	22.1	13.5	0.240
26 May 2008	18.3 b	12.1 ab	15.4 ab	13.8 ab	9.0 a	0.022
			NO_3^--N			
24 July 2007	17.3	17.3	17.3	17.3	17.3	--
28 Aug. 2007	30.3 b	20.1 ab	14.5 ab	10.2 a	26.9 b	0.005
19 Sept. 2007	10.2 b	6.8 ab	3.7 a	4.7 a	5.9 ab	0.005
9 Oct. 2007	12.8 b	7.0 ab	3.0 a	3.2 a	5.1 ab	0.006
30 Oct. 2007	15.1 b	7.4 ab	1.5 a	1.7 a	5.8 ab	0.002
23 Nov. 2007	12.4 b	8.6 ab	3.0 a	4.4 ab	2.5 a	0.015
21 Apr. 2008	11.5	6.2	11.1	8.5	7.1	0.146
5 May 2008	16.5	9.7	12.4	13.5	9.8	0.435
26 May 2008	13.8	7.4	10.9	9.7	5.5	0.053
			NH_4^+-N			
24 July 2007	6.2	6.2	6.2	6.2	6.2	--
28 Aug. 2007	5.1	5.9	5.7	5.1	5.4	0.848
19 Sept. 2007	3.4	2.4	2.3	2.1	1.7	0.546
9 Oct. 2007	4.9	4.7	4.7	5.2	4.4	0.728
30 Oct. 2007	4.1 ab	5.6 b	3.5 ab	3.2 a	3.9 ab	0.039
23 Nov. 2007	5.7	6.1	7.2	5.2	7.0	0.581
21 Apr. 2008	3.9	3.7	3.4	3.1	3.8	0.941
5 May 2008	4.6	4.6	6.4	6.4	3.3	0.383
26 May 2008	3.7	3.2	4.3	3.6	3.4	0.728

† OSR, oilseed radish; OSR+rye, oilseed radish plus rye.

‡ Within rows, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

Table 2.8. Plant available nitrogen (PAN) during the cover crop growing season at Bothwell.

Date	No cover	Oat	OSR+rye†	Rye	*P* value
	----------------------kg N ha^{-1} ----------------------				
12 July 2006			93.8		--
31 Aug. 2006	58.1‡	47.0	35.1	44.7	0.066
6 Oct. 2006	62.2 ab	49.7 a	78.4 b	56.3 ab	0.034
12 Dec. 2006	30.3 a	177.3 d	129.8 c	81.8 b	<0.001
3 May 2007	47.7 a	139.2 b	115.1 b	102.4 b	0.001
15 May 2007	48.2 a	144.5 b	124.5 b	145.7 b	0.001

† OSR+rye, oilseed radish plus rye.

‡Within rows, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

Table 2.9. Plant available nitrogen (PAN) during the cover crop growing season at Ridgetown.

Date	No cover	Oat	OSR†	OSR+rye	Rye	*P* value
	----------	----------	kg N ha^{-1}	----------	----------	
24 July 2007	151.0	151.0	151.0	151.0	151.0	--
28 Aug. 2007	205.2 b‡	147.4 b	79.6 a	81.4 a	180.4 b	<0.001
19 Sept. 2007	237.7	277.1	302.6	244.6	166.1	0.198
9 Oct. 2007	192.0	196.7	150.5	167.7	168.2	0.641
30 Oct. 2007	156.3	187.1	186.8	142.2	148.9	0.382
23 Nov. 2007	179.7 ab	178.2 ab	317.2 b	229.3 ab	122.7 a	0.026
21 Apr. 2008	116.4	120.1	217.0	148.7	149.0	0.053
5 May 2008	105.6	111.1	140.8	131.3	116.5	0.251
26 May 2008	114.0	124.5	164.7	137.4	128.7	0.491

† OSR, oilseed radish; OSR+rye, oilseed radish plus rye.

‡ Within rows, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

Table 2.10. Sweet corn shoot biomass over the growing season at Bothwell.

	29 May 2007	19 June 2007	10 July 2007	26 July 2007
	---------------------------kg ha^{-1} --------------------------			
		Cover crop treatment		
No cover	160.6‡	1281.9	2383.8	3045.0
Oat	172.1	1381.9	2867.2	2855.0
OSR+rye†	172.1	1358.6	2675.1	2814.1
Rye	164.4	1163.1	2212.4	2848.2
P value	0.933	0.455	0.152	0.630
		N treatment		
0N	169.8	1227.8	2210.0 a	2850.2
140N	164.7	1364.9	2859.2 b	2931.0
P value	0.503	0.191	0.006	0.427

† OSR+rye, oilseed radish plus rye; 0N, no fertilizer; 140N, 140 kg N ha^{-1} pre-plant broadcast incorporated calcium ammonium nitrate.

‡ Within a column, for a given treatment group, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

Table 2.11. Sweet corn shoot biomass over the growing season at Ridgetown.

	26 May 2008	16 June 2008	14 July 2008
	--------------------kg ha^{-1} -------------------		
	Cover crop treatment		
No cover	107.5‡	1056.0	2829.8
Oat	100.0	1238.3	2972.7
OSR†	105.9	1146.4	2936.8
OSR+rye	99.7	1421.4	2913.0
Rye	101.7	1381.3	3090.5
P value	0.971	0.716	0.980
	N treatment		
0N	99.8	1261.8	3062.7
140N	106.2	1235.6	2834.4
P value	0.264	0.748	0.067

† OSR, oilseed radish; OSR+rye, oilseed radish plus rye; 0N, no fertilizer; 140N, 140 kg N ha^{-1} pre-plant broadcast incorporated calcium ammonium nitrate.

‡ Within a column, for a given treatment group, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

Table 2.12. Total and marketable sweet corn yield at Bothwell.

	Total yield				Marketable yield
N treatment	No cover	Oat	OSR+rye†	Rye	
	$t\ ha^{-1}$				$t\ ha^{-1}$
0N	6.5 a‡	11.4 bc	11.4 bcd	6.7 ab	5.4 a
140N	12.2 cd	15.2 d	14.0 cd	13.7 cd	9.5 b
P value	0.038				0.001

† OSR+rye, oilseed radish plus rye; 0N, no fertilizer; 140N, 140 kg N ha^{-1} pre-plant broadcast incorporated calcium ammonium nitrate.

‡ Within a given yield group, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

Table 2.13. Total and marketable sweet corn yield at Ridgetown.

N treatment	Total yield	Marketable yield
	-----------------t ha^{-1} ---------------	
	Cover crop treatment	
No cover	39.2‡	18.5
Oat	38.4	20.6
OSR†	46.8	17.5
OSR+rye	43.8	20.7
Rye	44.0	25.7
P value	0.054	0.690
	N treatment	
0N	40.0 a	22.4
140N	45.9 b	19.5
P value	0.001	0.310

†OSR, oilseed radish; OSR+rye, oilseed radish plus rye; 0N, no fertilizer; 140N, 140 kg N ha^{-1} pre-plant broadcast incorporated calcium ammonium nitrate.

‡Within a column, for a given treatment group, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

Table 2.14. Shoot, cob and total aboveground N in the sweet corn crop at harvest.

	Shoot N†		Cob N		Total N	
	Bothwell	Ridgetown	Bothwell	Ridgetown	Bothwell	Ridgetown
	kg N ha^{-1}					
	Cover crop treatment					
No cover	46.4 ‡	53.7	41.4	118.0	88.4	172.1
Oat	41.5	54.6	70.1	115.4	116.1	170.4
OSR§	--	67.9	--	129.5	--	195.1
OSR+rye	46.5	65.4	51.7	135.2	99.3	204.8
Rye	40.6	61.9	52.6	134.2	94.5	196.2
P Value	0.405	0.515	0.167	0.477	0.482	0.444
	N treatment					
0N	38.1 a	55.3 a	41.7	113.5 a	81.5	169.1 a
140 N	49.6 b	66.1 b	66.6	140.0 b	118.8	206.8 b
P Value	0.003	0.001	0.061	0.002	0.067	<0.001

†Shoot N, shoot %N by shoot dry weight; cob N, cob %N by cob dry weight; total N, shoot N + cob N.

‡ Within a column, for a given treatment group, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

§ OSR, oilseed radish; OSR+rye, oilseed radish plus rye; 0N, no fertilizer; 140N, 140 kg N ha^{-1} pre-plant broadcast incorporated calcium ammonium nitrate.

Table 2.15. Sweet corn aboveground plant N content over the growing season at Bothwell.

	19 June 2007	10 July 2007	26 July 2007	13 Aug. 2007
	kg N ha^{-1}			
	Cover crop treatment			
No cover	7.3‡	19.2	33.0	47.5
Oat	7.5	26.8	44.4	41.8
OSR+rye†	8.4	22.1	39.4	46.7
Rye	6.7	21.7	30.7	41.2
P value	0.358	0.439	0.087	0.293
	N treatment			
0N	7.0	18.9 a	26.9 a	39.8 a
140N	8.1	26.0 b	46.8 b	48.8 b
P value	0.105	0.042	<0.001	0.006

† OSR+rye, oilseed radish plus rye; 0N, no fertilizer; 140N, 140 kg N ha^{-1} pre-plant broadcast incorporated calcium ammonium nitrate.

‡ Within a column, for a given treatment group, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

Table 2.16. Sweet corn aboveground plant N content over the growing season at Ridgetown.

	16 June 2008	14 July 2008	6 Aug. 2008
	---------- kg N ha^{-1} ----------		
	Cover crop treatment		
No cover	4.7‡	34.3	55.8
Oat	4.5	38.5	55.9
OSR†	4.3	46.8	68.2
OSR+rye	4.4	39.8	66.1
Rye	4.5	45.2	62.4
P value	0.960	0.715	0.600
	N treatment		
0N	4.3	39.2	56.2 a
140N	4.6	42.6	67.1 b
P value	0.226	0.210	0.001

† OSR, oilseed radish; OSR+rye, oilseed radish plus rye; 0N, no fertilizer; 140N, 140 kg N ha^{-1} pre-plant broadcast incorporated calcium ammonium nitrate.

‡ Within a column, for a given treatment group, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

Table 2.17. Soil mineral N during the sweet corn growing season as affected by cover crops at Bothwell.

	0-60 cm					60-90 cm				
Date	No cover	Oat	OSR+rye†	Rye	*P* value	No cover	Oat	OSR+rye	Rye	*P* value
	------------------------kg N ha^{-1} -----------------					-------------------kg N ha^{-1} --------------				
	Total mineral N					Total mineral N				
29 May 2007	106.6‡	124.7	121.7	95.7	0.374	27.1 ab	28.5 b	17.6 ab	13.7 a	0.028
19 June 2007	205.9 b	145.1 ab	161.2 ab	122.3 a	0.010	24.6	26.2	21.4	14.3	0.127
10 July 2007	131.0	122.1	93.6	83.2	0.238	105.9	88.1	63.5	49.4	0.226
26 July 2007	140.3 b	112.7 ab	108.1 ab	83.4 a	0.012	39.1 b	27.6 ab	24.9 ab	16.8 a	0.012
13 Aug. 2007	129.1	10.30	127.1	92.8	0.150	21.6	15.5	15.6	13.4	0.405
	NO_3^--N					NO_3^--N				
29 May 2007	74.4	87.3	90.6	62.5	0.148	17.4 ab	20.1 b	9.9 ab	6.1 a	0.003
19 June 2007	166.6 b	120.1 ab	134.5 b	87.3 a	0.004	18.6	21.1	14.3	7.9	0.050
10 July 2007	94.8	86.5	60.4	45.0	0.110	83.3	72.6	46.7	29.6	0.112
26 July 2007	105.2 b	79.4 ab	78.9 ab	54.8 a	0.021	26.3 b	18.1 ab	14.8 ab	7.5 a	0.016
13 Aug. 2007	105.8	84.3	106.5	66.8	0.123	15.3	12.2	8.9	5.9	0.201
	NH_4^+-N					NH_4^+-N				
29 May 2007	29.9	34.8	29.3	32.1	0.928	8.1	8.2	8.6	6.8	0.823
19 June 2007	38.5	24.3	24.7	31.0	0.076	5.2	4.8	5.8	5.7	0.897
10 July 2007	33.7	30.8	28.3	30.9	0.628	21.5	13.2	14.9	11.9	0.232
26 July 2007	32.8	28.9	25.4	26.2	0.296	10.4	8.5	8.7	8.4	0.760
13 Aug. 2007	22.1	17.0	18.4	20.1	0.380	5.2	5.0	5.6	6.0	0.464

† OSR+rye, oilseed radish plus rye.

‡Within a row, for a given soil depth, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

Table 2.18. Soil mineral N during the sweet corn growing season as affected by N treatment at Bothwell.

	0-60 cm			60-90 cm		
Date	0N†	140N	*P* value	0N	140N	*P* value
		Total mineral N			Total mineral N	
29 May 2007	77.7 a‡	160.2 b	<0.001	17.4 a	24.7 b	0.013
19 June 2007	111.3 a	218.1 b	<0.001	15.7 a	28.3 b	0.006
10 July 2007	75.3 a	148.2 b	0.002	41.2 a	131.3 b	0.001
26 July 2007	74.0 a	161.4 b	<0.001	18.6 a	36.1 b	<0.001
13 Aug. 2007	62.5 a	200.5 b	<0.001	12.6 a	21.0 b	0.004
		NO_3^--N			NO_3^--N	
29 May 2007	51.5 a	117.8 b	<0.001	9.6 a	15.1 b	0.011
19 June 2007	84.4 a	181.7 b	<0.001	10.3 a	20.5 b	0.011
10 July 2007	43.6 a	108.4 b	0.001	29.3 a	98.6 b	0.001
26 July 2007	47.0 a	127.7 b	<0.001	9.2 a	24.9 b	<0.001
13 Aug. 2007	45.3 a	175.7 b	<0.001	6.6 a	14.9 b	0.001
		NH_4^+-N			NH_4^+-N	
29 May 2007	24.7 a	40.1 b	0.006	6.9	9.1	0.094
19 June 2007	24.4 a	34.8 b	0.03	4.7 a	6.2 b	0.047
10 July 2007	27.2 a	34.9 b	0.020	10.5 a	21.3 b	0.002
26 July 2007	24.6 a	32.3 b	0.004	8.4	9.6	0.154
13 Aug. 2007	15.5 a	24.1 b	0.001	5.3	5.5	0.685

† 0N, no fertilizer; 140N, 140 kg N ha^{-1} pre-plant broadcast incorporated calcium ammonium nitrate.

‡Within a row, for a given soil depth, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

Table 2.19. Soil mineral N from 0-60 cm during the sweet corn growing season as affected by cover crops at Ridgetown.

Date	No cover	Oat	OSR†	OSR+rye	Rye	*P* value
	------------------------	kg N ha^{-1}	-----------------			
			Total mineral N			
26 May, 2008	89.1‡	73.9	123.2	93.8	72.5	0.187
16 June, 2008	221.6	187.0	246.5	187.0	215.9	0.621
14 July, 2008	137.6	186.5	127.8	143.4	147.6	0.439
6 Aug. 2008	80.2	71.4	111.4	121.1	84.1	0.052
			NO_3^--N			
26 May, 2008	72.6	57.5	107.0	79.0	57.4	0.155
16 June, 2008	182.5	161.6	224.3	189.7	176.1	0.481
14 July, 2008	116.0	161.5	105.3	122.2	125.2	0.484
6 Aug. 2008	62.2 ab	51.5 a	89.2 ab	92.1 b	57.5 ab	0.018
			NH_4^+-N			
26 May, 2008	13.7	14.5	16.1	14.5	14.9	0.769
16 June, 2008	32.3	23.6	21.3	22.3	30.3	0.392
14 July, 2008	18.3	22.0	19.4	18.6	20.0	0.663
6 Aug. 2008	14.3	16.0	17.8	16.3	14.8	0.730

† OSR, oilseed radish; OSR+rye, oilseed radish plus rye.

‡Within a row, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

Table 2.20. Soil mineral N from 60-90 cm during the sweet corn growing season as affected by cover crops at Ridgetown.

	60-90 cm					
Date	No cover	Oat	OSR†	OSR+rye	Rye	*P* value
	--------------------------kg N ha^{-1} --------------------					
			Total mineral N			
26 May, 2008	18.3 b‡	12.1 ab	15.4 ab	13.8 ab	9.0 a	0.022
16 June, 2008	21.3	19.1	26.5	21.1	17.0	0.162
14 July, 2008	23.9 ab	25.4 b	16.4 a	19.0 ab	18.2 ab	0.034
6 Aug. 2008	16.6	11.6	17.8	16.1	9.2	0.051
			NO_3^--N			
26 May, 2008	13.8	7.4	10.9	9.7	5.5	0.053
16 June, 2008	18.2 ab	13.7 ab	22.0 b	13.8 ab	10.0 a	0.020
14 July, 2008	17.0	20.0	10.7	13.8	13.0	0.053
6 Aug. 2008	11.8	7.0	12.5	11.9	6.1	0.065
			NH_4^+-N			
26 May, 2008	3.7	3.2	4.3	3.6	3.4	0.728
16 June, 2008	6.2	4.6	4.3	6.5	6.4	0.150
14 July, 2008	4.6	4.5	4.6	5.0	4.9	0.984
6 Aug. 2008	3.8	3.9	5.4	3.8	3.3	0.081

† OSR, oilseed radish; OSR+rye, oilseed radish plus rye.

