GROWTH, YIELD AND NITROGEN CONTENT OF LENTIL (*Lens culinaris* Medic) AS AFFECTED BY NITROGEN AND DIQUAT APPLICATION

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ABSTRACT

As an indeterminate crop, lentil continues its vegetative growth after flowering under favourable conditions of water and nitrogen (N). Such conditions may delay its maturity due to excessive growth. Furthermore, lentil is a leguminous crop; late season N_2 fixation could prolong its growth and maturity. The objective of this research was to determine the role of N supply and diquat application in suppressing post-flowering growth and biomass. Two experiments were designed for two distinct soil zones of Saskatchewan during 2007 and 2008. In the first experiment, different combinations of nitrogen, phosphorus and inoculation were employed to determine their effect on growth, yield, biomass and N accumulation in lentil. In a second experiment, diquat was applied at two rates (lower than recommended) at two post-flowering stages (earlier than end-of-season desiccation) to control lentil growth.

In both experiments, post-flowering vegetative growth was greater at Indian Head (IH) compared to Saskatoon (SKA). Regardless of the site features, greater N availability resulted in increased biomass production at both locations. The yield trend was, however, different. At IH, highest yield was obtained with 10 kg N ha^{-1} (lowest N applied), while at SKA, yield was not significantly affected by fertility treatments. The hypothesis that greater amounts of N application may reduce post-flowering biomass accumulation by curtailing N_2 fixation is not supported by the data since biomass increased with increasing N application. In addition, both biomass and N accumulation after flowering were not affected significantly by the fertility treatments, showing that post-flowering physiology in lentils is governed more by N_2 fixation instead of N application. The overall lack of response of lentil biomass and N accumulation after flowering to the individual fertility treatments suggested that source and availability of N does not change within plant. Instead, environmental conditions were more likely to influence portioning of biomass and N to seed through remobilization from vegetative parts in mid to late-season reproductive growth.

Diquat application successfully suppressed biomass and plant growth at maturity. However, a reduction in biomass was obtained at the cost of yield loss at both sites. This loss in yield was great when diquat was applied at the earlier stage (one WAF) at half rate at both sites. Early application of diquat at low rate at IH reduced biomass by 25% compared to the control without significantly affecting yield. The same treatment, however, reduced biomass by 45% at SKA with huge yield loss. The results suggested low rate of diquat application at earlier crop growth stage to avoid yield loss in lentil.

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DEDICATION

This thesis is dedicated to my parents, Muhammad Iqbal Sarshar (Dad) and Rasheeda Begum (Mom), whose prayers are always a source of encouragement and inspiration for me.

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1. INTRODUCTION

Lentil (*Lens culinaris* Medic.) is one of the oldest annual grain legumes consumed and cultivated in the world. Originating from South western Asia as early as 6000 B.C., lentil is rich in proteins and contains high concentrations of essential amino acids like isoleucine and lysine, as well as other nutrients like dietary fiber, folate, vitamin B_1, and minerals (Rozan et al., 2001). Lentil is widely consumed in various parts of the world as loaves, soups, pies, curries etc., especially in vegetarian cultures. It is also an important source of dietary protein in the Mediterranean and South Asian regions.

Lentil is a cool season pulse crop and is also relatively tolerant to drought. It is grown throughout the world especially in India, Canada and Turkey. Canada is the largest exporter and the second largest world producer of lentil with 98% grown in the province of Saskatchewan (Agriculture and Agri-Food Canada, 2002). Cultivation of this valuable crop has substantially increased in Saskatchewan due to diversified cropping systems and higher returns to the farmers. In 2010, Saskatchewan farmers grew lentil on 953 thousand hectares with annual production and average yield of 1480 thousand tonnes and 1568 kg ha^{-1}, respectively (Saskatchewan Ministry of Agriculture, 2011). However, the adaptability of this crop to the unpredictable environment of Saskatchewan challenges its yield potential. A range of 852 to 1568 kg $ha^{-1}$of seed yield over 10 years (2001-2010) indicates the instability of lentil yield from year to year (Saskatchewan Ministry of Agriculture, 2011).

One of the important reasons for unstable lentil yield is the indeterminate growth habit of lentil plants. Extensive vegetative growth, lodging, pod abortion due to limited light interception in the lower part of the canopy, excessive flower and pod shedding, and competition between pods and vegetative parts for photosynthates are all the consequences of indeterminacy and late maturity. For lentil, all genotypes are indeterminate and branched (Erskine and Goodrich, 1991). As a result, lentil yield frequently in Saskatchewan suffers from delayed maturity, lowered harvest index, disease infestation and frost damage. Under wet conditions with sufficient availability of soil moisture, indeterminacy is further aggravated with high N availability (Gan et al., 2009). Cool and wet growing conditions during the crop maturity are common in

Saskatchewan. Such conditions result in excessive lentil growth with less partitioning of N and photosynthate to seed, both resulting in low and unstable yield of lentil over time.

Being a leguminous crop, lentil can make use of atmospheric N_2 to fulfill its N requirements through biological nitrogen fixation (Badarneh, 1995). Nitrogen fixation in legumes is governed by several factors like rhizobial strains as well N and P availability in the soil. Phosphorus (P) and nitrogen (N) play specific roles in symbiotic N_2-fixation through their effects on nodulation and N_2-fixation process (O' Hara et al., 2002). Symbiotic nitrogen fixation has a high P demand indirectly because the process consumes large amounts of energy (Schulze et al., 2006) and energy generating metabolism strongly depends upon the availability of P (Israel, 1987; Plaxton, 2004). The abundant N supply through N_2 fixation is thought to exacerbate the indeterminate growth habit of lentil. In addition, when a legume crop like lentil has access to N fertilizer, the crop favours fertilizer N uptake instead of nitrogen fixation, due to nitrate or ammonium uptake being a less energy consuming process for the plant. Inhibiting effects of nitrate on legume N_2 fixation have also been described in the literature (Bremer et al., 1988, Doughton et al., 1993; Mathhews, 2009; Osborne and Riedell, 2006; Salvagiotti et al., 2008). Therefore, the N supply to lentil particularly due to N_2 fixation could play a role in delayed maturity.

Lentil maturity, like other annual crops, is initiated by leaf senescence. Leaf senescence is triggered by plant hormones, drought, and insufficient supply of nutrients, especially N (Lim et al., 2007). Because soil water availability and sites of soil N mineralization are not controlled in dryland agriculture, soil N management and desiccant application are practical strategies to induce maturity in indeterminate crops (Gan et al., 2009). Earlier maturity due to late season N deficiency reduces lentil biomass, harvest index and seed yield (Whitehead et al., 2000). In indeterminate crops, N remobilization from shoots and roots to seeds is low (Munier-Jolain et al., 1996), therefore, yield may suffer from late season N deficiency (Whitehead et al., 2000). The association of using late-season N deficiency to trigger earlier maturity infers that lentil has a high seed demand for N and low N remobilization ability. Any N management strategy should target reducing late season N uptake in lentil, because N deficiency during maximum growth may reduce yield to a greater extent than late season N deficiency.

For indeterminate crops like lentil, herbicides can be used as harvest aids at crop maturity to desiccate weed and crop foliage. Desiccant application is important in years of warm and wet springs, and cool and wet summers, conditions that promote luxuriant plant growth. Under such conditions lentil will continue to flower and set pods, and weeds will continue to grow as long as moisture is available. Crop topping with a desiccant herbicide has been advocated as a mean of enabling early harvest and controlling weeds (Teofilo et al., 1999; Santos et al., 2004).

The present study is composed of two types of experiments to address lentil management through fertility and diquat application practices. The objectives of this research work were to:

1) To determine if N and P fertilizer in combination with rhizobia inoculant can be used to enhance better early-set yield and earlier maturity in lentil grown in Black and Dark Brown soil zones of Saskatchewan.

2) To determine if a lower rate of diquat (than current farming practice), sprayed at early pod growth stages, can be used to enhance earlier maturity without a yield penalty in lentil.

The ultimate goal of this research is to determine if nitrogen and desiccant application rates can be used as practical management options for Saskatchewan growers to control excessive indeterminacy in lentil crop. This thesis will begin with a Literature Review, which provides background information from similar studies. Next, the Materials and Methods section presents an overview of how the project was set up and executed, followed by the Results and Discussion section in which the findings of this project are presented. In closing, there is a Summary and Conclusions section in which the final results will be presented, followed by a list of References.

2. LITERATURE REVIEW

The following chapter will explore lentil cultivation in Saskatchewan, its morphology and N_2 fixation and effects of nitrogen, phosphorus, inoculation and desiccant application on lentil with examples of other pulse crops.

2.1 Lentil Production in Saskatchewan

Lentil (*Lens culinaris* Medic) is a member of the leguminosae (fabaceae) family and an important pulse crop grown in Western Canada. Lentil was first grown in southwest Asia in 7,000 B.C. (McVicar et al., 2010). Production of this cool season annual crop spread to the Mediterranean area, Asia, Europe and finally the Western Hemisphere (Oplinger et al., 1990). Today, India, Canada, Turkey, Australia, Nepal, USA, Bangladesh and China are the world's top producers of lentil with Canada being the second largest producer and the largest exporter of lentil in the world. In 2009, worldwide lentil production was 3917 thousand tonnes on cultivated area of 3700 thousand hectares (FAO, 2011). Commercial production of lentil in Canada began in Saskatchewan in 1970 (McVicar et al., 2010). Increasing emphasis on environmental sustainability and economic growth has stimulated producers in Western Canada to include pulse and oilseed crops in their crop rotations (Miller et al. 2002). The area seeded to lentil in this region has increased from less than 600 ha in 1970 to 960,000 ha in 2009 (McVicar et al., 2010). This annual legume is being used to diversify cereal-based crop rotations (Miller et al., 2003), replace conventional summer fallow and conserve soil quality (Zentner et al., 2001), and enhance productivity of subsequent cereal and oilseed crops (Gan et al., 2002). In Western Canada, lentil production is concentrated in the semiarid Brown and Dark Brown soil zones where moisture stress in the later part of the growing season helps terminate its indeterminate growth.

2.2 Lentil consumption

Lentil is an essential source of inexpensive protein in many parts of the world. It is also an excellent source of vitamin A and provides fibre, potassium, B vitamins and iron. Lentil seeds contain high levels of protein, including the essential amino acids isoleucine and lysine, and unlike meat, poultry, fish and eggs, this protein source contains no cholesterol and virtually no fat. Lentil, eaten with a grain such as rice, wheat or barley, provides all the essential amino acids required by human body in a balanced diet. Most lentil production is consumed by humans as a protein source in a diverse range of products from desserts to soups.

2.3 Lentil morphology

The botanical features of cultivated lentil can be described as an annual bushy herb, much-branched, softly hairy with slender stems (Duke, 1981; Muehlbauer et al., 1985). The leaves are alternate with 4-7 leaflet pairs. Flowers are small, pale blue, purple, white or pink. A single plant can produce from 10 to 150 peduncles (stalks), each having 2.5 to 5 flowers on each peduncle (Muehlbauer et al., 1985). Flowering proceeds acropetally (emerging from base to apex). Germination is hypogeal and this keeps the developing seedlings below ground level which reduces deleterious effects of freezing and other desiccating environmental conditions (Muehlbauer et al., 1985). Maximum node number and biomass accumulation in lentil occur between maximum flowering and early pod formation stages (Kurdali et al., 1997 and van Kessel, 1994). The plant develops primary, secondary and tertiary branches. The number of branches produced by the plant varies with plant population density (Wilson and Teare, 1972). On average the main stem, primary and higher order branches carry 18, 52 and 30% of the plant's pods, respectively (Erskine and Goodrich, 1991). Seed size in lentil is categorized into two major groups of large seeded (macrosperm: greater than 50 g per 1000 seeds) and small seeded (microsperm: 40 g or less per 1000 seeds). Lentil has two main market classes, green and red, that are marketed as whole seed or de-hulled and split forms (Saxena, 2009).

2.4 Indeterminate growth and lentil maturity

Thomson et al. (1997) reported that required degree days for seedling emergence, flowering and pod formation of lentil were reduced in drier sites and drier years. They concluded that slow emergence, long vegetative growth, late flowering and the duration of pod formation of lentil is not synchronized with the environment of low rainfall and a short growing season of Canadian Prairies. As an indeterminate crop, longer days to maturity in lentil may affect yield by increasing the number of high order branches (secondary and tertiary branches), which carry fewer pods than main stem and primary branches. However, Erskine and Goodrich (1991) did not find a significant correlation between seed yield and the number of branches. They reported that a prolonged lifecycle and delayed maturity increased plant height, indicating that post-flowering growth increased branch length instead of branch number.

Lentil maturity is affected by temperature, rainfall and sowing date and ranges from 75 to 180 days (Saxena, 2009). In the northern Great Plains of Americas, lentil matures in 88 to 101 days after sowing (Miller et al., 2003). Although longer days to maturity may increase biomass and yield, it may reduce harvest index, delay maturity and leave the crop susceptible to frost damage (Thomson et al., 1997). Lentil requires 944 to 1270 heat units (GDD) from seeding to maturity to complete its growth. This heat requirement is generally achieved in most parts of the Great Plains (Miller et al., 2002). Cooler temperatures may reduce yield by reducing harvest index. In drier conditions, early flowering cultivars tend to increase harvest index by increasing the length of pod-filling period, and harvest index is also improved by late-season drought (Silim et al., 1993).

The flexible growth habit of indeterminate cultivars in low yield potential environments is considered advantageous for plant survival and yield. In soybean, indeterminate cultivars yielded more than the determinate cultivars in late-planted crops, because they produced more stems and seed per plant and had a longer seed-fill phase than determinate cultivars (Sohedjie and Weaver, 1995). In contrast, terminal drought forced lentil to maturity and enhanced partitioning of assimilates to seeds by reducing sink-source competition (Silim et al., 1993).

