THE EFFECT OF CANOLA CULTIVAR ON WATER EXTRACTION AND NITROGEN AND SULPHUR UPTAKE

BY

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"The Effect of Canola Cultivar on Water Extraction and Nitrogen and Sulphur Uptake"

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Marla Rae Riekman

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirement of the degree

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ABSTRACT

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The objective of this study was to assess the mechanism that leads to enhanced uptake of N and S by a hybrid canola cultivar. Two canola cultivars, one hybrid (45H21) and one open-pollinated (Conquest) were grown at a single location near Rosebank, MB during the 2003 growing season to study the impact of canola cultivar and S fertilization on the uptake of water, N and S from the soil. The experimental design was a Randomized Complete Block where each cultivar was exposed to three fertilizer treatments: a control, 160 kg N ha^{-1}: 0 kg S ha^{-1}, and 160 kg N ha^{-1}: 27 kg S ha^{-1}. Soil and plant N and S concentrations were measured at midseason and maturity to determine the uptake of N and S by each cultivar. Soil moisture content was monitored throughout the growing season to study the activity of the canola roots. As well, soil cores were removed at midseason to determine the difference in rooting depth by each cultivar. The year following the canola crop experiment, AC Barrie spring wheat was seeded to the canola stubble without N fertilizer to study the effect of N and S uptake by each canola cultivar on a subsequent crop.

Biomass was greatest for the hybrid canola cultivar at both sample periods. The concentration of N and S in the canola tissue at midseason was higher in the open-pollinated cultivar, which offset the biomass difference; therefore, the total N and S

accumulated by each cultivar was not statistically different. At maturity, the difference in tissue concentrations was seen for S only. The addition of fertilizer caused an increase in biomass production as well as a significant increase in N accumulation at midseason and maturity, and an increase in S accumulation at maturity only. Seed yield was highest for the hybrid cultivar and increased with fertilizer application for both cultivars. There was no interaction between cultivar and fertilizer treatment, indicating that each cultivar responded similarly to fertilizer addition.

There was no significant difference in rooting depth between the two cultivars; however, the hybrid cultivar removed 58 mm more water than the open-pollinated cultivar over the 10 to 110 cm soil depth during the growing season, for the N plus S fertilizer treatment only. The difference in root activity may be attributed to the greater biomass of the hybrid canola, leading to higher rates of transpiration. Water use efficiency (WUE) was greater for the hybrid canola cultivar due primarily to the higher seed yield of this cultivar.

The biomass accumulated by the wheat seeded onto the open-pollinated canola stubble was numerically greater than that on the hybrid stubble, but this was significant for the midseason sampling period only. Biomass accumulation and total recovery (biomass and soil) of N and S by the wheat seeded onto the open-pollinated stubble was numerically greater, but not significantly so. Again, there was no interaction between cultivar and fertilizer treatment on either accumulation or recovery of N and S by the wheat crop.

FOREWORD

This thesis has been prepared in the traditional format in adherence with the guidelines established by the Department of Soil Science. The reference style of the Canadian Journal of Soil Science has been used throughout this document. Only one site year of data was analyzed for each experiment in this study. A second site year was established for the canola crop experiments; however, due to poor weather conditions, soil conditions and a loss of treatments, the data from this site year is not included in this thesis.

As well, a wheat crop experiment was seeded in 2003 to the Westco N:S ratio plots from 2002. The previous canola experiment included three canola cultivars, two hybrid and one open-pollinated and two fertilizer treatments, a control and the 160 kg N ha^{-1}: 27 kg S ha^{-1} treatment. Therefore, since the canola cultivar and fertilizer treatments that preceded the 2003 wheat experiment were different than those for the 2004 wheat, we chose the latter portion of the experiment in order to simplify the analysis of the follow crop experiment.

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1. INTRODUCTION

Canola is a major oilseed crop for producers in Western Canada. In 2003, roughly 11.5 million acres of canola were harvested (Canola Council of Canada 2003). Of the canola acreage reported for 2003, 35 percent were hybrid varieties, up from 15 percent in 2000 (Pioneer Hi-Bred Limited 2004). Hybrid canola cultivars typically have a higher yield potential than the traditional open-pollinated varieties (Brandt et al. 2002; Karamanos et al. 2002; Van Deynze et al. 1992); therefore, they are gaining in popularity with today's producers.