‡Within a row means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

Table 2.21. Soil mineral N during the sweet corn growing season as affected by N treatment at Ridgetown.

	0-60 cm			60-90 cm		
Date	0N†	140N	*P* value	0N	140N	*P* value
		Total mineral N			Total mineral N	
26 May, 2008	--	--	--	--	--	--
16 June, 2008	160.6 a‡	284.3 b	0.001	20.2	21.3	0.593
14 July, 2008	102.6 a	211.5 b	<0.001	18.3 a	22.6 b	0.027
6 Aug. 2008	56.6 a	144.2 b	<0.001	13.3	14.4	0.327
		NO_3^--N			NO_3^--N	
26 May, 2008	--	--	--	--	--	--
16 June, 2008	130.2 a	264.9 b	<0.001	14.6	15.4	0.666
14 July, 2008	82.4 a	188.8 b	<0.001	12.6 a	16.9 b	0.018
6 Aug. 2008	39.0 a	126.9 b	<0.001	8.7	10.1	0.141
		NH_4^+-N			NH_4^+-N	
26 May, 2008	--	--	--	--	--	--
16 June, 2008	25.7	25.5	0.959	5.9	5.1	0.231
14 July, 2008	18.6 a	20.6 b	0.017	4.7	4.8	0.842
6 Aug. 2008	16.1	15.5	0.392	4.1	3.9	0.575

† 0N, no fertilizer; 140N, 140 kg N ha^{-1} pre-plant broadcast incorporated calcium ammonium nitrate.

‡Within a row, for a given soil depth, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

Table 2.22. Plant available N (PAN) during the sweet corn growing season Bothwell.

	29 May 2007	19 June 2007	10 July 2007	26 July 2007	13 Aug. 2007
			---------- kg N ha^{-1} ----------		
			Cover crop treatment		
No cover	110.5‡	221.8	174.8	192.2 b	152.6
Oat	116.8	169.6	186.4	171.0 ab	202.4
OSR+rye†	122.6	186.2	139.2	163.8 ab	166.7
Rye	110.6	139.9	130.8	120.9 a	208.2
P value	0.885	0.099	0.376	0.024	0.251
			N treatment		
0N	81.6 a	129.5 a	108.1 a	103.2 a	103.8 a
140N	148.6 b	229.2 b	207.6 b	220.8 b	261.2 b
P value	0.001	<0.001	0.002	<0.001	<0.001

† OSR+rye, oilseed radish plus rye; 0N, no fertilizer; 140N, 140 kg N ha^{-1} pre-plant broadcast incorporated calcium ammonium nitrate.

‡Within a column, for a given treatment group, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

Table 2.23. Plant available N (PAN) during the sweet corn growing season Ridgetown.

	26 May 2008	16 June 2008	14 July 2008	6 Aug. 2008
	------------------------- kg N ha^{-1} -------------------			
		Cover crop treatment		
No cover	69.3 a‡	202.4	189.9	145.4
Oat	78.3 a	171.9	240.5	140.5
OSR†	124.4 b	263.1	201.6	206.6
OSR+rye	97.0 ab	245.5	189.9	190.8
Rye	74.2 a	235.7	209.1	166.6
P value	0.018	0.142	0.583	0.064
		N treatment		
0N	--	156.3 a	148.3 a	114.6 a
140N	--	291.2 b	264.1 b	225.4 b
P value	--	<0.001	<0.001	<0.001

† OSR, oilseed radish; OSR+rye, oilseed radish plus rye; 0N, no fertilizer; 140N, 140 kg N ha^{-1} pre-plant broadcast incorporated calcium ammonium nitrate.

‡Within a column, for a given treatment group, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

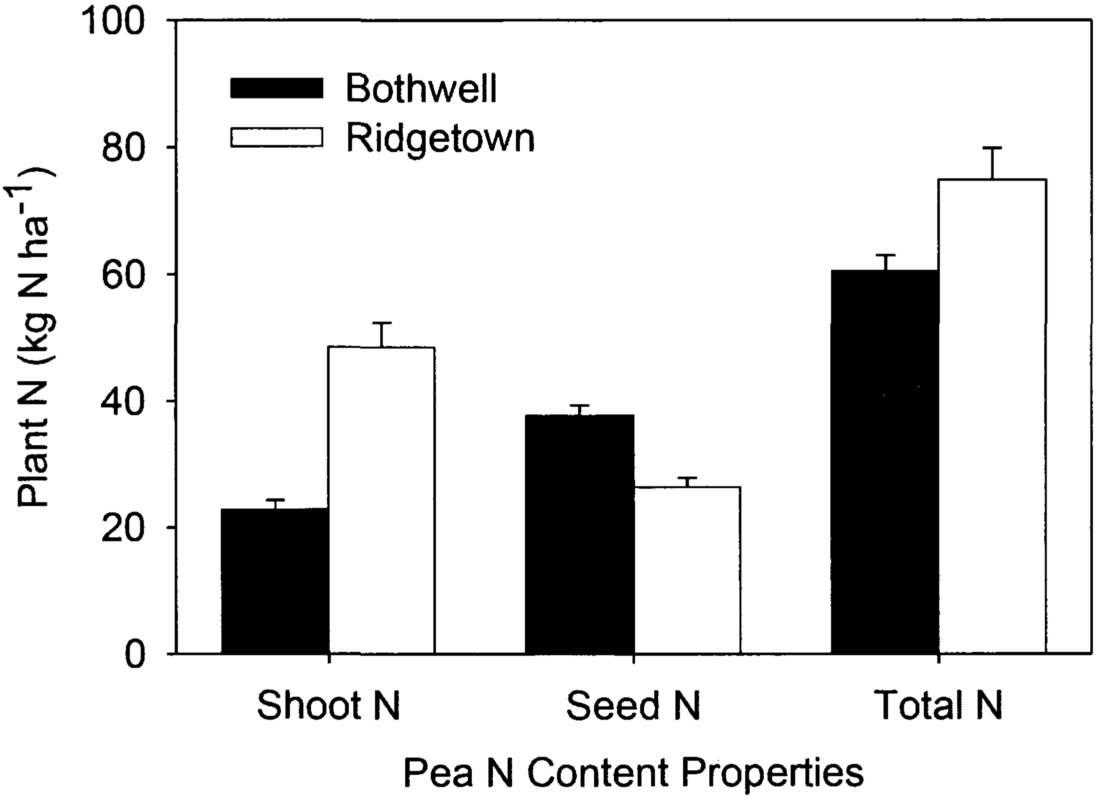


Fig. 2.1. Shoot, seed and total aboveground N in the pea crop. Error bars represent the standard error of the means.

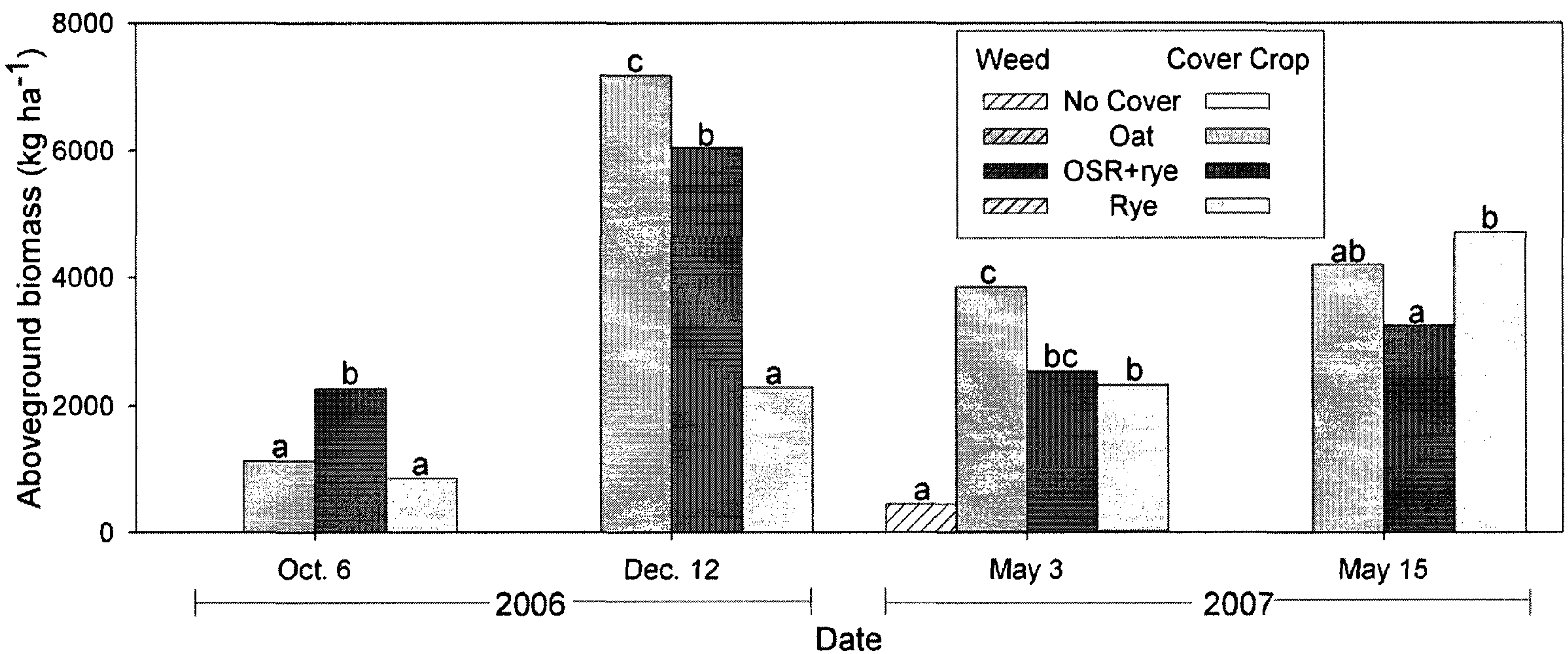


Fig. 2.2. Cover crop and weed aboveground dry biomass production at Bothwell. OSR+rye, oilseed radish plus rye. Bars represent total biomass of cover crops and weeds in each treatment; hashed areas represent weed biomass, solid areas represent cover crop biomass. For a given date, bars with different letters are significantly different based on Tukey-Kramer means separation (0.05).

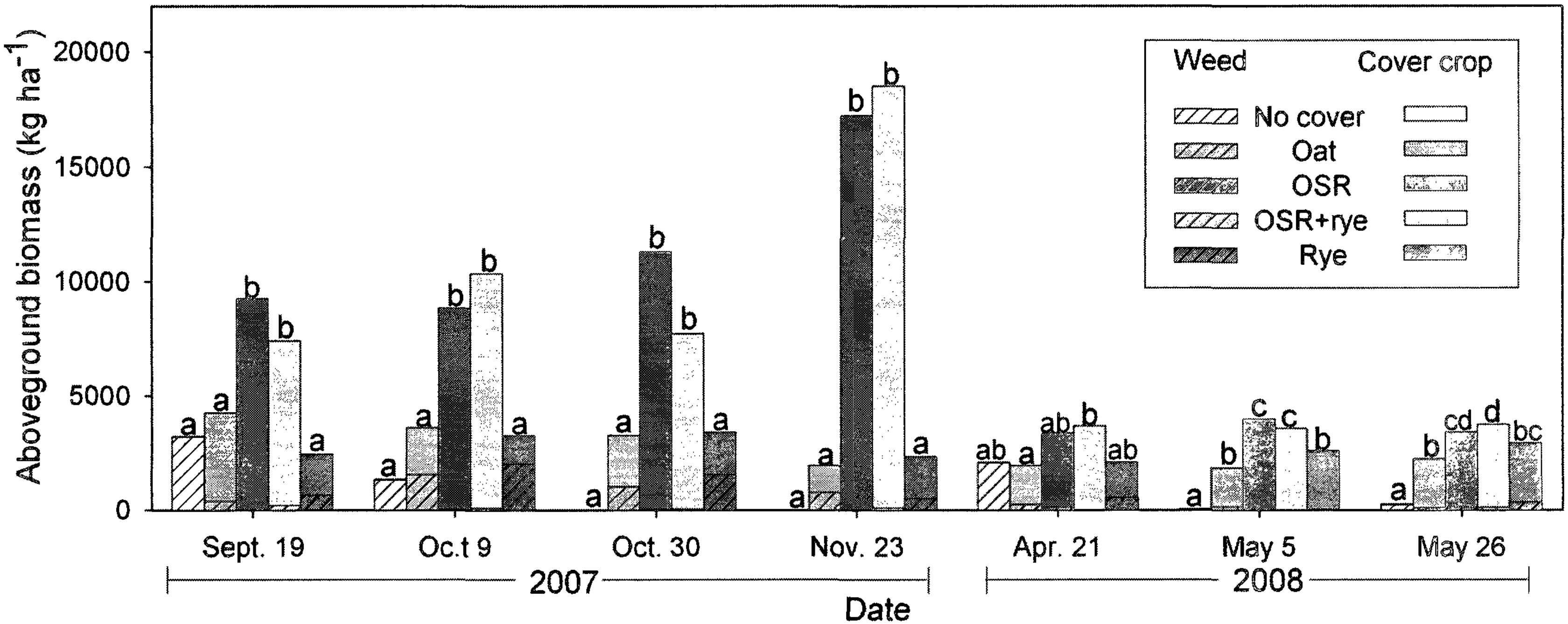


Fig. 2.3. Cover crop and weed aboveground dry biomass production at Ridgetown. OSR, oilseed radish; OSR+rye, oilseed radish plus rye. Bars represent total biomass of cover crops and weeds in each treatment; hashed areas represent weed biomass, solid areas represent cover crop biomass. For a given date, bars with different letters are significantly different based on Tukey-Kramer means separation (0.05).

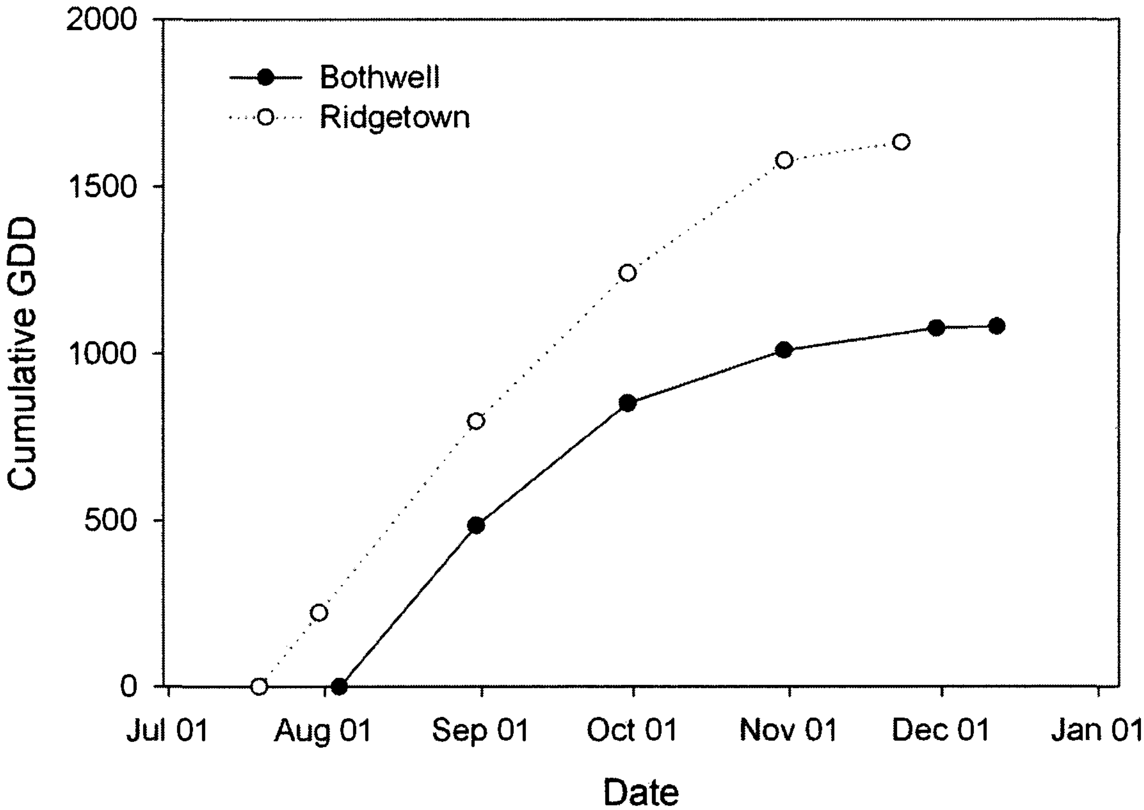


Fig. 2.4. Cumulative growing degree days (GDD base 4.4°C) during the fall cover crop growing season, beginning at cover crop planting and ending at the last cover crop sample date for each site.

