THE IMPACT OF LENTIL AND FIELD PEA SEEDING RATES ON DINITROGEN FIXATION AND SUBSEQUENT NITROGEN BENEFITS IN AN ORGANIC CROPPING SYSTEM

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ABSTRACT

There is a demand for new recommendations for pulse seeding rates that will meet the needs of organic farmers. This study was conducted to determine the impact of seeding rate on N_2 fixation and N accumulation in lentil and pea and to examine the impact of different seeding rates of lentil and pea on the productivity and N-uptake (i.e., N benefit) in a subsequent wheat crop.

The study was performed between 2005 and 2007. Two sites were selected each year of the two-year experiment on certified organic farms in central Saskatchewan. At each location, lentil (*Lens culinaris L.*) cultivar CDC Sovereign and field pea (*Pisum sativum L.*) cultivar CDC Mozart were each seeded at five different rates. Wheat (*Triticum aestivum L.*) cultivar AC Elsa was sown as a non-fixing reference crop at a plant population density of 250 seeds m^{-2}. In the following year, wheat was sown to assess the effect of the pulse seeding rate treatments on the succeeding crop.

The pulse crop seeding rates significantly affected the quantity of N_2 fixed of lentil and field pea, although %Ndfa (80 to 88% and 79 to 85% for lentil and pea, respectively) typically was unaffected by seeding rate. Yield parameters of following wheat crop were not affected by the seeding rates of the previous pulses. Typically, N contributions increased with increasing seeding rates of both lentil and pea, but there was no detectable difference in N uptake by the following wheat grown on the both pulse stubble.

The different seeding rates of organically grown lentil and field pea have impacts on the amount of N_2 fixed and N contribution to the soil. However, the differences in N remaining in the soil at different seeding rates of the pulse crops were not detectable in the following wheat crop and the soil N in the following year.

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DEDICATION

This thesis is dedicated to my loving wife, Enkhee, who always provided me with endless encouragement and inspiration.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
CGSB	Canadian General Standards Board
DAP	Days after planting
EC	Electrical conductivity
HI	Harvest index
IFOAM	International Federation of Organic Agriculture Movements
KCl	Potassium chloride
LSD	Least significant difference
N	Nitrogen
NA	$\delta^{15}N$ natural abundance method
ND	^{15}N isotope dilution method
Ndfa	Nitrogen derived from the atmosphere
Ndfs	Nitrogen derived from the soil
NHI	Nitrogen harvest index
NH_4	Ammonium
$NH4^+$-N	Ammonium nitrogen
NO_3	Nitrate
NO_3^--N	Nitrate nitrogen
NS	Not significant
N_2	Dinitrogen
P	Probability
PAMI	Prairie Agricultural Machinery Institute
SPSS	Statistical Package for Social Sciences
ºC	Degrees Celsius (centigrade)

1. INTRODUCTION

The western provinces are leading Canada's organic industry, with more than fifty percent of the country's 3,782 organic producers residing in the west (Holmes and Macey, 2009). The sales value of the Canadian market was established at one billion dollars in 2006 and the majority of the organic sales were produced on the Prairies (Macey, 2007). The area under organic management on the Prairies in 2007 was 475,900 hectares. According to a recent report (Holmes and Macey, 2009), Saskatchewan is the province with the highest number of certified organic crop producers, (n=1,104), with a total area of 264,734 hectares. Alberta and Manitoba similarly have a large organic land base, following Saskatchewan in second and fifth places, respectively, when compared to other provinces Canada-wide (Holmes and Macey, 2009).

Organic farming is often described as more holistic as compared to conventional farming practices in terms of organic food and fibre production and typically uses practices that are intended to have a positive environmental impact which therefore promotes sustainable agriculture (Pacini et al., 2003). Importantly, organic farming differs from conventional farming in that it releases a smaller volume of man-made pollutants into the environment. Some studies also have demonstrated that fields where organic farming is practiced have greater biological diversity (Coughlin, 2000; Tamm, 2001; Manhoudt et al., 2007) and the fertility and physical attributes of the soil are improved (Shepherd, 2003).

Furthermore, it is argued that organic farming uses less energy per surface unit or performance unit than conventional agriculture (Macilwain, 2004).

Organic agriculture has been on the fringe of the agricultural mainstream for most of the past 50 years whereas the use of synthetic pesticides and fertilizers has dominated farm production. In recent years, however, increased consumer demand and concerns for the environment have driven organic farming to re-emerge as a viable alternative to conventional farming.

Organic producers must follow standards to have their products certified as organic and to be able to obtain the premiums that are paid for organically-produced commodities (Stockdale et al., 2001). Although many certification bodies have emerged and regulations have been developed in certain countries where the organic industry is well-developed, the certification procedures are not internationally recognized. While there is no international regulation of the organic industry, the International Federation of Organic Agriculture Movements (IFOAM) maintains basic standards to which member organizations are expected to comply. According to IFOAM (2008), organic agriculture is an agricultural production system that promotes environmentally, socially and economically sound production of food and fibres, and excludes the use of synthetically compounded fertilizers, pesticides, growth regulators, livestock feed additives and genetically modified organisms. The purpose of organic agriculture is to optimize the health and productivity of independent communities of soil life, plants, animals and people.

As organic production standards develop, many countries are expanding organic food production oriented towards export markets. For instance, 37,947 tonnes of organic wheat were sold between 2004 and 2005 by the Canadian Wheat Board (Macey, 2006). Of reported organic wheat sales, 18,404 tonnes (48.5%) were sold to Europe and 12,143 tonnes (32%) to the USA (Macey, 2006).

Due to organic standards, organic producers are prohibited from using synthetic substances, especially fertilizers and pesticides (CGSB, 2006). Therefore, organic farmers are keenly interested in soil nutrient issues and weed control. As with conventional farmers, organic farmers are motivated to grow appropriate crops in rotation and use other management techniques to increase their profits while maintaining environmentally and economically sustainable farming.

To fill the N requirements of organic farming, N_2-fixing grain legumes are grown to compensate for the non-fixing, cereal-based crops, with their associated soil N contributions (Campbell et al., 1989; Hoeppner, 2001; Stockdale et al., 2001). By planting grain legumes, cereal rotational diseases and weeds can be interrupted and reduced, and soil structure is improved, together with enhanced nutrient availability (Stevenson and Van Kessel, 1996). Growing crops in an appropriate sequence allows the available resources to be used more efficiently and improves soil productivity. However, pulse crops generally are poor competitors with weeds (Wall et al., 1991; Saskatchewan Pulse Growers, 2000). Consequently weed populations in organic systems are more diverse than in conventionally managed fields, that is, there are more weed species in organically managed fields (Leeson, 1998; Li and Kremer, 2000; Liebman and Davis, 2000). Therefore, organic farmers have concerns about weed suppression when including a pulse crop in a rotation. However, use of higher pulse crop seeding rates may increase the ability of the pulse crop to compete with weeds (Mohler, 1996; Paolini et al., 2003).

In organic systems, synthetic chemicals (including N fertilizers) can not be used.

Thus, there is a need to maximize N_2 fixation to benefit both the pulse crop and succeeding crops in rotation. It was hypothesized that N_2 fixation in pulses could be enhanced by altering the seeding rate. Consequently, subsequent crop fertility could be enhanced. The objectives of the study were to determine the impact of seeding rate on N_2 fixation and N accumulation in lentil and pea and to examine the impact of different seeding rates of lentil and pea on the productivity and N-uptake (i.e., N benefit) in a subsequent wheat crop.

The study was conducted as a part of a larger project. In a related experiment, Baird (2007) examined the impact of seeding rates in organic production systems on lentil and fild pea biomass accumulation and crop yield, soil phosphorus (P) concentration and uptake, weed population, soil water storage, arbuscular mycorrhizal fungi colonization of pulse crop roots and plant uptake of P. Results of this related research have been published (Baird, 2007; Baird et al., 2009).

2. LITERATURE REVIEW

2.1. Organic Farming in Western Canada

The western provinces have been pioneers of the organic movement in Canada for the last century, and have been leading the organic industry in the country. Western Canada has the largest area (0.476 million hectare) in organic production in Canada, with 3,782 certified organic farms, equalling fifty two percent of all Canadian organic producers (Holmes and Macey, 2009). Organic production in western Canada has increased in economic value to $170 million per annum in 2004 (Macey, 2005) and, from 1992 to 2000, the number of organic producers on the Prairies increased by roughly four times (Macey, 2003).

The rapidly increasing number of organic farms and the rising price of organically produced products are apparently expressions of the heightened demands of the organic market. Consumers are now able to access a wide range of product to satisfy their growing consumption habits. The range and quality of organic products has increased not only in the areas of grains, fresh fruit and vegetables, but also in dried and packaged goods such as cereals, whole grain products, flour, nuts, dried fruits, meat and dairy products (Beland Organic Foods, 2008). To produce the various types of products to meet the requirements of the green market, the size of organically managed land has grown. By the end of 2005, there was about 1.044 million hectares of organic land, including 0.465 million hectares of certified organic fields, 0.37 million hectares of transitional land, as well as 0.219 million hectares of uncultivated land in organic programs in western Canada (Macey, 2006). The land that is certified organic in the entire nation in 2007 increased to 0.556 million hectares (Holmes and Macey, 2009). More farmers are looking at organic agriculture as a viable economic option, given the lower input costs and premium prices that can be obtained for organic commodities.

From the pioneering of the holistic system of agriculture in Canada in the last century into the 21st century, the core development of organic husbandry has occurred primarily in the Prairies. As Macey (2006) reports, approximately fifty percent of the 0.465 million hectares of organically managed land in western Canada is utilized for field crops and oil seeds. Interestingly, the Prairie Provinces grow more than ninety-nine percent of the field crops and oilseeds organically grown in western Canada on a total of 208,638 hectares (Macey, 2006). Certified organic producers in British Columbia rely more on other types of organic products for ninety-six percent of their 13,387 hectares. Eighty-seven percent of certified organic farmers in BC produce products other than field crops and oilseeds, whereas eighty three percent of those of Prairie Provinces focus on field crops and oilseeds.

2.1.1. Historical perspective of organic production on the Canadian Prairies

Organic farming has been practiced on the Prairies since European settlers arrived in the late 1800s (Weseen, 2000). Since then, the Prairies have been pioneering and leading organic agriculture in Canada. The historical course of organic development on the Prairies can be understood as a significant part of Canadian holistic agricultural perspectives from the past. From very modest beginnings in the second half of the last century, organic farming has grown dramatically in importance and influence on the Prairies. Driving forces to the green movement include the increasing awareness among Canadians of the connections between food and health, between our lifestyle and the degradation of the environment, and of the sad state of the farm economy (Hill and MacRae, 1999).

The historical development of organic agriculture on the Prairies can be summarized in three main phases, which are the same as the phases in a global perspective described by Tate (1994). During the first period of establishment, from the 1920s to 1970, most of the agricultural community and society in general disregarded the principles of organic systems as unscientific or regressive (MacRae, 1990). In the second period, from 1970 to 1990, farmers began turning to organic agriculture as a solution to problems associated with conventional agriculture. Research on organic agriculture accelerated in pace with organic practices. For instance, researchers at the Saskatchewan Research Council (SRC) began investigating organic systems in the late 1970s and reported their findings at the Earthcare conferences (Coxworth and Thompson, 1978). While certification organisations were established to develop standards and to certify organic production systems, more research was becoming available to justify organic agriculture as a sustainable approach to food and fibre production. In the third period, from 1990 to the present, organic farming was recognized as a viable solution for ecological and socio-economical agriculture. Consumers are now able to access a wide range of plant-originated products, not only grains and unprocessed fresh produce but also end-processed and consumer-ready packages. Thus, the green movement is considered to be a mainstream agricultural production system on the Prairies.

Although Prairie farmers produce a wide range of plants and cultivars for the green market, the largest portion of certified organic farms on the Prairies produce field crops. According to recent reports, the Prairie Provinces manage a total of 189,374 hectares of land in organic field crops and oilseeds in 2003 and that area had grown to 208,638 hectares by 2005 (Table 2.1).

Table 2.1. Certified organic fields in the Prairie Provinces and Canada.

Year†	Prairie Provinces			Canada
	Alberta	Saskatchewan	Manitoba	
	----------hectares----------			
2003	20 139	156 193	13 042	222 209
2005	26 579	172 195	9 865	230 553

† Source of data: Macey, 2003; Macey, 2006

Oilseed and pulse crops increase market diversification since oilseeds and pulse crop prices respond somewhat independently of cereal markets (Zentner et al., 2002). Oilseed and pulse crops also increase production diversification due to differential responses to growing season rainfall and temperature patterns (Johnston et al., 2002; Miller et al., 2002). Growing field crops in an appropriate sequence in well-managed rotational systems, particularly in organic farming, is imperative to maintaining productivity levels and reducing the challenges of organic fields such as weed competition, soil fertility, and pest and disease control (Foster, 1996a, 1996b, 1996c, 1996d). Organic farmers concentrate on looking for appropriate crops, rotations and techniques to decrease the challenges and increase their profits while maintaining environmentally and economically sustainable farming.

2.1.2. Crop rotations and management strategies

Increasing the diversity of species in space and time to maximize biological and ecological services are emphasized in organic crop husbandry (Horsley, 2000). The level of crop diversity determines the significance and degree of the rotational benefits. Well-designed crop rotations contribute to the prevention of disease, pest and weed problems, and to soil fertility maintenance and improved nutrient management (Wallace, 2001a; Zentner et al., 1990; Zentner et al., 2001). A rotation should be as diverse as possible and include cereals, pulses, oilseeds and legume green manures (Wallace, 2001a).

Early studies in organic agriculture contended that legumes should be considered and promoted by organic organizations as part of a soil conservation component in the rotation, as less than half of the producers included legumes into their organic crop rotations in Saskatchewan (Green, 1990). Nitrogen-fixing annual grain legumes can be beneficial to the non-fixing cereal in an organic rotation due to the associated soil N contributions. By planting perennial grain legumes, cereal diseases and weeds can be interrupted and reduced (Entz et al., 1995; Leeson, 1998), and soil structure is improved and nutrient availability is increased (Stevenson, 1996). Nowadays the majority of the organic farmers on the Prairies rely on cereal-dominated production (Macey, 2006). Zentner et al. (2002) reported that diversification and intensification of wheat-based cropping systems have been key to sustaining farm profitability in the driest parts of the Canadian Prairies. Pulse crops could be a great contributor and diversifier for various crop rotations, as is well documented (Bremer and Van Kessel, 1996; Matus et al., 1996; Stevenson and Van Kessel, 1996; Beckie et al., 1997; Zentner et al., 2002; Gan et al., 2003; Miller et al., 2003; Miller et al., 2005; Miller et al., 2006).

2.2. Pulse Crops in Organic Crop Rotations

For organic farming, crop rotation is very important. Leguminous crops in organic rotation can be used to maximize inputs of atmospheric N to the soil and to maintain or increase nutrient availability to the soil and to following crops (Evans et al., 1989; Wright, 1990; Evans et al., 1991; Stevenson and Van Kessel, 1996a, 1996b). On the Prairies, lentil and field pea are grown by organic farmers as potential sources of N to enhance their rotation. According to Macey (2003, 2006), the majority of lentil and field pea crops included in organic rotations are grown on the Prairies in Canada (Table 2.2).

Table 2.2. Organically grown pulse crops on certified crop farms on the Prairies and Canada in 2005.

Name of Crop	Prairie Provinces‡			Canada
	Alberta	Saskatchewan	Manitoba	
	hectares			
Lentil	79	14 859	4	14 942
Pea	1 025	10 674	174	12 293
Other Pulse Crops	12	55	3	112

† According to the source, the data probably incomplete because some farmers did not submit reports.

Although pulses bring a variety of advantages into the organic rotation, they are known to be poorly competitive with weeds (Wall et al., 1991). Since chemicals are prohibited in organic systems, the use of mechanical means to manage weeds in organic field crop production dominates. Frequent soil tillage is used extensively in organic farming (Mohler, 2001). Increased mechanical soil tillage could be destructive to soil structure and lead to soil erosion. Moreover, additional costs of cultivation must be taken into account (Wallace, 2001b). Those disadvantages could become a hindrance to the development of organic farming, unless given proper attention.

2.2.1. Benefits of pulse crops in organic rotations

2.2.1.1. Nitrogen fixation by lentil and pea

Pulses can enhance the N supplying power of the soil (Power, 1987; Badaruddin and Meyer, 1990; Mahler and Hemamda, 1993; Biederbeck et al., 1995) and help maintain and increase the organic matter content of the soil (Campbell et al., 1989; Biederbeck, 1990). In general, organic systems must rely on a closed N cycle and on N inputs via N_2 fixation by legumes (Niemsdorff and Kristiansen, 2006). Nitrogen fixation by lentil and pea is well-documented on the Canadian Prairies under various conditions (Rennie and Dubetz, 1986; Bremer, 1987; Cowel et al, 1989; Kucey, 1989; Bremer, 1991; Van Kessel, 1994; Waterer et al., 1994; Androsoff et al., 1995; Armstrong et al., 1997; Beckie et al., 1997; Matus et al., 1997; Mooleki, 2000; Clayton et al., 2004; Soon and Arshad, 2004). Levels of N_2 fixation by field pea of approximately 180 kg ha^{-1} have been reported for a study at Beaverlodge, Alberta (Clayton et al., 2004), whereas the N_2 fixation levels by lentil as high as 149 kg ha^{-1} were observed at Outlook, Saskatchewan (Van Kessel, 1994). In studies conducted at Outlook, Saskatchewan and Roskilde, Denmark, the maximum daily rate of lentil N_2 fixation was 4.4 kg ha^{-1} day^{-1} (Van Kessel, 1994) and for pea was 10.3 kg ha^{-1} day^{-1} (Jensen, 1987), respectively.

The level of N_2 fixation by legumes varies considerably and variability occurs both spatially and temporally in response to a host of environmental and ecological factors (Vitousek et al., 2002). For instance, Carranca et al. (1999) reported that precipitation in the vegetative period affects N_2 fixation of pea. Annual rates of N_2 fixation by uninoculated pea varied from 31 to 107 kg N ha^{-1} with regular precipitation, and from 4 to 37 kg N ha^{-1} under drought stress.

Many practical and external factors such as soil moisture (Rennie and Dubetz, 1986; Bremer, 1987), tillage (Matus et al., 1997), intercropping (Danso et al., 1987; Morris and Weaver, 1987; Cowell et al., 1988; Waterer et al., 1994; Jensen, 1996; Geijersstam and Martensson, 2006), application of inoculants, inorganic fertilizers and herbicides (Bremer, 1996; Singh and Wright, 1999; Clayton et al., 2004; Shah et al., 2004), landscape positions (Mahler et al., 1979; Androsoff et al., 1995; Mooleki, 2000), weeds and insects (Corre-

Hellou and Crozat, 2005), and available soil nutrients (Cowie et al., 1990; Shah et al., 2004; Corre-Hellou and Crozat, 2005) significantly affect N_2 fixation of pulses.

Matus et al. (1997) reported that N_2 fixation was 10% higher for lentil and 31% higher for pea when grown using zero tillage as compared to conventional tillage practices. Shah et al. (2004) found no significant effect of tillage on the N_2 fixation of lentil. While soil tillage influences N_2 fixation, cropping techniques also affect N_2 fixation. Dinitrogen fixation by lentil was influenced by crop rotation, being greater in highly diversified than in less diversified crop rotations (Matus et al., 1997).

Intercropping can affect N_2 fixation by legumes. For example, Cowell et al. (1988) documented that intercropped legumes such as pea and lentil had significantly higher levels of fixed N than when monocropped. Similar results were reported for intercropped pea with forage oat in different ratios, showing an increasing N_2 fixation trend with an increasing ratio of oat to pea, compared to pure stands of pea (Geijersstam and Martensson, 2006). Surprisingly, Jensen (1996) found that the amount of symbiotic N_2 fixation in the intercrop was less than expected from its composition and fixation in monocrops. However, a higher proportion of total N in peas was derived from N_2 fixation in the intercrop than in the monocrop, 82% and 62%, respectively. Although the cropping systems differ, the majority of total N comes from N_2 fixation in both cropping practices. Similar studies found higher N contents in the non-legumes when intercropped with legumes (Dalal, 1974; Leihner 1983; Mason et al., 1986), which may be due to excretion or transfer of N from the pulses, or to less competition for available soil N (Danso et al., 1987; Morris and Weaver, 1987). The actual reason could be that legumes reduce the symbiotic N_2 fixation with the increase of plant-available N in the soil (Viosin et al., 2002). Furthermore, Corre-Hellou and Crozat

(2005) observed the same pattern in a pulse and weed competition study. Fixed N was enhanced by an increase in weed infestation, and %Ndfa was increased almost two-fold as compared to situations with low weed infestations. The explanation was that increased levels of soil nitrates under conventional tillage decreased N_2 fixation (Cowie et al., 1990) and weeds are more competitive than pea for soil N and rely on soil-available N rather than fixed N (Corre-Hellou and Crozat, 2005).

Plant density also has an impact on N_2 fixation. Strydhorst et al. (2008) found that in the absence of weed competition and a high plant density of pulses, including pea, pulse seed and N_2 fixation yields were increased. Ayaz et al. (2004) reported similar trends, with pea and lupin (*Lupinus angustifolius L.*) straw whereby N yields typically increased in response to increasing plant populations.

Quantification of dinitrogen fixation. Nitrogen-isotope techniques such as ^{15}N natural abundance (Delwiche and Stein, 1970; Haulk, 1973; Kohl and Shearer, 1980), ^{15}N isotope dilution (Haulk and Bremner, 1976; Fried & Middleboe, 1977; Warembourg, 1993) and the N difference method (Williams et al., 1977) are widely used in field experiments. The principle of the techniques is that N_2 fixing species have lower $\delta^{15}N$ values than the non-fixing control or the soil in which the tested species were grown (Delwiche and Stein, 1970). Therefore, the difference in $\delta^{15}N$ between N_2-fixing and non-fixing species is used to estimate the amount of N_2 fixed.

The N difference method is based solely on the difference in total N between a fixing crop and a non-fixing reference crop (Rennie, 1984). The assumption of this method is that the reference crop obtains the same amount of N from the soil N pool as the fixing crop. This does not often occur because the reference crop may take up soil N with a different efficiency, or from a different soil N pool than the fixing system (Rennie and Rennie, 1983). The error that occurs with the method is that it underestimates N_2 fixation because it substitutes fixed N_2 for soil N (Amarger et al., 1979; Rennie, 1984). However, in some cases equal and greater soil N uptake by the fixing system was also observed (Boddey et al., 1984; Rennie, 1984).

Use of ^{15}N tracer techniques has permitted quantification of N_2 fixation in pulses by labelling soil (Legg and Sloger, 1975; Kohl and Shearer, 1981; Rennie, 1982; Rennie et al., 1982). The ^{15}N dilution (ND) method works by labelling the soil instead of relying on atmospheric N_2. The extent to which this ^{15}N enrichment is diluted by atmospheric N_2 in a fixing plant reflects the magnitude of fixation (Warembourg, 1993). This method has been used to accurately quantify N_2 fixation in legumes under field conditions (Rennie et al., 1978; Vose et al., 1981). However, it is often difficult to label the soil mineral N pool uniformly. Mineralization of unlabelled N will also lead to a decrease in the ^{15}N enrichment over time (Viera-Vargas et al., 1995). As well, this technique is more costly when used in large field experiments.

Natural abundance with positive and negative $\delta^{15}N$ values can be considered as tracer materials with low levels of ^{15}N enrichment or depletion (Hauck 1973). It has been suggested for legumes and non-legumes (Rennie et al., 1976; Delwiche et al., 1979; Kohl and Shearer, 1980; Rennie, 1982; Rennie et al, 1982) that the $\delta^{15}N$ of plant N can be used to indicate the source of plant N, either soil, fertilizer, or atmospheric. Atmospheric N has an atom % ^{15}N value of 0.3663 (Junck and Svec, 1958; Mariotti, 1983), equivalent to a $\delta^{15}N$ value of 0. The natural abundance (NA) method is a common technique for field experiments, but small differences in $\delta^{15}N$ values may not be detectable. Bergersen and Turner (1983) observed significant differences between $\delta^{15}N$ natural abundance and ^{15}N enriched isotope dilution methods early in the growing season, when quantifying N_2 fixation in subterranean clover (*Trifolium subterraneum L.*) mixed with perennial ryegrass (*Lolium perenne L.*). Haynes et al. (1993) found that the %Ndfa values were consistently higher when barley (*Hordeum vulgare L.*) rather than the oilseed rape (*Brassica napus L.*) was used as the non-N_2-fixing reference crop. Domenach and Chalamet (1979) reported that the largest difference in $\delta^{15}N$ and ^{15}N enriched isotope dilution methods was 8% for estimating N_2 fixation of soybean using ryegrass as reference crop.

Ledgard et al. (1984) estimated N_2 fixation by ND and NA methods for clover using ryegrass as a reference crop. The results were identical throughout the experiment, but when phalaris (*Phalaris aquatica L.*) was used as a reference crop, the NA method gave significantly higher values than ND. This was attributed to an underestimation of N_2 fixation by the ND method due to phalaris obtaining a lower ratio of fertilizer to soil-derived N than clover. Thus the accuracy of the techniques depend on the selection of a suitable reference crop.