Canola has been identified as being a high N-requiring crop, on average removing a total of 125 kg N ha^{-1} during the growing season (Manitoba Agriculture and Food 2001). Overall, N fertilization influences the growth and development of the crop by significantly increasing above ground plant growth (Grant and Bailey 1993) and total dry matter accumulation (Asare and Scarisbrick 1995; Hocking et al. 2002; Rathore and Manohar 1989) which, in turn, leads to greater seed yield production. Along with N, canola also has a high requirement for S to achieve maximum yield (Grant et al. 2004; Grant et al. 2003; Malhi and Gill 2002); approximately 1.5 kg of S is needed to produce 100 kg of seed (Grant and Bailey 1993). When S is limiting, especially at flowering, the result will be a loss in yield (Grant and Bailey 1993), even if visual symptoms of a deficiency are lacking (McGrath and Zhao 1996). As a result, it is important that canola fertilization practices are well-planned, so that the S requirement of the plant can be met.

A balance between N and S must be maintained in canola production, since the demand for each nutrient is high and an interaction between N and S controls the rate of uptake for each nutrient. Sulphur is a component in nitrate reductase, required for the conversion of NO_3^- to amino acids and proteins within the plant, and N is used to form ATP-sulphurylase, the enzyme responsible for sulphate assimilation (Ahmad and Abdin 2000). Therefore, if either N or S is deficient, the assimilation of the other nutrient would decrease, creating a deficiency in that nutrient as well.

The current fertilizer practices for canola production have been developed to maintain the balance of N and S for optimal yield. Agronomists recommend applying fertilizer based on an N:S ratio of 7:1 (Saskatchewan Agriculture, Food and Rural Revitalization 2003; Manitoba Agriculture, Food and Rural Initiatives 2003), as this ratio mimics the N and S uptake generally exhibited by canola (Janzen and Bettany 1984). Sulphur fertilizer is often recommended on soils that have adequate soil test S concentrations, in order to ensure high canola yields. The recommended fertilizer N:S ratio is based on research carried out on the more traditional open-pollinated varieties of canola. However, in the past few years, as hybrid canola acreage has increased, research has begun to focus on the specific fertilizer needs of these new, higher-yielding varieties. In research on the impact of fertilizer N:S ratio on hybrid and open-pollinated canola cultivars, Karamanos et al. (200) found that open-pollinated varieties tend to respond to a decrease in N:S fertilizer ratio (increase in S rate), even on soils with adequate soil test S. In contrast, hybrid cultivars have shown little to no response to fertilizer S (Karamanos et al. 2002). Deibert et al. (2002) postulated that hybrids may be more efficient at using plant-available S, as the seed of the hybrid canola in their experiment had higher S contents than that of the open-pollinated varieties.

Along with higher yields, hybrid canola cultivars typically exhibit more vigorous above ground growth than open-pollinated cultivars (Brandt et al. 2002; Harker et al. 2003; Zand and Beckie 2002). The higher biomass production may be driving the need for increased fertilizer N; however, one would also expect an increase in need for fertilizer S. It is possible that the increase in above ground biomass production may be matched by a similar increase in below ground biomass. Therefore, the hybrid canola may have an increased root number and/or be rooting deeper than open-pollinated canola, gaining greater access to the available SO_4^{2-} at depth in the soil. In essence, the hybrid cultivars may be more efficient "scavengers" of soil nutrients (Karamanos and Flore 2002; Karamanos et al. 2002) due to their ability to access more nutrients and utilize these nutrients more efficiently than traditional open-pollinated canola cultivars.

A greater uptake of N and S by hybrid canola cultivars may have an impact on the fertilizer additions required for the next growing season. For example, if hybrid canola extracts more N from the soil, then more fertilizer N may be needed to maintain the following crop. Therefore, it is important to fully understand the rates of N and S uptake by hybrid canola cultivars, as it may have an effect on future fertilization practices.

The overall objective of this project was to assess the mechanism that leads to the enhanced uptake of N and S by higher yielding canola cultivars. Specifically, the purpose was to investigate the impact of S fertilization on different canola cultivars, in terms of its effect on N and S accumulation, rooting depth and rooting activity. Water loss was used as a measure of rooting activity, as both NO_3^- and SO_4^{2-} are water soluble nutrients that move toward plant roots by mass flow. As well, wheat was seeded the following season to determine the amount of recoverable N and S remaining after growing the canola cultivars. For this study, two canola cultivars, one hybrid and one open-pollinated were utilized; however, with only one cultivar representing each type of canola, the results of these experiments may not apply to hybrid and open-pollinated cultivars, in general.