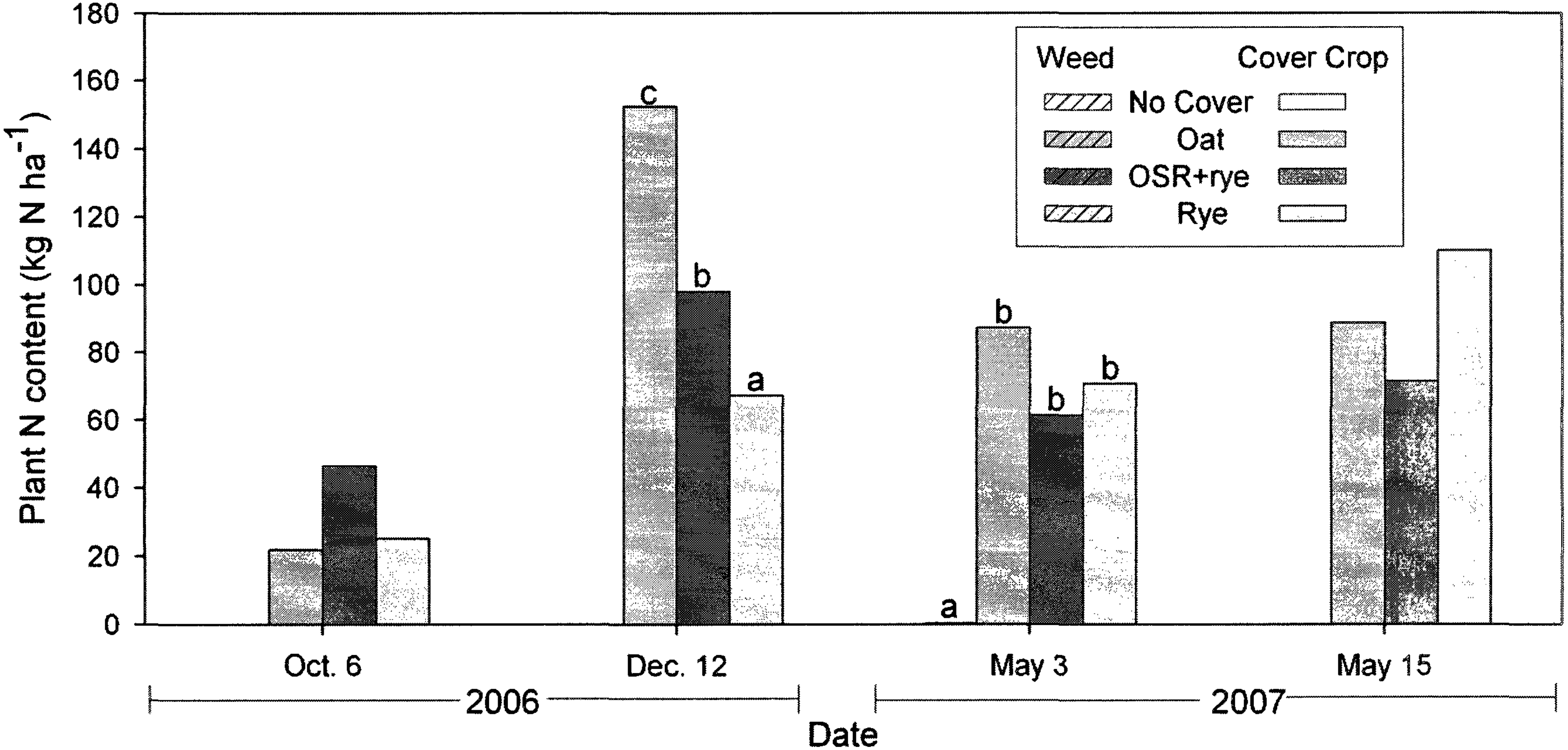


Fig. 2.5. Cover crop and weed aboveground N content at Bothwell. OSR+rye, oilseed radish plus rye. Bars represent N content of cover crops and weeds in each treatment; hashed areas represent weed N content, solid areas represent cover crop N content. For a given date, bars with different letters are significantly different based on Tukey-Kramer means separation (0.05).

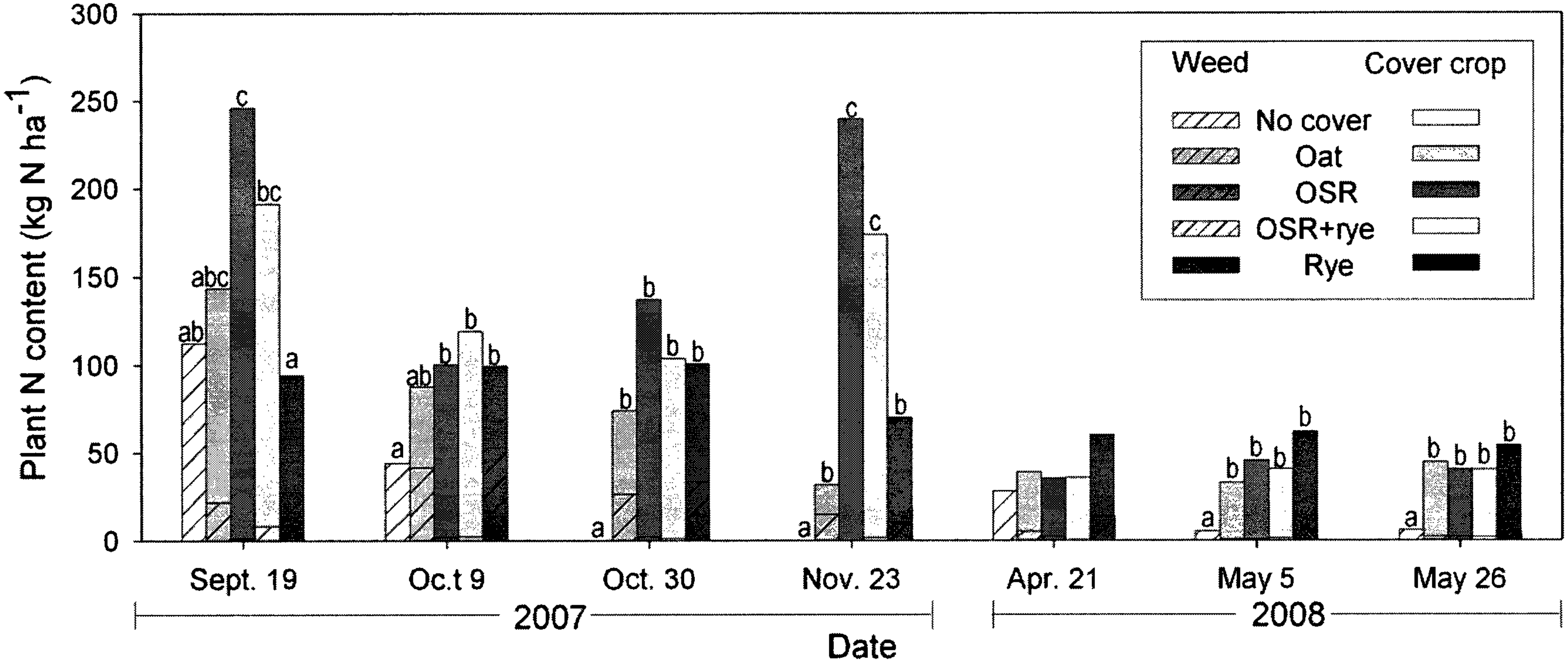


Fig. 2.6. Cover crop and weed aboveground N content at Ridgetown. OSR, oilseed radish; OSR+rye, oilseed radish plus rye. Bars represent N content of cover crops and weeds in each treatment; hashed areas represent weed N content, solid areas represent cover crop N content. For a given date, bars with different letters are significantly different based on Tukey-Kramer means separation (0.05).

CHAPTER 3

WEED POPULATIONS AND SWEET CORN YIELD UNDER WINTER COVER CROP SYSTEMS

3.1. INTRODUCTION

Sweet corn is one of the major field-grown vegetable crops in Canada with over 30,000 ha of land in production, resulting in 250,000 to 300,000 t of corn per year (Pesticide Risk Reduction Program, 2006). Ontario is the largest sweet corn producer in Canada, with approximately 50% of the national acreage and a farm value of $25.5 million in 2007 (Mailvaganam, 2008). It is therefore vital that sweet corn production systems not only optimize returns, but also manage system inputs, such as fertilizer and pesticides, within that system in an efficient manner in order to maximize output. Cover crops are currently being incorporated into many production systems due to their ability to reduce soil erosion and runoff, increase soil aeration, water infiltration and soil organic matter, and improve nutrient cycling (Hartwig and Ammon, 2002; Lu et al., 2000; Snapp et al., 2005). The inclusion of cover crops in a management system may also lead to the suppression of weeds through competition for resources, physical obstruction of weed emergence, and allelopathy/phytotoxicity (Creamer et al., 1996; Curran et al., 1994; Moore et al., 1994).

Numerous studies have examined the ability of cover crops to suppress weeds (Burgos and Talbert, 1996; Galloway and Weston, 1996; Malik et al., 2008; Peachey et al., 2004; Ngouajio and Mennan, 2005; Brennan and Smith, 2005); however, results have varied depending on the cover crop, the following main crop, and the season. Cereals, such as oat, barley and especially rye, are commonly grown cover crops also used for their weed suppression abilities. In sweet corn, rye may reduce weeds by 50 to 99% during early crop growth; however, this effect does not continue throughout the entire corn growing season (Burgos and Talbert, 1996; Galloway and Weston, 1996; Malik et al., 2008). Similarly, in sweet corn, fall-planted cereal cover crops can lower weed biomass in the spring before crop planting (Peachey et al., 2004). In some cases, cereal cover crops can control weeds throughout crop production, such as rye in subsequent cucumber production (Ngouajio and Mennan, 2005) and oat in subsequent sweet corn production in California (Brennan and Smith, 2005). Brassica species, such as OSR and wild radish, may also be effective weed suppressors due to allelopathic effects of the glucosinolates which they produce (Brennan and Smith, 2005). However, this effectiveness may be limited to the fall and spring and not during main crop growth (Malik et al., 2008). Mixtures of cover crops, such as rye and hairy vetch, may also control weeds in sweet corn (Carrera et al., 2004). Mixtures can improve resource capture relative to the monocultures of their respective component crops over both space and time (Fukai and Trenbath, 1993). This improvement in resource capture can increase cover crop biomass production, which in turn can result in a decrease in weed emergence (Mohler and Teasdale, 1993).

Despite the various potential benefits of cover crops, many growers are hesitant to include them in their management systems. This may be due to concerns regarding the potential for cover crops to increase weed pressure in the following crop, harbor unwanted pests and/or make seedbed preparation more difficult in the spring. Growers may also be wary of possible negative effects of cover crops on main crop yield. With additional costs of seeds, spraying and cultivation, there are also concerns over the economic feasibility of incorporating cover crops into their rotation. Due to these possible drawbacks of including cover crops in a production system, it is important to assure growers that cover crops will be effective within their current system. There is currently little data available regarding some of these concerns in Ontario vegetable production, especially the effect of cover crops on weeds in subsequent sweet corn production under normal herbicide regiments. Such information is critical in attracting growers to incorporate cover crops into their current production practices. Consequently, the objective of this study was to determine the impacts of various cover crops on weed dynamics and yield in sweet corn production in Ontario under typical herbicide treatments.

3.2. MATERIALS AND METHODS

3.2.1. Experimental Design

Research was conducted from 2006 to 2007 in a production field near Bothwell, ON (42°66'N latitude, 81°95'W, longitude) and from 2007 to 2008 at the University of Guelph Ridgetown Campus, Ridgetown, ON (42°46'N latitude, 81°89'W, longitude). Soil types were a Brady Loamy Sand (Canada Experimental Farms Services, 1957) and a Brookston Sandy Loam (Anonymous, 1936) (Typic Hapludalfs) at Bothwell and Ridgetown, respectively. The experiment, which was part of a larger study (O'Reilly and Van Eerd, 2008), was a split-plot arrangement in a randomized complete block design with four replications in a pea – cover crop – sweet corn rotation. The main plot factor was winter cover crop type and the split-plot factor was presence (weedy) or absence (non-weedy) of weeds in the sweet corn. The cover crop treatments included a no cover crop control, oat (cv. Manotick), perennial rye (cv. Common #1), OSR (cv. Common #1)

(Ridgetown only), and OSR plus perennial rye (OSR+rye). Due to weed pressure, non-weedy sections were hand hoed from the time of sweet corn emergence (Ridgetown) or 42 days after planting (Bothwell) to harvest; while weedy sections were not hoed. Each main plot was 6 m by 8 m, while each weedy split-plot was three 76 cm rows (2.3 m) wide by 8 m long, and each non-weedy split-plot was five 76 cm rows (3.8 m) wide by 8 m long.

Typical Ontario production practices for peas were followed for seeding rate, pest management, fertilization, and other field management (Table 3.1). Immediately after pea hand harvest samples were collected, the entire trial was sprayed with glyphosate [isopropylamine salt of N-(phosphono- methyl)glycine] at 810 g a.i. ha^{-1}, disked and cultivated prior to cover crop planting. Oat, rye, OSR, and ORS+rye were planted with a drill at rates of 81, 67, 16, and 9+34 kg ha^{-1}, respectively. At Ridgetown, the no cover plots were sprayed with diquat [6,7-dihydrodipyrido (1,2-a:2',1'-c) pyrazinediium dibromide] at 300 g a.i. ha^{-1} and glyphosate at 810 g a.i. ha^{-1} to keep the no cover treatment weed free to study N dynamics (O'Reilly and Van Eerd, 2008). The following spring, to kill the rye cover crops, the entire trial was sprayed with glyphosate at 810 g a.i. ha^{-1}at both sites. The entire trial was disked and cultivated before sweet corn planting. Sweet corn (cv. Temptation) was planted at 59,300 plants ha^{-1}. Plant row and within row spacing was 76.2 and 21.6 cm, respectively. Calcium ammonium nitrate (27-0-0) was hand broadcast applied at 140 kg N ha^{-1} and incorporated. The entire trial was sprayed with nicosulfuron (2-[[(4,6-dimethoxypyrimidin-2-yl)aminocarbonyl]aminosulfonyl]-N,N-dimethyl-3-pyridinecarboxamide) at 25 g a.i. ha^{-1} with nonionic surfactant nonylphenoxy polyethyoxyethanol at 445 mL a.i. ha^{-1} and sodium bentazon [3-(1-

methylethyl)-1H-2, 1,2-benzothiadiazin-4(3H)-one 2,2-dioxide] at 816 g a.i. ha^{-1} at Bothwell and s-metolachlor(+safener) [Acetamide, 2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl]-,(S)] at 1556 g a.i. ha^{-1} and nicosulfuron at 25 g a.i. ha^{-1} with nonylphenoxy polyethyoxyethanol at 445 mL a.i. ha^{-1}

at Ridgetown (Table 3.1). Typical Ontario production practices for sweet corn were followed for fertilization and other field management.

3.2.2. Data Collection

At Bothwell, aboveground biomass of cover crops was collected three times in the fall using one 0.5 m^2 quadrat $plot^{-1}$ and twice in the spring using two 0.5 m^2 quadrats $plot^{-1}$. A spring weed survey, including species count and total weed weight, was completed using two 1 m^2 quadrats $plot^{-1}$. At Ridgetown, aboveground biomass of cover crops and weeds was collected four times in the fall using one 0.5 m^2 quadrat $plot^{-1}$. The following spring, cover crop biomass was collected three times using two 0.5 m^2 quadrats $plot^{-1}$. A spring weed survey, including count and weight by species, was completed using four 0.25 m^2 quadrats $plot^{-1}$. Quadrat size was based on weed density and the crop present. At both locations, weed surveys were conducted in the weedy split-plots using two 0.25 m^2 quadrats split-$plot^{-1}$ at 28 and 56 days after herbicide application (DAT) in the sweet corn crop.