There are several suggested criteria for selecting reference crops for accurate estimates of N_2 fixation: a) the reference crop should not fix N (Warembourg, 1993); b) the reference crop has a similar pattern of soil N uptake as the fixing crop because the ^{15}N enrichment of the soil N pool decreases with time (Rennie, 1986; Witty, 1993); c) the growing period of both non-fixing and fixing crops should be almost the same (i.e. they must be planted, mature, and harvested at the same time) (Rennie and Rennie, 1983); d) the reference crop must take soil N up from the same pool as the fixing crop (Chalk, 1985); and

e) ^{15}N may not spread equally throughout the plant parts and therefore the ^{15}N enrichment of the whole plant must be used for analysis (Rennie et al., 1978; Shearer et al., 1980).

2.2.1.2. Nitrogen benefits to the succeeding crops

The organic crop production principle prohibits the use of any synthetic chemicals or inputs into the system (Vogt, 2007). Therefore, there is a need for an organic nutrient supply for the crop rotation. Pulse crop management practices that improve symbiotic N_2 fixation would be expected to increase subsequent crop yields. In addition to the direct benefits to the pulse crop obtained through symbiotic N_2 fixation, pulse crops also can contribute to the N economy of a crop rotation via increased N benefits to the succeeding crops (Bremer and Van Kessel, 1996; Matus et al., 1996; Stevenson and Van Kessel, 1996; Beckie et al., 1997; Knight, 2000; Zentner et al., 2002; Gan et al., 2003; Miller et al., 2003; Miller et al., 2005; Miller et al., 2006). Some studies reported that growing legumes in the rotation provides both N and non-N benefits to subsequent crops (Bremer, 1991; Stevenson and Van Kessel, 1996a, 1996b; Beckie and Brandt, 1997; Hoeppner, 2001). Stevenson and Van Kessel (1996) reported that subsequent wheat crops benefited from increased availability of P, K and S from previous pea crop residues.

Both N and non-N benefits can be important source of nutrients to the unfertilized succeeding cereal crops in the organic system. Miller et al. (2002) concluded that the positive benefits of pulse crops on subsequent wheat yield and protein resulted from increased soil N rather than increased available water. Therefore, pulse crops are considered as an essential source of nutrients in this predominantly cereal rotation.

The accumulation of crop residues with frequent inclusion of pulse crops in a rotation is shown to improve the biochemical and physical properties of the soil by increasing labile organic matter (Biederbeck et al., 1994). The benefits of increased nutrient availability are also reported in earlier studies, which indicate that incorporating legumes into rotations can provide numerous benefits to succeeding crops, such as higher protein levels, higher yields, weed control, and improved soi1 physical properties (Spratt, 1966; Badaruddin and Meyer, 1989; Hoyt and Leitch, 1983; Entz et al., 1995).

Previous studies documented that pulse N benefits conferred to the following wheat crop were not large (Bremer, 1991; Jenson, 1994; Stevenson, 1996). Bremer (1991) reported that only 5.5% of ^{15}N applied was assimilated by following wheat crop on lentil stubble. For field pea, the residual N benefit was 5 to 8% (Jenson, 1994; Stevenson, 1994). The limited N benefit to the following wheat could be caused by various factors. Janzen and Kucey (1988) indicated that N will not be mineralized from crop residue until the decomposing substrate reaches a critical N concentration. Thus, the critical concentration had not been fully attained because of factors such as soil inorganic N availability (Wagger et al., 1985). Also, it is possible that the mineralization from pulse residue was not temporarily synchronized with the N demand of the subsequent wheat crop (Wagger et al., 1985). The mineralized N not utilized by the wheat crop may have been immobilized, denitrified, or leached (Wagger et al., 1985; Jensen, 1994). Moreover, the N benefit by pulses to the subsequent crop could possibly be released in long-term rotation. Miller et al. (2006) reported that the benefit of field pea residue was observed within the context of 2-yr cropping sequence, and thus a different response may be obtained in a long-term rotation.

2.2.2. Challenges of using pulse crops in organic rotations

2.2.2.1. Competitive ability of pulse crops

Organically managed production systems often experience greater weed pressure than their conventional counterparts, potentially causing yield losses and increased weed seed build-up. Falloon and White (1980) reported that plant population density strongly influenced the intensity with which neighbouring plants compete for limited supplies of water, light or mineral nutrients. The competitive ability of a crop stand is important for reducing weed competition (Salonen et al., 2005) and can be determined by a number of factors such as growth habit, weed species and climate (Boerboom and Young, 1995). Spies (2008) reported that longer vined cultivars of pea significantly decreased weed biomass.

Weed populations in organic systems are more diverse than conventionally managed fields; that is, there are more weed species in organically managed fields (Leeson, 1998; Li and Kremer, 2000; Liebman and Davis, 2000). Leeson (1998) found higher weed densities in organically managed fields compared to conventionally managed fields. Pulse crops can make many contributions in rotation but they are poor competitors with weeds (Wall et al., 1991; Saskatchewan Pulse Growers, 2000).

Lentil competes poorly with weeds due to its poor seedling vigour and short stature, which is further compounded when the growing season temperatures are low (Basler, 1981; Siddique et al., 1998; Elkoca et al., 2005; Baird, 2007; McDonald et al., 2007). The critical period for weed competition in lentil varies and is dependent on region, climate and weed species present. Furthermore, the degree of yield loss depends on the natur.e of the weeds, and the stage and duration of weed-crop competition (Radosevich et al., 1997; Day et al., 2006). Lentil yield losses due to weed competition can reach 80% (Boerboom and Young, 1995). When crop density is too low, lentils have low capacity to compete (Siddique et al., 1998). Paolini et al. (2003) reported that yield losses due to weed competition reached 80% at 125 plants m^{-2} compared with 358 plants m^{-2} in their lentil seeding rate study.

Field pea has a greater ability than lentil to compete with weeds and reduce weed seed production and dispersal (Mishra et al., 2006). In a study in Saskatchewan, the competitive ability of various pulse crops was determined by the ability of a plant to maximize its own biomass production while minimizing weed biomass production (Lawley, 2004). Using this criterion, the tested field pea cultivar was more competitive in weed suppression compared with lentil (Lawley, 2004). Grevsen (2003) reported that yield reductions of pea reached 40 to 80% due to weed competition. Boerboom and Young (1995) reported that pea yield was reduced by 30 to 40% due to weed competition in herbicide-free conditions.

2.2.2.2. Soil tillage considerations

Organic systems rely on tillage for weed control. Some practices such as post-emergent harrowing for weed control are effective (PAMI, 2003; Shirtliffe and Johnson, 2007), but destructive to the soil (Foster, 1996). Organic producers may need to use additional or heavier cultivation measures to suppress weeds. The type of tillage is often defined by the time of year the tillage operation occurs. Pre-seeding tillage is practiced by both organic and conventional farmers to prepare the seed bed for planting and to kill weeds, including surviving perennials and/or winter or spring annuals. Fall tillage is a common practice for killing winter annual and biennial weeds. In many cases fall tillage reduces the potential for moisture conservation by disturbing standing stubble, which diminishes its effectiveness as a snow trap and exposes the soil to erosion. In addition, increased soil tillage may inhibit pulse N_2 fixation due to the higher concentrations of soil nitrates (Cowie et al., 1990).

2.3. Impact of Seeding Rate on Pulse Production

In pulse production, one of the most important factors limiting yield is weed competition. Some plant population density experiments for lentil and pea take into consideration the effect of weeds (Lawson, 1982; Townley-Smith and Wright, 1994; Wall and Townley-Smith, 1996; Ball et al., 1997). Pulse crops have less capacity than many cereals to compete against weeds, but higher seeding rates may increase the ability of the pulse crop to compete (Paolini et al., 2003). Increasing the population density of a crop can result in increased crop yield and decreased weed biomass (Mohler, 1996). Lemerle et al. (2006) in Australia found that grain yield of field pea was reduced more at low crop densities (10 to 40 plants m^{-2}) and in the presence of weeds. Percentage yield losses from weed competition were approximately 40 to 90% at the low densities and 5 to 50% at a higher seeding rate (60 plants m^{-2}).

Pageau et al. (2007) evaluated the effect of plant populations ranging from 50 to 150 plants m^{-2} on the productivity of two semi-leafless peas. The authors concluded that a seeding rate of 100 seeds m^{-2} resulted in higher grain yields without increasing lodging. A similar pattern was found in a vetch (*Vicia narbonensis L.*) study in Turkey where seed yield, green forage yield, and dry matter yield increased as the number of plants increased per unit area (Yulmaz, 2008). The highest seed yield, above-ground biomass, green-forage yield, and dry matter yield were obtained with the highest plant density (100 plants m^{-2}). A similar study in western Canada found that seed yields of all legumes increased with increasing plant density when the crops were grown on conventional summerfallow, but seedling emergence was decreased at the highest seeding rates (Gan et al., 2003). The highest seed yields were obtained with 40 to 45 plants m^{-2} for kabuli chickpea (*Cicer arietinum L.*), 45 to 50 plants m^{-2} for desi chickpea, and 75 to 80 plants m^{-2} for dry pea. However, the increase in seeding rate must be economically profitable. Siddique et al. (1998) was concerned that the higher cost of organic seed may be prohibitive in increasing seeding rates beyond a threshold level.

2.3.1. Recommended seeding rates of lentil and pea

There are a number of recommended plant population densities for seed production of field pea with conventional production in western Canada. In field pea, a density of 88 plants m^{-2} (Saskatchewan Pulse Growers, 2000), 75 to 90 plants m^{-2} (Park and Lopetinsky, 1999), or 60 to 80 plants m^{-2} (Wallace, 2001) have been recommended. There have been suggestions that reduced seeding rates of field pea can help reduce seed costs, but this could increase yield losses due to inadequate weed control (Wall and Townley-Smith, 1996). They found that increasing plant density reduced both weed numbers and weed biomass in western Canada under weedy conditions. Similarly, Townley-Smith and Wright (1994) recommended that field pea should be seeded at no less than 90 plants m^{-2} in order to maximise both weed control and yield of field pea. The same result was found in a study in western Canada, where seeding rates greater than the recommended rate, up to 100 plants m^{-2}, were beneficial in weedy fields (Johnston et al., 2001). Lawley (2004) also recommended a seeding rate of 90 plants m^{-2} in weedy conditions based on a study of optimal plant densities of field peas for green manure in organic farming. Baird (2007) reported that the optimum crop density of field pea on organic farming of central Saskatchewan is 120 plants m^{-2}. Spies (2008) indicated that the economic optimal plant densities depending on cultivars are 65 to 106 plants m^{-2} in central Saskatchewan.

The recommended target lentil plant density for conventional farming systems is 130 plants m^{-2} (Saskatchewan Pulse Growers, 2000). According to Park and Lopetinsky (1999), the optimum plant density is 108 plants m^{-2}. The Canadian Organic Grower's field crop handbook recommends a plant density of 80 to 130 plants m^{-2} (Wallace, 2001). A report that examined pulse production in Saskatchewan determined that the optimal plant density for narrow-spaced lentil grown organically is 195 to 260 plants m^{-2} (Johnson, 2002). Biederbeck et al. (1993) used a target seeding rate to obtain approximately 200 plants m^{-2} for green manure lentils. In general, high seeding rates of lentil reduced weed populations, and increased lentil yields (Ball et al., 1997; Paolini et al., 2003; McDonald et al., 2007). Ball et al. (1997) reported a suppressive effect of increasing lentil seeding rates on weed biomass under herbicide-free conditions. Baird et al., (2009) similarly reported that optimum density of organic lentil production is 229 plants m^{-2} to achieve maximum yield and weed suppression.

2.3.2. Impact of crop density on dinitrogen fixation

A recent pulse plant density study found that the absence of weed interference and a high density of the pulse increased N_2 fixation and subsequent seed yield (Strydhorst et al., 2008). Ayaz et al. (2004) reported similar trends with pea and lupin straw N yields typically increasing in response to increasing plant populations. Similarly Materon and Danso (1991) documented that the total amount of N_2 fixed was significantly increased by the indirect effect of higher seeding densities increasing biomass and total N yields, but emphasized that planting density did not influence %Ndfa in alfalfa (*Medicago spp.*).

Kapustka and Wilson (1990) reported that nodule activity and plant density are related and the relationship influences N_2 fixation. Specifically, in both field and pot studies using soybean (*Glycine max L.* Merr.) as the test crop, N_2 fixation per gram nodule was higher at high planting densities as compared to at low planting densities; however, both nodule number and mass were reduced.

Weed removal increased %Ndfa in a pea crop (Soon et al., 2004). Keatinge et al. (1988) reported that weed removal increased the amount of N fixed by several legume species and improved protein yields of a subsequent hay crop.

2.3.3. Impact of crop density on weed distribution

Plant densities higher than conventionally recommended in field pea effectively suppressed weed growth (Marx and Hagedorn, 1961; Anderson and White, 1974; Lawson and Topham, 1982; Townley-Smith and Wright, 1994). Townley-Smith and Wright (1994) reported that increasing the pea seeding rate reduced both weed numbers and weed dry matter production in a seeding rate study in western Canada. Recent studies show that weed biomass was reduced by 68% in field pea and 59% in lentil between the lowest (pea=10 and lentil=15 seeds m^{-2}, respectively) and highest (pea=250 and lentil=375 seeds m^{-2}, respectively) seeding rates (Baird, 2007). Weed biomass decreased by 30 to 50% when the seeding rate of green pea was increased from 90 to 150 seeds m^{-2}(Grevson, 2003). A reduction in weed biomass was observed when crop density was increased by more than 50% above the recommended rate of 88 plants m^{-2} for pea and 130 plants m^{-2} for lentil, although the weed density did not decrease (Boerboom and Young (1995).

Higher lentil seeding rates typically reduce weed populations while enhancing yield (Ball et al., 1997; Paolini et al., 2003; Baird, 2007; McDonald et al., 2007). According to Paolini et al. (2003), lentil suppressed weeds at plant densities higher than 177 plants m^{-2}. Therefore, crop density had a larger influence on the ability of field pea and lentil to compete with weed populations. However, the pattern of increasing plant density and decreasing weed population may be not absolute. As Boerboom and Young (1995) found, there was no significant decrease in weed density, when increasing seeding rate of field pea and lentil up to 50% higher than recommended.

2.3.4. Impact of crop density on disease

Dense foliage can increase leaf diseases by providing a large surface area for infection and can promote a wet soil surface by shadowing (Foster, 1996). Moisture abundance and high humidity in the pea canopy at the base of the plants may explain the high disease scores in the lower parts of the plants (Tivoli et al., 1996). Hence higher disease scores were usually found on the lower parts of the plants, and in low positions on the uppermost parts (Tivoli et al., 1996). A prostrate growth habit and humid canopy conditions were also more conducive to disease development, especially in dense canopies (Johnston et al., 2002).

2.3.5. Impact of crop density on soil quality

There are very few studies examining the influence of plant population density of pulses on soil quality. A recent study reported that plant density of pea and lentil probably affects soil available phosphorus although results were inconsistent and highly variable (Baird, 2007). It was suggested that the high degree of variability was likely due to spatial variability within each site rather than treatment effects. According to Baird (2007), soil water storage did not change between treatments measured to 30 cm. Similarly, Gan et al. (2007) looked at post-harvest residual soil water effects of different seeding rates of dry pea, desi chickpea and kabuli chickpea, but no differences were found up to 60 cm on all pulse treatments. Interestingly, pulses grown on fallow used 66% more water than when grown on stubble. Both studies revealed that water use efficiency increased with increasing plant density for all the pulses studied (Baird, 2007; Gan et al., 2007).

Given the uncertainty regarding the impact of pulse seeding rates on N_2 fixation, subsequent N benefits and soil quality, there is a need to address these parameters to reveal their responses to plant densities.

3. EFFECT OF SEEDING RATES OF ORGANICALLY GROWN LENTIL ON DINITROGEN FIXATION AND THE NITROGEN BENEFIT TO THE FOLLOWING WHEAT CROP

3.1. Introduction

Recommended seeding rates for organic production of lentil have not been established for western Canada. Therefore, organic farmers rely on seeding rates recommended for conventional production. Conventional seeding rates were established in conjunction with herbicide application and may not be suitable for organic production where competition with weeds is an integral part of the system (Vogt, 2007). Importantly, pulses are able to meet some of their N requirements via N_2 fixation. Consequently, inclusion of pulses in an organic cropping system is highly beneficial as N is supplied to the pulse crop and also benefits subsequent crops (Stevenson, 1996). An experiment was initiated to examine the effect of seeding rate of organically grown lentil on N_2 fixation and subsequent N benefit. The experiment was conducted over two growing seasons (Baird, 2007). During the first growing season, lentil was seeded at five different seeding rates and the impact of seeding rate on N_2 fixation and various crop production parameters was assessed. In the subsequent growing season, wheat was seeded into the lentil stubble and the impact of the lentil residue on N availability and consequent wheat yield parameters was determined.

3.2. Materials and Methods

3.2.1. Lentil treatment-Year 1

3.2.1.1. Site description

Four field research sites were selected, two in the Black soil zone and two in the Dark Brown soil zone. The sites were located on fields that were certified for organic production for 8 to 20 yrs (Appendix 1). In 2005, the site in the Black soil zone was located near Vonda, SK (Vonda-05) (52° 18' 25"N, 106° 06' 03"W), and the site in Dark Brown soil zone was located near Delisle, SK (51° 49' 31"N, 107° 19' 01"W). In 2006, a third site was established in the Black soil zone near Vonda, SK (Vonda-06) (52° 17' 50"N, 106° 06' 05"W) and a fourth near Vanscoy, SK (51° 57' 24"N, 106° 56' 44"W) in the Dark Brown soil zone. The site locations, soil zones and associations, farming history, and soil characteristics in the upper 15 cm are described in Appendix 1. The sites established in 2005 were seeded into barley stubble, and the sites established in 2006 were seeded into wheat stubble. Prior to seeding, soil samples were taken with a 5 cm (inner diameter) soil corer at depth increments of 0- to 15-, 15- to 30-, 30- to 60-cm and 60- to 120-cm at three random locations within the trial area. These samples were measured for bulk density by determining the volume of each sample, then weighing the sample before and after drying at 105°C for 48 h to remove soil water. Soil samples from 0- to 15-cm and 15- to 30-cm depths at five random locations within each site were bulked and sent to ALS Laboratory Group (Saskatoon, SK) and analyzed for pH, cation exchange capacity and macronutrient analyses (Appendix 1).

3.2.1.2. Treatments

Treatments for Year#1 in this study consisted of five seeding rates of organic lentil. Summerfallow and green manure treatments also were included as treatment controls.

To achieve five target plant densities for lentil, the cultivar CDC Sovereign (*Lens culinaris L.*) was seeded at rates equivalent to15, 38, 94, 235 and 375 seeds m^{-2}. CDC Indianhead lentil was planted as a green manure control. The lentil varieties were chosen in consultation with the organic industry and pulse breeders. In 2005, a seeding rate of 235 seeds m^{-2} was chosen for the green manure control based on results from Lawley (2004). In 2006, an additional green manure treatment with modified seeding rate was added to the newly selected sites (Vonda-06 and Vanscoy). The lentil green manure seeding rate was increased to 375 seeds m^{-2} for the additional green manure treatment.

The number of seeds planted in each treatment was increased based on the percent germination to achieve target plant densities. The germination test was performed by placing 100 seeds on moist paper towel stored in the dark for 7 d, and then determining the number of seeds germinated. At seeding, Nodulator® granular *Rhizobium* inoculant for lentil (Becker Underwood, Saskatoon, SK) was placed with the seed at the recommended rate (i.e., 5.6 kg ha^{-1}).

3.2.1.3. Experimental design

The experimental plots were organized in a randomized complete block design with four replicates. In 2005, the plot size of the lentil treatments was 2 m wide by 6 m long. In 2006, the individual plot size increased to 4 m x 6 m to allow for an undisturbed 2 m strip for mechanical harvesting. All sampling was performed on the left hand side sub-plot of the 4 m wide plots.

For estimating N_2 fixation in each treatment, wheat (*Triticum aestivum L.*) cultivar AC Elsa was sown as a non-fixing reference crop at right angles to the treatment plots in the alleys between the blocks. Wheat was seeded on the same day as the pulse crops in all plots at seeding rate of 250 seeds m^{-2}.

3.2.1.4. Plot management

The plot management operations and dates are summarized in Table 3.1. Lentil was seeded in 20-cm row spacing and 2.5 cm deep. The experiments were seeded with a small-plot disc seeder after the experimental area was cultivated using a heavy duty cultivator. In-crop harrowing was performed with two passes using a flex-tine harrow as required to control weeds during the early stages of the experiments (Table 3.1). The number of crop and weed plants were counted in two randomly selected 0.25 m^{-2} quadrants in each plot after the in-crop harrowing was performed (Baird, 2007).

Table 3.1.Field operations for the experimental sites of organically grown lentil in central Saskatchewan in 2005 and 2006.

Operation	2005		2006	
	Delisle	Vonda-05	Vanscoy	Vonda-06
	DAP†			
Seeding	May-20	May-11	May-16	May-18
In-crop harrowing	27	26	15	13
Summerfallow tillage # 1	47	56	43	49
Green manure ploughdown‡	61	53	50	51
Summerfallow tillage # 2	104	113	80	79
Sampling at Physiological maturity	82	89	83	79
Hand harvest	94§	103	85	92
Mecahnical harvest	NP¶	NP	92	97

† Days after planting

‡ A second green manure ploughdown was performed on the same date as summerfallow tillage # 2 at both Delisle and Vonda-05 plots.

§ The maturity of two replicates of lentil was delayed and was harvested 120 days after planting when maturity was reached.

¶ NP, not performed because of sampling and hand-harvesting disturbance.

The optimal crop stage for green manure ploughdown in Saskatchewan is the early bud stage (Lawley, 2004). The green manure was ploughed down at the late flowering stage, 61 days after planting (DAP) at Vonda and at the mid-flowering stage, 53 DAP, at Delisle. Inclement weather caused delays in ploughing down the crop at both sites. The ploughdown was performed in two passes using a tandem disc for both the summerfallow and green manure treatments.

In 2005, prior to the green manure ploughdown, a heavy infestation of wild mustard (*Sinapis arvensis L.*) occurred on one corner of the experimental area at the Delisle site. Because the infestation occurred in a localized patch, the wild mustard was removed by hand-weeding.

Above-ground biomass sampling of both crop and weeds occurred at physiological maturity. Above-ground crop samples were hand-harvested from 1-m long rows (equivalent to 0.81 m^{-2}) from both lentil crop and the reference wheat for measuring N_2 fixation. Plants were cut as close as possible to the soil surface. A reference wheat sample for ^{15}N analysis was taken from the closest row to each lentil plot.

In 2005, lentil did not mature evenly across the replicates at the Delisle site. Therefore, hand harvesting was delayed in replicates three and four (120 DAP vs 94 DAP in replicates one and two). In 2005, only hand-harvested samples (1 m x 1 m) were collected because the 2-m wide plots were disturbed by sampling. In 2006, the undisturbed 2-m strip at the right half of the plots was mechanically harvested by one pass of a plot combine (1.6 m x 6 m).

Two soil samples were taken and bulked within each plot using a hand auger in 0- to 15-cm and 15- to 30-cm depths after harvesting. Gravimetric soil moisture content and inorganic N were determined.

3.2.1.5. Analytical techniques

Harvested plant material was separated into crop, broadleaf weed species and grassy weed species. Crop biomass samples were air-dried for 1 wk, and dried further in a forced air heated room at approximately 40°C to constant weight. Samples were threshed using a threshing machine. Weights of seed and straw were determined separately to calculate harvest index. Seed weight was determined from the cleaned, threshed seed weight, and vegetative weight was determined by subtracting seed weight from the total biomass sample weight. One-hundred seed weight was determined by weighing two samples of 100 seeds from each sample and determining an average weight. Lentil and reference wheat samples were ground in a Wiley Mill (2 mm) and subsequently ball-milled for 24 h for mass spectrometer analysis.

The percentage N derived from atmospheric N_2 (%Ndfa) in the lentil was determined using the ^{15}N natural abundance technique (Shearer and Kohl, 1986), that compares the $\delta^{15}N$ values of paired non-fixing reference and N_2-fixing crop samples. Total N and $\delta^{15}N$ were determined by mass spectrometery (Isotech, Middlewich, England) analysis of plant tissue samples of lentil and reference wheat.

Natural ^{15}N abundance was calculated as follows (Rennie and Dubetz, 1986):

$$\delta^{15}N = \left(\frac{\text{atom \% 15 N (sample)} - \text{atom \% 15N (standard)}}{\text{atom \% 15N (standard)}} \right) 1000 \qquad [3.1]$$

where the standard was atmospheric N_2 (0.3663 atom % ^{15}N).

