NITROGEN MANAGEMENT FOR BREAD WHEAT PRODUCTION IN QUEBEC

by

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ABSTRACT

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The effect of level and timing of nitrogen (N) fertilizer application on grain yield (YLD), grain protein (GPC), and breadmaking ability of four hard red spring wheat cultivars and on soil residual nitrate was investigated. Nitrogen fertility caused an increase in YLD, lodging, several yield components, GPC, and breadmaking quality and caused a reduction in N harvest index and grain ash, and N use efficiency (NUE) resulting in an increase in soil residual NO_3-N. Split N application reduced lodging, tillers and spikes m^{-2} and caused an increase in grain weight, GPC, loaf volume and NUE. Grain yield increases were largely due to increases in the grain $spike^{-1}$ and tillers m^{-2}. Absolute protein content was found to be critical in determining GPC. Cultivars showed plastic responses to N. Despite its high YLD and flour yield, Hege 155-85 may be risky to produce because of its high dependence on N. Mineralization of N occurred during winter. Marked differences existed between the sites.

RESUME

REGIE AZOTEE POUR LA PRODUCTION DE BLE PANIFIABLE AU QUEBEC.

L'effet du taux et du temps de l'épandage de la fumure azotée (N) sur le rendement en grain (RG), la concentration du grain en protéines (CGP), la panification de quatre cultivars de blé roux de printemps et les nitrates du sol a été étudié. Une augementation de l'N a causé une augmentation du RG, de la verse, de plusieurs composantes du RG, de la CPG, et la qualité de la panification, et a réduit l'efficacité de l'utilisation de l'azote (EUN) résultant en une augmentation des nitrates dans le sol, a réduit l'indice de rendement azoté et le taux des cendres. L'épandage fractionné d'N a minimisé la verse, a réduit le nombre de talles et d'épis m^{-2}, a augmenté le poids de 1000 grains, la CPG, l'EUN et le volume des pains. L'augmentation du RG était due à une augmentation du nombre des grains $épi^{-1}$ et des talles m^{-2}. On a trouvé que la quantité absolue des protéines dans le grain déterminait CPG. Les cultivars avaient des réponses plastiques a l'azote. Malgré son haut RG, la production de Hege 155-85 pourrait être risquée à cause de sa dépendence sur l'N. Durant l'hiver, une mineralization de l'N eut lieu dans le sol. Des différences marquées ont été observées entre les deux sites.

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CONTRIBUTIONS OF CO-AUTHORS TO MANUSCRIPTS FOR PUBLICATION

This thesis is submitted in the form of original papers suitable for journal publication. The first two sections are, respectively, an introduction and a literature review presenting the theory and previous knowledge on this topic. The next four sections represent the body of the thesis (each is a complete manuscript). The last section is a general discussion and a synthesis of the major conclusions. This thesis format has been approved by the Faculty of graduate Studies and Research, McGill University, and follows the conditions outlined in the Guidelines Concerning Thesis Preparation, section B.2 "Manuscripts and Authorship" which are as follows:

"The candidate has the option, **subject to the approval of the Department**, of including as part of the thesis the text, or duplicated published text of an original paper, or papers. - Manuscript-style thesis must still conform to all other requirements explained in the Guidelines Concerning Thesis Preparation. - Additional material (procedural and design data as well as descriptions of equipment) must be provided in sufficient detail (e.g. in appendices) to allow clear and precise judgment to be made of the importance and originality of the research reported. - The thesis should be more than a mere collection of manuscripts published or to be published. It must include a general abstract, a full introduction and literature review and a final overall conclusion. Connecting texts which provide logical bridges between the different manuscripts are usually desirable in the interest of cohesion.

It is acceptable for theses to include, as chapters, authentic copies of papers already published, provided these are duplicated clearly and bound as an integral part of the thesis. In such instances, connecting texts are mandatory and supplementary explanatory material is always necessary. - Photographs or other materials which do not duplicate well must be included in their original form. - While the inclusion of manuscripts co-authored by the candidate and others is acceptable, the candidate is required to make and explicit statement in the thesis of who contributed to such work and to what extent, and supervisors must attest to the accuracy of the claims at the Ph.D. Oral Defense. Since the task of the Examiners is made more difficult in these cases, it is in the candidate's interest to make the responsibilities of authors perfectly clear.

Although all the work reported here is the responsibility of the candidate, the project was supervised by Dr. D. L. Smith, Department of Plant Science, Macdonald Campus of McGill University. The manuscripts will be co-authored by Dr. D. L. Smith. For consistency and convenience, all manuscripts follow the same format. The copies that will be sent to the respective journals, however, will follow the requirements of each journal.

Section 1
INTRODUCTION

Currently, the province of Québec produces only 12 % of the bread wheat (*Triticum aestivum* L.) consumed by its mills. Québec millers import 500,000 T of bread wheat per year into the province. A premium is usually paid to farmers for bread wheat of a higher than 125 mg g^{-1} grain protein concentration. Because it may offer economic returns for farmers and may save the province its import cost, bread wheat has the potential to be a more prominent crop than is currently the case. Bread loaf volume is closely associated to grain and flour protein concentration (McNeal et al. 1971). The latter are known to increase with increasing levels of N fertility (McNeal et al. 1971). The effect of N management on grain and flour ash is not clear. There is a need to investigate N management for bread wheat production in Québec.

1.1 HYPOTHESIS

The level and timing of N fertilizer application will affect the level of grain protein and ash, and will affect farinograph determinations and the baking quality of hard red spring wheats, and the responses to these variables will vary with cultivar. High levels of fertilizer N will increase the protein content and split applications will allow this to occur with a minimum of, or no lodging and with a minimum increase in ash content.

1.2 OBJECTIVES

In this study, field experiments were conducted in 1990 and 1991 at the Emile A. Lods Agronomy Research Centre at the Macdonald Campus of McGill University, and at the COOP Fédérée Research Farm at Ste-Rosalie. The general objectives of the study were:

(i) to investigate the effect of N fertilizer level and timing of application on grain yield, yield components and lodging of four hard red spring wheat cultivars: Columbus, Katepwa, Hege 155-85 and Max, and to determine which yield component was most affected by N fertilizer additions.

(ii) to investigate the effect of N level and timing of application on grain protein concentration and content of the above mentioned cultivars.

(iii) to investigate the effect of N level and timing of application on aspects of wheat flour quality, specifically grain ash concentration, flour protein concentration, flour farinograph behaviour and bread loaf volume, of the afore mentioned cultivars.

(iv) to investigate the possible production of the cultivar Hege 155-85 for breadmaking in the south-western Québec.

(v) to investigate the impact of the experiment on the soil nitrate residues.

(vi) to investigate possible environment by cultivar or environment by N management interactions in south-western Québec.

Section 2
LITERATURE REVIEW

2.1 General

Wheat (*Triticum* spp.)is among the oldest crops. The process of its domestication began around 10,000 B.C., in the Middle East (Orth and Shellenberger 1988).

Currently wheat provides more nourishment to the people of the world than any other crop, and contributes to domestic animal feed (Stoskopf 1985a, Orth and Shellenberger 1988).

As the world's most widely cultivated crop it occupies over 33% (i.e. 226.5 million ha) of the area devoted to cereal production compared to almost 22 % (i.e. 145.4 million ha) for rice, which ranks second in importance and production (Statistical Handbook 1989).

In 1989, out of 22 million ha of cereals produced in Canada, 13.6 million ha were grown with wheat, compared to 4.7 million ha of barley (*Hordeum vulgare*) and 1 million ha of maize (*Zea maze*). This represented a production of 24.4 million T, or 51 % of the Canadian total cereal production (Production report 1989). Ten million T of this wheat production were exported (Statistical Handbook 1989). In 1990, 30 million T of wheat were produced. Twenty one percent of this production was used domestically, either as bread wheat or feed grain, while 65 % was exported (giving a return value of $1 7 billion), and 14 % was placed in stored stocks (Market Commentary 1990). Wheat is considered to be the main agricultural grain crop and agricultural commodity of Canada.

2.2 Uses of wheat and its classification.

Through the centuries and throughout the course of civilization, wheat has been intimately associated with human food uses, mainly bread and pasta. Besides being a major component of most world food diets, wheat serves as a source of starch and

gluten. Starch is used as a sweetener (after depolymerization) and as a raw material for adhesives. Gluten is used as a protein supplement for animal feed and to stabilize some processed foods. Both are used as additives to dough or batter to improve their quality (Bushuk 1986).

In relation to end use and grain hardness (protein level) wheat is classified as follows:

Wheat type	Protein content mg g^{-1}	End product
Durum	140 - 150	Pasta
Hard	135 - 150	High protein flour
Mixed	115 - 135	Pan bread
	100 - 125	Noodles, flat bread
Soft	85 - 95	Cakes and biscuits

(from Moss 1973)

Wheat is also classified according to bran colour, grain hardness and growth habit. Thus bread wheat, for instance, may fall into the hard red spring or hard red winter category (Stoskopf 1985b).

In Canada, wheat is graded as commercially clean or not, thus permitted for export or not, according to the presence of foreign material (other cereals, weeds or even minerals i.e soil particles) in the cleaned samples, and to their protein content. The Canada grain act established the following classes. Red spring, Amber durum (Canada Western), White winter (Canada Eastern), Red winter, Soft white spring, Mixed winter (Canada Eastern), Utility and feed wheat.

2.3 Wheat chemistry

The wheat kernel is a caryopsis and can be divided into 3 parts:

1) Endosperm which forms 83 % of the kernel and comprises the starchy central material and the aleurone layer (rich in alpha amylase).

2) Bran which forms 14 % of the kernel and envelops it.

3) Germ which forms 3 % and includes the scutellum and the embryo.

(Bushuk 1986)

Kernel composition depends on the composition and proportions of the latter structures.

Davis et al. (1981) evaluated 5 wheat market classes for 231 varieties over 49 locations and 3 crop years. On a dry weight basis, they found the protein content to range between 83 mg g^{-1} and 193 mg g^{-1} with an average of 138.5 mg g^{-1} and significant differences between years, classes and locations. The ash content varied between 11.7 mg g^{-1} and 29.6 mg g^{-1} with an overall average of 18 mg g^{-1}. Carbohydrate content was found to lie between 654 mg g^{-1} and 789 mg g^{-1}, with an overall mean of 724 mg g^{-1}. In a similar study, Davis et al. (1980) found the fat content to vary significantly by class and crop year and to range between 0.88 and 33.3 mg g^{-1} with an overall mean of 23.4 mg g^{-1}.

2.3.1 Carbohydrates:

The carbohydrates contained in the wheat kernel are mainly composed of starch which comprises 80 % of the endosperm carbohydrate. This starch is deposited in small (2-10 microns) spherical granules and larger (20-25 microns) lens shaped granules. When heated in excess water these granules are broken down and the starch gelatinizes. During flour milling the starch granules adsorb some water and become susceptible to alpha amylase activity. These properties are important in bread making and dough mixing (Bushuk 1986).

2.3.2 Proteins:

2.3.2.1 Structure:

Bushuk and Wrigley (1974) used a modified Osborne solubility fractionation of hard red spring wheat endosperm proteins. They obtained 5 different fractions differing in solubility:

Solvent	Fraction	Amount mg g^{-1}
Water	Albumin	15
0.5 N NaCl	Globulin	5
70% Ethanol	Gliadin	33
0.05 N Acetic Acid	Glutenin(s)	14
	Glutenin(n.s.) or residue	33

Albumins and globulins (also called soluble proteins) have nutritionally better amino-acid compositions and therefore have more nutritional value than other wheat proteins. This is largely due to their higher lysine (an essential amino acid) and lower glutamine contents (Lazstity 1984). Albumins were found to be richer in tryptophan than globulins which have a high content of arginine (Pence and Elder 1953). On the other hand, gluten (gliadins and glutenins) is deficient in lysine. Gliadins (i.e. wheat prolamins) as compared to glutenins have a low molecular weight and a large content of prolamine, glutamine, glutamic acid, cysteine, isoleucine and phenylalanine. Glutenins are made of many different molecules ranging from single polypeptide chains of fairly low molecular weight to molecules cross linked by disulfide bonds, due to cysteine at the amino end, resulting in very high molecular weight subunits (Bushuk 1985) Both glutenins and gliadins are rich in prolamine and glutamic acid. The primary structure of glutenin contains a hydrophobic side chain; a region like this facilitates hydrophobic association with other proteins or with non-protein molecules (Bushuk 1985). Glutenins and gliadins, because of their low content of lysine, histidine and arginine (i.e low ionic strength), and because of the disulfide and hydrophobic bonds, are able to form stable viscoelastic aggregates. These two properties make wheat gluten alone suitable for breadmaking. In fact, when water is added to flour, proteins rapidly become hydrated and aggregate first into fibres and then into continuous films or membranes (Bushuk 1985). The "network" formed will contain non-protein constituents such as specific carbohydrates and lipids.

2.3.2.2 Functionality in breadmaking:

It is well established that high quality bread (i.e. high loaf) volume is positively and directly correlated with the relatively high flour protein content (Finney et al. 1948). Further more, Finney (1943) found that regression analysis of loaf volume and protein content revealed a linear relationship between the limits of 70 or 80 mg g^{-1} to at least 200 mg g^{-1}. Working with 2 wheat genotypes of different qualities, Bushuk (1985) showed linearity in a narrower range of protein (from 85 to 160 mg g^{-1}). The narrower range was probably because of the use of more sensitive

methods. Besides quantity, protein quality also influences the functionality of flour in the bread making process. There was no correlation between the content of aloumins and globulins and increasing loaf volume (Bushuk 1984). However, the level of these proteins were positively correlated to kernel hardness. The literature is somewhat controversial with regard to gliadins and glutenins effects on dough and loaf volume. According to Bushuk (1984), gliadins play a role only in contributing fluidity to dough, while Macritchie (1987) and Hamada et al. (1982), argue that these proteins depressed loaf volume and dough strength respectively. On the contrary, Hoseney et al. (1969) [as reported by Chakraborty and Khan (1980)] found gliadin rich protein to control loaf volume. Macritchie (1987), Preston and Tipples (1980), Hamada et al. (1982), Ewart (1980), and Chakraborty and Khan (1988) reported that glutenins induced large increases in loaf volume. Macritchie (1987) added that this trend was reversed by the final residue protein. Loaf volume was positively correlated with total protein content but negatively correlated with the percentage of glutenin and residue protein (Marais and D'Appolonia 1980), whereas Khan et al (1989) in a study of 44 hard red spring wheat varieties found a positive correlation between both gliadin and glutenin fractions to loaf volume. Branlard and Dardevet (1985) even suggested that gliadins and glutenins subunits interact in producing the rheological characteristic of the dough.

2.4 Wheat agronomic traits

As with all plants, wheat is affected directly by environmental conditions (climate, soil type, nutrient availability, water, light, temperature, pH, etc.) and biotic factors or through the interaction of both kinds of factors. Among all these factors N is the major concern of our work.

2.4.1 Nitrogen versus yield

In a study of the relative contribution of management and plant breeding inputs to wheat yield increases since 1954, Feyerherm et al. (1988) found that N fertilizer applications accounted for about 22 % of the observed increases in the yield of wheat grown in the American great plains and corn belt.

Terman et al (1969) reported the findings of a study of N fertility on winter wheat in drylands. Nitrogen was applied at rates between 0 and 90 kg ha^{-1}. These researchers found that N fertilization increased yield when applied with adequate water. In a pot experiment Terman (1979) studied protein/yield relationships in soft and hard red winter wheats and observed that all cultivars increased similarly in grain and straw yield, as the amount of applied N increased.

Similar results were reported by Dubetz (1977) in a study on the cultivar Neepawa, where yield was maximized with about 100 Kg N ha^{-1}, applied on low fertility soils. It seems that N fertility may increase wheat yield with no limits, but we should not be mislead by this. Frederick and Marshall (1985), investigating the influence of management factors on components of soft red winter wheat yield in northeastern U.S A. found that topdressing N may decrease wheat yield when soil N reserves are high. Soft red winter cultivars produced the maximum yields at 94 Kg N ha^{-1} applied as a top dressing (Bruckner and Morey 1988). Similarly, Roth et al. (1984) observed that soft red winter wheat grain yield decreased with fertilizer applications above a level as low as 34 Kg N ha^{-1}. In Nebraska the maximum yields of the cultivar during the period 1968 to 1970 were observed to occur at about 45 Kg N ha^{-1} (Johnson et al. 1973).

The apparent contradictions among these reports may be explained by the quadratic relationship between yield and N fertility (Mason 1979). In Manitoba, increments of urea N increased the grain and straw yields of all 6 spring wheat cultivar tested, but excessive N fertilizer significantly reduced the grain yield (Gehl et al. 1990). In such cases, reductions in grain yield may be due to lodging, increased disease frequency or to physiological reactions by the plant itself (Sinclair and DeWit 1975).

2.4.2 Nitrogen versus proteins:

Grain yield is not the only parameter influenced by N fertility, grain protein concentration and content have been reported to vary as well.

Grain protein increased by 51.3 kg ha^{-1} with an increment of 67.3 Kg N ha^{-1} over the check in testing 5 red spring wheat cultivars (McNeal et al. 1971). Johnson

et al. (1973) found that both hard winter wheat varieties used showed highly consistent and predictable increases in the protein content of the grain. Hunter and Stanford (1973) found that the protein concentration increased from 109 mg g-1 with no N applied to 143 mg g^{-1} when N was applied in an experiment where 2 soft winter wheat cultivars were studied. Dubetz (1977) found that the concentration of total and grain N in the cultivar Neepawa increased with each 50 kg ha^{-1} increment of N up to a 150 kg ha^{-1} application. Brucknet and Morey (1988), working with red winter wheat, examined the effect of N fertility levels ranging from 0 to 134 kg ha^{-1} on the yield and quality of soft red winter wheat. Biomass production increased with N fertilizer application up to 106 kg N ha^{-1} while seed yield increased up to 94 kg N ha^{-1}. But, fertilizer application above 67 kg N ha^{-1} produced protein levels too high for good quality soft flour. Similarly, Jacobsen and Westerman (1988) found that the protein concentration of winter wheat seeds increased from 121 to 154 mg g^{-1} as the applied N fertilizer rate increased from 0 to 250 kg ha^{-1}. The protein concentration and total protein yield will continue to increase at N fertility levels above which there is little or no yield increase. Fowler et al. (1989), examining wheat and rye, found N fertilizer to have a significant influence on protein concentration in 78 % of winter wheats, they also found that grain protein concentration exhibited sigmoidal responses to N fertilizer.

2.4.3 Timing of nitrogen application:

Several studies have demonstrated the importance of time of N application to optimize wheat yield. For winter wheat it is generally accepted that all the N should not be added at seeding. The percent uptake of the fertilizer by winter wheat is markedly related to the N fertilizer split application schedule (Riga et al 1980).

Long and Sherbakoff (1951) showed that, for winter wheat, a split application where one half of the N was applied in the fall and one half as a spring topdressing resulted in the highest yield. They also reported that Bayfield (1936) showed a small increase in yield when he delayed N dressing until heading. Doll (1962) showed that the application of all N to winter wheat at the time of seeding, in the fall, resulted in a low level of response to the added N due to leaching losses, which were in turn

related to winter precipitation levels. Consistent with these findings were the results obtained by Hunter and Stanford (1973). Cox et al. (1989) examined the effect of 67 kg N ha^{-1} applied at Zadoks' growth stage (ZGS) 25 (Zadoks et al. 1974) with or without a second application of the same amount at ZGS 31, on winter wheat in New York state. The second application increased the yield from 5.6 to 6.3 kg ha^{-1}. Baethgen and Alley (1989) found an increase of about 2 T ha^{-1} in winter wheat grown in Virginia as N application at ZGS 25 increased from 1 to 125 kg ha^{-1} and a response up to 2 T ha^{-1} from a second application at ZGS 30 if 56 kg ha^{-1} or less were added at ZGS 25. Welch et al. (1966) observed, during a 3 years study in Illinois, that the relative efficiency of fall applied N averaged 67 % of spring applied N.

Finney et al. (1957) sprayed urea on the leaves of wheat plants during the period from flowering to ripening. This treatment increased wheat protein from 93 to 161 mg g^{-1}. Spiertz and Ellen (1978) increased grain yield from 6.4 to 8.2 t ha^{-1} when they applied 100 kg N ha^{-1} as first application and 50 kg N ha^{-1} as a second application on the winter wheat cultivar Levy.

Darwinkle (1983) found that when N was supplied at the beginning of tillering, tiller formation and spikelet initiation were promoted. When N was applied at the onset of stem elongation head number increased Nitrogen applied from stem elongation until head emergence from the flag leaf affected the number of grains per head, and kernel weight was affected when N was applied at head emergence. When postponed to ZGS 39, N increased spikelet fertility and grain yield. Maximum grain yield was attained when N was applied at ZGS 30. Applying N at ZGS 47 was too late to achieve a high grain number, although it clearly favoured grain filling.

Gravelle et al (1988) applied 80 and 120 lb N $acre^{-1}$ at ZGS 23 to 27 or at ZGS 23 to 27, 45, or 58. They observed a 3 to 12 % increase in yield but no significant difference between 2 or 3 splits.

Lutcher and Mahler (1988) suggested that the time of spring N application be before ZGS 31 as this improved N use efficiency, although Spiertz and Ellen (1978) reported a yield increase from N application as late as ZGS 47.

In addition to matching N availability with crop demand, split application also reduced lodging (Gravelle et al. 1988) so that it can reduce potential yield losses at harvesting.

Splitting N application did more than increase wheat yields. In some instances, it also affected grain protein content (Miezan et al. 1977). Split application increased grain protein concentration (Fowler and Brydon 1989, Hucklesby et al. 1971) when applied at anthesis (Altman et al. 1983, Miezan et al. 1977), especially when plants were subjected to a water stress conditions (-8 bars) at this stage (Dubetz 1977). The grain protein content of the cultivar Neepawa was increased by 51 to 76 % through the application of high rates of N to soil or as urea on leaves at anthesis (Dubetz 1977). Similar results were observed by Altman et al. (1983) where foliar urea application around flowering increased grain protein by 10 to 16 %.

Hucklesby et al. (1971) found that although protein quantity was affected by N split dressing,protein quality was not.

2.4.4 Nitrogen fertility versus environmental factors:

Clearly, N fertility is not the only management or environmental factor which can limit wheat yields. Numerous studies have shown interactions between N fertility and other biotic or abiotic factors.

Eck (1988), working with winter wheat in Texas found no response to any level of N fertilizer application without the addition of irrigation water.

Fowler et al. (1989) found that, under dry land conditions near Saskatoon, yield was not affected by N application unless sufficient soil moisture was available, but that kernel protein increased from 93 to 231 mg g^{-1} as the level of applied N fertilizer increased from 0 to 303 kg ha^{-1}.

On the other hand high moisture stress applied between the first appearance of the flag leaf and anthesis increased the response of grain protein to high N fertility (Campbell et al 1981, Dubetz 1977). Irrigation to provide available water in the root zone up to the time of maturity maintained acceptably low protein content of soft winter wheat (Bole and Dubetz 1986).

Water level is not the only environmental factor to interact with N fertility. Sulphur has been found, when added to N fertilizer to increase yield by 40 to 110 %, and to the affect amino acid composition of the grain protein. Without the added S, grain contained less than half the amount of cystine, cysteine and methionine as a percentage of the total amount of amino acids present (Byers and Bolton 1979).

Numerous studies have shown an interaction between the effect of N fertilizer on yield and/or grain protein concentration and wheat genotype (Darwinkle 1983, Gehl et al. 1990, Bruckner and Morey 1988, Miezan et al. 1977).

2.4.5 Yield versus protein concentration

Although exceptions have been observed (McNeal et al. 1971, 1972, Spiertz and Allen 1978), the general trend is a negative correlation between grain protein concentration and grain protein yield (Stewart and Dwyer 1990, Terman et al. 1969, Terman 1979, McNeal et al. 1966, Dubetz 1972, Dubetz and Bole 1973, Fowler and Brydon 1989, Fowler et al. 1989, Campbell and Davidson 1979). Kibite and Evans (1984) rationalized this by suggesting that there is a limited amount of protein diluted by a by a larger mass of carbohydrates which may take the form of a limited amount of protein deposited in a larger number of kernels.

2.4.6 Nitrogen fertility and bread making.

It has been shown that plant available soil N has a direct influence on grain protein yield. Long and Sherbakoff (1951) reported that the quality of wheat flour was influenced by N fertility applied to the wheat, particularly when applied at a late development stage of the plant.

Finney et al. (1948), in a review of wheat quality indicated that higher protein levels lead to higher quality hard wheat. McNeal et al. (1971) observed an increase in bread loaf volume corresponding to increase protein concentration due to N fertility. Tipples et al. (1977) reported that very high protein concentrations (> 170 mg g^{-1}) can be associated, in several instances, with a marked weakening of physical dough characteristics and a deterioration in baking quality. Bushuk et al. (1978) showed that for Neepawa wheat samples at the top of protein range, N fertility decreased loaf volume. They tried to explain their observations by the probable

change in glutenin protein solubility, a gradual decrease in the amount of starch damaged during the milling process and the increased ratio of soluble over insoluble glutenins.

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Preface to section 3

Section 3 is the material contained in a manuscript which will be submitted for publication. The current format conforms with guidelines set by the Faculty of Graduate Studies. Tables, figures and literature cited are presented at the end of this section.

In this section we discuss the effects of N fertilizer levels and time of application, and wheat cultivars on the grain yield and yield components, and the relative contribution of various yield components to yield.

Section 3

EVALUATION OF N FERTILITY LEVEL AND TIMING OF APPLICATION ON HARD RED SPRING BREAD WHEAT YIELD AND YIELD COMPONENTS IN EASTERN CANADA

3.1 ABSTRACT

In order to assess the potential manipulation of N management to allow bread quality wheat production in eastern Canada, an experiment was conducted for two years at each of two sites in Québec to study the effect of level and timing of nitrogen (N) fertilizer application on grain yield, yield components and lodging level of four hard red spring wheat cultivars known to have potential as bread wheat. The soil types were Bearbrook clay and Ste-Rosalie clay. The experiment was 4x4x2 factorial. The cultivars were: Columbus, Katepwa, Max and Hege 155-85. In both years 0, 60, 120 and 180 kg N ha^{-1} were applied either 100 % at seeding time or 60 % at seeding and 40 % at anthesis. Grain yield, plant height, lodging, tillers m^{-2}, spikes m^{-2} and grains $spike^{-1}$ were increased with increasing N fertility, and maturity was delayed. Split application of N fertilizer decreased yield in one site-year, reduced the risk of lodging, caused a reduction in the number of tillers m^{-2} and spikes m^{-2} and caused an increase in grain weight and test weight. Grain yield increases were largely due to increases in the number of grains $spike^{-1}$ and tillers m^{-2}. The cultivar Hege 155-85 gave the highest grain yield and was the most resistant to lodging. It had a plastic response to N fertilizer addition. Differences in N management effects and cultivar responses were observed among the four site-years. These results indicate that N management can reduce the risk of lodging and give an acceptable grain yield. However, under these experimental conditions the most important management decision is the choice of cultivar.

3.2 INTRODUCTION:

3.2.1 Nitrogen versus yield

Increasing levels of N fertilizer improve grain yield (Nielsen and Halvorson 1991, Nuttall and Malhi 1991, Bittman et al. 1990, Strong 1982). In a study of the relative contribution of management and plant breeding inputs to wheat yield increases since 1954, Feyerherm et al. (1988) found that N fertilizer applications accounted for about 22% of the observed increases in the yield of wheat grown in the American great plains and corn belt. Wheat yield was maximized when N fertilizer was applied to low fertility soils (Dubetz 1977). Soil nitrate status was correlated with grain yield (Binford et al. 1992). However, when soil N reserves are high, wheat yield response to N fertilizer may be small (Penny et al. 1983) or even negative (Frederick and Marshall 1985) Numerous studies have shown interactions between N fertility levels and other environmental factors. Water availability determines the crop yield response to applied N fertilizer: a positive yield response to N fertilizer will only occur with adequate moisture supply (Terman et al. 1969, Fowler et al. 1989). Nielsen and Halvorson (1991) found that water stress limited wheat yield response to N fertility while N fertility in combination with an adequate environment increased wheat yield. There are limits, however, and wheat yields have been reported to attain a maximum at some level of N fertilizer which varies with climate and cultivar (Bruckner and Morey 1988, Johnson et al. 1973), above which yields decrease (Gehl et al. 1990, Roth et al. 1984, Benzian and Lane 1981). There is usually a quadratic relationship between yield and N fertility (Mason 1987). The reductions in grain yield at very high levels of N fertility may be due to lodging, increased disease frequency or to physiological reactions by the plant itself (Sinclair and DeWit 1975, Blade and Baker 1991).