Species richness, *S*, was calculated as the total number of species in each plot. At both sites, monocots were grouped as a species for the spring weed surveys because monocot species were at too early a growth stage for proper identification. Species evenness, *E*, was calculated based on Simpson's dominance index (Simpson, 1949) :

$$E = \left(1/\sum_{i=1}^{S} p_i^2\right)/S \qquad [1]$$

where p_i is the proportional biomass of species i. Species evenness was calculated at the Ridgetown site only for the spring sampling date, as weight by species was not recorded at the Bothwell site.

At sweet corn harvest, 6 m of the center row(s) of each weedy and non-weedy fully fertilized split-plot were hand harvested. At Ridgetown, weedy and non-weedy plots were harvested on the same day; at Bothwell, the weedy plots were harvested three days after the non-weedy plots due to availability of staff required for harvesting. Harvested ears were separated into marketable and non-marketable categories based on a stringent examination of each ear. This involved opening the husk of each ear and examining ear size, kernel development and insect damage. If any insect damage or poor kernel development was found, the ear was considered non-marketable. This was completed due to additional insect research being completed at the sites. Weight and the number of marketable and non-marketable ears were recorded. All plant tissue, including yield, was weighed fresh, dried at 60°C and weighed dry.

3.2.3. Statistical Analyses

Data were analyzed using the GLM procedure of SAS Version 9.1 after testing for normality and homogeneity of variance (SAS Institute, Cary, NC). Data were subjected to ANOVA and means were separated using the Tukey-Kramer adjustment test at the 0.05 probability level. A split-plot analysis was used, where the split-plot factor was date for the cover crop datasets and fall and summer weed datasets and where the split-plot factor was presence of weeds for the yield dataset (Bowley, 1999). A split-plot analysis was not required for the spring weed data because samples were taken on only one date and weedy plots had not yet been split. Non-orthogonal contrasts were also used to analyze the weed population data. This was done to compare between the no cover and the other cover crop treatments, as well as between the OSR treatments and the no cover control and the cereal treatments. These contrasts were selected because OSR has been shown to be effective at reducing weeds (Charles et al., 2006; Stivers-Young, 1998). Outliers were determined using the boxplot method (Tukey, 1977). When outliers were present, they were removed from the analysis only if the results were significantly affected by their removal. All data from each site were analyzed separately due to the differences in treatments, sampling dates, and physical and environmental factors between the two site-years.

3.3. RESULTS AND DISCUSSION

3.3.1. Cover Crop Biomass Production

3.3.1.1. Fall

At Bothwell, cover crop biomass production was affected by cover crop species at both sample dates (Oct., $P = 0.016$; Dec, $P = <0.001$) (Fig. 3.1A). In October, the OSR+rye treatment had higher biomass than the cereals. However, by December, oat and OSR+rye had produced significantly more biomass than rye, which is consistent with the typical slow shoot growth of rye in the fall. Weed biomass was not collected at Bothwell in the fall, therefore, a comparison could not be made between biomass production of the cover crops and the no cover control.

At Ridgetown, cover crop biomass production was also affected by cover crop species at all sample dates (Sept., Oct.9 and Oct. 30, $P = <0.001$; Nov. 23, $P = 0.001$)

(Fig. 3.1B). The OSR+rye and OSR treatments consistently produced more biomass than either oat or rye. The relatively low biomass production for oat and rye in comparison to the OSR treatments, especially in the later sampling dates, may have been due to the high weed pressure at this site in the fall (Fig. 3.2). The high biomass production of the OSR and OSR+rye treatments may have been due to high soil N levels. At the time of cover crop planting, total mineral soil N from the 0-30 cm depth was 22.21 and 106.41 kg N ha^{-1} at Bothwell and Ridgetown, respectively. When fertilized with N, OSR has the potential to produce nearly twice as much biomass as unfertilized plants under the same conditions (Schomberg et al., 2006). A comparison between cover crop and weed biomass production in the cover crop plots and weed biomass in the no cover plots can be made only for the September sample date due to the herbicide applications to the no cover plots in the fall. In September, weed biomass in the no cover plot was 3175.5 kg ha^{-1}, which was no different than the cereal treatments, but lower than the OSR treatments.

Biomass production was generally higher at Ridgetown than at Bothwell. This may be because of the earlier planting date at Ridgetown, which in turn affected the accumulated growing degree days (GDD, base 4.4°C) at each site (Charles et al., 2006; Stivers-Young, 1998). Accumulation of GDD between cover crop planting and the last fall sampling date at Ridgetown (1631 GDD) was higher than at Bothwell (1081 GDD) (Fig. 3.3). Between cover crop planting and the first fall sample date, Ridgetown accumulated 318 more GDD than Bothwell. This, combined with early fall rainfall at Ridgetown (Table 1.1), led to good establishment and quick growth of the cover crops and weeds (Fig. 3.1 & 3.2); whereas at Bothwell, growth was more limited in the early season due to less rain and fewer GDD. It is not uncommon for cover crops to produce varying quantities of biomass between years due to differences in weather, cover crop planting date and cover crop spring kill date (Barberi and Mazzoncini, 2001; Clark et al., 1995).

3.3.1.2. Spring

At Bothwell, cover crop biomass was affected by cover crop species at both sample dates (May 5, $P = 0.010$; May 15, $P = 0.014$) (Fig. 3.4A). In early May, oats had higher biomass than both the OSR+rye and rye treatments. However, by late May rye more than doubled in biomass, resulting in higher biomass in the rye than the OSR+rye treatment. This was due to rye over-wintering and growing in the spring, while oat and OSR were killed by frost in the fall. The rye component of the OSR+rye treatment, however, produced significantly less biomass than the rye treatment and may be the result of the phytotoxic effects of the OSR (Fahey et al., 2001). Other Brassica species have been shown to reduce germination and growth rates of monocots such as barley and oat (Tawaha and Turk, 2003; Turk and Tawaha, 2003). Low rye growth in the spring in the OSR+rye treatment may also be due to lower rye biomass in the fall in the OSR+rye treatments, leading to less rye available for regrowth in the spring. Weed biomass in the no cover treatment was sampled only in early May. At this time, biomass in the no cover treatment was 233 kg ha^{-1}, less than the cover crop treatments ($P = 0.001$).

At Ridgetown, cover crop biomass production was affected by cover crop species at all sample dates (Apr. 21& May 26, $P = 0.003$; May 5, $P = 0.001$) (Fig. 3.4B). The OSR+rye and OSR cover crops had higher biomass than the oat and rye treatments, with the exception of rye and OSR in late May, due to larger quantities of fall biomass that remained on the soil surface in the spring. Biomass from the no cover treatment was collected on May 5, and was lower than in the other cover crop treatments (P = <0.001), indicating that more biomass tissue is present on the soil in the spring under the studied cover crops in comparison to a no cover control.

3.3.2. Effect of Cover Crops on Weed Populations

3.3.2.1. Fall

Weed biomass was not collected in the fall at Bothwell, as this site was located within a commercial production field and weed pressure was very low. The Ridgetown site was previously used for weed research trials, resulting in elevated weed pressure. Weed biomass production was affected by cover crop species at all sample dates (Sept. 19 & Nov. 23, p=0.001; Oct. 9 & 30, p=<0.001) (Fig. 3.2). Weed biomass declined with time for the no cover treatment (Fig. 3.2) because these plots were sprayed with diquat on 25 September 2007 and glyphosate on 17 October 2007. At the first two sample dates, which occurred before the second herbicide application, none of the cover crop treatments resulted in more weed production than the control (P = <0.001). This may suggest that the cover crops do not result in an increased need for fall weed management practices.

Prior to the second herbicide application, the OSR and OSR+rye treatments had 131.3 g m^{-2} less weed biomass than the no cover control (Fig. 3.2). The application of both diquat and glyphosate was required to reduce weed populations in the no cover treatment to levels found in the OSR treatments. Therefore, the use of an OSR cover crop during the fall may prove effective at reducing fall weed spray applications and consequently, may be useful in pesticide-reduction programs.

The OSR treatments had 59 g m^{-2} less weed biomass than the cereal cover crops. Similar results have been found for other Brassica cover crop species (Brennan and Smith, 2005). The effectiveness of OSR and OSR+rye at reducing weeds, in comparison to the other treatments, may be due to the allelopathic effects of glucosinolates and isothiocyanates produced by OSR and/or through the prevention of weed germination due to quick biomass production and canopy development (Brennan and Smith, 2005; Malik et al., 2008). By early October, the OSR treatments had produced significantly more biomass than the cereals (Fig. 3.1); as a result, weed biomass levels in the OSR treatments fell below those in the cereal treatments for the remainder of the fall season (Fig. 3.2). Oilseed radish is a broadleaf species that produces tall plants with large leaves, which grew to nearly one meter in height. With its rapid establishment, it is likely that OSR quickly outcompeted weed species for resources, such as sunlight. Therefore, cover crop treatments including an OSR component are likely more effective at reducing weed biomass production in the fall than the cereal species used in this research.

3.3.2.2. Spring

Dicotyledonous weeds accounted for 99% of the total spring weed population density at both Bothwell and Ridgetown. The dominant species at Bothwell were common chickweed [*Stellaria media* (L.) Vill.], Canada fleabane [*Conyza canadensis* (L.) Cronquist], and henbit (*Lamium amplexicaule* L.). The dominant species at Ridgetown were common ragweed (*Ambrosia artemisiifolia* L.), OSR, and woodsorrel (*Oxalis sp.*). At Ridgetown, OSR set viable seed in the fall, due to the earlier planting date, the lack of an early killing frost and a greater number of GDD compared to Bothwell. This led to a high number of volunteer OSR plants in the spring in the OSR and OSR+rye treatments.

Oilseed radish volunteers were hand-weeded on 7 June 2008 from the weedy and non-weedy sections of these plots, so as not to impede sweet corn growth. At the time of hoeing, OSR volunteer plants ranged from 82 to 684 plants m^{-2}. Oilseed radish, therefore, has the potential to become a weed in the following growing season. Consequently, it is imperative that growers ensure that viable seed is not set in the fall or be prepared to adjust weed management practices the subsequent spring.

At Bothwell, all of the covers reduced total weed biomass compared to the control, but only rye and OSR+rye had lower weed density than the no cover treatment (Table 3.2). In addition, the cover crops, as a group, had lower weed biomass and density than the no cover treatment ($P = 0.001$ and 0.001, respectively). Peachey et al. (2004) also found that cover crops of rye, barley and oats reduced weed biomass in the spring compared to a no cover control. Weed suppression by cover crops in the spring generally tends to be related to cover crop biomass production in the fall (Ngouajio and Mennan, 2005). Decomposing cover crop residue on the soil surface in the spring may provide both phytotoxic and physical obstruction to weed growth. Effects of these decomposing residues include a decrease in soil temperature, a reduction in diurnal temperature fluctuations, and physical obstruction of weed seed germination (Teasedale, 1996). Rye can also affect weed growth and emergence through physical obstruction.

At Bothwell, the no cover treatment had a mean *S* of 2.4, which was higher than that of OSR+rye and rye (Table 3.2). The cover crops, as a group, had lower *S* compared to the no cover treatment, and the OSR treatments had lower *S* than the cereals ($P = 0.001$ and 0.032, respectively). These differences in *S* may be attributed to the strong reduction in weed biomass and density by the cover crops in comparison to the control, where the

OSR+rye and rye treatments reduced weed density to below 1 plant m^{-2}. Species evenness was not calculated for the Bothwell site because weight by species was not possible.

At Ridgetown, cover crops had no effect on weed biomass (Table 3.2; $P = 0.847$). Although, cover crops did not reduce weed density compared to the no cover control, rye had lower weed density than OSR+rye. Also the OSR treatments, as a group, had higher density than the cereals ($P = 0.019$), which was due to the high number of OSR volunteers. Ngouajio and Mennan (2005) also found no effect of cover crops on weed density 13 d before cover crop desiccation in cucumber production. The lack of a cover crop effect on weed biomass at Ridgetown may have been due to high weed pressure. The Ridgetown site was previously used for weed management trials and therefore had a higher weed seed bank than typical production fields. Ridgetown had higher weed density and S than the Bothwell site (Table 3.2). In addition, the no cover plots had considerable weed biomass in the fall, which may have left enough residue on the surface to mimic the weed suppressive effects of the cover crops residues.

Species richness ranged from 4.7 to 5.7 at Ridgetown (Table 3.2), but there were no differences among the treatments, which is consistent with the contrast analyses ($P \geq 0.432$). Rye had higher E than both the OSR and OSR+rye treatments; however, none of the cover crops were different from the no cover control. The relatively low E values indicate that a few species were dominant at Ridgetown even though five species, on average, were present. In the no cover and cereal plots ragweed and woodsorrel were dominant, while in the OSR treatments OSR was also a dominant weed. Consistent with contrasts for other parameters at Ridgetown, there was no difference among the covers as a group or the OSR treatments as a group compared to the no cover control. However, the OSR treatments did have lower E compared to the cereals, due primarily to rye, not oats.

Inconsistencies in cover crop weed suppression between years in the spring have also been reported by others (Barberi and Mazzoncini, 2001; Ngouajio and Mennan, 2005); however Peachey et al. (2004) found results similar to those at Bothwell in two consecutive years. Overall, the differences between the two sites can be largely attributed to the higher weed pressure at Ridgetown. Generally, weed biomass, density, and S were all higher at Ridgetown than Bothwell, indicating a larger quantity and variety of weeds. Also, the high OSR volunteer density in the spring at Ridgetown elevated weed density levels in the OSR and OSR+rye treatments compared to Bothwell, where no OSR volunteers were present. Therefore, under low weed pressure, cover crops, especially those that resume growth in the spring or contain a sterile OSR component, may be effective at reducing weed populations. Although the cover crops tested were ineffective at reducing weed populations under heavy weed pressure in the spring, none of the cover crops led to an increase in weed populations.

3.3.2.3. Sweet Corn

At Bothwell, monocots accounted for 94% of the total summer weed population. The dominant species was long-spined sandbur [*Cenchrus longispinus* (Hack.) Fern.], which accounted for 88% of weeds by dry weight. At Ridgetown, dicots accounted for 81% of the weed population. The dominant species was common ragweed (*Ambrosia artemisiifolia* L.), which accounted for 63% of weeds by dry weight. Dates were pooled for each analysis, except for weed biomass at Bothwell, where there was a significant cover crop x sampling date interaction ($P = 0.041$).

At Bothwell, none of the individual cover crops lowered weed biomass below the no cover control at either sampling date (Table 3.3); however, when the cover crops were grouped together, weed biomass was lower than the control ($P = 0.004$). As well, the OSR treatment did not reduce weed biomass compared to the no cover or the cereal treatments ($P = 0.100$ and 0.058, respectively). There was no difference in density, S or E among the treatments, individually or grouped, with the exception that the cover crops as a group had higher weed density than the no cover due to higher weed density in the rye (Table 3.3; $P = 0.032$).

At Ridgetown, none of the cover crops, individually or grouped, had weed biomass different from the no cover (Table 3.3). However, both oat and rye had significantly higher weed biomass than the OSR+rye treatment and the grouped OSR treatments had lower weed biomass compared to the cereals (Table 3.3; $P = 0.003$). Individually, none of the cover crops effected total weed density compared to one another (Table 3.3). However, the OSR treatments combined were more effective at reducing density than the cereal covers combined ($P = 0.009$). The no cover control had S of 2.3, which was no different than OSR, but lower than the other treatments. As well, the no cover treatment had lower S than all cover treatments grouped and the OSR treatments. Species evenness ranged from 0.3 to 0.5, and oat and rye had lower E than the no cover. In addition, the covers, as a group, had lower E than the no cover, while weed populations were more evenly distributed in the OSR treatments than the cereals.

Similar to this study, others have observed inconsistencies in S reduction among cover crop treatments between years (Ngouajio et al., 2003; and Ngouajio and Mennan, 2005). The differences between sites in this study may be attributed to differences in the number and type of species present. At Bothwell, the weed population consisted almost entirely of one species (long-spined sandbur), while at Ridgetown, more species were present, but one species (common ragweed) dominated the population. In some cases, high *S* may reduce the density of competitive species in a weed population; however, the high density of the one competitive species at Ridgetown as seen by the low *E* ratios, reduces the effects of the changes in *S* (Moonen and Barberi, 2004). Therefore, the differences in *S* between the treatments may be inconsequential at the Ridgetown site.

Although there were some differences in weed biomass among cover crop species, the cover crop treatments did not greatly affect weed biomass or density in either a positive or negative respect compared to the control at either site during the sweet corn growing season (Table 3.3). Similar results have been found in sweet corn at 4 wk (Malik et al., 2008; Peachey et al., 2004) and 8 wk after planting (Galloway and Weston, 1996), and in field corn (Barberi and Mazzoncini, 2001; Johnson et al., 1993). In soybean (*Glycine max* L.), rye was also ineffective at lowering weed density and biomass below the no cover treatment (Koger et al., 2002). However, cover crops have lowered weed biomass below the no cover control in cucumber (Ngouajio and Mennan, 2005) and lettuce (*Lactuca sativa* L.) (Ngouajio et al., 2003); however, these studies involved the use of summer cover crops and therefore may have affected weed populations differently.