The percentage N derived from atmosphere (% Ndfa) by the $\delta^{15}N$ method was calculated, according to Ledgard (1989):

$$\% \text{ Ndfa} = [(x - y) / (x - c)]100 \qquad [3.2]$$

where x is the $\delta^{15}N$ of the reference plant, y the $\delta^{15}N$ of the N_2-fixing plant, and c the $\delta^{15}N$ of the N_2-fixing plant grown in N-free medium. The value of c for lentil was assumed to be 0.0 (Bremer, 1991). The total amount of N fixed was determined by calculating the product of %Ndfa and N yield (kg ha^{-1}) (Hardarson, 1985; Rennie and Dubetz, 1986) as follows:

$$N_2 \text{ fixed (kg ha}^{-1}\text{)} = (\%\text{Ndfa} / 100) \times \text{N yield (kg ha}^{-1}\text{)} \qquad [3.3]$$

The N contribution of pulses to the soil N pool via symbiotic N_2 fixation and the N derived from the soil to the harvested seed (Ndfs) was determined according to Doughton et al. (1993):

$$\text{N contribution to the soil} = \text{kg Ndfa}_{\text{seed+straw}} \text{ ha}^{-1} + \text{N in original seed} - \text{kg N}_{\text{seed}} \text{ ha}^{-1} \qquad [3.4]$$

Therefore, N contribution of lentil to the soil was considered to be the difference in N inputs (i.e., input of N_2 fixation in the intact plant plus N from the original planted seed) and the output of N removed with seed yield.

The N derived from the soil in the harvested lentil seed (i.e., $\text{Ndfs}_{\text{seed}}$) was calculated as follows:

$$\text{kg Ndfs}_{\text{seed}} \text{ ha}^{-1} = \text{kg N}_{\text{seed}} \text{ ha}^{-1} - \text{kg Ndfa}_{\text{seed}} \text{ ha}^{-1} \qquad [3.5]$$

To determine the N input from the original seed, the total N in the seed was determined using a CNS-LECO combustion analyzer (LECO Corporation, St. Joseph, MI, USA). Then the total N input from the seed was converted to kg N $ha^{-1}$for the corresponding seeding rates.

A gravimetric method was used to determine soil moisture content (Gardner, 1986). Gravimetric soil water measurements were made using the weights before and after drying in a 105ºC oven for 48 h.

3.2.2. Wheat recropping-Year 2

3.2.2.1. Site and treatment

The wheat recropping experiment was conducted in 2006 and 2007 on the same plots as the Year#1 lentil treatments of 2005 and 2006. The lentil seeding rate experiments were seeded to wheat the following year (2006 and 2007). Locations and site descriptions are given in Appendix 1 and the weather data are reported in Appendix 2.

3.2.2.2. Plot management

In 2006, wheat, cultivar AC Elsa was seeded at a rate of 250 seeds m^{-2} into the lentil stubble on 05 May and 18 May at Delisle and Vonda-05, respectively. Seeding dates in 2007 were delayed due to excess soil moisture. Therefore, Vanscoy and Vonda-06 were seeded on 25 May and 04 June. Prior to seeding, the field was cultivated to a depth of approximately 8- to 10-cm using a heavy-duty cultivator to control early emerging weeds.

Lambs quarter (*Chenopodium album L.*) occurred across the Delisle site and Canada thistle (*Cirsium arvense L.*) and wild mustard (*Sinapsis arvensis L.*) were unevenly distributed at the Vonda-05 and Delisle sites in the 2006 test wheat experiments. Therefore, the weeds were pulled by hand on 60 and 49 DAP at Delisle and Vonda-05, respectively, because the infestations were not spatially homogeneous throughout the trial and were not associated with the treatment plots.

In the 2007 experiment only, wheat biomass was sampled biweekly throughout the growing season to determine the effects of previous lentil seeding rates on wheat biomass and wheat N uptake. Biomass was sampled from 0.25 m quadrats at both ends of each plot. Plants were cut as close as possible to the soil surface. Wheat and weeds were separated and dried at 40ºC to constant weight. The dried wheat and weeds were weighed and ground for total N analysis. Biomass samples were taken at 48, 62 and 74 DAP at Vanscoy and 42, 56 and 71 DAP at Vonda-06.

Soil samples were taken for soil inorganic N and gravimetric moisture measurements the spring before seeding wheat and in the fall after harvesting wheat in both 2006 and 2007. Fall soil sampling was done on 20 and 22 August, 2006 at Delisle and Vonda-05 sites, respectively; and 17 and 18 September, 2007 at Vanscoy and Vonda-06, respectively. Soil samples were taken from 0- to 15-cm, 15- to 30-cm and 30- to 60-cm depths using a Dutch auger. Two soil cores were obtained from each plot, combined and well mixed. Soil samples were analyzed within 24 h of sampling.

In 2006, a 1 m^{-2} sub-plot was hand-harvested from each plot 83 and 101 DAP in Vonda-05 and Delisle, respectively. The Delisle site received hail 96 DAP, thus the hand-harvesting was carried out 5 d after the hail and no mechanical harvest was done. An area 1.6 m x 6 m was mechanically harvested 92 DAP at Vonda-05. In 2007, the hand harvests were performed 97 and 81 DAP; and the mechanical harvest was performed 116 and 100 DAP at Vanscoy and Vonda-06, respectively.

3.2.2.3. Lab analyses

Soil inorganic N and gravimetric moisture were determined for each soil. Soil inorganic N was extracted by shaking 5 g of field moist soil with 50 mL of *2 M* KCl for 1 h (Maynard and Kalra, 1993). Quantification of the NH_4 and NO_3 fractions were determined colorimetrically using a Technicon auto-analyser (Technicon Industrial Systems, Tarrytown, N.J.).

Total N was analyzed in wheat and weed biomass separately using a CNS-LECO combustion analyzer (LECO Corporation, St. Joseph, MI, USA). Plant tissue was ground prior to the analysis. The hand-harvested samples taken at maturity were analyzed for total N in seed and straw separately.

3.2.3. Statistical analyses

Statistical analysis was performed using SPSS Version 15 (SPSS Inc., Chicago, IL). Analysis of variance (ANOVA) was carried out for a randomized complete block design. A significant ANOVA result indicates that at least one of the treatment means was different from the others (Zar, 1999). Replicates were regarded as random effects and treatments were treated as fixed effects. Treatment effects were considered significant at $P \leq 0.05$ using the Least Significant Difference (LSD) method. Sites and years were combined for each crop to compare the deviation of the individual sites and years from the averaged mean. The fit of the equation for the variables determined by linear and quadratic regression using SPSS version 18 (SPSS Inc., Chicago, IL) and Data Analyses features of Microsoft EXCEL version 2007 (Microsoft Corp., Redmond, WA).

3.3. Results

3.3.1. Weather

Precipitation and temperature data were recorded during the growing season using weather stations in close proximity to the research plots (Appendix 2). Between 2005 and 2006, the mean precipitation for the growing season was significantly higher than the 30-yr average due to rainfall events in June and September for both years and all sites (Appendix 2). However, the precipitation in April and May for both years was lower than the long-term average, except at Vanscoy in April 2006 and at Vonda in May 2006. The mean daily temperature for both years was generally near the long-term average for all sites. In both 2006 and 2007, rainfall in July and August for the following wheat years was considerably lower than the 30-yr average, although it was 2 to 3 times greater than long-term average in June for enhancing crop emergence.

3.3.2. Lentil treatment-Year 1

3.3.2.1. Lentil N_2 fixation and N uptake

The percentage Ndfa by lentil was unaffected by seeding rate; however, a significant negative linear trend ($P \leq 0.05$) was detected at Delisle (Table 3.2). There were significant differences in the total quantity of fixed N in the grain and straw. The mean quantity of fixed N in lentil grain ranged from 8.9 to 38.2 kg N ha^{-1}, increasing with seeding rates up to 235 seeds m^{-2} (Fig.3.1). There was no difference in fixed Nin the grain between the two highest seeding rates. The pattern of higher seeding rates accumulating more fixed N_2 was due to the higher grain yield at those rates. Vonda-06 site did not show any significant trend for any of the parameters (Table 3.2). However, the quadratic curves for the quantity of N_2 fixed in grain and total N_2 fixed averaged for sites showed the highest value at 311 seeds m^{-2} (N_2 fixed=37 kg ha^{-1}) and 383 seeds m^{-2} (N_2 fixed=55 kg ha^{-1}), respectively (Fig. 3.1).

The N concentration in lentil grain and straw did not vary significantly among the five seeding rates for both years (Table 3.3). The mean N concentration ranged from 38.2 mg N g^{-1} to 39.0 mg N g^{-1} for the 15 seeds m^{-2} and 375 seeds m^{-2} rates, respectively. No significant differences in the concentration of N in the straw were detected.

As there were no differences in N concentration for the lentil seeding rates, differences in N yield among seeding rates were affected by varied biomass production across all of the sites and years (Table 3.3). Mean total N levels in the lentil grain were 46.4 kg N ha^{-1} and 41.9 kg N ha^{-1} when lentil was seeded at rates of 375 and 235 seeds m^{2}, respectively.

Table 3.2. Percentage nitrogen derived from atmosphere (% Ndfa) in grain and the amount of nitrogen fixed in grain and straw of organically grown lentil in central Saskatchewan in 2005 and 2006.

Target Seeding Rate	2005		2006	
	Delisle	Vonda-05	Vanscoy	Vonda-06
	% Ndfa			
15 seeds m^{-2}	64	95	88	98
38 seeds m^{-2}	74	94	85	99
94 seeds m^{-2}	65	89	88	98
235 seeds m^{-2}	60	92	81	93
375 seeds m^{-2}	49	92	80	98
LSD$_{(0.05)}$	NS †	NS	NS	NS
Linear trend$_{(0.05)}$§	*P* =0.04	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS	NS
	N Fixed in Grain (kg ha $^{-1}$)			
15 seeds m^{-2}	9.0 *c* ‡	19.2 *c*	1.6 *b*	5.7 *c*
38 seeds m^{-2}	10.2 *c*	28.6 *c*	5.4 *b*	17.6 *bc*
94 seeds m^{-2}	12.4 *bc*	39.6 *b*	9.7 *b*	25.1 *ab*
235 seeds m^{-2}	28.7 *a*	61.6 *a*	19.5 *ab*	33.7 *a*
375 seeds m^{-2}	26.4 *ab*	71.3 *a*	25.4 *a*	29.5 *ab*
LSD$_{(0.05)}$	15.7	10.5	9.0	15.7
Linear trend$_{(0.05)}$	*P* =0.03	*P* =0.005	*P* =0.002	NS
Quadratic trend$_{(0.05)}$	NS	*P* =0.009	*P* =0.01	NS
	N Fixed in Straw (kg ha $^{-1}$)			
15 seeds m^{-2}	2.6 *c*	5.5 *c*	0.4 *c*	2.6 *c*
38 seeds m^{-2}	3.4 *c*	6.0 *c*	1.7 *c*	5.7 *bc*
94 seeds m^{-2}	4.5 *bc*	9.1 *b*	2.6 *bc*	8.9 *ab*
235 seeds m^{-2}	8.7 *ab*	15.2 *a*	5.2 *b*	9.8 *ab*
375 seeds m^{-2}	10.4 *a*	16.4 *a*	9.0 *a*	10.9 *a*
LSD$_{(0.05)}$	4.6	2.5	2.8	4.9
Linear trend$_{(0.05)}$	*P* =0.002	*P* =0.008	*P* =0.001	NS
Quadratic trend$_{(0.05)}$	*P* =0.03	*P* =0.02	NS	NS
	Total N Fixed (kg ha $^{-1}$)			
15 seeds m^{-2}	11.7 *c*	24.7 *c*	2.0 *b*	8.4 *b*
38 seeds m^{-2}	13.6 *c*	34.5 *c*	7.1 *b*	23.3 *ab*
94 seeds m^{-2}	16.9 *bc*	48.7 *b*	12.4 *b*	34.0 *a*
235 seeds m^{-2}	37.5 *a*	76.8 *a*	24.7 *a*	43.6 *a*
375 seeds m^{-2}	36.8 *ab*	87.7 *a*	34.4 *a*	40.4 *a*
LSD$_{(0.05)}$	20.1	12.1	11.6	20.3
Linear trend$_{(0.05)}$	*P* =0.02	*P* =0.004	*P* =0.0007	NS
Quadratic trend$_{(0.05)}$	NS	*P* =0.003	*P* =0.02	NS

† Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

‡ Values within a site and column followed by the same letter are not significantly different according to the LSD $P \leq 0.05$).

§ Linear and quadratic functions were applied to seeding rate data.

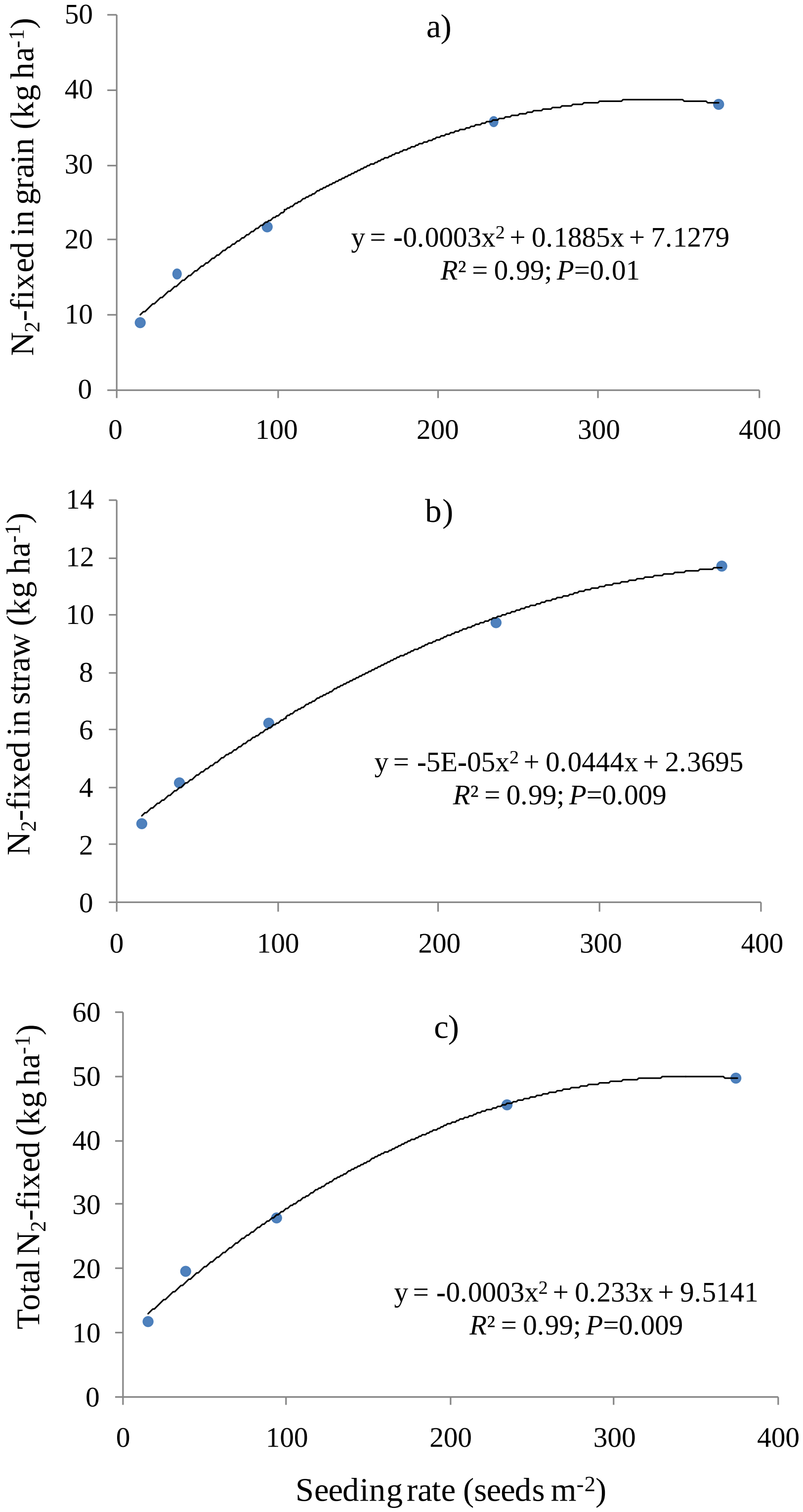

Figure 3.1. Effect of seeding rate on a) fixed N in the grain; c) fixed N in the straw; d) total fixed N of organically grown lentil averaged for four sites. Points represent data averaged over all sites and years.

Table 3.3. Concentration and quantity of nitrogen in seed and straw and nitrogen harvest index for different seeding rates of organically grown lentil in central Saskatchewan in 2005 and 2006.

Site/Year	N concentration		N yield			NHI†
Target Seeding Rate	Grain	Straw	Grain	Straw	Total	
	------------mg g^{-1}-----------		--------------------------kg ha^{-1}----------------------			
Delisle-2005						
15 seeds m^{-2}	39.5	2.1	10.4 *b* ‡	3.0 *c*	13.4 *b*	0.78
38 seeds m^{-2}	37.8	1.8	12.9 *b*	4.3 *c*	17.2 *b*	0.75
94 seeds m^{-2}	37.6	2.0	18.2 *b*	6.7 *c*	24.8 *b*	0.73
235 seeds m^{-2}	39.5	1.9	41.1 *a*	13.1 *b*	54.2 *a*	0.76
375 seeds m^{-2}	40.2	2.1	46.4 *a*	18.4 *a*	64.7 *a*	0.72
LSD$_{(0.05)}$	NS§	NS	15.0	3.9	18.3	NS
Vonda-2005						
15 seeds m^{-2}	38.2	1.9	19.9 *c*	5.6 *c*	25.5 *c*	0.78
38 seeds m^{-2}	39.7	1.6	30.1 *c*	6.3 *c*	36.4 *c*	0.83
94 seeds m^{-2}	37.2	1.5	44.7 *b*	10.2 *b*	54.9 *b*	0.81
235 seeds m^{-2}	39.5	1.6	67.0 *a*	16.5 *a*	83.5 *a*	0.80
375 seeds m^{-2}	39.6	1.6	77.5 *a*	17.8 *a*	95.4 *a*	0.81
LSD$_{(0.05)}$	NS	NS	11.0	2.4	12.2	NS
Vanscoy-2006						
15 seeds m^{-2}	39.2	6.9	1.8 *c*	0.5 *c*	2.3 *c*	0.79
38 seeds m^{-2}	40.0	7.1	6.2 *bc*	1.9 *c*	8.1 *c*	0.77
94 seeds m^{-2}	40.8	7.5	11.1 *b*	3.0 *c*	14.1 *c*	0.79
235 seeds m^{-2}	40.8	7.9	23.6 *a*	6.1 *b*	29.8 *b*	0.79
375 seeds m^{-2}	40.7	8.7	31.4 *a*	11.3 *a*	42.7 *a*	0.74
LSD$_{(0.05)}$	NS	NS	9.1	3.0	11.8	NS
Vonda-2006						
15 seeds m^{-2}	35.9	9.2	5.8 *c*	2.6 *c*	8.4 *c*	0.69
38 seeds m^{-2}	35.4	9.4	18.0 *bc*	5.8 *bc*	23.8 *bc*	0.76
94 seeds m^{-2}	34.9	10.5	25.8 *ab*	9.0 *ab*	34.8 *ab*	0.74
235 seeds m^{-2}	36.4	8.9	35.9 *a*	10.4 *ab*	46.2 *ab*	0.78
375 seeds m^{-2}	35.6	10.4	30.3 *ab*	11.2 *ab*	41.5 *ab*	0.73
LSD$_{(0.05)}$	NS	NS	15.7	5.0	20.3	NS
Mean of Site and Year						
15 seeds m^{-2}	38.2	5.0	9.5 *c*	2.9 *d*	12.4 *c*	0.76
38 seeds m^{-2}	38.2	5.0	16.8 *bc*	4.6 *cd*	21.4 *bc*	0.79
94 seeds m^{-2}	37.6	5.4	24.9 *b*	7.2 *c*	32.2 *bc*	0.78
235 seeds m^{-2}	39.0	5.1	41.9 *a*	11.5 *b*	53.4 *a*	0.78
375 seeds m^{-2}	39.0	5.7	46.4 *a*	14.7 *a*	61.1 *a*	0.76
LSD$_{(0.05)}$	NS	NS	10.8	2.9	13.0	NS

† Nitrogen Harvest Index = grain N yield / total above ground N.

‡ Values within a site and column followed by the same letter are not significantly different according to the LSD ($P \leq 0.05$).

§ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

The lowest total N level of 9.5 kg N ha^{-1} was achieved when lentil was seeded at a rate of 15 seeds m^{-2}. Lentil straw had 2.9 kg N ha^{-1} for the lowest seeding rate with the second highest and highest seeding rate treatments taking up significantly greater N (i.e., 11.5 and 14.7 kg N ha^{-1}, respectively) (Table 3.3). Above-ground biomass production of lentil increased with higher plant population densities, and consequently the total amount of N in lentil grain and straw also increased.

The nitrogen harvest index (NHI) of lentils showed no significant differences between the seeding rates across all of the sites (Table 3.3). On average, the NHI for the site and year ranged between 0.76 and 0.79.

3.3.2.2. Nitrogen contribution

The mean amount of N in the seed originating from the soil N differed significantly between the highest and the lower seeding rates, but the two highest rates did not differ significantly from each other (Table 3.4). At all of the sites the proportion of total seed N derived from the soil declined as the seeding rate decreased.

The N contribution indicated that all the seeding rates left greater amounts of N in the soil than the N removed in the harvested seed at all the sites (Table 3.5). Moreover the N contribution increased linearly with seeding rate (Fig 3.2) with no evidence of a plateau having been achieved. At the Delisle site, the N contribution did not show any differences between the rates and the values were lower than all other sites except for Vanscoy (Table 3.5). At all sites, the N contribution was positive for all the seeding rates. That is, the N inputs exceeded the quantity of N removed in the harvested grain.

Table 3.4. The impact of seeding rate on the source of nitrogen in the seed of organically grown lentil in central Saskatchewan in 2005 and 2006.

Site/Year Target Seeding Rate	Total N in Seed A	Ndfa in Seed† B	Seed Ndfs‡ A-B
	------------------kg N ha^{-1}------------------		
Delisle			
15 seeds m^{-2}	10.4 *b* §	9.0 *c*	1.4 *c*
38 seeds m^{-2}	12.9 *b*	10.2 *c*	2.7 *c*
94 seeds m^{-2}	18.2 *b*	12.4 *bc*	5.8 *bc*
235 seeds m^{-2}	41.1 *a*	28.7 *a*	12.4 *b*
375 seeds m^{-2}	46.4 *a*	26.4 *ab*	20.0 *a*
LSD$_{(0.05)}$	15.0	15.7	7.4
Vonda-05			
15 seeds m^{-2}	19.9 *c*	19.2 *c*	0.7 *b*
38 seeds m^{-2}	30.1 *c*	28.6 *c*	1.5 *ab*
94 seeds m^{-2}	44.7 *b*	39.6 *b*	5.1 *ab*
235 seeds m^{-2}	67.0 *a*	61.6 *a*	5.5 *ab*
375 seeds m^{-2}	77.5 *a*	71.3 *a*	6.2 *a*
LSD$_{(0.05)}$	11.0	10.5	4.9
Vanscoy			
15 seeds m^{-2}	1.8 *c*	1.6 *b*	0.2 *c*
38 seeds m^{-2}	6.2 *bc*	5.4 *b*	0.8 *c*
94 seeds m^{-2}	11.1 *b*	9.7 *b*	1.4 *c*
235 seeds m^{-2}	23.6 *a*	19.5 *a*	4.1 *b*
375 seeds m^{-2}	31.4 *a*	25.4 *a*	6.0 *a*
LSD$_{(0.05)}$	9.1	9.0	1.3
Vonda-06			
15 seeds m^{-2}	5.8 *c*	5.7 *c*	0.1 *b*
38 seeds m^{-2}	18.0 *bc*	17.6 *bc*	0.4 *b*
94 seeds m^{-2}	25.8 *ab*	25.1 *ab*	0.7 *b*
235 seeds m^{-2}	35.9 *a*	33.7 *a*	2.2 *a*
375 seeds m^{-2}	30.3 *ab*	29.5 *ab*	0.8 *b*
LSD$_{(0.05)}$	15.7	15.7	1.4
Mean over Sites and Years			
15 seeds m^{-2}	9.5 *c*	8.9 *d*	0.6 *c*
38 seeds m^{-2}	16.8 *bc*	15.4 *c*	1.3 *bc*
94 seeds m^{-2}	24.9 *b*	21.7 *b*	3.2 *bc*
235 seeds m^{-2}	41.9 *a*	35.9 *a*	6.0 *ab*
375 seeds m^{-2}	46.4 *a*	38.2 *a*	8.2 *a*
LSD$_{(0.05)}$	10.8	5.1	5.0

† Ndfa denotes N derived from the atmosphere.

‡ Ndfs denotes N derived from the soil.

§ Means with the same letter within a site and column are not significantly according to the LSD ($P \leq 0.05$).

Table 3.5. Nitrogen contribution (kg N ha^{-1}) from the above-ground biomass of organically grown lentil grown in 2005 and 2006 in central Saskatchewan.