3.2.2 Timing of nitrogen application

Several studies have demonstrated that time of N application is important for optimizing wheat yields. For winter wheat, it is generally accepted that all the N should not be added at seeding because of leaching losses related to winter precipitation (Doll 1962, Welch et al. 1966, Hunter and Stanford 1973). The

proportional uptake of N fertilizer by winter wheat is strongly affected by the fertilizer split application schedule (Riga et al. 1980). Cox et al. (1989), Baethgen and Alley (1989), Gravelle et al. (1988) and Spiertz and Ellen (1978) examined the effects of N fertilizer applied in split regimes at different stages of crop development. They all observed increases in yield due to split applications but no significant difference between 2 or 3 splits. Late N application affected tillering as long as the operation was not delayed beyond the end of the tillering stage (Mascagni and Sabbe 1991). Other yield components (grains spike^{-1}, spikelet fertility, grain size, harvest index) were also positively affected by late N treatments (Zebarth et al. 1992, Strong 1986, Darwinkle 1983). However, Powlson et al. (1987) found that urea applied at ZGS 37 or 69 did not alter yield or thousand kernel weight and Johnston and Fowler (1991) found that delaying spring broadcast of N by three weeks prevented early N uptake, thus reducing grain yield. In addition to matching N availability with crop demand, split application also reduced lodging (Gravelle et al 1988) so that it can reduce potential yield losses at harvesting.

Most of the wheat in Canada is grown on the prairies. Because it may offer higher economic returns than feed wheat, or any of the feed grains, bread wheat has the potential to be a more important crop in eastern Canada than is currently the case In addition, increasing N fertility increases grain yield. With the exception of a single paper, limited to a single cultivar at one location (Caldwell and Starratt 1987), there is no published data on the yield potential of bread wheats, and the influence of N fertility on bread wheat yield and yield components in eastern Canada To assess the potential manipulation of N management to allow bread wheat production in Eastern Canada, an experiment was conducted for two years at each of two sites to determine the effect of level and timing of N fertilizer application on grain yield, yield components and lodging level of four hard red spring wheat cultivars known to be potentially suitable for bread making.

3.3 MATERIALS AND METHODS:

The study was conducted on Bearbrook clay soil (fine, mixed, non-acid, frigid, typic Humaquept), at the Lods Agronomy Research Center, McGill University, Macdonald Campus, and on Ste-Rosalie clay soil (fine, non-acid, frigid, typic Humaquept) at the COOP Fédérée research farm, Ste-Rosalie, Québec, Canada in 1990 and 1991. For 1990, the previous crop was oat (Avena sativa L.) at the Macdonald Campus site and mixed forages at Ste-Rosalie. In 1991, the previous crop at both locations was hard red spring wheat (Triticum aestivum L.). Prior to seeding at both sites, the land received adequate amendment of P and K. In 1991, the experiment was repeated in the same fields. The experimental design was a 4 X 4 X 2 factorial, arranged in randomized complete block design with 4 replicates. The bread wheat cultivars sown were Columbus, which is normally acceptable as a bread wheat under the western Canada Red Spring grades (Agriculture Canada, 1980); Max, which has an acceptable performance in Eastern Canada, and was recommended for milling and bread making (Agriculture Canada, 1987); Katepwa, which has good milling and baking properties (Campbell and Czarnecki 1987); and Hege 155-85 which is currently being tested for possible licensing as a bread wheat in Eastern Canada.

The cultivars received 0, 60, 120 or 180 kg N ha^{-1} in the form of granular ammonium nitrate, either all at seeding, or 60 % at seeding and 40 % at anthesis. The fertilizer was broadcast by hand on the plot surface and incorporated by hand raking. After trimming, each plot at Macdonald was 180 cm x 456 cm with 12 rows spaced 15 cm apart in both years. After trimming, plot size at Ste-Rosalie in 1990 was 90 cm x 500 cm, and in 1991 90 cm x 525 cm with 6 rows spaced 15 cm apart. Plots were trimmed just prior to harvest to eliminate edge effects due to the pathways. The plots were sown at 450 seed m^{-2} with a cone-type plot seeder (Wintersteiger America Inc., Lincoln, Nebraska) using certified seeds treated with Vitaflo 280 (15% carbathiin (5-6-dihydro-2-methyl-N-phenyl-1, 4-oxathiin-3-carboxamide) and thiram (13 % tetramethyl-thiuramdisulfide)). Seeding was done on the first and eleventh of May at Macdonald, and on the tenth and twenty first of May at Ste-Rosalie in 1990

and 1991 respectively. Weeds at Macdonald were controlled with Pardner (bromoxynil: 3, 5-dibromo-4-hydroxybenzonitrile) applied at 1 L ha^{-1} at the two-leaf stage. Weeds at Ste-Rosalie were controlled with a mixture of 280 g a.i. ha^{-1} of bromoxynil and 280 g a.i. ha^{-1} of MCPA (2-methyl-4-chlorophenoxyaceticacid) also applied at the two-leaf stage.

Stand counts were made shortly after seedling emergence in a pre-marked 1-m long section of the third row and are expressed as plants m^{-2}. Plant heights (HGT) and Belgium lodging scores (LDG) (Oplinger and Wiersma, 1984) were determined at ZGS 83; lodging scores were taken again a few days prior to harvest. The lodging index for each plot was calculated from the average of the two readings. At crop maturity, the plants in the pre-marked 1 meter long sample-rows were hand harvested by uprooting, and air-dried indoors for approximately 15 days. For each sample, the number of fertile tillers (TN m^{-2}) and main stems (MN) were determined. The total number of spikes was determined and was likewise converted to spikes (SN) m^{-2}. In this case a spike refers to a culm with at least one fully-formed seed. Dried plants were weighed to determine the total above ground biomass, and then threshed to determine grain weight. Harvest Index (HI) was expressed as the ratio of grain dry matter to total above-ground dry matter The total number of grains in the meter samples was counted with an electronic seed counter (Automation Devices, Fairview, PA) and number of grains $spike^{-1}$ (GSPK) was calculated as follows: total number of grain/total number of spikes. The trimmed plots were combine harvested for yield (YLD) determination. Plot yields are expressed on a t ha^{-1} basis at 14 % moisture. Subsamples were taken for 1000-kernel weight and test weight determination. Twenty g of grain were counted using an electronic seed counter, weighed and 1000-kernel weight (TKW) calculated. Seeds from each sample were allowed to fall from a cone into a 100 ml plastic cup, the seeds were weighed and the test weight (HLW) recorded. Heading (HDG) dates were recorded as the number of days from seeding to 50 percent heads completely emerged from the leaf sheath. Maturity (MAT) dates were recorded as the number of days from seeding to 50 percent heads mature (hard dough stage).

Data were analyzed using SAS (SAS Institute, 1985). The F-test (Steel and Torrie, 1980) was used to determine whether the variations caused by the treatments and their interactions were significant. Probabilities of less than or equal to 0.05 were considered significant for main effects and interactions. The F-test was also used to test for homogeneity of the experimental error variances among site-years (Steel and Torrie, 1980). No combined analysis of variance across years or locations were performed because the experimental error variances were not homogenous. Stand count was used as a covariable to adjust for effects of uneven seeding on yield components. The least square means of treatments are presented when the covariable was significant. A protected Duncan's new multiple range test was performed to compare means of variables found to vary significantly by the F-test. In 1991, the fourth replicate at Ste-Rosalie showed wide variability due to the presence of weeds in some plots, therefore only means of 3 replicates were considered in this analysis. The general linear model procedure of SAS was used to determine regression parameters.

3.4 RESULTS:

3.4.1 Yield:

Average site-year grain yields ranged from a minmum of 2.4 t ha^{-1} (Ste-Rosalie, 1990) to a maximum of 5.3 t ha^{-1} (Macdonald, 1991). The effect of N fertilizer was significant in all 4 site-years. Significant responses to split N applications occurred in 1991 but not in 1990 (Tables 3.1 and 3.2). Nitrogen fertilizer application caused mean yield increases ranging over all site-years, from 27 % to 81 %, while split application caused a 5.5 % reduction in yield at all N levels at Ste-Rosalie and a 9.1 % reduction at the Macdonald site at the 120 kg N ha^{-1} level (Tables 3.3 and 3.4). There were also significant yield differences between cultivars except at the 1990 Ste-Rosalie site (Tables 3.1 and 3.2). Generally, the cultivar Hege 155-85 had the highest yields (average over site-years 4.22 t ha^{-1}) and Columbus the lowest yields (average over site-years 3.7 t ha^{-1}). Regression parameters from

quadratic equations were calculated. Regression lines (Figure 3.1) show that 120 kg N ha^{-1} was optimal for grain yield.

3.4.2 Yield components:

3.4.2.1 Main stems m^{-2} (MN): The production of mature main stems was positively influenced by increasing N fertility at the Macdonald site, but not at the Ste-Rosalie site. The increase at Macdonald was probably because N fertility improved the survival of main stems (Tables 3.1 and 3.2). A difference in MN among cultivars was often observed (Tables 3.1 and 3.2). In general, Columbus and Katepwa had the highest MN compared to Hege 155-85 and Max. In general, MN were not significantly influenced by N fertilizer split applications, although MN was significantly affected by the three way interaction (Table 3.2).

3.4.2.2 Tillers m^{-2} (TN): The formation of tillers was significantly increased by increasing N fertilizer level (Tables 3.1 and 3.2). At Ste-Rosalie, TN were increased by 60 % in 1990 and were from 50 % to 112 % greater than the control value in 1991 (Tables 3.3 and 3.5). In 1990 at Macdonald, TN doubled when 120 or 180 kg N ha^{-1} were added compared to the control or to plots which received only 60 kg N ha^{-1}. Tillers m^{-2} at Ste-Rosalie were never influenced by the N fertilizer schedule, while at Macdonald in 1990, this treatment caused a reduction in TN of Columbus and Hege 155-85 (Table 3.6). In general, Katepwa had the highest tiller density while Max had the least. There was a significant three way interaction at Macdonald in 1991. However the data show no particular trend in this interaction despite of small yet significant effect on the cultivar Katepwa when addition of 120 or 180 kg N ha^{-1} was split (Table 3.7).

3.4.2.3 Spikes m^{-2} (SN): N fertilizer addition significantly increased SN at all site-years (Tables 3.1 and 3.2). Spikes m^{-2} were increased by 9 % in 1990 and from 17 to 33 % in Ste-Rosalie in 1991, while at the Macdonald site, SN increased by an average of 20 % in both years (Tables 3.3, 3.5, 3.8 and 3.9). Splitting the N application affected SN only at Macdonald in 1990, where it caused a 4 % reduction (Table 3.8). Varietal differences in SN were observed in all four site years. Spikes

m^{-2} of Katepwa were significantly higher than SN of the other three cultivars, among which there were slight or no differences (Tables 3.3, 3.5, 3.8 and 3.9).

3.4.2.4 Grains spike^{-1} (GSPK): In three out of four site-years, increasing level of N fertilizer significantly increased GSPK, although sometimes there was little or no difference when the rate was increased from 120 to 180 kg N ha^{-1} (Tables 3.5, 3.8 and 3.9). The increases ranged from 13 to 33 %. There was no N timing effect on GSPK, but GSPK varied among cultivars. The cultivars Hege 155-85 and Max produced significantly higher GSPK than the cultivars Columbus and Katepwa.

3.4.2.5 Thousand kernel weight (TKW) and test weight (HLW): In general, TKW and HLW were significantly affected by N fertilizer level in 50 % of the site-years (Tables 3.1 and 3.2). In 1991 at Macdonald, N fertilizer addition caused a 7 % increase in TKW, but with no difference among the 60, 120 or 180 kg N ha^{-1} (Table 3.9). Thousand kernel weight was negatively correlated to YLD in 1990 at the Macdonald site, while it was positively correlated to YLD in the other site-years (Table 3.11). In 1990, at the Macdonald site, a split application of N fertilizer increased the test weight by 0.7 kg hl^{-1}, however, this effect was not present in 1991. A split N addition also favoured bigger kernels in 1990 at Ste-Rosalie and in 1991 at Macdonald: TKW was increased by 0.7 g and 0.5 g respectively. In general, the test weights of the cultivar Columbus were the highest and those of Hege 155-85 were the lowest (Tables 3.3, 3.5, 3.8 and 3.9). In 1991 at Macdonald, the test weights of the cultivars Katepwa, Max and Hege 155-85 were slightly influenced by N fertilizer addition and that of the cultivar Columbus was not influenced by the N treatment. A significant cultivar by N level interaction was observed for TKW in 1990 at Ste-Rosalie. The TKW of the cultivar Katepwa was increased by fertilizer addition, but there was no difference among treatments to which N was added. The TKW of the cultivar Columbus increased steadily with increasing N fertility. The TKW of the cultivar Max was slightly increased by fertilizer addition and that of the cultivar Hege 155-85 was actually reduced by 9.5 % by N fertilizer addition (Table 3.10). In general, the TKW of Columbus was the highest and TKW of Max the lowest.

3.4.2.6 Heading dates and maturity In a general manner, N fertilizer application at seeding caused a delay in heading and maturity. The cultivar Katepwa was the earliest maturing, and Hege 155-85 the latest maturing (Tables 3.3, 3.5, 3.8 and 3.9). A significant N level by timing of application interaction on heading dates at Ste-Rosalie in 1990 showed that a single N application caused a one day delay in only at the 120 kg N ha^{-1} level (Table 3.4).

3.4.2.7 Harvest Index (HI): At all site-years HI was unchanged by N application treatments and ranged from 0.35 to 0.41. Harvest index was significantly different among cultivars only in 1991 at Ste-Rosalie when ranked from highest to lowest in the order: Katepwa, Max, Columbus then Hege 155-85.

3.4.3 Height and lodging:

In all instances, increasing N levels up to 120 kg N ha^{-1} increased plant height, i.e. vegetative growth was enhanced (Nielsen and Halvorson 1991). In all four sites years, the cultivar Columbus was from 9 to 20 cm taller than the other cultivars, and the cultivar Max was the shortest by 6 to 22 cm. In 1990, split N application reduced the height of the plants by 2 cm while this treatment had no significant effect in 1991. The presence of high residual nitrate levels in the root zone (an average of 20 kg N ha^{-1} at Ste-Rosalie and of 31 kg N ha^{-1} at Macdonald) at the beginning of the 1991 growing season may be the reason for the non-significance of split N applications.

Two and three-way interaction influenced Belgian lodging scores in 1990 and 1991 respectively (Tables 3.1 and 3.2). In 1990, increasing N fertilizer rates did not cause the cultivars Hege 155-85 or Max to lodge, Hege 155-85 is a relatively short cultivar, while Max has a relatively thick stem At Macdonald increasing N rates increased the lodging risk of cultivars Katepwa and Columbus commencing at 60 and 120 kg of N ha^{-1}, respectively. A similar cultivar response occurred at Ste-Rosalie commencing at 120 kg N ha^{-1} for both cultivars (Table 3.10) In 1991, at the Ste-Rosalie site, a split application of 60 and 120 kg N ha^{-1} but not of 180 kg N ha^{-1} strongly reduced lodging by Katepwa. The schedule or the rate of N fertilizer application did not significantly influence the other three cultivars At the Macdonald site, increasing N fertilizer increased lodging for all cultivars, but there was a

significant reduction in lodging when the fertilizer was applied in a split application, with the exception of the cultivar Katepwa at 180 kg N ha^{-1}. In general, the cultivar Katepwa was always most prone to lodging, followed by Columbus, Max, and Hege 155-85 in this order.

3.5 DISCUSSION:

In this study, N fertilizer application at seeding influenced grain yield positively with little or no significant difference between 120 and 180 kg N ha^{-1}. Since relatively high grain yields were reached, one can consider the N fertilizer added to have been non-limiting, and the rate of 120 kg N ha^{-1} optimal (Nuttal and Malhi 1991). Nitrogen addition above the optimum does not increase yield, and as noted by Benzian and Lane (1981), may cause a decline in yield. Nitrogen fertilizer enhances dry matter accumulation by all plant parts (Boatwright and Haas 1961) hence the vegetative growth of the wheat plant is enhanced and also the grain yield since final grain yield is known to be positively correlated to the total phytomass at anthesis (Entz and Fowler 1990). In this study, N addition did not influence HI suggesting that fertilizer addition enhanced vegetative growth and grain yield in equal proportions. Grain yield is determined by its components, thus grain yield response to the treatments may be attributed to the responses of its components. Grain yield was best correlated with the number of grains m^{-2} (data not shown) and the GSPK was less correlated with TKW (Table 3.11). This suggests that the observed improvements in grain yield were largely due to an increase in the GSPK as observed by Major et al (1992), rather than grain weight, especially at the Macdonald site. For example, in 1991 at the Macdonald site, the relatively higher TKW of the cultivar Columbus did not compensate for its relatively lower GSPK. Compared to the Macdonald site, higher average TKW at Ste-Rosalie did not compensate for the lower average number of GSPK, grain yield at Ste-Rosalie was numerically lower than that at Macdonald. The larger kernels produced when N addition was split did not result in an increase in grain yield. Split N applications occasionally reduced grain yield. This treatment may not provide adequate available N to the plant, causing a reduction in vegetative growth (Strong 1986, Christenson and Killorn 1981) thus reducing grain

yield potential (Fowler et al. 1989, 1990). This reduction in vegetative growth and hence plant height, produced a beneficial reduction in the risk of lodging. Gravelle et al. (1988) observed that the susceptibility of a crop to lodging increased as the number of tillers increased, so that the reduction in lodging when N application was split may also be due to a decrease in TN in such a treatment. Tillers were found to be enhanced by N application (Birch and Long, 1990) early in the season (Zebarth and Sheard 1992). The TN, and to a lesser extent TKW, are also important components of grain yield since a positive correlations exist between these two variables and grain yield.

The variations in yield and its components observed between sites are probably due to the differences in the soil texture, the water level and the soil nutrient level (Dubetz 1977). In addition denitrification may have occurred in the poorly drained soils at the Ste-Rosalie site, potentially, resulting in less N availability during the growing season (Mascagni et. al, 1991). The average over both years of residual nitrate level in the root zone was by 11 kg ha^{-1} lower at the Ste-Rosalie site than at Macdonald (data not shown).

Varietal differences can occur as has been reported in the literature (Major et al. 1992, Pushman and Bingham 1976). In this experiment, the cultivars Columbus and Katepwa were the least responsive to N addition in terms of yield and its components. These cultivars are very well adapted to the low input management of the Canadian prairies. In general, the cultivar Hege 155-85 had a plastic response to N addition with regard to its yield components while those of the cultivar Max were not influenced by increasing increments of N fertilizer, although in a study by Caldwell and Starratt (1987) this cultivar responded well to management inputs in the maritimes. Hege 155-85 was a high yielding cultivar with high biomass production One can conclude that this cultivar has good overall growth and may use the available resources better than the other three cultivars tested

3.6 CONCLUSIONS:

The grain yield of the four bread wheat cultivars tested was increased by N fertilizer addition at seeding mainly due to increases in GSPK although TN and TKW often made a contribution to yield as well. The cultivar Hege 155-85 had the best yields and was most resistant to lodging at high N levels in all four site-years. The cultivar Max also seldom lodged, but its response to N inputs varied widely among site years. The cultivars Columbus and Katepwa yielded less than the other two and Katepwa was very prone to lodging. It can be concluded that the new cultivar Hege 155-85 may provide the best yields for bread wheat production under the conditions prevailing in Eastern Canada. There was a clear difference in the responses of the cultivars at each site. This is demonstrated by the two and three way interactions that occurred and suggests that environmental differences between locations and years may play an important role in the effectiveness of bread wheat production in Eastern Canada. Splitting the N application may hinder grain production in one region but not in the other, thus it is probably not the best way to reduce lodging. A careful choice of the cultivar would be a better method. The different cultivars responded differently to the N inputs. Although different in specific details, the N addition effects were similar at the different sites, hence the amount of the N addition should be chosen according to the cultivar, the extractable nitrate available in the soil, the type of soil and the microclimate.

This is the first report to demonstrate the variability in yield and yield components of bread wheat cultivars and the effect of location, N fertility and application schedule on these variables under Eastern Canadian conditions.

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Table 3.1 Analysis of variance of yield and its components in 1990

	YLD	HGT	LDG	MN	TN	SN	GSPK	HDG	MAT	TKW	HLW	HI
Macdonald												
N	**	**	**	**	**	**	**	**				
T		*	*		*	*					**	
C	**	**	**	**	**	**	**	**			**	
N*T			**									**
N*C			**									
T*C					*							
N*T*C												
C.V.	6	6	6	14	54	15	29	2	1	6	1	12
Ste-Rosalie												
N	*	**	**		**	**	*		**	**	*	
T		**	**							*	*	
C		**	**		*	**	*	**	**	**	**	
N*T								*				
N*C			**							**	**	
T*C			*									
N*T*C												
C.V.	14	14	60	19	47	17	34	1	1	4	2	10

* significant at the 0.05 level, ** significant at the 0.01 level, YLD=grain yield (t ha), HGT=height (cm), LDG=Belgian lodging scores, MN=main stems m^{-2}, TN=tillers m^{-2}, SN=Spikes m^{-2}, GSPK=grains $spike^{-1}$, HDG=heading (days), MAT= maturity (days), TKW=thousand kernel weight (g), HLW=test weight (kg hl^{-1}), HI=harvest index. N=N level kg ha^{-1}, T=timing, C=cultivar.

Table 3.2 Analysis of variance of yield and its components in 1991

	YLD	HGT	LDG	MN	TN	SN	GSPK	HDG	MAT	TKW	HLW	HI
Macdonald												
N	**	*	**	*	**	**	**	*	**	**	**	
T								*		**		
C	**	**	**	**	**	**	**	**	**	**	**	
N*T	**				*							
N*C			*								**	
T*C												
N*T*C			*		**							
C.V.	8	5	54	19	48	15	13	0.6	2	3	1	7
Ste-Rosalie												
N	**	**	**		**	**			**			
T	**								*			
C	**	**	**	**	**	**	**	**	**	**	*	**
N*T												
N*C			**									
T*C			*									
N*T*C			**	**								
C.V	8	4	54	15	39	17	17	9	2	5	4	5

* significant at the 0.05 level, ** significant at the 0.01 level, YLD=grain yield (t ha^{-1}), HGT=height (cm), LDG=Belgian lodging scores, MN=main stems m^{-2}, TN=tillers m-2, SN=Spikes m-2, GSPK=grains $spike^{-1}$, HDG=heading (days), MAT= maturity (days), TKW=thousand kernel weight (g), HLW=test weight (kg hl^{-1}), HI=harvest index. N=N level, T=timing, C=cultivar.

Table 3.3 Main effects of N level, timing and cultivars at Ste-Rosalie in 1991

	YLD	HGT	LDG	MN	TN	SN	GSPK	HDG	MAT	TKW	HLW	HI
Ste-Rosalie												
N level (kg ha^{-1})												
0	2.6 b	78 b	0.5 c	357	130 d	449 c	18	48	87.4 b	30	70	0.36
60	2.9 a	81 a	1.3 b	364	195 c	527 b	20	48	88.9 a	30	71	0.37
120	3.0 a	80 a	1.6 a	348	236 b	574 a	20	47	88.0 a	30	70	0.36
180	3.1 a	82 a	1.7 a	328	275 a	598 a	21	48	88.8 a	29	69	0.36
difference	*	*	*	n.s.	*	*	n.s.	n.s.	*	n.s.	n.s.	n.s.
Cultivars												
Columbus	2.8 a	84 a	0.5 b	378 a	225 b	548 b	16	48 a	88 b	30.3 a	72 a	0.35 c
Hege155-85	3.3 a	84 a	0.5 b	317 b	168 c	501 bc	22	48 a	91 a	29.5 b	67 c	0.34 d
Katepwa	3.1 ab	80 b	3.6 a	370 a	317 a	639 a	17	44 b	87 b	28.8 c	69 b	0.38 a
Max	2.9 c	73 c	0.4 b	330 b	127 d	459 c	22	49 a	87 b	29.2 b	72 a	0.37 b
difference	*	*	*	*	*	*	n.s.	*	*	*	*	*
Timing												
single	3.1 a	81	1.4	354	216	542	19	47	89 a	29	70	0.36
Split	2.9 b	80	1.1	344	202	531	20	48	88 b	29	70	0.36
difference	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	*	*	n.s.	n.s.

n.s. not significant, * significant at the 0.05 level, YLD=grain yield (t ha^{-1}), HGT=height (cm), LDG=Belgian lodging scores, MN=main stems m^{-2}, TN=tillers m^{-2}, SN=Spikes m^{-2}, GSPK=grains spike^{-1}, HDG=heading (days), MAT=maturity (days), TKW=thousand kernel weight (g), HLW=test weight (kg hl^{-1}), HI=harvest index. Values followed by the same letter are not significantly different from each other by an ANOVA-protected Duncan's new multiple range test.

Table 3.4 Effects of N level and timing on agronomic traits

		Macdonald 1990	Ste-Rosalie 1991	Ste-Rosalie 1990
N level kg ha^{-1}	Timing	LDG	YLD	HDG days
0	Single	0.6 c	3.5 d	54 b
	Split	0.7 c	3.7 d	55 a
60	Single	2.1 c	5.4 c	55 ab
	Split	2.4 c	5.4 c	55 ab
120	Single	8.2 a	6.2 a	55 a
	Split	4.4 b	5.6 b	54 ab
180	Single	8.2 a	6.3 a	55 a
	Split	8.0 a	6.3 a	55 a
difference		*	*	*

* significant at the 0.05 level
Values followed by the same letter are not significantly different from each other by an ANOVA-protected Duncan's new multiple range test.
LDG= Belgian lodging score, YLD= grain yield (Tha^{-1}), HDG= heading (days).

Table 3.5 Main effects of N level, timing and cultivar on agronomic traits at Ste-Rosalie in 1990

	YLD	HGT	LDG	MN	TN	SN	GSPK	HDG	MAT	TKW	HLW	HI
N level(kg ha^{-1})												
0	1.6 c	54 c	0.2 c	458	125 b	578 b	15 b	55.0	101 c	31.5 b	73.4 c	0.39
60	2.4 b	71 b	0.2 c	449	148 b	596 b	20 a	55.0	101 bc	33.7 a	74.6 a	0.38
120	2.8 a	78 a	0.4 b	483	196 a	681 a	17 ab	55.0	102 a	33.5 a	74.4 bc	0.37
180	2.9 a	78 a	0.7 a	439	198 a	630 ab	19 ab	55.0	102 a	33.1 a	73.7 bc	0.38
difference	*	*	*	n.s.	*	*	*	n.s.	*	*	*	n.s.
Cultivars												
Columbus	2.4	79 a	0.5 a	468	158 b	618 b	17 ab	56 b	101 b	34.5 a	75.9 a	0.37
Hege155-85	2.5	66 b	0.2 b	443	160 ab	605 b	19 a	54 c	103 a	32.6 b	71.6 c	0.37
Katepwa	2.3	77 a	0.6 a	488	202 a	689 a	16 b	54 c	100 c	34.0 a	74.5 b	0.38
Max	2.5	59 c	0.2 b	431	145 b	573 b	19 a	57 a	102 b	30.6 c	74.1 b	0.39
difference	n.s.	*	*	n.s.	*	*	*	*	*	*	*	n.s.
Timing												
Single	2.4	71 a	0.4 a	454	170	628	18	55	102	32.6 b	73.6 b	0.37
Split	2.5	69 b	0.3 b	461	155	614	18	55	101	33.3 a	74.4 a	0.38
difference	n.s.	*	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	*	*	n.s.

n.s. not significant, * significant at the 0.05 level, YLD=grain yield (t ha^{-1}), HGT=height (cm), LDG=Belgian lodging scores, MN=main stems m^{-2}, TN=tillers m^{-2}, SN=Spikes m^{-2}, GSPK=grains spike^{-1}, HDG=heading (days), MAT=maturity (days), TKW=thousand kernel weight (g), HLW=test weight (kg hl^{-1}), HI=harvest index. Values followed by the same letter are not significantly different from each other by an ANOVA-protected Duncan's new multiple range test.