Cover crops usually have not provided adequate weed suppression through the entire corn growing season (Barberi and Mazzoncini, 2001; Teasdale, 1996). In fact, tillage may have a greater effect on weed populations than cover crops, as no-till planting produced significantly lower densities for some weeds regardless of cover crop when compared to conventional planting in sweet corn (Peachey et al., 2004). The effectiveness of the OSR treatments compared to the cereals was inconsistent between sites, and although the OSR treatments were more effective than the cereals at Ridgetown, they still did not lower weed populations relative to those in the no cover treatment in the sweet corn growing season. The general lack of difference in performance of the OSR and cereal treatments is consistent with Malik et al. (2008) where, in sweet corn, there was no difference in weed density in wild radish and rye treatments.

Although cover crops did not provide consistent weed reduction during sweet corn growth, none of the cover crop treatments resulted in higher weed populations than the no cover treatment under typical herbicide regimes, if OSR is prevented from setting viable seed. This indicates that fall cover crops may not lead to an increased need for weed management during sweet corn production. Therefore, growers should be able to adhere to their usual weed management regime when including fall cover crops in their sweet corn production system, if viable seeds are controlled.

3.3.3. Effect of Cover Crop and Weed Populations on Sweet Corn Yield

There were no cover crop x weed treatment interactions on sweet corn total or marketable yield. There was no difference among the cover crop treatments in marketable yield at either site (Bothwell, $P = 0.129$; Ridgetown, $P = 0.419$) (Table 3.4). As well, at both sites, all cover crop treatments produced total yields equal to or higher than that of the no cover control (Table 3.4). This general lack of effect of cover crops on sweet corn yield is consistent with other studies (Carrera et al., 2004; Galloway and Weston, 1996; Malik et al., 2008) and is important for demonstrating to growers that, generally, cover crops do not lead to a decrease in yield.

At Bothwell, the weedy and non-weedy treatments had no effect on marketable or total yield ($P = 0.170$ & $P = 0.469$, respectively). This was likely because weed pressure was lower at Bothwell than at Ridgetown and weedy plots were harvested three days after the non-weedy plots, giving time for sweet corn cobs in the weedy plots to mature and increase yields. At the Ridgetown site, weedy and non-weedy plots were harvested on the same day. Here, the non-weedy treatment had higher total and marketable yields than the weedy plots ($P = <0.001$), highlighting the importance of eliminating weeds in sweet corn production.

3.4. SUMMARY AND CONCLUSIONS

The results of this study indicate that, after one crop rotation, the cover crops tested do not pose a need for increased weed management during the sweet corn growing season under typical pesticide programs. In addition, in the fall, cover crops with an OSR component were effective at reducing weed biomass compared to a no cover control. It is possible with long term use of OSR that this cover crop could reduce weed populations in the following year. In a long-term study, rye significantly reduced weed seedbank density, which included weeds with differing germination seasonality, indicating that cover crops may not only effect the weed seedbank species related to the cover crop growing season, but also those related to the corn growing season (Moonen and Barberi, 2004). The objectives of this study were to examine the effects of cover crops on weed populations after one crop rotation. However, long-term studies are needed to assess the effectiveness of OSR at reducing weed populations during sweet corn growth. Cover crops did not result in sweet corn yield losses, nor did they cause any additional weed management issues provided the OSR did not set viable seed. Therefore, cover crops are viable options to include in conventional sweet corn management systems, although the cost-benefits of including cover crops in a cropping system should be taken into account.

Table 3.1. Chronology of field operations and sampling.

Crop Activity	Bothwell	Ridgetown
Pea Crop		
Fertilization	10 May 2006	20 April 2007
Planting	10 May 2006	24 April 2007
Basagran, Assist and Excel Super Application	2 Jun 2006	28 May 2007
Harvest	12 July 2006	29 June 2007
Cover Crop		
Planting	4 Aug. 2006	19 July 2007
Diquat application to no cover plots	--	25 Sept. 2007
Glyphosate application to no cover plots	--	17 Oct. 2007
Cover crop and (weed*) sampling	6 Oct. 2006 12 Dec. 2006 3 May 2007 15 May 207	19 Sept. 2007* 9 Oct. 2007* 30 Oct. 2007* 23 Nov. 2007* 21 Apr. 2008 5 May 2008 26 May 2008
Spring weed survey	3 May 2007	5 May 2008
Glyphosate application (entire trial)	10 May 2007	8 May 2008
Sweet Corn Crop		
S-metolachlor application	--	29 May 2008
Fertilization	25 May 2007	4 June 2008
Planting	28 May 2007	4 June 2008
Nicosulfuron application	19 June 2007	13 June 2008
Sodium bentazon application	26 June 2007	--
Summer weed surveys	23 July, 2007 16 Aug. 2007	11 July 2008 7 Aug. 2008
Weedy sweet corn harvest	13 Aug. 2007	5 Aug. 2008
Non-weedy sweet corn harvest	16 Aug. 2007	5 Aug. 2008

Table 3.2. Weed population parameters in the spring following different cover crops.

	Biomass		Density		Richness (S)‡		Evenness (E)§	
Cover crop	Bothwell	Ridgetown	Bothwell	Ridgetown	Bothwell	Ridgetown	Bothwell	Ridgetown
	------------g m^{-2}-----------		-------plants m^{-2}------					
No cover	23.3 b†	2.3	10.4 b	87.3 ab	2.4 c	5.3	--	0.5 ab
Oat	0.8 a	7.4	1.9 ab	70.0 ab	1.0 bc	4.7	--	0.4 ab
OSR¶	--	2.0	--	80.9 ab	--	5.0	--	0.3 a
OSR+rye	0.3 a	2.3	0.4 a	155.8 b	0.1 a	5.7	--	0.4 a
Rye	0.6 a	1.0	0.5 a	64.8 a	0.3 ab	4.7	--	0.6 b
P value	0.001	0.088	0.006	0.044	0.001	0.899	--	0.020

†Within a column, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

‡ S calculated as the total number of species per plot.

§ E calculated based on Simpson's dominance index [$E = (1/\Sigma_i p_i^2)/S$].

¶OSR, oilseed radish; OSR+rye, oilseed radish plus rye; --, indicates that either no sample was taken (OSR treatment not present at Bothwell) or that E was not calculated because it was not possible to take weights by species at Bothwell.

Table 3.3. Weed population parameters in sweet corn following different cover crops.

	Biomass			Density		Richness (S)‡		Evenness (E)§	
Cover crop	Bothwell		Ridgetown	Bothwell	Ridgetown	Bothwell	Ridgetown	Bothwell	Ridgetown
	28 DAT¶	56 DAT							
	------------------g m^{-2}------------------			--------plants m^{-2}--------					
No cover	62.6 ab†	59.5 ab	66.1 ab	12.2	33.6	1.6	2.3 a	0.9	0.5 b
Oat	63.9 ab	242.5 b	77.4 b	12.1	37.8	1.3	3.6 b	0.8	0.3 a
OSR	--	--	55.0 ab	--	21.1	--	3.2 ab	--	0.4 ab
OSR+rye	37.1 a	194.6 b	44.1 a	20.6	28.3	1.3	3.4 b	0.9	0.4 ab
Rye	61.1 ab	222.9 b	77.6 b	33.2	46.1	1.6	4.0 b	0.8	0.3 a
P value	0.041		0.027	0.293	0.066	0.316	0.002	0.777	0.012

†Within a column, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05), except for weed biomass at Bothwell where means are compared between both columns because of a date by cover crop interaction.

‡ S calculated as the total number of species per plot.

§ E calculated based on Simpson's dominance index [$E = (1/\Sigma\, p_i^2)/S$].

¶DAT, days after herbicide treatment; OSR, oilseed radish; OSR+rye, oilseed radish plus rye.

Table 3.4. Total and marketable sweet corn yield as affected by cover crop and weed treatments.

	Total yield		Marketable yield	
	Bothwell	Ridgetown	Bothwell	Ridgetown
	t ha^{-1}			
	Cover crop treatment			
No cover	12.0 a†	24.4	8.5	5.2
Oat	15.5 b	23.2	12.4	6.7
OSR‡	--	30.1	--	7.5
OSR+rye	13.0 a	29.0	9.4	7.9
Rye	13.1 ab	29.2	9.0	14.7
P value	0.017	0.103	0.129	0.419
	Weed treatment			
Weedy	13.2	15.9 a	10.3	3.0 a
Non-weedy	13.8	45.9 b	9.1	19.6 b
P value	0.469	<0.001	0.170	<0.001

†Within a column, for a given treatment group, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

‡ OSR, oilseed radish; OSR+rye, oilseed radish plus rye.

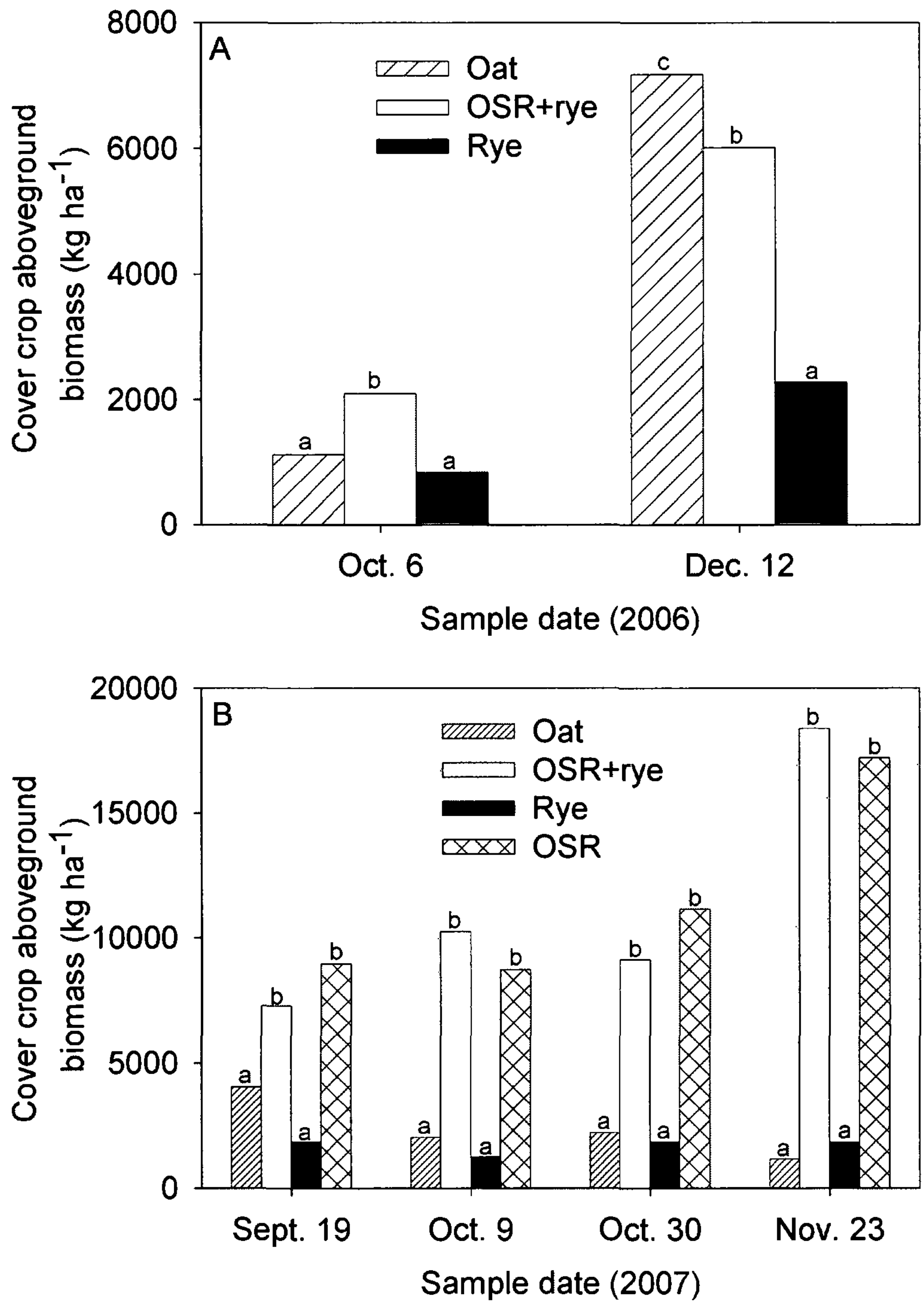


Fig. 3.1. Fall cover crop aboveground biomass dry weight at Bothwell (A) and Ridgetown (B). At each date, bars with different letters are significantly different based on Tukey-Kramer means separation (0.05).OSR, oilseed radish; OSR+rye, oilseed radish plus rye.

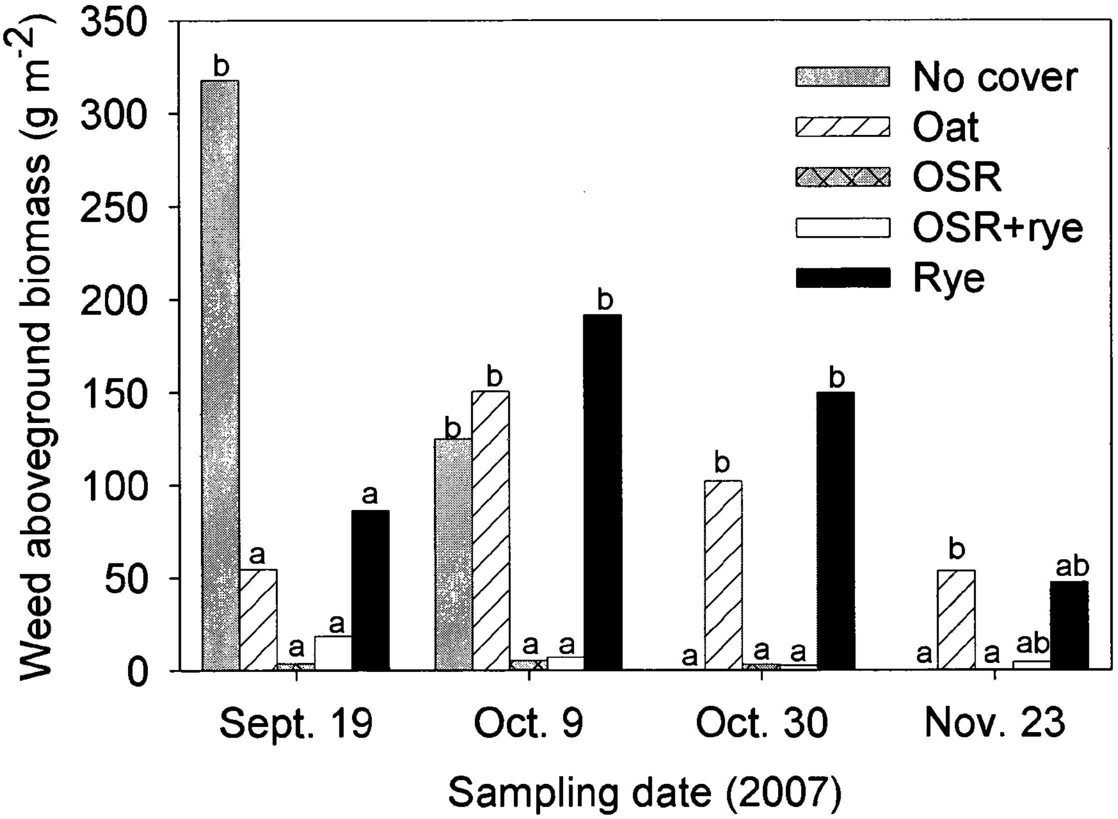


Fig. 3.2. Fall weed aboveground biomass dry weight at Ridgetown. For each date, bars with different letters are significantly different based on Tukey-Kramer means separation (0.05). OSR, oilseed radish; OSR+rye, oilseed radish plus rye.