Target Seeding Rates	N Inputs		N Demand	Nitrogen Contribution
	Total N Fixed† A	N in Original Seed‡ B	Total N in Harvested Seed, C	A+ B-C
Delisle				
15 seeds m^{-2}	11.6 *c* §	0.6	10.4 *b*	1.9
38 seeds m^{-2}	13.6 *c*	1.6	12.9 *b*	2.3
94 seeds m^{-2}	16.9 *bc*	3.9	18.2 *b*	2.6
235 seeds m^{-2}	37.4 *a*	9.7	41.1 *a*	6.0
375 seeds m^{-2}	36.8 *ab*	15.4	46.4 *a*	5.8
$LSD_{(0.05)}$	20.1	-	15.0	NS ¶
Vonda-05				
15 seeds m^{-2}	24.7 *c*	0.6	19.9 *c*	5.4 *b*
38 seeds m^{-2}	34.5 *c*	1.6	30.1 *c*	6.0 *b*
94 seeds m^{-2}	48.7 *b*	3.9	44.7 *b*	7.9 *b*
235 seeds m^{-2}	76.8 *a*	9.7	67.0 *a*	19.4 *a*
375 seeds m^{-2}	87.7 *a*	15.4	77.5 *a*	25.6 *a*
$LSD_{(0.05)}$	12.1	-	11.0	6.3
Vanscoy				
15 seeds m^{-2}	2.0 *b*	0.6	1.8 *c*	0.8 *d*
38 seeds m^{-2}	7.1 *b*	1.6	6.2 *bc*	2.5 *cd*
94 seeds m^{-2}	12.4 *b*	3.9	11.1 *bc*	5.2 *c*
235 seeds m^{-2}	24.7 *a*	9.7	23.6 *a*	10.7 *b*
375 seeds m^{-2}	34.4 *a*	15.4	31.4 *a*	18.5 *a*
$LSD_{(0.05)}$	11.6	-	11.0	2.9
Vonda-06				
15 seeds m^{-2}	8.4 *b*	0.6	5.8 *c*	3.2 *d*
38 seeds m^{-2}	23.3 *ab*	1.6	18.0 *bc*	6.9 *d*
94 seeds m^{-2}	34.0 *a*	3.9	25.8 *ab*	12.1 *c*
235 seeds m^{-2}	43.6 *a*	9.7	35.9 *a*	17.4 *b*
375 seeds m^{-2}	40.4 *a*	15.4	30.3 *ab*	25.6 *a*
$LSD_{(0.05)}$	20.3	-	15.7	2.9

† N fixed in seed plus straw.

‡ Total N determined in initial seed.

§ Values with the same letter within a site and column are not significantly different according to the LSD ($P \leq 0.05$).

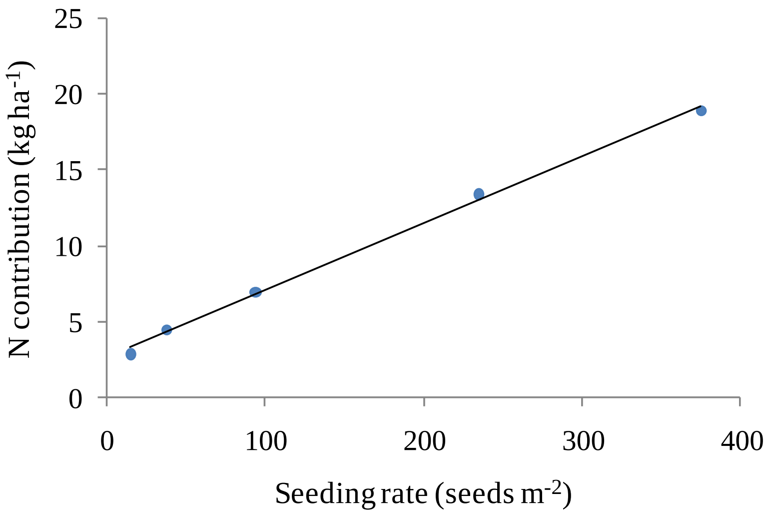

Figure 3.2. Nitrogen contribution from the above-ground biomass of organically grown lentil grown in 2005 and 2006 averaged for four sites in central Saskatchewan.
Line equation: y=0.0442x+2.5858; R^2=0.99; *P*<0.001. Dots represent the averaged data for sites and years. Values under the same letters are not significantly different according to the LSD (*P*≤0.05).

3.3.3. Impact of lentil seeding rates on the succeeding wheat crop-Year 2

3.3.3.1. Soil water and inorganic nitrogen

The spring gravimetric moisture and inorganic N in the soil were determined at Vonda-06 and Vanscoy in 2007 for the 0- to 15-cm, 15- to 30-cm and 30- to 60-cm depths. Pre-seeding soil moisture did not differ significantly between the lentil seeding rates and the summerfallow and the green manure controls (Table 3.6).

According to the ANOVA (*P*≤0.05), levels of inorganic NH_4^+-N and NO_3^--N before seeding were not different between the seeding rates, with a single exception at the Vanscoy site (Table 3.7 and 3.8).

Generally, both linear and quadratic trends were not significant for all the depths and sites with minor exceptions Biweekly measurements of inorganic NH_4^+-N and NO_3^--N amounts did not reveal any differences among the treatments including the controls at any sampling date.

Table 3.6. Soil gravimetric moisture in the spring 2007 following the lentil seeding rate experiments conducted in 2006 at Vanscoy and Vonda-06 sites.

Target Seeding Rate	Soil Moisture			
	0- to 15-cm	15-to 30-cm	30-to 60-cm	0- to 60-cm
Vanscoy	-- cm --			
Summerfallow	2.08	2.75	1.95	6.80
GrM 235 seeds m^{-2}†	2.40	2.93	2.53	7.85
GrM 375 seeds m^{-2}	2.25	2.70	1.98	7.00
$LSD_{(0.05)}$	NS	NS	NS	NS
15 seeds m^{-2}	2.63	3.05	1.40	7.08
38 seeds m^{-2}	2.35	2.80	1.68	6.80
94 seeds m^{-2}	2.35	2.78	2.18	7.30
235 seeds m^{-2}	2.58	2.75	2.53	7.90
375 seeds m^{-2}	2.20	2.83	1.80	6.80
$LSD_{(0.05)}$	NS‡	NS	NS	NS
Vonda-06				
Summerfallow	3.25	3.33	3.90	10.48
GrM 235 seeds m^{-2}	3.38	3.55	4.10	11.03
GrM 375 seeds m^{-2}	3.45	3.53	3.80	10.78
$LSD_{(0.05)}$	NS	NS	NS	NS
15 seeds m^{-2}	4.05	3.50	4.20	11.75
38 seeds m^{-2}	4.05	3.65	4.60	12.33
94 seeds m^{-2}	3.70	3.65	4.68	11.98
235 seeds m^{-2}	3.73	3.98	4.90	12.65
375 seeds m^{-2}	3.83	3.20	4.05	11.10
$LSD_{(0.05)}$	NS	NS	NS	NS

† Green manure treatment.

‡ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

Table 3.7. Inorganic nitrogen in the 0- to 15-cm, 15- to 30-cm and 30- to 60-cm depths measured in spring of 2007 prior to wheat being seeded on lentil seeding rate treatments in 2006 at Vanscoy.

Target Seeding Rate	Vanscoy											
	NO_3^--N				NH_4^+-N				NO_3^--N + NH_4^+-N			
	0 to 15 cm	15 to 30 cm	30 to 60 cm	0 to 60 cm	0 to 15 cm	15 to 30 cm	30 to 60 cm	0 to 60 cm	0 to 15 cm	15 to 30 cm	30 to 60 cm	0 to 60 cm
	kg ha^{-1}											
Summerfallow	7.2	10.8	10.7	28.8	3.3	6.5	7.0 *a* §	16.7	10.5	17.3	17.7	45.5
GrM 235 seeds m^{-2}†	3.0	6.1	8.3	17.4	2.1	6.7	4.8 *b*	13.6	5.1	12.8	13.1	31.1
GrM 375 seeds m^{-2}	9.8	10.4	9.7	29.9	4.1	5.6	4.5 *b*	14.2	13.9	16.0	14.2	44.1
LSD$_{(0.05)}$	NS‡	NS	NS	NS	NS	NS	1.7	NS	NS	NS	NS	NS
15 seeds m^{-2}	1.8	3.4	1.6	6.8	1.3	6.0	4.3 *bc*	11.5	3.1	9.3	5.8	18.3
38 seeds m^{-2}	1.4	5.0	1.9	8.3	1.1	5.4	4.4 *abc*	10.9	2.5	10.3	6.4	19.2
94 seeds m^{-2}	0.0	1.3	4.5	5.7	3.1	5.9	5.9 *a*	14.8	3.1	7.1	10.3	20.5
235 seeds m^{-2}	2.6	0.4	1.8	4.8	3.3	5.1	5.7 *ab*	14.2	6.0	5.1	7.5	18.5
375 seeds m^{-2}	2.2	0.8	2.3	5.3	1.6	6.5	3.9 *c*	12.1	3.9	7.3	6.2	17.4
LSD$_{(0.05)}$	NS	NS	NS	NS	NS	NS	1.4	NS	NS	NS	NS	NS
Linear trend$_{(0.05)}$¶	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS	NS	NS	NS	P =0.04	NS	NS	NS	NS	NS

† Green manure treatment.

‡ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

§ Values within a site and column followed by the same letter are not significantly different according to the LSD ($P \leq 0.05$).

¶ Linear and quadratic functions were applied to seeding rate data.

Table 3.8. Inorganic nitrogen in the 0- to 15-cm, 15- to 30-cm and 30- to 60-cm depths measured in spring of 2007 prior to wheat being seeded on lentil seeding rate treatments in 2006 at Vonda.

Target Seeding Rate	Vonda-06											
	NO_3^--N				NH_4^+-N				NO_3^--N + NH_4^+-N			
	0 to 15 cm	15 to 30 cm	30 to 60 cm	0 to 60 cm	0 to 15 cm	15 to 30 cm	30 to 60 cm	0 to 60 cm	0 to 15 cm	15 to 30 cm	30 to 60 cm	0 to 60 cm
	--------------------kg ha^{-1}--------------------											
Summerfallow	15.4	9.4	19.2	44.0	2.2	4.5	3.0	9.7	17.6	13.9	22.1	53.6
GrM 235 seeds m^{-2}†	9.7	10.9	14.7	35.3	1.8	4.1	3.5	9.5	11.5	15.0	18.2	44.7
GrM 375 seeds m^{-2}	9.7	7.8	21.9	49.4	4.7	3.2	2.9	10.9	14.5	10.9	34.9	60.3
$LSD_{(0.05)}$	NS‡	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
15 seeds m^{-2}	6.5	5.1	5.8	17.3	3.1	4.5	3.7	11.3	9.5	9.6	9.5	28.6
38 seeds m^{-2}	8.4	5.7	7.3	21.3	2.0	6.3	4.5	12.8	10.3	12.0	11.8	34.1
94 seeds m^{-2}	7.9	4.3	8.3	20.5	5.4	2.7	5.1	13.2	13.3	7.1	13.4	33.7
235 seeds m^{-2}	7.8	4.4	8.8	21.1	3.1	5.1	4.9	13.1	10.9	9.6	13.7	34.2
375 seeds m^{-2}	8.2	6.7	18.9	33.7	2.5	3.7	3.8	10.0	10.7	10.4	22.7	43.8
$LSD_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Linear $trend_{(0.05)}$§	NS	NS	$P = 0.03$	NS	NS	NS	NS	NS	NS	NS	$P = 0.02$	$P = 0.05$
Quadratic $trend_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

† Green manure treatment.

‡ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

§ Linear and quadratic functions were applied to seeding rate data.

Table 3.9. Mineralized inorganic nitrogen in the 0- to 15-cm increment of test wheat plots measured biweekly during the summer of 2007 on lentil seeding rate treatments in 2006 at Vanscoy and Vonda-06 sites.

Target Seeding Rate	NO_3^- -N						NH_4^+ -N					
	31-May	14-Jun	28-Jun	12-Jul	26-Jul	09-Aug	31-May	14-Jun	28-Jun	12-Jul	26-Jul	09-Aug
Vanscoy	--						--kg ha^{-1}--					
Summerfallow	55.7	7.2	3.3	9.0	0.1	4.7	26.2	3.3	4.8	7.4	4.9	4.5 *a* ‡
GrM 235 seeds m^{-2}†	23.1	3.0	3.4	12.1	0.0	6.2	24.2	2.1	4.9	10.7	4.6	4.6 *a*
GrM 375 seeds m^{-2}	33.1	9.9	3.6	9.9	0.0	4.6	26.0	4.1	5.0	7.2	4.9	3.6 *b*
LSD$_{(0.05)}$	NS§	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.6
15 seeds m^{-2}	19.2	1.8	1.2	9.2	0.0	4.3	27.0	1.3	6.6	8.2	4.5	4.2
38 seeds m^{-2}	30.9	1.4	2.6	6.8	0.0	5.1	25.8	1.1	5.1	4.0	5.1	5.1
94 seeds m^{-2}	14.5	6.2	2.4	10.6	0.0	4.4	24.7	3.1	4.9	13.1	4.2	4.7
235 seeds m^{-2}	15.6	2.6	1.4	10.2	0.0	4.1	30.6	3.3	5.1	7.3	3.5	3.7
375 seeds m^{-2}	39.3	2.2	1.2	12.8	0.0	4.3	26.8	1.6	6.5	11.2	4.3	4.8
LSD$_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Linear trend$_{(0.05)}$¶	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Vonda-06	29-May	12-Jun	26-Jun	10-Jul	24-Jul	7-Aug	29-May	12-Jun	26-Jun	10-Jul	24-Jul	07-Aug
Summer Fallow	18.8	15.4	10.9	21.1	4.5	1.3	19.8	2.2	8.9	8.7	2.6	6.7 *a*
GrM 235 seeds m^{-2}	18.8	9.7	7.1	16.0	2.2	1.9	14.8	1.8	8.6	7.4	4.4	3.8 *b*
GrM 375 seeds m^{-2}	17.2	9.7	14.8	13.6	1.1	2.7	16.9	4.7	8.5	6.5	4.7	3.8 *b*
LSD$_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	2.4
15 seeds m^{-2}	7.6	6.5	9.1	17.1	2.6	1.0	20.1	3.1	10.0	5.5	5.7	5.6
38 seeds m^{-2}	4.8	8.4	13.7	17.6	2.2	0.9	15.2	2.0	8.2	7.3	3.3	5.9
94 seeds m^{-2}	6.6	7.9	8.5	18.0	1.7	1.1	17.9	5.4	8.4	7.1	3.9	15.5
235 seeds m^{-2}	16.9	7.8	12.7	15.2	3.2	2.0	22.8	3.1	7.5	7.6	7.3	5.4
375 seeds m^{-2}	10.8	8.2	13.1	12.4	1.3	1.4	16.9	2.5	8.7	5.2	3.6	15.0
LSD$_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Linear trend$_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS	P =0.74	NS	NS	NS	NS	NS	NS	NS	NS

† Green manure treatment.

‡ Values within a column followed by the same letter are not significantly different according to the LSD ($P \leq 0.05$).

§ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

¶ Linear and quadratic functions were applied to seeding rate data.

3.3.3.2. Wheat biomass and yield parameters

Wheat biomass determined on four different sampling dates showed no difference among the seeding rates at all sites in 2007 (Table 3.10). About one-half of the N in wheat biomass grown on lentil stubble was accumulated after 19 July. Significant linear and quadratic trends ($P \leq 0.05$) were detected in weed biomass on wheat plots between the previous seeding rate treatments. Specifically, weed biomass apparently increased as seeding rate of the previous lentil crop increased at 19 July and 02 August sampling dates at Vonda (Table 3.11).

Table 3.10. Weight of wheat biomass at different sampling dates in 2007 following the lentil seeding rate experiment in 2006 at Vanscoy and Vonda sites.

Sampling date Target Seeding Rate	05-Jul	19-Jul	02-Aug	23-Aug
Vanscoy	--kg ha^{-1}	--		
Summerfallow	1202	2054	3455	4955
GrM 235 seeds m^{-2}†	1449	2189	3968	5290
GrM 375 seeds m^{-2}	1602	2614	4511	5040
LSD$_{(0.05)}$	NS ‡	NS	NS	NS
15 seeds m^{-2}	620	863	1393	2085
38 seeds m^{-2}	525	749	1254	2315
94 seeds m^{-2}	452	610	1086	1630
235 seeds m^{-2}	746	976	1490	2565
375 seeds m^{-2}	480	634	1487	2100
LSD$_{(0.05)}$	NS	NS	NS	NS
Linear trend$_{(0.05)}$§	NS	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS	NS
Vonda-06				
Summerfallow	1156	2083	3588	4640
GrM 235 seeds m^{-2}	915	1773	3552	3675
GrM 375 seeds m^{-2}	830	1579	3369	3890
LSD$_{(0.05)}$	NS	NS	NS	NS
15 seeds m^{-2}	452	785	1485	2120
38 seeds m^{-2}	650	1006	1625	2595
94 seeds m^{-2}	667	1269	1899	2655
235 seeds m^{-2}	646	1113	1678	2530
375 seeds m^{-2}	888	1161	2006	2635
LSD$_{(0.05)}$	NS	NS	NS	NS
Linear trend$_{(0.05)}$	NS	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS	NS

† Green manure treatment.

‡ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

§ Linear and quadratic functions were applied to seeding rate data.

Table 3.11. Weight of weed biomass at different sampling dates in 2007 in the wheat plots following the 2006 lentil seeding rates experiment at Vanscoy and Vonda sites.

Sampling date Target Seeding Rate	05-Jul	19-Jul	02-Aug
Vanscoy	----------------------------------	kg ha^{-1}	--------------------------------
Summerfallow	354	1646	2501
GrM 235 seeds m^{-2}†	279	2366	2590
GrM 375 seeds m^{-2}	296	2046	2489
$LSD_{(0.05)}$	NS‡	NS	NS
15 seeds m^{-2}	522	1467	2234
38 seeds m^{-2}	759	1861	2415
94 seeds m^{-2}	675	1782	2867
235 seeds m^{-2}	548	1870	2314
375 seeds m^{-2}	1037	2127	2848
$LSD_{(0.05)}$	NS	NS	NS
Linear $trend_{(0.05)}$§	NS	NS	NS
Quadratic $trend_{(0.05)}$	NS	NS	NS
Vonda-06			
Summerfallow	307	1121	1154
GrM 235 seeds m^{-2}†	307	913	1011
GrM 375 seeds m^{-2}	457	848	886
$LSD_{(0.05)}$	NS	NS	NS
15 seeds m^{-2}	298	930	1163
38 seeds m^{-2}	177	918	1221
94 seeds m^{-2}	169	900	1249
235 seeds m^{-2}	233	966	1308
375 seeds m^{-2}	237	1209	1927
$LSD_{(0.05)}$	NS	NS	NS
Linear $trend_{(0.05)}$	NS	$P = 0.04$	$P = 0.04$
Quadratic $trend_{(0.05)}$	NS	$P = 0.02$	NS

† Green manure treatment.

‡ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

§ Linear and quadratic functions were applied to seeding rate data.

Wheat seed and straw yield indicated no significant differences associated with responses to N residues of the previously grown lentil seeding rate treatments (Table 3.12 and Fig. 3.3). Both grain and straw yield preceded by summerfallow and green manure

Table 3.12. Yield parameters of test wheat in 2006 and 2007 following the lentil seeding rate treatments of 2005 and 2006.

Site/Year Target Seeding Rate	Hand Harvested Seed	Hand Harvested Straw	HI†	1000 Seed Weight
Delisle	--------------------------kg ha^{-1}	--------------------------		--g 1000 $seeds^{-1}$--
Summerfallow	1098	3285	0.25	30.5
GrM 235 seeds m^{-2}‡	1256	3441	0.27	31.3
$LSD_{(0.05)}$	NS§	NS	NS	NS
15 seeds m^{-2}	477	1611	0.23	30.7
38 seeds m^{-2}	651	2107	0.24	30.9
94 seeds m^{-2}	484	1841	0.21	30.9
235 seeds m^{-2}	711	1984	0.26	30.9
375 seeds m^{-2}	746	2266	0.25	30.6
$LSD_{(0.05)}$	NS	NS	NS	NS
Vonda-05				
Summerfallow	1479	2966	0.33	31.1
GrM 235 seeds m^{-2}	1591	3128	0.34	30.8
$LSD_{(0.05)}$	NS	NS	NS	NS
15 seeds m^{-2}	1574	3153	0.33	31.3
38 seeds m^{-2}	1623	3144	0.34	31.4
94 seeds m^{-2}	1729	3630	0.32	30.6
235 seeds m^{-2}	1768	3535	0.33	31.2
375 seeds m^{-2}	1462	2667	0.35	30.6
$LSD_{(0.05)}$	NS	NS	NS	NS
Vanscoy				
Summerfallow	1125	3830	0.23	30.8
GrM 235 seeds m^{-2}	1076	4214	0.20	32.2
GrM 375 seeds m^{-2}	971	4069	0.19	33.7
$LSD_{(0.05)}$	NS	NS	NS	NS
15 seeds m^{-2}	312	1773	0.15	27.5
38 seeds m^{-2}	457	1858	0.20	28.9
94 seeds m^{-2}	320	1310	0.20	25.6
235 seeds m^{-2}	362	2203	0.14	29.1
375 seeds m^{-2}	263	1837	0.13	27.3
$LSD_{(0.05)}$	NS	NS	NS	NS
Vonda-06				
Summerfallow	1580	3060	0.34	34.3
GrM 235 seeds m^{-2}	1419	2006	0.41	33.6
GrM 375 seeds m^{-2}	1357	2533	0.35	31.6
$LSD_{(0.05)}$	NS	NS	NS	NS
15 seeds m^{-2}	924	1196	0.44	32.0
38 seeds m^{-2}	963	1632	0.37	25.1
94 seeds m^{-2}	1088	1567	0.41	27.6
235 seeds m^{-2}	1017	1513	0.40	31.7
375 seeds m^{-2}	1062	1573	0.40	32.8
$LSD_{(0.05)}$	NS	NS	NS	NS

† Harvest Index = grain yield / total above ground yield of hand harvest

‡ Green manure treatment.

§ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

treatments were greater than those of all the seeding rate treatments (Fig. 3.3). The harvest index did not change between seeding rates and also no differences were found between the controls (Table 3.12). Thousand seed weights did not change significantly between the treatments except for Vanscoy in 2006 (Table 3.12). At Vanscoy, the green manure control (375 seeds m^{-2}) had the highest thousand seed weight (i.e., 33.7 g) and 94 seeds m^{-2} treatment had the lowest (i.e., 25.6 g).

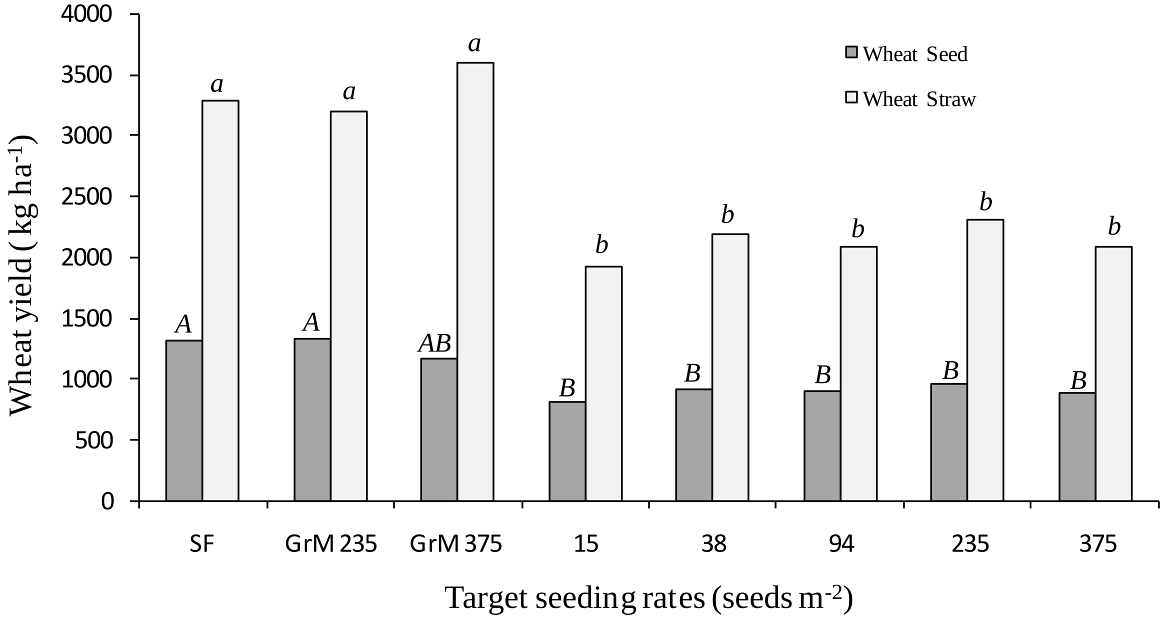

Figure 3.3. Mean wheat seed and straw yield combined over sites in 2006 and 2007 on organically grown lentil stubble of seeding rate experiments conducted in the previous years (2005 and 2006). SF=summerfallow control; GrM=green manure control. The same shading of bars flagged with the same letters are not significantly different according to LSD ($P \leq 0.05$).

3.3.3.3. Wheat nitrogen uptake

The total N in the dry matter of wheat biomass at four different sampling dates in 2007 showed no significant differences between the seeding rates of the previous lentils for all the sampling dates and sites, except for a significant linear trend detected at 02 August sampling date at Vonda (Table 3.13). However, the total N in wheat grown after the summerfallow and green manure controls was significantly greater than those of the seeding rate treatments on all sampling dates, except for 05 July and 02 August at the Vonda site (Table 3.13).