Table 3.6 Effect of cultivars and timing of N fertilizer application on Belgian lodging scores and tillers m^{-2} in 1990.

		Ste-Rosalie	Macdonald
Cultivar	Timing	Lodging	Tillers m^{-2}
Columbus	Single	0.7a	176 a
	Split	0.4b	102 bc
Hege 155-85	Single	0.2c	113 bc
	Split	0.2c	62 d
Katepwa	Single	0.7a	141 ab
	Split	0.5b	175 a
Max	Single	0.2c	87 cd
	Split	0.2c	70 cd
Difference		*	*

* significant at the 0.05 level
Values followed by the same letter are not significantly different from each other by an ANOVA-protected Duncan's new multiple range test.

Table 3.7 Effect of N level, timing and cultivar in 1991

N level kg ha^{-1}	Timing	Cultivar	---Macdonald---- LDG	TN m^{-2}	---Ste-Rosalie--- LDG	MN m^{-2}
0	Single	Columbus	0.2 e	56 c-f	0.4 c	511 a
		Hege 155-85	0.2 e	25 c-f	0.4 c	307 d-f
		Katepwa	0.2 e	43 c-f	0.7 c	336 c-f
		Max	0.2 e	38 d-f	0.4 c	327 d-f
	Split	Columbus	0.2 e	27 ef	0.4 c	376 c-e
		Hege 155-85	0.2 e	12 f	0.4 c	324 d-f
		Katepwa	0.2 e	29 d-f	0.8 c	358 c-f
		Max	0.2 e	11 f	0.4 c	315 d-f
60	Single	Columbus	0.2 e	47 c-f	0.4 c	349 c-f
		Hege 155-85	0.2 e	39 d-f	0.4 c	362 c-f
		Katepwa	0.2 e	92 bc	4.5 b	365 c-f
		Max	0.8 abc	50 c-f	0.4 c	378 b-e
	Split	Columbus	0.2 e	88 b-d	0.4 c	384 b-c
		Hege 155-85	0.2 e	39 d-f	1.2 c	320 d-f
		Katepwa	0.4 de	78 b-d	1.5 c	445 ab
		Max	0.4 de	35 d-f	0.4 c	307 d-f
120	Single	Columbus	0.2 e	125 b	0.6 c	349 c-f
		Hege 155-85	0.2 e	45 c-f	0.4 c	300 ef
		Katepwa	0.7 a-d	181 a	5.7 a	413 bc
		Max	0.9 ab	63 c-e	0.4 c	373 c-e
	Split	Columbus	0.6 b-e	87 b-d	0.4 c	349 c-f
		Hege 155-85	0.2 e	62 c-f	0.4 c	345 c-f
		Katepwa	0.4 de	123 b	4.5 b	351 c-f
		Max	0.8 abc	52 c-f	0.4 c	318 d-f
180	Single	Columbus	0.7 bcd	89 b-d	0.6 c	333 c-f
		Hege 155-85	0.4 de	58 c-f	0.4 c	295 f
		Katepwa	0.5 cde	80 b-d	5.4 ab	353 c-f
		Max	1.0 a	57 c-f	0.4 c	318 d-f
	Split	Columbus	0.2 e	84 b-d	0.8 c	387 b-d
		Hege 155-85	0.4 de	49 c-f	0.4 c	287 f
		Katepwa	0.5 cde	181 a	5.5 ab	340 c-f
		Max	0.7 bcd	55 c-f	0.4 c	309 d-f
difference			*	*	*	*

* significant at the 0.05 level
Values followed by the same letter are not significantly different from each other by an ANOVA-protected Duncan's new multiple range test.

Table 3.8 Main effects of N level, timing and cultivar on agronomic traits at Macdonald in 1990

	YLD	HGT	LDG	MN	TN	SN	GSPK	HDG	MAT	TKW	HLW	HI
N level(kg ha^{-1})												
0	4.0 c	78 c	0.6 d	433 b	62 b	499 c	20 b	56.6 b	98.9	36.1	77.4	0.40
60	5.0 b	89 b	2.2 c	448 ab	92 b	538 c	25 a	56.8 b	98.9	37.0	78.0	0.39
120	5.2 a	93 a	6.3 b	481 a	148 a	598 b	24 a	56.8 b	99.0	36.4	77.6	0.38
180	5.3 a	93 a	8.1 a	478 a	161 a	601 a	23 ab	57.3 a	99.3	36.3	77.6	0.37
difference	*	*	*	*	*	*	*	*	n.s.	n.s.	n.s.	n.s.
Cultivars												
Columbus	4.5 b	98 a	6.0 b	492 a	139 a	585 a	19 b	56.0 c	98.9	36.6	79.1 a	0.35
Hege155-85	5.4 a	85 c	0.6 c	432 c	87 b	538 b	28 a	60.0 a	99.3	36.4	74.7 c	0.39
Katepwa	4.3 b	93 b	10.1 a	468 ab	158 a	607 a	15 c	53.0 d	99.0	36.4	78.2 b	0.37
Max	5.3 a	77 d	0.6 c	447 bc	79 b	506 b	29 a	59.0 b	98.9	36.3	78.5 b	0.43
difference	*	*	*	*	*	*	*	*	n.s.	n.s.	*	n.s.
Timing												
Single	4.9	65	4.8	452	129 a	575 a	23	57.0	99.1	36.7	77.3 b	0.38
Split	4.9	63	3.9	467	109 b	542 b	23	57.0	99.0	36.1	78.0 a	0.39
difference	n.s.	n.s.	n.s.	n.s.	*	*	n.s.	n.s.	n.s.	n.s.	*	n.s.

n.s. not significant, * significant at the 0.05 level, YLD=grain yield (t ha^{-1}), HGT=height (cm), LDG=Belgian lodging scores, MN=main stems m^{-2}, TN=tillers m^{-2}, SN=Spikes m^{-2}, GSPK=grains spike^{-1}, HDG=heading (days), MAT=maturity (days), TKW=thousand kernel weight (g), HLW=test weight (kg hl^{-1}), HI=harvest index. Values followed by the same letter are not significantly different from each other by an ANOVA-protected Duncan's new multiple range test.

Table 3.9 Main effects of N level, timing and cultivars at Macdonald in 1991

	YLD	HGT	LDG	MN	TN	SN	GSPK	HDG	MAT	TKW	HLW	HI
Macdonald												
N level (kg ha^{-1})												
0	3.6 d	65 c	0.2 c	356 b	30 c	384 b	14 c	48.5 a	75 b	31 b	78 b	0.39
60	5.4 c	75 b	0.3 b	398 a	58 b	437 a	21 b	48.4 ab	76 b	33 a	79 a	0.40
120	5.9 b	77 a	0.5 a	375 ab	92 a	463 a	21 b	48.2 c	76 b	33 a	79 a	0.41
180	6.3 a	78 a	0.5 a	403 a	81 a	459 a	23 a	48.3 bc	77 a	34 a	79 a	0.41
difference	*	*	*	*	*	*	*	*	*	*	*	n.s.
Cultivars												
Columbus	5.1 d	78 a	0.3 bc	379 ab	74 b	449 a	18 b	48.1 b	76 b	34 a	81 a	0.40
Hegel55-85	5.7 a	75 b	0.2 c	390 a	41 c	430 ab	22 a	50.0 a	77 a	33 b	77 d	0.40
Katepwa	5.1 d	73 c	0.4 b	416 a	101 a	466 a	19 b	47.0 c	74 c	31 d	79 c	0.41
Max	5.3 bc	69 d	0.6 a	349 b	45 c	400 b	21 a	48.2 b	77 a	33 c	80 b	0.42
difference	*	*	*	*	*	*	*	*	*	*	*	n.s.
Timing												
Single	5.4	74	0.4	391	68	443	20	48.4 a	76	32.5 b	79	0.40
Split	5.4	73	0.4	376	63	420	20	48.3 b	76	33.0 a	79	0.41
difference	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	*	n.s.	*	n.s.	n.s.

n.s. not significant, * significant at the 0.05 level, YLD=grain yield (t ha^{-1}), HGT=height (cm), LDG=Belgian lodging scores, MN=main stems m^{-2}, TN=tillers m^{-2}, SN=Spikes m^{-2}, GSPK=grains spike^{-1}, HDG=heading (days), MAT=maturity (days), TKW=thousand kernel weight (g), HLW=test weight (kg hl^{-1}), HI=harvest index. Values followed by the same letter are not significantly different from each other by an ANOVA-protected Duncan's new multiple range test.

Table 3.10 Effect of N level and cultivar on agronomic traits

N level	Cultivar	Macdonald 1990 LDG	Macdonald 1991 HLW (kg hl^{-1})	Ste-Rosalie 1990 LDG	Ste-Rosalie 1990 TKW (g)
0	Columbus	0.6 d	79.6 c-f	0.2 d	32.2 def
	Hege 155-85	0.6 d	76.8 h	0.2 d	33.6 cd
	Katepwa	0.8 d	77.8 gh	0.2 d	31.7 efg
	Max	0.6 d	79.2 ef	0.2 d	28.3 h
60	Columbus	0.6 d	80.7 abc	0.3 d	35.0 abc
	Hege 155-85	0.6 d	77.4 h	0.2 d	34.0 bc
	Katepwa	8.1 c	78.6 fg	0.2 d	34.5 abc
	Max	0.6 d	80.7 abc	0.2 d	31.4 efg
120	Columbus	9.6 c	80.9 ab	0.7 c	35.7 a
	Hege 155-85	0.6 d	77.0 h	0.2 d	32.5 de
	Katepwa	12.8 b	79.1 ef	0.5 cd	34.9 abc
	Max	0.6 d	80.4 a-d	0.2 d	30.9 fg
180	Columbus	13.2 b	81.1 a	1.0 b	35.2 ab
	Hege 155-85	0.6 d	75.7 i	0.2 d	30.4 g
	Katepwa	17.9 a	79.9 b-e	1.5 a	35.0 abc
	Max	0.6 d	79.4 def	0.2 d	31.7 efg
difference		*	*	*	*

* significant at the 0.05 level, values followed by the same letter are not significantly different from each other by an ANOVA-protected Duncan's new multiple range test. LDG= Belgian lodging score, YLD= grain yield (t ha^{-1}), HLW= test weight (kg hl^{-1}).

Table 3.11 Pearson's correlation coefficients.

		Ste-Rosalie		Macdonald	
		1990	1991	1990	1991
SN	TN	0.67 ***	0.88 ***	0.70 **	0.60 **
	YLD	0.20 *	0.40 ***	-0.04	0.40 ***
	TKW	0.17 *	-0.014	-0.08	0.20 *
	GSPK	-0.48 ***	-0.56 ***	-0.39 ***	0.01
GSPK	TN	-0.03	-0.40 **	-0.33 ***	0.09
	YLD	0.20	0.30 **	0.60 ***	0.75 ***
	TKW	-0.02	0.09	-0.24 **	0.40 ***
YLD	TKW	0.20 *	0.30 **	-0.03 ***	0.62 ***
	TN	0.23 *	0.40 ***	-0.06	0.31 ***

SN=spike m^{-2}, TN=tiller m^{-2}, TKW=1000 kernel weight (g), YLD= grain yield (t ha^{-1}), GSPK=grain $spike^{-1}$.
*, **, *** significant at the 0.05, 0.01 and 0.0001 levels respectively.

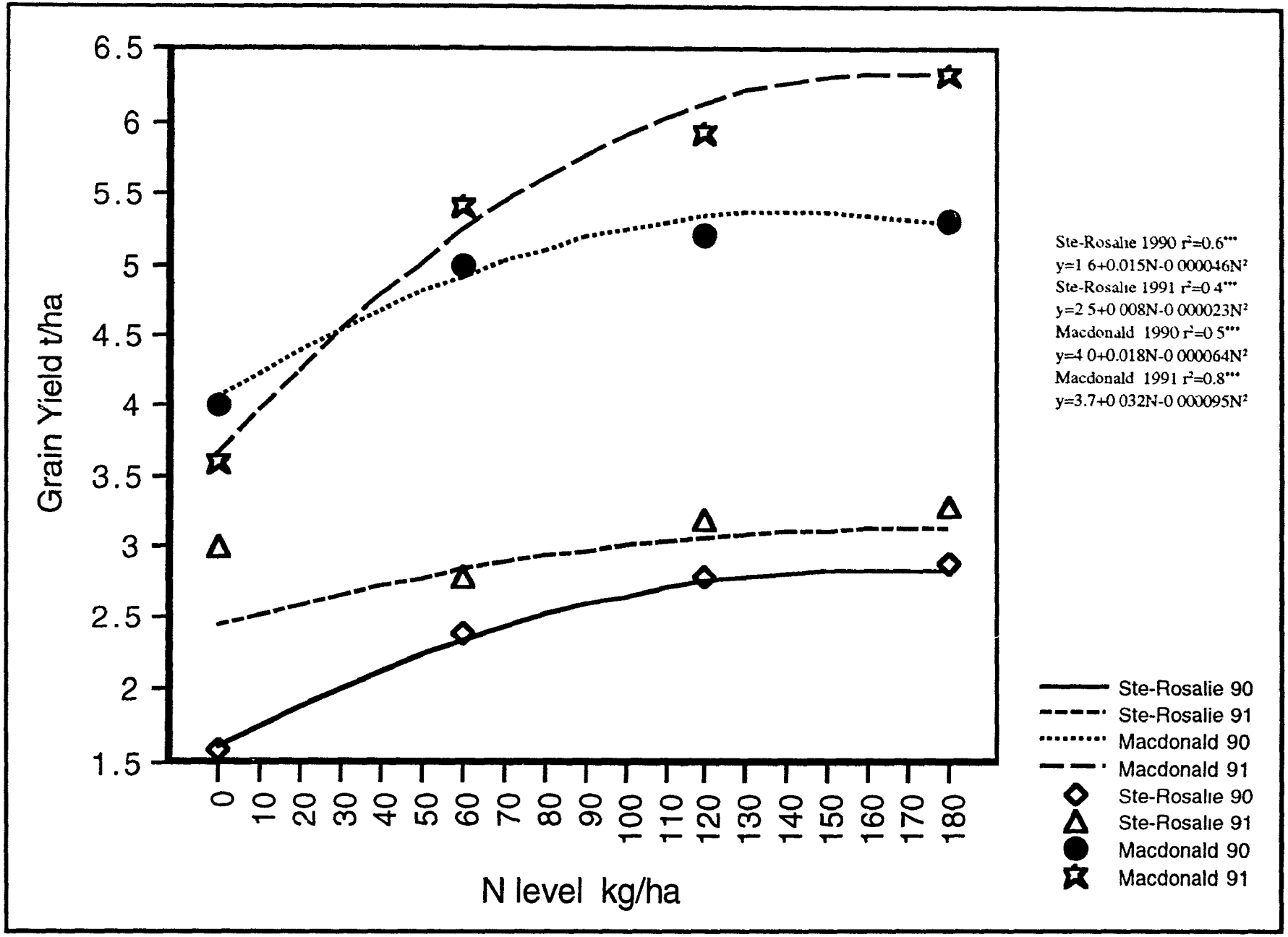
Grain Yield t/ha
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
N level kg/ha
Ste-Rosalie 1990 r²=0.6***
y=1 6+0.015N-0 000046N²
Ste-Rosalie 1991 r²=0 4***
y=2 5+0 008N-0 000023N²
Macdonald 1990 r²=0 5***
y=4 0+0.018N-0 000064N²
Macdonald 1991 r²=0.8***
y=3.7+0 032N-0 000095N²
Ste-Rosalie 90
Ste-Rosalie 91
Macdonald 90
Macdonald 91
Ste-Rosalie 90
Ste-Rosalie 91
Macdonald 90
Macdonald 91

Figure 3.1 Grain yield estimates and observations at the four site-years.

Preface to section 4

Section 4 is the material contained in a manuscript which will be submitted for publication. The current format conforms with guidelines set by the Faculty of Graduate Studies. Tables, figures and literature cited are presented at the end of this section.

In this section we discuss the effects of N fertilizer levels, time of application and cultivars on the grain protein concentration and content and grain protein yield, and the importance of grain protein content.

Section 4

EVALUATION OF THE EFFECT OF N FERTILIZER LEVEL AND TIMING OF APPLICATION ON GRAIN PROTEIN CONCENTRATION OF FOUR HARD RED BREAD SPRING WHEAT CULTIVARS IN EASTERN CANADA.

4.1 ABSTRACT

In order to assess the potential manipulation of N management to allow bread quality wheat production in Eastern Canada, an experiment was conducted for two years at each of two sites in Québec to study the effect of level and timing of nitrogen (N) fertilizer application on grain protein concentration and grain protein yield of four hard red spring wheat cultivars known to have potential as bread wheat. The soil types were Bearbrook clay and Ste-Rosalie clay. The experiment was 4x4x2 factorial The cultivars were: Columbus, Katepwa, Max and Hege 155-85. In both years 0, 60, 120 and 180 kg N ha^{-1} were applied either 100 % at seeding time or 60 % at seeding and 40 % at anthesis. Grain protein concentration (GPC mg g^{-1}) and grain protein yield (GPY t ha^{-1}) increased consistently with increasing N fertilizer and with split N application. Nitrogen use efficiency (NUE) nor nitrogen harvest index (NHI) were improved by increasing applications of N fertilizer while NUE was improved by split N application especially at low N levels. Under such conditions, where N is not limiting, protein content per seed is more critical in determining GPC than non-protein seed dry matter. In general, the cultivars Columbus and Katepwa had the highest GPC.

4.2 INTRODUCTION

Currently wheat provides more nourishment (mainly as bread) to the people of the world than any other food source (Stoskopf 1985, Orth and Shellenberger 1988). It is well established that high quality bread, i.e high loaf volume, is positively correlated with the relatively high protein content of the grain and flour (Gooding et al. 1991, Bushuk 1985, Finney and Barmore 1948). The functionality of flour in the bread making process is also influenced by protein quality (Chakraborty and Khan

1988, Marais and D'Appolonia 1980). Grain protein concentration (GPC) and content are influenced by N fertility (Zebarth and Sheard 1992, Campbell et al. 1991, Clare et al. 1990) Smith et al (1990) and Clare et. al (1990), found that the protein concentration of wheat seeds increased as the applied N fertilizer rate increased from 0 to 250 kg ha^{-1} Nitrogen fertilizer addition also affects protein quality (Gupta et al. 1992 and Randall et al. 1990), thus affecting baking characteristics. During grain filling, N is either translocated from the vegetative tissues of the plant or taken up from the soil (Cox et. al 1986). Thus, the time of N application is an important factor in optimizing wheat GPC (Johnston and Fowler 1991, Powlson et al. 1987, Miezan et al. 1977) N fertilizer application at anthesis (Altman et al. 1983, Miezan et al. 1977), especially when plants at this stage were subjected to a water stress conditions (eg -8 bars) (Dubetz 1977) and or to high temperatures (Campbell and Davidson 1979) caused an increase in GPC. Split N dressings also reduce N volatilisation from the plant (Papakosta and Gagiana 1991) and early leaching losses from the root zone According to Baethgen and Alley (1989) daily N uptake of winter wheat was maximal at or shortly after anthesis and N use efficiency was improved by split N dressings as long as they occurred before anthesis (Lutcher and Mahler 1988). However, Penny et al. (1986), reported that N taken up by the grain is always larger with single than with divided N dressings and Strong (1982), observed that split N application increased the quantity of N accumulated in the straw more than in the grain. Numerous studies have shown an interaction between the effect of N fertilizer on GPC and wheat genotype (Darwinkle 1983, Bruckner and Morey 1988, Gehl et al. 1990), or environment (Dubetz 1977 and Miezan et al. 1977). Evidence suggests that differences in GPC's between wheat cultivars is not only attributable to environmental conditions (McNeal et al 1968) but also to genetically inherited characteristics (Johnson et al 1973) Most of the work in this area has been conducted on winter wheat and in the U S A, Western Canada, Australia or across Europe. Little information exists regarding the response of bread type hard red spring wheats to N fertilizer in Eastern Canada, a region with a short growing season and relatively high seasonal precipitation. This study was conducted to test the effect of N fertilizer

application rate and schedule on the GPC of four hard red spring wheat cultivars recommended for bread baking, grown at each of two sites in Eastern Canada.

4.3 MATERIALS AND METHODS:

The study was conducted on Bearbrook clay soil (fine, mixed, non-acid, frigid, typic Humaquept), at the Lods Agronomy Research Centre, McGill University, Macdonald Campus, and on Ste-Rosalie clay soil (fine, non-acid, frigid, typic Humaquept) at the COOP Fédérée research farm, Ste-Rosalie, Québec, Canada during the 1990 and 1991 crop seasons. For 1990, the previous crop was oat (Avena sativa L.) at the Macdonald Campus and mixed forages at Ste-Rosalie. For 1991, the previous crop at both locations was hard red spring wheat (Triticum aestivum L.). Prior to seeding the land at both sites received adequate amendment of P and K. In 1991, the experiment was repeated in the same fields as in 1990. The experimental design was a 4 X 4 X 2 factorial, arranged in a randomized complete block design with 4 replicates. The bread wheat cultivars sown were: Columbus which is normally acceptable under the Canada Red Spring grades (Agriculture Canada, 1980), Max which has an acceptable performance in Eastern Canada and was recommended for milling and bread making, (Agriculture Canada, 1987), Katepwa which has good milling and baking properties, (Campbell and Czarnecki 1987) and Hege 155-85 which is still being tested for possible production as a bread wheat in Eastern Canada The cultivars received 0, 60, 120 or 180 kg N ha^{-1} in the form of solid ammonium nitrate, either all at seeding, or 60 % at seeding and 40 % at anthesis. The fertilizer was broadcast by hand on the plot surface and incorporated by hand raking. After trimming, each plot at Macdonald was 180 cm x 456 cm with 12 rows spaced 15 cm apart. After trimming, plot size at Ste-Rosalie in 1990 was 90 cm x 500 cm, and in 1991 90 cm x 525 cm, with 6 rows spaced 15 cm apart. Trimming was done just prior to harvest to eliminate edge effects due to the pathways. The plots were sown at 450 seeds m^{-2} using certified seed treated with Vitaflo 280 (15 % carbathiin (5,6-dihydro-2-methyl-n-phenyl-1,4-oxathiin-3-carboxamide)and 13 % thiram(tetramethyl thiuram disulfide)), and using a cone-type plot seeder (Wintersteiger America Inc.,

Lincoln, Nebraska). Seeding was conducted on the first and eleventh of May at Macdonald, and on the tenth and twentyfirst of May at Ste-Rosalie in 1990 and 1991 respectively. Weeds at Macdonald were controlled with Pardner (bromoxynil: 3, 5-dibromo-4-hydroxybenzonitrile) applied at 1 L ha^{-1} at the two leaf stage. Weeds at Ste-Rosalie were controlled with a mixture of 280 g a. i. ha^{-1} of bromoxynil and 280 g a. i. ha^{-1} of MCPA (2-methyl-4-chlorophenoxyaceticacid) also applied at the two leaf stage. At crop maturity, plants in a pre-marked 1 meter rows were hand harvested by uprooting, and air-dried indoors for approximately 15 days. Yield component data such as spike number, tiller number were taken from those samples prior to threshing. Grain was milled on a Udy cyclone mill (Udy Corp, Fort Collins, CO.) and straw was milled on a Wiley mill in both cases through a 1mm mesh. In 1990, the whole meal samples were subsequently used for GPC (mg g^{-1}) determination by near infrared reflectance (NIR) (Inframatic 8600, Percon Prufgerate GmbH, Germany). Representative samples were selected by the instrument software and were used to determine the GPC on a moisture free basis, by the Kjeldahl method (N x 5.7) using a Tecator Kjeltec System I (Tecator AB, Hoganas, Sweden). The analytical data sets obtained were used to calibrate the NIR data solving the following equation by multiple regression analysis: $GPC = C_0+(C_1xL_1+\ldots+C_{20}xL_{20})xC_{21}$ where C_0 was the bias factor (or intercept) specific to the parameter under investigation, C_1-C_{20} were filter constants for the particular wavelengths, L_1-L_{20} were the log of the reflection values for different wavelengths, and C_{21} was the slope of the regression curve. Grain protein percentage in 1991 as well as all straw protein concentration were determined by the Kjeldahl method (N x 5.7). Grain protein concentration figures were always corrected to 14 % moisture basis. Calculated variables were derived with the following formulas:

Nitrogen Harvest Index (NHI) = GPC/(above ground dry matter protein concentration);

Nitrogen use efficiency (NUE) = (grain N from treatment - grain N from control)/(total soil N in treatment - soil N in control);

Grain Protein Yield (GPY, t ha^{-1}) = grain yield x GPC;

Seed protein content (PPSD, mg) = weight of thousand kernels x GPC;

Non-protein seed dry matter (NPM, mg) = seed weight - seed protein content.

The materials and methods of section 6 contains a full description of soil sampling, handling and chemical analysis.

Data were analyzed with the SAS system (SAS Institute, 1985). The F-test (Steel and Torrie, 1980) was used to determine whether the variations caused by the treatments and their interactions were significant. Probabilities of less than or equal to 0.05 were considered significant for main effects and interactions. In 1990, for the Ste-Rosalie site, only three out of four replicates were analyzed for main effects of the treatments on NHI because of missing values. The F-test was also used to test for homogeneity of the experimental error variances among site-years (Steel and Torrie, 1980). No combined analysis of variance across the years or locations was performed because the experimental error variances were found to be non-homogenous. An ANOVA protected Duncan's new multiple range test was performed to compare means of variables found to vary significantly by the F-test. The GLM procedure (SAS Institute, 1985) was used to find regression equations of GPY and GPC over N levels. Pearson's correlation coefficient was calculated between NHI and grain yield (Y), GPC, GPY, PPSD, NPM, HI and residual nitrate levels in the soil in 1991.

Weather data:

The 20-years mean values for precipitation during the cereal growing season (May-August) indicate that the Ste-Rosalie site is usually a wetter environment than the Macdonald Campus site. The 20-years mean values of mean temperature are similar at the two sites. At the Macdonald site, the 1990 season was characterized by higher than normal monthly precipitations (from 188 % to 140 % of normal), fairly well distributed over the season (frequency), while at the Ste Rosalie site, the months of May and July were dry (79 % and 87 % of normal respectively) and the month of June was wet with 190 % precipitation of normal. At both sites, the 1991 season was characterized by fewer rainy days, especially during the months of June and July although rain accumulation on certain days surpassed 40 mm (Figures 4.1 and 4.2). Rain at the Ste-Rosalie site accumulated during the months of May, June and July was

94, 68 and 61 % of normal. At the Macdonald site, the rain accumulation during the month of May was 36 % higher than normal but the month of June was dry (72 % of normal) and the month of July received 7 % more rain than normal. During both seasons at the two sites mean monthly temperatures did not vary widely from normal but the daily maximum temperatures in 1991 were often above 30°C.

4.4 RESULTS AND DISCUSSION:

4.4.1 Grain protein concentration:

In 1990, GPC (mg g^{-1}) increased with increasing levels of N fertilizer (Tables 4.1 and 4.2). There was a significant N level by time of application interaction. As reported by Wuest and Cassman (1992a), the GPC increase was higher with N fertilizer applied at anthesis. The GPC increase was 13 % to 31 % higher than the control when the N fertilizer addition was split and only from 0 % to 22 % higher than the control when the N fertilizer was added all at seeding (Table 4.2).