2.5 N_2 fixation in lentil

Lentil is a legume and fulfils most of its N requirement through atmospheric N_2 fixation with the symbiotic help of rhizobia living in its root nodules. Generally, the level of N_2 fixation in legumes depends on host genotypes, rhizobial strains, environment and their interactions. Lentil cultivars have shown genetic variability in their ability to symbiotically fix N_2 (Rennie and Dubetz, 1986), therefore genotypes with high N_2 fixation and high seed yield are desirable for sustainable agriculture. Kurdali et al. (1997) carried out a field experiment to assess the source of nitrogen (N_2 fixation, soil and fertilizer), N assimilation, partitioning and mobilization in rain-fed lentil at various growth stages using ^{15}N isotopic dilution. The study was conducted on five lentil cultivars differing in seed size. They reported that there was a strong cultivar effect on both N_2 fixation and soil N uptake beyond flowering, and the plants were characterised by either current N_2 fixation or soil N uptake, or by negligible N assimilation from either source. The results showed net mobilization of N (43% to 94%) from shoots and roots to pods. They concluded that when both soil and atmospheric N sources are limited, translocation of N from the pre-existing N pool in vegetative tissues became the major source of N for pod filling. However, this phenomenon was affected considerably by plant cultivar.

Nitrogen for developing pods can be supplied from soil, atmospheric N_2, and from the mobilization of existing N in plant tissues. The relative importance of these sources depends on several factors including plant species, genotype, drought stress, plant and soil N status, and N_2 fixation ability (Kurdali et al., 1997). Senaratne and Ratnasinghe (1993) reported that N_2 fixation in legumes is highest between flowering and early pod fill and all legumes derived about 90% of their N from the atmosphere by 80 days after emergence. Using wheat as a reference crop, van Kessel (1994) found that lentil accumulated more DM and N content during the latter part of the growing season. The reproductive plant parts had higher values for % Ndfa (percentage of N derived from the atmosphere) than the vegetative components which indicates that N in the reproductive plant parts was derived largely from current N_2 fixation and lentil continued to fix N until the end of the pod fill stage (van Kessel, 1994).

2.6 Nitrogen application on lentil

Like most annual legumes, lentil can provide a part of its own N requirement through symbiotic N_2 fixation when the plants are inoculated. Sosulski and Buchan (1978) reported that rhizobial inoculation alone is not enough for obtaining high yields of legumes because of poor nodulation and nitrogenase activity. They concluded that annual legumes may require a high level of plant N fertility to achieve maximum yield. Indigenous populations of rhizobia for legumes may be present in prairie soils, but these indigenous populations may be ineffective for inducing N_2 fixation under semiarid environments (Kucey and Hynes, 1989). Small doses of N fertilizers applied to an annual pulse are beneficial if nodule initiation is delayed (Mahon and Child, 1979). In dry pea, N application at 20 to 60 kg ha^{-1} increased seed yield by an average of 9% in one quarter of 58 trials conducted in Alberta (McKenzie et al., 2001). When spring soil NO_3-N (0 to 30 cm depth) was less than 20 kg N ha^{-1}, the use of fertilizer N increased pea yield by an average of 11% in one-third of the trials. Similarly, application of fertilizer N increased dry bean

(*Phaseolus vulgaris* L.) seed yield proportionally in southern Manitoba (McAndrew and Mills, 2000). Most producers in Western Canada inoculate the seed or the soil with a rhizobia strain and provide little or no fertilizer N to their lentil crops. Due to the lag period between rhizobial root colonization infection and the onset of nodule functioning, the young lentil plants may require a small dose of additional N (i.e., starter- N) from external sources to achieve vigorous vegetative growth and establish N_2-fixing symbiosis.

2.7 Phosphorus application on lentil

Phosphorus plays a major role in many plant processes, including storing and transfer of energy; stimulation of root growth, flowering, fruiting and seed formation; nodule development and N_2 fixation (Mclaren and Cameron, 1996; Ali et al., 1997). Phosphorus application on legumes can also increase leaf area, yield of tops, roots and grain; nitrogen concentration in tops and grain; number and weight of nodules on roots; and increased acetylene reduction rate of the nodules (Jessop et al., 1989; Idris et al., 1989; Yahiya et al., 1995). Research documents the influence of P on nodule development and N_2 fixation by legumes (Israel, 1987). The N_2-fixation process in legumes is sensitive to P deficiency due to reduced nodule mass and decreased ureide production (Sinclair and Vadez, 2002; Vance, 2001). Nodules are a strong P sink and nodule P concentration normally exceeds that of roots and shoots (Sa and Israel, 1991; Drevon and Hartwig, 1997). Therefore, nodule number, volume, and dry weight can be increased by treating P deficient soils with fertilizer P (Cassman et al., 1981). However, Bremer et al. (1989) found that P application increased dry matter and grain yield but did not affect N_2 fixation indicating that the legume host was more responsive to P application than the rhizobia.

Saskatchewan soils generally test low to medium in available phosphorus (Henry, 1980), a nutrient required in relatively large amounts by pulse crops. Total P in Saskatchewan soils ranges from about 400 to 2200 kg ha^{-1} in the top 15 cm of soil, but only a very small amount of the total P is available to the crop during a growing season (Saskatchewan Ministry of Agriculture, 2006). Although crops can sometimes be grown for a few years without adding P fertilizer, yields sooner or later begin to decline. Phosphorous is relatively immobile (moves very little) in the soil. Most crops recover only 10 to 30% of the P in fertilizer the first year following application (Havlin et al., 2005). Recovery varies widely depending on soil type and conditions, the crop grown and application method. However, Saskatchewan research has shown that the newly formed soil P reaction products are more plant available than the native soil P minerals and crops can continue to recover fertilizer P for several years after application (Saskatchewan Ministry of Agriculture, 2006). Granular monoammonium phosphate (MAP) (12-51-0 or 11-55-0) is the most common P fertilizer used in Saskatchewan (Saskatchewan Ministry of Agriculture, 2006). Lentils are sensitive to high rates of P fertilizer placed directly in the seed rows. Research conducted over a three year period indicated that increasing rates of seed-placed MAP (11-55-0) resulted in reduced stands of lentil but high yield per plant as compared to side-banded P application (McVicar et al., 2010).

Lentil has a relatively high requirement for phosphorus to promote development of its extensive root systems and vigorous seedlings; and may benefit from improved frost, disease, and drought tolerance because of P application (McVicar et al., 2010). Bremer et al. (1989) reported that P response is more prevalent in the Black soils, which had the most favorable growing conditions and lowest available soil P levels, than in Brown or Dark Brown soils of Saskatchewan.

2.8 Rhizobial inoculation of lentil

Grain legumes respond most strongly to inoculation when they are introduced into new areas where soils lack appropriate rhizobia (van Kessel and Hartley, 2000). There is presumably a yield advantage to crop inoculation in soils with inadequate inorganic N supply. However, the yield response to inoculation was highly variable and affected by inherent field variability, and by differences in environmental and edaphic conditions (van Kessel and Hartley, 2000). Effective indigenous strains of *Rhizobium leguminosarum* biovar *viceae* are lacking in most prairie soils, and therefore inoculation is essential to ensure adequate nodulation and N fixation for maximum yields (Bremer et al., 1988). When chickpea (*Cicer arietinum*) and lentil were introduced to North America, both crops responded strongly to inoculation. In subsequent years, and as the resident population of effective rhizobia in soils increased, N_2 fixation remained significant but responses to further inoculation diminished (Bremer et al., 1989). Thies et al. (1991) concluded that legume response to inoculation was largely dependent on the number of rhizobia already established in the soil, the availability of soil N, and the demand for N by the crop.

Most producers in Saskatchewan inoculate the seed or the soil with a rhizobial strain and provide little or no fertilizer N to their lentil crops. Response to inoculation remains highly site specific and depends on factors beyond the effectiveness and competitiveness of the strain(s) used and host cultivar(s) seeded. N_2 fixation in grain legumes has focused on selection of superior rhizobial strains; however, significant variation in strain effectiveness has been observed in different trials (Hobbs and Mahon, 1982; Rennie and Kemp, 1983; Graham and Temple, 1984; Bremer et al., 1990; Bliss, 1993; Carter et al., 1995; Rosas et al., 1998). If soil N is sufficient to meet the N demand of the crop, even the most effective rhizobia-host plant symbiosis will fix little N_2. Indeed, a less effective rhizobia-host plant symbiosis may well fix more N when the demand of N by the host is increased by management practices and adequate nutrient availability. Mengel (1994) concluded that nitrogenase activity is a flexible process that adjusts to the N demand of the host. The amount of N_2 fixed becomes much more dependent on the demand of N by the host than on the intrinsic capacity of the rhizobia to fix N. Therefore, management practices that increase N demand will likely be a more effective means of increasing the amount of N_2 fixed by grain legumes compared to attempting to improve the effectiveness of the rhizobia-host plant symbiosis.

Table 2.1: Rhizobium species required for legume crops (Source: Saskatchewan Ministry of Agriculture)

pea, lentil, faba bean, chickling vetch	*Rhizobium leguminosarum*
Chickpea	*Rhizobium ciceri*
dry bean	*Rhizobium phaseoli*
Soybean	*Bradyrhizobium japonicum*
alfalfa, sweet clover	*Rhizobium meliloti*
Clover	*Rhizobium trifolii*
Fenugreek	*Rhizobium spp. Strain RGFU1*

Researchers have identified efficient strains of rhizobium for each pulse crop. Single-strain inoculants contain rhizobium particularly effective in one pulse crop. For example, a rhizobium strain may be able to produce nodules in both lentil and pea, but may be much more effective in pea. Inoculants are also available in mixed-strain formulations. Mixed-strain inoculants like Cell-Tech C, Nitragen Powder-GC or Tag Team; may contain bacteria effective in initiating nitrogen fixation in more than one pulse crop or may contain two or more strains specific to a single pulse crop.

2.9 Plant desiccation with chemicals

Plant growth regulators (PGRs) are organic compounds other than nutrients that, in small amounts, promote, inhibit, or otherwise modify any physiological process in plants. Five major classes of PGRs include auxins, cytokinins, gibberellins, abscisic acid and ethylene. Each of them performs distinct functions in plant growth and development. Besides these naturally occurring compounds, research has led to develop certain artificial organic compounds which when applied to plants, affect their growth. Desiccants are one class of such compounds which are used to control vegetative growth in plants and to desiccate foliage. Desiccation is the chemically accelerated drying of plants or plants parts, and does not require active functioning on the part of the plant. It differs from defoliation which requires the functioning of living tissues at the leaf base and involves plant hormones (auxins and ethylene). The tissue contacted by the defoliant rapidly loses moisture and dies. Contiguous tissues die somewhat later, but remote tissues remain unaffected unlike the first contacted. Like contact herbicides, desiccants kill all aerial parts except seeds. Desiccants are applied on crop plants to enhance maturation, to desiccate foliage for early harvesting so as to control vegetative growth and for ease of harvesting. As with lentil, chemical desiccants are used on other grain crops prior to harvest for the purposes of reducing seed moisture, preserving seed quality and yield, and the control of weeds that interfere with mechanical harvest and storage (Baur et al., 1977; Bovey et al., 1999; Yenish and Young, 2000). Crops, including wheat (*Triticum aestivum* L.), flax, field pea, chickpea and common bean are routinely desiccated in Canada (Bovey and McCarty, 1965; Yenish and Young, 2000; Gubbels et al., 1993). Some of the literature is reviewed in the following section.

2.9.1 Sunflower: Full-season sunflower crops grown in regions with short growing seasons such as the northern Great Plains often are subject to prolonged achene (seed plus hull) dry down due to shorter days, decreasing temperatures, and damp conditions associated with late fall.

Management decisions for earlier harvest may prompt producers to apply chemical desiccants to hasten plant dry-down. Gubbels and Dedio (1985) reported sunflower harvest advancement with diquat ranging from 0 to 26 days with desiccant effectiveness dependent on weather conditions after desiccation. Cool and damp weather after desiccation reduced the effectiveness of diquat. Diquat applications at achene moisture levels of >450 g kg^{-1} resulted in reduced achene yield, oil content, seed weight, and meal protein content (Gubbels and Dedio, 1985). Stay-green hybrids senesced more slowly than conventional hybrids and leaves, stalks, and receptacles remained green after achenes reach physiological and harvest maturity. Therefore, stay-green sunflower hybrids may pose a greater need for desiccation than conventional hybrids (Thelwell and Benett, 1988).

2.9.2 Cotton: In cotton (*Gossypium hirsutum* L.), cultural practices and environmental conditions are conducive to its continued growth and delayed maturity. These factors often result in plants with several late-season bolls that are apparently mature, but which fail to dehisce or open sufficiently for a single pass of a spindle picker harvest before inclement weather conditions develop. Research reports suggest that the boll-opening process could be accelerated and harvest schedules advanced by applying either an ethylene-releasing compound or a desiccant chemical to the plants (Simpson and Marsh, 1977; Morgan et al., 1971). Cathey et al. (1982) reported that growth regulators can be used to accelerate boll dehiscence in cotton and to increase first harvest percentage. However, the quality of the harvested product may be lowered if treatments are made when many immature bolls are present. In USA, harvest aids are widely used on cotton with many commercial products available, like Harvard, Pix and Ginstar.