2. LITERATURE REVIEW

2.1. Nitrogen in Canola Production

Of the mineral nutrients required by plants for growth and development, nitrogen is the most important from an agricultural perspective. N is essential for the composition of amino acids and proteins and plays an important role in the generation of carbohydrates from light energy via photosynthesis (Havlin et al. 1999). Therefore, it is required by plants in amounts greater than any other nutrient (Taiz and Zeiger 2002). The use of N fertilization practices in canola production causes increases in seed and oil yields, while also increasing the overall growth of the plant.

2.1.1. Physiological and Metabolic Roles of Nitrogen

Nitrogen is an essential nutrient for plant growth, required for the composition of many proteins, amino acids, enzymes and chlorophyll (Grant and Bailey 1993; Havlin et al. 1999; Taiz and Zeiger 2002; Olson and Kurtz 1982). Upon assimilation into amino acids, N is incorporated into proteins that become the building blocks for chloroplasts, mitochondria and other biochemically-active structures (Havlin et al. 1999). Therefore, the amount of N available to the plant will determine the rate of photosynthesis and the amount of carbohydrates produced. Adequate N supplies will also stimulate the formation of proteins from these carbohydrates (Havlin et al. 1999).

2.1.2. Nitrogen Uptake and Distribution in Canola, Rapeseed and Mustard

Nitrogen can be absorbed by the plant in the form of ammonium, NH_4^+, or nitrate, NO_3^- (Havlin et al. 1999; Taiz and Zeiger 2002; Olson and Kurtz 1982). Upon absorption into the roots, NH_4^+ is quickly assimilated into amino acids, because high levels of NH_4^+ can be toxic to plants. The NO_3^- that is absorbed by plant roots is reduced to nitrite, NO_2^-, via the nitrate reductase enzyme. The NO_2^- generated by this process is then transported to either the chloroplasts in leaves or the plastids in roots where it is further reduced to NH_4^+. The NH_4^+ is quickly converted into amino acids, in order to avoid NH_4^+ toxicity (Taiz and Zeiger 2002).

Due to the mobility of N in the plant, N deficiency symptoms are observed in the older leaves (Havlin et al. 1999). If N is limiting for crop growth and development, N will be removed from the old leaves and used for new tissue development. Most of the N accumulated by canola is taken up prior to anthesis (Hocking and Stapper 2001). As the plant matures, the concentration of N in the plant tissue decreases and seed N concentrations increase (Rood et al. 1984). Between anthesis and maturity, canola plants can lose approximately 35% of total N in the shoots (Hocking et al. 2002). Even with adequate N supply, movement of N from old tissue is important for reproductive development, as the translocated N is used to develop buds, pods and seeds.

2.1.3. Distribution and Plant Availability of Soil Nitrogen

Of the two forms of N available for plant uptake, the most commonly absorbed is NO_3^-. NO_3^- is a water soluble nutrient; therefore, it moves freely with water through the soil

(Hillel 1998). This is due to the negative charge of the ion, which is repelled by the net negative charge exhibited by most soils. As a result, NO_3^- is not adsorbed to soil surfaces. Soil NO_3^- concentration fluctuates throughout the growing season, unlike exchangeable NH_4-N, which remains low and constant (Campbell and Biederbeck 1982). For this reason, NO_3-N is most often examined in studies of soil N levels.

The distribution of nitrate in the soil is extremely variable, depending on soil properties, such as texture, which affects the rate of water movement through the soil and landscape position, which affects transfer of water from one area of a field to another. Soil nitrate concentrations will also differ from one area to another due to environmental influences, such as the amount of N added by fertilizer or the recycling of dead plant material. As well, the amount of moisture that falls on a field, as rain or irrigation water, will affect how deeply the nitrate penetrates the soil.

The majority of N extracted by plants as NO_3^- is usually from the upper surface of the soil profile (Hocking et al. 2002; Rood et al. 1984). Hocking et al. (2002) reported that canola and Indian mustard removed a significant amount of mineral-N from the 0 to 50 cm depth. As a result of the higher root extraction of N in the upper soil depth, any N that moves below this depth may accumulate lower in the soil profile. Research by Rood et al. (1984) found an increase in NO_3-N concentration at the 33 to 66 cm and 66 to 100 cm depths mid-way through the growing season, indicating that NO_3^- was being leached down through the profile from the shallow depths once the crop's demand for soil N had decreased. The density of roots at the 60 to 120 cm depth is low and active extraction of water and nutrients occurs for only a short time during the growing season (Campbell and Biederbeck 1982). The low root activity at greater soil depths allows for NO_3^- to leach below the rooting zone; therefore, concentrations of NO_3^- may be very high deep in the soil profile.