The GPC increase between the two schedules of fertilizer addition was different at the different fertilizer levels (Table 4.3). At the Ste-Rosalie site the highest increase due to a split application occured when the fertilizer rate was 60 or 120 kg ha^{-1} (9.8 and 10.3 % respectively) while at the Macdonald site this occured when 60 kg N ha^{-1} was applied. At the latter site, when 120 or 180 kg N ha^{-1} were split the increase in GPC over a single application was by only 2.5 %. For split N applications, GPC was always equal to or greater than that of single applications at seeding (Table 4.3). No significant interaction was observed in 1991 between N level and N application schedule. In 1991, GPC increased from 6 % to 23.5 % over the control when N fertilizer was added and was increased by splitting the N addition at the Macdonald site but not at the Ste-Rosalie site In 1991, at Ste-Rosalie the NUE was low (0.21) and there was no difference in NUE between the two application schedules. The land at the Ste-Rosalie site was not very well drained so that denitrification may have occured, or high soil nitrate levels may have meant that N fertilizer application at seeding time resulted in maximal GPC. The second fertilizer application took place on the ninth of July and was followed by hot dry days

intersparsed with rainy days. Low mobility of the N in clay soil may have limited the uptake of the second application.

The GPC values observed in 1991 were generally higher than in the previous year. The months of June and July were hotter and drier than in the first year. These conditions coinciding with the grain filling period may have hindered carbohydrate production or deposition in the kernel thus resulting in higher GPC (Campbell et al. 1981). In three out of four site-years, there was a cultivar by N application interaction for GPC. The GPC of the cultivar Columbus ranged from 142 mg g^{-1} in the control plots to a high of 186 mg g^{-1} when 180 kg N ha^{-1} were added. Similarly, the GPC of the cultivar Katepwa ranged from 135 to 181 mg g^{-1}. When it received 180 kg N ha^{-1}, the GPC of the cultivar Max was not significantly different from the GPC of the cultivars Katepwa and Columbus when they received only 120 kg N ha^{-1}. The GPC of the cultivar Hege 155-85 was the lowest in all four site-years. It was increased, sometimes up to 26 % of its control value, by increasing N fertilizer levels but was never higher than the GPC of the other three cultivars at lower N fertilizer levels (Table 4.4). The GPC of the cultivars Columbus, Katepwa and Max were above the 125 mg g^{-1} required by the Canadian grain commission for bread wheat grading. The GPC of cultivar Hege 155-85 was more variable. At the Ste-Rosalie site in the year 1990, the cultivar Hege 155-85 needed the addition of at least 60 kg N ha^{-1} to have a GPC equal to or higher than 125 mg g^{-1}.

Fowler et al. (1989) reported that GPC shows a sigmoidal response to N fertilizer. A minimum protein concentration is maintained for the first increments of the added N fertilizer, then when grain yield becomes limited by environmental or genotypic factors, N is used mainly for grain protein production, the concentration of which increases to an asymptotic value. The regression equations calculated at each of the four site-years show, when this treatment was significant, that adding the N fertilizer in split fashion had a positive effect on GPC. At the Ste-Rosalie site in 1990, each of the four cultivars reached its asymptotic maximum when the N fertilizer was split (Figure 4.3), while when the N was applied only at seeding, the maximum GPC of each of the cultivars was lower than in the previous case (Figure

4.4). Splitting the N application at the Macdonald site in 1990 caused the highest relative increase of the GPC levels when 60 kg N ha^{-1} were added (Figure 4.5). At such a low level of N, when the fertilizer application is split, the plant is N depleted at the beginning of the season and N added later is used more efficiently. A significant cultivar by N level interaction existed for three of the four site-years (Table 4.5). Figures 4.4, 4.6 and 4.7 show that even at high levels of N fertility, the GPC of the cultivars Hege 155-85 and Max were lower than the GPC of the cultivars Columbus an Katepwa at lower levels of N fertility. Figures 4.4 and 4.6 also show significantly long lag phases in the N response curve of the cultivars Hege 155-85 and Max indicating that these cultivars were not very sensitive to low level N applications and that N fertilizer above the level of 180 kg N ha^{-1} may have increased their GPC to even higher concentrations Caldwell and Starratt (1987) found that GPC of the cultivar Max did not respond to N fertilizer levels below 100 kg ha^{-1}.

When the N fertilizer is added at seeding time, it increases grain yield (Fowler et al. 1990) but when environmental factors become limiting for subsequent increases in grain yield, N is mainly utilized for seed protein production, and thus increased GPC is observed (Fowler et al. 1990) But with late N addition (eg. at anthesis), the N taken up by the roots or retranslocated (Spiertz and Ellen, 1978) is mainly utilized for grain protein production. If the N added is in excess of that required to maximize grain yield (Christensen and Killorn, 1981) GPC is increased.

4.4.2 Grain protein yield:

Grain protein yield (GPY, t ha^{-1}) like grain yield and GPC, increased significantly with increasing levels of N fertilizer (Table 4.2). The range of GPY increase was from 15 % up to 63 % depending on the site-year. Splitting the N application increased GPY significantly but only by 3 %. Significant N fertilizer level by N fertilizer timing interactions existed at two of four site years (Table 4.2). When the N application was split, GPY increased by 56 to 250 %, while the range of GPY increase was only by 40 to 100 % when the fertilizer was applied only at seeding. Although grain yield was unaffected by split N application, GPY response to such a treatment was large and followed the same trend as GPC. Wuest and

Cassman (1992b) reported that N acquired during grain filling is efficiently partitioned to the grain with the result that GPC increased even if grain yield did not. A significant varietal difference for GPY existed, and varied with site-years (Table 4.2). At the Ste-Rosalie site in 1990, the response of GPY to N fertilizer was variable at different N levels. The GPY of the cultivars Max, Katepwa and Hege 155-85 increased consistently with increasing fertilizer N level. The GPY of the cultivar Columbus did not increase with the addition of 180 kg N ha^{-1} despite the positive effect of such an addition on GPC (Table 4.4). It seems in this case that the increase in GPC was not enough to result in an increase in GPY since no grain yield increase at the level of 180 kg N ha^{-1} was noted (section 3).

4.4.3 Protein per seed:

At the Macdonald site, the absolute amount of protein per seed (PPSD, mg $seed^{-1}$) increased consistently when the N application was split (Tables 4.2 and 4.5). When some of the N fertilizer was applied at anthesis, PPSD increased by 6 % in 1990 and 13 % in 1991. At the Ste-Rosalie site, the increase in 1990 reached 33 % but only when 60 kg N ha^{-1} were split. This indicates the contribution of root N uptake to protein accumulation in the wheat kernel after anthesis (Wuest and Cassman, 1992b). Significant N level by cultivar interactions existed in the four site years and there was a significant three way interaction at the Macdonald site in 1991 (Table 4.4). The PPSD of the different cultivars showed different responses to N fertility. All cultivars usually had more PPSD when they received the N fertilizer in a split application than when the N was applied once (Table 4.5). In 1991 at Ste-Rosalie, PPSD of the cultivar Hege 155-85 remained the same throughout the entire range of N fertilizer (Table 4.4). In 1990, PPSD of Hege 155-85 was slightly improved by N fertilizer additions, with the maximum increase being 15 % greater than control (Table 4.4). In three out of four site-years, PPSD did not show a response to the addition of 180 kg N ha^{-1} for the cultivar Columbus (Table 4.4). The PPSD of Katepwa and Max increased consistently with increasing N fertility levels (Tables 4.4 and 4.5). In 1991, at the Macdonald site, PPSD of the cultivar Columbus reached a high of 6.5 mg $seed^{-1}$, however this value was lower than the maximum for

this cultivar in the previous year (Tables 4.4 and 4.5), suggesting that N fertility was not limiting.

4.4.4 Non protein seed dry matter:

Non protein seed dry matter (NPM, mg seed^{-1}) was not influenced by the schedule of N fertilizer application. If the plant is N depleted, as is likely to happen with split N applications, N will be translocated to the grain from the vegetative parts thus negatively affecting photosynthesis and leading to earlier senescence, thereby shortening the grain filling period (Sinclair and Dewit, 1975) and affecting NPM accumulation. In the year 1990, NPM responses of the different cultivars varied with N fertilizer level and location (Tables 4.1 and 4.4). There was a significant decline (by 1.7 mg seed^{-1} at Macdonald to 3.8 mg seed^{-1} at Ste-Rosalie) by the cultivar Hege 155-85 NPM with the addition of 120 and 180 kg N ha^{-1}, which, along with the slight increase in PPSD, explains the increase in the GPC (Table 4.4). Alternatively NPM of each of the cultivars Columbus, Katepwa and Max increased, on average, by 7 % with the addition of N fertilizer at the Ste-Rosalie site with little or no difference between the different N levels. The response was quite variable at the Macdonald site, tending to decrease with increasing N levels (Table 4.4). The responses of PPSD and NPM to N fertility explain that of GPC. In general, the increase in NPM did not dilute PPSD, resulting in a GPC increase due to N addition (Table 4.4). On the other hand a decline in NPM must result in an increase in GPC, if PPSD is relatively constant.

The NPM of the cultivars Columbus and Hege 155-85 were usually higher than NPM of the cultivars Katepwa and Max (Table 4.4). Taken together with the respective PPSD values, NPM explains the ranking of the cultivars in terms of their kernel weight (see section 3). The previous discussion suggests that any change in thousand kernel weight due to N fertilizer (see section 3) was due to more protein deposited into the grain since no more carbohydrates were getting deposited because N is not limiting. A positive correlation ($r=0.4^{***}$, 0.51^{***} and 0.54^{***}) existed for three site-years between PPSD and NPM suggests that in an environment where N fertilizer is not a limiting factor for yield, protein deposition in the grain may be sink

limited. Thus breeding for larger kernels would increase kernel capacity for protein deposition. However GPC would eventually reach a plateau since grain size is genetically set. This could be of an interest to bread wheat producers if larger kernels are not offset by other yield components which would then contribute to a decrease in yield.

A strong positive relationship was found between GPC and PPSD ($r=0.9^{***}$) while a negative relationship ($r=-0.2^{**}$ and $r=-0.3^{**}$) existed between GPC and NPM. This suggests that PPSD is, under such conditions, more critical than NPM in determining GPC (Bulman and Smith, 1992).

The hypothesis that GPC is sink limited in a non-N-limiting environment is reinforced by the positive correlation ($p<0.0001$) found between NHI (the proportion of the plant N in the seed) and harvest index (the proportion of the plant dry matter in seeds): grain yield increase is accompanied by grain N increase (Table 4.6).

4.4.5 Nitrogen use efficiency:

Nitrogen use efficiency (NUE) decreased when N fertilizer application level increases i.e. N at the levels of 120 and 180 kg ha^{-1} were not limiting. When N fertilizer is added, the plants continued to take up more N as the amount of soil available N increased. However, the plants took up smaller proportions of the soil N pool. The N remaining in the soil is potentially leached away or denitrified if soil moisture conditions are adequate (i.e N is lost). On the other hand, since the plant can not take up all the N it needs at once, over time N will potentially leach deeper into the soil profile and may move out of the zone occupied by plant roots, thus reducing the efficiency of the plant. The higher NUE that occured when N fertilizer application was split demonstrated the importance and practicality of such a management technique in trying to increase bread wheat GPC while reducing N losses (Table 4.2). Baethgen and Alley (1989) reported that the maximum daily N uptake of winter wheat wase attained at or shortly after anthesis. Wuest and Cassman (1992b) also observed that N applied at anthesis markedly increased hard red spring wheat N uptake. They also suggested that the observed negative relationship between grain yield and GPC (Terman et al. 1969) in part results from a limited late season N

supply as opposed to a genetic or physiological barrier. But if neither moisture nor N is limiting (as was the case in our experiments), an increase in GPC [GPC=PPSD/(PPSD+NPM)] means PPSD is increased while NPM remains constant or also increases since there was a positive relationship between PPSD and NPM. This implies bigger kernels and probably higher yield. If N is limiting but water is not, NPM might be increased without any increase in PPSD and thus GPC may decrease, hence the negative relationship between grain yield and GPC.

4.4.6 Nitrogen harvest index:

Nitrogen harvest index (NHI) decreased with increasing N levels in three out of four site-years. Since NHI is the proportion of plant N in the grain, and since PPSD is positively influenced by increasing N fertilizer level, one may conclude that N partitioning into the grain is altered with increasing N fertilizer levels. It seems that higher N fertilizer levels cause an increase in PPSD and a relatively higher increase in straw N content (not concentration). This suggested (although we have no evidence) that N partitioning into the grain is higher at lower levels of N fertility. In fact high N levels increased N concentration in straw at harvest (unpublished data). Varietal differences in NHI were significant only in 1991. Columbus always had the highest NHI (0.68 and 0.69) and Max the lowest (0.62 and 0.58). Although it improves NUE, splitting the N application did not significantly affect NHI except at Macdonald in 1991 where splitting the application of 60 kg N ha^{-1} slightly reduced NHI (Table 4.3). Split N application did not affect positively N retranslocation from the vegetative parts of the plant to the grains. In all four site-years, NHI was positively correlated to HI (Table 4.6) suggesting that in such an environment, increasing grain yield along with GPC is possible.

4.5 CONCLUSIONS:

This study has shown that split N application improves GPC by improving PPSD and NUE, that increasing N fertilizer levels is not beneficial to NUE or NHI, and that the PPSD is more critical to GPC than NPM in such an environment.

4.6 List of references

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Table 4.1 Analysis of variance of grain protein concentration (GPC,mg g^{-1}), grain protein yield (GPY, t ha^{-1}), protein per seed (PPSD,mg), seed dry matter(NPM,mg), nitrogen harvest index (NHI) and nitrogen use efficiency (NUE).

	1990						1991					
	GPC	GPY	PPSD	NPM	NHI	NUE	GPC	GPY	PPSD	NPM	NHI	NUE
Macdonald												
N	**	**	**	**	**	**	**	**	**	**	n.s.	**
T	**	**	**	n.s.	n.s.	n.s.	**	**	**	n.s.	n.s.	n.s.
C	**	**	**	**	n.s.	n.s.	**	**	**	**	**	n.s.
N*T	**	n.s.	n.s.	n.s.	n.s.	*	n.s.	**	n.s.	n.s.	*	n.s.
N*C	n.s.	n.s.	**	**	n.s.	n.s.	**	n.s.	**	n.s.	n.s.	n.s.
T*C	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
N*T*C	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	**	n.s.	n.s.	n.s.
C.V.	3.0	7.6	5.6	4.2	14.1	33.3	4.2	7.9	4.5	3.5	10.5	23.8
R^2	0.96	0.90	0.91	0.62	0.48	0.49	0.90	0.94	0.93	0.65	0.4	0.53
Ste-Rosalie												
N	**	**	**	**	**	**	**	**	**	**	**	**
T	**	**	**	n.s.	n.s.	**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C	**	**	**	**	n.s.	**	**	**	**	**	**	**
N*T	**	**	**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
N*C	**	**	**	**	n.s.	n.s.	*	n.s.	**	n.s.	n.s.	n.s.
T*C	**	n.s.	**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
N*T*C	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C.V	3.2	14.6	5.6	4.2	13.2	25.7	5.1	12.7	6.2	3.8	7.3	52.5
R^2	0.95	0.86	0.93	0.72	0.53	0.69	0.64	0.76	0.82	0.54	0.71	0.55

N = nitrogen level, C = cultivar, T = nitrogen timing.
** significant at the 0.01 level, n.s. not significant

Table 4.2 Main effects of N level (kg ha^{-1}), timing of N fertilizer application and cultivars on GPC (mg g^{-1}), GPY (t ha^{-1}), PPSD (mg seed^{-1}), NPM (mg seed^{-1}), NHI and NUE.

	1990						1991					
Macdonald	GPC	GPY	PPSD	NPM	NHI	NUE	GPC	GPY	PPSD	NPM	NHI	NUE
N level (kg ha^{-1})												
0	129 d	0.51 d	4.7 c	31.9 a	0.72 a	-	136 d	0.5 d	4.2 d	26.8 b	0.66	-
60	144 c	0.71 c	5.4 b	31.9 a	0.66 b	0.56 a	147 c	0.8 c	4.9 c	28.3 a	0.66	0.75 a
120	157 b	0.81 b	5.7 a	30.5 b	0.60 c	0.44 b	159 b	0.9 b	5.3 b	28.0 a	0.67	0.64 b
180	163 a	0.86 a	5.8 a	29.7 c	0.56 c	0.34 c	168 a	1.1 a	5.6 a	27.9 a	0.6	0.55 c
significance	*	*	*	**	**	*	**	*	*	*	n.s.	*
Cultivars												
Columbus	163 a	0.73 ab	6.2 a	31.9 a	0.65	0.46	161 a	0.83 a	5.5 a	28.5 a	0.69 a	0.63
Hege155-85	131 d	0.71 bc	4.6 d	31.1 b	0.61	0.42	143 c	0.821ab	4.7 c	28.3 a	0.64 b	0.60
Katepwa	160 b	0.70 c	5.9 b	30.7 bc	0.64	0.44	159 a	0.822a	5.0 b	26.4 d	0.70 a	0.64
Max	140 c	0.75 a	4.9 c	30.3 c	0.66	0.47	146 b	0.79 b	4.8 c	27.8 c	0.62 b	0.70
significance	*	**	*	**	n.s.	n.s.	**	*	*	*	**	n.s.
Timing												
Single	146 b	0.72 b	5.3 b	31.0	0.63	0.42	148 b	0.80 b	4.8 b	27.7	0.66	0.65
Split	151 a	0.74 a	5.6 a	31.0	0.64	0.47	157 a	0.84 a	5.2 a	27.8	0.66	0.63
significance	*	**	**	n.s.	n.s.	n.s.	**	*	*	n.s.	n.s.	n.s.
Ste-Rosalie												
N level (kg ha^{-1})												
0	130 d	0.21 d	4.1 d	27.4 c	0.69 a	-	148 d	0.39 c	4.4 c	25.5 a	0.68 a	-
60	137 c	0.33 c	4.7 c	29.1 a	0.62 b	0.42 a	157 c	0.45 b	4.7 b	25.2 a	0.65 b	0.29 a
120	153 b	0.43 b	5.2 b	28.3 b	0.58 b	0.33 b	164 b	0.49 b	4.9 ab	24.7 b	0.65 c	0.19 b
180	162 a	0.47 a	5.4 a	27.7 c	0.62 b	0.25 c	168 a	0.51 a	5.0 a	24.5 b	0.58 d	0.15 b
significance	*	**	**	**	**	**	*	*	*	*	**	*
Cultivars												
Columbus	157 a	0.37 a	5.4 a	29.1 a	0.67	0.31 b	174 a	0.50 a	5.3 a	25.3 ab	0.65 b	0.20 b
Hege155-85	133 c	0.34 b	4.3 b	28.3 b	0.59	0.27 b	141 d	0.40 b	4.2 d	25.5 a	0.60 d	0.20 b
Katepwa	154 a	0.37 a	5.3 a	28.8 ab	0.64	0.39 a	166 b	0.48 b	4.8 b	24.2 c	0.70 a	0.28 a
Max	139 b	0.36 b	4.3 b	26.3 c	0.61	0.37 a	156 c	0.40 b	4.6 c	25.0 b	0.61 c	0.16 b
significance	*	**	**	**	n.s.	**	*	*	*	*	**	*
Timing												
Single	140 b	0.34 a	4.6 b	28.0	0.62	0.28 b	159	0.47	4.7	25.0	0.62	0.20
Split	151 a	0.38 b	5.1 a	28.2	0.64	0.39 a	159	0.45	4.7	25.0	0.64	0.22
significance	*	**	**	n.s.	n.s.	**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

** significant at the 0.01 level, * significant at the 0.05 level, n.s. not significant
Values at the same site, in the same column followed by the same letter are not significantly different by an ANOVA-protected Duncan's new multiple range test. GPC= grain protein concentration, GPY= grain protein yield, PPSD= protein per seed, NPM= non protein dry-matter, NHI= nitrogen harvest index, NUE= nitrogen use efficiency

Table 4.3 Simple effects of N level (kg ha^{-1}) and timing of N fertilizer applicationon GPC (mg g^{-1}), GPY (t ha^{-1}), PPSD (mg $seed^{-1}$), NHI and NUE.

		---Ste-Rosalie 1990---			-Macdonald 1991-		-Macdonald 1990-	
N level	timing	GPC	GPY	PPSD	GPY	NHI	GPC	NUE
0	Single	130 e	0.22 g	4.1 f	0.50 g	0.64 bc	128 f	-
	Split	130 e	0.20 g	4.1 f	0.52 f	0.68 abc	131 f	-
60	Single	131 e	0.31 f	4.4 e	0.75 e	0.69 a	139 e	0.48 bc
	Split	144 d	0.35 e	5.0 cd	0.81 d	0.63 c	148 d	0.64 a
120	Single	146 d	0.39 d	4.8 d	0.95 c	0.66 abc	155 c	0.46 c
	Split	161 b	0.46 bc	5.5 b	0.93 c	0.67 abc	159 b	0.43 cd
180	Single	155 c	0.44 c	5.1 c	1.0 b	0.65 abc	161 b	0.33 d
	Split	170 a	0.50 a	5.7 a	1.09 a	0.65 abc	165 a	0.35 d
significance		*	*	*	*	*	*	*

* significant at the 0.05 level
Values at the same site, in the same column followed by the same letter are not significantly different by an ANOVA-protected Duncan's new multiple range test.
GPC= grain protein concentration, GPY= grain protein yield, PPSD= protein per seed, NPM= non protein dry-matter, NHI= nitrogen harvest index, NUE= nitrogen use efficiency

Table 4.4 Simple effects of N level (kg ha) and cultivar on GPC (mg g^{-1}), GPY (t ha^{-1}), PPSD (mg seed^{-1}) and NPM (mg seed)

		Ste-Rosalie						Macdonald		
		1990				1991		1990		1991
N level	Cultivar	GPC	GPY	PPSD	NPM	GPC	PPSD	PPSD	NPM	GPC
0	Columbus	142 f	0.24 g	4.6 d	27.6 cd	158 fg	4.8 d	5.4 c	32.2 ab	142 e
	Hege 155-85	119 i	0.21 g	4.0 f	29.6 a	138 i	4.3 f	4.3 g	33.2 a	134 fg
	Katepwa	135 g	0.19 g	4.3 ef	27.4 c-e	159 gh	4.4 ef	5.0 de	30.8 b-e	141 ef
	Max	123 hi	0.19 g	3.5 g	24.9 g	144 hi	4.3 f	4.3 g	31.3 b-e	128 g
60	Columbus	148 e	0.35 ef	5.2 c	29.7 a	171 cd	5.2 b	6.1 b	32.3 ab	155 d
	Hege 155-85	125 h	0.32 f	4.3 ef	29.7 a	138 i	4.2 f	4.8 fg	32.3 ab	134 fg
	Katepwa	148 e	0.36 ef	5.2 c	29.7 a	165 d-f	4.8 d	6.0 b	31.7 b-d	156 cd
	Max	128 h	0.31 f	4.0 f	27.4 c-e	155 g	4.7 de	4.9 ef	31.5 b-c	141 e
120	Columbus	165 bc	0.45 bc	6.0 ab	29.8 a	182 ab	5.6 a	6.7 a	32.0 a-c	167 b
	Hege 155-85	139 fg	0.39 de	4.5 de	28.0 bc	145 hi	4.3 f	4.9 ef	30.2 de	149 d
	Katepwa	163 cd	0.42 cd	5.7 b	29.0 a	168 de	4.8 d	6.0 b	30.0 e	164 b
	Max	147 e	0.44 cd	4.6 d	26.3 ef	160 efg	4.7 de	5.2 cd	29.9 e	154 d
180	Columbus	168 ab	0.45 bc	5.9 ab	29.3 a	186 a	5.7 a	6.7 a	31.1 b-e	181 a
	Hege 155-85	150 e	0.41 cd	4.6 d	25.9 fg	145 hi	4.1 f	4.9 ef	28.5 f	152 d
	Katepwa	172 a	0.51 a	6.0 a	28.9 ab	177 bc	5.16 bc	6.6 a	30.7 c-e	176 a
	Max	160 d	0.49 ab	5.0 c	26.7 d-f	165 d-f	4.9 cd	5.2 cd	28.4 f	162 bc
significance		*	*	*	*	*	*	*	*	*

* significant at the 0.05 level
Values at the same site, in the same column followed by the same letter are not significantly different by an ANOVA-protected Duncan's new multiple range test. GPC= grain protein concentration, GPY= grain protein yield, PPSD= protein per seed, NPM= non protein dry-matter, NHI= nitrogen harvest index, NUE= nitrogen use efficiency

Table 4.5 Simple effects of N level (kg ha^{-1}), timing of N fertilizer application and cultivar on protein per seed (PPSD, mg $seed^{-1}$), at Macdonald 1991.

N level	Timing	Cultivar	PPSD
0	Single	Columbus	4.4 l-o
		Hege 155-85	3.9 pq
		Katepwa	4.1 n-p
		Max	3.8 q
	Split	Columbus	4.5 l-n
		Hege 155-85	4.7 k-m
		Katepwa	4.3 n-p
		Max	4.1 op
60	Single	Columbus	5.0 h-j
		Hege 155-85	4.3 m-o
		Katepwa	4.8 ı-l
		Max	4.4 l-o
	Split	Columbus	5.6 de
		Hege 155-85	4.7 ȷ-l
		Katepwa	5.07 g-ȷ
		Max	4.9 h-k
120	Single	Columbus	5.6 ef
		Hege 155-85	4.7 ı-l
		Katepwa	5.0 h-j
		Max	5.08 g-ı
	Split	Columbus	6.0 bc
		Hege 155-85	5.2 f-h
		Katepwa	5.4 e-g
		Max	5.09g-ı
180	Single	Columbus	6.3 ab
		Hege 155-85	5.0 h-k
		Katepwa	5.4 e-g
		Max	5.2 f-h
	Split	Columbus	6.5 a
		Hege 155-85	5.2 f-h
		Katepwa	5.9 cd
		Max	5.6 de
significance			*

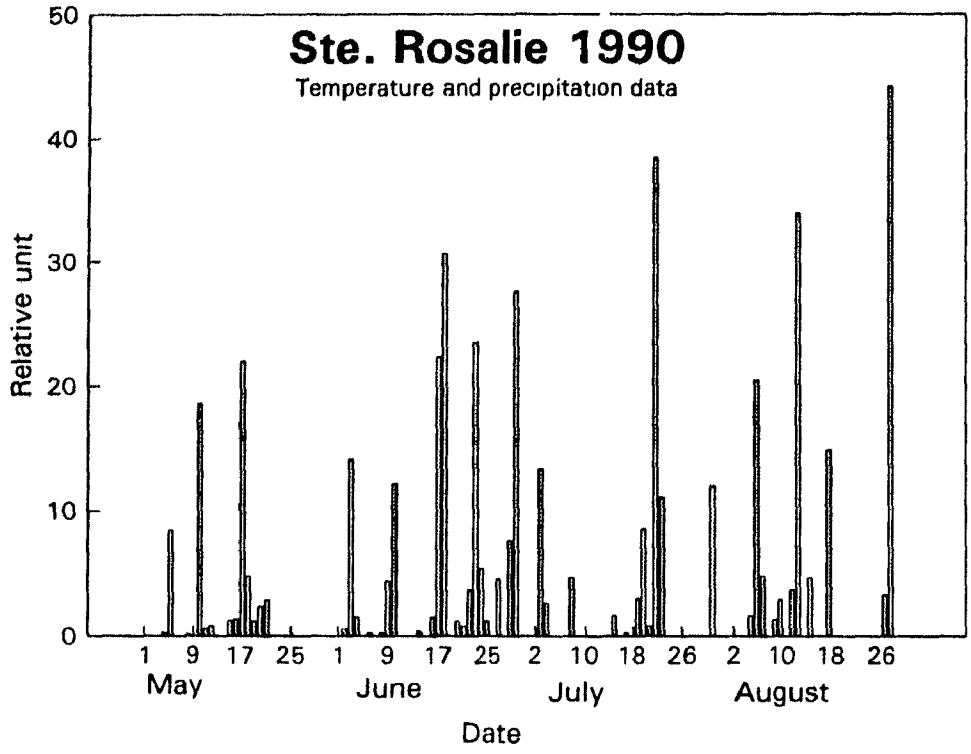
* significant at the 0.05 level
Values in the same column followed by the same letter are not significantly different by an ANOVA-protected Duncan's new multiple range test.

Table 4.6 Simple effects of cultivar and timing of N fertilizer application on GPC (mg g^{-1}) and PPSD (mg $seed^{-1}$) at Ste-Rosalie in 1990.