2.9.3 Potato: Plant desiccation is used extensively to remove potato (*Solanum tuberosum* L.) tops before mechanical harvest in most potato-producing areas of North America. Desiccants may also retard the spread of viruses in seed potatoes, regulate tuber size, enhance periderm development and improve potato storability. Glufosinate-ammonium is registered for use in Canada and United States as a desiccant on nonseed potato crops. Montambault (1988) found that although glufosinate-ammonium is an effective potato-top desiccant, at high rates of application it had adverse effects on daughter seed tuber sprouting.

2.9.4 Flax: Stand-retting of fibre flax (*Linum usitatissimum* L.) using diquat was first reported in Canada in 1981 (Gubbels & Kenaschuk 1981), where it was observed that application of the diquat resulted in the fibre bundles separating in a similar manner to that achieved by dew- or water-retting. Gubbels et al. (1993) found that flax yields could be improved through advancing maturity with applications of diquat (Reglone®), glufosinate-ammonium (Liberty®) or glyphosate (Roundup®). Timing of desiccation can be important to seed quality following harvest, depending on the crop and its end use.

2.9.5 Soybean: Kappes et al. (2009) applied 400 g ha^{-1} of diquat and paraquat to soybean at four different stages of the crop production cycle, equivalent to 113, 117, 121 and 125 days after sowing (DAS). The control treatment had no desiccant applied and had a culture cycle of 127 days. They presumed that desiccant should be applied at 125 DAS- only 2 days before the complete production cycle ended. Philbrook and Oplinger (1989) reported that soybean seed yield loss increased linearly at a rate 0.2% per day as harvest was delayed out to 42 days. However, paraquat performed effectively to control growth and reduced the number of green stems, pods, and leaves, allowing harvest to proceed 1 to 2 weeks earlier than physiological maturity.

2.9.6 Pulse crops: Due to the indeterminate growth habit of most pulse crops, the plant canopy may remain green and healthy even up to the time the mature dry pods are ready for harvesting. Moreover, the presence of moisture on the plants due to rain or dew makes mechanical harvesting difficult and crop losses are particularly heavy due to non-uniform maturity. Desiccation of foliage is, therefore, recommended to prevent moisture formation on the leaves thus facilitating mechanical harvesting of the crop. Santos et al. (2004) evaluated the effects of desiccation on seed quality of common bean (*Phaseolus vulgaris* L.). Desiccation was performed by applying 5 rates (0, 10, 30, 60 and 120 g ha^{-1}) of carfentrazone-ethyl at three application times, 25, 30 and 35 days after flowering (DAF). They reported that desiccant application between 10 and 30 g ha^{-1} applied 30 DAF gave higher yield and seed quality without a negative effect on seed germination. Teofilo et al. (1999) did not find a difference when common bean was treated with paraquat alone or in combination with diquat. They reported that plant desiccation and weed control was effectively achieved in the final maturation stage by all treatments, however, none of the treatments accelerate crop maturation itself. Macvigar and Gibson (1955) evaluated crop desiccation in different legumes and reported an appreciable reduction in moisture content by the desiccant treatments. Seed yields were, however, not increased with evidence of extensive shattering due to the application of the desiccants. The data obtained did not indicate that the pre-harvest spraying of legume seed-crops would be a profitable practice in areas such as eastern Ontario where seed yields are generally low.

Diquat is registered for desiccant use in Canada on common bean, soybean, flax, lentil, mustard, canola, pea, chickpea, sunflower and potato. It is a non-selective, fast-acting desiccant herbicide, which damages only the parts of a plant to which it is applied. It is used agriculturally and also has a number of outdoor residential weed control applications. It strongly binds with soil, and has low mobility in the environment. Diquat diverts energy from photosynthesis, producing peroxide radicals, which result in rapid cell desiccation and onset of phytotoxic symptoms (Black and Meyers, 1966; Funderburk and Lawrence, 1964). It is odourless and highly soluble in water with high affinity for soil. It is commercially sold under different brand names like Aquacide, Aquakill, Dextrone, Diquat, Reglone, Reglox, Reward, Tag, Torpedo, Vegetrole, and Weedtrine-D.

Glyphosate (Roundup) is another commonly used herbicide to enhance maturity and weed control in lentil fields. However, the difference in the maximum residue limit (MRL) for glyphosate is quite low in the European Union (0.1 ppm) as compared to Canada (4.0 ppm). Europe is a major market for Canadian lentils, the difference in MRL results in the trade barrier imposed by European Union on Canadian lentil shipments. The MRL for diquat is same (0.2 ppm) in both EU and Canada. With $110 million in Canadian lentil exports to the EU (Saskatchewan Pulse Growers, 2011), this technical trade barrier has significant implications for Canadian growers and emphasizes to switch from glyphosate to diquat use.

3. Effect of nitrogen, phosphorus and rhizobial application on growth and yield of two different maturing lentil cultivars

ABSTRACT

Field experiments were conducted at Indian Head (IH) and Saskatoon (SKA) sites in 2007 and 2008 to determine the effect of N and P application on growth and yield of two lentil cultivars CDC Plato and CDC Blaze. Fertility treatments included control, Inoculation only, P only, P with inoculation, and three N levels (10, 20 and 50 kg ha^{-1}) with P and inoculation. Experiments were carried out in randomized completer block design (RCBD). At IH, highest yield was obtained with 10 kg N ha^{-1}, while at SKA; yield was not affected by fertility treatments due to its drier weather. Biomass and N accumulation after flowering were not affected significantly by the fertility treatments at both locations, showing that post-flowering physiology in lentils is governed by N_2 fixation instead of N application. The results suggested that greater amounts of N application were not effective in reducing post-flowering biomass accumulation since biomass was increased with increasing N rate.

3.1 Introduction

Saskatchewan has the greatest proportion (44%) of Canada's total cultivated farmland. A thriving Saskatchewan crop industry contributes to and benefits from an increasing local and global demand for food, feed, fuel and fibre. Commercial production of lentil in Saskatchewan began in 1970, when approximately 600 hectares (ha) were grown (McVicar et al., 2010). Lentil cultivation in Saskatchewan increased to about 1.3 million ha over 40 years (Saskatchewan Ministry of Agriculture, 2011). However, lentil shows large variation in yield due to its indeterminate growth habit and non-uniform maturity.

There are four distinct soil zones in Saskatchewan; black, dark brown, brown and gray. These soil zones vary in their inherent organic matter content and hence differ in the soil fertility levels. Among those, black and dark-brown zones are intensively cultivated. The majority of Canadian-grown lentils are produced in Saskatchewan in a continental climate. The seasonal variations in temperature and less frost-free days provide a short growing season in the province. On the average Indian Head and Saskatoon locations support 105 and 118 frost-free days, respectively (Padbury et al., 2002).

Lentil is best adapted to the Brown and Dark Brown soil zones of Saskatchewan, but can be grown successfully in the Black soil zone as well. A major limitation to crop production on the Canadian prairies is the short growing season from May to August, with limited heat units. Moreover, post-flowering vegetative growth of lentil due to excessive water and N availability towards the end of the season can lower harvest index, delay maturity and reduce yield (Wallace et al., 1990). In time constrained production systems (like Saskatchewan), maximizing the limited solar radiation with improved crop management practices could lead to yield improvement and stability.

The biological nitrogen fixation process is critically influenced by soil N content (Walley et al., 2001; Matthews, 2009) and is reduced when availability of soil N is high. Lentil in Saskatchewan is mostly sown with rhizobium inoculation to optimize N_2 fixation, and N fertilizer is not typically added to the soil. Although legumes can theoretically obtain all of their N requirements from N_2 fixation, economic responses to N fertilizer may still occur because N deficiencies may be experienced by the legume plant after seed N has been depleted and before sufficient N is available from its developing nodules (Sprent and Minchin, 1983). By eliminating this period of N deficiency, nodule development and N_2 fixation may be stimulated (Pate and Dart, 196l; Harper, 1974). Although the addition of small doses of N has a beneficial effect on legumes grown in N-free media under controlled conditions (Streeter, 1988), it is unclear if the same response would be observed under field conditions where small amounts of available N are likely to be present. Field trials with low "starter" rates of N fertilizer have not been conclusive (Parker and Harris, 1977; Semu and Hume, 1979). Starter N effects will depend on available soil N levels, host plant, rhizobium strain and other environmental conditions (Sprent and Minchin, 1983). One report indicated that high rates of N fertilizer led to greater growth (Allos and Bartholomew, 1955) while others found that added N merely substituted for fixed N_2, with no increase in overall yield (Weber, 1966; Lawn and Brun, 1974). In general, under conditions of high soil N availability legumes take up soil N rather than fix N, because the energy requirement of the former is lower (Ryle et al., 1978).

Plants need P throughout their life cycle, but especially during early growth stages for cell division. Saskatchewan soils are inherently low in available P and phosphatic fertilizer is required on about 85 per cent of Saskatchewan cropland (Saskatchewan Ministry of Agriculture, 2006).

N management strategies are, therefore, needed in lentil that can effectively control excessive vegetative growth, increase harvest index and final yield while maximizing N_2 fixation and reducing reliance on N fertilizer. I hypothesized that applying some N fertilizer may reduce N_2 fixation in lentil at latter growth stages and result in N deficiency towards the end of the growing season, provided that to fertilizer inhibited N fixation and supplied enough N for lentil growth for most of the first part of season. This late season N deficiency would curtail its vegetative growth and result in earlier crop maturity, without a large yield penalty. This study aimed at investigating the response of lentil growth, yield, biomass accumulation and N accumulation to different levels of N, P and inoculation in two contrasting soil zones of Saskatchewan.

3.2 Objectives of the study:

1. Measuring the effects of different nitrogen, phosphorus and inoculant applications on growth and yield of lentil
2. Investigating the response of two different maturing lentil cultivars to different levels of N for obtaining high yield
3. Evaluating the patterns of N accumulation in lentil grown under different fertility levels

3.3 Materials and methods

3.3.1 Site description: Field experiments were conducted in Saskatoon (SKA) and Indian Head (IH) in 2007 and 2008. Both these locations differ in their weather and soil type, representing two distinct environments of Saskatchewan. The experimental sites were located at 52° N and 106° W for Saskatoon and 50° N and 103° W for Indian Head, representing Dark Brown Chernozem Bradwell sandy loam and Black Chernezem Oxbow loam soils, respectively.

3.3.2 Treatments and experimental design: Two lentil cultivars CDC Plato (large green class with medium to late maturity) and CDC Blaze (red market class with early maturity) were sown under the following fertility treatments:

Table 3.1: Fertility treatments used in the experiment

Fertility Treatments	**N rate ($kg\ ha^{-1}$)**	**P_2O_5 rate ($kg\ ha^{-1}$)**	**Inoculation**
Control	0	0	Uninoculated
Inoc only	0	0	Inoculated
P only	0	15	Uninoculated
P and Inoc	0	15	Inoculated
10N+15P+Inoc	10	15	Inoculated
20N+15P+Inoc	20	15	Inoculated
50N+15P+Inoc	50	15	Inoculated

The experiment was laid out in a randomized complete block design (RCBD) with a factorial arrangement. In both sites, plot sizes were different. At SKA, plots were 2.42 m x 10.60 m (8 ft x 35 ft) providing an individual plot area of 25.65 m^2 with a row spacing of 20.32 cm (8 inches). At IH, however, plots were 1m x 13.66 m (3.3 ft x 45.07 ft) with an individual plot area of 13.66 m^2 and a row spacing of 30 cm (12 inches). Reduced spacing was kept at SKA to overcome weed competition especially for limited soil moisture in dark brown soils. Plots were seeded using a Fabro small plot seeder (Fabro enterprises Ltd., Swift Current, SK) at both sites. In both years and locations, plots were seeded in the first week of May. A granular formulation of Nodulator Rhizobium inoculant (Becker Underwood Inc., Saskatoon, SK) was placed in the seed rows at 7 kg ha^{-1} in the inoculated plots. The seeder was then used to side drilled ammonium nitrate (34-0-0) and superphosphate (0-45-0) as sources of fertilizer in the subsequent plots according to fertility treatments (Table 3.1). Weed control strategies included pre-planting applications of glyphosate (Roundup), followed by in-crop herbicide applications of sethoxydim (Poast Ultra) and metribuzin (Sencor) at recommended rates along with hand weeding. Grasshoppers were controlled with chloropyrifos (Lorsban) in both years. Precipitation and temperature data were recorded during the growing season by Environment Canada (Saskatoon Diefenbaker Airport, 25 km distance from the plots at Saskatoon; Indian Head CDA, 2 km distance from the plots at Indian Head).

3.3.3 Plant measurements: Plant population density was counted for 1-m length of three randomly selected rows in each plot, two weeks after germination. Biomass samples were cut from each plot at four physiological stages: flowering, early pod-fill, late pod-fill and physiological maturity, as two 0.3-m strips taken from two adjacent rows. The outside border rows were never used for biomass sampling. Plant samples were cut at ground level, bagged and dried in an oven at 60°C for three days. Dry sample weights were then recorded for each plot. The final samples taken at physiological maturity were also used for harvest index (HI) measurement. These samples were oven dried, weighed, and threshed using a stationary belt drive thresher (Agriculex SPT-1, Guelph, ON) which separated seed from vegetative material. The seeds were then weighed to determine harvest index (HI) by using the following formula:

$$HI = \text{seed yield (g)}/\text{total biomass (g)}.$$

A sub-sample was also taken at maturity for measuring N content in biomass as the original sample was threshed. Seed and biomass samples were ground and analyzed for N content measurement by the combustion method, using a Leco carbon-nitrogen determinator (LECO CNS 2000, St. Joseph, MI, USA). Total plant N content was calculated by the following formula:

$$\text{Plant N content (g m}^{-2}\text{)} = \text{(Plant N\%/100) x (Plant DW gm}^{-2}\text{)}$$

Days to maturity (DTM) were calculated by counting the Julian days from seeding to physiological maturity. Final seed yield was measured by harvesting the plots in the second week of October with Wintersteiger Elite combine (Wintersteiger, Salt Lake City, UT). Seeds were dried and cleaned to eliminate trash and weed seeds. Yield from individual plots was converted into kg ha^{-1}.