2.1.4. Effect of Nitrogen Fertilization on Canola, Rapeseed and Mustard Yield and Quality

A typical canola crop in Manitoba will remove a total of 125 kg N ha^{-1} (Manitoba Agriculture and Food 2001); therefore, it is recommended that 78 to 100 kg N ha^{-1} be applied when growing canola on most Manitoba soils. Due to their high N requirement, the use of N fertilizer in canola, rapeseed and mustard production can significantly increase overall seed yield (Allen and Morgan 1972; Asare and Scarisbrick 1995; Holmes and Ainsley 1977; Mason and Brennan 1998; Ramsay and Callinan 1994; Rathore and Manohar 1989; Taylor et al. 1991; Zhao et al. 1993) by influencing the growth and development of the crop. A greater number of branches, buds, and flowers per plant, in combination with more vigorous above-ground plant growth cause an increase in seed production (Grant and Bailey 1993). Specifically, higher yields with N application are due to an increase in the number of pods per plant (Allen and Morgan 1972; Asare and Scarisbrick 1995; Zhao et al. 1993). Zhao et al. (1993) reported that the greater seed yield in N fertilized rapeseed was due primarily to the higher number of potential and fertile pods on each plant. Asare and Scarisbrick (1995) determined that the number of pods was higher on the terminal raceme of the N fertilized rapeseed plants compared to the unfertilized plants, leading to increased seed yields. Other research has also found that a significant increase in the primary and secondary branches per plant may occur with higher N application rates (Rathore and Manohar 1989). A greater number of branches and pods allow canola and rapeseed plants to produce a higher number of seeds.

The application of N fertilizer may also affect the weight of each seed; however, research has shown this to be a variable effect. Zhao et al. (1993) found N application to increase the thousand kernel seed weight at one of two experimental sites and decrease seed weight at the other. In other studies, N fertilizer caused a small increase in seed weight (Allen and Morgan 1972; Asare and Scarisbrick 1995). Variability is also a factor in the measurement of seed number per pod. Zhao et al. (1993) observed an overall decrease in the number of seeds per pod, whereas Asare and Scarisbrick (1995) found no effect of N on seed number per pod.

As well as affecting seed yield, the application of N fertilizer also has an effect on the quality of seed produced. The protein content of canola and rapeseed has been shown to increase with application of N fertilizer (Asare and Scarisbrick 1995; Mason and Brennan 1998; Ramsay and Callinan 1994; Zhao et al. 1993). In general, the oil content of the seed will decrease with increasing N rate, resulting in an inverse relationship between protein and oil content in response to N application (Allen and Morgan 1972; Asare and Scarisbrick 1995; Hocking et al. 2002; Hocking et al. 1997; Holmes and Ainsley 1977; Mason and Brennan 1998; Ramsay and Callinan 1994; Taylor et al. 1991; Zhao et al. 1993). However, as with the variability in canola and rapeseed weight response, the effect that N rate has on oil content also shows some variable results. In some of the experiments, the reduction in oil content was not statistically significant at all sites (Holmes and Ainsley 1977; Mason and Brennan 1998). Ramsey and Callinan (1994) reported that one of their experimental sites had an overall increase in seed protein of canola with addition of N fertilizer. The particular site had very low concentrations of soil N; therefore, severe N deficiencies would have caused very low yields in the control treatment, resulting in an unusually large increase in seed yield due to N fertilization. The low soil N concentration may explain the atypical response of seed oil content to N application rate. Even with the decrease in seed oil content, the total oil yield of canola and rapeseed on a per hectare basis increases with N rate, due to the overall increase in seed yield (Allen and Morgan 1972; Holmes and Ainsley 1977; Taylor et al. 1991).

Along with increasing seed and oil yield, N fertilization may also increase the total dry matter produced by canola, rapeseed and mustard plants (Asare and Scarisbrick 1995; Hocking et al. 2002; Rathore and Manohar 1989). Allen and Morgan (1972) reported that the leaf area index of oilseed rape was greater when the crop was fertilized with N. As well, addition of N has been shown to cause a significant increase in canola straw yield (Nuttall et al. 1992).

The increase in leaf area due to N fertilization is an important factor because it may allow for greater supply of N to the seed during development (Allen and Morgan 1972). Asare and Scarisbrick (1995) observed a lengthened "green-time" with N fertilization, where the fertilized rapeseed plants senesced later than the non-fertilized plants. This allows the plant to assimilate more N for seed filling, resulting in higher yields. Similar findings were reported by Wright et al. (1988) in Australia, where the addition of fertilizer N delayed crop maturity, allowing for further N uptake, thus increasing canola yield.