Cultivar	Timing	GPC	PPSD
Columbus	Single	148 b	5.0 c
	Split	164 a	5.8 a
Hege155-85	Single	130 e	4.2 e
	Split	137 d	4.5 d
Katepwa	Single	148 b	5.0 c
	Split	161 a	5.6 b
Max	Single	136 d	4.1 e
	Split	143 c	4.4 d
significance		*	*

* significant at the 0.05 level
Values in the same column followed by the same letter are not significantly different by an ANOVA-protected Duncan's new multiple range test. GPC= grain protein concentration, PPSD= protein per seed.

Figure 4.1 Daily maximum (dotted line) and minimum temperature (°C)(solid line), and precipitation (mm) (bars) for the 1990 and 1991 growing season at Ste-Rosalie.


Ste. Rosalie 1990
Temperature and precipitation data
Relative unit
50
40
30
20
10
0
1 9 17 25 1 9 17 25 2 10 18 26 2 10 18 26
May
June
July
August
Date

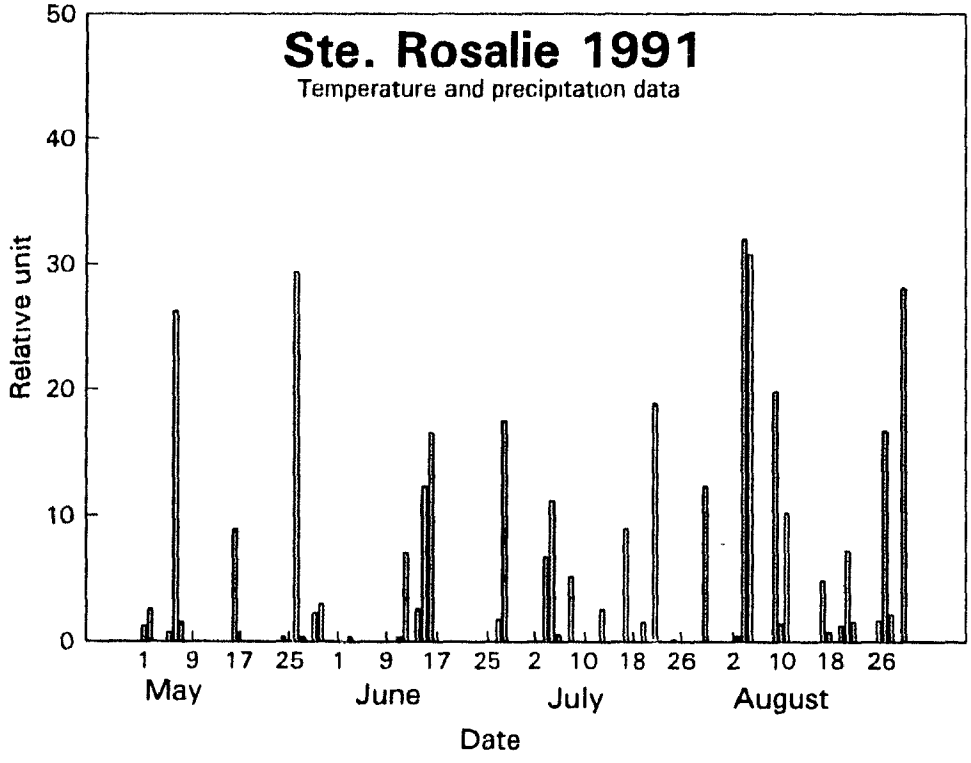
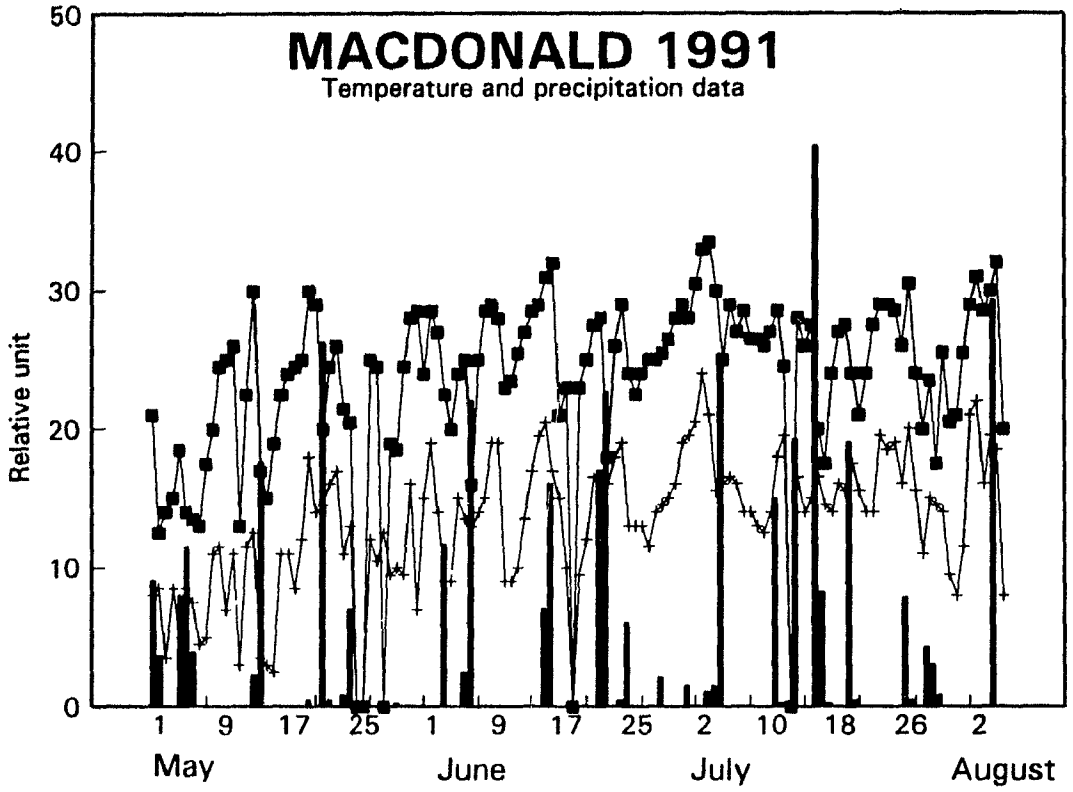

Ste. Rosalie 1991
Temperature and precipitation data
Relative unit
50
40
30
20
10
0
1 9 17 25 1 9 17 25 2 10 18 26 2 10 18 26
May
June
July
August
Date

Figure 4.2 Daily maximum (squares) and minimum temperature (°C)(dashes), and precipitation (mm) (bars) for the 1990 and 1991 growing season at Macdonald.


MACDONALD 1991
Temperature and precipitation data
Relative unit
50
40
30
20
10
0
1 9 17 25 1 9 17 25 2 10 18 26 2
May
June
July
August

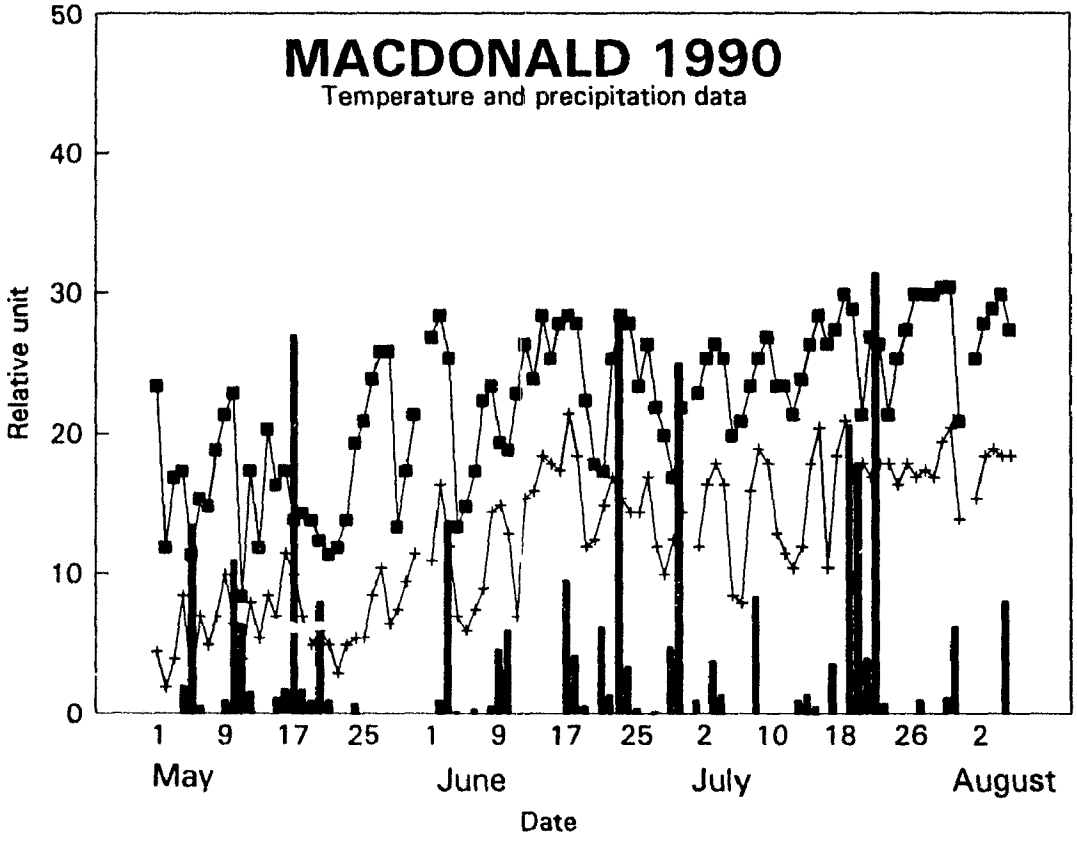

MACDONALD 1990
Temperature and precipitation data
Relative unit
50
40
30
20
10
0
1 9 17 25 1 9 17 25 2 10 18 26 2
May
June
July
August
Date

Figure 4.3 Grain protein concentration (mg g^{-1}) estimates and observations with split N applications at Ste-Rosalie in 1990.

Ste-Rosalie 1990

Grain Protein Concentration, split appl.

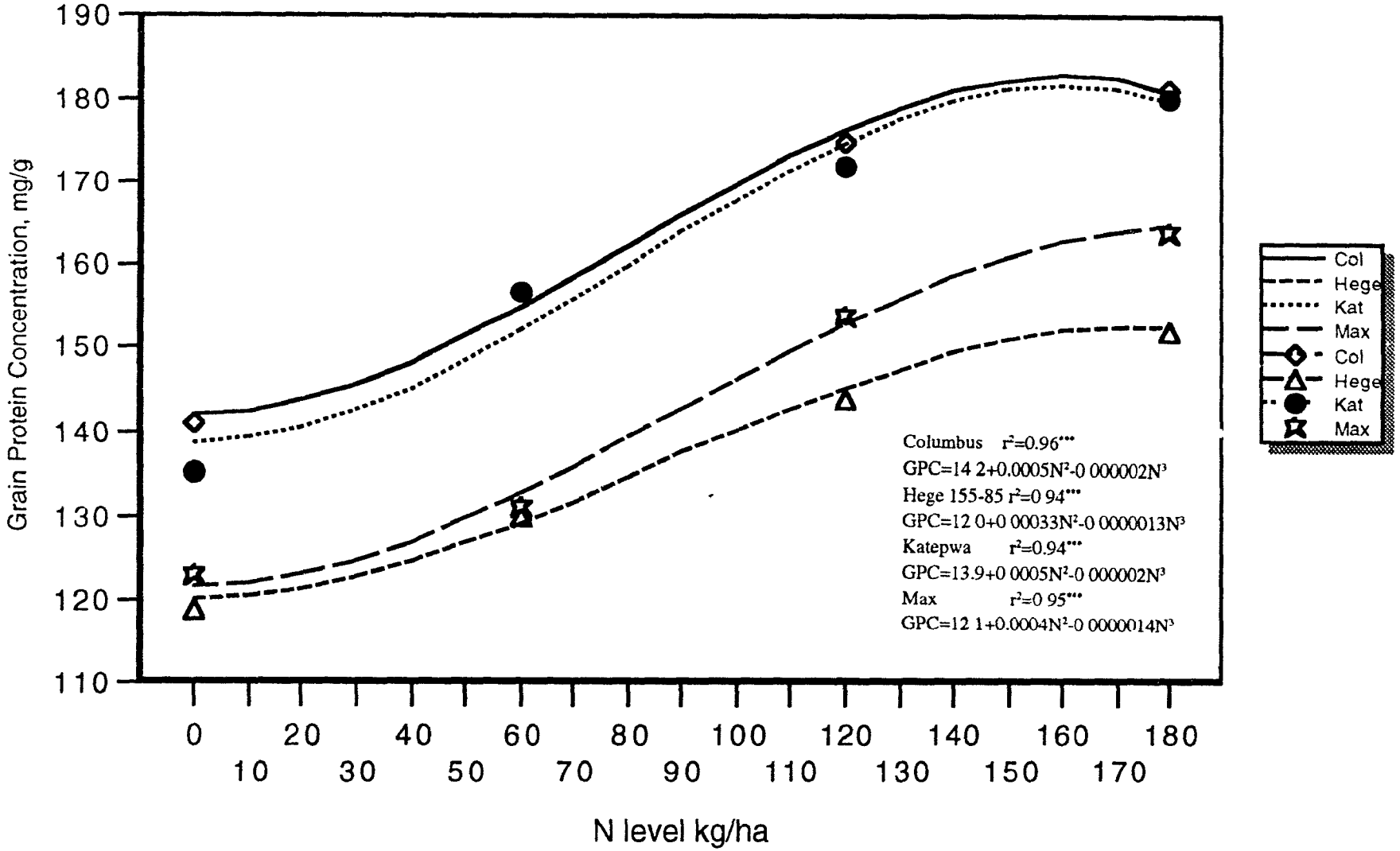


Figure 4.4 Grain protein concentration (mg g^{-1}) estimates and observations with single N application at Ste-Rosalie in 1990.

Ste-Rosalie 1990

Grain Protein Concentration,single appl.

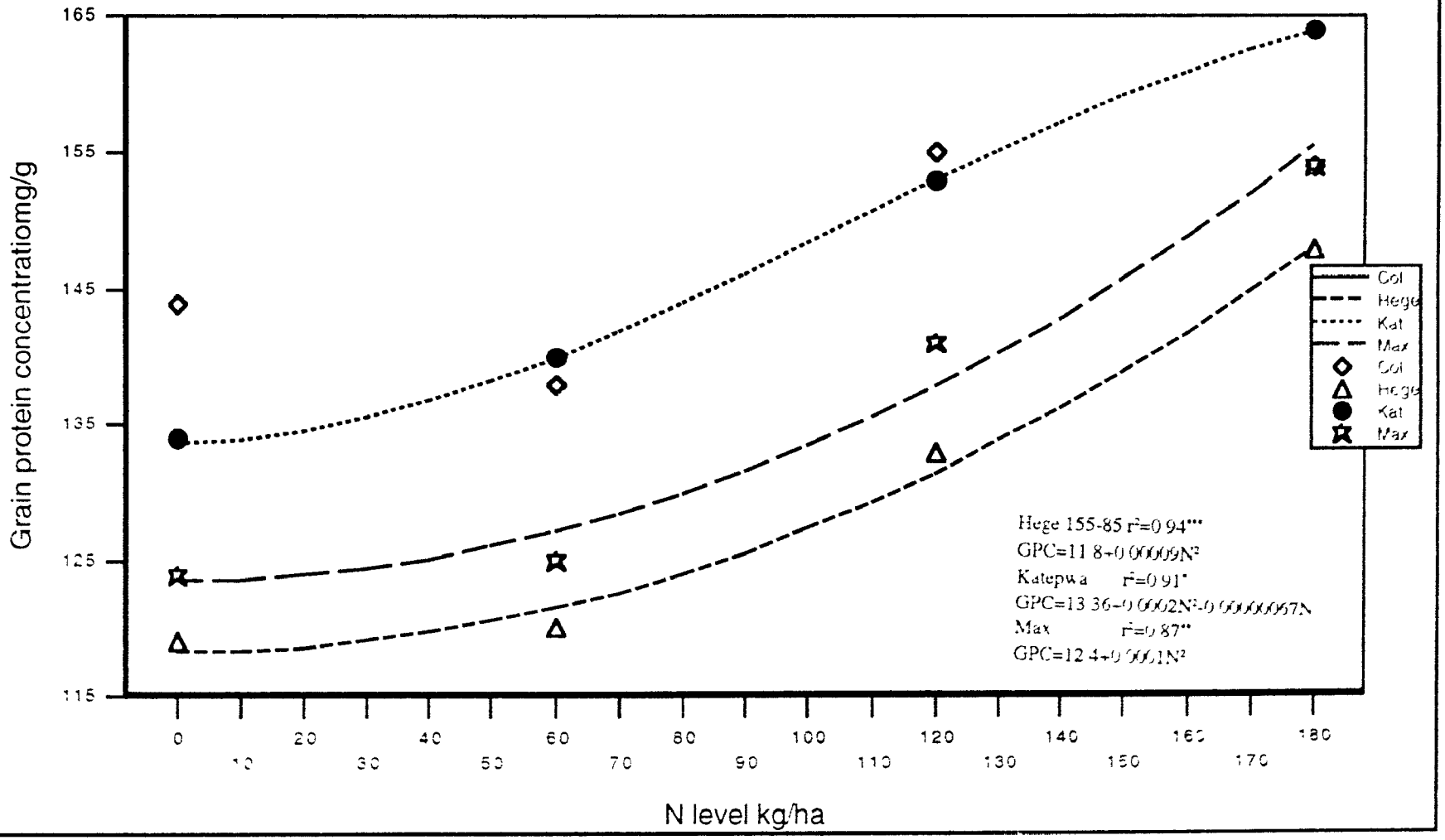


Figure 4.5 Grain protein concentration (mg g^{-1}) estimates and observations at Macdonald in 1990.

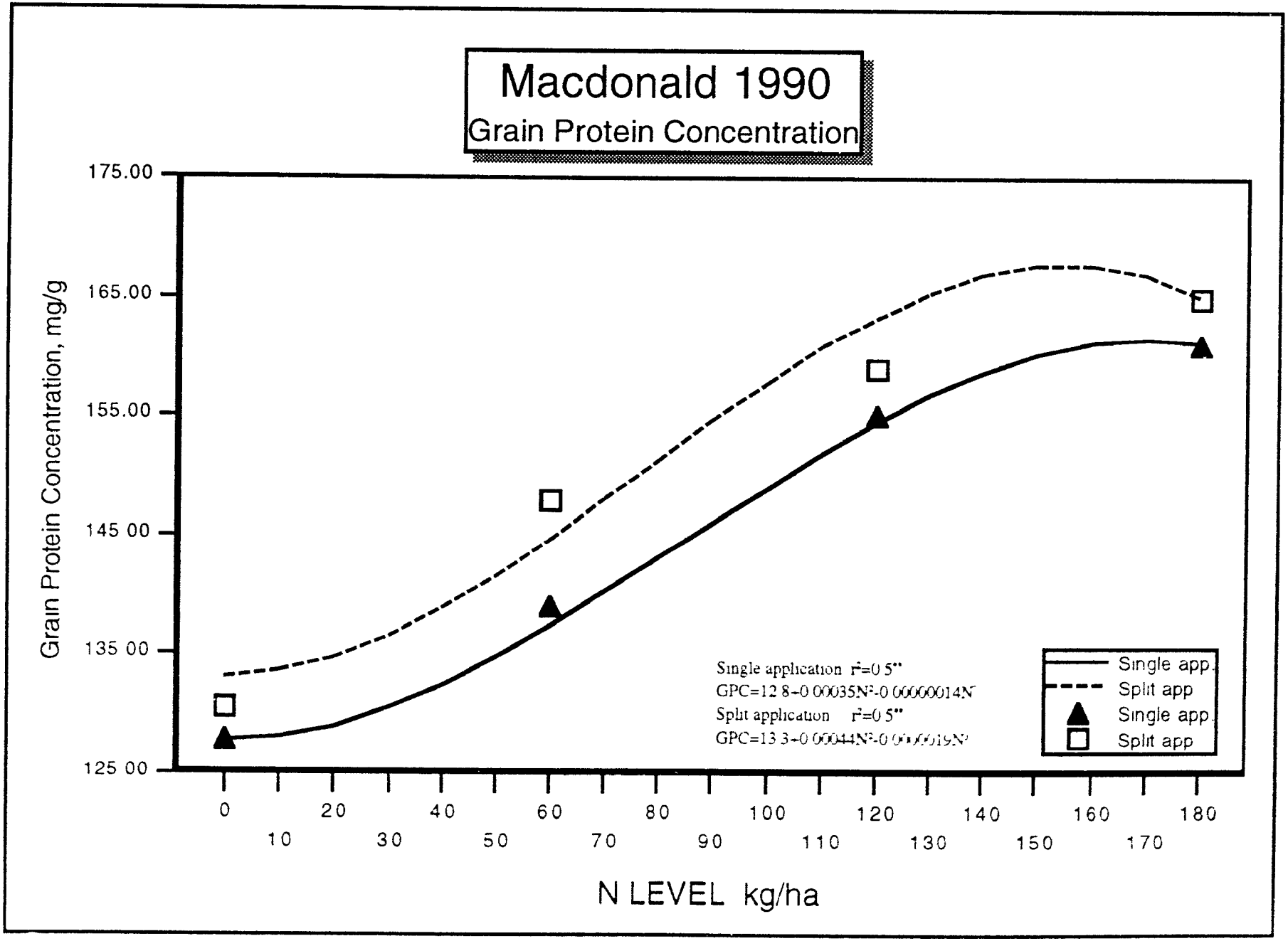

Macdonald 1990
Grain Protein Concentration
Grain Protein Concentration, mg/g
175.00
165.00
155.00
145 00
135 00
125 00
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
N LEVEL kg/ha
Single application r²=0 5**
GPC=12 8+0 00035N²-0 00000014N³
Split application r²=0 5**
GPC=13 3+0 00044N²-0 00000019N³
Single app.
Split app
Single app.
Split app

Figure 4.6 Grain protein concentration (mg g^{-1}) estimates and observations at Macdonald in 1991, by cultivar.

MACDONALD 1991

Grain Protein Concentration, by cultivar

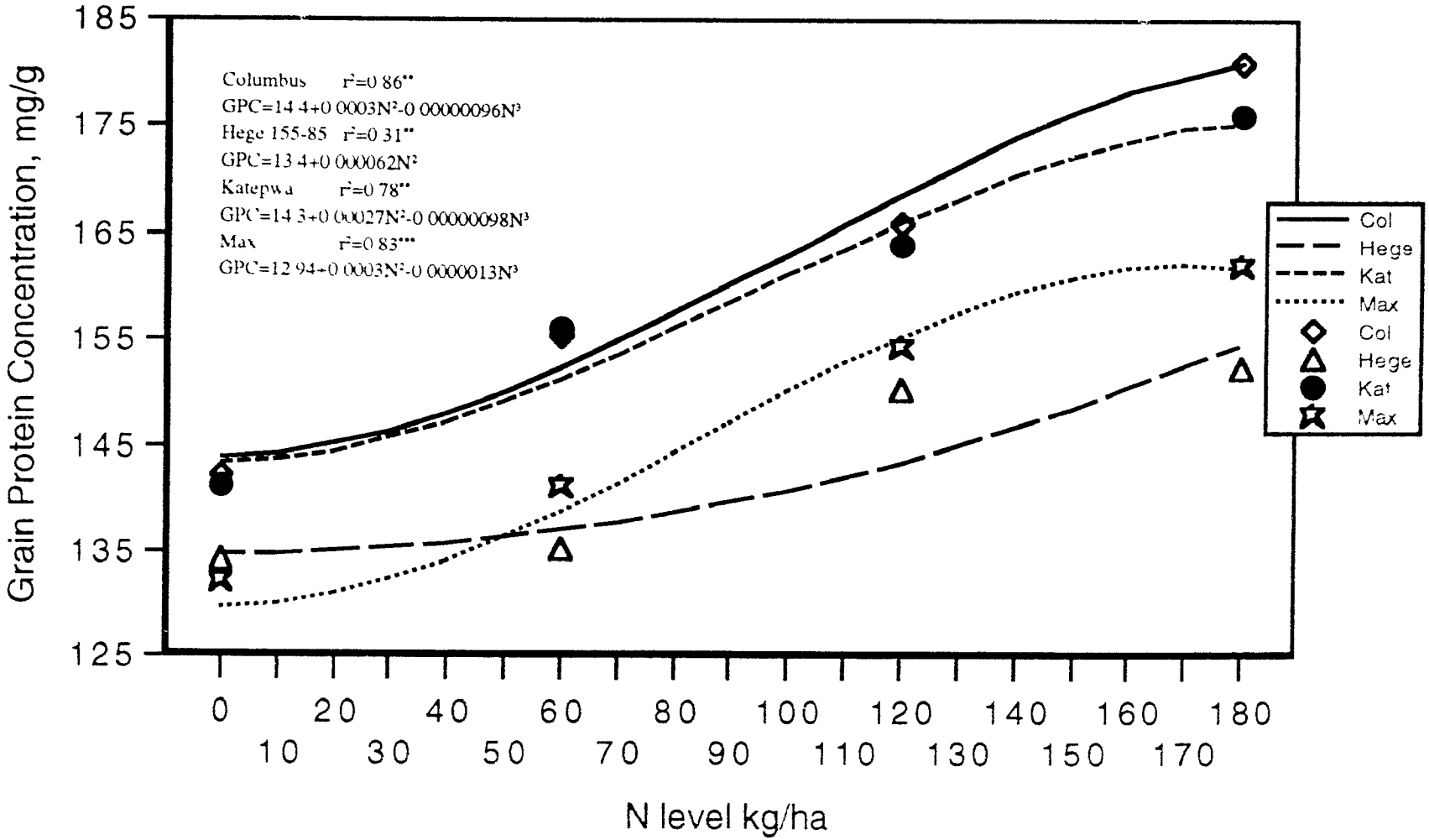
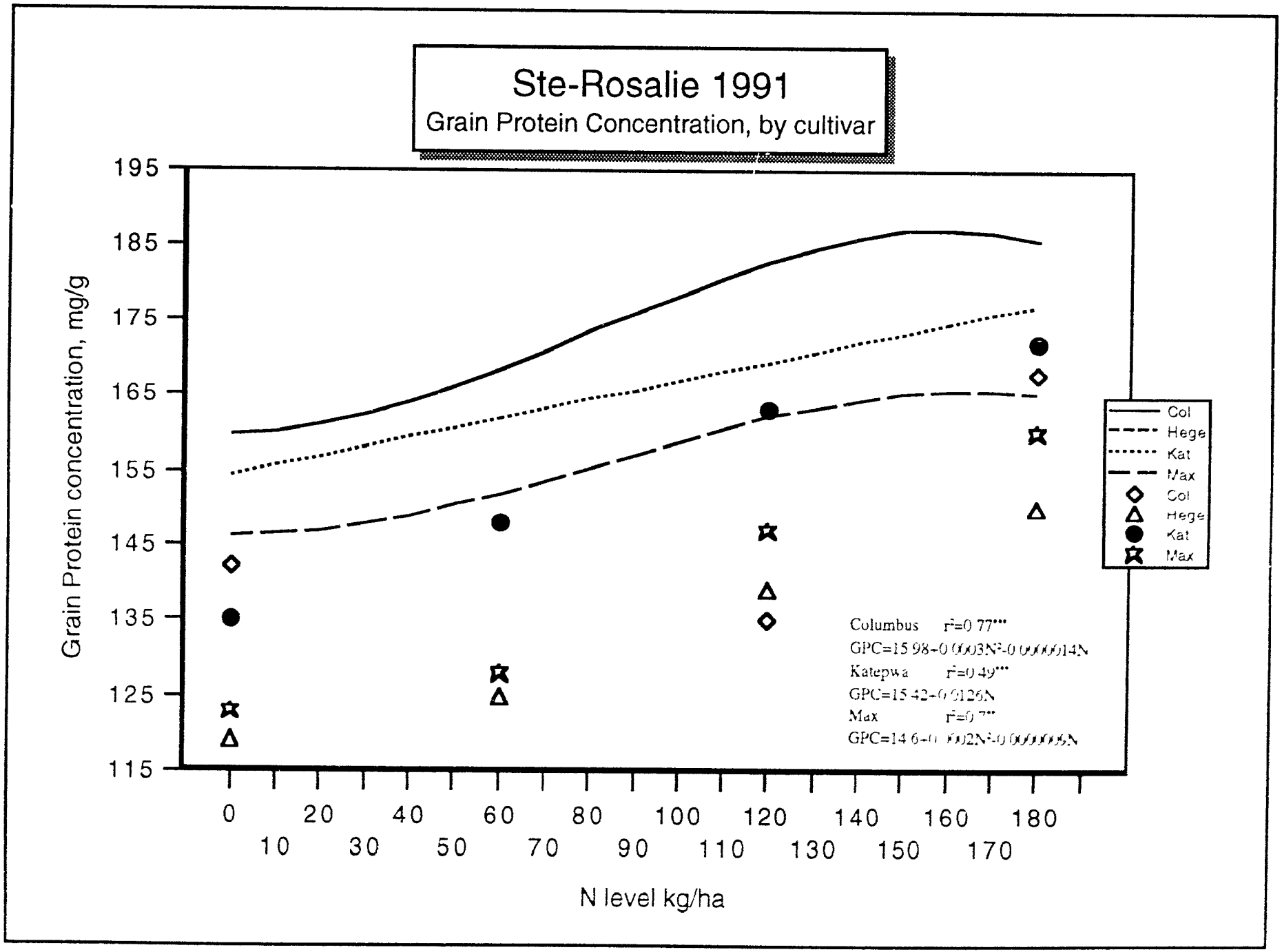


Figure 4.7 Grain protein concentration (mg g^{-1}) estimates and observations at Ste-Rosalie in 1991, by cultivar.