3.3.4 Soil analysis: Soil samples in both years were collected from both sites at three depths 0-15, 15-30 and 30-60 cm from random locations. Soil samples from each depth were bulked, subsampled, air-dried, ground and analyzed for inorganic N (NH_4^+ and NO_3^-) by KCl extraction (Maynard and Kalra, 1993). Soil samples were also measured for pH (MacLean, 1982), phosphorus (Bray and Kurtz, 1945), potassium (Carson, 1980) and organic carbon (Ball, 1964).

Table 3.2: Initial level of soil NO_3^-, NH_4^+, P, K and organic C at different soil depths (2007)

Soil Depths	pH	NO_3^- (µgg^{-1})	NH_4^+ (µgg^{-1})	P_2O_5 (µgg^{-1})	K (µgg^{-1})	Organic C (%)
Location			**Indian Head**			
0-15 cm	7.9	12.8	10.0	15	291	1.4
15-30 cm	8.0	14.1	8.5	13	240	-
30-60 cm	8.0	15.5	8.5	14	243	-
Location			**Saskatoon**			
0-15 cm	8.0	10.1	9.8	16	349	1.6
15-30 cm	8.0	10.2	6.9	14	328	-
30-60 cm	8.0	10.1	6.2	14	215	-

Table 3.3: Initial level of soil NO_3^-, NH_4^+, P, K and organic C at different soil depths (2008)

	pH	NO_3^- (μgg^{-1})	NH_4^+ (μgg^{-1})	P_2O_5 (μgg^{-1})	K (μgg^{-1})	Organic C (%)
Location			**Indian Head**			
0-15 cm	7.8	12.8	11.0	15	310	1.4
15-30 cm	7.9	14.2	8.8	14	252	-
30-60 cm	8.0	13.6	8.2	15	240	-
Location			**Saskatoon**			
0-15 cm	7.9	10.0	9.9	17	364	1.6
15-30 cm	8.0	10.7	8.9	12	324	-
30-60 cm	8.0	10.3	8.0	13	280	-

Indian Head soils contained more N (both NO_3^- and NH_4^+) as compared to Saskatoon at all the three soil depths. The difference was more pronounced for NO_3^- especially at lower soil profiles. P level was almost same at both sites with higher K and organic C at Saskatoon.

3.3.5 Statistical analysis: Data were analyzed in the mixed model procedure of SAS, version 9.2 (SAS Institute, 1996). Year and block were treated as random effects and the fertility treatments, locations and cultivars were considered as fixed effects. The Least Significant Difference (LSD) test was applied to test the significance of the fertility treatments on lentil growth, yield, biomass accumulation and nitrogen concentration.

3.4 RESULTS AND DISCUSSION

3.4.1 Weather conditions:

Growth of lentil plant is highly sensitive to weather conditions, especially rainfall, high temperature and early frost. Precipitation after flowering favours vegetative growth. Excessive wet conditions at the time of sowing delay its sowing, which results in the late development of lentil plant, leaving the crop vulnerable to summer heat. High temperature stresses flowers, resulting in no podding and/or excessive flower and pod shedding. Late planting may also result in inadequate root development and the vulnerability of crop to early frost in the fall.

Average monthly mean temperature during the growth period varied among the four environments. Saskatoon in both 2007 and 2008 had a warmer spring than Indian Head. The mean temperature during August, when lentil was maturing, was almost the same (SKA was 0.3° C higher than IH). During the two years of study, rainfall distribution varied among the environments. In 2007, SKA received 240.5 mm of rainfall as compared to 229.6 mm for IH. The major rainfall distribution difference was in the months of June (SKA received about 3 times higher rainfall as compared to IH) and August (IH received 3.5 times more rainfall as compared to SKA). In 2008, SKA and IH received rainfalls of 196 and 243.6 mm, respectively. IH received much higher rainfall especially in the months of May, August and September as compared to SKA in 2008 (Table 3.4). These weather conditions have an impact on the results obtained which are covered during discussion

Table 3.4: Average monthly temperatures and total monthly rainfall from Saskatoon International Airport for Saskatoon and Indian Head CDA station for Indian Head locations. Long term means are based on Canadian Climate Normals (1971-2000).

Environment	**Month**	**Temperature**			**Cumulative Rainfall**	**Long-term means**	
		Mean (˚C)	Minimum (˚C)	Maximum (˚C)	mm	Mean Temp (˚C)	Cumulative Rainfall (mm)
SKA 2007	May	11.2	4.6	17.9	46.0	11.5	49.4
	June	15.0	8.1	21.8	131.0	16.0	61.1
	July	21.0	14.4	27.7	22.0	18.2	60.1
	August	15.8	9.0	22.5	17.5	17.3	38.8
	Sept	10.4	3.7	17.1	24.0	11.2	30.7
SKA 2008	May	10.7	2.7	18.7	5.0	SAME AS ABOVE	
	June	15.0	7.4	22.5	65.5		
	July	17.8	10.9	24.7	93.0		
	August	17.8	10.2	25.4	19.5		
	Sept	11.5	3.4	19.6	13.0		
IH 2007	May	9.6	3.3	15.7	46.0	11.4	55.7
	June	15.0	8.1	21.9	46.2	16.1	78.9
	July	19.9	12.4	27.4	50.6	18.4	67.1
	August	15.5	8.5	22.4	62.8	17.5	52.7
	Sept	11.1	3.1	19.0	24.0	11.4	41.3
IH 2008	May	8.5	5.1	17.0	20.6	SAME AS ABOVE	
	June	13.9	7.0	20.8	60.4		
	July	16.8	9.5	24.0	90.4		
	August	17.5	9.7	25.2	47.4		
	Sept	11.0	3.0	19.0	24.8		

Table 3.5: ANOVA for the effects of fertility treatments (F), cultivars (C) and their interactions with each other on lentil growth, yield and N content

Effect	DF	Grain Yield ($kgha^{-1}$)	Harvest Index (%)	Seed Nitrogen (gm^{-2})	Max Biomass (gm^{-2})	Plant Height (cm)	Nitrogen Harvest Index (%)	Plant Population (m^{-2})
Location	1	<0.01	<0.01	<0.01	<0.01	0.20	<0.01	0.72
Cultivar	1	<0.01	<0.01	0.51	<0.01	<0.01	<0.01	0.25
Fertility	6	0.93	0.29	0.89	0.23	0.53	0.17	0.52
L x C	1	<0.01	<0.01	0.04	0.78	0.30	<0.01	0.51
L x F	6	0.85	0.86	0.99	0.47	0.05	0.54	0.41
C x F	6	0.80	0.98	0.99	0.83	0.84	0.99	0.74
L x C x F	6	0.96	0.93	0.95	0.32	0.90	0.86	0.64

Combined analysis of variance with year as a random effect showed that the two locations Saskatoon (SKA) and Indian Head (IH) differed significantly for yield, harvest index, seed N, maximum biomass and NHI (Table 3.5). Plant height and plant stand were controlled by the cultivar and the other management practices e.g. sowing method, therefore, they did not differ significantly across locations. The cultivars differed significantly for yield, harvest index, maximum biomass, plant height and NHI. Seed N content and plant stand remained statistically similar for the two cultivars. Fertility levels did not affect the measured parameters for the pooled data. This might be due to the fact that soils at both locations contained enough indigenous rhizobial population to allow maximum growth and yield; therefore, fertility treatments were not able to produce significant impact on these parameters. This was also evident by the findings of Thies et al. (1991), who concluded that legume response to inoculation was largely dependent on the number of rhizobia already established in the soil, the availability of soil N, and the demand for N by the crop. Once rhizobia have established in a field, subsequent inoculation is less likely to further benefit the host. However, according to Stevenson and van Kessel (1997), the benefit of inoculation and N application should not be underestimated just by comparing yield, but N accumulation and grain protein content as well as total soil N should also be considered when evaluating the impact of fertility treatments on legumes. The interactions between Fertility and Location, except for plant height, as well as Fertility and Cultivar and the three-way interaction were all non-significant. Since the two locations differed significantly for most of the parameters, further discussion is based on the analysis of the data separately for each location.

Table 3.6: ANOVA for the effects of fertility treatments (F), cultivars (C) and their interactions on lentil growth, yield and N content at Indian Head and Saskatoon (data pooled over two years for each location)

Locations	**Indian Head**			**Saskatoon**		
Measurements	C	F	C x F	C	F	C x F
Biomass at Flowering (g m^{-2})	0.14	<0.01	0.50	0.23	0.04	0.79
Biomass at early pod-fill (g m^{-2})	0.70	0.99	0.98	0.62	0.82	0.98
Biomass at late pod-fill (g m^{-2})	0.16	0.97	0.98	0.23	0.89	0.98
Biomass at maturity (g m^{-2})	0.11	1.00	0.99	0.22	0.97	0.99
Grain yield (kg ha^{-1})	<0.01	0.05	0.60	0.89	0.99	0.99
Harvest index (%)	0.72	0.72	0.96	<0.01	0.03	0.97
Plant height (cm)	<0.01	0.04	0.91	<0.01	0.05	0.91
Plant stand (plants m^{-2})	0.05	0.04	0.85	0.66	0.05	0.47
N content at flowering (g N m^{-2})	0.05	<0.01	0.62	0.04	<0.01	0.49
N content at early pod-fill (g N m^{-2})	0.84	0.99	0.98	0.39	0.81	0.99
N content at late pod-fill (g N m^{-2})	0.81	0.99	0.99	0.69	0.50	0.79
N content at maturity (g N m^{-2})	061	0.99	0.99	0.34	0.96	0.98
Seed N content (g N m^{-2})	0.62	0.99	0.99	0.10	0.43	0.97
Nitrogen harvest index (%)	0.62	0.04	0.88	<0.01	0.03	0.96
Days to maturity	0.85	0.45	0.57	0.25	0.52	0.63

Table 3.7: Effect of fertility treatments and cultivars on lentil biomass accumulation at each of the four growth stages

Effect	Biomass at flowering (gm^{-2})		Biomass at early pod-fill (gm^{-2})		Biomass at late pod-fill (gm^{-2})		Biomass at maturity (gm^{-2})	
	IH	SKA	IH	SKA	IH	SKA	IH	SKA
Cultivars								
CDC Blaze	105^{NS}	98^{NS}	367^{NS}	346^{NS}	621^{NS}	341^{NS}	484^{NS}	303^{NS}
CDC Plato	115	108	382	366	704	415	568	346
LSD	12	12	154	154	175	175	164	164
Fertility treatments								
0N+0P-Inoculant	96c	100bc	364^{NS}	335^{NS}	659^{NS}	359^{NS}	521^{NS}	330^{NS}
0N+0P+Inoculant	79d	93c	356	344	720	379	530	317
0N+15P-Inoculant	114b	104abc	353	315	629	346	534	347
0N+15P+Inoculant	107bc	97c	366	321	667	350	525	289
10N+15P+Inoculant	113b	92c	393	394	615	385	524	313
20N+15P+Inoculant	106bc	115a	385	374	691	404	517	331
50N+15P+Inoculant	153a	118a	406	408	655	420	531	347
LSD	15	15	155	155	177	177	165	165

IH and SKA denote Indian Head and Saskatoon sites respectively. For cultivars or fertility treatments, means followed by the same letter within columns are not significantly different at $P \leq 0.05$. NS means Not Significantly different within columns at $P \leq 0.05$.

3.4.2. Biomass accumulation trend:

The two cultivars did not differ significantly in the biomass accumulated at different growth stages (Table 3.7). Extent of indeterminacy was mostly governed by edaphic and environmental factors even though the two cultivars come from different maturity groups. Fertility treatments did not significantly change biomass obtained at each of early pod-fill, late pod-fill and maturity stages. Biomass at flowering was significantly affected by the fertility levels in both locations. At both sites, highest biomass was obtained with 50 N (highest rate). At IH, highest and lowest biomass at flowering was obtained with 50 N and Inoc only treatments, respectively. At SKA, highest biomass at flowering was obtained with 50 N but this did not differ significantly from the flowering biomass obtained at 20 N and P only, which in turn did not differ significantly from those of other treatments. The plants attained maximum biomass at the late pod-fill stage, after which biomass declined due to seed shattering and leaf fall. Late pod-fill stage was not affected by either cultivar and fertility levels at both locations, with this parameter appearing to be controlled by environmental factors. Importantly, biomass differed significantly for both locations, being higher at IH as compared to SKA especially at late pod-fill and maturity. More biomass later in the season at IH is attributed to the initial high soil N content (Table 3.2 and 3.3) and high late-season rainfall in both years at this site, which favoured excessive vegetative growth.