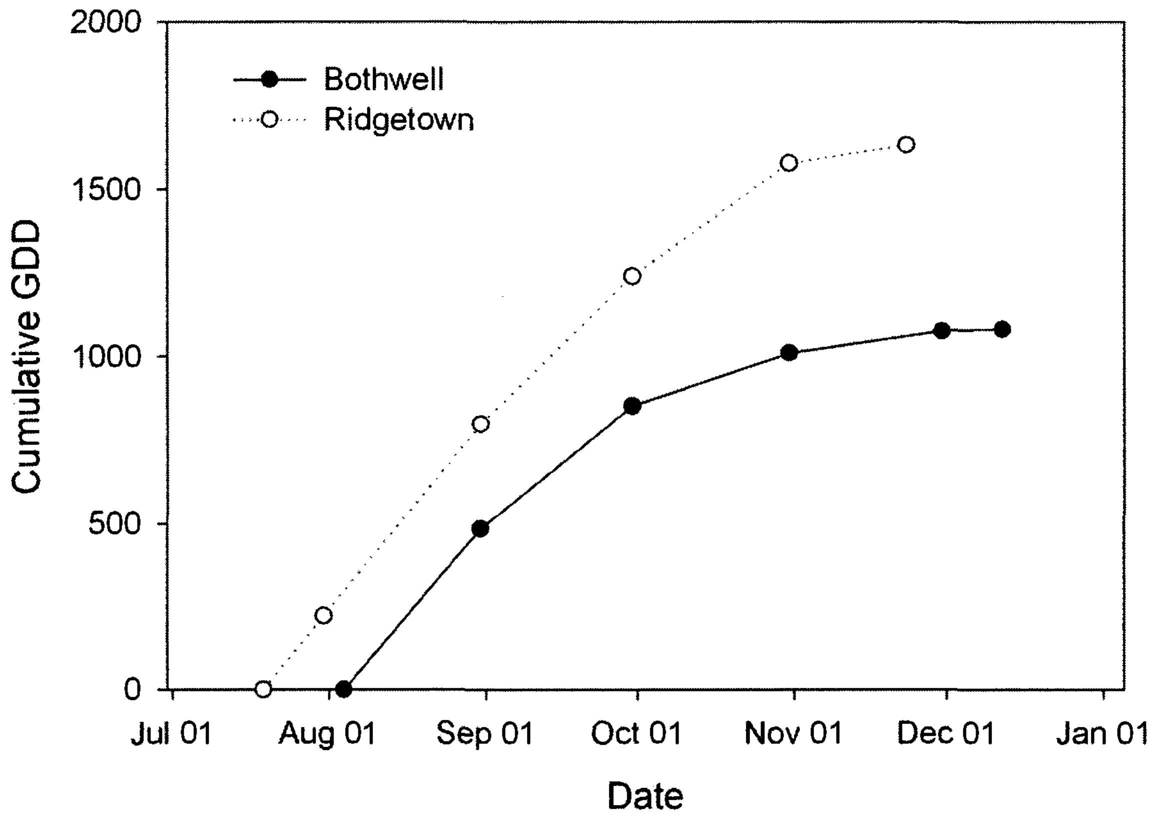
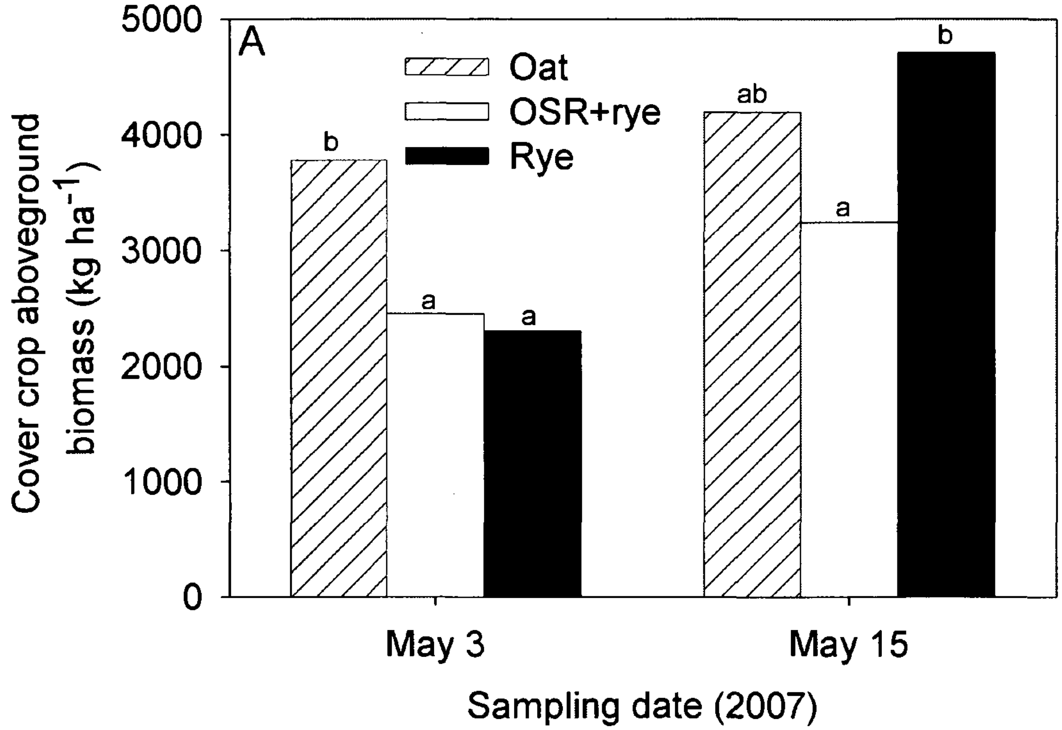


Fig. 3.3. Cumulative growing degree days (GDD base 4.4°C) during the fall cover crop growing season, beginning at cover crop planting and ending at the last cover crop sample date for each site.



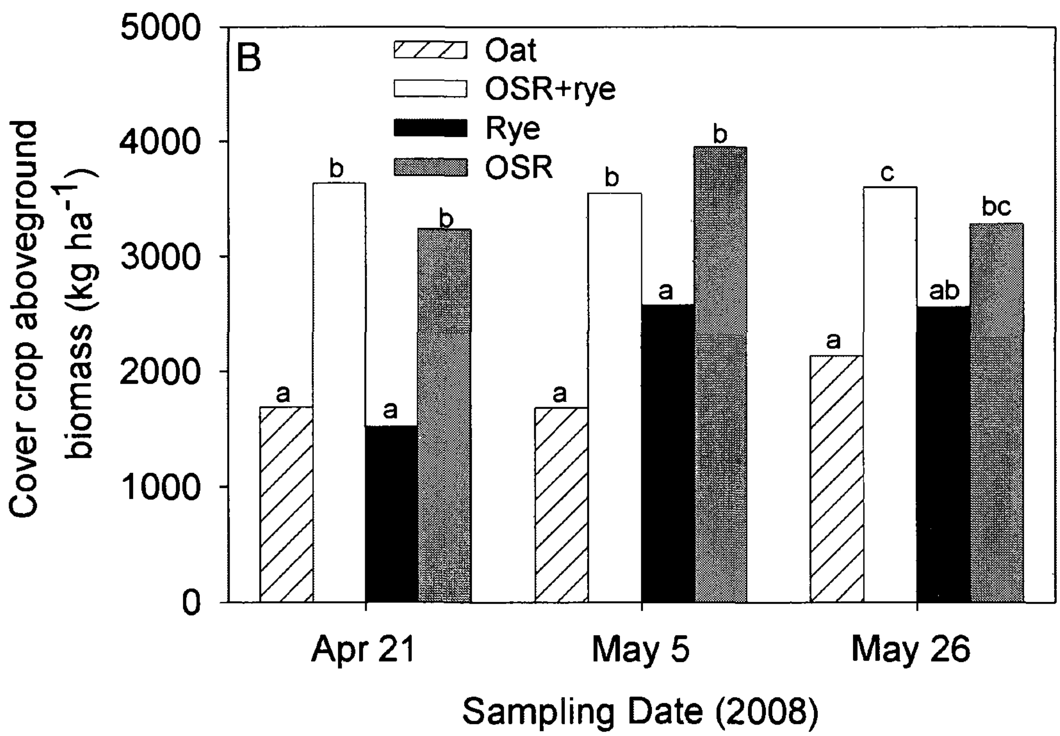


Fig. 3.4. Spring cover crop aboveground biomass dry weight at Bothwell (A) and Ridgetown (B). For each date, bars with different letters are significantly different based on Tukey-Kramer means separation (0.05). OSR, oilseed radish.

CHAPTER 4

INTERACTIONS OF NITROGEN FERLIZATION AND WEED PRESSURE ON SWEET CORN PRODUCTION

4.1. INTRODUCTION

In fresh market production, the sweet corn crop requires high quantities of N throughout the growing season for the production of corn with long ears and long, dark green husks that many consumers desire (Swiader and Ware, 2002). In Ontario, the recommended application rate of N is 90 kg N ha^{-1} (OMAFRA, 2008). However, broadcast application of N in the spring for sweet corn production may also effect the germination, emergence and growth of weeds common in agricultural fields (Sweeney et al., 2008). Some weeds can consume large quantities of N and weed growth can be greatly enhanced by high soil mineral N, which can influence crop-weed competitive interactions (Blackshaw et al., 2003; Blackshaw and Brandt, 2008). Thus, the application of N fertilizer may unintentionally result in increased growth and competitiveness of weeds instead of the main crop (Blackshaw and Brandt, 2008). Therefore, the objective of this study was to investigate the response of weed growth to N fertilizer application in sweet corn production, and the subsequent effects on sweet corn yield and the N budget at sweet corn harvest.

4.2. MATERIALS AND METHODS

4.2.1. Experimental Design

For the purpose of this experiment, data were used from only the no cover treatments from the larger cover crop study, to negate the effects of cover crops on weed populations. As well, only data acquired at the harvest sample dates were used in this analysis. For detailed descriptions of soil and crop measurements and weed collection information please refer to the Materials and Methods section of Chapter 2 and Chapter 3, respectively.

4.2.2. Statistical Analyses

Data were analyzed using the MIXED procedure of SAS Version 9.1 after testing for homogeneity of variance (SAS Institute, Cary, NC). Means were separated using the Tukey-Kramer adjustment test at the 0.05 probability level. A split-plot analysis was used in the N budget and yield analyses, where N rate was the split-plot factor (Bowley, 1999). A split-plot analysis was not required for the weed analyses as weed populations were not measured in the non-weedy plots. Outliers were determined using the boxplot method (Tukey, 1977). When outliers were present, they were removed from the analysis only if the results were significantly affected by their removal. All data from each site were analyzed separately due to the differences in treatments, sampling dates, and physical and environmental factors between the two site-years.

4.3. RESULTS AND DISCUSSION

4.3.1. Weed Populations at Harvest

Nitrogen fertilization had no effect on weed biomass, density, *S* or *E* at harvest at either site (Table 4.1). The effect of N fertilizer application on weed emergence and growth can be variable. Charles et al. (2006) also found no significant effect of N fertilizer rate in no cover treatments on total weed biomass and density, weed species composition or *S*. Although Sweeney et al. (2008) found that several weed species were affected by N fertilization when weed seeds were hand sown; most of the same species grown from the natural seed bank were unaffected by increasing rates of N. Several other studies, as documented by Sweeney et al. (2008) have also shown variable effects of N rates on common weeds.

The lack of effect of N rate on weed populations seen in this study may be due to several factors. First, the response of weed growth to N application is species specific (Blackshaw et al., 2003). Although, most species increase in shoot growth with increasing N application, the response varies with species, with some, such as common groundsel (*Senecio vulgaris* L.) and Persian darnel (*Lolium persicum* Boiss. & Hohen. ex Boiss), resulting in very little increased growth. Long-spined sandbur and common ragweed were the dominant species during the sweet corn growing season at the Bothwell and Ridgetown sites, respectively. It is possible that these two species also exhibit low growth responses to N; however, no work could be found on the effect of N on these two specific species. In conjunction with this, it is possible that soil N levels prior to sweet corn fertilization were high enough for optimal growth of these weeds. At Bothwell and Ridgetown, respectively, total mineral N in the top 60 cm in the unfertilized plots was 77.7 and 90 kg N ha^{-1}. Therefore, the additional fertilizer N may have had no increased effect.

Second, emergence of weeds is affected by several factors including soil temperature and moisture, light and N (Sweeney et al., 2008). The effects and interactions of these different factors may result in differing N stimulus effects. Native seed banks have a wide variety of dormancy states and seed exposure to light from tillage prior to sweet corn planting may have resulted in a response that negated the effect of N fertilizer application (Sweeney et al., 2008).

Third, timing of N fertilization may also affect weed emergence. Although application of fertilizer in the early spring (April) may result in increased emergence, this may not be the case when applied later in the season because the seed may have already responded to other environmental cues, or N may already be in greater supply due high rates of mineralization and nitrification under the warm moist late spring conditions (Sweeney et al., 2008).

4.3.2. Nitrogen Budget

There were no N x weed treatment interactions in the N budget analysis at either site. At Bothwell, N treatment had a significant effect on the N budget at sweet corn harvest (Table 4.2). The 140N treatment had higher soil, shoot, cob and total N than the 0N treatment. This is generally consistent with the effect of N treatment on these parameters in the Chapter 2 analyses (Tables 2.14 & 2.18) and are consistent with other research (Mullins et al., 1999; Ayoub et al., 1995; Mooleki et al., 2004). Nitrogen treatment did not, however, affect weed N. This is likely because fertilization did not result in significantly more weed biomass than the unfertilized treatment, which is an important factor in plant N uptake (Wagger, 1989) and indicates a lack of response by long-spined sandbur to N which is a weed commonly found in low fertility soils.

Although numerically higher, the non-weedy treatment did not result in significantly higher soil, shoot or total N available at sweet corn harvest at Bothwell compared to the weedy treatment (Table 4.2). Dyck et al. (1995) found that lambsquarters (*Chenopodium album* L.) reduced soil mineral N under sweet corn at 56 days after planting. Significant differences like those found by Dyck et al. (1995) and at Ridgetown may not have been seen at Bothwell because of its relatively low weed biomass production. At Ridgetown, weeds produced a mean of 61.3 g m^{-2} more weed biomass than at Bothwell, while weed densities observed by Dyck et al. (1995) were a mean of 45 more plants m^{-2} at harvest than at Bothwell. Therefore, there may not have been enough weed biomass at Bothwell to immobilize sufficient N to significantly affect soil N or corn shoot N levels. In contrast, at Bothwell, the non-weedy treatment had 42% more N in the corn cob than the weedy treatment. This may be because N that would otherwise have been available to be taken up by the sweet corn plants in the non-weedy treatment was taken up by weeds in the weedy treatment. There was more weed N in the weedy treatments than the non-weedy treatments, which is consistent with the fact that the non-weedy treatments were kept weed free throughout the sweet corn growing season. Despite these differences, total N available was not different in the budget at harvest between the weedy and non-weedy treatments.

Unlike at Bothwell, N fertilization had little effect on the N budget at Ridgetown (Table 4.2). Differences between the two N treatments were only seen in soil N. The lack of significant effects of N treatment on sweet corn N levels were unexpected as fertilization was found to significantly increase sweet corn N use at harvest in Chapter 2 analyses (Table 2.14). However, N levels were numerically higher under the 140N treatment than the 0N for all parameters, and significant differences may not have been seen due to the small sample size used in this analysis. Total N available in the budget at harvest was 170.4 and 271.6 kg N ha^{-1} in the 0N and 140 N treatments, respectively.

Weed treatment at Ridgetown affected the N budget at harvest (Table 4.2). The non-weedy treatment had higher soil, corn and total N levels than the weedy treatment. Higher soil N in the non-weedy treatments is consistent with other literature (Dyck et al., 1995). As well, the 36% decrease in corn shoot N under the weedy treatment is consistent with the 35-47% decrease observed by Dyck et al. (1995). These differences are likely due to the high weed biomass production (173.0 g m^{-2}) at this site. Total N available in the budget at harvest was 182.3 and 253.8 kg N ha^{-1} in the weedy and non-weedy treatments, respectively.

4.3.3. Sweet Corn Yields

There were no N x weed treatment interactions in the sweet corn yield analysis at either site. At Bothwell, N treatment affected total yields; however, marketable yields were unaffected (Table 4.3). Nitrogen treatment had no effect on sweet corn yields at Ridgetown (Table 4.3). The lack of N response at Ridgetown was unexpected because the 140N treatment typically had higher yields than the 0N treatment in other analyses (Table 2.13) and most research indicates a positive N-yield response (Burket et al., 1997; Cline and Silvernail, 2002; Griffin et al., 2000; Mullins et al., 1999; Teasdale et al., 2008). However, high soil mineral N levels at Ridgetown may have resulted in the unfertilized plots having sufficient N for maximum yields, resulting in no N effect. The lack of effect of N treatment on yield in this analysis at Ridgetown and in marketable yields at Bothwell, may be due to the relatively low sample size. In order the omit any cover crops effects on weed populations in sweet corn, yield data was analyzed from the four no cover plots only. Therefore, variability in yield between N treatments observed in the larger cover crop study may not have been well displayed. However, in Chapter 2, no difference was seen in marketable yield between N treatments at Ridgetown.

At Bothwell, weed treatment had no effect on yields (Table 4.3). Similar to analyses in Chapter 3, this is likely because weedy plots were harvested three days after the non-weedy plots, giving time for sweet corn cobs in the weedy plots to mature and increase yields. At Ridgetown, where weedy and non-weedy plots were harvested on the same day, the non-weedy treatment had higher yields than the weedy treatment. This is also consistent with Chapter 3 analyses.