2.2. Sulphur in Canola Production

Sulphur is the 13th most abundant element found in the crust of the earth (Havlin et al. 1999) and the fourth most important nutrient for crop production (Grant and Bailey 1993). S is especially important in canola nutrition as canola has a high requirement for S-containing amino acids, such as cysteine and methionine. S deficiencies have the greatest effect on the reproductive organs of canola, causing major decreases in yield, as opposed to N deficiencies which have a greater effect on dry matter production (Fismes et al. 2000; Singh and Nad 2000). However, with proper S fertilization practices, producers can achieve high yielding, high quality canola, even on soils that are naturally deficient in S.

2.2.1. Physiological and Metabolic Roles of Sulphur

S is an essential nutrient in plant metabolism as it is a major constituent of the amino acids cystine, cysteine and methionine (Grant and Bailey 1993; Thompson et al. 1986; Von Uexkull 1986). Sulphate, SO_4^{2-}, is reduced and incorporated into cysteine in the chloroplasts, which may then be incorporated in methionine (Taiz and Zeiger 2002; Thompson et al. 1986). Cysteine and methionine may also be synthesized into metabolites such as coenzyme A, biotin, and thiamin, important components in plant metabolism although they are present in the plant in lesser amounts (Thompson et al. 1986). Sulphur plays a role in the synthesis of chlorophyll (Grant and Bailey 1993), aids in the function of nitrate reductase which converts NO_3–N into amino acids in the plant (Ahmad and Abdin 2000) and exists in proteins as iron-sulphide bonds that function as electron carriers (Thompson et al. 1986).

In plants of the family *Cruciferae*, S is a major component of the mustard oils, or glucosinolates, which are characteristic of this family (Von Uexkull 1986). Glucosinolates are volatile oils that accumulate in cruciferous plants (Grant and Bailey 1993) as a defence mechanism. High concentrations of glucosinolates decrease the palatability of the crop, which in turn affects canola meal quality. Therefore, canola is now bred to have low glucosinolate content (Grant and Bailey 1993; Nuttall et al. 1987) to increase the quality of the seed.

2.2.2. Sulphur Uptake and Distribution in Canola, Rapeseed and Mustard

The primary form of S that is taken up by plants is as a divalent anion, SO_4^{2-} (Grant and Bailey 1993; Scherer 2001). Sulphate uptake primarily occurs in the root hair region using an H^+/SO_4^{2-} cotransport system (Scherer 2001; Taiz and Zeiger 2002). Smaller quantities of S can also be absorbed by the plant through stomates on the underside of the leaf, from atmospheric SO_4^{2-} concentrations (Scherer 2001).

Upon absorption by the plant roots, SO_4^{2-} is transported to the leaf by the xylem (Blake-Kalff et al. 1998; Scherer 2001). The transport process involves a number of transmembrane and long-distance transport steps within the xylem itself (Scherer 2001). As the newest leaves develop, they become strong S-sinks (Blake-Kalff et al. 1998) as they are the primary location of SO_4^{2-} assimilation (Taiz and Zeiger 2002). However, after the leaves have fully expanded, they exhibit a net loss of S (Blake-Kalff et al. 1998) due to the movement of assimilates toward the shoot apex for new tissue development (Taiz and Zeiger 2002). The requirement of canola for S becomes highest at the flowering and bud stage (Grant and Bailey 1993), as the assimilated S is utilized for seed and pod formation.

The concentration of S in the plant is temporally variable between growth stages and spatially variable between different plant tissues. Generally, the highest concentrations are seen in the leaf tissue, as opposed to the stems (McGrath and Zhao 1996). However, there is variability in the form of S found within the different leaves of the plant. For example, in oilseed rape leaves, Blake-Kalff et al. (1998) found that 42% of S in the youngest leaves was accumulated as SO_4^{2-}, as compared to 70% to 90% of S as SO_4^{2-} in the older leaves.

2.2.3. Distribution and Plant Availability of Soil Sulphates

In the soil, S occurs in both organic and inorganic forms, the organic form of S being the most abundant in noncalcareous surface soils, composing nearly 90% of total S (Havlin et al. 1999). The inorganic S content of well-drained, aerated soils is generally composed of water-soluble SO_4^{2-} and SO_4^{2-} absorbed to clays, and Fe and Al oxides (Trudinger 1986). In calcareous soils, SO_4^{2-} may be coprecipitated with calcium to form $CaSO_4$ (Trudinger 1986), an abundant compound in many Manitoba soils.