Table 3.8: Effect of fertility treatments and cultivars on plant growth ad grain yield of lentil

Effect	Grain yield (kg ha^{-1})		HI (%)		Plant height (cm)		Plant stand (plants m^{-2})	
	IH	SKA	IH	SKA	IH	SKA	IH	SKA
Cultivars								
CDC Blaze	1596b	1531^{NS}	56.22^{NS}	46.32a	33.43b	33.58b	93.98a	91.02^{NS}
CDC Plato	2410a	1539	55.78	35.69b	42.51a	43.98a	88.66b	89.56
LSD	228	228	3.32	3.32	1.82	1.82	3.46	3.46
Fertility treatments								
Control	1887b	1552^{NS}	57.56^{NS}	42.65a	38.25b	39.33ab	88.57bc	96.86a
0N+0P+Inoculant	1972ab	1489	56.86	42.21a	36.99bc	38.86abc	98.42a	87.76bcd
0N+15P-Inoculant	1983ab	1466	55.55	44.21a	40.42a	36.94c	91.87b	97.33a
0N+15P+Inoculant	1936b	1593	55.52	42.83a	37.67b	39.39ab	85.51c	92.41ab
10N+15P+Inoculation	2214a	1512	57.73	42.98a	38.92ab	37.50bc	87.82bc	89.67bc
20N+15P+Inoculation	2010ab	1512	54.53	35.54b	35.24c	38.80abc	88.17bc	85.04cd
50N+15P+Inoculation	2002ab	1623	54.26	36.62b	38.30b	40.61a	88.86bc	82.97d
LSD	256	256	4.12	4.12	2.07	2.07	5.76	5.76

IH and SKA denote Indian Head and Saskatoon sites respectively. For cultivars or fertility treatments, means followed by the same letter within columns are not significantly different at $P \leq 0.05$. NS means Not Significantly different within columns at $P \leq 0.05$.

3.4.3 Grain Yield:

Combined data showed the two cultivars produced statistically similar yield at SKA, but significantly different yield was recorded at IH where CDC Plato outperformed CDC Blaze with 51% higher yield (Table 3.8). The similar yield for both cultivars at SKA was due to the different trend obtained in 2008, where CDC Blaze produced higher yield than CDC Plato. It was, however, not the case in the other three location years. That trend for the one year resulted in non-significant difference when data was pooled over the years for SKA site. The higher yield of CDC Blaze was attributed to higher harvest index obtained in that year. High rainfall amounts were recorded in July 2008 at both locations (93.0mm in SKA and 90.4mm in IH). This rainfall had a different impact on the two cultivars at the two locations. This rainfall adversely affected late maturing CDC Plato due to promotion of vegetative plant growth in that year. CDC Blaze, however, was likely less affected due to its early maturity. CDC Blaze was progressing through late pod-fill stage and, therefore, could utilize the moisture to efficiently convert photosynthates into seed yield. Even though CDC Plato produced higher biomass than CDC Blaze at all growth stages, its seed yield obtained was less than CDC Blaze, showing its inefficiency in translating photosynthates into yield.

Grain yield was not significantly affected by fertility and inoculant treatments at SKA. At IH, however, 10 N (with 15P and inoculation) produced the highest seed yield of 2214 kg ha^{-1}. This was the only treatment that produced grain yield significantly higher than the unfertilized uninoculated control. Higher rates of N combined with P and inoculation did not produce significantly higher yield than obtained by that treatment. The lowest yield was obtained by control treatment. The yield was reduced by 9.2% when N was increased from 10 kg ha^{-1} to higher amounts. Results are supportive of previous studies indicating a small starter N dose along with P and inoculation is optimum to obtain high lentil grain yield. The non-significant effect of fertility treatments on grain yield reflects that the effect of N application is masked by the initial soil N level as both sites contained more than 10μgg^{-1} of initial soil NO_3^- (Table 3.2 and 3.3).

3.4.4 Harvest Index:

There were some significant differences in harvest indices among treatments for SKA but not for IH (Table 3.8). The harvest index obtained was 27% less at SKA as compared to IH (average of the two cultivars) and much lower for CDC Plato at SKA than at IH (0.36 vs. 0.56). The lower harvest index for CDC Plato at SKA was mainly due to poor harvest index obtained in 2008 for CDC Plato (0.21). High rainfall occurred in the month of July 2008 at both locations (93.0mm at

SKA and 90.4mm in IH) that would adversely affect late maturing CDC Plato due to its excessive vegetative growth.

Fertility treatments did not significantly affect harvest index at IH due to initial higher soil N pool (Table 3.2 and 3.3) which masked the effectiveness of added N. However, at SKA, the harvest index was significantly reduced by higher N application, but not significantly by P or inoculant additions compared to the control. This reflects that higher N application increases vegetative growth and biomass of indeterminate crops like lentil.

3.4.5 Plant height:

Plant height is both a genetically and environmentally controlled characteristic. CDC Plato produced significantly taller plants than CDC Blaze at both locations. Soil fertility levels affected plant height significantly at both locations. At IH, the tallest plants (40.4 cm) were found with P only. The lowest plant height at IH was obtained with 20N+15P+Inoc that was slightly but significantly lower than the control. The effect of N application on plant height is noticeable at SKA (low soil N level) where a linear trend in plant height was found with N application i.e. 37.5, 38.8 and 40.6 cm with 10, 20 and 50 kg N ha^{-1}, respectively.

3.4.6. Plant stand:

At IH, plant stand differ significantly for the two cultivars while at SKA, the two cultivars produced statistically similar plant stand. Overall, plant stands were similar among cultivars and range from 89-94 plants m^{-2}. Fertility levels affected the plant significantly at both locations. At IH, maximum plant stand (98.42 plants m^{-2}) was obtained with Inoc only. It was followed by 15 P only treatment which was statistically similar to all other treatments. At SKA, maximum and minimum plant stands were obtained with 15 P only and 50 N, respectively. A decrease in plant stand with N application was obvious at both locations. This could be explained by seedling injury from high rates of N fertilizer due to NH_4-N toxicity. Another interesting observation is that inoculants significantly increased plant stand at IH. Adding P also reduced plant stand most probably due to some salt effect injury.

Table 3.9: Effect of fertility treatments and cultivars on N accumulation of lentil (g N m^{-2}) at different growth stages

Effect	Flowering N (g N m^{-2})		Early pod-fill N (g N m^{-2})		Late pod-fill N (g N m^{-2})		N at maturity (g N m^{-2})	
	IH	SKA	IH	SKA	IH	SKA	IH	SKA
<u>Cultivars</u>								
CDC Blaze	3.80b	3.26b	10.75^{NS}	8.00^{NS}	18.13^{NS}	5.84^{NS}	15.48^{NS}	7.58^{NS}
CDC Plato	4.18a	3.49a	10.98	8.78	18.59	8.36	16.38	8.32
LSD	0.21	0.21	3.72	3.72	4.47	4.47	4.72	4.72
<u>Fertility levels</u>								
Control	3.52c	3.13c	10.48^{NS}	7.83^{NS}	18.02^{NS}	6.77^{NS}	15.67^{NS}	8.07^{NS}
0N+0P+Inoculant	2.92d	3.13c	10.65	8.41	19.62	7.36	15.60	7.81
0N+15P-Inoculant	4.27b	3.11c	10.37	7.42	18.40	6.09	17.01	8.34
0N+15P+Inoculant	3.75c	3.08c	10.94	7.70	19.50	6.80	16.87	7.09
10N+15P+Inoculation	4.22b	2.93c	11.43	9.36	16.79	7.13	15.54	7.53
20N+15P+Inoculation	3.82c	3.85b	11.16	8.39	18.59	7.61	15.21	8.35
50N+15P+Inoculation	5.46a	4.43a	11.02	9.63	17.63	7.95	15.62	8.46
LSD	0.38	0.38	3.75	3.75	4.59	4.59	4.79	4.79

IH and SKA denote Indian Head and Saskatoon sites respectively. For cultivars or fertility treatments, means followed by the same letter within columns are not significantly different at $P \leq 0.05$. NS means Not Significantly different within columns at $P \leq 0.05$.

3.4.7. Nitrogen content in biomass at flowering:

At both locations, late maturing CDC Plato accumulated more N by flowering time as compared to early maturing CDC Blaze (Table 3.9). The fertility treatments affected the N content at flowering. At both locations, highest N content was found with 50 kg added N ha^{-1}. At IH site, N content obtained with Inoc only was significantly lower than the N content obtained in the control treatment, while at SKA; it was statistically similar. The reason for inoculation lowering the N content at flowering at the SKA site is not known. Addition of P tended to enhance plant N at flowering. The plant N uptake at the other measurement times was not significantly affected by the treatments.

Table 3.10: Effect of fertility treatment and cultivars on seed N content, nitrogen harvest index (NHI) and days to maturity (DTM)

Effect	Seed N ($g\ N\ m^{-2}$)		NHI (%)		DTM (Julian days from seeding to maturity)	
	IH	SKA	IH	SKA		
Cultivars						
CDC Blaze	12.46^{NS}	5.26^{NS}	79.91^{NS}	70.80a	96.57^{NS}	94.37^{NS}
CDC Plato	13.20	3.85	78.93	52.62b	97.25	95.25
LSD	3.32	3.32	3.96	3.96	2.55	2.55
Fertility treatments						
Control	13.14^{NS}	4.86^{NS}	82.33a	64.13ab	97.45^{NS}	97.02^{NS}
0N+0P+Inoculant	12.83	4.81	81.86a	62.97ab	98.53	96.55
0N+15P-Inoculant	13.14	5.32	77.44ab	67.50a	97.25	98.45
0N+15P+Inoculant	12.85	4.12	76.04b	62.19b	96.15	97.76
10N+15P+Inoculation	13.07	4.74	82.39a	66.93ab	98.78	97.53
20N+15P+Inoculation	12.10	3.82	78.23ab	52.72c	97.85	98.40
50N+15P+Inoculation	12.65	4.22	77.66ab	55.50c	96.55	96.08
LSD	3.42	3.42	5.21	5.21	3.79	3.79

IH and SKA denote Indian Head and Saskatoon sites respectively. For cultivars or fertility treatments, means followed by the same letter within columns are not significantly different at $P \leq 0.05$. NS means Not Significantly different within columns at $P \leq 0.05$. NHI denotes Nitrogen Harvest index which is N partitioning, measured as the ratio of grain N to total plant N. DTM denotes days to maturity which were calculated by counting the Julian days from seeding to physiological maturity.

3.4.8 Seed N contents and nitrogen harvest index:

N accumulation in biomass was not affected at later growth stages (early pod-fill, late pod-fill and maturity) by either cultivars or fertility treatments (Table 3.9). This trend could be explained by the growth habit of lentil. Being a leguminous crop, lentil becomes self sufficient in its N requirements after flowering, by fixing atmospheric N_2 (van Kessel, 1994) and becomes independent of soil fertility treatments for accumulating N in its biomass. Also this might be due to time of N remobilization. At IH, N accumulation was much higher as compared to SKA especially after flowering. At IH, large increase in N accumulation from flowering to late pod-fill was observed which was only from flowering to early pod-fill at SKA. That might be due to the previous rotation not removing as much N or due to more rain at IH which led to efficient translocation of N from biomass to seed by both cultivars regardless of their maturity time.

High soil N content at IH delayed maturity for early maturing CDC Blaze, which accumulated the same amount of N by maturity (Table 3.9) as CDC Plato due to an increase in the duration of the crop life cycle. At SKA, however, CDC Blaze produced significantly higher NHI due to less biomass production and more translocation of N into seed because of a short growing season. Low inherent soil N at SKA, in contrast to IH, led to higher efficiency in N transfer to seed by CDC Plato (late maturing). The fertility treatments significantly affected NHI at both locations. At IH, the highest NHI was obtained with the control, Inoc only and 10N+15P+Inoc treatments. The lowest NHI at IH was obtained with P + Inoc. A reduction in NHI was also noted at SKA with N above 10 kg ha^{-1}. It is, therefore, evident that starter N increased NHI in low N soil while in high soil N (black), it adversely affected NHI.

At IH (high N soils), none of the fertility treatments produced significant effect on biomass at late pod-fill (maximum biomass attained by plant), yield, harvest index, seed N content and nitrogen harvest index. This shows that high soil N reduce the effectiveness of N application. However, at SKA (low N soils) the addition of N fertilizer lowered atmospheric N fixation which was evident by less biomass production especially after mid pod-fill stage. Harvest index was significantly reduced (19.61%) at SKA with application of 20 kg ha^{-1} of N (20N+15P+Inoc) as compared to 0N and 0 Inoc (0N+15P-Inoc). That is due to more vegetative growth and eventually more biomass production with N application. Higher N application (50N+15P+Inoc), however, did not adversely affect harvest index due to higher seed yield. At SKA, nitrogen accumulation was significantly less than at IH especially at late pod-fill and maturity stages. This resulted in certain treatment comparisons being significant for nitrogen harvest index values. Higher doses of N (20 and 50 kg N ha^{-1}) significantly lowered NHI as compared to starter N (10N+15P+Inoc) as well as when only P (N0+P15-Inoc) was applied. Higher N application increased biomass production at later growth stages, which reduced the plant efficiency to transfer nitrogen content from biomass to seed, thereby, lowering nitrogen harvest indices.

Table 3.11 Correlation between yield and explanatory variables (measured as adjusted R^2 values)

Location	Plant stand	Plant height	Biomass at late-pod fill stage	N at late-pod fill stage
Indian Head (IH)	0.00	0.25	0.01	-0.01
Saskatoon (SKA)	0.17	0.01	-0.50	0.30

At IH, yield was not affected by plant density, whereas at SKA yield increased with plant density. This different trend might be due to the less soil N (Table 3.2 and 3.3) in dark-brown soil of SKA where higher plant density compensated less dry matter production per plant. Plant height added to final yield at IH with visually strong plants. While in SKA, the yield did not increase by plant height due to lodging of taller plants. Plants were weak at SKA and taller plants were not able to support themselves and lodged resulting in yield losses at harvesting. At IH, plants gained much biomass after flowering as compared to SKA (Table 3.7) which resulted in higher yields. At SKA, however, yield was drastically reduced with increase in biomass as a result of less seed production and excessive shattering. Maximum N content was obtained at late pod-fill stage. At SKA, yield increased with the increase in plant N content. That is evident by more lodging recorded at SKA where stronger plants with higher plant N contributed to yield. A non-significant correlation between yield and plant N content at IH demonstrated a less competition for soil N at initial plant growth stage.