Table 3.13. Total nitrogen in test wheat biomass at different sampling dates in 2007 following the lentil seeding rates experiment in 2006 at Vanscoy and Vonda sites.

Sampling date Target Seeding Rate	05-Jul	19-Jul	02-Aug	23-Aug
Vanscoy	kg ha^{-1}			
Summerfallow	32.2	37.1	32.5	55.0
GrM 235 seeds m^{-2}†	37.3	41.3	40.6	55.8
GrM 375 seeds m^{-2}	46.1	49.5	45.9	54.8
LSD$_{(0.05)}$	NS ‡	NS	NS	NS
15 seeds m^{-2}	12.1	12.7	10.2	15.8
38 seeds m^{-2}	10.2	11.1	9.4	19.0
94 seeds m^{-2}	9.2	8.9	7.7	15.2
235 seeds m^{-2}	14.6	13.6	9.8	20.4
375 seeds m^{-2}	9.1	8.7	11.0	18.3
LSD$_{(0.05)}$	NS	NS	NS	NS
Linear trend$_{(0.05)}$§	NS	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS	NS
Vonda-06				
Summerfallow	39.6	39.5	33.7	52.8
GrM 235 seeds m^{-2}	30.3	31.7	26.8	47.3
GrM 375 seeds m^{-2}	30.2	28.5	37.8	43.6
LSD$_{(0.05)}$	NS	NS	NS	NS
15 seeds m^{-2}	12.4	12.0	12.3	24.3
38 seeds m^{-2}	18.5	14.7	13.9	27.1
94 seeds m^{-2}	17.4	18.5	15.2	29.3
235 seeds m^{-2}	18.6	17.6	14.7	28.9
375 seeds m^{-2}	25.9	17.2	17.8	31.3
LSD$_{(0.05)}$	NS	NS	NS	NS
Linear trend$_{(0.05)}$	NS	NS	P =0.04	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS	NS

† Green manure treatment.

‡ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

§ Linear and quadratic functions were applied to seeding rate data.

Although wheat seed N uptake was not affected by seeding rate at three sites out of four, both ANOVA ($P \leq 0.05$) and linear regression detected a difference at Delisle (Table

3.14). The lowest seeding rate (15 seeds m^{-2}) accumulated significantly less N in the seed at Delisle. The combined mean of wheat seed N uptake ranged from 16.9 to 20.6 kg N ha^{-1} but was not significantly different between the seeding rate treatments across all the sites. Total N in the wheat seed produced on the summerfallow and green manure treatments did not differ significantly, although these values were higher than those from wheat grown on lentil stubble (Table 3.14).

Table 3.14. Total nitrogen in the test wheat seed at harvest in 2006 and 2007 following the lentil seeding rates experiments in 2005 and 2006.

Site/Year Target Seeding Rate	2006 Delsile	 Vonda-05	2007 Vanscoy	 Vonda-06	Mean
	---kg ha^{-1}---				
Summerfallow	30.9	29.4	32.1	35.5	32.0
GrM 235 seeds m^{-2}†	36.7	32.1	32.6	32.1	33.4
GrM 375 seeds m^{-2}	- §	-	29.5	29.6	29.5
LSD$_{(0.05)}$	NS ¶	NS	NS	NS	NS
15 seeds m^{-2}	9.9 *c* ‡	32.1	7.7	17.9	16.9
38 seeds m^{-2}	13.0 *abc*	33.4	10.9	18.8	19.0
94 seeds m^{-2}	11.8 *bc*	37.1	7.8	21.5	19.5
235 seeds m^{-2}	16.0 *ab*	36.4	9.1	20.9	20.6
375 seeds m^{-2}	18.4 *a*	28.7	6.8	22.0	19.0
LSD$_{(0.05)}$	5.7	NS	NS	NS	NS
Linear trend$_{(0.05)}$#	P =0.01	NS	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS	NS	NS

† Green manure treatment.

‡ Values within a column followed by the same letter are not significantly different according to LSD ($P \leq 0.05$).

§ The control was not established in the given year.

¶ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

Linear and quadratic functions were applied to seeding rate data.

Weeds competed with wheat for N on the lentil stubble. Nitrogen in the weed biomass on three different sampling dates during the growing season was unaffected by the previous lentil seeding rates (Table 3.15). Weed N was relatively high compared to the N in wheat grown at Vanscoy (Table 3.15), and was two to three times higher than that of wheat for the various sampling dates. An analysis of N uptake into wheat and weeds combined did not reveal any differences among the seeding rate treatments (Appendix 3).

Table 3.15. Total nitrogen in weed biomass at different sampling dates in 2007 in the wheat plots following the 2006 lentil seeding rates experiment at Vanscoy and Vonda sites.

Sampling date Target Seeding Rate	05-Jul	19-Jul	02-Aug
Vanscoy	------------------------------	----kg N ha^{-1}----	------------------------------
Summerfallow	12.2	34.9	30.3
GrM 235 seeds m^{-2}†	9.2	45.2	32.4
GrM 375 seeds m^{-2}	10.9	47.2	34.5
LSD$_{(0.05)}$	NS‡	NS	NS
15 seeds m^{-2}	14.2	23.4	20.3
38 seeds m^{-2}	20.0	28.4	22.6
94 seeds m^{-2}	17.0	28.0	25.6
235 seeds m^{-2}	17.9	30.0	19.7
375 seeds m^{-2}	27.8	33.0	23.3
LSD$_{(0.05)}$	NS	NS	NS
Linear trend$_{(0.05)}$§	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS
Vonda-06			
Summerfallow	11.3	18.1	12.3
GrM 235 seeds m^{-2}	10.0	15.6	10.6
GrM 375 seeds m^{-2}	15.3	15.1	10.5
LSD$_{(0.05)}$	NS	NS	NS
15 seeds m^{-2}	7.2	12.9	10.8
38 seeds m^{-2}	5.2	13.5	11.9
94 seeds m^{-2}	4.8	12.7	11.2
235 seeds m^{-2}	7.1	14.9	11.8
375 seeds m^{-2}	7.0	18.4	17.7
LSD$_{(0.05)}$	NS	NS	NS
Linear trend$_{(0.05)}$	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS

† Green manure treatment.

‡ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

§ Linear and quadratic functions were applied to seeding rate data.

3.4. Discussion

Between 80 to 88% N in organically grown lentil was derived through biological N_2 fixation, which was high compared to findings reported by Walley et al. (2007) who combined results of 11 trials in the Northern Great Plains and reported that the median level for lentils was ~60%. In our experiment, weed pressure was greater in the plots during early growth stages of lentil at all sites. Therefore, the high N demand of the weeds and lentil probably depleted the soil inorganic pool in earlier growth stages, thus making atmospheric N_2 the main source of N for lentil (Bremer et al., 1988). Others similarly observed that competition from non-fixing plants can force pulses to fulfill their N requirements by N_2 fixation. For example, Danso et al. (1987) reported that the %Ndfa for intercropped faba bean (*Vicia faba L.*) was approximately 18% higher than mono-cropped faba bean. Soon et al. (2004) reported that the longer pea was subjected to weed competition, the greater the proportion of N derived from symbiotic fixation. Thus, the relatively high levels of N_2 fixation achieved by lentil grown in this study are consistent with the finding that weed competition increased N_2 fixation. Baird (2007) working at this site, reported proportionally greater weed suppression at lower seeding rates.

Although the linear trend indicated that higher seeding rates fixed less N_2 at one site (Delisle in 2005), similar trends were not observed at other sites (Table 3.2). Bremer (1991) also found no difference in %Ndfa (i.e., 74 to 81% and 23 to 34%) at two sites for three lentil cultivars, when the seeding rates ranged from 45 to 110 kg ha^{-1}. In Bremer’s study, the number of plants per square meter was not noted, but the highest seeding rate used falls within the range of the seeding rate treatments in our study, in which the rates ranged between 14 and 346 kg ha^{-1}. Their study used the natural abundance method to quantify N_2 fixation, as also was done in our study. Although the %Ndfa was largely unaffected by seeding rate, the significant differences in the quantity of N_2 fixed between the seeding rates (Table 3.2) were due to the significant increase in the lentil yield with the increasing rates, as was reported by Baird (2007). According to the quadratic regression, the amount of N_2 fixed in grain and total N_2 fixed averaged across all sites reached a maxima at 311 seeds m^{-2} (N_2 fixed=37 kg ha^{-1}) and 383 seeds m^{-2} (N_2 fixed=55 kg ha^{-1}), respectively (Fig. 3.1). These results are relatively low when compared to amounts of N_2 fixed in other studies. Rennie and Dubetz (1986) reported that the amount of total N_2 fixed by lentil was 162 kg ha^{-1} at the seeding rate of 80 kg ha^{-1} when grown under irrigation using a conventional production practices in western Canada. The lower amount of N_2 fixed was might be due to the decrease of lentil biomass yield by weed suppression and enhanced water availability as the biomass yield in their study was two to three times higher than that of our study (Rennie and Dubetz, 1986; Baird, 2007). In agreement with this, Cowell et al., (1989) reported that lentil yields were reduced by 28 to 49% when grown as an intercrop. Moreover, fixed N in lentil grain also was reduced in the intercropped lentil.

The N harvest index (NHI) did not show any trends or differences in our study, but Ayaz et al. (2004) reported that the general trend was for NHI, for four different legumes, to increase with plant population. In their study, the differences might have been enhanced by the large increment of change in plant population which ranged from 10, 100 and 400 plants m^{-2}, whereas we were unable to detect any differences in the NHI associated with the smaller increments in seeding rates in our study.

In our study, we observed a significant trend for increased lentil N yield with the increasing seeding rates from the lowest to the highest, i.e., 15 to 375 seeds m^{-2} (Table 3.3). The significant differences in N yield were subject to the greatly varied lentil yield between the seeding rates. Ayaz et al. (2004) reported that N yield of lentil tended to increase when the seeding rates increased from 15 to 600 plants m^{-2}. The total N yield in our study ranged between 12.1 and 61.4 kg ha^{-1}for the lowest and highest seeding rates, respectively. These total N yields were relatively low compared to those reported for other studies (Rennie and Dubetz, 1986; Bremer, 1991). However, our trials were established in organic production with limited nutrient supply. Moreover, weed suppression was problematic, limiting the crop yield and N uptake.

The overall N contribution or N left in the soil (i.e., N balance) was positive for all treatments and showed a significant trend of increased N contribution from the lower rates to the highest seeding rate (i.e., 2.8 to 18.9 kg N ha^{-1}) (Table 3.6). Evans et al. (2001) reported that the N balance was positively correlated with the proportion of N derived from N_2 fixation. Moreover, Walley et al. (2007) found that lentil grown in the northern Great Plains typically needed to derive more than 60% of the crop N from fixation in order to achieve a positive N balance. In our study, %Ndfa values ranged from 79.8 to 87.8%, which was adequate to achieve a positive N balance (Table 3.5).

Wheat grown on lentil stubble was largely unaffected by the seeding rate of the previous crop. This result was somewhat surprising as increasing lentil seeding rates resulted in increased N contribution to the soil (Table 3.5).

It was assumed that different seeding rates may have led to differences in soil water, because high biomass production would be expected to use more soil water. However, no differences in soil water were detected in our study for the three different soil depth increments of 0- to 15-cm, 15- to 30-cm and 30- to 60-cm. These results could be attributed to high precipitation in late fall and early spring and snow run-off effects (Appendix 1). In a similar study, in which lentil seeding rates were 110 and 80 kg ha^{-1}, it was observed that if soil water is not excessive, significant differences between the treatments in soil water could be detected (Bremer and Van Kessel, 1991). Bremer and Van Kessel (1991) found that significant changes were detected between treatments in the spring soil water content up to 120-cm, when the overwinter precipitation was negligible and spring precipitation was 23% lower than the long-term average. Thus, higher water inputs may alter any differences that existed or eliminate slight differences in soil moisture content between treatments. Additionally, the affect of soil water depletion by the abundant weed population may have eliminated any effect of seeding rate.

The higher N content of pulse residue could have promoted the mineralization processes (Janzen and Kucey, 1988), thus the impacts of the increased N remaining from the higher seeding rates of lentil was expected to be detected in the soil for the following season.

Differences in levels of inorganic N in the soil in the spring among the lentil stubble treatments were not detected according to the ANOVA ($P \leq 0.05$). However, according to the regression ($P \leq 0.05$), NO_3^--N and total inorganic N in the 30- to 60-cm depth at Vonda-06 and NH_4^+-N in 30- to 60-cm depth at Vanscoy showed significant trends. Specifically, inorganic N levels had a tendency to increase with increasing seeding rates, although levels remained low in all treatments. This might be affected by the weed population density in the preceding growing season. As reported in Baird (2007), weed suppression was greater on lower seeding rates, thus, the high weed population possibly depleted soil inorganic N in lower seeding rate treatments.

The total inorganic N in the soil in 0- to 60-cm depth just before seeding ranged from 23 to 31 kg ha^{-1} for sites in 2007. Past studies that examined N effects of lentil conducted on unfertilized soils under conventional farming practices, reported higher levels of soil inorganic N than our findings (Bremer and Van Kessel, 1991; Adderley et al., 2006). Bremer and Van Kessel (1991) reported 35 kg N ha^{-1} and 94 kg N ha^{-1}for previous lentil seeding rates of 110 and 80 kg ha^{-1}, respectively, in the Brown soil zone of Saskatchewan. Adderley et al. (2006) indicated that pre-seeding total inorganic N (NH_4^+-N + NO_3^--N) was 56 to 68 kg N ha^{-1}and 31 to 95 kg N ha^{-1} in the 0- to 15-cm depth, respectively, in the Dark Brown soil zone of Saskatchewan. The lower inorganic N levels observed on our study may be partly explained by the depletion of soil N by shared crop and weed N utilization in the lentil year. Besides this, abundant moisture content was observed before seeding in the wheat year, especially at the Vonda site where seeding was delayed due to the high moisture content in the soil in 2007. Because the soil was saturated in early spring, substantial N losses probably occurred as a result of denitrification (Miller et al., 2006). Thus, the spring water saturation likely reduced soil inorganic N levels and thus may have obliterated any treatment difference that otherwise might have existed.

Bremer and Van Kessel (1991) reported that N in the lentil residue was not sufficiently high to support net N mineralization in the following year. They observed that net N addition by lentil was negligible at one site and negative at another. A similar finding by Jensen (1994) also indicated that the benefit of residue N to a succeeding non-legume crop is usually less than 5%. Stevenson and Van Kessel (1991) examined residual N from lentil residue and reported that the N benefit for the following year was 8% of the total N contribution. In our study, the measured N contribution by lentil remaining to the succeeding wheat was 2.8 to 18.9 kg N ha^{-1}(Table 3.5). Assuming an N benefit of approximately 5% from the amount of N contributed in the preceding year, as reported in previous studies, the available N benefit in our study for the following wheat would be only 0.1 to 0.9 kg N ha^{-1}. Therefore, the amount of N benefit from lentil residue in the following year in our study might not be sufficient to show detectable differences between the previous lentil stubble in N uptake in the following crop.

3.5. Conclusion

The impact of lentil seeding rate on %Ndfa was not apparent at three of four sites. However, the quantity of N_2 fixed was significantly different between the seeding rate treatments due to the large differences in total N in lentil grain. Thus, there was a significant relationship between the quantity of N_2 fixed and lentil N accumulation. The higher %Ndfa and amounts of N_2 fixed influenced the N contribution to the soil; thus, seeding rates also had a significant positive relationship with N contribution.

All of the lentil treatments took up additional N from the soil N pool to produce the seed (Table 3.4). The Ndfs combined for sites ranged from 0.6 to 8.2 kg N ha^{-1} for the lowest and highest seeding rate treatments. Higher seeding rates utilized significantly greater amount of N from the soil. However, higher lentil seeding rates contributed higher N benefits because of higher levels of fixed N_2, particularly in the straw residue (Table 3.5).

There was no detectable difference between the treatments in N effects from previous lentil stubble on the wheat grown in the following year. Soil inorganic N determined pre-seeding and during the wheat growing season generally did not differ due to seeding rate. Any evidence of N benefit from different seeding rates of the lentil stubble was not detected for N uptake into wheat grain and wheat biomass. The biomass weight and N uptake of the wheat crop was noticeably suppressed by the relatively high weed pressure. However, the results of analyses on combined weed and wheat biomass and N uptake did not detect any differences in total N uptakes due to seeding rates of the previous lentil crop.

Generally, it can be concluded that the impact of lentil seeding rates on the amount of N_2 fixed and N contribution to the soil were, at best, minimal. The small amount of residue N remaining in the lentil crop did not contribute to measurable differences in N benefit to the following wheat crop.

4. EFFECT OF SEEDING RATES OF ORGANICALLY GROWN FIELD PEA ON DINITROGEN FIXATION AND THE NITROGEN BENEFIT TO THE SUCCEEDING WHEAT CROP

4.1. Introduction

Soil nutrient deficiencies, such as N deficiency, and increased weed pressure are common issues in organic crop management systems and may lead to crop yield reductions (Waldon et al., 1998; Clark et al., 1999; Ryan et al., 2004). Organic producers are prohibited from using synthetic substances, especially fertilizers and pesticides (CGSB, 2006). Weeds can be controlled using various tillage regimes (Barberi et al., 2000), crop rotations and intercrops (Hartl, 1989), changes to crop seeding density (Korres and Froud-Williams, 2002), and the use of competitive cultivars (Huel and Hucl, 1996; Lemerle et al., 1996). By including grain legumes in cereal-based rotations, weeds and diseases can be reduced, soil structure improved, and nutrient availability enhanced (Stevenson and Van Kessel, 1996).

To meet the N requirements of organic cropping systems, N_2-fixing grain legumes can be grown to provide some of the N required by the non-fixing crops in cereal-based rotations (Campbell et al., 1989; Hoeppner, 2001; Stockdale et al., 2001). Seeding rates recommendations for organic production of field pea have not been fully established in western Canada. Thus, organic farmers rely on seeding rates recommended for conventional production of pea. Appropriate seeding rates for organically produced field pea should be determined in order to maximize both N_2 fixation and the residual benefit of the pulse crop to the succeeding crops. The objectives of the study were to determine the relationship between the seeding rate of organically grown field pea and N_2 fixation, and the subsequent N benefits of the pea crop to the succeeding wheat crop in a cereal-dominated rotation. The experiment was conducted over two years and was conducted as a component of a larger study which examined the economically optimal pea seeding rate (Baird, 2007). In the first year, field pea was seeded at five different seeding rates and the relationship between seeding rate and N_2 fixation was examined. In the subsequent growing season, wheat was seeded into the pea stubble and the impact of pea residue on the following wheat crop was determined.

4.2. Materials and Methods

4.2.1. Field pea treatment-Year 1

4.2.1.1. Site description

Sites were established on existing organic farms near Delisle and Vonda, SK in 2005 and Vanscoy and Vonda, SK in 2006. All sites were organically managed for 8 to 20 yrs. Site descriptions are provided in Sections 3.2.1.1 and Appendix 1.

Precipitation and temperature data were recorded during the growing season at weather stations in close proximity to the research plots (Appendix 2).

4.2.1.2. Treatments and experimental design

Field pea (*Pisum sativum*) cultivar CDC Mozart was seeded at five rates equivalent to 10, 25, 62, 156 and 250 seeds m^{-2}. Additionally, summerfallow and green manure treatments were included as controls. Green manure treatments were seeded with the field pea cultivar CDC Trapper. One green manure and one summerfallow treatment were included in each replicate at each site. In 2005, field pea was seeded as the green manure control at a rate of

62 seeds m^{-2} which was determined to be the optimal seeding density for field pea green manure (Lawley, 2004). In 2006, one additional green manure control was added on the newly selected sites (Vonda-2006 and Vanscoy). This modification was made due to poor crop emergence in all green manure plots in 2005. The intent to include a higher seeding rate green manure treatment was to achieve the target plant density which previously had not been achieved. The pea green manure seeding rate was increased to 156 seeds m^{-2} for the second green manure treatment.

The experimental plots were organized in a randomized complete block design with four replicates. Plot size of the field pea and control treatments was 2 m x 6 m in 2005 and expanded to 4 m x 6 m in 2006.

The spring wheat cultivar AC Elsa was sown as a non-fixing reference crop in the alleys between the blocks for estimating N_2 fixation in each treatment. Further information regarding experimental design is provided in Section 3.2.1.3 and Baird et al. (2009).

4.2.1.3. Plot management

The experimental plots were seeded with a small-plot disc seeder after the experimental area was cultivated to a depth of 10 to 12 cm using a heavy duty cultivator. In-crop harrowing was performed with two passes using a flex-tine harrow, as required, to control weeds in early stages of the experiments. The plot management operations and dates are summarized in Table 4.1.

Above-ground crop samples were hand-harvested from 1-m long four rows (equivalent to 0.81 m^{-2}) from both the field pea and the reference wheat for measuring N_2 fixation. Plants were cut as close as possible to the soil surface. Reference wheat was seeded between the blocks and the samples for ^{15}N analysis were taken from the closest row to each field pea plot. In addition, 1-m rows were harvested on July 5, July 19, Aug 2 and Aug 23.

In 2006, a Canada thistle infestation was hand-weeded two days prior to the green manure ploughdown in the field pea trial at Vonda, as the occurrence of the weed was not homogeneous throughout the trial and was not associated with the treatment plots. Moreover, the extremely competitive nature of Canada thistle may have strongly influenced growth of the field pea treatments where it occurred within plots.

Table 4.1. Field operations for the experimental sites of organically grown field pea in central Saskatchewan in 2005 and 2006.

Operation	2005		2006	
	Delisle	Vonda-05	Vanscoy	Vonda-06
	Days after planting			
Seeding	May-20	May-11	May-12	May-18
In-crop harrowing	33	26	21	13
Summerfallow tillage # 1	47	56	47	49
Green manure ploughdown†	61	53	54	51
Summerfallow tillage # 2	104	113	84	79
Sampling at Physiological maturity	82	89	77	72
Hand harvest	94	103	83	83
Mecahnical harvest	NP‡	NP	96	97

† A second green manure ploughdown was performed on the same date as summerfallow tillage # 2 at both Delisle and Vonda-05 plots.

‡ NP, not performed

In 2005, only hand-harvested samples (1 m x 1 m) were collected because the 2-m wide plots were disturbed by sampling. In 2006, an undisturbed 2-m strip at the right half of the treatment plots was mechanically harvested (1.6 m x 6 m).

After harvest, two soil samples were taken at 0- to 15-cm and 15- to 30-cm depths using a hand auger after harvesting. Samples for each depth were bulked. Gravimetric soil moisture and inorganic N were determined as described in Section 3.2.2.3.

4.2.1.4. Analytical techniques

One-hundred seed weight was determined by weighing two subsamples of 100 seeds from each sample and determining an average weight. Field pea and reference wheat samples were ground and subsequently ball-milled for 24 h for mass spectrometery analysis.

The percentage N derived from atmospheric N_2 (%Ndfa) in the field pea was determined using the ^{15}N natural abundance technique (Shearer and Kohl, 1986). Atmospheric N_2 fixed in straw was estimated by assuming that the %Ndfa did not differ between the seed and straw. However, Walley et al. (2007) cautions that this assumption likely overestimates the contribution of N in the shoot residues from N_2 fixation, as seed N is known to have higher %Ndfa values than shoot biomass (Van Kessel, 1994).

Total N in the plant tissue was determined using a CNS-LECO combustion analyzer (LECO Corporation, St. Joseph, MI, USA). The N input from the original seed was determined and was converted to kg N $ha^{-1}$for the corresponding seeding rates. Plant sampling and subsequent laboratory analyses were performed as previously described for the lentil experiment (Section 3.2.1.5).

A gravimetric method was used to determine soil moisture content (Gardner, 1986). Gravimetric soil water measurements were made using the weights before and after drying in a 105ºC oven for 48 h.

4.2.2. Wheat recropping-Year 2

4.2.2.1. Site and treatment

The wheat recropping experiment was conducted on the same plots as the Year#1-field pea treatments of 2005 and 2006 (Section 4.2.1.1). The wheat recropping experiment was established on Delisle and Vonda-05 sites in 2006 and on Vanscoy and Vonda-06 sites in 2007. Wheat (cv AC Elsa) was planted at a rate of 250 seeds m^{-2} into the previous field pea stubble treatments and the controls. Locations and site descriptions are presented in Appendix 1 and weather data are in Appendix 2.

4.2.2.2. Plot management and sampling

Identical field operations as used in the wheat recropping into lentil stubble were performed for this experiment (Section 3.2.2.2). Briefly, wheat (cultivar AC Elsa) was seeded into the field pea stubble. Prior to seeding, the field was cultivated to a depth of approximately 8- to 10-cm using a heavy-duty cultivator to control early-emerging weeds.

In the 2007 experiment only, wheat and weed biomass were sampled biweekly to determine N uptake. Biomass was sampled from 0.25 m^{-2} at both ends of each plot. Sampling techniques and methods were identical to those described for the lentil experiment (Section 3.2.2.2).

Soil samples were collected for soil inorganic N and gravimetric moisture measurements the spring before seeding wheat and in the fall after harvest in both 2006 and 2007. Fall soil sampling was done on 20 and 22 August 2006 at Delisle and Vonda-05 sites, respectively. The same sampling was done on 17 and 18 September 2007 at Vanscoy and Vonda-06, respectively. Soil samples were taken from 0- to 15-cm, 15- to 30-cm and 30- to 60-cm depths using a Dutch auger.