At Bothwell, weedy plots did not affect N budget or yield values. This is likely due two reasons i) not enough weed biomass was produced at this site to negatively affect N availability to the sweet corn plants, and ii) differences in harvest dates between weed treatments allowed for increased cob maturation in weedy plots. However, at Ridgetown, the weedy treatment produced higher biomass which led to a negative effect on N availability to the sweet corn and because sweet corn was harvested on the same day for both weed treatments, the weedy treatments also reduced yield.

4.4. SUMMARY AND CONCLUSIONS

Weed populations were unaffected by N fertilization in this study. This information, combined with other research, suggests that the influence of N fertilization on weed populations is likely site specific and strongly affected by composition of the natural seedbank and cultural practices at the site. There were no N treatment by weed treatment interactions in either the N budget or yield analyses at both sites, indicating that in a system where N application has no effect on weed populations, weediness and fertilization influence sweet corn production independently. Initial soil N levels and weed biomass production were the most important factors which affected the influence of fertilization and weed presence on N within the system. Thus, the individual and combined effects of weed and N fertilization on sweet corn are dependent on individual site characteristics and cultural practices.

Table 4.1. Weed population parameters in the spring.

	Biomass		Density		S‡		E§	
Cover crop	Bothwell†	Ridgetown	Bothwell	Ridgetown	Bothwell	Ridgetown	Bothwell	Ridgetown
	------------g m^{-2}-----------		----------plants m^{-2}---------					
0N¶	163.8	148.0	16.7	19.7	2.5	3.1	0.7	0.4
140N	59.5	198.0	10.4	29.5	1.4	2.2	0.9	0.5
P value	0.081	0.190	0.247	0.385	0.096	0.095	0.086	0.144

†Within a column, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

‡ S calculated as the total number of species per plot.

§ E calculated based on Simpson's dominance index [$E = (1/\Sigma_i p_i^2)/S$].

¶ 0N, no fertilizer; 140N, 140 kg N ha^{-1} pre-plant broadcast incorporated calcium ammonium nitrate.

Table 4.2. Nitrogen budget at sweet corn harvest.

	N treatment			Weed treatment		
	0N†	140N	*P* value	Weedy	Non-weedy	*P* value
	-------- kg N ha^{-1} ------			-------- kg N ha^{-1} ------		
		Bothwell			Bothwell	
Soil N‡	87.6 a§	190.5 b	0.036	119.0	140.3	0.414
Corn shoot N	34.8 a	51.7 b	0.036	39.9	45.2	0.208
Corn cob N	19.6 a	44.9 b	0.012	22.6 a	38.8 b	0.001
Weed N	3.9	2.0	0.060	21.6 b	0.0 a	<0.001
Total N	168.3 a	300.2 b	0.022	221.7	227.8	0.782
		Ridgetown			Ridgetown	
Soil N	53.1 a	105.9 b	0.030	70.2 a	80.1 b	0.010
Corn shoot N	37.8	45.2	0.430	33.1 a	51.6 b	0.024
Corn cob N	45.9	69.9	0.102	27.7 a	115.9 b	<0.001
Weed N	3.8	5.3	0.078	48.8 b	0.0 a	<0.001
Total N	170.4	271.6	0.088	182.3 a	253.8 b	0.011

†0N, no fertilizer; 140N, 140 kg N ha^{-1} pre-plant broadcast incorporated calcium ammonium nitrate.

‡Total mineral soil N from 0-60 cm.

§ Within a row, for a given treatment group, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

Table 4.3. Total and marketable sweet corn yield.

	Total yield		Marketable yield	
	Bothwell†	Ridgetown	Bothwell	Ridgetown
	---------------------------t ha^{-1} ---------------------------			
		N treatment		
0N‡	6.6 a	23.2	4.5	13.8
140N	12.0 b	28.6	8.8	9.9
P Value	0.017	0.075	0.186	0.254
		Weed treatment		
Weedy	9.2	11.5 a	6.7	2.5 a
Non-weedy	9.4	40.3 b	6.6	21.1 b
P value	0.703	<0.001	0.904	0.001

†Within a column, for a given treatment group, means followed by different letters are significantly different based on Tukey-Kramer means separation (0.05).

‡0N, no fertilizer; 140N, 140 kg N ha^{-1} pre-plant broadcast incorporated calcium ammonium nitrate.

CHAPTER 5

GENERAL SUMMARY AND CONCLUSIONS

In the N dynamics study, the cover crops increased PAN over the fall and spring in comparison to the no cover control at Bothwell, indicating that they are capable of reducing N loss during otherwise fallow periods. At Ridgetown, the cover crops did not affect PAN relative to the control in either the fall or spring. Differences between the two sites in the cover crops' effectiveness at increasing PAN may have been due to precipitation, as rainfall was higher during cover crop growth at Bothwell than Ridgetown. Ridgetown may not have received enough rainfall to lead to adequate leaching or denitrification losses to take place for the cover crops to have a positive effect. Despite this, the cover crops were generally ineffective at increasing PAN during sweet corn growth. The absence of effect of cover crops on sweet corn PAN is likely due to a lack of synchrony between cover crop mineralization and N demand in the sweet corn. Alternatively, immobilization of N may have resulted in a decrease in PAN over the sweet corn growing season through preemptive competition. Although the cover crops were effective at conserving N over the otherwise fallow periods and did not affect sweet corn yields, the covers did not provide an N credit to the following sweet corn crop. This suggests that including these cover crops into a rotation is unlikely to decrease the need for inorganic N fertilizer applications to subsequent sweet corn crops.

In the weed dynamics study, OSR cover crops were more effective at reducing weed biomass in the fall cover crop growing season compared to both cereal cover crops and in Ridgetown provided similar weed control as a no cover treatment with two herbicide applications. This indicates that fall OSR cover crops may be useful in pesticide-reduction programs. It is also possible that long term OSR cover crop use may reduce weeds during the growth of the following main crop; however, long term studies are needed to assess this possibility. Although not able to reduce weed populations throughout the sweet corn growing season, after one rotation, cover crops did not necessitate increased weed management, provided the OSR did not set viable seed. Nor did the cover crops result in sweet corn yield losses. Therefore, OSR may prove useful in pesticide-reduction programs if properly controlled and weed management should not be a limitation for growers if cover crops are incorporated into a sweet corn rotation. Mowing or tillage in the fall may be required to prevent OSR from setting viable seed. According to 2006 prices, it is estimated that mowing or tilling OSR to prevent seed production would cost the farmer an additional 109-149 \$ ha^{-1} for expenditure on machinery operations (Fletcher, 2007).

In the N fertilization and weed interaction study, N fertilization did not affect weed populations, suggesting that composition of the natural seedbank and cultural practices at the site are the major influences on weed populations. At both sites, there were no interactions between N and weed treatments in either the N budget or yield analyses. This indicates that weediness and fertilization influence sweet corn production independently. The influence of fertilization and weed presence on N within the system was most strongly affected by soil N levels and weed biomass production. Consequently, the individual and combined effects of weed and N fertilization on sweet corn are dependent on individual site characteristics and cultural practices.

All three of the hypotheses developed for this study were therefore rejected. The first hypothesis - cover crops will increase plant available N over the cover crop – sweet corn rotation - was rejected on the basis that PAN was not higher under the cover crop treatments for the entire growing season at either site. The second hypothesis - cover crops will reduce weed biomass and density during the cover crop – sweet corn rotation - was rejected on the basis that weed biomass and density was not consistently reduced by cover crops at either site during the entire rotation. Finally, the third hypothesis - weed control and N fertilization will lead to a discernable increase in plant available N at sweet corn harvest – was rejected because neither N fertilization or weed control resulted in increased PAN at sweet corn harvest consistently at both sites.

Cover crops have the potential to provide many benefits to an agronomic system; however, different cover crops are more suited to providing certain benefits than others and the ability of these covers to provide the intended benefits is often dependent on individual site characteristics, site-specific cultural practices and variation in climatic conditions. Therefore, it is difficult to recommend the cover crops in this study to growers on the basis of successful N dynamics or weed control without more evidence of under which circumstances they are consistently effective.

Consequently, in conjunction with this study, future research should incorporate different variables, such as soils, weather patterns, N fertilization rates, time of N application and cover crop desiccation and incorporation timing in order to account for the environmental and cultural variability found in Ontario vegetable production. This information will better assist in using cover crops to improve N use and weed control best management practices.

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APPENDIX A

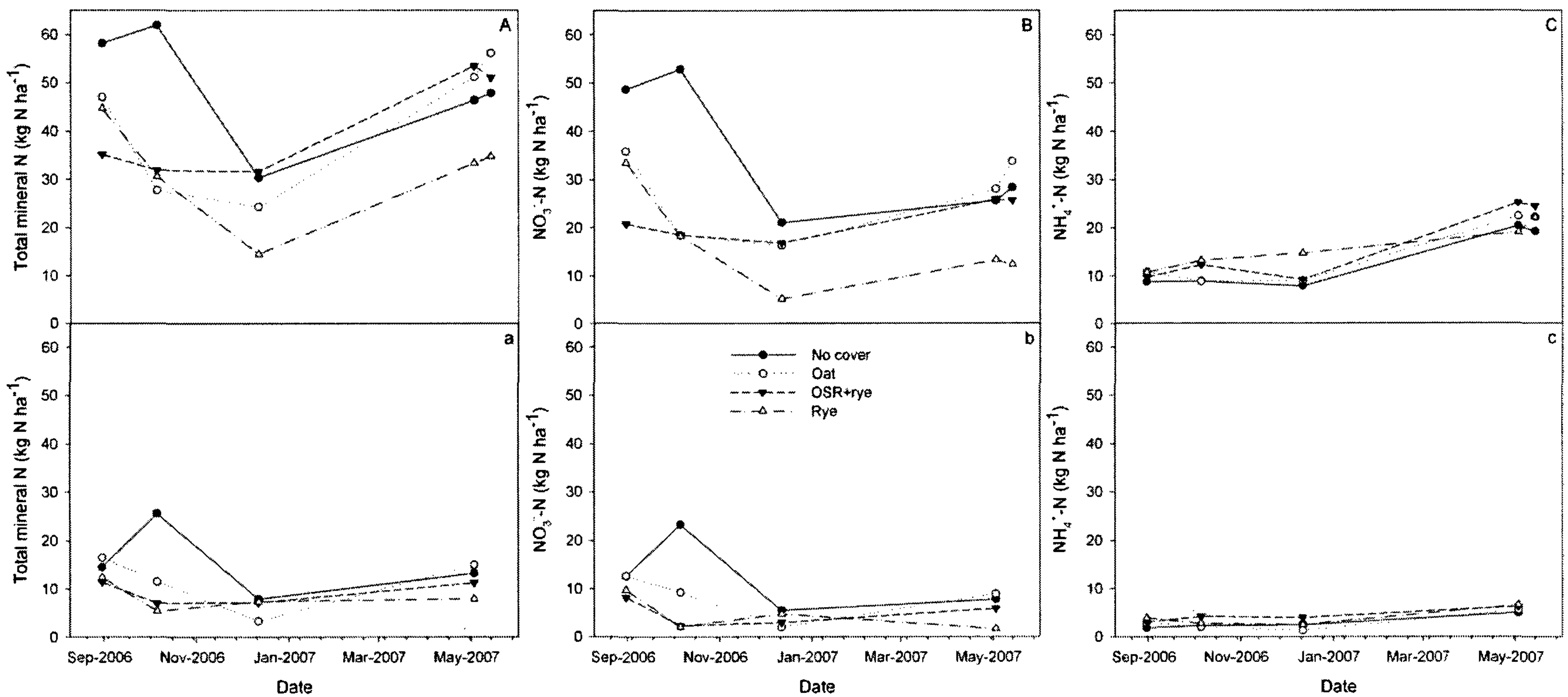
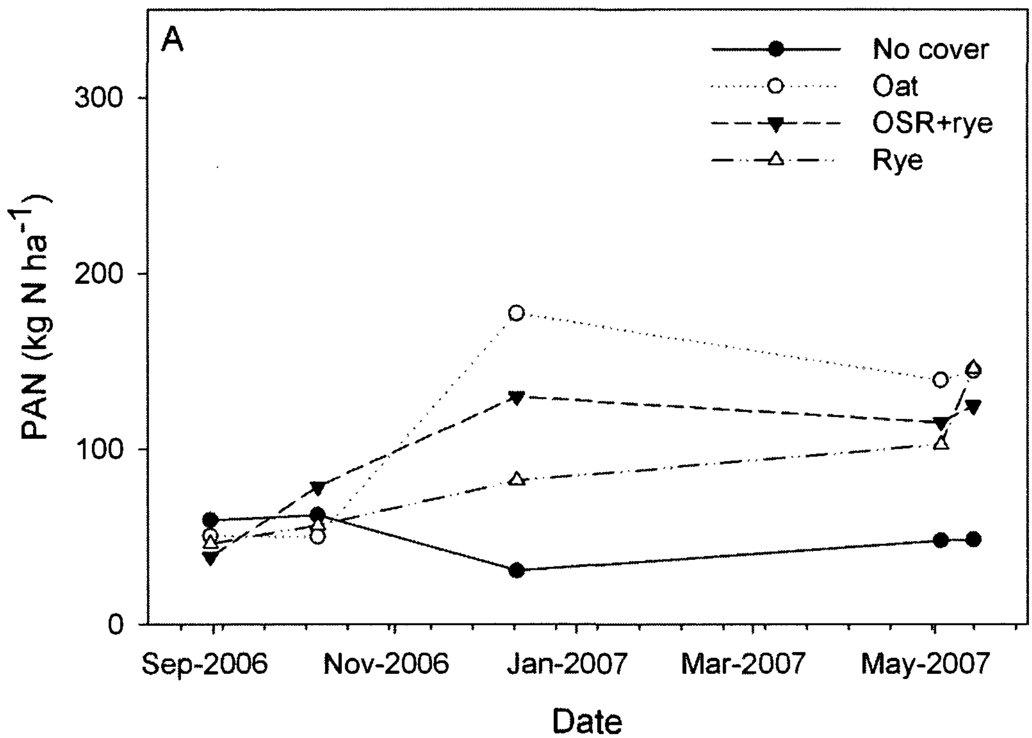


Fig. A.1. Soil total mineral N (A), NO_3^--N (B), and NH_4^+-N (C) from 0-60 cm (uppercase) and 60-90 cm (lower case) during the cover crop growing season at Bothwell. OSR+rye, oilseed radish plus rye.



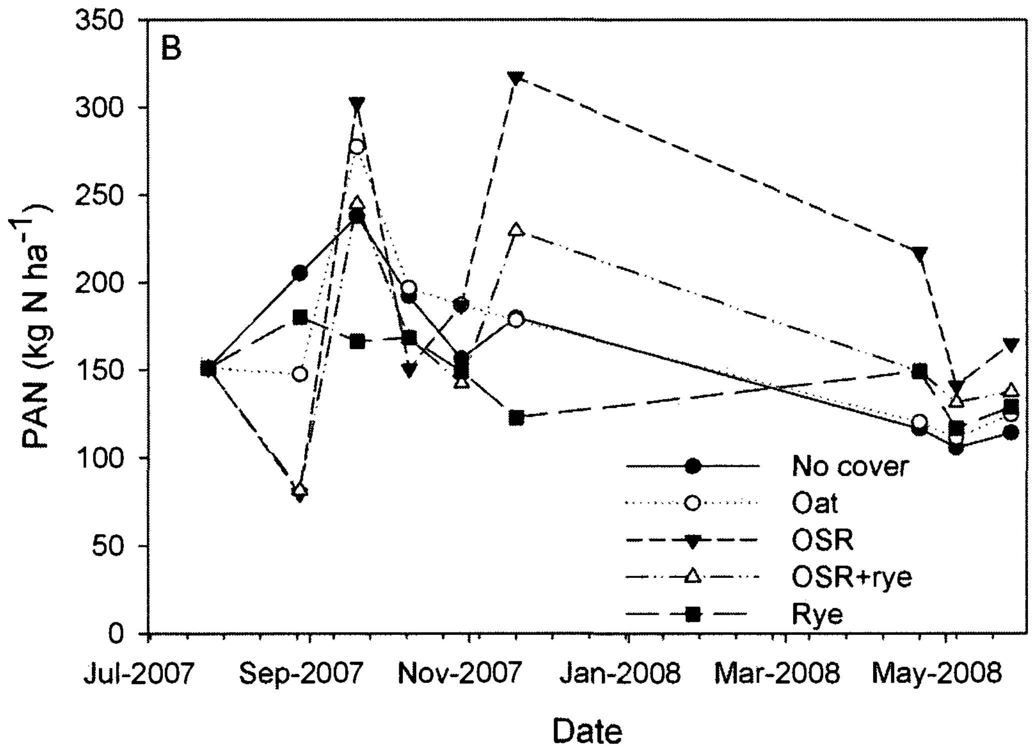


Fig. A.2. Plant available N (PAN) during the cover crop growing season at Bothwell (A) and Ridgetown (B). OSR, oilseed radish; OSR+rye, oilseed radish plus rye.