3.4.9 Days to maturity (DTM):

Days to maturity were measured at both locations but they did not differ significantly for both cultivars and fertility levels. At Indian Head site desiccant was applied which matured the crop at the same time regardless of the treatments. While at Saskatoon, CDC Plato was affected by stemphylium blight with a confounding and non-significant effect on days to maturity.

3.5 CONCLUSION

Initial soil N and P levels are shown in Table 3.2 and 3.3. At IH site; located in black soil zone with high soil N, higher precipitation and reduced evapotranspiration; biomass accumulation was much higher as compared to SKA with low soil N and greater incidence of severe moisture stress. Higher biomass production and N accumulation was evident at later growth stages at IH. This excessive vegetative growth, however, did not reduce yield due to better conversion of photosynthates into seed yield. Overall CDC Plato produced greater biomass and yield than CDC Blaze. CDC Plato, with large green cotyledons and its late maturing nature, was well synchronized with the soil and weather of IH. Although planting late maturing cultivars is considered risky in Western Canada due to cultivars requiring 110 days of growing season, at Indian Head, however, the extended days to maturity resulted in higher dry matter production. The greater biomass and N accumulation by late maturing lentil is in agreement with soybean (Isfan 1991).

IH is traditionally a wheat growing area. Cultivation of grain crops over the years has reduced indigenous rhizobia in its soil; therefore, rhizobial inoculation would be beneficial for cultivating lentils. A starter dose of N at10 kg ha^{-1} along with inoculation and P application gave highest yield. Yield was reduced by 9.2% when N was increased from 10 to 20 kg ha^{-1}. Lentil being a leguminous crop does not need high level of N application, especially in fertile soil at IH. However, a starter N dose along with P and inoculation is the best combination to obtain high lentil yield. At IH, N accumulation was much higher as compared to SKA especially after flowering. This led to the efficient transfer of N from biomass to seeds by both cultivars regardless of their maturity time.

At SKA, there was a non-significant effect of fertility treatments on lentil yield which might be due to the dry conditions at Saskatoon. Under water stress, the response of nitrogen is limited (Engel *et al*., 2001). Dark brown soils could benefit from higher N application in wet seasons. Harvest index was reduced with higher doses of N (20 and 50 kg ha^{-1}), showing less assimilation of photosynthates into seed yield at higher N rates. At SKA, lentil had the capacity to perpetuate late-season growth, delay maturity and lower harvest index with N application without adversely affecting yield. N accumulation in biomass as well as in seed was not affected at growth stages after flowering by either cultivar or fertility treatments at both locations. This trend is supported by the indeterminate nature of lentil. Lentil becomes self sufficient after flowering to fix atmospheric N_2 and becomes independent of fertility levels for accumulating N in its biomass. Partitioning of dry matter and N to seed was affected by environment because lentil yield depended more on total biomass than on harvest index. The overall lack of response of lentil biomass after flowering and N accumulation to the individual fertility treatments suggested that source and availability of N does not change partitioning within the plant. Instead, environmental conditions were more likely to influence partitioning of biomass and N to seed through remobilization from vegetative parts in mid to late-season reproductive growth.

4. Growth, yield and N content of lentil as affected by diquat application under different fertility regimes

ABSTRACT

Field experiments were conducted for two years at Saskatoon (2007and 2008) and one year for Indian Head (2007) to determine the role of diquat application in enhancing lentil maturity. Treatments included two cultivars (CDC Plato and CDC viceroy), three fertility levels (control, inoculation and 50 kg N ha^{-1}) and five diquat treatments (control, quarter rate and half rates applied one and three weeks after flowering). The experiments were carried out in split plot design. Diquat application successfully suppressed biomass and plant growth at maturity. However, the reduction in biomass was obtained at the cost of yield loss at both sites. The yield loss was higher when diquat was applied at the earlier stage (one WAF) at half rate. Early application of diquat at low rate at IH reduced biomass by 25% compared to the control without significantly affecting yield. The same treatment, however, reduced biomass by 45% at SKA with huge yield loss. The results suggested low rate of diquat application at earlier crop growth stage to avoid yield loss in lentil. The results found no significant interaction between the three factors under study (desiccant, fertility and cultivar) for most of the measured parameters.

4.1 Introduction

The pulse crops including dry bean, pea, lentil, faba bean and chickpea are increasing in economic importance in the rotations of Western Canada. Saskatchewan growers began commercially producing lentil in 1970. In 2010, Saskatchewan farmers grew lentil on 953 thousand hectares with annual production of 1480 thousand tonnes and average yield of 1568 kg ha^{-1}, respectively (Saskatchewan Ministry of Agriculture, 2011). Historic yield comparisons for lentil grown on the Prairies demonstrate fluctuations linked to agronomic and climatic factors. Part of the yearly variation in yield is due to poor climatic adaptation of the indeterminate growth habit of lentil in the short growing season of the Prairies. These yield fluctuations not only pose tremendous challenges in the breeding of more stable cultivars, but they present increased uncertainty and risk of crop failure for agricultural producers.

A major limitation to crop production on the Canadian prairies is the shortness of the growing season from May to August, with the frost-free period of generally only 120 days (Schantz, 1923). Crop yield is a function of radiation intercepted over the growing season, the efficiency of converting the intercepted radiation to biomass and the partitioning efficiency of biomass to seed yield (Sinclair, 1993). In time constrained production systems like Saskatchewan, maximizing the limited solar radiation with improved crop management practices could lead to yield improvement.

Indeterminacy is the characteristic of most pulse crops. An indeterminate crop continues vegetative growth even after entering the reproductive phase. Such a growth habit results in delayed crop maturity, influencing yield and crop quality (McVicar et al., 2010). For indeterminate crops like lentil, herbicides can be used as harvest aids at crop maturity to desiccate weed and crop foliage. Desiccant application is important in years of warm and wet springs, and cool and wet summers, conditions that promote luxuriant plant growth. Under such conditions lentils will continue to flower and set pods, and weeds will continue to grow as long as moisture is available. Crop topping, which is the technique of applying a herbicide to a mature crop to kill any green weeds and sterilize any weed seeds, has been advocated to enable early harvest of crops (Teofilo et al., 1999; Santos et al., 2004). Desiccation is similar to crop topping but the herbicide is applied at the physiological maturity of the crop or earlier and an earlier growth stage of the weed than with crop topping (Holding and Bowcher, 2004). Desiccants can speed drying of immature plants and allow earlier harvest, but desiccant applications made prior to physiological maturity can have detrimental effects on seed quality (Azlin and McWhorter, 1981; Baur et al., 1977; Bovey et al., 1975; Cerkauskas et al., 1982; Ratnayake and Shaw, 1992; Whigham and Stoller, 1979). Despite the popularity of forcing maturity prior to mechanical harvest in Canada, almost no literature exists documenting the effects of desiccant treatment method and timing on yield and seed quality of lentil, let alone the effects on milling parameters.

Pre-harvest glyphosate and diquat application are registered treatments for weed control in lentil fields (Purcell, 2011). The maximum residue limit (MRL) for glyphosate in lentil is quite low in European Union (0.1 ppm) as compared to Canada (4.0 ppm). This results in the recent trade barrier imposed by European Union on Canadian lentil shipments. The MRL for diquat is the same (0.2 ppm) in both EU and Canada. With $110 million in Canadian lentil exports to the EU (Saskatchewan Pulse Growers, 2011), this technical trade barrier has significant implications for Canadian growers and emphasizes to switch from glyphosate to diquat use.

Reglone™ (diquat bromide) is a non-selective plant growth regulating chemical registered as a Group 22 herbicide for agricultural use in Canada. It is registered for use in a variety of legume crops including chickpea, common bean, field pea and lentil (Saskatchewan Ministry of Agriculture, 2008). The current recommendation for lentil is to spray 1.25 to 1.70 litres ha^{-1} of Reglone when the majority of the pods of individual plants are ripe but before they shatter (Syngenta, 2002). The present experiment was conducted to determine the effect of lower rates of diquat application i.e. quarter and half rates of the recommended 1.70 litres ha^{-1}; on the growth, yield and N content in lentil. This study hypothesized that rhizobium inoculated lentil should be more indeterminate than 50 kg N $ha^{-1}$and unfertilized control treatments. This chapter tests my second hypothesis that low levels of diquat application applied at later growth stages on lentil will shift vegetative growth into reproductive growth without affecting yield adversely. The ultimate aim was to enhance earlier maturity by stressing vegetative growth and controlling lentil indeterminacy.

4.2 Objectives of the study:

1. Measuring the effects of diquat application at quarter and half of registered rates on growth and yield and N content of lentil.
2. Assessing the difference between spraying diquat at one week and three weeks after flowering on lentil, both applications being earlier than current grower practices.
3. Determining the interaction between indeterminacy, soil fertility and diquat application.

4.3 Materials and methods

4.3.1 Site description: Field experiments were conducted in Saskatoon (SKA) for two years (2007 and 2008) and at Indian Head (IH) in 2007 only. Both these locations differ in their weather and soil type, representing two distinct environments in Saskatchewan province. The experimental sites were located at 52° N and 106° W for Saskatoon and 50° N and 103° W for Indian Head, representing Dark Brown Chernozem Bradwell sandy loam and Black Chernezem Oxbow loam soils, respectively.

4.3.2 Treatments and experimental design: Two lentil cultivars "CDC Plato" (large green class with medium to late maturity) and "CDC Viceroy" (small seeded green market class with early maturity) were sown under the following diquat application treatments:

Table 4.1: Desiccant treatments used in the experiment

Desiccant Treatments	Timing
Control (water plus surfactant only)	one week after full flowering
Quarter rate of diquat (0.425 litres a.i ha^{-1})	one week after full flowering
Half rate of diquat (0.85 litres a.i. ha^{-1})	one week after full flowering
Quarter rate of diquat (0.425 litres a.i ha^{-1})	three weeks after full flowering
Half rate of diquat (0.85 litres a.i. ha^{-1})	three weeks after full flowering

Fertility treatments consisted of a zero N check (without fertilizer and inoculant), 50 kg ha^{-1} of N as urea fertilizer, and rhizobial inoculant. All plots received 15 kg ha^{-1} of phosphorus fertilizer as triple superphosphate. The experiment was laid out in split plot design with desiccant treatments randomized in main plots and a factorial combination of fertility treatments and cultivars randomized in sub-plots. At both locations, Saskatoon (SKA) and Indian Head (IH), sub-plots were 2.42 m x 10.60 m (8 ft x 35 ft) providing an individual plot area of 25.65 m^2 with a row spacing of 20.32 cm (8 inches). Plots were seeded using a Fabro small plot seeder (Fabro Enterprises Ltd., Swift Current, SK) in the first week of May. A granular formulation of

Nodulator Rhizobium inoculant (Becker Underwood Inc., Saskatoon, SK) was placed in the seed rows at 7 kg ha^{-1} in the inoculated plots. The seeder was then used to apply superphosphate (0-45-0) in all plots and ammonium nitrate (34-0-0) in the N fertilized plots. Weed control strategies included pre-planting applications of glyphosate (Roundup) along with hand weeding. Grasshoppers were controlled with chloropyrifos (Lorsban). Precipitation and temperature data were recorded during the growing season by Environment Canada (Saskatoon Diefenbaker Airport, 25 km distance from the plots at Saskatoon; Indian Head CDA, 2 km distance from the plots at Indian Head).

4.3.3 Plant measurements: Plant density was counted in 1-m length of three randomly selected rows in each plot, two weeks after germination. Biomass samples were cut from each plot at four physiological stages i.e. flowering, early pod-fill, late pod-fill and physiological maturity, as two 0.3-m strips taken from two rows side by side. The outside border rows were never used for biomass sampling. Plant samples were cut at ground level, bagged and dried in an oven at 60°C for three days. Dry sample weights were then recorded for each plot. The final samples taken at physiological maturity were also used for harvest index (HI) measurement. These samples were oven dried, weighed, and threshed using a stationary belt drive thresher (Agriculex SPT-1, Guelph, ON) which separated seed from vegetative material. The seeds were then weighed to determine harvest index (HI) by using the following formula:

$$HI = \text{seed yield (g)} / \text{total biomass (g)}$$

A sub-sample was also taken at maturity for measuring N content in biomass as the original sample was threshed. Seed and biomass samples were ground and analyzed for N content measurement by combustion method, using a Leco carbon-nitrogen determinator (LECO CNS 2000, St. Joseph, MI, USA). Total plant N content was calculated by the following formula

$$\text{Plant N content (g m}^{-2}\text{)} = \text{(Plant N\%/100) x (Plant DW gm}^{-2}\text{)}$$

Days to maturity (DTM) were calculated by counting the Julian days from seeding to physiological maturity. Final seed yield was measured by harvesting the plots in the second week of October with Wintersteiger Elite combine (Wintersteiger, Salt Lake City, UT). Seeds were dried and cleaned to eliminate trash and weed seeds. Yield from individual plots was converted into kg ha^{-1}. Soil samples in both years were collected from both sites at three depths 0-15, 15-30 and 30-60 cm from random locations. Soil samples from each depth were bulked, subsampled, air-dried, ground and analyzed for inorganic N (NH_4^+ and NO_3^-) by KCl extraction (Maynard and Kalra, 1993). Soil samples were also measured for pH (MacLean, 1982), phosphorus (Bray and Kurtz, 1945), potassium (Carson, 1980) and organic carbon (Ball, 1964) (Table 3.2 and 3.3).