In the 2007 experiment, soil samples were collected biweekly in 0- to15-cm depth throughout the growing season from each wheat plot for determining differences in N mineralization. For all soil sampling, two soil cores were obtained from each plot in each depth and then combined and well mixed. Soil samples were kept in a cold room at 4°C and analyzed within 24 h of sampling.

In 2006, a 1 m^{-2} sub-plot was hand-harvested from each plot 83 and 101 DAP in Vonda-05 and Delisle, respectively. An area 1.6 m x 6 m was mechanically harvested 92 DAP in 2006 at Vonda-05. Because of hail damage, a mechanical harvest was not performed at Delisle. In 2007, hand harvesting was performed 97 and 81 DAP; and the mechanical harvest was performed 116 and 100 DAP at Vanscoy and Vonda-06, respectively.

4.2.2.3. Lab analyses

Lab analyses for the wheat recropping after field pea experiment also were performed the same way as for the wheat recropping after lentil experiment described in Section 3.2.2.3. Briefly, soil inorganic N and gravimetric moisture were determined for each soil. Soil inorganic N was extracted by shaking 5 g of field moist soil with 50 mL of *2 M* KCl for 1 h (Maynard and Kalra, 1993). Quantification of the NH_4^+-N and NO_3^--N fractions were analyzed colorimetrically using a Technicon auto-analyser (Technicon Industrial Systems, Tarrytown, N.J.). Total N in wheat and weed biomass was analyzed separately using a CNS-LECO combustion analyzer (LECO Corporation, St. Joseph, MI, USA). Plant tissues were ground prior to the analysis. The hand-harvested samples taken at maturity were analyzed for total N in seed and straw separately.

4.2.3. Statistical analyses

Statistical analysis was performed using SPSS version 15 (SPSS Inc., Chicago, IL). Analysis of variance (ANOVA) was conducted. A significant ANOVA result indicates that at least one of the treatment means was different (Zar, 1999). Replicates were regarded as random effects and treatments were treated as fixed effects. Means separation was conducted using the Least Significant Difference (LSD) ($P \leq 0.05$). Sites and years were combined for each crop to compare the deviation of the individual sites and years from the averaged mean.

The fit of the equation for the variables determined by linear and quadratic regression using SPSS version 18 (SPSS Inc., Chicago, IL) and Data Analyses features of Microsoft EXCEL version 2007 (Microsoft Corp., Redmond, WA).

4.3. Results

4.3.1. Weather

During the experimental years, the mean precipitation for the growing season was significantly higher than the 30-yr average due to the greater rainfalls in June and September for both 2005 and 2006 at all sites (Appendix 1). In both 2006 and 2007, rainfall in July and August for the following wheat experiments was considerably lower than the 30-yr average, although it was greater than the long-term average in June and enhanced crop emergence.

4.3.2. Field pea treatment-Year 1

4.3.2.1. N_2 fixation and N uptake

The %Ndfa of field pea was unaffected by seeding rate (Table 4.2). The mean %Ndfa combined over all sites ranged from 75 to 81 % (Table 4.2). However, based on the above-ground biomass N yield (Baird, 2007), the average quantity of fixed N_2 in the grain increased significantly from the lower seeding rates to higher seeding rates at all site and ranged from a low of 2.2 kg N ha^{-1}at Delisle to 57.9 kg N ha^{-1} at Vonda-05. Averaged across sites, total fixed N_2 ranged from 5.5 to 42.3 kg N ha^{-1} (Fig. 4.1). The mean amount of fixed N_2 averaged across sites indicated that a maxima was not achieved, even at the highest seeding rate, although the slope of the response line was less at the highest seeding rates (Fig. 4.1).

No differences in N concentration in the field pea straw and grain were detected between the seeding rates at all sites and years (Table 4.3). However, N yield averaged across

Table 4.2. Percentage of nitrogen derived from atmosphere (% Ndfa) in grain and amount of nitrogen fixed in grain and straw of organically grown field pea in central Saskatchewan in 2005 and 2006.

Target Seeding Rate	2005		2006	
	Delisle	Vonda-05	Vanscoy	Vonda-06
	% Ndfa			
10 seeds m^{-2}	58	96	73	97
25 seeds m^{-2}	48	98	72	97
62 seeds m^{-2}	41	95	67	95
156 seeds m^{-2}	42	95	77	98
250 seeds m^{-2}	50	94	74	94
LSD$_{(0.05)}$	NS †	NS	NS	NS
Linear trend$_{(0.05)}$¶	NS	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS	NS
	N Fixed in Grain (kg ha^{-1})			
10 seeds m^{-2}	2.2 *b*	12.2 *c* ‡	3.6 *c*	4.2 *c*
25 seeds m^{-2}	10.3 *ab*	20.3 *bc*	7.1 *bc*	14.1 *bc*
62 seeds m^{-2}	17.0 *ab*	30.9 *bc*	18.7 *b*	21.8 *bc*
156 seeds m^{-2}	22.6 *a*	49.8 *a*	38.6 *a*	32.3 *ab*
250 seeds m^{-2}	29.4 *a*	57.9 *a*	38.4 *a*	43.5 *ab*
LSD$_{(0.05)}$	20.2 §	16.6	11.6	20.2
Linear trend$_{(0.05)}$	P =0.02	P =0.006	P =0.02	P =0.007
Quadratic trend$_{(0.05)}$	NS	P =0.008	P =0.005	NS
	N Fixed in Straw (kg ha^{-1})			
10 seeds m^{-2}	0.5 *c*	4.1 *d*	1.5 *c*	1.9 *d*
25 seeds m^{-2}	2.6 *c*	7.2 *cd*	3.2 *bc*	4.9 *cd*
62 seeds m^{-2}	4.8 *bc*	10.9 *c*	7.3 *b*	9.1 *bc*
156 seeds m^{-2}	6.8 *ab*	19.1 *b*	15.0 *a*	12.2 *ab*
250 seeds m^{-2}	11.7 *a*	28.0 *a*	18.3 *a*	16.7 *a*
LSD$_{(0.05)}$	5.9	6.5	5.2	6.1
Linear trend$_{(0.05)}$	P =0.004	P =0.002	P =0.003	P =0.008
Quadratic trend$_{(0.05)}$	NS	P =0.03	P =0.003	NS
	Total N Fixed (kg ha^{-1})			
10 seeds m^{-2}	2.7 *c*	16.3 *c*	5.1 *c*	6.1 *c*
25 seeds m^{-2}	12.9 *bc*	27.5 *bc*	10.4 *bc*	19.0 *bc*
62 seeds m^{-2}	21.8 *abc*	41.7 *b*	26.0 *b*	30.9 *bc*
156 seeds m^{-2}	29.4 *ab*	68.9 *a*	53.5 *a*	44.5 *ab*
250 seeds m^{-2}	41.1 *a*	85.8 *a*	56.8 *a*	60.2 *a*
LSD$_{(0.05)}$	26.0	22.7	15.7	26.2
Linear trend$_{(0.05)}$	P =0.01	P =0.002	P =0.01	P =0.007
Quadratic trend$_{(0.05)}$	NS	P =0.01	P =0.002	NS

† Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

‡ Values within a site and column followed by the same letter are not significantly different according to the LSD ($P \leq 0.05$).

§ Significantly different at LSD ($P \leq 0.05$).

¶ Linear and quadratic functions were applied to seeding rate data.

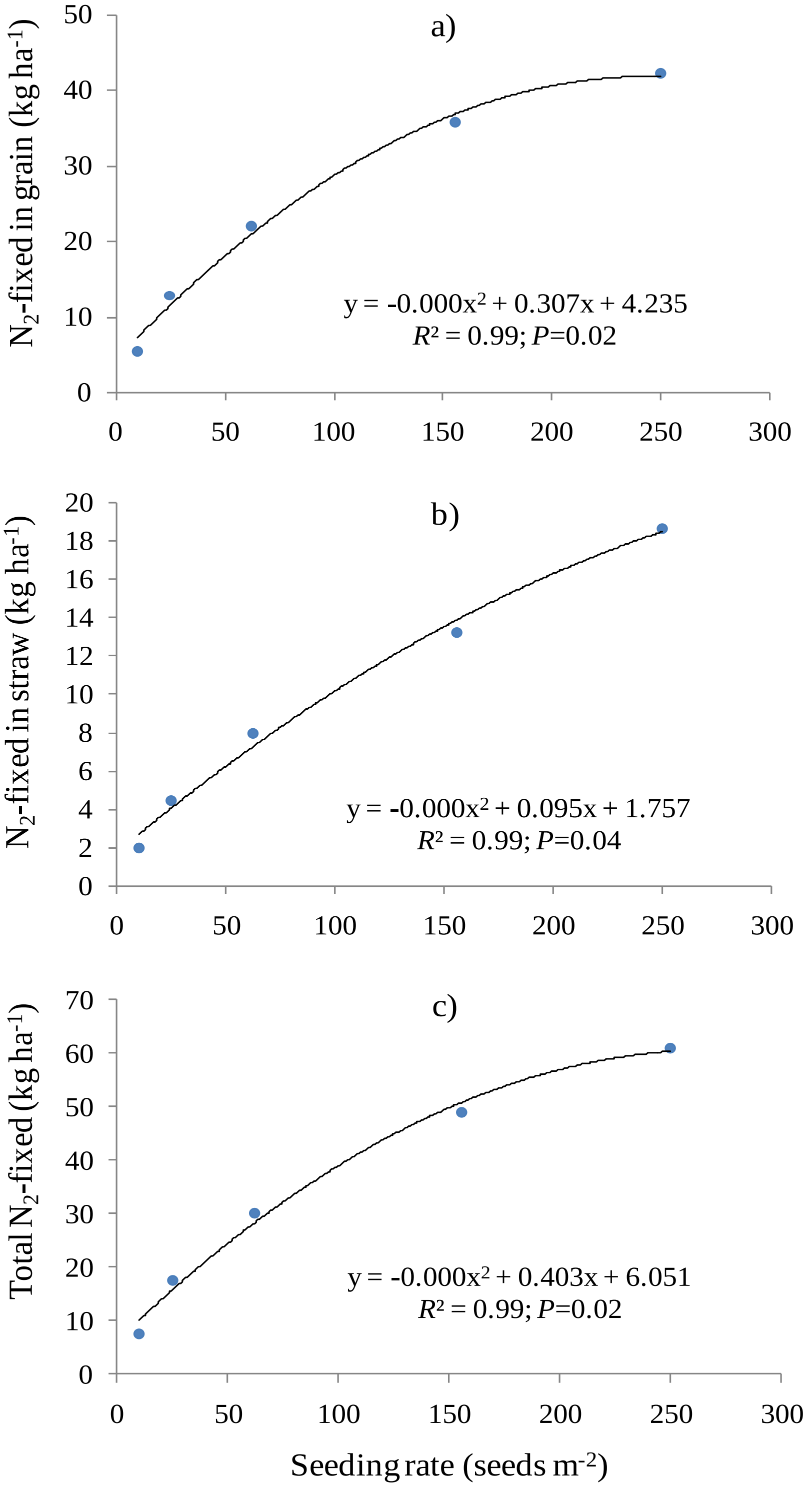

Figure 4.1. Effect of seeding rate on a) fixed N in the grain; b) fixed N in the straw; c) total fixed N of organically grown lentil averaged for four sites. Points represent data averaged over all sites and years.

Table 4.3. Concentration and quantity of nitrogen in seed and above-ground plant residues and nitrogen harvest index for different seeding rates of organically grown field pea in central Saskatchewan in 2005 and 2006.

Site/Year	N concentration		N yield			NHI†
Target Seeding Rate	Grain	Straw	Grain	Straw	Total	
	--------------mg g^{-1}--------------		------------------------------kg ha^{-1}------------------------------			
Delisle						
10 seeds m^{-2}	36.9	1.5	5.7 *c* ‡	1.5 *d*	7.2 *c*	0.79
25 seeds m^{-2}	36.6	2.4	19.3 *bc*	5.8 *cd*	25.1 *bc*	0.77
62 seeds m^{-2}	35.8	2.5	42.2 *ab*	12.5 *bc*	54.7 *ab*	0.77
156 seeds m^{-2}	34.8	2.4	53.9 *a*	17.6 *ab*	71.5 *a*	0.75
250 seeds m^{-2}	35.7	2.7	53.3 *a*	22.3 *a*	75.6 *a*	0.70
LSD$_{(0.05)}$	NS§	NS	25.3	8.0	32.7	NS
Vonda-05						
10 seeds m^{-2}	30.7	2.2	12.7 *b*	4.2 *c*	17.0 *b*	0.75
25 seeds m^{-2}	28.3	2.3	19.9 *b*	7.1 *c*	27.1 *b*	0.74
62 seeds m^{-2}	29.5	2.3	31.0 *b*	10.9 *c*	41.9 *b*	0.74
156 seeds m^{-2}	30.0	2.4	52.2 *a*	19.9 *b*	72.1 *a*	0.72
250 seeds m^{-2}	32.6	2.9	60.7 *a*	29.2 *a*	89.9 *a*	0.68
LSD$_{(0.05)}$	NS	NS	19.6	7.5	26.8	NS
Vanscoy						
10 seeds m^{-2}	38.9	2.6	5.0 *c*	2.1 *c*	7.1 *c*	0.70
25 seeds m^{-2}	38.6	2.4	9.9 *bc*	4.5 *bc*	14.4 *c*	0.69
62 seeds m^{-2}	39.5	2.6	28.5 *b*	11.1 *b*	39.6 *b*	0.72
156 seeds m^{-2}	39.7	2.5	50.4 *a*	19.6 *a*	70.0 *a*	0.72
250 seeds m^{-2}	39.1	2.9	53.5 *a*	25.7 *a*	79.2 *a*	0.68
LSD$_{(0.05)}$	NS	NS	17.4	8.1	23.9	NS
Vonda-06						
10 seeds m^{-2}	32.6	2.5	4.3 *c*	2.0 *c*	6.3 *c*	0.69
25 seeds m^{-2}	31.9	2.4	14.6 *bc*	5.0 *bc*	19.7 *bc*	0.74
62 seeds m^{-2}	28.3	2.4	22.6 *bc*	9.4 *b*	32.0 *bc*	0.71
156 seeds m^{-2}	31.2	2.4	33.2 *ab*	12.6 *ab*	45.7 *ab*	0.72
250 seeds m^{-2}	32.1	2.2	46.3 *a*	17.9 *a*	64.2 *a*	0.72
LSD$_{(0.05)}$	NS	NS	20.9	6.3	27.1	NS
Mean of Site and Year						
10 seeds m^{-2}	34.7	2.2	6.9 *d*	2.4 *d*	9.4 *e*	0.74
25 seeds m^{-2}	33.9	2.4	15.9 *c*	5.6 *d*	21.5 *d*	0.74
62 seeds m^{-2}	33.3	2.5	31.1 *b*	11.0 *c*	42.1 *c*	0.74
156 seeds m^{-2}	33.9	2.4	47.4 *a*	17.4 *b*	64.8 *b*	0.73
250 seeds m^{-2}	34.9	2.7	53.4 *a*	23.8 *a*	77.2 *a*	0.69
LSD$_{(0.05)}$	NS	NS	7.5	3.3	10.2	NS

† Nitrogen Harvest Index = grain N yield / total above ground N.

‡ Values within a site and column followed by the same letter are not significantly different according to the LSD ($P \leq 0.05$).

§ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

sites increased from the lowest to highest seeding rates, from 6.9 to 53.4 and from 2.4 to 23.8 kg N ha^{-1} for grain and straw, respectively (Table 4.3). This significant difference in total N in the seed and straw was due to the large differences in the yield, as no differences in N concentration were detected. For the individual sites, the differences were observed at the two higher seeding rates relative to the lower seeding rates. No differences, however, were found among the lower rates as well as between the two highest seeding rates.

The ANOVA did not detect any significant differences in the nitrogen harvest index (NHI) among the treatments. The average values for NHI ranged from 0.69 to 0.74 across the experimental sites and years (Table 4.3).

4.3.2.2. Nitrogen contribution

The average N contribution to the soil, averaged over sites, differed significantly among seeding rates, with values ranging between 1.9 and 39.2 kg N ha^{-1} (Fig. 4.2). For the individual sites, differences were not detected among the three lowest seeding rates but the N contribution to the soil for the two highest rates were significantly greater than the lower seeding rates and also differed from each other (Table 4.4). The only exception was at Delisle where the only significant difference occurred between the highest seeding rate and the other seeding rates. The highest seeding rate contributed from 21.2 to 52.0 kg ha^{-1} more N to the soil than the lowest seeding rate.

The N contribution to the soil by field pea was positive for all treatments, with the exception of Delisle-2005 (Table 4.4). That is, although the total N yield was similar to that of the other sites, NHI at Delisle was comparatively higher than at the other sites indicating that the N output (i.e., seed N yield) was greater than N in the straw (Table 4.3). Therefore, the negative N contribution was affected by the ratio of N returned in the straw to the soil and the N output harvested with the seed. At Delisle, however, N contribution became positive at the highest seeding rate. Moreover, the positive N contribution was enhanced at the highest seeding rates at all the other sites.

Table 4.4. Nitrogen contribution (kg N ha^{-1}) of organically grown field pea to the soil based on above-ground values in 2005 and 2006 in central Saskatchewan.

Target Seeding Rates	N Inputs		N Demand	Nitrogen Contribution A+B-C
	Total N Fixed† A	N in Original Seed‡ B	Total N in Harvested Seed, C	
Delisle				
10 seeds m^{-2}	2.7 *c* §	1.3	5.7 *c*	-1.7 *b*
25 seeds m^{-2}	12.9 *bc*	3.2	19.3 *bc*	-3.2 *b*
62 seeds m^{-2}	21.8 *abc*	7.8	42.2 *ab*	-12.6 *b*
156 seeds m^{-2}	29.4 *ab*	19.7	53.9 *a*	-4.8 *b*
250 seeds m^{-2}	41.1 *a*	31.6	53.3 *a*	19.5 *a*
LSD$_{(0.05)}$	26.0	-	25.3	14.3
Vonda-05				
10 seeds m^{-2}	16.3 *c*	1.3	12.7 *b*	4.8 *d*
25 seeds m^{-2}	27.5 *bc*	3.2	19.9 *b*	10.8 *cd*
62 seeds m^{-2}	41.7 *b*	7.8	31.0 *b*	18.5 *c*
156 seeds m^{-2}	68.9 *a*	19.7	52.2 *a*	36.4 *b*
250 seeds m^{-2}	85.8 *a*	31.6	60.7 *a*	56.8 *a*
LSD$_{(0.05)}$	22.7	-	19.6	8.5
Vanscoy				
10 seeds m^{-2}	5.1 *c*	1.3	5.0 *c*	1.4 *c*
25 seeds m^{-2}	10.4 *bc*	3.2	9.9 *c*	3.7 *c*
62 seeds m^{-2}	26.0 *b*	7.8	28.5 *b*	5.3 *c*
156 seeds m^{-2}	53.5 *a*	19.7	50.4 *a*	22.9 *b*
250 seeds m^{-2}	56.8 *a*	31.6	53.5 *a*	34.9 *a*
LSD$_{(0.05)}$	15.7	-	17.4	4.7
Vonda-06				
10 seeds m^{-2}	6.1 *c*	1.3	4.3 *c*	3.1 *d*
25 seeds m^{-2}	19.0 *bc*	3.2	14.6 *bc*	7.6 *d*
62 seeds m^{-2}	30.9 *bc*	7.8	22.6 *bc*	16.1 *c*
156 seeds m^{-2}	44.5 *ab*	19.7	33.2 *ab*	31.1 *b*
250 seeds m^{-2}	60.2 *a*	31.6	46.3 *a*	45.6 *a*
LSD$_{(0.05)}$	26.2		17.4	6.5

† N fixed in seed plus straw.

‡ Total N determined in initial seed.

§ Values with the same letter within a site and column are not significantly different according to the LSD ($P \leq 0.05$).

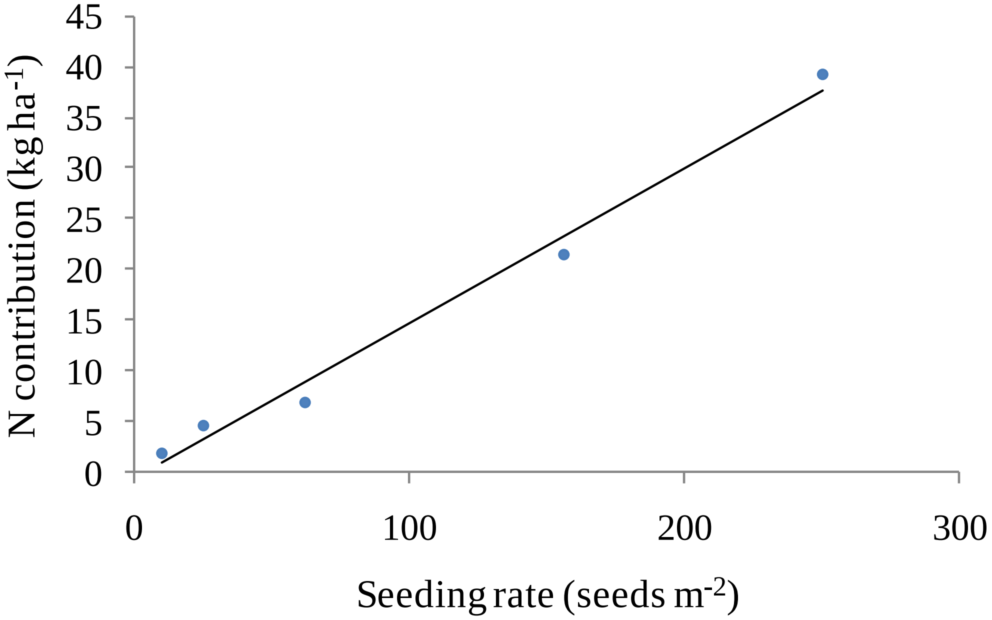

Figure 4.2. Nitrogen contribution from the above-ground biomass of organically grown pea grown in 2005 and 2006 averaged for four sites in central Saskatchewan. Line equation: $y=0.1534x+0.6528$; $R^2=0.99$; $P<0.001$. Dots represent the averaged data for sites and years. Values under the same letters are not significantly different according to the LSD ($P \leq 0.05$).

During field pea growth, the crop accumulated less N from the soil than N_2 fixed in the seed at all seeding rate treatments except for at Delisle (Table 4.5). The N derived from the soil (Ndfs) in field pea seed showed significant differences among the seeding rates at two of the four sites. The significantly higher differences were associated with the 62 to 250 seeds m^{-2} rates versus the two lower seeding rates at Delisle-2005 and Vanscoy-2006. Averaged over sites, the lowest Ndfs value was 1.4 kg N ha^{-1} at the 10 seeds m^{-2} rate and the highest was 11.6 kg N ha^{-1} at the 156 seeds m^{-2} (Table 4.5). Generally, the higher seeding rates utilized more N from the soil due to the increased N output with the higher seed yield. Seed Ndfs was greater at the Delisle site than at all other sites for all the treatments, which indicated higher N usage from the soil.

Table 4.5. The impact of seeding rate on the source of nitrogen in the seed of organically grown field pea in central Saskatchewan in 2005 and 2006.

Site/Year Target Seeding Rate	Total N in Seed A	Ndfa in Seed† B	Seed Ndfs‡ A-B
	kg N ha^{-1}		
Delisle			
10 seeds m^{-2}	5.7 *c* §	2.2 *b*	3.5 *c*
25 seeds m^{-2}	19.3 *bc*	10.3 *ab*	9.0 *bc*
62 seeds m^{-2}	42.2 *ab*	17.0 *ab*	25.2 *a*
156 seeds m^{-2}	53.9 *a*	22.6 *a*	31.3 *a*
250 seeds m^{-2}	53.3 *a*	29.4 *a*	23.9 *a*
LSD$_{(0.05)}$	25.3	20.2	14.2
Vonda-05			
10 seeds m^{-2}	12.7 *b*	12.2 *c*	0.5
25 seeds m^{-2}	19.9 *b*	20.3 *bc*	-0.4
62 seeds m^{-2}	31.0 *b*	30.9 *bc*	0.2
156 seeds m^{-2}	52.2 *a*	49.8 *a*	2.4
250 seeds m^{-2}	60.7 *a*	57.9 *a*	2.8
LSD$_{(0.05)}$	19.6	16.6	NS ¶
Vanscoy			
10 seeds m^{-2}	5.0 *c*	3.6 *c*	1.4 *b*
25 seeds m^{-2}	9.9 *bc*	7.1 *bc*	2.8 *b*
62 seeds m^{-2}	28.5 *b*	18.7 *b*	9.8 *a*
156 seeds m^{-2}	50.4 *a*	38.6 *a*	11.8 *a*
250 seeds m^{-2}	53.5 *a*	38.4 *a*	15.1 *a*
LSD$_{(0.05)}$	17.4	11.6	6.4
Vonda-06			
10 seeds m^{-2}	4.3 *c*	4.2 *c*	0.1
25 seeds m^{-2}	14.6 *bc*	14.1 *bc*	0.5
62 seeds m^{-2}	22.6 *bc*	21.8 *bc*	0.8
156 seeds m^{-2}	33.2 *ab*	32.3 *ab*	0.9
250 seeds m^{-2}	46.3 *a*	43.5 *ab*	2.8
LSD$_{(0.05)}$	20.9	20.2	NS
Mean over Sites and Years			
10 seeds m^{-2}	6.9 *d*	5.5 *c*	1.4 *c*
25 seeds m^{-2}	15.9 *c*	12.9 *bc*	3.0 *bc*
62 seeds m^{-2}	31.1 *b*	22.1 *b*	9.0 *abc*
156 seeds m^{-2}	47.4 *a*	35.8 *a*	11.6 *a*
250 seeds m^{-2}	53.4 *a*	42.3 *a*	11.1 *ab*
LSD$_{(0.05)}$	7.5	9.2	8.3

† Ndfa denotes N derived from the atmosphere.