Ste-Rosalie 1991
Grain Protein Concentration, by cultivar
Grain Protein concentration, mg/g
195
185
175
165
155
145
135
125
115
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
N level kg/ha
Col
Hege
Kat
Max
Col
Hege
Kat
Max
Columbus r²=0.77***
GPC=15.98+0.0003N²-0.000014N
Katepwa r²=0.49***
GPC=15.42+0.0126N
Max r²=0.7**
GPC=14.6+0.002N²-0.000006N

Preface to section 5

Section 5 is the material contained in a manuscript which will be submitted for publication. The current format conforms with guidelines set by the Faculty of Graduate Studies. Tables, figures and literature cited are presented at the end of this section.

In this section we discuss the effects of N fertilizer levels, time of application and cultivars on the breadmaking quality variables, mainly flour yield, farinograph parameters and loaf volume.

Section 5

EVALUATION OF THE EFFECT OF N FERTILIZER LEVEL AND TIMING OF APPLICATION ON THE BREADMAKING QUALITY OF FOUR HARD RED SPRING WHEAT CULTIVARS IN EASTERN CANADA.

5.1 ABSTRACT

In order to assess the potential manipulation of nitrogen (N) management to allow bread quality wheat production in Eastern Canada, an experiment was conducted for two years at each of two sites in Quebec to study the effect of level and timing of N fertilizer application on breadmaking quality and grain ash of four hard red spring wheat cultivars known to have potential as bread wheat. The soil types were Bearbrook clay and Ste-Rosalie clay. The experiment was 4x4x2 factorial. The cultivars were: Columbus, Katepwa, Max and Hege 155-85. In both years 0, 60, 120 and 180 kg N ha^{-1} were applied either 100 % at seeding time or 60 % at seeding and 40 % at anthesis. Increasing N fertilizer levels caused a reduction in grain and flour ash concentration while it caused an increase in flour protein concentration, Hagberg falling number and flour absorption. Splitting the N application was beneficial for flour protein content and bread loaf volume. Cultivar by N level interaction often occurred for farinograph variables. The interactions showed that farinograph reading of Max and Hege 155-85 were improved by higher N fertilizer application. Despite its high grain and flour yield, Hege 155-85 may not be economical to produce because of high N fertilizer needs in the field and gluten supplements added to the flour.

5.2 INTRODUCTION:

Currently wheat provides more human nourishment (mainly bread) than any other food source (Stoskopf 1985, Orth and Shellenberger 1988). Wheat is classified for end use according to its grain protein concentration. Wheat graded for bread production should have a grain protein concentration ranging between 115 and 150 mg g^{-1} (Statistical Handbook 1989). During the baking process, when water is added

to flour, proteins rapidly become hydrated and aggregate first into fibres and then into continuous films or membranes (Bushuk 1985). The "network" formed will contain non-protein constituents such as specific carbohydrates and lipids. The low ionic strength of two of the protein fractions, glutenins and gliadins, and their disulfide and hydrophobic bonds are responsible for the viscoelastic aggregates which makes wheat gluten (protein) the most suitable for bread making.

It is well established that high quality bread, i.e high loaf volume, is positively and directly correlated with the relatively high protein content of the flour (Finney et al. 1948). Further more, Finney (1943) and Bushuk (1985) found that the relationship between loaf volume and protein content was linear.

Grain protein concentration (mg g^{-1}) and content (g $seed^{-1}$) have been reported to vary with N fertilizer levels. Dubetz (1979) found that the grain N concentration of the cultivar Neepawa increased with each 50 kg ha^{-1} increment of N up to a 150 kg ha^{-1} application. Similarly, Jacobsen and Westerman (1988) found that the grain protein concentration of winter wheat increased from 121 to 154 mg g^{-1} as the applied N fertilizer rate increased from 0 to 250 kg ha^{-1}. Several studies have demonstrated the importance of time of N application for optimal wheat yield, increased grain protein concentration and reduced N losses. For winter wheat it is generally accepted that all the N should not be added at seeding because of leaching losses related to winter precipitation levels. Fertilizer uptake by winter wheat was much greater when split application of N fertilizer was made (Riga et al. 1980). Split application increased grain protein concentration (Fowler et al. 1989, Hucklesby et al. 1971, section 4) when applied at anthesis (Altman et al. 1983, Miezan et al. 1977), especially when plants were subjected to a water stress conditions (-8 bars) at this stage (Dubetz 1977). Hucklesby et al. (1971) found that although protein quantity was affected by split N application, protein quality was not. On the contrary, Long and Sherbakoff (1951) reported that such a late application influenced the quality of wheat flour. McNeal et al. (1971) observed an increase in bread loaf volume as a result of increased protein concentration due to N fertility, while Tipples et al. (1977) reported that high protein concentrations (> 170 mg g^{-1}) can be associated with a

marked weakening of physical dough characteristics and a deterioration in baking quality. Bushuk et al. (1978) showed that for Neepawa wheat samples in the top protein range, N fertility decreased loaf volume. They explained their observations as being due to a probable change in glutenin protein solubility, a gradual decrease in the amount of starch damaged during the milling process and the increased ratio of soluble over insoluble glutenins.

No information exists regarding the response of bread type hard red spring wheats to N fertilizer in Eastern Canada, a region with a short growing season and relatively high seasonal precipitation. This study was conducted to test the effect of N fertilizer application rate and timing on the baking quality and related characteristics of four hard red spring wheat cultivars recommended for bread baking.

5.3 MATERIALS AND METHODS:

The study was conducted on Bearbrook clay soil (fine, mixed, non-acid, frigid, typic Humaquept), at the Lods Agronomy Research Centre, McGill University, Macdonald Campus, and on Ste-Rosalie clay soil (fine, non acid, frigid, typic Humaquept) at the COOP Fédérée research farm, Ste Rosalie, Quebec, Canada during the 1990 and 1991 crop seasons. For 1990, the previous crop was oat (Avena sativa L.) at the Macdonald Campus and mixed forages at Ste-Rosalie. For 1991, the previous crop at both locations was hard red spring wheat (Triticum aestivum L.). Prior to seeding, land received adequate amendment of P and K. The experimental design was a 4 X 4 X 2 factorial, arranged in a randomized complete block design with 4 replicates. The bread wheat cultivars sown were: Columbus [normally acceptable under the Canada Red Spring grades (Agriculture Canada, 1980)], Max [has an acceptable performance in Eastern Canada and was recommended for milling and bread making, (Agriculture Canada, 1987)], Katepwa [has good milling and baking properties, (Campbell and Czarnecki 1987)] and Hege 155 85 [still being tested for possible production as a bread wheat in Eastern Canada]. The cultivars received 0, 60, 120 or 180 kg N ha^{-1} in the form of solid ammonium nitrate, either all at seeding, or 60 % at seeding and 40 % at anthesis. The fertilizer was broadcast by

hand on the plot surface and incorporated by hand raking. After trimming, each plot at Macdonald was 180 cm x 456 cm with 12 rows spaced 15 cm apart. After trimming, plot size at Ste Rosalie in 1990 was 90 cm x 500 cm, and in 1991 90 cm x 525 cm, with 6 rows spaced 15 cm apart. Trimming was done just prior to harvest to eliminate edge effects due to the pathways. The plots were sown at 450 seeds m^{-2} using certified seed treated with Vitaflo 280 (carbathiin and thiram), and using a cone-type plot seeder (Wintersteiger America Inc., Lincoln, Nebraska). Seeding was conducted on the first and eleventh of May at Macdonald, and on the tenth and twentyfirst of May at Ste-Rosalie in 1990 and 1991 respectively. Weeds at Macdonald were controlled with Pardner (bromoxynil 3, 5-dibromo-4-hydroxybenzonitrile) applied at 1 l ha^{-1} at ZGS 12. Weeds at Ste-Rosalie were controlled with a mixture of 280 g a. i. ha^{-1} of bromoxynil and 280 g a. i. ha^{-1} of MCPA (2-methyl 4 chlorophenoxyaceticacid) also applied at ZGS 12. At crop maturity, the plants were combine harvested (Wintersteiger America Inc., Lincoln, NB.). A subsample of the grain was ground with a Udy cyclone mill (Udy Corp, Fort Collins, CO.) through a 1mm mesh. Two g of the whole meal samples were ashed at 600°C in a muffle furnace for 2 hours to determine grain ash concentration (GAC) (AACC method n° 08-03). Due to constraints on time and labour, further baking quality tests were performed each year only on the samples from two replicates from the Macdonald site. Grain was cleaned in a dockage tester and moisture content was determined (AACC method n° 44-19). After being tempered to 15.5 % moisture basis (m.b.), grain was milled into white flour in an experimental Buhler mill (Buhler Brothers Ltd., Switzerland). Flour coming out from the six streams was weighed and flour extraction percentage determined. The flour was mixed for 20 min. in a rotating elbow to give a homogenous mixture. Flour subsamples were taken for further ash and moisture determination. Flour protein concentration (FPC) was determined by the Kjeldahl method (N x 5.7) using a Tecator Kjeltec System I (Tecator AB, Hoganas, Sweden) and the values are reported at 14 % m.b. Mixing properties of the doughs from the samples were determined with the farinograph (C.W. Brabender Instruments Inc., N.J., U.S.A.) method using

a 50 g Brabender mixer (AACC method n° 54-21). Breadmaking quality was evaluated by the remix method (Kilborn and Tipples 1981). Each year, whole meal alpha-amylase activity was tested by the Hagberg Falling Number (HFN) (AACC method n° 56-81B).

Data were analyzed with the SAS system (SAS Institute, 1985). The F test (Steel and Torrie, 1980) was used to determine whether the variations caused by the treatments and their interactions were significant. Probabilities of less than or equal to 0.05 were considered significant for main effects and interactions. The t test was also used to test for homogeneity of the experimental error variances among years (Steel and Torrie, 1980). No combined analysis of variance across the years or locations was performed because the experimental error variances were found to be non-homogenous. An ANOVA protected Duncan's new multiple range test was performed to compare means of variables found to vary significantly by the F test.

5.4 RESULTS AND DISCUSSION:

5.4.1 Grain and flour ash concentrations

Hinton (1959) found that 60 % of the grain ash concentration (GAC) exists in the aleurone layer. Thus if the bran is not well separated from the endosperm during milling, this would lead to a higher flour ash concentration (FAC). FAC is usually related to the efficiency of the milling process (Hinton 1959).

Nitrogen fertilizer effect on GAC was significant in three out of four site years (Table 5.1). At the Ste-Rosalie site, in 1990, any addition of N fertilizer caused a 25 % average reduction in mean GAC. At the same site, in 1991, due to N fertilizer addition, GAC was only in the range of 15 mg g^{-1} to 22 mg g^{-1} (Table 5.2). The only significant interaction was for N level x timing at the Macdonald site in 1991, when compared to a single application, split N applications increased GAC (Table 5.3). These increases in GAC were smaller at higher levels of N fertility (Table 5.3) and not significant at 180 kg N ha^{-1}. The GAC was also different among the cultivars in three out of four site-years (Table 5.1). The cultivar Columbus always had the highest GAC (ranging between 20 and 23 mg g^{-1}), and the cultivar Hege 155 85

always had the lowest (ranging from 18 to 21 mg g^{-1}). On the other hand flour ash concentration (FAC) was only affected by N fertilizer level at the Macdonald site in 1991 (Table 5.4). Increasing levels of N fertility caused a beneficial reduction in FAC (Table 5.5). It seems that in the regions tested, wheat N fertilizer management has no detrimental effect on GAC nor FAC.

5.4.2 Flour extraction

In both years, flour extraction (FE) differed among cultivars (Table 5.4). Columbus always had the highest FE (736 and 749 g kg^{-1} in 1990 and 1991 respectively). The FE of the other cultivars were lower, with no particular order in both years (Tables 5.5 and 5.6). A significant N level x timing interaction existed in 1990 only (Table 5.4), when the fertilizer was applied only at seeding, any addition of N increased the FE by 5 %. When the N fertilizer application was split, there was no difference among the effects of the different levels on FE. Splitting the N application had a detrimental effect on FE compared to a single N addition (Table 5.3). In 1991, any N fertilizer addition caused a 1.4 % increase in FE (Table 5.5). A N fertilizer effect on FE is not surprising since a correlation is observed between FE and grain protein concentration (GPC) ($r=0.3^{*}$, 0.34^{**} in 1990 and 1991 respectively).

5.4.3 Flour protein concentration:

During the milling procedure, the wheat kernel gets debranned and degermed. The starchy endosperm is crushed to yield the flour. The constituents of the endosperm and flour are expected to be similar, and factors affecting the first are thus expected to affect the latter in the same way. The GPC was closely correlated to flour protein concentration (FPC) in both years ($r=0.98^{***}$ in 1990 and $r=0.70^{***}$ in 1991). Increasing N fertilizer levels and split N application both affected FPC (Table 5.4) and GPC (section 4) positively. In 1990, FPC increased from 11 % to 29 % and in 1991, it increased from 13 % to 21 % due to N fertilizer application (Tables 5.5 and 5.6). In the first year, FPC increased consistently with each increment of N fertilizer. In the second year, the application of 60 kg N ha^{-1} did not improve FPC, probably due to the presence of 38 kg residual N ha^{-1} in the root zone (section 6). Compared to a single application, splitting the N fertilizer application improved FPC

by 3 % and 8 % in 1990 and 1991 respectively (Tables 5.5 and 5.6). No significant interaction was observed. The cultivars used covered the GPC range from 130 to 174 mg g^{-1} (section 4). Their FPC ranged between 102 and 13 5 mg g^{-1} in 1990 and 121 and 136 mg g^{-1} in 1991 (Tables 5.5 and 5.6). In the first year, a clear segregation in FPC existed among the cultivars. They ranked in the following order from highest to lowest: Columbus, Katepwa, Max and Hege 155-85 In the second year, the FPC of Hege 155-85 approached that of Max because Hege 155-85 may have been more sensitive to the residual nitrates, and the FPC of Max approached that of Katepwa.

5.4.4 Hagberg Falling Number:

No kernel sprouting was visible in the field in either year. Nonetheless, Hagberg falling number (HFN) was determined and the values obtained confirm that the alpha-amylase activity in the grain was optimal for bread making or even low (operation manual of the instrument) (Tables 5.5 and 5.6) Millers prefer low levels of endogenous alpha-amylase as its activity is unwanted. It negatively affects the bread crumb and quality (Perten, 1964) In 1990, significant interactions often occurred (Table 5 4) When N application was split, HFN were lower than when the N application was single (Table 5.3) but were increased by any addition of N fertilizer only with single applications. Gooding et al. (1986) suggested that the alpha-amylase activity is reduced (i.e HFN increased) by N application due to a delay in maturity Our data (sections 3 and 4) do in fact show a delay in maturity due to N fertilizer application and earlier maturing plants when the N application was split. However, this does not explain the HFN differences observed among cultivars Columb had the lowest alpha-amylase activity (i e. highest HFN) followed by the other cultivars in the order. Katepwa, Max then Hege 155-85 although the cultivar Hege 155-85 matured the last (section 4). This suggests that the alpha amylase activity is highly heritable In 1991, there was no significant interaction nor N level effect on HFN High residual nitrates in the root zone (average of 33 kg N ha^{-1}, unpublished data) may have been the reason for the absence of a fertilizer effect in 1991. When N fertilizer application was split, mean HFN increased by 2.3 % which is in contradiction with the data from the previous year (Table 5 5). It is noted that

maturity dates were not affected by splitting the N fertilizer application, however, total soil residual nitrate data show a slightly higher value in the plots where N fertilizer application was split (section 6) which resulted in a slightly higher total N in plots that had received the split application compared to the plots where N was added in a single application The cultivars ranked in the same order as in 1990 (Tables 5.5 and 5.6).

5.4.5 Flour water absorption:

Increasing N levels in both years affected flour water absorption (Abs) significantly, increasing it from 3.8 % to 6.3 % in 1990 and from 1.9 % to 2.6 % in 1991 (Tables 5.5 and 5.6) A significant cultivar by fertilizer application timing existed in 1990 (Table 5 4). The Abs of the cultivar Hege 155-85 was reduced by 2.1 % when N fertilizer application was split as compared to a single application while the Abs of the other three cultivars was not affected (Table 5.8). In 1991, split application of the N fertilizer had the opposite effect, Abs was increased by 1.9 % when the N fertilizer application was split compared to when the fertilizer was added in a single application In 1991, the cultivars Columbus and Katepwa had equivalent Abs which was 2 5 % higher that the Abs of Max and 7 9 % higher than the Abs of Hege 155-85 (Table 5 5). Along with other flour constituents, mainly damaged starch, flour protein plays a key role in determining the rate and capacity of water absorption by flour (Bushuk, 1985) This explains the response of Abs to N treatments in this study, and Abs was is highly correlated with FPC ($r=0.95^{***}$ in 1990 and $r=0.60^{**}$ in 1991) This makes the response of the cultivar Hege 155-85 to N split application surprising

5.4.6 Dough development time:

In 1990, a significant N level by cultivar interaction existed for dough development time (DT)(Table 5.4). Nitrogen fertilizer level increased the dough development time (DT) of all cultivars but the nature of the increase varied among cultivars The DT of the cultivars Columbus and Katepwa improved with the addition of 60 kg N ha^{-1}. The DT of the cultivar Max started improving only at 120 kg N ha^{-1} while only a slight increase of the DT of the cultivar Hege 155-85 existed over the

entire fertilizer range. At the levels of 0, 60, and 120 kg N ha^{-1}, the DT of the cultivar Columbus was the longest followed by Katepwa, Max, then Hege 155-85. At the N fertilizer level of 180 kg ha^{-1}, the DT of Columbus, Katepwa and Max were equivalent and 300 % longer than the DT of the cultivar Hege 155-85 (Table 5.7). There was no significant effect of the timing of the N fertilizer application on DT in 1990 (Table 5.4). On the other hand, in 1991 such an effect was significant (Table 5.4); mean DT was by 19 % longer when N fertilizer application was split as compared to a single application. Nitrogen fertilizer level had a positive effect on DT. An addition of 60 kg N ha^{-1} increased DT by 39 % while an addition of 120 or 180 kg N ha^{-1} increased DT by 77 % (Table 5.5). As observed in the previous year, the DT of Columbus was the longest and DT of Hege 155-85 was the shortest (Tables 5.5 and 5.6). Dough development, according to Preston and Kilborn (1984) is related to changes occurring in the gluten protein during mixing. Dough development N response follows the FPC response. The correlation between the two parameters was found to be highly significant ($r=0.84^{**}$ in 1990 and $r=0.63^{**}$ in 1991). This corresponds to the findings of Bushuk et al. (1969).

5.4.7 Dough stability time:

In 1990, a significant N fertilizer level by application timing interaction occurred for dough stability time (Stab) (Table 5.4). The Stab gets longer only with a single addition of N fertilizer, starting at the levels of 120 or 180 kg N ha^{-1}, but increases with an increasing level of N fertilizer in a split application (Table 5.3). In both years, a significant interaction existed between N level and cultivar (Table 5.4). The cultivars showed different sensitivities to N fertilizer applications. In 1990, Stab of the cultivar Columbus improved by 51 % with the addition of any level of N fertilizer. There was an improvement up to 66 % in Stab of Katepwa with increasing N additions up to the level of 120 kg N ha^{-1} but not with the application of 180 kg N ha^{-1}. The response of the cultivar Max occurred starting at 120 kg N ha^{-1}. This was also the case for the cultivar Hege 155-85. At 180 kg N ha^{-1}, the cultivar Max had the longest Stab followed closely by Hege 155-85, Katepwa then Columbus. In 1991, only the Stab of the cultivar Hege 155-85 increased with increasing N levels and

reached a maximum of 9.6 min at the level of 180 kg N ha^{-1}. The Stab of the other cultivars remained the same throughout the entire N fertilizer range (Table 5.7).

5.4.8 Index of tolerance:

In 1990, splitting the N application improved the dough index of tolerance (IT) by 18 % (i.e increased the dough strength) compared to a single fertilizer application (Table 5.6). In both years, N fertilizer levels affected the IT of the cultivars differently. The IT of the cultivar Columbus was not influenced by N fertilizer addition in either year. In 1990, the dough strength of the cultivar Hege 155-85 was improved by 14 % to 60 % with increasing levels of N fertilizer. In 1991, the addition of 60 kg N ha^{-1} or 120 kg N ha^{-1} improved the dough strength of Hege 155-85 by 41 % and the addition of 180 kg N ha^{-1} by 61 %. In 1991, Katepwa and Max were not influenced by N fertilizer additions. In 1990 both were improved by N fertilizer addition, Max had the strongest dough among all the cultivars when it received 180 kg N ha^{-1}. In 1991, Hege 155-85 had the strongest dough at the highest N level. In either year, when Columbus received no fertilizer, it had the strongest dough (Table 5.7).

5.4.9 Bread loaf volume.

In 1990, there was a significant three way interaction for bread loaf volume (BLV) (Table 5.9). The BLV of the cultivar Columbus was high throughout the range of N fertilizer additions, not affected by the schedule of fertilizer application. The BLV of the cultivar Katepwa was second when no fertilizer was added, but it increased when 60 kg N ha^{-1} were added in a split fashion and at higher N fertilizer levels regardless of the schedule of fertilizer application. The cultivar Max was responsive to N fertilizer levels up to 120 kg N ha^{-1} and had larger a BLV when N fertilizer application was split as compared to a single application, sometimes of a higher N level. The larger increase in BLV of the cultivar Hege 155-85 was observed when N fertilizer application was split. Single application increased BLV of Hege 155-85 by 32 % while split application of the N fertilizer caused an increase of 121 %. When the cultivars received 180 kg N ha^{-1} in a split application, they all gave bread loaves of equivalent volumes (Table 5.9). In 1991, the N level by cultivar

interaction was significant. The cultivar Columbus showed no significant response to N fertilizer addition. It always had a BLV greater than 900 cc^{-1}. The control BLV of Katepwa and Max were not different. When the cultivar Katepwa received 60 kg N ha^{-1}, its BLV was increased to the maximum attained i.e. by 23 %. The BLV of Max increased to the maximum attained when it received 120 kg N ha^{-1} and did not respond to the lower level of N fertilizer addition. The BLV of the cultivar Hege 155-85 was increased by 20 % due to the addition of 60 kg N ha^{-1} or 120 kg N ha^{-1} and by 42 % due to the addition of 180 kg N ha^{-1} (Table 5.7).

5.4.10 Classification of the flour:

Preston and Kilborn (1984), classified wheat flours according to their protein concentration and dough characteristics as follows:

	FPC mg g^{-1}	Abs mg g^{-1}	DT mm	IT FU
Weak	75 - 90	< 550	2.5	> 100
Medium	100 - 115	540-600	2.5 - 4	60 - 100
strong	> 115	> 580	4 - 8	15 - 50

In both years flour from Columbus and Katepwa could be classified as strong. In 1990, flour from Max had rather medium FPC and Abs, but DT and IT of a strong flour when N fertilizer was used. In 1991, flour from Max could be clearly classified as strong. In 1990, flour from Hege 155-85 had FPC and Abs of a medium range, DT of a weak flour, IT of a medium quality at low levels of N fertility and of strong quality at high levels of N fertility. In 1991, flour from Hege 155-85 could be classified as medium with strong protein. The difference between 1990 and 1991 for flour of Max and Hege 155-85 is probably due to the higher soil nitrate levels at planting in the second year.

5.4.11 Economical consideration:

Based on the 1992 market prices, on flour extraction rates and on respective protein concentrations, we calculated a higher return ha^{-1} from the grain of Columbus despite its low yield, than from Hege 155-85 or Max. For the latter two cultivars, high potential yields were offset by N fertilizer and application costs. In 1990, flour

returns ha^{-1} were higher for Columbus and Katepwa than for Hege 155-85 and Max as the latter needed gluten supplement to meet bakers' protein requirement. In 1991, despite the gluten supplement needed, we calculated a higher return ha^{-1} for Hege 155-85 and Max than for Columbus and Katepwa. Assuming that all the flour reaching the bakery has a protein concentration at or above 125 mg g^{-1}, in 1990, flour of Hege 155-85 gave on average 9 % more loaves ha^{-1} than the others while in 1991 the figure rose to 18-29 %. Based on a fixed return per loaf, the cultivar Hege 155-85 may be the most profitable per ha.

5.5 CONCLUSIONS:

This experiment has demonstrated that, under such conditions, all cultivars tested may be acceptable for bread wheat production. At high levels of N fertilizer, Max and Hege 155 85 were equivalent in their bread scores to Katepwa and Columbus Nitrogen fertilizer time of application positively affects bread wheat baking quality variables thus giving a chance to reduce the level of N fertilizer application yet have the same financial result. In a year of high precipitation causing N leaching, Hege 155-85 could be risky for producers.

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Table 5.1 Analysis of variance of grain ash percentage (GAP)

	1990	1991	1990	1991
	Macdonald		Ste-Rosalie	
N level (N)	n.s.	**	**	*
N application (T)	n.s.	**	n.s.	n.s.
Cultivar (C)	**	**	n.s.	**
N*T	n.s.	**	n.s.	n.s.
N*C	n.s.	n.s.	n.s.	n.s.
T*C	n.s.	n.s.	n.s.	n.s.
N*T*C	n.s.	n.s.	n.s.	n.s.

* significant at the 0.05 level, ** significant at the 0.01 level
n.s. not significant.

Table 5.2 Main effects of N levels, timing of N fertilizer application and cultivar on grain ash concentration (mg g^{-1})

	Macdonald		Ste-Rosalie	
	1990	1991	1990	1991
N level (kg ha)				
0	22	20.0 a	38 a	20.00 a
60	22	19.0 b	30 b	19.99 ab
120	22	18.8 c	27 b	19.91 bc
180	22	18.8 c	27 b	19.85 b
significance	n.s.	*	*	*
Cultivar				
Columbus	23 a	19.9 a	30	20.7 a
Hege155-85	21 b	18.2 c	28	19.1 c
Katepwa	22 a	19.7 a	30	19.7 b
Max	21 b	19.3 b	35	20.5 a
significance	*	*	n.s.	*
N Timing				
Single	22	19 b	31	20.0
Split	22	20 a	30	20.0
significance	n.s.	*	n.s.	n.s.

* significant at the 0.05 level, n.s. not significant
Values in the same column followed by the same letter are not significantly different from each other by a protected Duncan's new multiple range test.