4.3.4 Statistical analysis: Data were analyzed in the GLM version of proc mixed of SAS, version 9.2 (SAS Institute, 1996). Environment and block were treated as random effects and the cultivars, fertility levels and desiccant treatments were considered as fixed effects. The least Significant Difference (LSD) test was applied to test the significance of the fertility treatments on lentil growth, yield, biomass accumulation and nitrogen concentration. In addition, contrast statements to test the effect of diquat timing and diquat rate were constructed.

4.4 RESULTS AND DISCUSSION

4.4.1 Weather conditions: For detail on weather conditions prevailing during the experiments, please refer to Table 3.4. Average monthly mean temperature and total rainfall during the plant growth varied among the environments. Saskatoon in both 2007 and 2008 had a warmer spring than Indian Head. However, the mean temperature during August, when lentil was podding, was almost the same (SKA was 0.3°C higher than IH). In 2007, SKA received high rainfall in the month of June when the plants were flowering while in July and August, IH received high rainfall when the plants were in podding and towards maturity. In 2008, SKA received high rainfall in the month of July followed by a dry period up to harvesting. The results of the experiments were affected by the prevailing weather conditions and are discussed separately for each location-year.

4.4.2 Indian Head-2007

As shown in the Table 4.2, desiccant treatments significantly affected parameters measured at the late pod-fill stage; whereas parameters measured at maturity remained unaffected. Desiccant application burned leaf foliage and reduced biomass, reduced leaf chlorophyll content (SPAD reading), and lowered TPN content. These findings are in line with those of Osman et al. (1983) who found that desiccation reduced nitrogenase activity in peanut; thereby reducing nodule formation, N fixation and adversely affecting plant N content. Lentil yield, harvest index and NHI remained unaffected by the desiccant application. This is a sought-after response of the lentil crop because any adverse affect on final yield parameters would penalize growers. Fertility treatments did not affect any parameter except yield where highest yield was obtained with inoculation, emphasizing the importance of inoculation for legumes. The two cultivars differed significantly for biomass and TPN content. All interactions between diquat treatments, fertility levels and cultivars were non-significant.

Table 4.2: ANOVA of the effects of desiccant treatments, fertility levels and cultivars on lentil at Indian Head-2007 (parameters measured at late pod-fill and maturity stages). Probabilities are indicated for yield, harvest index (HI), nitrogen harvest index (NHI), biomass (biomass obtained at late pod-fill stage), total plant nitrogen (TPN) and leaf chlorophyll content (SPAD reading)

	At maturity			At late pod-fill		
	Yield	**HI**	**NHI**	**Biomass**	**TPN**	**SPAD**
Desiccant (D)	0.05	0.05	0.04	0.02	0.06	0.05
Fertility (F)	<0.01	0.75	0.74	0.51	0.58	0.92
Cultivar (C)	0.14	0.34	0.47	0.03	0.04	0.55
FxC	0.53	0.41	0.49	0.27	0.17	0.14
DxF	1.00	0.74	0.94	0.84	0.57	0.92
DxC	0.14	0.12	0.28	0.84	0.72	0.99
DxFxC	0.75	0.08	0.05	0.83	0.73	0.63

SPAD stands for Special Products Analysis Division (A division of Minolta and manufacturer of chlorophyll meter SPAD 502)

4.4.2.1 Grain yield:

At IH-2007, the highest yield (1802 kg ha^{-1}) was obtained with the untreated control which was statistically similar to the yield of the ¼ rate application of diquat (both one and three weeks after flowering) (Table 4.3). Yield was reduced significantly by the higher rate (½ rate of diquat). The lowest yields were obtained with ½ rate of diquat applied one and three weeks after flowering (WAF). The high rate of diquat, therefore, adversely affected yield regardless of the time of application. The rate of diquat application was important as a large yield reduction of 538 kg ha^{-1} was associated with applying ½ rate of diquat as compared to ¼ rate at the same growth stage (one WAF). The impact of time of application was not significant, as both rates produced statistically similar yields at the two growth stages of application. The trend of yield reduction was, however, opposite where ¼ rate produced lower yield when applied three WAF and ½ rate reduced yield when applied one WAF. The results suggest that early application of diquat with ½ rate burned flowers and early pods, which otherwise would be contributing to final yield. Late application of diquat (three WAF) desiccated leaves and other succulent tissues without harming pods as most pods had already accumulated enough dry matter to escape destructive desiccation. In terms of fertility, yield was not affected by N application as both control and 50 kg N ha^{-1} produced similar yields (Table 4.3). The highest yield was, however, obtained with inoculation which agrees with observation of other researchers who emphasized the importance of inoculation on legumes (Bremer et al. 1988; Rennie and Hynes 1993).

4.4.2.2. Days to maturity:

Besides producing lowest yield, half rate of diquat one WAF significantly increased the days to maturity emphasizing that early application with high rate of diquat is not effective in enhancing lentil maturity (Table 4.3). All other desiccant treatments had non-significant effect on days to maturity. No impact of fertility was observed with regard to days to maturity. CDC Viceroy, an early maturing cultivar, behaved accordingly in the experiment and matured four days earlier than CDC Plato.

Table 4.3:- Effect of diquat desiccant, nitrogen fertility and cultivars on mean lentil yield, days to maturity, biomass at late-pod fill, leaf chlorophyll content (SPAD), total plant nitrogen (TPN), harvest index (HI) and nitrogen harvest index (NHI) at Indian Head 2007 (values labelled with different letters differ significantly at P<0.05)

Treatments	Yield (kg ha^{-1})	Days to Maturity (days)	Biomass at late-pod fill (g m^{-2})	SPAD	TPN (g m^{-2})	HI (%)	NHI (%)
	DESICCANT TREATMENTS						
Control	1802a	96.50b	383.8a	41.38a	8.80a	47.40a	81.34a
¼ rate one WAF	1693a	96.50b	287.8bc	34.66b	6.99b	43.52ab	71.82ab
½ rate one WAF	1155c	99.27a	257.2c	34.59b	6.37b	39.99b	66.11b
¼ rate 3 WAF	1583ab	96.05b	314.9b	38.05ab	7.24b	42.35ab	75.33ab
½ rate 3 WAF	1382bc	95.72b	297.4bc	40.46a	7.08b	42.76ab	74.56ab
LSD	272	1.16	46.5	4.76	1.02	5.67	10.12
	FERTILITY LEVELS						
Control	1410b	96.77^{NS}	298.1^{NS}	37.99^{NS}	7.06^{NS}	42.80^{NS}	73.67^{NS}
50 kg N ha^{-1}	1418b	96.97	307.9	37.41	7.39	42.67	72.57
Inoculation	1742a	96.73	318.7	38.08	7.43	44.14	75.26
LSD	207	0.88	35.5	3.63	0.78	4.33	7.72
	CULTIVARS						
CDC Plato	1586^{NS}	99.07a	324.4a	38.27^{NS}	7.64a	44.06^{NS}	72.96^{NS}
CDC Viceroy	1460	94.58b	292.1b	37.38	6.95b	42.35	74.71
LSD	168	0.72	28.8	2.95	0.63	3.51	6.26

SPAD stands for Special Products Analysis Division (A division of Minolta and manufacturer of chlorophyll meter SPAD 502)

4.4.2.3. Biomass at late pod-fill stage:

Maximum biomass at late pod-fill stage (383.8 g m^{-2}) was found in the control treatment, which was significantly higher than all other desiccant treatments (Table 4.3). This showed that diquat application reduced plant biomass regardless of its concentration and time of application. The lowest biomass was obtained with ½ rate diquat one WAF which was statistically similar to that of ¼ rate one WAF and ½ rate three WAF and similar to the effect on grain yield. The finding is in line with those of Teofilo et al., 1999 and Santos et al., 2004. Although biomass was not affected significantly by the fertility levels, the highest biomass was recorded with N application followed by inoculation. An increase in biomass with N application was also reported by Gan et al. (2009). Late maturing CDC Plato produced significantly higher biomass than early maturing CDC Viceroy.

4.4.2.4 Leaf chlorophyll content (SPAD reading):

The leaf chlorophyll contents were measured at the late pod-fill stage. The highest leaf chlorophyll content was recorded for the control treatment which was statistically similar to that of the late application of diquat (½ and ¼ rates three WAF). Early application of diquat reduced leaf chlorophyll content due to desiccating foliage and leaves. Low chlorophyll content is, therefore, the main cause of reduced biomass production by diquat application. No significant effect of fertility levels and cultivars was observed for leaf chlorophyll content.

4.4.2.5 Total Plant Nitrogen (TPN):

All diquat treatments regardless of rate and time of application reduced TPN. Diquat burned plant foliage interrupting complex plant growth processes and subsequently lowered TPN. The result was similar to the finding of Agren (1985) who suggested that below an optimum internal N concentration, a simple linear relationship exists between plant N concentration and relative plant growth rate. Late maturing CDC Plato accumulated significantly higher TPN than early maturing CDC Viceroy, suggesting that duration of N accumulation is important in developing high N (protein) cultivars. The effect of fertility levels on TPN was non-significant.

4.4.2.6 Harvest Index and Nitrogen Harvest Index:

Increasing seed protein content while maintaining yield, is an important challenge in pulse crops. Seed protein content and yield are complex and unstable traits, integrating all the processes occurring during the plant life cycle. During filling, seeds are the main sink to which assimilates are preferentially allocated at the expense of vegetative organs. Nitrogen seed demand is satisfied partly by nitrogen acquired by the roots, but also by nitrogen remobilized from vegetative organs. Both indices showed similar trend and were affected the same way by the treatments. The highest and lowest indices (both HI and NHI) were obtained with control and half rate diquat one WAF, respectively. It is important to note that the same diquat treatment produced lowest biomass and also the lowest seed yield. Both indices were not affected by fertility levels and cultivars.

4.4.3 Saskatoon-2007

Table 4.4: ANOVA of the effects of desiccant treatments, fertility levels and cultivars on lentil at Saskatoon-2007 (parameters measured at late pod-fill and maturity stages). Probabilities are indicated for yield, harvest index (HI), nitrogen harvest index (NHI), biomass (biomass obtained at late pod-fill stage), total plant nitrogen (TPN) and leaf chlorophyll content (SPAD)

	At maturity			**At late pod-fill**		
	Yield	HI	NHI	Biomass	TPN	SPAD
Desiccant (D)	<0.01	<0.01	0.01	<0.01	<0.01	<0.01
Fertility (F)	<0.01	0.04	0.26	0.02	0.05	0.83
Cultivar (C)	<0.01	0.36	0.16	<0.01	<0.01	0.14
FxC	<0.01	0.59	0.81	0.41	0.47	0.93
DxF	0.26	0.64	0.68	0.81	0.22	0.35
DxC	0.13	0.24	0.69	0.66	0.38	0.35
DxFxC	0.32	0.38	0.08	0.67	0.78	0.97

SPAD stands for Special Products Analysis Division (A division of Minolta and manufacturer of chlorophyll meter SPAD 502)

As shown in Table 4.4, all the measured parameters were significantly affected by desiccant treatments. Fertility treatments significantly affected yield, harvest index and biomass; while the two cultivars differed significantly for yield, biomass and TPN. All interactions between desiccant treatments, fertility levels and cultivars were non-significant except FxC interaction for yield. That location year was a wet season during flowering with dry conditions at maturity. The impacts of treatments with respect to site features are discussed below:

4.4.3.1 Grain yield:

All diquat treatments significantly reduced yield in this site year (Table 4.5). The highest yield (1736 kg ha^{-1}) was recorded with control treatment followed by late application of diquat. The two late application treatments (¼ and ½ rate) produced similar yields of 1426 and 1462 kg ha^{-1}. The lowest yield (321 kg ha^{-1}) was obtained with ½ rate diquat applied one WAF. The wet season during early growth resulted in excessive growth and biomass at flowering and early-pod fill stages. The results demonstrated that early application of diquat under such conditions burned flowers and early pods, which otherwise would have contributed to the final yield. Late application of diquat, however, desiccated leaves and other succulent tissues without harming pods as most pods had already accumulated enough dry matter to escape desiccation for diquat, therefore, resulting in less adverse effects on yield. Both N application and inoculation produced higher yield than the unfertilized control emphasizing that N in either source (from BNF or soil mineralization/fertilizer) is important for harvesting higher lentil yields in SKA soils.

4.4.3.2. Biomass at late pod-fill stage, leaf chlorophyll content and total plant nitrogen:

Early application of diquat (one WAF) significantly reduced biomass at mid pod-fill stage, irrespective of the rate. The biomass obtained by three WAF was not significantly different from the control. The biomass reduction by early application of diquat was associated with the least leaf chlorophyll content measured. Total plant nitrogen (TPN) was also reduced by the diquat application. However, the TPN reduction caused by late application (both ½ and ¼ rates) was non-significant. The lowest TPN was obtained with ¼ rate diquat applied one WAF. The relationship between these three parameters is obvious as early application burned plant foliage at early stage resulting in low chlorophyll content, less N uptake and ultimately less total plant nitrogen. A strong positive correlation reported by Evans (1983) between N uptake and chlorophyll content in wheat crop was confirmed by our data.