‡ Ndfs denotes N derived from the soil.

§ Means with the same letter within a site and column are not significantly according to the LSD ($P \leq 0.05$).

¶ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

4.3.3. Impact of field pea seeding rates on the succeeding wheat crop-Year 2

4.3.3.1. Soil moisture and inorganic nitrogen

Pre-seeding soil moisture at all depths at both sites in 2007 was not significantly different between treatments (Table 4.6). The soil moisture level at Vonda and Vanscoy was remarkably different for the spring sampling, with the former being excessively wet and the

Table 4.6. Soil gravimetric moisture in the spring of 2007 following the field pea seeding rate experiments conducted in 2006 at Vanscoy and Vonda-06 sites.

Target Seeding Rate	Soil Moisture			
	0- to 15-cm	15-to 30-cm	30-to 60-cm	0- to 60-cm
Vanscoy	-- cm --			
Summerfallow	2.15	2.60	1.73	6.45
GrM 62 seeds m^{-2}†	1.93	2.40	1.63	5.95
GrM 156 seeds m^{-2}	1.90	2.60	1.30	5.78
$LSD_{(0.05)}$	NS‡	NS	NS	NS
10 seeds m^{-2}	1.75	2.23	1.25	5.20
25 seeds m^{-2}	1.70	2.43	1.35	5.45
62 seeds m^{-2}	1.88	2.60	1.20	5.70
156 seeds m^{-2}	1.80	2.23	1.23	5.30
250 seeds m^{-2}	2.00	2.48	1.28	5.75
$LSD_{(0.05)}$	NS	NS	NS	NS
Vonda-06				
Summerfallow	3.65	3.78	4.40	11.83
GrM 62 seeds m^{-2}	3.70	3.73	4.40	11.78
GrM 156 seeds m^{-2}	3.80	3.95	4.63	12.38
$LSD_{(0.05)}$	NS	NS	NS	NS
10 seeds m^{-2}	3.85	3.55	4.30	11.70
25 seeds m^{-2}	3.73	3.53	4.55	11.80
62 seeds m^{-2}	4.28	3.73	4.03	12.03
156 seeds m^{-2}	3.90	3.98	4.63	12.45
250 seeds m^{-2}	3.93	3.75	4.85	12.53
$LSD_{(0.05)}$	NS	NS	NS	NS

† Green manure treatment.

‡ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

latter having far less available soil moisture. However, a lack of significant differences in soil moisture between treatments was observed at both sites. Summerfallow and green manure controls also did not differ in soil moisture relative to the seeding rate treatments.

Pre-seeding soil inorganic N (NH_4^+-N + NO_3^--N) tended to increase from the lowest to the highest seeding rate in few instances (Table 4.7 and Table 4.8). Nitrate and NH_4^+-N + NO_3^--N levels in the 0- to 15-cm depth at Vanscoy (Table 4.7) and NH_4^+-N in the 15- to 30-cm depth at Vonda showed significant increasing trends with higher seeding rates (Table 4.8). Biweekly measurements of inorganic N in the 0- to 15-cm depth during the wheat year also were not affected by the field pea stubble of differing seeding rates except for a linear trend detected at 07 August sampling date at Vonda (Table 4.9).

4.3.3.2. Wheat biomass and yield parameters

There were no significant differences in wheat biomass production between the pea seeding rate stubble treatments over the growing season at each of the four sampling dates (Table 4.10). During the entire growing season, both experimental sites were affected by weed growth. However, biomass of weeds in the wheat crop was not significantly different between the treatments (Table 4.11).

The yield components of wheat showed no significant differences between the previous pea seeding rate treatments, other than a few minor differences in seed and straw weight at Delisle (Table 4.12). In both cases, the highest seeding rate had higher seed and straw weight than all other seeding rates. However, consistent with the biomass production, the mean weight of wheat seed and straw on summerfallow and green manure controls was also greater than field pea stubble treatments except for the highest seeding rate (Fig. 4.3).

Table 4.7. Inorganic nitrogen in the 0- to 15-cm, 15- to 30-cm and 30- to 60-cm depths measured in the spring of 2007 prior to wheat being seeded on field pea seeding rate treatment seeding rate treatments in 2006 at Vanscoy.

Target Seeding Rate	Vanscoy											
	NO_3^--N				NH_4^+-N				NO_3^--N + NH_4^+-N			
	0 to 15 cm	15 to 30 cm	30 to 60 cm	0 to 60 cm	0 to 15 cm	15 to 30 cm	30 to 60 cm	0 to 60 cm	0 to 15 cm	15 to 30 cm	30 to 60 cm	0 to 60 cm
	---kg ha^{-1}---											
Summerfallow	16.7	31.9	28.9	77.5	4.3	5.8	4.2	14.3	21.0	37.7	33.1	91.8
GrM 62 seeds m^{-2}†	12.1	19.9	31.4	63.4	5.5	6.4	4.5	16.3	17.6	26.2	35.8	79.7
GrM 156 seeds m^{-2}	23.5	37.0	25.9	86.4	6.1	7.6	4.2	17.9	29.6	44.6	30.1	104.3
LSD$_{(0.05)}$	NS‡	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
10 seeds m^{-2}	3.0 *b* §	4.6	6.0	13.7	3.5	4.6	5.5	13.7	6.6	9.2 *c*	11.5	27.3 *b*
25 seeds m^{-2}	4.5 *b*	7.4	7.1	19.0	4.6	6.5	4.3	15.5	9.1	14.0 *abc*	11.4	34.5 *ab*
62 seeds m^{-2}	5.3 *b*	8.9	7.8	21.9	7.1	5.2	4.6	16.9	12.3	14.1 *abc*	12.4	38.8 *a*
156 seeds m^{-2}	4.9 *b*	6.5	7.8	19.2	7.0	4.6	5.2	16.8	11.9	11.2 *bc*	13.0	36.0 *ab*
250 seeds m^{-2}	9.8 *a*	9.7	7.9	27.4	5.8	6.4	4.8	17.0	15.6	16.1 *a*	12.7	44.4 *a*
LSD$_{(0.05)}$	3.3	NS	NS	NS	NS	NS	NS	NS	NS	4.3	NS	9.5
Linear trend$_{(0.05)}$¶	P =0.04	NS	NS	NS	NS	NS	NS	NS	P =0.04	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

† Green manure treatment.

‡ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

§ Values within a site and column followed by the same letter are not significantly different according to the LSD ($P \leq 0.05$).

¶ Linear and quadratic functions were applied to seeding rate data.

Table 4.8. Inorganic nitrogen in the 0- to 15-cm, 15- to 30-cm and 30- to 60-cm depths measured in the spring of 2007 prior to wheat being seeded on field pea seeding rate treatments in 2006 at Vonda-06.

Target Seeding Rate	Vonda-06											
	NO_3^--N				NH_4^+-N				NO_3^--N + NH_4^+-N			
	0 to 15 cm	15 to 30 cm	30 to 60 cm	0 to 60 cm	0 to 15 cm	15 to 30 cm	30 to 60 cm	0 to 60 cm	0 to 15 cm	15 to 30 cm	30 to 60 cm	0 to 60 cm
	kg ha^{-1}											
Summerfallow	10.1	10.9	14.1	35.1	4.1	3.8	7.4	15.2	14.1	14.7	21.5	50.3
GrM 62 seeds m^{-2}†	8.6	5.7	13.0	27.3	6.1	4.8	8.9	19.8	14.7	10.5	21.9	47.1
GrM 156 seeds m^{-2}	6.5	5.7	4.9	17.2	3.5	4.7	5.0	13.2	10.0	10.4	9.9	30.3
LSD$_{(0.05)}$	NS‡	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
10 seeds m^{-2}	6.0	3.9	3.6	13.4	3.3	4.4	3.9	11.5	9.3	8.3	7.4	25.0
25 seeds m^{-2}	7.8	4.1	4.2	16.1	3.1	3.5	6.8	13.4	10.9	7.5	11.1	29.5
62 seeds m^{-2}	6.9	4.5	3.6	15.1	4.5	4.9	7.1	16.4	11.4	9.4	10.7	31.4
156 seeds m^{-2}	5.9	4.1	4.0	14.0	3.5	6.0	4.2	13.6	9.4	10.1	8.1	27.7
250 seeds m^{-2}	7.6	5.2	4.5	17.3	5.3	6.4	8.8	20.5	13.0	11.6	13.3	37.8
LSD$_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Linear trend$_{(0.05)}$§	NS	NS	NS	NS	NS	$P = 0.03$	NS	NS	NS	$P = 0.01$	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

† Green manure treatment.

‡ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

§ Linear and quadratic functions were applied to seeding rate data.

Table 4.9. Mineralized inorganic nitrogen in field condition in the 0- to 15-cm increment of test wheat plots measured biweekly during the summer of 2007 on field pea seeding rate treatments in 2006 at Vanscoy and Vonda-06 sites.

Target Seeding Rate	NO_3^- -N						NH_4^+ -N					
	31-May	14-Jun	28-Jun	12-Jul	26-Jul	09-Aug	31-May	14-Jun	28-Jun	12-Jul	26-Jul	09-Aug
Vanscoy	----------kg ha^{-1}----------											
Summerfallow	36.4	16.6	4.4	6.5	0.4	5.4	25.7	4.3	4.9	9.8	4.7	4.4
GrM 62 seeds m^{-2}†	27.4	12.1	3.1	5.1	0.5	4.8	24.4	5.5	5.0	8.6	6.6	2.1
GrM 156 seeds m^{-2}	22.5	23.5	4.9	6.1	0.7	6.0	23.2	6.1	5.8	7.1	6.1	3.0
LSD$_{(0.05)}$	NS ‡	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
10 seeds m^{-2}	21.4	3.0	5.6	9.1	0.1	8.5	34.3	3.5	4.4	8.8	6.5	4.6
25 seeds m^{-2}	11.5	4.4	3.9	4.5	0.0	5.8	38.0	4.6	5.2	7.4	3.9	3.3
62 seeds m^{-2}	20.9	5.2	2.9	5.4	0.7	4.9	23.5	7.1	5.5	7.9	6.4	2.8
156 seeds m^{-2}	24.2	4.8	3.7	4.5	0.4	5.5	23.8	7.0	4.9	7.0	7.7	3.6
250 seeds m^{-2}	20.4	9.8	4.8	9.5	0.0	5.2	28.8	5.8	4.4	6.5	7.4	4.2
LSD$_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Linear trend$_{(0.05)}$§	NS	P =0.04	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Vonda-06	29-May	12-Jun	26-Jun	10-Jul	24-Jul	7-Aug	29-May	12-Jun	26-Jun	10-Jul	24-Jul	07-Aug
Summer Fallow	33.6	10.1	16.9	25.7	3.3	2.3	15.6	4.1	4.0	8.9	1.2	49.7
GrM 62 seeds m^{-2}	11.9	8.6	14.2	28.5	4.4	2.2	13.7	6.1	5.1	8.6	2.5	43.6
GrM 156 seeds m^{-2}	13.6	6.5	16.4	29.8	3.5	3.0	14.0	3.5	3.7	7.5	2.8	37.8
LSD$_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
10 seeds m^{-2}	3.9	6.0	12.7	21.2	3.1	1.5	14.5	3.3	4.0	9.8	1.1	68.1
25 seeds m^{-2}	9.7	7.8	13.3	25.8	3.6	1.0	17.0	3.1	3.5	6.6	4.8	50.2
62 seeds m^{-2}	8.3	6.9	9.3	26.1	2.9	1.7	14.4	4.5	3.9	6.3	1.9	21.5
156 seeds m^{-2}	5.5	5.9	10.2	24.7	2.9	2.4	12.7	3.5	4.4	6.7	2.6	56.6
250 seeds m^{-2}	11.0	7.6	14.9	22.4	2.7	3.3	14.0	5.3	3.3	8.8	1.7	51.3
LSD$_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Linear trend$_{(0.05)}$	NS	NS	NS	NS	NS	P =0.009	NS	NS	NS	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

† Green manure treatment.

‡ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

§ Linear and quadratic functions were applied to seeding rate data.

Table 4.10. Wheat biomass at different sampling dates in 2007 following the field pea seeding rate experiment in 2006 at Vanscoy and Vonda.

Sampling date Target Seeding Rate	05-Jul	19-Jul	02-Aug	23-Aug
Vanscoy	--------------------	--------kg ha^{-1}--------	--------------------	--------------------
Summerfallow	1770	2917	6375	6665
GrM 62 seeds m^{-2}†	1497	3338	5294	5520
GrM 156 seeds m^{-2}	1663	3056	6002	6775
$LSD_{(0.05)}$	NS ‡	NS	NS	NS
10 seeds m^{-2}	1147	1848	2471	3480
25 seeds m^{-2}	978	1698	3104	3350
62 seeds m^{-2}	1162	1610	3059	3975
156 seeds m^{-2}	1115	1775	2805	3520
250 seeds m^{-2}	1050	1994	3471	3680
$LSD_{(0.05)}$	NS	NS	NS	NS
Linear $trend_{(0.05)}$§	NS	NS	NS	NS
Quadratic $trend_{(0.05)}$	NS	NS	NS	NS
Vonda-06				
Summerfallow	832	2166	3211	3710
GrM 62 seeds m^{-2}	926	1360	2509	3235
GrM 156 seeds m^{-2}	737	1561	2949	2965
$LSD_{(0.05)}$	NS	NS	NS	NS
10 seeds m^{-2}	563	974	1433	1875
25 seeds m^{-2}	477	826	1074	1785
62 seeds m^{-2}	632	902	1224	1865
156 seeds m^{-2}	543	920	1074	1720
250 seeds m^{-2}	548	892	1458	2185
$LSD_{(0.05)}$	NS	NS	NS	NS
Linear $trend_{(0.05)}$	NS	NS	NS	NS
Quadratic $trend_{(0.05)}$	NS	NS	NS	NS

† Green manure treatment.

‡ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

§ Linear and quadratic functions were applied to seeding rate data.

Table 4.11. Weed biomass at different sampling dates in 2007 in the wheat plots following the 2006 field pea seeding rate experiment at Vanscoy and Vonda.

Sampling date Target Seeding Rate	05-Jul	19-Jul	02-Aug
Vanscoy		---kg ha^{-1}---	
Summerfallow	495	1023	3525
GrM 62 seeds m^{-2}†	584	1521	3958
GrM 156 seeds m^{-2}	252	1512	3204
LSD$_{(0.05)}$	NS‡	NS	NS
10 seeds m^{-2}	194	1483	3904
25 seeds m^{-2}	410	1611	3278
62 seeds m^{-2}	441	1603	3059
156 seeds m^{-2}	407	1781	2028
250 seeds m^{-2}	275	1436	3503
LSD$_{(0.05)}$	NS	NS	NS
Linear trend$_{(0.05)}$¶	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS
Vonda-06			
Summerfallow	441	491 *b* §	669
GrM 62 seeds m^{-2}	343	1056 *a*	1430
GrM 156 seeds m^{-2}	263	883 *a*	937
LSD$_{(0.05)}$	NS	302	NS
10 seeds m^{-2}	235	1052	1395
25 seeds m^{-2}	194	1246	1455
62 seeds m^{-2}	250	1210	1321
156 seeds m^{-2}	221	1402	1430
250 seeds m^{-2}	269	1133	1504
LSD$_{(0.05)}$	NS	NS	NS
Linear trend$_{(0.05)}$	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS

† Green manure treatment.

‡ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

§ Values within a site and column followed by the same letter are not significantly different according to the LSD ($P \leq 0.05$).

¶ Linear and quadratic functions were applied to seeding rate data.

Table 4.12. Yield parameters of test wheat in 2006 and 2007 following the field pea seeding rates experiment of 2005 and 2006.

Site/Year Target Seeding Rate	Hand Harvested Seed	Hand Harvested Straw	HI†	1000 Seed Weight
Delisle	----------------------------kg ha^{-1}	---------------------------		--g 1000 seeds^{-1}--
Summerfallow	883	2939	0.23	30.2
GrM 62 seeds m^{-2}‡	757	2258	0.25	29.9
LSD$_{(0.05)}$	NS §	NS	NS	NS
10 seeds m^{-2}	381 *d*	1097 *d*	0.26	29.7
25 seeds m^{-2}	429 *d*	1329 *d*	0.24	29.8
62 seeds m^{-2}	605 *bc*	1355 *d*	0.31	29.9
156 seeds m^{-2}	525 *cd*	1433 *cd*	0.27	29.8
250 seeds m^{-2}	785 *a*	1995 *bc*	0.28	30.6
LSD$_{(0.05)}$	133	627	NS	NS
Vonda-05				
Summerfallow	1150	1985 *b*	0.37	29.4
GrM 62 seeds m^{-2}	1721	3069 *a*	0.36	29.4
LSD$_{(0.05)}$	NS	1007	NS	NS
10 seeds m^{-2}	1503	2752	0.35	30.1
25 seeds m^{-2}	1400	2625	0.35	29.1
62 seeds m^{-2}	1495	2680	0.36	29.1
156 seeds m^{-2}	1499	2656	0.36	30.1
250 seeds m^{-2}	1697	3053	0.36	29.4
LSD$_{(0.05)}$	NS	NS	NS	NS
Vanscoy				
Summerfallow	1720	4220	0.29	31.3
GrM 62 seeds m^{-2}	1470	4050	0.27	32.0
GrM 156 seeds m^{-2}	1824	4951	0.27	28.2
LSD$_{(0.05)}$	NS	NS	NS	NS
10 seeds m^{-2}	940	2541	0.27	31.5
25 seeds m^{-2}	989	2361	0.30	33.1
62 seeds m^{-2}	1016	2959	0.26	32.3
156 seeds m^{-2}	951	2569	0.27	32.3
250 seeds m^{-2}	897	2483	0.27	31.3
LSD$_{(0.05)}$	NS	NS	NS	NS
Vonda-06				
Summerfallow	1476	2234	0.40	34.4
GrM 62 seeds m^{-2}	1273	1962	0.39	32.2
GrM 156 seeds m^{-2}	1132	1833	0.38	32.0
LSD$_{(0.05)}$	NS	NS	NS	NS
10 seeds m^{-2}	872	1003	0.47	29.8
25 seeds m^{-2}	711	1074	0.40	31.7
62 seeds m^{-2}	658	1207	0.35	29.1
156 seeds m^{-2}	639	1081	0.37	30.2
250 seeds m^{-2}	837	1348	0.38	30.8
LSD$_{(0.05)}$	NS	NS	NS	NS

† Harvest Index = grain yield / total above ground yield of hand harvest

‡ Green manure treatment.

§ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

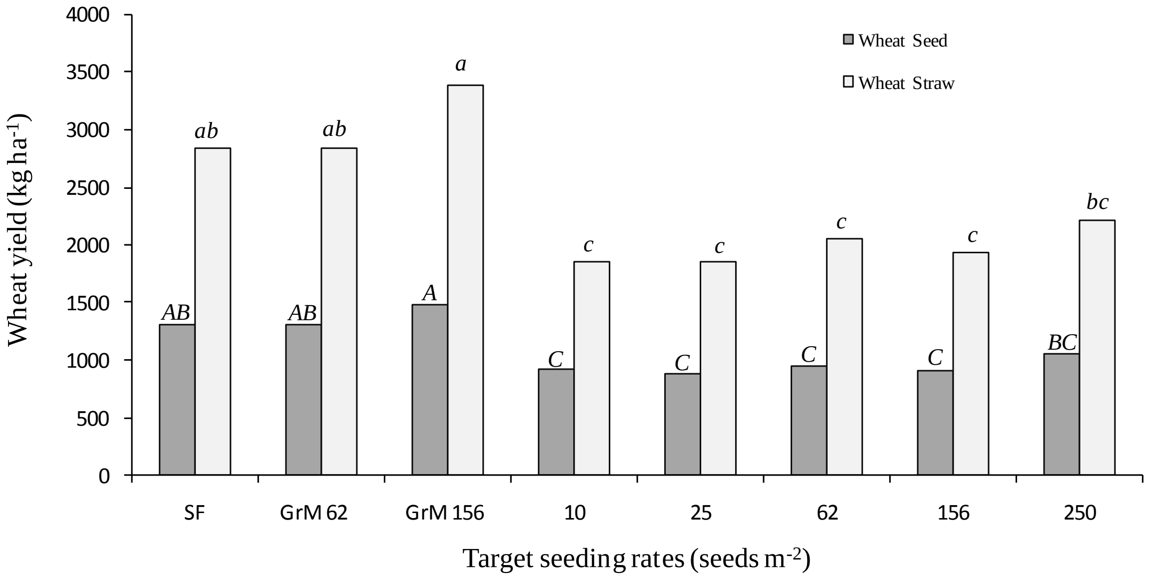

Figure 4.3. Mean wheat seed and straw yield combined over sites in 2006 and 2007 on organically grown field pea stubble of seeding rate experiments conducted in the previous year (2005 and 2006). SF=summerfallow control; GrM=green manure control; the same color of bars flagged with the same letters are not significantly different according to LSD (*P*≤0.05).

4.3.3.3. Nitrogen uptake by wheat

Nitrogen uptake by wheat during the growing season was largely unaffected by the previous field pea seeding rate treatments (Table 4.13). Consistently, the amount of total N in the grain of wheat at harvest was not affected by the previous pea seeding rate treatments. Generally, N uptake into wheat biomass during the growing season in the treatment plots was greater on summerfallow and the green manure controls than on the field pea seeding rate

Table 4.13.Total nitrogen in test wheat biomass at different sampling dates in 2007 following the field pea seeding rates experiment in 2006 at Vanscoy and Vonda.

Sampling date Target Seeding Rate	05-Jul	19-Jul	02-Aug	23-Aug
	--------kg N ha^{-1}--------			
Vanscoy				
Summer Fallow	56.0	58.5	71.3	82.0
GrM 62 seeds m^{-2}†	49.9	68.6	53.3	65.0
GrM 156 seeds m^{-2}	53.9	59.4	63.4	78.5
LSD$_{(0.05)}$	NS ‡	NS	NS	NS
10 seeds m^{-2}	31.7	31.3	21.4	37.6
25 seeds m^{-2}	25.9	32.2	32.9	38.5
62 seeds m^{-2}	30.9	29.8	29.2	44.8
156 seeds m^{-2}	30.1	28.9	22.4	37.0
250 seeds m^{-2}	28.7	33.0	29.1	43.6
LSD$_{(0.05)}$	NS	NS	NS	NS
Linear trend$_{(0.05)}$§	NS	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS	NS
Vonda-06				
Summer Fallow	30.0	37.3	30.9	46.9
GrM 62 seeds m^{-2}	30.7	26.2	25.3	41.8
GrM 156 seeds m^{-2}	23.4	30.5	27.9	36.8
LSD$_{(0.05)}$	NS	NS	NS	NS
10 seeds m^{-2}	15.3	19.0	11.8	22.4
25 seeds m^{-2}	12.5	13.6	9.2	20.8
62 seeds m^{-2}	17.7	13.9	11.5	20.4
156 seeds m^{-2}	14.7	14.5	9.7	19.4
250 seeds m^{-2}	15.7	14.7	12.4	26.4
LSD$_{(0.05)}$	NS	NS	NS	NS
Linear trend$_{(0.05)}$	NS	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS	NS

† Green manure treatment.

‡ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

§ Linear and quadratic functions were applied to seeding rate data.

treatments on all sampling dates (Table 4.13). Averaged across all sites, the N uptake in the harvested seed ranged from 20.7 to 24.9 kg N ha^{-1} (Table 4.14).

Table 4.14. Total nitrogen in the test wheat seed at harvest in 2006 and 2007 following the field pea seeding rate experiments in 2005 and 2006.

Site/Year	2006		2007		Mean
Target Seeding Rate	Delisle	Vonda-05	Vanscoy	Vonda-06	
	------kg ha^{-1}------				
Summerfallow	25.6	22.3 *b* ‡	60.0	32.4	35.1
GrM 62 seeds m^{-2}†	22.3	37.1 *a*	43.3	28.4	32.8
GrM 62 seeds m^{-2}	- §	-	55.5	24.5	40.0
LSD$_{(0.05)}$	NS	12.9	NS	NS	NS
10 seeds m^{-2}	8.1 *d*	32.7	26.8	17.4	21.3
25 seeds m^{-2}	9.0 *d*	29.2	29.9	15.0	20.7
62 seeds m^{-2}	13.2 *bc*	30.7	31.3	13.8	22.2
156 seeds m^{-2}	12.9 *c*	31.3	28.0	13.3	21.4
250 seeds m^{-2}	18.2 *a*	34.6	28.7	17.9	24.9
LSD$_{(0.05)}$	3.3	NS	NS	NS	NS
Linear trend$_{(0.05)}$¶	*P* =0.02	NS	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS	NS	NS

† Green manure treatment.