Table 5.3 Simple effects of N level and timing of N fertilizer application on GAP, Extr., Stab and HFN

N level (kg ha^{-1})	N timing	1991 GAC (mg g^{-1})	1990 FE (g kg^{-1})	1990 Stab (min)	1990 HFN
0	Single	20.4 a	707 b	4.45 d	464 c
	Split	20.2 ab	707 b	4.45 d	463 c
60	Single	18.7 de	748 a	5.97 d	512 ab
	Split	19.8 b	714 b	7.20 cd	490 bc
120	Single	18.4 e	738 a	7.01 cd	534 a
	Split	19.3 c	700 b	10.90 a	470 c
180	Single	18.6 de	749 a	8.86 ab	514 b
	Split	19.0 cd	693 bc	11.76 a	464 c
significance		*	*	*	*

* significant at the 0.05 level, FE = flour extraction, Stab = dough Stability, HFN = Hagberg Falling Number, GAC = grain ash concentration. Values in the same column followed by the same letter are not significantly different from each other by a protected Duncan's new multiple range test.

Table 5.4 Analysis of variance of flour quality variables at Macdonald.

Year 1990	N level (N)	N timing (T)	Cultivar (C)	N*C	N*T	C*T	N*C*T
FPC	**	*	**				
FAC							
FE	**	**	**		**		
Abs	**		**			**	
DT	**		**	*			
Stab	**	**	**	**	*		
IT	**	*	**	**			
BLV	**	**	**	**	**	*	*
HFN	**	**	**		*	*	
Year 1991							
FPC	**		**				
FAC							
FE	**		**				
Abs	**	**	**				
DT	**	**	**				
Stab	**			**			
IT	**			**			
BLV	**		**	*			
HFN		**	**				

* significant at 0.05 level, ** significant at 0.01 level, FPC = flour protein concentration (mg g^{-1}), Abs = flour water absorption (mg g^{-1}), DT = dough development time (min), IT = Index of tolerance (farinograph unit), HFN = Hagberg falling number, FE = flour extraction (g kg^{-1}), FAC = flour ash concentration(mg g), BLV = bread loaf volume (cc^{3}).

Table 5.5 Main effects of N level, timing of N fertilize and cultivar on flour quality variables at the Macdonald site in 1991.

N level kg ha^{-1}	FPC mg g^{-1}	FAC mg g^{-1}	FE g kg^{-1}	Abs mg g^{-1}	DT min	IT FU	Stab min	BLV cc^{3}	HFN
0	117 c	5.4 a	730 b	585 c	3.1 c	52.4 a	5.1 b	790 d	387
60	123 c	5.2 ab	740 a	596 b	4.3 b	42.8 b	6.4 a	872 c	402
120	132 b	5.0 b	740 a	607 a	5.4 a	44.5 b	6.8 a	928 b	396
180	142 a	5.0 b	743 a	613 a	5.7 a	41.0 b	7.3 a	996 a	402
significance	*	*	*	*	*	*	*	*	n.s.
Cultivar									
Columbus	136 a	5.1	749 a	620 a	5.5 a	41.0	6.8	957 a	461 a
Hege 155-85	121 c	5.0	731 bc	570 c	3.6 c	46.0	6.7	822 c	282 d
Katepwa	131 ab	5.2	728 c	610 a	4.7 b	46.0	6.0	922 ab	432 b
Max	125 bc	5.3	740 b	600 b	4.6 b	47.0	6.1	886 b	413 c
significance	*	n.s.	*	*	*	n.s.	n.s.	*	*
N application									
Single	123 b	5.1	739	595 b	4.2 b	46	6.1	883	392 b
Split	133 a	5.2	736	606 a	5.0 a	45	6.7	910	401 a
significance	*	n.s.	n.s.	*	*	n.s.	n.s.	n.s.	*
C.V.	9	7	2	2	14	19	20	8	4

* significant at the 0.05 level, n.s.= not significant, FPC = flour protein concentration, Abs = flour water absorption, DT = dough development time, IT = index of tolerance, HFN = Hagberg falling number, FE = flour extraction, FAC = flour ash concentration, BLV = bread loaf volume, FU = farinograph unit.
Values in the same column followed by the same letter are not significantly different from each other by a protected Duncan's new multiple range test.

Table 5.6 Main effects of N level, timing of N fertilizer application and cultivar on flour quality variables at the Macdonald site in 1990.

N level kg ha^{-1}	FPC mg g^{-1}	FE g kg^{-1}	Abs mg g^{-1}	IT FU	DT min	Stab min	BLV cc^{3}	HFN
0	103 d	706 c	574 d	45.9 a	2.5 a	4.5 c	630 d	463 b
60	114 c	731 a	597 c	41.5 a	6.3 b	6.6 b	766 c	501 a
120	125 b	718 b	606 b	27.4 b	4.2 b	9.0 a	834 b	502 a
180	132 a	721 b	610 a	24.6 b	5.6 c	10.3 a	899 a	489 a
significance	*	*	*	*	*	*	*	*
Cultivar								
Columbus	135 a	736 a	620 a	26.0 c	6.2 a	9.2 a	934 a	559 a
Hege 155-85	102 d	711 c	570 d	51.0 a	2.0 d	5.1 c	654 c	415 c
Katepwa	128 b	719 bc	610 b	29.0 bc	5.0 b	8.4 ab	890 a	491 b
Max	111 c	713 bc	590 c	35.0 b	4.0 c	7.7 b	719 b	490 b
significance	*	*	*	*	*	*	*	*
N application								
Single	117 b	736 a	599	38.53 a	3.96	6.6 b	719 b	506 a
Split	120 a	703 b	596	32.14 b	3.99	8.6 a	845 a	472 b
significance	*	*	*	*	n.s.	*	*	*
C.V.	3	2	0.86	24	25	25	9	6

* significant at the 0.05 level, n.s.= not significant, FPC = flour protein concentration, Abs = flour water absorption, DT = dough development time, IT = index of tolerance, HFN = Hagberg falling number, FE = flour extraction, FAC = flour ash concentration, BLV = bread loaf volume, FU = farinograph unit.
Values in the same column followed by the same letter are not significantly different from each other by a protected Duncan's new multiple range test.

Table 5.7 Simple effects of N levels and cultivar on flour quality variables

N level (kg ha^{-1})	Cultivar	1990 DT min	1990 IT FU	1990 Stab min	1991 Stab min	1991 IT FU	1991 Loaf vol cc3
0	Columbus	4.1 e-g	28.9 g-n	7.1 d-g	6.5 cd	41 cb	905 ab
	Hege 155-85	1.5 m	70.0 a	1.8 j	3.4 d	71 a	682 d
	Katepwa	2.5 g-l	37.5 e-i	5.8 f-h	5.4 c	50 b	785 cd
	Max	1.8 l-m	55.0 b-d	3.3 h-j	5.1 cd	47 b	790 cd
60	Columbus	5.5 b-e	24.0 k-n	10.7 a-c	6.7 cb	42 bc	945 a
	Hege 155-85	1.8 k-m	59.5 a-c	2.4 ij	6.0 cb	42 bc	814 bc
	Katepwa	4.8 d-f	31.5 f-m	8.3 c-f	6.8 cb	42 bc	944 a
	Max	2.1 i-m	50.9 c-e	4.9 g-i	6.1 cb	45 b	784 cd
120	Columbus	6.4 ab	24.3 j-n	10.1 a-d	7.1 cb	39 bc	995 a
	Hege 155-85	2.0 j-m	45.3 d-f	5.9 e-h	7.9 ab	43 b	822 bc
	Katepwa	4.9 c-f	24.0 k-n	9.6 a-d	6.2 cb	45 b	937 a
	Max	3.7 f-i	16.3 n	10.4 a-c	5.9 cb	51 b	960 a
180	Columbus	7.3 a	28.8 h-n	9.0 b-d	6.8 cb	43 b	982 a
	Hege 155-85	2.2 h-m	27.8 i-n	10.2 a-c	9.6 a	28 c	970 a
	Katepwa	6.5 ab	23.3 l-n	9.9 a-d	5.5 c	48 b	1022 a
	Max	6.6 ab	18.5 mn	12.2 a	7.2 c	45 b	1010 a
significance		*	*	*	*	*	*

* significant at the 0.05 level, DT= development time, IT = index of tolerance, Stab = Stability, FU = farinograph unit. Values in the same column followed by the same letter are not significantly different from each other by a protected Duncan's new multiple range test.

Table 5.8 Simple effects of timing of N fertilizer application and cultivar at Macdonald in 1990

N timing	Cultivar	Abs mg g^{-1}	HFN
Single	Columbus	623 a	571 a
	Hege 155-85	575 b	448 d
	Katepwa	609 c	515 b
	Max	589 d	489 bc
Split	Columbus	629 a	547 a
	Hege 155-85	563 e	381 e
	Katepwa	612 c	467 cd
	Max	585 d	491 bc
significance		*	*

* significant at the 0.05 level, Abs = water absorption, HFN = Hagberg falling number
Values in the same column followed by the same letter are not significantly different each other by a protected Duncan's new multiple range test.

Table 5.9 Simple effects of N level, timing of N fertilizer application and cultivar on bread loaf volume at Macdonald in 1990

N level	N timing	Cultivar	Loaf vol.cc[1]
0	Single	Columbus	845 a-h
		Hege 155-85	416 o
		Katepwa	795 f-h
		Max	462 no
	Split	Columbus	845 a-h
		Hege 155-85	417 o
		Katepwa	795 gh
		Max	462 no
60	Single	Columbus	841 c-h
		Hege 155-85	584 i-n
		Katepwa	842 b-h
		Max	509 l-o
	Split	Columbus	895 a-g
		Hege 155-85	722 h-j
		Katepwa	933 a-g
		Max	803 e-h
120	Single	Columbus	937 a-g
		Hege 155-85	508 m-o
		Katepwa	912 a-g
		Max	577 j-n
	Split	Columbus	998 a
		Hege 155-85	874 a-g
		Katepwa	933 a-g
		Max	932 a-g
180	Single	Columbus	964 a-g
		Hege 155-85	557 k-o
		Katepwa	811 d-h
		Max	953 a-g
	Split	Columbus	1017 a
		Hege 155-85	921 a-g
		Katepwa	1009 a
		Max	965 a-g
significance			*

* significant at the 0.05 level.
Values in the same column followed by the same letter are not significantly different from each other by a protected Duncan's new multiple range test.

Preface to section 6

Section 6 is the material contained in a manuscript which will be submitted for publication. The current format conforms with guidelines set by the Faculty of Graduate Studies. Tables, figures and literature cited are presented at the end of this section.

In this section we discuss the effects of N fertilizer levels, time of application and cultivars on soil nitrate levels in the 0-60 cm layer of soil.

Section 6

EVALUATION OF N FERTILIZER LEVEL AND TIMING AND CULTIVARS ON SOIL NITRATE RESIDUES

6.1 ABSTRACT

In order to assess the potential manipulation of nitrogen management to allow bread quality wheat production in Eastern Canada, an experiment was conducted for two years at each of two sites in Québec to study the effect of level and timing of N fertilizer application on residual soil NO_3-N levels in the soil layers from 0-20 cm and 20-60 cm. The cultivars used are known to have potential as bread wheat. The soil types were Bearbrook clay and Ste-Rosalie clay. The experiment was 4 x 4 x 2 factorial. The cultivars were: Columbus, Katepwa, Max and Hege 155-85. In both years 0, 60, 120 and 180 kg N ha^{-1} were applied either 100 % at seeding time or 60 % at seeding and 40 % at anthesis. Cultivar effects on soil nitrate levels existed only at Ste-Rosalie, suggesting that the cultivars used seemed better adapted to the conditions at Macdonald. Changes in soil NO_3-N levels over winter suggested that mineralization had occurred. Nitrogen balance sheet values were higher than the actual measured NO_3-N residue in the fall of each year, indicating that there was a loss of NO_3-N from the system, possibly due to denitrification. Potential increases, thus potential pollution, in residual soil NO_3-N existed only at the level of 180 kg N ha^{-1}. Overwinter changes in soil NO_3-N levels were proportional to the inverse of the fall NO_3-N levels. Differences between the sites were marked.

6.2 INTRODUCTION:

When N fertilizer is applied to a field, it can be a benefit through increased crop yields, however the risks associated with potential residual NO_3-N levels becomes a concern (Onken et al. 1985). Soil NO_3-N may be subject to leaching to ground water (Hahne et al. 1977) and be a health hazard (Timmons and Dylla 1981). Soil NO_3-N is also subject to denitrification which may produce N_2O, an agent of ozone layer destruction (Liang et al. 1991). Whenever NO_3-N moves below the root

zone, it then becomes unavailable to plants, and at a minimum represents an economic loss to crop producers (Timmons and Dylla 1981).

Nitrate leaching, accumulation and depletion in the soil depend largely on the amount of N fertilizer added, cultural practices used, and soil characteristics (Onken et al. 1985).

An experiment was conducted at two locations in Eastern Canada to test the effect of N fertilizer level and timing, and spring wheat cultivar on the fate of applied fertilizer in the soil.

6.3 MATERIALS AND METHODS:

The study was conducted on Bearbrook clay soil (fine, mixed, non-acid, frigid, typic Humaquept), at the Lods Agronomy Research Centre, McGill University, Macdonald Campus, and on Ste-Rosalie clay soil (fine, non-acid, frigid, typic Humaquept) at the COOP Fédérée research farm, Ste-Rosalie, Québec, Canada in 1990 and 1991. The previous crop at the 1990 site was oat (Avena sativa L.) for the Macdonald Campus site and mixed forages for the Ste-Rosalie site. In 1991, the experiment was repeated on the same fields, thus the previous crop at both locations was hard red spring wheat (Triticum aestivum L.). Prior to seeding, the land for all four site-years received adequate amendment of P and K. The experimental design was a randomized complete block arranged as 4 X 4 X 2 factorial with 4 replicates. The wheat cultivars sown were, Columbus, which is normally acceptable as a bread wheat under the western Canada Red Spring grades (Agriculture Canada, 1980); Max, which has an acceptable performance in Eastern Canada, and was recommended for milling and bread making (Agriculture Canada, 1987), Katepwa, which has good milling and baking properties (Campbell and Czarnecki 1987), and Hege 155 85 which is currently being tested for licensing as a bread wheat in Eastern Canada. The cultivars received 0, 60, 120 or 180 kg N ha^{-1} in the form of granular ammonium nitrate, either all at seeding, or 60 % at seeding and 40 % at anthesis. The fertilizer was broadcast by hand on the plot surface and incorporated by hand raking.

The plots were sown at 450 seed m^{-2} with a cone-type plot seeder (Wintersteiger America Inc , Lincoln, Nebraska) using certified seed treated with Vitaflo 280 (15 % carbathiin (5-6-dihydro-2-methyl-N-phenyl-1, 4-oxathiin-3-carboxamide) and 13 % thiram (tetramethyl-thiuramdisulfide)). Seeding was done on the first and eleventh of May at Macdonald, and on the tenth and twenty first of May at Ste-Rosalie in 1990 and 1991 respectively. Weeds at Macdonald were controlled with Pardner (bromoxynil 3, 5-dibromo-4-hydroxybenzonitrile) applied at 1 L ha^{-1} at the two-leaf stage Weeds at Ste-Rosalie were controlled with a mixture of 280 g a.i. ha^{-1} of bromoxynil and 280 g a.i ha^{-1} of MCPA (2-methyl-4-chlorophenoxyaceticacid) also applied at the two-leaf stage At plant maturity, pre-marked 1 m row samples were hand harvested by uprooting and air-dried indoors at room temperature for 15 days. Plots were trimmed just prior to harvest to eliminate edge effects due to pathways. After trimming, each plot at Macdonald was 180 cm x 456 cm with 12 rows spaced 15 cm apart in both years. After trimming, plot size at Ste-Rosalie in 1990 was 90 cm x 500 cm, and in 1991 90 cm x 525 cm with 6 rows spaced 15 cm apart Trimmed plots were combine harvested for yield (YLD) determination. Plot yields are expressed on a t ha^{-1} basis at 14 % moisture. Subsamples of grain were milled in a Udy cyclone mill (Udy Corp, Fort Collins, CO.) and straw from the 1 m samples was milled using a Wiley mill in both cases through a 1 mm mesh Protein (N x 5.7) was determined on grain and straw by the Kjeldahl method using a Tecator Kjeltec System I (Tecator AB, Hoganas, Sweden)

Each year after harvest and in 1991 prior to planting, one soil sample was taken from individual plots from the 0-20 and 20-60 cm soil layers Prior to planting in 1990 only four replicates were taken from each site. The core diameter was 12.5 cm. The samples were stored in a cold room at 1°C prior to extraction for NO_3-N and NH_4-N Analyses of soil were done by shaking 15-20 g of fresh soil, in 100 ml of 1 *M* KCl solution for 60 min. The suspension was filtered and the filtrate was analyzed colorimetrically on a Technicon Autoanalyzer. A soil subsample was oven dried to determine moisture content The concentration of NO_3-N in the soil was converted to total NO_3-N using soil bulk density and moisture content values. Change

of NO_3-N levels over winter were calculated as the difference between spring and fall NO_3-N values.

Nitrogen fertilizer use efficiency (NUE) was generated as follows:

$$\frac{\text{Grain N from treatment - grain N from control}}{\text{Total soil N in treatment - Soil N in control}}$$

N balance sheets were generated as follows:

Spring soil NO_3-N + Fertilizer N - Crop N uptake.

Data were analyzed using SAS (SAS Institute, 1985). The F-test (Steel and Torrie, 1980) was used to determine whether the variations caused by the treatments and their interactions were significant. Probabilities of less than or equal to 0.05 were considered significant for main effects and interactions. An ANOVA-protected Duncan's new multiple range test or contrasts were performed to compare means of variables found to vary significantly by the F-test. Contrasts were used to compare means of variables affected by N fertilizer level. The general linear model procedure of SAS was used to determine regression parameters

Weather data for all four site-years are presented in section 4.

6.4 RESULTS AND DISCUSSION:

Initial spring distribution of NO_3-N in the soil varied with depth. Nitrate-N levels in the surface samples were always numerically lower than the NO_3-N at the lower depth, although significance of the difference could not be tested (Tables 6.2 and 6.8). Nitrate-N values frequently varied significantly due to N fertilizer level In the four site-years (Table 6.1), soil NH_4-N values were low, and no agronomically significant variability among treatments occurred. Thus NH_4-N has not been discussed here.

6.4.1 N fertilizer effects:

6.4.1.1 Ste-Rosalie site:

Fall 1990 soil NO_3-N values were significantly increased with added N fertilizer only in the 0-20 cm soil layer ($P<0.01$)(Table 6.1). The absence of such a significance in the 20-60 cm profile suggests that little or no NO_3 moved downwards

in that first growing season and/or that immobilization of the NO_3-N in the top profile could have occurred. Interaction effects in the fall of 1990, were significant for total soil NO_3-N residues. Since there were no significant main effects of the treatments, these interactions have not been discussed here.

Prior to planting in 1991, the N fertilizer effect was significant on soil NO_3-N only in the 20-60 cm profile ($P < 0.05$)(Table 6.1). Overwinter mineralization and precipitation (868.1 mm in total) caused NO_3-N to leach into the deeper layer of the soil (Von Jolly and Pierre 1977) and may have resulted in the observed significance.

Fall 1991 soil NO_3-N values in the two soil layers were significantly increased only when 180 kg N ha^{-1} are added (increases of 54 % in the top soil and 38 % in the sub soil) (Table 6.2). In the 0-20 cm soil layer, this increase was due to spring N fertilizer application. The presence of this effect in the 20-60 cm soil layer was probably due to the sum of residual NO_3-N and the downward movement of the spring applied added fertilizer.

Higher residual NO_3-N in the soil, especially in the plant root zone, when higher N fertilizer is added may also be explained by a significantly lower plant fertilizer N use efficiency (NUE) at higher fertilizer levels (Table 6.3). With increasing N fertilizer levels, NUE decreased linearly (Table 6.3). The differences in NUE among the different levels of N fertilizer mean that the plants took up smaller proportions of soil N as N levels increased, and that N fertilizer levels added were not limiting for plant growth (sections 3 and 4).

Spring 1991 NO_3-N values were higher than fall values. Changes overwinter were positive suggesting that mineralization occurred and this was significantly decreased as N fertilizer levels increased (Table 6.4). Soil NO_3-N values reached a constant by spring sampling periods (Table 6.2). A linear relationship existed between NO_3-N changes overwinter and fall NO_3-N levels (Table 6.5). Regression equations show that when fall NO_3-N levels were higher, overwinter NO_3-N increases were lower. A significant interaction existed between N level and cultivar on over winter changes but showed no particular trend (Table 6.6).

In both years, N balance values were positively influenced by N fertilizer levels. Values increased consistently with increasing N fertilizer level (Table 6.7) Values were positive, meaning that N input was higher than plant N uptake. Values were higher than the actual measured NO_3-N residue in the fall of each year, and this was especially true at the higher N fertilizer levels. This indicates that there was a loss of NO_3-N from the system, possibly due to denitrification, immobilization or leaching below 60 cm depth.

6.4.1.2 Macdonald site:

In the fall of both 1990 and 1991, increasing levels of added N fertilizer increased soil NO_3-N in both the 0-20 cm and the 20-60 cm soil layers (Table 6.1). The significance of the treatment effects between 20 and 60 cm suggests that leaching of the NO_3-N may have occurred during the growing season This phenomenon did not occur in the first growing season at Ste-Rosalie. In the fall of 1990, in the 0-20 cm soil layer, soil NO_3-N levels were increased consistently with increasing N fertilizer levels (Table 6.8) The largest increase was 108 % of the control (Table 6.8). In the fall of 1990 in the 20-60 cm soil layer as well as in both the 0-20 and 20-60 cm soil layers in the fall of 1991, residual NO_3-N values were higher only when 180 kg N ha^{-1} was added (Table 6 8).

As observed at the Ste-Rosalie site, overwinter NO_3-N changes in the 0-20 cm soil layer were significantly affected by N fertilizer level (Table 6.1) The greatest change occurred at the lowest level of N fertilizer level, while little change occurred at the 180 kg N ha^{-1} level (Table 6 4)

Residual NO_3-N values for the spring of 1991 were not significantly different among N fertilizer rates used and they were greater than levels in the fall of 1990 (Table 6.8). This indicates that greater mineralization may have occurred during the winter. The NO_3-N residuals in the fall of 1991 were usually lower than the spring values of the same year except at 180 kg N ha-1 (Table 6 8). This was mainly due to different plant NUE among the different N fertilizer levels.

As at the Ste-Rosalie site, NUE declined significantly with increasing levels of N fertilizer, resulting in increasing residual NO_3-N residuals at the higher N fertilizer levels (Table 6.8) The relationship between overwinter NO^3-N change and previous fall residual NO_3-N was found to be linear (Table 6.5).

The N balance was significantly affected by N fertilizer level in both years (Table 6.9). In the control plots and in the plots that received 60 kg N ha^{-1} (with the single exception of the cultivar Max, in 1990), N balance values were negative (Table 6.10) indicating that crop N uptake was higher than the N input plus the spring soil NO_3-N levels. Mineralization of soil N probably supplied the remainder of the crop N need. At 120 and 180 kg N ha^{-1}, or at 60, 120 and 180 kg N ha^{-1} for the cultivar Max in 1990, N balance values were positive, indicating a sufficient N input (Table 6.10). However values were lower than the actual residual NO_3-N measured suggesting that mineralization may have occurred in this growing season too.

6.4.2 Cultivar effect:

6.4.2.1 Ste-Rosalie site:

Only in the fall of 1990, were there significant differences among NO_3-N residuals due to cultivars (Table 6 1) These differences were most pronounced in the 0-20 cm soil layer ($P<0.01$). Under the cultivar Max, NO_3-N levels in the 0-20 cm soil layer were 40 % lower than levels under other cultivars (Table 6 2). In 1990, Max and Katepwa showed a better efficiency in N fertilizer use than the other two cultivars (Table 6.7). Since NO_3-N overwinter changes were noted to vary linearly with fall NO_3-N, a cultivar effect on overwinter changes was not entirely surprising (Tables 6.5 and 6.9 respectively).

Mineralization rates under the cultivar Max were about 10 fold under cultivars Katepwa and Hege 155-85 Under the cultivar Columbus, mineralization was, surprisingly, intermediate (Table 6.4). There was no cultivar effect on N balance values (Table 6.9).

6.4.2.2 Macdonald site:

All parameters studied failed to vary significantly among cultivars at the Macdonald site (Tables 6.1 and 6.9).

6.4.3 Time of N application effect:

6.4.3.1 Ste-Rosalie site:

There were no significant N timing effects on overwinter NO_3-N changes or N balance (Table 6.9). Split N application affected NUE significantly only in 1991 (Table 6.9). Nitrogen applied at anthesis has been reported to increase hard red spring wheat N uptake markedly (Wuest and Cassman 1992), therefore NUE is likely to be higher than when all N fertilizer is applied at seeding. Despite N timing effect on NUE, no such significant effect was observed on soil NO_3-N levels in either year (Table 6.1). Splitting the N fertilizer application may be beneficial to the plants, however, it does not seem to be more environmentally sound.

6.4.3.2 Macdonald site:

The only significant effect of N fertilizer application time occurred in 1990 when NUE was higher when 60 kg N ha^{-1} was split than when all of this N was added at seeding (Tables 6.1, 6.9 and 6.11). No such significance was observed at the higher fertilizer levels, meaning that the fertilizer added was not limiting to plant growth, even if it was all applied at seeding.

At Ste-Rosalie in 1991, total preplanting and after-harvest residual NO_3-N values were much larger than at Macdonald. Along with plant performances (sections 3, 4 and 5), this indicated that soil N supply was lower at Macdonald, or leaching was greater compared to Ste-Rosalie.

Cultivar effects existed only at Ste-Rosalie probably due to an interaction between soil type and genotype which did not occur at Macdonald. The cultivars used seemed better adapted to the physical conditions at Macdonald.

6.5 CONCLUSIONS:

This study showed that potential increases in residual soil NO_3-N, thus effect on the soil environment, existed only at the level of 180 kg N ha^{-1}, in three out of four site years. Overwinter changes were inversely proportional to the fall NO_3-N, thus it is important to minimize the latter to reduce these changes. Differences between the sites were marked. These differences may be due to climate, management or drainage.

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Table 6.1 Analysis of variance of soil NO_3-N values (kg N /ha) as a function of N level and timing of N fertilizer application and cultivar.

	N level	Timing	Cultivar	N*C	N*T	C*T	N*C*T
Ste-Rosalie 90 after harvest (fall)							
0-20 cm	**		**				
20-60 cm			*				
total			*				
Ste-Rosalie 91 pre-planting (spring)							
0-20 cm							
20-60 cm	*						
total				*			*
Ste-Rosalie 91 after harvest (fall)							
0-20 cm	*						
20-60 cm	**						
total	**						
Macdonald 90 after harvest (fall)							
0-20 cm	*						
20-60 cm	**						
total	**						
Macdonald 91 pre-planting (spring)							
0-20 cm							
20-60 cm			no significance				
total							
Macdonald 91 after harvest (fall)							
0-20 cm	*						
20-60 cm	*						
total	*						

* significant at the 0.05 level
** significant at the 0.01 level

Table 6.2 Fffects of fertılizer N level, tımıng of N fertilızer application and cultivar on soıl NO_3-N levels (kg N ha^{-1}) ın the fall of 1990, sprıng of 1991 and fall of 1991 at Ste-Rosalıe.

	0 -20 cm			20 - 60 cm			Total		
N level kg ha^{-1}	Fall 90	Sprıng 91	Fall 91	Fall 90	Sprıng 91	Fall 91	Fall 90	Spring 91	Fall 91
0	11.4	22.0	12.2	46.6	73.0	56.0	59.0	95.0	68.4
60	12.1	20.0	13.2	43.8	67.0	53.0	56.0	86.5	65.8
120	16.9	18.3	12.5	45.6	66.0	51.0	62.0	84.1	63.3
180	19.9	22.9	19.5	53.4	63.0	73.0	73.0	85.6	93.1
Trend	lin.	n.s.	lin.	n.s.	n.s.	quad.	n.s.	n.s.	quad.
Cultivar									
Columbus	14.6 a	21.9	14.5	41.5 b	70.0 a	54.9	56.0 bc	92.0	69.4
Hege	17.0 a	20.3	16.0	52.0 ab	71.2 a	66.1	69.0 ab	91.5	81.9
Katepwa	18.5 a	19.4	13.0	55.6 a	67.6 ab	52.1	75.0 a	87.0	65.1
Max	10.3 b	21.9	13.9	40.4 b	59.1 b	60.3	51.0 c	80.7	74.1
Significance	*	n.s.	n.s.	*	*	n.s.	*	n.s.	n.s.
N Timing									
Sıngle	15.6	20.9	13.3	44.5	64.8	56.5	60.3	85.7	69.8
Splıt	14.5	20.8	15.4	50.2	69.2	60.2	65.1	89.9	75.5
Sıgnıfıcance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

* sıgnıfcant at the 0.05 level, n.s. not significant
Values ın the same column followed by the same letter are not sıgnificantly different from each other by an ANOVA-protected Duncan's new multıple range test. Hege=Hege 155-85. Lin=lınear, quad=quadratıc.