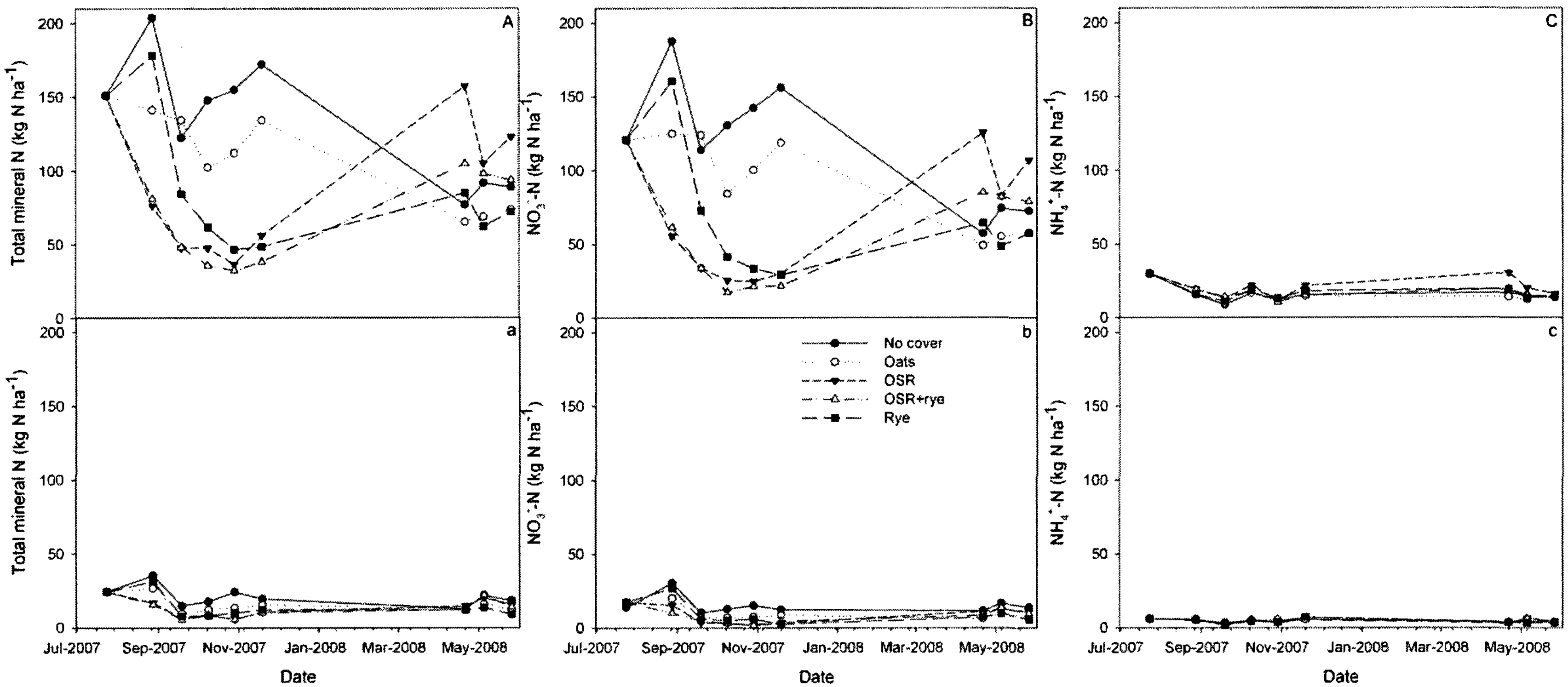


Fig. A.3. Soil total mineral N (A), NO_3^--N (B), and NH_4^+-N (C) from 0-60 cm (uppercase) and 60-90 cm (lower case) during the cover crop growing season at Ridgetown. OSR, oilseed radish; OSR+rye, oilseed radish plus rye.

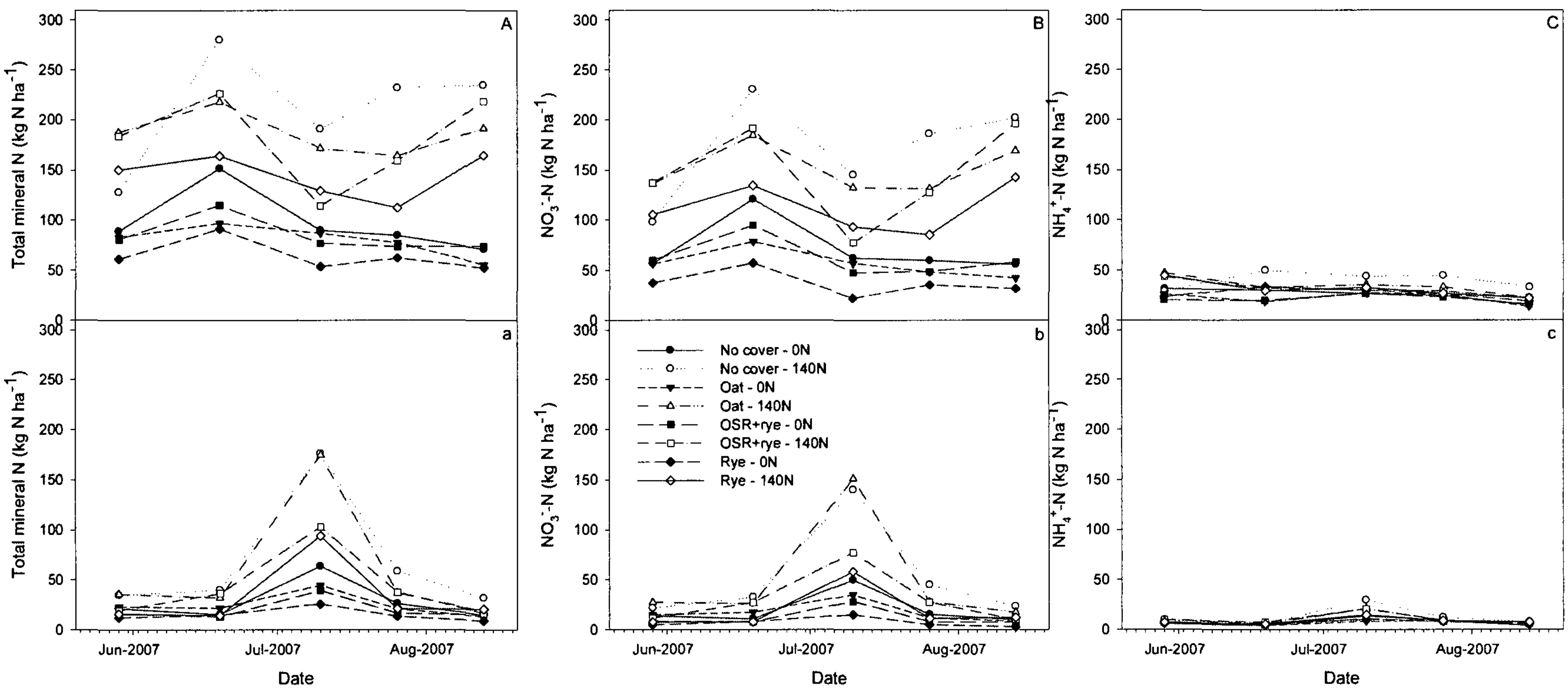


Fig. A.4. Soil total mineral N (A), NO_3^--N (B), and NH_4^+-N (C) from 0-60 cm (uppercase) and 60-90 cm (lower case) during the sweet corn growing season at Bothwell. OSR+rye, oilseed radish plus rye.

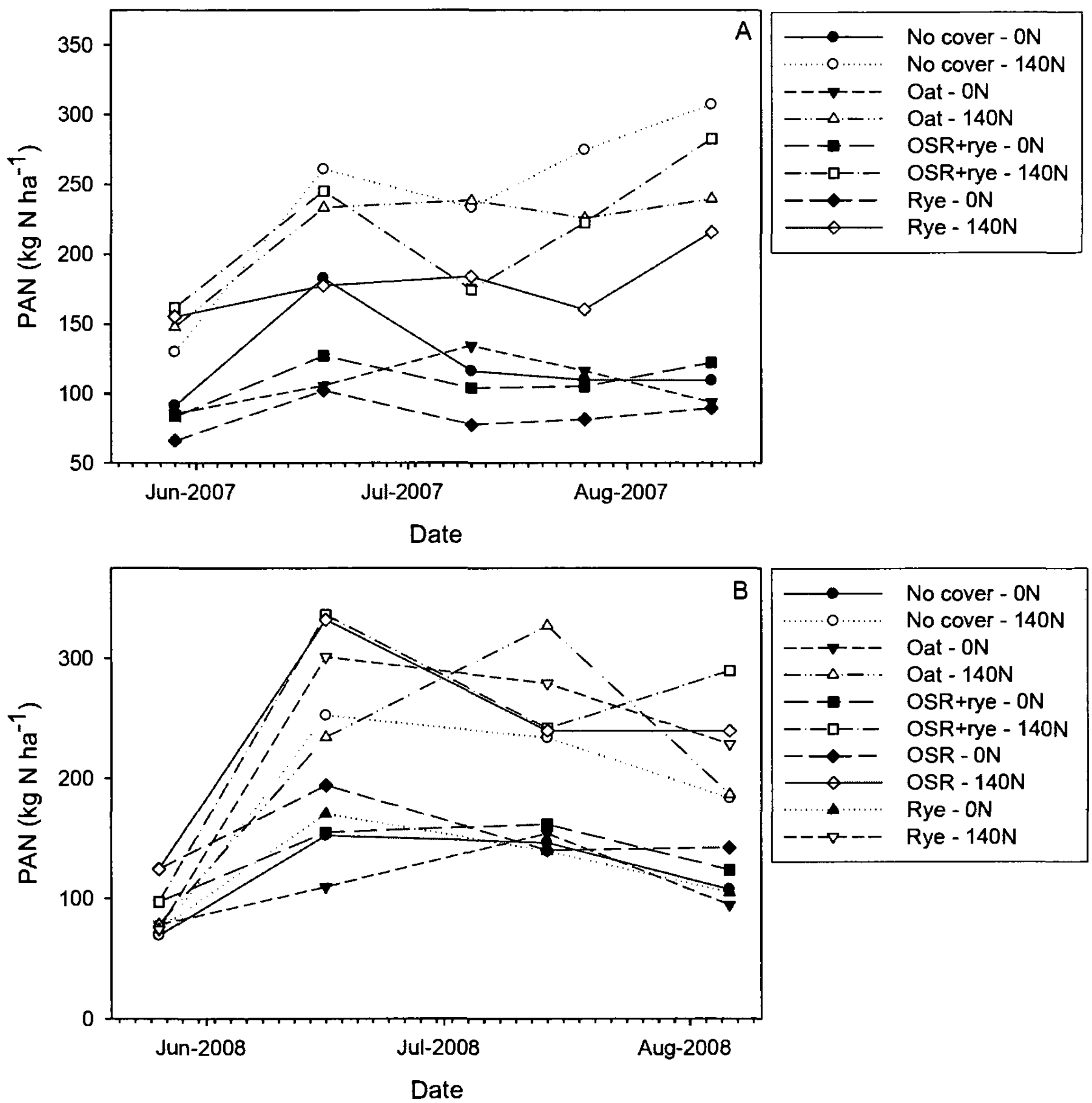


Figure A.5. Plant available N (PAN) during the sweet corn growing season at Bothwell (A) and Ridgetown (B). OSR, oilseed radish; OSR+rye, oilseed radish plus rye

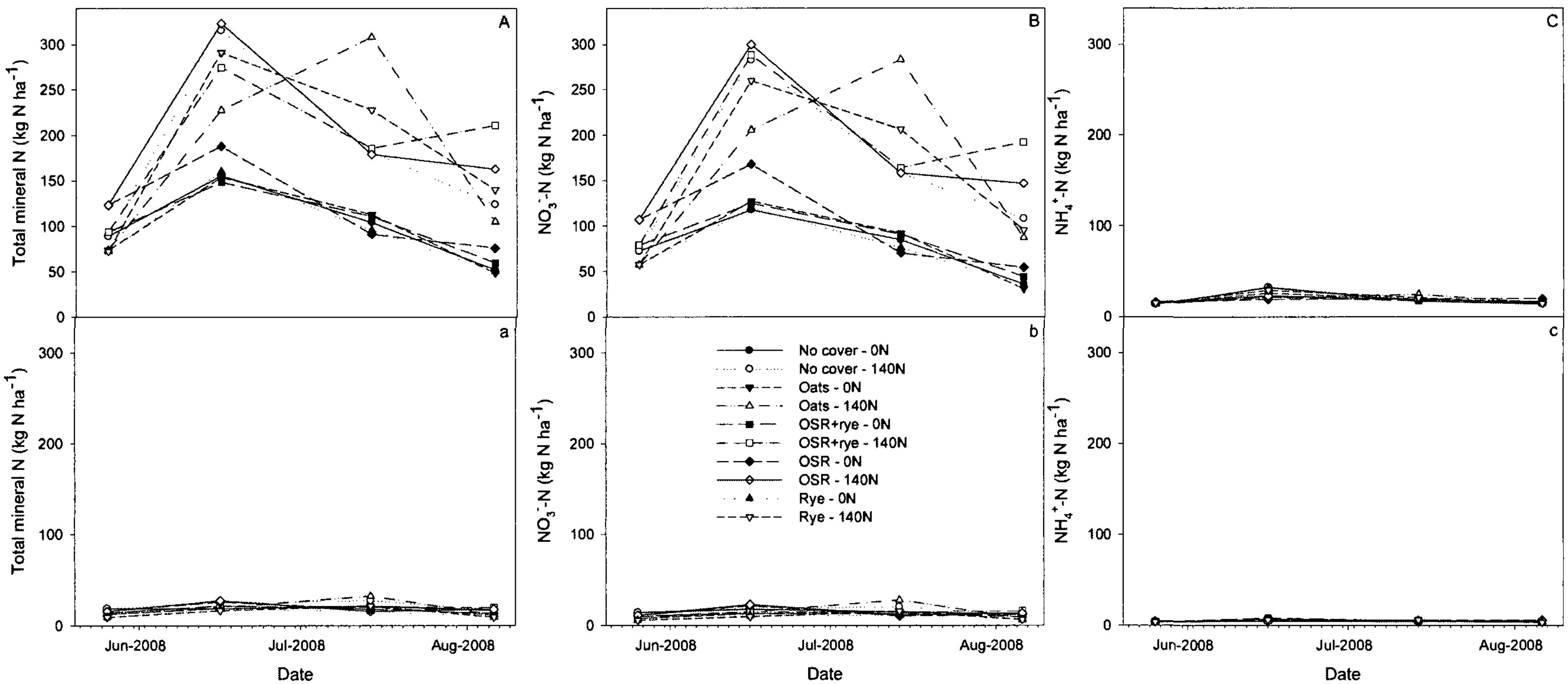


Fig. A.6. Soil total mineral N (A), NO_3^--N (B), and NH_4^+-N (C) from 0-60 cm (uppercase) and 60-90 cm (lower case) during the sweet corn growing season at Ridgetown. OSR, oilseed radish; OSR+rye, oilseed radish plus rye.

APPENDIX B

Table B.1. Cover crop plant %N at Bothwell.

Date	No cover	Oat	OSR+rye	Rye
	---------- Plant % N ----------			
6 Oct. 2006	--†	2.0	2.1	3.0
12 Dec. 2006	--	2.1	1.6	3.0
3 May 2007	1.1	2.3	2.6	2.5
15 May 2007	2.6	2.1	2.5	2.3

†No samples taken at this date for the specified cover crop.

Table B.2. Cover crop plant %N at Ridgetown.

Date	No cover	Oat	OSR	OSR+rye	Rye
	---------- Plant % N ----------				
28 Aug. 2007	--†	4.0	3.8	4.0	4.9
19 Sept. 2007	3.5	3.3	4.8	3.1	4.0
9 Oct. 2007	3.4	2.4	1.6	1.8	3.4
30 Oct. 2007	--	2.2	1.5	1.6	3.0
23 Nov. 2007	--	1.8	1.6	1.1	2.7
21 Apr. 2008	1.4	2.1	1.0	1.5	2.7
5 May 2008	3.4	1.9	1.2	1.1	2.5
26 May 2008	2.0	2.1	1.2	1.1	1.9

†No samples taken at this date for the specified cover crop.