‡ Values within a column followed by the same letter are not significantly different according to LSD ($P \leq 0.05$).

§ The control was not established in the given year.

¶ Linear and quadratic functions were applied to seeding rate data.

All of the plots were weedy during the wheat growing season, and hence weed N uptake needed to be taken into account. However, total N in the weed biomass also generally did not differ significantly between treatments (Table 4.15). An analysis of N uptake into wheat and weeds combined did not reveal any differences among the seeding rate treatments (Appendix 4).

4.4. Discussion

In this study, %Ndfa did not differ significantly between the field pea seeding rates. Strydhorst et al. (2008) similarly reported that the planting density of field pea, lupin and

Table 4.15. Total nitrogen in weed biomass at different sampling dates in 2007 in the wheat plots following the 2006 field pea seeding rates experiment at Vanscoy and Vonda sites.

Sampling date Target Seeding Rate	05-Jul	19-Jul	02-Aug
Vanscoy		--kg N ha^{-1}--	
Summerfallow	18.5	24.7	64.9
GrM 62 seeds m^{2}†	24.1	40.2	70.6
GrM 156 seeds m^{-2}	10.5	35.4	52.8
LSD$_{(0.05)}$	NS‡	NS	NS
10 seeds m^{-2}	7.1	33.8	55.8
25 seeds m^{-2}	14.0	33.4	55.4
62 seeds m^{-2}	14.2	32.3	45.5
156 seeds m^{-2}	13.1	34.7	36.3
250 seeds m^{-2}	9.0	28.0	47.8
LSD$_{(0.05)}$	NS	NS	NS
Linear trend$_{(0.05)}$	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS
Vonda-06			
Summerfallow	14.6	8.3 *b* §	8.9
GrM 62 seeds m^{2}	10.4	19.0 *a*	15.1
GrM 156 seeds m^{-2}	10.2	14.6 *ab*	9.2
LSD$_{(0.05)}$	NS	3.2	NS
10 seeds m^{-2}	6.4	15.9	14.3
25 seeds m^{-2}	5.5	16.7	12.9
62 seeds m^{-2}	8.1	17.1	11.4
156 seeds m^{-2}	6.7	19.6	12.6
250 seeds m^{-2}	7.2	17.0	16.2
LSD$_{(0.05)}$	NS	NS	NS
Linear trend$_{(0.05)}$	NS	NS	NS
Quadratic trend$_{(0.05)}$	NS	NS	NS

† Green manure treatment.

‡ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

§ Values within a site and column followed by the same letter are not significantly different according to the LSD ($P \leq 0.05$).

fababean did not affect %Ndfa, except when the plant density increased 2.0 times the lowest seeding rate, which resulted in a significant linear increase of %Ndfa for lupin at two of four sites. In our study, the values of %Ndfa were within the range of the findings of other studies (Stevenson and van Kessel, 1996; Beckie et al., 1997; Matus et al., 1997; Soon et al., 2004; Walley et al., 2007).

According to a report by Sprent and Minchin (1983), soil inorganic N availability inhibits N_2 fixation. Thus, higher plant populations may be expected to fix more N due to faster depletion of the soil available inorganic N; however, %Ndfa by field pea remained unaffected by seeding rates in our study. It is possible that %Ndfa was affected by the higher weed suppression during the entire growing season. High weed populations at the lower seeding rates depleted the soil inorganic N faster, thus the pea started fixing atmospheric N_2 in the earlier stages of the growth season. Therefore, %Ndfa was maximized and no differences in %Ndfa were detected between seeding rate treatments.

In our study, from 71 to 81% of total N in field pea crop was attributable to N_2 fixation (Table 4.2 and 4.3). Evans et al. (1989) combined findings of 21 trials at 10 locations in Australia and concluded that N_2 fixation provided more than 50% of N for field pea. For field pea, average N_2 fixation was 61%, although estimates were highly variable and ranged from 20 to 95%. Kucey (1989) reported that 57% of the plant N was obtained through N_2 fixation for a Trapper pea crop. Soon et al. (2004) reported %Ndfa values for field pea ranging from 44 to 79% in a 1997 trial and from 67 to 89% of total N in a 1998 trial in Alberta.

The mean total fixed N accumulation in whole plant ranged from 7.6 to 61.0 kg N ha^{-1} in our study. This was felt in the range of 16 to 177 kg N ha^{-1} reported by Evans et al. (1989) for pea grown at 21 sites in Australia. Stevenson and Van Kessel (1996) reported 36 kg N ha^{-1} total N_2 fixed by field pea sown at 120 plants m^{-2} at a Saskatchewan location, which is consistent with our findings for the 156 to 250 seeds m^{-2} rates. However, our findings for quantity of N_2 fixed were lower than reported for many other studies. Sparrow et al. (1995) reported that field pea fixed between 65 to 123 kg N ha^{-1}, as determined by the N-difference method using barley as a reference crop in Alaska. Strydhorst et al. (2008) reported values from 78 to 147 kg N ha^{-1} when plant densities were 38 to 150 seeds m^{-2} in

Alberta. The lower amount of N_2 fixed in our study might be due to the lower yield of field pea because of higher weed suppression (Baird, 2007).

In our study, total accumulation of fixed N_2 averaged across sites consistently increased with seeding rate, although there was no significant difference between the two lowest seeding rates (Fig. 4.1). In agreement with our study, Strydhorst et al. (2008) found a significant increase in N_2 fixation yields in response to increasing plant densities of field pea, lupin and fababean. Similar trends were also reported by Ayaz et al. (2004), with pea and lupin straw N yields typically increasing in response to increasing plant populations.

Pea seed N uptake was generally lower than in other reports which may reflect overall lower N availability associated with organic production. Kucey (1989) reported that field pea (Trapper) grown in Alberta using conventional practices accumulated 219 kg N ha^{-1} in the grain and 115 kg N ha^{-1} in the straw. Stevenson and Van Kessel (1996) reported that field pea grown in Saskatchewan and seeded at a rate of 120 plants m^{-2} accumulated 69 to 94 kg ha^{-1} total N in grain. Similarly, Beckie et al. (1997) found that the total N uptake of field pea grain was 70 to 75 and 71 to 83 kg N ha^{-1} in a two year experiment in Saskatchewan depending on landscape slope position. In a cropping sequence trial, the grain N yield of pea was 28 to 65 kg N ha^{-1}, when planted at a rate of 90 plants m^{-2} and with mid-season fertilizer applied (Miller et al., 2006). However, our study was undertaken in an organic system, and hence total grain N yield was likely controlled by the limited nutrient supply and weed suppression as compared to the other studies that used conventional systems. Thus, the total N in field pea grain was consistently lower than that reported in other studies.

The N contribution of field pea to the soil averaged over for all sites varied significantly between the seeding rate treatments. Moreover, all treatments resulted in positive N contributions and ranged from 1.9 to 39.2 kg N ha^{-1}. The N contribution in our study were within to the range reported by Evans et al. (1989) (i.e., -32 to 96 kg N ha^{-1}) and Stevenson (1996) (i.e., 18 to103 kg N ha^{-1}). The greater N contribution for the higher rates was largely the result of the greater N input with the original seed, and the amount of fixed N_2 with the increased seed yield due to the higher rates. In fact, the higher rates accumulated greater N in the seed from the soil (Table 4.5).

According to Evans et al. (2001) and Walley et al. (2007), %Ndfa required to achieve a positive N contribution for field pea was 41.9 and 46.7, respectively. In our study, %Ndfa was 75 to 81%, which was enough to achieve a positive N contribution (Table 4.4). This was also consistent with the observation of Evans et al. (2001), who observed that the N contribution was positively correlated with the amount of N derived from N_2 fixation.

Due to the high amount of precipitation in the preceding fall, which was 1.4 and 1.6 times higher than the 30-yr average at Vanscoy and Vonda, respectively, the soil water content in the spring 2007 was remarkably high, especially at Vonda. However, precipitation in July was lower than the 30-yr average and the mean daily temperature was approximately 3ºC lower than the long-term average. It was the peak period of wheat biomass accumulation (Table 4.10), and therefore, soil moisture might not have been sufficient for peak growth.

Pre-seeding soil total inorganic N (NH_4^+-N + NO_3^--N) in the 0- to 15-cm depth were relatively low and largely unaffected by the previous treatments except for fewer trends (Table 4.7 and Table 4.8). The lack of detectable differences in our study might be explained by the excessive soil water content which occurred between the fall and spring, which may have inhibited the N mineralization of the soil and residue. The excessive water saturation in the soil may also have caused N losses as a result of denitrification (Miller et al., 2006).

The presence of weeds likely affected wheat yields and may have eliminated possible differences between treatments. In a cereal and weed competition study performed in an organic system, it was observed that the mean grain yield of 11 different wheat cultivars was reduced by 23 to 34% due to weed competition (Mason et al., 2007). Similarly, Soon et al. (2004) reported that the date of weed removal at 1 and 4 weeks after planting in field pea plots reduced yields by 213 and 353 kg ha^{-1}, respectively.

Wheat yields achieved in our study were relatively low. However, the low seed yield in our study might be due to increased weed pressure and soil nutrient deficiencies typical of organic systems, which may lead to crop yield reductions (Clark et al., 1999; Ryan et al., 2004).

According to our results, the residual N from the previous field pea treatment did not enhance N accumulation in the following wheat crop. Others similarly have reported that the N contribution from pulse crops to the following wheat was not significantly different from that of wheat following wheat (Bremer and Van Kessel, 1992; Fu, 2000). Bremer and Van Kessel (1992) observed that N availability for the following wheat crop from lentil straw and wheat straw was negligibly smaller and similar to each other. Specifically, only 5.5% of ^{15}N applied was assimilated by the following wheat crop. Fu (2000) similarly examined the N benefit of chickpea and reported that no difference existed in the N benefit to the succeeding wheat between ^{15}N-labeled chickpea and wheat residues. In contrast, Soon et al. (2004) found a significant N benefit, 9 to 25 kg N ha^{-1}, from a preceding pea crop to the following barley crop. However, this result was detected in a weed control trial in which herbicides were used in the preceding pea crop. Therefore, weed suppression during the field pea year might considerably affect the N dynamics in both years.

4.5. Conclusion

The %Ndfa in field pea was unaffected by seeding rate. The mean %Ndfa for the five seeding rates ranged from 75 to 81 % for field pea. Seeding rate had a strong effect on the total quantity of N_2 fixed. The amount of fixed N_2 increased significantly from lower to higher seeding rates, which is consistent with significant linear increases in grain yield from the lowest to highest seeding rate (Baird, 2007).

Field pea seeding rate affected N contribution. Specifically, the N contribution was significantly greater at higher seeding rates, but showed no effect between the lower seeding rates. The higher the total quantity of N_2 fixed, the greater the observed N contribution. Hence

Year#1 field pea seeding rates had no effect on pre-seeding soil water in the following spring. During the growing season, no differences were detected in N uptake in wheat biomass. Thus, the N uptake dynamics of the wheat crop did not appear to be affected by the N added to the soil from the previous field pea treatments. Consistently, the N uptake in wheat grain was not affected by the previous pea seeding rate treatments. However, N uptake by the wheat crop grown on summerfallow and green manures was always significantly higher than N uptake by wheat grown on pea stubble.

High weed populations occurred in the wheat plots. However, both weed biomass and N uptake by weeds did not differ between any of the treatments, including the summerfallow and green manure controls, suggesting that the previous field pea seeding rates did not influence subsequent weed population.

Overall, increased seeding rates of field pea increased the amount of N_2 fixed because of higher seed yields. As the amount of N_2 fixed exceeded the N derived from the soil with increasing seeding rates, the field pea grown at higher seeding rates contributed more N to the soil. However, the N benefits from the field pea to the following wheat crop were not influenced by the previous seeding rate treatments.

5. GENERAL DISCUSSION

This study examined the impact of seeding rate on N_2 fixation and N accumulation in lentil and pea, and the subsequent residual N benefits to a following wheat crop.

Two main experiments were conducted between 2005 and 2007 on certified organic farms near Vonda, Vanscoy and Delisle, SK. The general structure of the experiments were designed to examine: 1) lentil and field pea seeding rate effects on N_2 fixation; and 2) subsequent N benefits of lentil and field pea treatments to the following wheat crop. Each experiment was conducted over two years. Year#1 was the treatment year when different seeding rates of the pulses were established and in Year#2 wheat was seeded into the pulse stubble to determine the N impacts on the following wheat crop.

Plant population density did not apparently influence %Ndfa for either lentil or field pea. Materon and Danso (1991) similarly observed that planting density of alfalfa did not influence %Ndfa. The %Ndfa for lentil in our study was 80 to 88%, which is high compared to findings from other studies (Bremer, 1991; Fu, 2000), while that of field pea was similar to results of other studies (Stevenson and Van Kessel, 1996; Beckie et al., 1997 and Soon et al., 2004). Both percentage and total N_2 fixation was possibly affected by the high weed population densities as reported by Strydhorst et al. (2008). Competition between the pulses and weeds for soil N may have depleted soil N more rapidly, stimulating more N_2 fixation than in conventional systems where weeds are controlled more effectively. Moreover, weed biomass significantly increased as seeding rates decreased, and in general, pulse yield was negatively affected by lower seeding rates (Baird, 2007). Therefore, although %Ndfa was generally unaffected by seeding rate, the amount of fixed N_2 was substantially reduced with lower pulse N yields. Seeding rate had an impact on the N accumulated via N_2 fixation, and was related to the biomass production of the pulses. The quantity of fixed N_2 was varied with seeding rate due to the significant difference in grain yield from the lowest to highest seeding rate. A similar result was reported by Materon and Danso (1991) in an alfalfa study.

The quantity of N_2 fixed showed a positive relationship to the N contribution to the soil. Nitrogen contribution to the soil was positive for all treatments and the higher seeding rates promoted a greater N contribution to the soil due, in part, to the increased N yield and N input in the planted seed. Soil N available for wheat growth in the spring following the lentil and field pea treatments was expected to differ among treatments, because seeding rate is known to influence biomass of both crops and weeds and thus can influence organic N inputs. However, the soil test for inorganic N in the spring following the pulse year did not reveal sufficient evidence of differences between the treatments. Moreover, no differences were detected by ANOVA ($P \leq 0.05$) during the growing season of the following wheat crop. Similar results were documented by other researchers who reported that differences in pea residue N content or presence was not detectable in the short-term (Miller et al., 2006).

Wagger et al. (1985) reported that the N mineralization from pulse residue was not temporally synchronized with the N demand of the subsequent wheat crop. However, if N mineralization from the pulse residues occurred within a short time period, the biweekly soil mineralization test may not have revealed differences between the treatments. Moreover, Janzen and Kucey (1988) indicated that N will not be mineralized from crop residue until the substrate being decomposed reaches a critical N concentration. If the N benefit by pulses to the subsequent crop is due to a gradual release of N in long-term rotations, differences between treatments may not have been substantial enough to detect during the growing season immediately following the pulse crop year. Miller et al. (2006) reported that the benefit of field pea residue on soil water, soil N and crop growth was not observed within the context of a 2-yr cropping sequence, and thus a different response may be found in a long-term rotation.

It is also possible that the lack of differences between the treatments in term of the residual N benefits to the succeeding wheat crop was due to the high population of weeds depleting the soil available N during the pulse year. Although the weed residues were left in the field with the pulse residues, the weeds reduced pulse biomass and consequently the overall quantity of N_2 fixed was reduced to a greater degree than would be expected in the absence of weeds. Therefore, less rotational N benefit was conferred to the following wheat. Consistent with this, Miller et al. (2004) reported that although the time of weed removal during pea cultivation affected the N contribution in the treatment year, it had no measurable effect on N availability to the subsequent barley crop. Moreover, pulse residues and weed residues may differ in decomposition rates and thus may release different quantities of N, at different times. There is no information on what proportion of the weed biomass N is mineralized in the following year and the benefit to the following wheat crop. It is most likely that the larger weed population accumulated more soil available N during the pulse year and held the N in the residues during the following growing season, because the weeds had lower initial N concentrations and higher C:N ratios than the pulses. Residues with high initial N concentration and low C:N ratio experience faster decomposition (Vazquez et al., 1995).

As determined by the wheat yield and N uptake in the wheat, no differences were detected between the previous pulse treatments. Although many studies have focused on the notion that pulse crops increase N availability to subsequent crops, detailed studies have found that the N contribution of pulses to subsequent crops was smaller than expected (Stevenson and Van Kessel 1996; Miller et al., 2006). Only 2 to 15% of the ^{15}N originally present in pea or lentil crops was accumulated in subsequent cereal crops (Bremer and Van Kessel 1992; Jensen, 1994; Fu, 2000). In our study, the differences in N contribution to the soil and the effects of N_2 fixed between the previous pulse treatments, were not detected in the following wheat. Therefore the N benefit was considered to be negligible or undetectable. However, the long-term importance of fixed N_2 in the cropping system must not be ignored (Campbell et al., 1992; Miller et al., 2006). Campbell et al. (1992) found evidence documenting the importance of this in a long-term study where the N-supplying power of the soil was enhanced in a wheat-lentil rotation when compared with monoculture wheat rotations. Miller et al. (2006) similarly observed the benefits of field pea residue for a 2-yr cropping sequence.

Generally, it might be concluded that the different seeding rates of organically grown lentil and field pea have no effect on the %Ndfa, and the differences in N remaining in the soil at different seeding rates of the pulse crops was not detectable in the following wheat crop and the soil N in the following year. However, higher seeding rates significantly increased pulse yield (Baird et al., 2009) and consequently contributed greater N to the soil. In the organic cropping system, weeds were a significant influence. The presence of weeds caused a decrease in pulse biomass and probably affected the overall N benefit to the following wheat, particularly with the lower seeding rate treatments. Because total N accumulation was correlated to biomass production, reduced pulse yields resulted in less N returning to the soil in the pulse residue.

To enhance N benefits and yield, additional weed control might be needed on organic farms, in addition to increasing plant densities. The higher seeding rates of both pulses reduced weed biomass (Baird, 2007), but these rates alone were not sufficient to adequately control the weeds. Consequently, alternative weed control methods are recommended in combination with higher seeding rates in organic cropping systems.

Although the pulse seeding rates did not show differences in subsequent N benefits to the following wheat, higher seeding rates must have greater potential in the longer-term. The N contribution and residue remaining in the soil were greater with higher seeding rates for both pulses. Also total N_2 fixed by lentil averaged for sites showed the highest value at 383 seeds m^{-2} (Fig. 3.1). Therefore, the highest seeding rates (i.e., 375 seeds m^{-2} for lentil and 250 seeds m^{-2} for pea) of the both pulses can be considered as recommendable seeding rate, based on performance in the pulse year. However, accurate economical analysis is required for those rates which were selected based solely on the agronomic outcomes.

Further research may be needed to focus on N benefits of pulse crops for long-term rotations and weed control methods to increase the productivity of pulse crops grown on organic systems.

6. APPENDICES

Appendix 1. Site characteristics in the upper 15 cm of the soil profile and farming history of the experimental sites in central Saskatchewan.

Characteristics	Site			
	Delisle	Vonda-05	Vanscoy	Vonda-06
Location	51° 49' 31"N 107° 19' 01"W	52° 18' 25"N 106° 06' 03"W	51° 57' 24"N 106° 56' 44"W	52° 17' 50"N 106° 06' 05"W
Soil Association†	Elstow	Oxbow	Asquith	Oxbow
Soil Parent Material	silty glacial lake deposits	medium to heavy textured glacial lake deposit	sandy glacial lake alluvial deposits	medium to heavy textured glacial lake deposit
Soil Texture‡	loam to clay loam	clay loam to clay	clay loam	clay loam to clay
Soil Classification§	Dark Brown Chernozem	Orthic Black Chernozem	Orthic Dark Brown Chernozem	Orthic & Calcareous Black Chernozem
Farming History¶	8	20	10	20
Previous Crop	Barley	Barley	Wheat	Wheat
pH‡	8.4	7.2	8.2	6.3
EC (mS cm^{-1})‡	0.2	0.3	0.2	0.2
Soil test NO_3-N (µg g^{-1})‡	9.4	12.5	7.2	5.0
Soil test P (µg g^{-1})‡	6.7	12.0	3.3	>30

† Soil Associations and parent materials as determined by Mitchell (1987).

‡ Determined by Enviro Test Lab (2005); and ALS Laboratory Group Agricultural Services (2006).

§ Soils were classified using The Canadian System of Soil Classification (SCWG, 1998).

¶ Number of years farmed organically.

Appendix 2. Monthly rainfall and mean daily temperature for experimental sites in central Saskatchewan in 2005, 2006 and 2007 and the long term (30-yr) average.

	Monthly Precipitation (mm)						
Year	2005		2006		2007		30-yr average†
Months	Delisle‡	Vonda§	Vanscoy¶	Vonda	Vanscoy	Vonda	
April	16	16	38	5	2	5	24
May	28	39	40	62	46	46	50
June	161	137	108	85	131	116	61
July	54	38	32	67	24	49	60
Aug	54	92	30	47	49	86	39
Sep	74	94	118	163	24	36	31
Total	387	416	366	429	276	338	264
	Mean Daily Temperature (°C)						
April	6.4	7.0	8.0	7.9	4.8	4.2	4.4
May	10.2	10.7	11.7	12.3	11.2	11.4	11.5
June	14.4	15.0	16.2	16.9	15.0	15.6	16.0
July	17.5	17.9	20.0	20.0	21.0	21.1	18.2
Aug	15.4	15.8	18.0	18.1	15.8	16.1	17.3
Sep	11.3	11.9	12.2	12.1	10.4	10.6	11.2

† Based on Saskatoon airport weather data in 1971-2000 from Environment Canada.

‡ Delisle 2005 climate data from nearest Environment Canada weather station (Saskatoon, SK.).

§ Vonda 2005-2007 climate data from nearest Environment Canada weather station (Osler, SK.).

¶ Vanscoy site was close to Delisle, therefore Delisle data is identical to Vanscoy in 2006.

Appendix 3. Combined total nitrogen in wheat and weed biomass at different sampling dates in 2007 in the wheat plots following the 2006 lentil seeding rates experiment at Vanscoy and Vonda sites.

Sampling date Target Seeding Rate	05-Jul	19-Jul	02-Aug
Vanscoy	------------------------	kg N ha^{-1}	------------------------
Summerfallow	44.4	72.0	62.7
GrM 235 seeds m^{-2}†	46.4	86.5	73.0
GrM 375 seeds m^{-2}	57.0	96.7	80.4
LSD$_{(0.05)}$	NS ‡	NS	NS
15 seeds m^{-2}	26.3	36.1	30.5
38 seeds m^{-2}	30.2	39.5	32.0
94 seeds m^{-2}	26.2	36.9	33.3
235 seeds m^{-2}	32.5	43.7	29.4
375 seeds m^{-2}	36.9	41.8	34.3
LSD$_{(0.05)}$	NS	NS	NS
Vonda-06			
Summerfallow	51.0	57.6	45.9
GrM 235 seeds m^{-2}	40.4	47.3	37.4
GrM 375 seeds m^{-2}	45.6	43.6	48.3
LSD$_{(0.05)}$	NS	NS	NS
15 seeds m^{-2}	19.6	24.9	23.1
38 seeds m^{-2}	23.6	28.3	25.8
94 seeds m^{-2}	22.2	31.2	26.4
235 seeds m^{-2}	25.7	32.5	26.5
375 seeds m^{-2}	33.0	35.6	35.5
LSD$_{(0.05)}$	NS	NS	NS

† Green manure treatment.

‡ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

Appendix 4. Combined total nitrogen in wheat and weed biomass at different sampling dates in 2007 in the wheat plots following the 2006 field pea seeding rates experiment at Vanscoy and Vonda sites.

Sampling date Target Seeding Rate	05-Jul	19-Jul	02-Aug
		---kg N ha^{-1}---	
Vanscoy			
Summerfallow	74.5	83.2	136.2
GrM 62 seeds m^{-2}†	74.0	108.8	123.9
GrM 156 seeds m^{-2}	64.4	94.8	116.2
LSD$_{(0.05)}$	NS ‡	NS	NS
10 seeds m^{-2}	38.8	65.1	77.2
25 seeds m^{-2}	39.9	65.7	88.3
62 seeds m^{-2}	45.0	62.0	74.6
156 seeds m^{-2}	43.2	63.6	58.7
250 seeds m^{-2}	37.7	61.0	76.9
LSD$_{(0.05)}$	NS	NS	NS
Vonda-06			
Summerfallow	44.6	45.6	39.7
GrM 62 seeds m^{-2}	41.1	45.2	40.4
GrM 156 seeds m^{-2}	33.7	45.1	37.2
LSD$_{(0.05)}$	NS	NS	NS
10 seeds m^{-2}	21.7	34.9	26.2
25 seeds m^{-2}	17.9	30.4	22.1
62 seeds m^{-2}	26.9	31.0	22.9
156 seeds m^{-2}	21.4	34.0	22.2
250 seeds m^{-2}	22.8	31.7	28.6
LSD$_{(0.05)}$	NS	NS	NS

† Green manure treatment.

‡ Not significantly different within a site and column according to the LSD ($P \leq 0.05$).

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