Table 6.3 Effects of fertilizer N level (kg ha-1), timing of N fertilizer application and cultivar on Nitrogen use efficiency (NUE, %).

	Ste-Rosalie		Macdonald	
N level	1990	1991	1990	1991
60	42	25	56	75
120	33	19	44	64
180	25	15	34	55
Trend	linear	linear	linear	linear
Cultivar				
Columbus	31 b	20 b	46	63
Hege 155-85	27 b	20 b	42	60
Katepwa	39 a	28 a	44	64
Max	37 a	16 b	47	70
Significance	*	*	n.s.	n.s.
N timing				
Single	28 b	20	42	65
Split	39 a	22	47	63
Significance	*	n.s.	n.s.	n.s.

* significant at the 0.05 level, n.s. not significant. Values in the same column followed by the same letter are not significantly different from each other by an ANOVA-protected Duncan's new multiple range test

Table 6.4 Main effects of N level (kg ha^{-1}), timing of N fertilizer application and cultivar on overwinter changes (kg N ha^{-1}).

	Ste-Rosalie		Macdonald	
N level	0-20 cm	20-60 cm	0-20 cm	20-60 cm
0	11	26	24	17
60	7	22	10	15
120	1	20	11	13
180	3	9	- 1	5
Trend	lin.	n.s.	lin.	lin.
Cultivar				
Columbus	7 ab	29	17	12
Hege 155-85	3 b	19	8	12
Katepwa	1 b	13	10	11
Max	12 a	16	9	14
Significance	*	n.s.	n.s.	n.s.
N timing				
Single	5	21	8	12
Split	6	18	14	13
Significance	n.s.	n.s.	n.s.	n.s.

* significant at the 0.05 level, n.s. not significant.
Values in the same column followed by the same letter are not significantly different from each other by an ANOVA-protected Duncan's new multiple range test. Lin=linear.

Table 6.5 Regression coefficients of NO_3-N overwinter changes.

Ste-Rosalie:

Depth:

0-20 cm	y=-22.5 + 1.1 x	R^2=0.56***
20-60 cm	y=-62.5 + 0.9 x	R^2=0.48***
Total	y=-84.2 + 1.0 x	R^2=0.56***

Macdonald:

Depth:

0-20 cm	y=-34.8 + 1.1 x	R^2=0.43***
20-60 cm	y=-33.3 + 0.9 x	R^2=0.54***
Total	y=-69.7 + 1.1 x	R^2=0.55***

y= overwinter NO_3-N changes (kg N ha^{-1})
x= Previous fall NO3-N (kg ha^{-1})

Table 6.6 Simple effects of N level (kg ha^{-1}) and cultivar on overwinter NO_3-N changes (kg ha^{-1}) in the 0-20 cm soil profile at Ste-Rosalie.

N level	Columbus	Hege155-85	Katepwa	Max
0	12	11	14	9
60	11	0	3	15
120	4	8	-11	5
180	3	-9	- 1	19
Trend	n.s.	lin.	quad.	n.s.

Lin=linear, quad=quadratic, n.s.=not significant.

Table 6.7 Main effects of N level (kg ha^{-1}), timing of N fertilizer application and cultivar on N balance (kg ha^{-1}).

	Ste-Rosalie		Macdonald	
N level	1990	1991	1990	1991
0	82	10	-54	-28
60	98	35	- 3	-40
120	129	79	46	0
180	185	135	83	31
Trend	quad.	quad.	lin.	quad.
Cultivar				
Columbus	122	68	14	- 8
Hege 155-85	122	64	11	-12
Katepwa	125	68	25	- 6
Max	125	60	22	-12
Significance	n.s.	n.s.	n.s.	n.s.
N timing				
Single	126	60	13	- 8
Split	121	70	23	-11
Significance	n.s.	n.s.	n.s.	n.s.

n.s. not significant
Lin=linear, quad=quadratic.

Table 6.8 Effects of fertilizer N level, timing of N fertilizer application and cultivar on soil NO_3-N levels (kg N ha^{-1}) in the fall of 1990, spring of 1991, and fall of 1991 at Macdonald.

	0 -20 cm			20 - 60 cm			Total		
	Fall 90	Spring 91	Fall 91	Fall 90	Spring 91	Fall 91	Fall 90	Spring 91	Fall 91
N level kg ha^{-1}									
0	13.4	37.9	19.0	18.0	34.7	24.3	31.5	72.0	43.3
60	17.4	27.0	16.0	18.2	33.2	24.3	36.1	60.2	40.2
120	22.6	33.5	18.2	23.6	36.5	27.1	46.2	70.0	46.0
180	36.6	35.0	30.5	33.7	38.5	46.2	70.0	73.8	76.7
Trend	quad.	n.s.	quad.	lin.	n.s.	quad.	quad.	n.s.	quad.
Cultivar									
Columbus	19.4	36.4	18.5	22.4	34.7	28.7	42.2	71.1	47.0
Hege	24.6	32.2	21.9	24.1	35.7	31.9	48.7	67.9	54.5
Katepwa	21.5	31.5	20.3	24.3	35.6	37.1	45.8	67.1	47.4
Max	24.5	33.6	23.0	22.8	36.9	34.3	47.3	69.9	57.3
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
N Timing									
Single	24.6	32.5	18.7	23.9	35.9	29.3	48.5	68.2	48.4
Split	20.4	34.4	23.0	22.9	35.6	31.6	43.5	69.8	54.7
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

n.s. not significant.
Hege=Hege 155-85. Lin=linear, quad=quadratic.

Table 6.9 Analysis of variance of overwinter changes (kg ha^{-1}), N balance (kg ha^{-1}) and nitrogen use efficiency (NUE).

	N level	Cultivar	N timing	N*T	N*C	C*T	N*C*T
Overwinter changes, Ste-Rosalie							
0-20 cm	*	*			*		
20-60 cm							
Overwinter changes, Macdonald							
0-20 cm	**						
20-60 cm							
NUE, 1990							
Ste-Rosalie	**	**	**				
Macdonald	**			*			
NUE, 1991							
Ste-Rosalie	**	*					
Macdonald	**						
N balance, 1990							
Ste-Rosalie	**						
Macdonald	**				*		
N balance, 1991							
Ste-Rosalie	**						
Macdonald	**						

* significant at the 0.05 level
** significant at the 0.01 level

Table 6.10 Simple effects of N level (kg ha^{-1}) and cultivar on N balance (kg ha^{-1}) at Macdonald 1990

N level	Columbus	Hege155-85	Katepwa	Max
0	-59 e	-68 e	-59 e	-31 de
60	- 7 cd	-26 de	-20 de	38 bc
120	36 bc	69 ab	69 ab	11 cd
180	86 ab	67 ab	109 a	72 ab
Trend	lin.	lin.	lin.	lin.
Significance	*	*	*	*

* significant at the 0.05 level.
Values followed by the same letter are not significantly different from each other by an ANOVA-protected Duncan's new multiple range test.

Table 6.11 Simple effects of N level (kg ha^{-1}) and timing of N fertilizer application on Nitrogen use efficiency (NUE, %) at Macdonald in 1990.

N level	Single	Split
60	48	64
120	46	43
180	30	35
Trend	linear	linear

Section 7
GENERAL DISCUSSION

7.1 CULTIVAR EFFECTS:

Responses to added N can vary among cultivars (Major et al. 1992, Pushman and Bingham 1987). In this experiment, the cultivars Columbus and Katepwa were the least responsive to N addition in terms of yield and its components. These cultivars are very well adapted to the low input management regimes of the Canadian Prairies. In general, the cultivar Hege 155-85 had the most yield component and GPC plastic responses to N addition while those of the cultivar Max were least influenced, although in a study by Caldwell and Starratt (1987) Max responded well to management inputs under maritime conditions. Hege 155-85 was a high yielding cultivar with high biomass production. Overall, this cultivar has good growth and may use the available resources better than the other three cultivars tested.

In the first year, there were differences among cultivars for FPC. In the second year, the FPC of Hege 155-85 approached that of Max because Hege 155-85 was more responsive to the higher soil nitrate levels, and the FPC of Max approached that of Katepwa.

In this experiment, a delay in maturity as suggested by Gooding et al. (1986) does not explain the HFN differences observed among cultivars. This suggests that alpha-amylase activity is highly heritable.

Bread loaf volume varied among cultivars and there were often level and cultivar interactions or even three way interactions for this variable. Bread loaf volume depends largely on the FPC which itself was significantly affected by N fertilizer level and time of application and soil nitrate levels.

Only at the Ste-Rosalie site, and only in the fall of 1990, were there significant differences among soil NO_3-N levels under different cultivars (Table 6.1), this was especially true in the 0-20 cm soil layer ($P<0.01$), probably due to varietal differences in NUE. Since NO_3-N overwinter changes were noted to vary linearly

with fall NO_3-N, a cultivar effect on overwinter changes was also found (Tables 6.5 and 6.9 respectively).

7.2 NITROGEN FERTILIZER LEVEL EFFECTS:

In this study, N fertilizer application at seeding influenced grain yield positively with little or no significant difference between 120 and 180 kg N ha^{-1}. Since relatively high grain yields were reached, one can consider the N fertilizer added to have been non-limiting, and the rate of 120 kg N ha^{-1} optimal (Nuttal et al. 1991). Nitrogen addition above the optimum does not increase yield, and as noted by Benzian et al. (1981) may cause a decline in yield. Nitrogen fertilization enhances dry matter accumulation by all plant parts (Boatwright and Haas 1961), hence both vegetative growth of the wheat plant and grain yield are enhanced. Final grain yield is known to be positively correlated to the total phytomass at anthesis (Entz and Fowler 1990). In this study, N addition did not influence HI suggesting that fertilizer addition enhanced vegetative growth and grain yield in equal proportions.

Grain yield is determined by its components, thus grain yield response to the treatments may be attributed to the responses of its components. Grain yield was best correlated with the number of grains m^{-2} (data not shown) and the number of grains $spike^{-1}$, and was less well correlated with TKW (Table 3.11). This suggests that the observed improvements in grain yield due to N fertilizer were largely due to an increase in the number of grains $spike^{-1}$, as observed by Major et al. (1992), rather than kernel weight, especially at the Macdonald site. For example, in 1991 at the Macdonald site, the relatively higher TKW of the cultivar Columbus did not compensate for its relatively lower number of kernels $spike^{-1}$. Compared to the Macdonald site, higher average TKW at Ste-Rosalie did not compensate for the lower average number of grains $spike^{-1}$, grain yield at Ste-Rosalie was numerically lower than that at Macdonald.

Tillers were found to be enhanced by N application (Birch and Long, 1990) early in the season (Zebarth et al. 1992). The number of tillers m^{-2}, and to a lesser

extent TKW, were also important components of grain yield since positive correlations exist between each of these two variables to grain yield (Table 3.11).

Nitrogen use efficiency decreased when N fertilizer application level increased i.e. N at the levels of 120 and 180 kg ha^{-1} was not limiting. When N fertilizer was added, the plants continued to take up more N as the amount of soil available N increased. However, the plants took up smaller proportions of the soil N pool. The N remaining in the soil is potentially leached away or denitrified if soil moisture conditions are adequate (i.e N is lost). On the other hand, since the plant can not take up all the N it needs at once, over time N will potentially leach deeper into the soil profile and may eventually move out of the zone occupied by plant roots, thus reducing the potential N uptake efficiency of the plant.

Nitrogen harvest index decreased with increasing N levels in three out of four site-years. Since NHI is the proportion of plant N in the grain, and since PPSD is positively influenced by increasing N fertilizer level, one may conclude that N partitioning into the grain is altered with increasing N fertilizer levels. It seems that higher N fertilizer levels cause an increase in PPSD and a relatively higher increase in straw N content (not concentration). This suggested (although we have no evidence) that N partitioning into the grain is higher at lower levels of N fertility. In fact high N levels increased N concentration in straw at harvest (unpublished data).

Hinton (1959) found that 60 % of the GAC exists in the aleurone layer. Thus if the bran is not well separated from the endosperm during milling, this would lead to a higher flour ash. Increasing levels of N fertility caused a beneficial reduction in FAC, which is usually related to the efficiency of the milling process (Hinton 1959). It seems that in the regions tested, wheat N fertilizer management has no detrimental effect on GAC nor FAC.

Grain protein concentration was closely correlated with FPC in both years ($r=0.98^{***}$ in 1990 and $r=0.70^{***}$ in 1991). Increasing N fertilizer levels and split N application both affected FPC (Table 4.1) and GPC (section 4) positively. In the second year, the application of 60 kg N ha^{-1} did not improve FPC, probably due to the presence of 38 kg residual N ha^{-1} in the root zone (section 6). A N fertilizer

effect on FE is not surprising since a correlation is observed between FE and grain protein concentration ($r=0.3^{*}$, 0.34^{**} in 1990 and 1991 respectively).

Flour water absorption is highly correlated with LPC ($r=0.95^{***}$ in 1990 and $r=0.60^{***}$ in 1991) and so is DT ($r=0.84^{***}$ in 1990 and $r=0.63^{***}$ in 1991). This explains the responses of these two variables to N fertilizer additions and this corroborates with findings of Bushuk et al. (1969).

At Ste-Rosalie, the absence of fertilizer N effect in the 20-60 cm soil layer suggests that little or no NO_3-N moved downwards in the first growing season and that immobilization of the NO_3-N in the top soil layer (0-20 cm) may have occurred. Overwinter mineralization may have occured. Precipitations equivalent to 868.1 mm of rain probably caused NO_3-N to leach to the deeper layer of the soil (Von Jolly and Pierre 1977) and may have resulted in a significant fertilizer N effect in the 20-60 cm layer.

Fall 1991 soil NO_3-N values in the two soil layers were significantly increased only when 180 kg N ha^{-1} are added. In the 0-20 cm soil layer, this increase is a result of spring N fertilizer addition. The presence of this effect in the 20-60 cm soil layer was probably due to the sum of residual NO_3-N and the downward movement of the spring applied added fertilizer.

Higher residual NO_3-N in the soil, especially in the plant root zone, when higher N fertilizer is added may also be explained by a significantly lower plant fertilizer NUE at higher fertilizer levels (Table 6.10). With increasing N fertilizer levels, NUE decreased linearly (Table 6.10). The differences in NUE among the different levels of N fertilizer mean that the plants took up smaller proportions of soil N as N levels increased and that N fertilizer levels added were not limiting for plant growth (sections 3 and 4).

Soil NO_3-N changes overwinter were positive suggesting mineralization occurred and this was significantly decreased as N fertilizer levels increased (Table 6.6). Soil NO_3-N values reached a constant by the spring sampling periods (Table 6.2). A linear relationship existed between NO_3-N changes overwinter and fall NO_3

N levels (Table 6.9). Regression equations show that as fall NO_3-N levels were greater, overwinter nitrate increases were lower.

In both years, N balance values increased consistently with increasing N fertilizer level (Table 6.5). Values were positive indicating that N input was higher than plant N uptake. Values were greater than the actual measured NO_3-N levels in the fall of each year, especially at the high N fertilizer levels. This indicates that there was a loss of NO_3-N which could possibly be associated with denitrification, immobilization or leaching below the 60 cm depth.

At the Macdonald site, in the fall of both 1990 and 1991, increasing levels of added N fertilizer increased soil NO_3-N in both the 0-20 cm and the 20-60 cm soil layers (Table 6.1). The significance of the treatment effect in 20-60 cm soil layer suggests that leaching of the NO_3-N may have occurred during the growing season.

As observed at the Ste-Rosalie site, overwinter NO_3-N changes in the 0-20 cm soil layer were significantly affected by N fertilizer level (Table 6.1). The highest change occurred at the lowest level of N fertilizer and practically no change occurred at the level of 180 kg N ha^{-1} (Table 6.6).

Residual NO_3-N levels in the spring of 1991 were not significantly different among the N fertilizer rates used and were greater than the residual levels in the fall of 1990 (Table 6.3). This indicates that greater mineralization may have occurred during the winter. The NO_3-N residues in the fall of 1991 were usually lower than the spring values of the same year except at the level of 180 kg N ha^{-1} (Table 6.3). This is mainly due to the plant N uptake during the growing season and varying plant NUE at different N fertilizer levels used.

As at the Ste-Rosalie site, NUE declined significantly with increasing levels of N fertilizer, resulting in increasing NO_3-N levels at the greater N fertilizer levels (Table 6.3). The relationship between overwinter NO_3-N change and previous fall's soil NO_3-N levels was found to be linear (Table 6.9).

The N balance was significantly affected by N fertilizer level in both years (Table 6.4). In the control plots and in the plots that received 60 kg N ha^{-1} (except for the cultivar Max, in 1990), N balance values were negative (Table 6.8) indicating

that crop N uptake was higher than the N input. There probably was mineralization occurring in the soil, that supplied the additional crop N requirements. At the levels of 120 and 180 kg N ha^{-1} (starting at the level of 60 kg N ha^{-1} for the cultivar Max in 1990), N balance values were positive indicating a sufficient N input (Table 6.8), but values were lower than the actual residual NO_3-N levels measured, suggesting that mineralization may have occurred as well.

7.3 NITROGEN TIMING EFFECTS:

The larger kernels produced when N addition was split did not result in an increase in grain yield. Split N applications occasionally reduced grain yield. This treatment may not provide adequate available N to the plant, causing a reduction in vegetative growth (Strong 1986, Christenson and Killorn 1981) thus reducing grain yield potential (Fowler et al. 1989, 1990). This reduction in vegetative growth and hence plant height, produced a beneficial reduction in the risk of lodging. Gravelle et al. (1988) observed that the susceptibility of a crop to lodging increased as the number of tillers increased, so that the reduction in lodging when N application was split may also be due to a decrease in tiller number m^{-2} in such a treatment.

The GPC increase can be higher with N fertilizer applied at anthesis (Wuest and Cassman 1992). The GPC for split N applications was always equal to or greater than that of single applications at seeding (Table 4.4). In 1991, at Ste-Rosalie the NUE was low (0.21) and there was no difference in NUE between the two application schedules. The land at the Ste-Rosalie site was not very well drained so that denitrification may have occurred, or high NO_3-N levels may have meant that N fertilizer application at seeding time resulted in maximal GPC. The second fertilizer application took place on the ninth of July and was followed by hot dry days interspersed with rainy days. Low mobility of the N in dry clay soil may have limited the uptake of the second application. The GPC observed in 1991 were generally higher than in the previous year. The months of June and July were hotter and drier than in the first year. These conditions coincided with the grain filling

period and probable hindered carbohydrate production or deposition in the kernel, thus resulting in higher GPC (Campbell et al. 1981).

When the N fertilizer is added at seeding time, it increases grain yield (Fowler et al. 1990) but when environmental factors become limiting for subsequent increases in grain yield, N is mainly utilized for seed protein production, and increased GPC is observed (Fowler et al 1990) But with late N addition (eg. at anthesis), the N taken up by the roots or retranslocated (Spiertz and Ellen, 1978) is mainly utilized for grain protein production If the N added is in excess of that required to maximize grain yield (Christensen and Killorn, 1981) GPC is increased Although grain yield was unaffected by split N application, GPY response to such a treatment was large and followed the same trend as GPC. Wuest and Cassman (1992) reported that N acquired during grain filling is efficiently partitioned to the grain with the result that GPC increased even if grain yield did not It seems in this case that the increase in GPC was not enough to result in an increase in GPY since no grain yield increase at the level of 180 kg N ha^{-1} was noted (section 3).

At the Macdonald site, PPSD increased consistently when the N application was split (Tables 4.2 and 4.3) This indicates the contribution of root N uptake to protein accumulation in the wheat kernel after anthesis (Wuest and Cassman, 1992).

Non protein seed dry matter was not influenced by the schedule of N fertilizer application If the plant is N depleted, as is likely to happen with split N applications, N will be translocated to the grain from the vegetative parts, thus negatively affecting photosynthesis and leading to earlier senescence, thereby shortening the grain filling period (Sinclair and Dewit, 1975) and affecting NPM accumulation

The higher NUE that occurred when N fertilizer application was split demonstrated the importance and practicality of such a management in trying to increase bread wheat GPC while reducing N losses (Table 4.2).

Although it improves NUE, splitting the N application did not significantly affect NHI except at Macdonald in 1991.

Split N application did not affect positively N retlanslocation from the vegetative parts of the plant to the developing grains

When N fertilizer application was split in 1991, mean HFN increased by 2.3 % which is contradictory to the data from the previous year (Table 5.3). Maturity dates were not affected by splitting the N fertilizer application, however, soil total NO_3-N levels showed a slightly higher value in the plots where N fertilizer application was split (section 6) which resulted in a slightly higher total N in plots that had received the split application compared to the plots where N was added in a single application.

7.4 STE-ROSALIE vs. MACDONALD:

The variations in yield and its components observed between sites are probably due to differences in the soil texture, water level and soil nutrient level (Dubetz 1977). In addition denitrification may have occurred in the poorly drained soils at the Ste-Rosalie site, potentially, resulting in less N availability during the growing season (Mascagni et. al, 1991). Averaged over both years, the residual nitrate level in the root zone was 11 kg ha^{-1} lower at the Ste-Rosalie site than at Macdonald (data not shown). At the Ste-Rosalie site, there was a significant N timing effect on NUE in 1991 (Table 4.4). Despite N timing effect on NUE, no such significant effect was observed on NO_3-N amounts in either year (Table 4.1). Splitting the N fertilizer application may be beneficial to the plants, it does not seem to be a more environmentally sound way for fertilizer application

At the Macdonald site, in 1990, NUE of the plants was higher when 60 kg N ha^{-1} was split than when all N was added at seeding (Tables 4.1, 4.4 and 4.7). No such significance was observed at the higher fertilizer levels meaning that the fertilizer added was not limiting for plant growth, even if it was all applied at seeding.

At Ste-Rosalie in 1991, total preplanting and after-harvest residual NO_3-N were much larger than at Macdonald. Along with plant performances (sections 3, 4

and 5), this indicated that soil N supply was lower at Macdonald, or leaching is greater compared to Ste-Rosalie

Cultivar effects existed only at Ste-Rosalie, probably due to an interaction between soil type and genotype which did not occur at Macdonald. The cultivars used were better adapted to the physical conditions at Macdonald.

7.5 CLASSIFICATION OF THE FLOUR:

Preston and Kilborn (1984), classified wheat flours according to their protein concentration and dough characteristics as follows:

	FPC mg g^{-1}	Abs mg g^{-1}	DT min	IT FU
Weak	75 - 90	< 550	2.5	> 100
Medium	100 - 115	540-600	2.5 - 4	60 - 100
strong	> 115	> 580	4 - 8	15 - 50

In both years flour from Columbus and Katepwa would have been classified as strong In 1990, flour from Max had rather medium FPC and abs., but DT and IT of a strong flour when N fertilizer was used. In 1991, flour from Max could be clearly classified as strong In 1990, flour from Hege 155-85 had FPC and abs. of a medium range, DT of a weak flour, IT of a medium quality at low levels of N fertility and of strong quality at high levels of N fertility. In 1991, flour from Hege 155-85 could be classified as medium with strong protein. The difference between 1990 and 1991 for flour from Max and Hege 155-85 was probably due to the residual soil nitrates at planting in the second year.

NOTE: All literature cited in the General Discussion can be found in the reference lists of previous sections

Section 8

GENERAL CONCLUSIONS

Nitrogen fertilizer addition at seeding increased grain yield mainly due to increases in the number of grains spike^{-1} although tillers m^{-2} and TKW often made some contribution to yield increases.

The cultivar Hege 155-85 provides the best grain yields for bread wheat production and was most resistant to lodging at high N levels under the conditions prevailing in Eastern Canada

The cultivar Max also seldom lodged, but its response to N inputs varied widely among site years.

The cultivars Columbus and Katepwa yielded less than the other two and Katepwa was very prone to lodging

Splitting the N application may hinder grain production in one region but not in the other, thus it is probably not the best way to reduce lodging. A careful choice of the cultivar would probably be a better method.

There was a clear difference in the responses of the cultivars to the N inputs tested here, suggesting that environmental, management and drainage differences between locations and years may play an important role in the effectiveness of bread wheat production in Eastern Canada

Although different in specific details, the N addition effects were similar at both sites, hence the amount of the N addition should be chosen according to the cultivar, the extractable nitrate available in the soil, the type of soil and the microclimate.

Split N application improves GPC by increasing PPSD and NUE, while increasing N levels caused a decrease in NUE and NHI

PPSD is more critical to GPC than NPM in such an environment

At high levels of N fertilizer, Max and Hege 155-85 were equivalent in their bread scores to Katepwa and Columbus but more expensive to produce in a first year of a crop system. In a second year of production, the figures were different, despite

the gluten supplement needed, we calculated a higher dollar return ha^{-1} for Hege 155-85 and Max than for Columbus and Katepwa.

Assuming equivalent quality, flour of Hege 155-85 gave more loaves than the others due to its high grain yield. Based on a fixed dollar return $loaf^{-1}$, the cultivar Hege 155-85 may be then the most profitable ha^{-1}.

Because of its very strong response to growing conditions, and year to year variation in climate, the production of the cultivar Hege 155-85 could bear high risks to the farmer.

Split N fertilizer application positively affects bread wheat baking quality variables thus giving a chance to reduce the level of N fertilizer application yet have the same financial result

Potential increases in residual soil NO_3-N (thus potential pollution) existed only at the level of 180 kg N ha^{-1} in three out of four site-years, which, along with the N fertilizer level effects on grain yield, makes 180 kg N ha^{-1} uneconomical for Eastern Canadian bread wheat.

Overwinter changes in soil NO_3-N levels are inversely proportional to the fall soil NO_3-N levels, thus it is best to try to keep the latter low.

Differences between the sites were marked. The differences between the sites may have been due to climate, management or drainage.

Section 9

CONTRIBUTIONS TO KNOWLEDGE

This study has shown that, in Eastern Canada and for hard red spring wheat:

1. Splitting the N application is not beneficial for grain yield but improves grain and flour protein concentration.
2. Increasing levels of N fertilizer decreases grain ash concentration.
3. The cultivars Columbus and Katepwa are more stable than the cultivars Max and Hege 155-85 in their responses to N management.
4. Residual soil nitrates may affect grain yield, grain and flour protein concentration and breadmaking quality of some cultivars.
5. The cultivar Hege 155-85 is more expensive to produce in both the first and second years of a crop cycle.
6. At the Ste-Rosalie site, cultivars were less efficient in taking up N than at the Macdonald site, leaving more residual nitrates in the soil
7. Nitrate leaching seems to be higher at the Macdonald site than at the ste-Rosalie site due to soil type, environment or management.
8. In a non limiting N environment, PPSD is more critical than NPM in determining GPC.
9. In a non limiting N environment, GPC appears to be sink limited.
10. For bread wheat production for grain in this area, N fertilizer addition should not exceed 120 kg N ha^{-1}.

Section 10

SUGGESTIONS FOR FUTURE RESEARCH

1. A flour protein extraction and separation could be conducted on samples from this experiment to test the effect of N level and timing on its quality and to try to relate it to breadmaking ability of the samples.

2. Study of ^{15}N labelled fertilizer in plant and soil to follow N retranslocation in the plant and nitrate movement in the soil.

3. Study the importance of the absolute amount of protein per seed with respect to grain protein concentration.

4. Hydrolysis of protein fractions from samples from this experiment could be conducted, and amino acid separation done by HPLC to characterize the nutritional value of the proteins.