Table 4.5:- Effect of diquat desiccant, nitrogen fertility and cultivars on mean lentil yield, biomass at late-pod fill, leaf chlorophyll content (SPAD), total plant nitrogen (TPN), harvest index (HI) and nitrogen harvest index (NHI) at Saskatoon-2007 (values labelled with different letters differ significantly at P<0.05)

Treatments	Yield (kg ha^{-1})	Biomass at late-pod fill (g m^{-2})	SPAD	TPN (g m^{-2})	Harvest Index (%)	NHI (%)
	DESICCANT TREATMENTS					
Control	1736a	247.1a	37.48a	5.13a	41.13a	71.07a
¼ rate one WAF	753c	134.7b	16.53d	2.81b	33.54b	53.60c
½ rate one WAF	321d	120.9b	14.43d	2.88b	21.9 c	34.61d
¼ rate 3 WAF	1426b	232.8a	31.25c	4.79a	38.48ab	58.88bc
½ rate 3 WAF	1462b	223.8a	34.47b	4.69a	42.12a	66.38ab
LSD	97	30.0	2.86	0.68	6.75	11.29
	FERTILITY LEVELS					
Control	1053b	173.2b	26.47^{NS}	3.86b	38.62a	60.87^{NS}
50 kg N ha^{-1}	1187a	198.3a	27.12	4.42 a	35.49ab	57.53
Inoculation	1177a	204.2a	26.92	3.89b	31.98b	52.32
LSD	74	22.9	2.18	0.52	5.15	8.61
	CULTIVARS					
CDC Plato	1235a	204.4a	27.50^{NS}	4.43a	36.33^{NS}	58.48^{NS}
CDC Viceroy	1043b	179.3b	26.17	3.69b	34.40	55.33
LSD	60	18.6	1.77	0.42	4.17	6.98

SPAD stands for Special Products Analysis Division (A division of Minolta and manufacturer of chlorophyll meter SPAD 502)

4.4.3.3. Harvest Index and Nitrogen Harvest Index:

Maximum transfer of dry matter (HI) and nitrogen (NHI) from biomass to seeds is considered necessary to obtain high yield and quality of lentil. Diquat application produced similar effects on both indices. The highest and lowest measurements for both HI and NHI were obtained with control and half rate diquat one WAF, respectively. The same diquat treatment (½ rate one WAF) produced lowest biomass and lowest seed yield. Both HI and NHI were not significantly affected by fertility levels and cultivars.

4.4.4 Saskatoon-2008

Table 4.6: ANOVA of the effects of desiccant treatments, fertility levels and cultivars on lentil at Saskatoon-2008 (parameters measured at late pod-fill and maturity stages). Probabilities are indicated for yield, harvest index (HI), nitrogen harvest index (NHI), biomass (biomass obtained at late pod-fill stage), total plant nitrogen (TPN) and leaf chlorophyll content (SPAD)

	At maturity			**At late pod-fill**		
	Yield	HI	NHI	Biomass	TPN	SPAD
Desiccant (D)	0.03	0.05	0.05	0.82	0.76	0.76
Fertility (F)	<0.01	<0.01	<0.01	<0.01	<0.01	0.69
Cultivar (C)	<0.01	<0.01	<0.01	<0.01	<0.01	0.26
FxC	<0.01	0.50	0.15	0.81	0.68	0.19
DxF	0.52	0.01	0.01	0.90	0.99	0.62
DxC	0.21	0.04	0.15	0.22	0.35	0.62
DxFxC	0.50	0.38	0.39	0.39	0.39	0.25

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Diquat application did not significantly affect any of the measured parameters at SKA-2008 (Table 4.6). The effect of both sprays (one and three WAF) was reduced due to rainfall shortly after spraying which brought non-significant effect of diquat application. Fertility levels and cultivars, however, differed significantly for the measured parameters except for leaf chlorophyll content. The interaction between DxF was significant for harvest and nitrogen harvest indices. All other interactions were, however, non-significant. The results demonstrate that although diquat is absorbed by plant tissues readily, its effect could have been minimized by rainfall shortly after spraying.

Table 4.7:- Effect of diquat desiccant, nitrogen fertility and cultivars on mean lentil yield, biomass at late-pod fill, leaf chlorophyll content (SPAD), total plant nitrogen (TPN), harvest index (HI) and nitrogen harvest index (NHI) at Saskatoon-2008 (values labelled with different letters differ significantly at P<0.05)

Treatments	Yield (kg ha^{-1})	Biomass at late-pod fill (g m^{-2})	SPAD	TPN (g m^{-2})	Harvest Index (%)	NHI (%)
Control	751bc	460.8^{NS}	20.60^{NS}	8.39^{NS}	21.26bc	38.23bc
¼ rate one WAF	710c	492.5	19.04	9.31	18.70c	32.87c
½ rate one WAF	821ab	482.4	17.23	8.60	26.98a	49.47a
¼ rate 3 WAF	778bc	488.1	18.12	8.71	24.52ab	43.54ab
½ rate 3 WAF	878a	494.6	18.19	8.54	25.81a	44.80a
LSD	95	50.3	4.25	0.99	3.47	6.53
			FERTILITY LEVELS			
Control	743b	423.1c	17.84^{NS}	7.41 c	25.33a	44.63a
50 kg N ha^{-1}	859a	494.2b	19.14	8.95 b	25.55a	46.93a
Inoculation	761b	533.8a	18.94	9.77 a	19.48b	33.78b
LSD	72	38.3	3.24	0.76	2.65	4.98
			CULTIVARS			
CDC Plato	585b	507.4a	19.39^{NS}	9.84 a	18.62b	32.26b
CDC Viceroy	990a	460.0b	17.88	7.58 b	28.28a	51.31a
LSD	59	31.1	2.63	0.61	2.15	4.04

SPAD stands for Special Products Analysis Division (A division of Minolta and manufacturer of chlorophyll meter SPAD 502)

4.4.4.1. Grain yield, biomass, leaf chlorophyll content and TPN:

The highest yield was obtained by the application of ½ rate of diquat three WAF which was statistically similar to the yield obtained by ½ rate one WAF which in turn was not significantly different from the control and ¼ rate three WAF. The lowest yield was obtained by ¼ rate one WAF which was statistically similar to yield obtained by the control treatment. Rainfall after spraying alleviated the effect of diquat application at SKA 2008 site. Therefore, a non-significant effect of diquat application was recorded for biomass at late pod-fill, leaf chlorophyll content and TPN. The effect of fertility was, however, significant on yield, biomass and TPN. The highest yield and biomass were obtained with N application and inoculation, respectively.

This trend shows that lentil indeterminacy was exacerbated with inoculation and N fertilizer application may help to reduce lentil indeterminacy caused by N_2 fixation and thereby, increase yield. This proposition was further strengthened because the highest TPN values were associated with inoculation. Inoculation resulted in more TPN due to N_2 fixation.

4.4.4.2. Harvest index and Nitrogen Harvest Index:

A similar trend was found for both HI and NHI where the ½ rate of diquat (both one and three WAF) produced statistically similar and highest values while ¼ rate one WAF resulted in the lowest values. For fertility levels, the highest values were recorded with N application which were statistically similar to those obtained with control treatment. Therefore, the N application did not contribute towards converting dry matter and N from biomass to seed, while inoculation accumulated much biomass due to N_2 fixation and reduced both HI and NHI.

4.5 CONCLUSION

Desiccating lentil crops is a useful tool for bringing forward the harvest date of crops that are ripening unevenly, or for drying down green weed material which can interfere with the harvesting process. The results of the experiment were diverse in three environments under study (IH-2007, SKA-2007 and SKA-2008). Although literature demonstrates that diquat is readily absorbed by plant tissues, results of the experimental site SKA-20008 shows that like other post-emergent herbicides, diquat is sensitive to precipitation and repeated spraying is recommended if rainfall occurs within an hour of spraying. Bovey et al. (1990) also reported that rainfall soon after application of foliar-applied herbicides may reduce their efficacy on weeds or plants. At the other two sites (IH-2007 and SKA-2007), diquat application successfully suppressed biomass and plant growth at maturity. However, reduction in biomass was obtained at the cost of yield loss at both sites. This loss in yield was drastic when diquat was applied at the earlier stage with high rate (half rate one WAF) at both sites. Early application of diquat at low rate brought in favorable results in IH-2007 where it reduced biomass by 25% compared to control without significantly affecting yield. The same treatment, however, reduced biomass by 45% in SKA-2007 with a huge yield loss (230%). The difference in the diquat effect at the two sites might be attributed to the extent of precipitation and initial soil N and at the two sites. IH site with more rainfall and soil N produced higher biomass which was efficiently converted into grain yield. Due to faster DM production, only plant foliage was affected by early application of diquat (one WAF) with quarter rate. This rate was small enough to kill early pods and they survived in the long run contributing to final yield. Similar rate, however, affected yield adversely in SKA-2007. This might be due to delayed seeding compared to IH and to slower plant growth and dry matter accumulation. Early foliage is very important in such conditions and contributes mainly to final yield; if it was killed as in SKA-2007, yield would obviously be affected. Later application of diquat is, therefore, suggested for SKA under similar conditions in order to provide enough time for foliage to convert into dry matter. At both locations, lower rate of diquat produced less adverse effect on yield. Spraying should be delayed at least three WAF, perhaps four weeks. The results found no significant interaction between the three factors under study (desiccant, fertility and cultivar) for most of the measured parameters.

The results of this trial demonstrated that rate of diquat application is critical to ensure grain yield. Early desiccation with higher rate led to significant yield penalties. Under hot and dry conditions, diquat stressed the canopy too much, and yield loss occurred. Therefore, spraying diquat should be avoided in hot and dry weather. Since the lentil yield was reduced with diquat regardless of time and rate of application, further research is proposed on diquat treatments to avoid yield loss.

5. 1 CONCLUSION

Successful crop production especially for an indeterminate crop like lentil is quite challenging within a limited growing season like Saskatchewan has. Lentil is a leguminous crop and N_2 fixation intensifies its indeterminate growth. Moreover, higher amounts of inorganic soil N like nitrite reduce plants' ability to fix atmospheric N_2, though some amount of soil N is required prior to the main plant N_2 fixation. In both experiments, post-flowering vegetative growth was much higher at IH as compared to SKA which confirmed that biomass reduction in lentil towards maturity was attributed to N deficiency.

Regardless of weather conditions, N availability favoured vegetative growth and yield. For instance, in fertility experiment, lentil produced greater biomass and yield with higher rates of N applied in both wet (IH) and dry (SKA) locations. High soil N in IH soils favoured vegetative growth and more biomass accumulation was obtained. Regardless of the site features, greater N availability resulted in higher growth at both locations.

At IH, highest yield was obtained with 10 kg N ha^{-1} (lowest N applied) which is significantly higher than control, while in SKA, N application did not produce any significant impact on lentil. The hypothesis that greater N application may reduce post-flowering biomass accumulation by curtailing N_2 fixation is not supported by the data since biomass increased with increasing N application. In addition, both biomass and N accumulation after flowering were not affected significantly by the fertility treatments, showing that post-flowering physiology in lentils is governed more by N_2 fixation than N application.

Harvest index was unaffected by fertility levels at IH, however, it was reduced with the higher rates of N (20 and 50 kg ha^{-1}) at SKA, depicting less assimilation of photosynthates into seed yield at higher N levels. At SKA, lentil had, therefore, capacity to perpetuate late-season growth, delay maturity and lower harvest index with N application without affecting yield.

Both cultivars produced similar yields at SKA. However, late maturing and large seeded CDC Plato produced 50% higher yield at IH than CDC Blaze. This demonstrated that late N_2 fixation in CDC Plato contributed more towards dry matter accumulation in seed rather than biomass.

Partitioning of dry matter and N to seed was affected by environments because lentil yield depended more on total biomass than on harvest index. The overall lack of response of lentil biomass and N accumulation after flowering to the individual fertility treatments suggested that source and availability of N did not change within plant. Instead, environmental conditions were more likely to influence partitioning of biomass and N to seed through remobilization from vegetative parts in mid to late-season reproductive growth.

Diquat application successfully suppressed biomass and plant growth at maturity. However, a reduction in biomass was obtained at the cost of yield loss at both sites. This loss in yield was drastic when diquat was applied at the earlier stage with ½ rate one WAF at both sites. Early application of diquat at the low rate brought in favorable results in IH-2007 where it reduced biomass by 25% biomass compared to the control without significantly affecting yield. The same treatment, however, reduced biomass by 45% in SKA-2007 with a huge yield loss (230%). The difference in the diquat effect at the two sites might be attributed to the difference in precipitation obtained at the two sites during the course of the experiment. Under wet conditions (IH), plant dry matter accumulation was fast and plant foliage was better controlled by early application of diquat (one WAF). Since pods (hard tissues) were not yet developed at that time, smaller rate (1/4 rate) of diquat was strong enough to control biomass at early stage. A similar rate, however, affected yield adversely at SKA-2007. This might be due to delayed plant growth and dry matter accumulation, or the higher temperatures at the spray times which drifted diquat spray. The current diquat application practice involves spraying it at full crop canopy (mid pod-fill) with 1.7 litres ha^{-1}. This research suggests application of diquat earlier than full crop canopy (three weeks after flowering) at ¼ rate of the current farming practice. However, due to limited number of replications of the experiment, further research is required on rates and time of diquat application for recommendation purposes. Swathing could also be explored as another option to control plant biomass and growth at maturity.

5.2 FUTURE WORK

In terms of the scope of this study, further research on lentil indeterminacy may include following measurements/ recommendations based on findings from this thesis

1. Experiments may include more replications to increase the power of the experiment.
2. Fertility experiments may be designed to include split application of N with or without phosphorus and rhizobial inoculation, to determine the effect of post-flowering N application on lentil indeterminacy.
3. Measuring plant growth over time e.g. crop growth rate (CGR), relative growth rate (RGR), leaf area index (LAI), leaf area duration (LAD) and leaf appearance (node counts) over time would be helpful to determine indeterminacy in lentil.
4. Measurements may be made on N_2 fixation along with partitioning of nitrogen to leaf, stem and pods.
5. Organic matter measurements should be made before and after experimentation to determine its role in N_2 fixation.
6. Experiments may be designed to include other post-emergence herbicides and swathing treatments along with diquat.
7. Diquat may be tested at more doses (especially lower than ¼ rate) applied at different growth stages.

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