THE EFFECTS OF CULTIVAR SELECTION, SEEDING RATE AND N FERTILITY ON CROP RESIDUE PRODUCTION AND GRAIN YIELD

BY

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THE EFFECTS OF CULTIVAR SELECTION, SEEDING RATE AND N FERTILITY ON CROP RESIDUE PRODUCTION AND GRAIN YIELD

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SCOTT C. HENRY

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University

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ABSTRACT

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THE EFFECTS OF CULTIVAR SELECTION, SEEDING RATE, AND N FERTILITY ON CROP RESIDUE PRODUCTION AND GRAIN YIELD

Major Professor: Dr. E.H. Stobbe, Department of Plant Science

Cereal crops grown in the Red River Valley in Manitoba frequently produce large amounts of residues that accumulate in soils because microbial decomposition is suppressed by cool wet soil conditions. The regular burning of residues facilitates tillage and seedbed preparation. However, this practice is no longer acceptable because of environmental, health, and safety reasons. Legislative constraints have been imposed on residue burning in Manitoba. Farmers must now find other methods for eliminating their straw. The objectives of these studies were (i) to determine the effect of cultivar selection on total residue production and the relative proportions of straw and chaff for wheat, barley, and oat cultivars, (ii) to determine the effects of seeding rate and rate of N fertilization on total residue, grain yield, and the relative proportions of straw and chaff for wheat and barley and (iii) to determine the effects of cultivar selection, seeding rate, and rate of N fertilization on estimated combine throughput and weight of straw left in the field as standing stubble. Small plot experiments were conducted at four different sites in 1993 and 1994. For wheat cultivars, stem length was positively correlated with straw production but not total residue. As a group, the semidwarf (SD) cultivars produced similar amounts of total residue similar to that of the conventional height (Tall) cultivars. Chaff production of the SD wheat cultivars accounted for about 30% of total residue compared to only 23% for Tall wheat cultivars. Strong correlations between stem length and total residue production for barley cultivars indicated that plant height was a good indicator of total residue production potential. Stem length and straw production were not related among oat cultivars. Straw production of the SD oat cultivar ranged from 87% to 97% of the highest producing Tall cultivar. Chaff production was greater for the SD oat cultivar, accounting for 18% of total residue compared to only 13% for the Tall oat cultivars. For both wheat and barley, straw and total residue production did not increase with seeding rate while grain yields tended to be larger at the lower seeding rates. Straw and residue production increased with increasing rates of N fertilizer; however, grain yield was not affected by N fertilizer. As a result, high seeding rates and high rates of N fertilizer caused the most unfavourable patterns of total residue to grain DM accumulation. Of the three factors examined in this study, cultivar selection showed the greatest effect on total residue production and grain yield. In areas where crop residue burning is restricted straw production and combine throughput can be minimized by growing semidwarf cultivars. Since a high proportion of semidwarf wheat and oat cultivar's total residue is in the form of chaff, more attention must be placed in chaff management. In future, cultivar choice should play a more important role in crop residue management.

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I. GENERAL INTRODUCTION

Grain producers in the Red River Valley and surrounding areas of Manitoba are concerned about crop residues management. There are benefits in retaining crop residues in the soil. They provide protection against wind and water erosion, and when buried at shallow depths or left on the surface they can have positive influences on the chemical and physical properties of our soil. However, in large quantities crop residues can affect subsequent tillage and seeding operations (especially reduced tillage and direct drilling practices that are becoming increasingly popular), interfere with crop germination and seedling emergence, and increase the incidence of stubble-borne diseases. When this happens, crop residues become more of a nuisance then a benefit to farmers and are considered to be "excessive". Until recently, producers in the Red River Valley eliminated much of their unwanted straw easily and economically by burning. Legislative constraints imposed against the practice of night-time stubble burning has forced many farmers to abandon this method of residue disposal and to turn to alternatives such as extensive tillage or baling. Both these alternative methods require large amounts of money, time, fuel and labour and consequently, are not as popular as burning.

Traditionally, when one thinks of alternative methods to stubble burning for crop residue disposal, one envisions post-harvest-type operations such as tillage, mowing or baling. These practices only deal with the problem of excessive crop residue once it has occurred without addressing the source of the problem. Reducing the amount of crop residues produced would alleviate the need for intensive residue management techniques.

Could pre-seeding production decisions have an impact on the amount of crop residue produced? The introduction of high yielding semidwarf wheat and barley cultivars in the 1980s has led to speculation that they may differ from conventional height (tall) cultivars in the amount of crop residue they produce. As a result, cultivar selection may be an important decision for managing crop residues. Numerous researchers have shown that changes in seeding rate affect plant stand. Could manipulation of the seeding rate of cereal crops minimize total residue production without concurrent losses in grain yield? Nitrogen fertility is another variable that is controlled by the producer. Could N fertility be managed to produce high grain yields with minimal straw production levels?

When large volumes of straw pass through the threshing area of a combine, combine performance and threshing speed is slowed. Could seeding rate, N fertility and cultivar selection be altered to reduce combine throughput and improve harvest speed and efficiency?

The specific objectives of this research were (i) to determine the effect of cultivar selection on total residue production and the relative proportions of straw and chaff for wheat, barley, and oat cultivars, (ii) to determine the effects of seeding rate and rate of N fertilization on total residue, grain yield, and the relative proportions of straw and chaff for wheat and barley cultivars, and (iii) to determine the effects of cultivar selection, seeding rate, and rate of N fertilization on combine throughput and weight of straw left in the field as standing stubble.

This study contributes to the scientific understanding of the nature of crop residue production as affected by pre-seeding management decisions. This study also contributes to our ability to make intelligent recommendations to grain producers on crop residue management.

II. LITERATURE REVIEW

2.1 Cultivar Effects on Residue Production and Grain Yield

Few studies have been reported on the effect of genotypic differences with straw and residue production. White (1987), working in Northern Ireland with 22 spring barley cultivars, determined that absolute straw production varied significantly among the different cultivars. Similar results have been noted by Sharma and Smith (1987) who worked with 10 winter wheat cultivars in Oklahoma and by Baker (1982) who worked with 8 spring wheat cultivars in Saskatchewan. White (1987) also concluded that although straw production was much more variable than grain yield, the cultivar-by-year variation for straw yield was much less than that for grain yield. Examination of the variance from straw and grain yields showed that the cultivar-by-year component represented only 6% of the pooled within-trial variance for straw yield but 142% of the variance for grain yield, confirming the presence of large cultivar-by-year variability for grain but not for straw.

The straw to grain ratio is similar to harvest index (HI). Thus, a low straw to grain ratio is equivalent to a high HI. It is now common practice to express straw yield as a ratio of grain yield on a dry matter basis. This has come about primarily because farmers seldom weigh the straw from their crops. Grain yields, however, are generally known with some accuracy, and a number of authorities have sought to obtain reliable estimates of straw yields by estimating definite ratios between straw and grain yields. Straw to grain ratios have been reported from various sources. Reitz, (1976) based on a literature review, recommended that a constant ratio of 1.75 to 1 for wheat be used while Jensen and Lund (1967) suggested a ratio of 1.5 to 1.

It is generally recognized that straw to grain ratios are not constant and change continually with fluctuations in yield. Under certain conditions, however, there is a good correlation between grain and straw yields (Gateley, 1975; Donald and Hamblin, 1976). Bauer and Zubrinski (1978) used actual straw to grain ratios from numerous hard red spring wheat trials in North Dakota between 1948 and 1976 to determine the functional relationship between straw to grain ratio and grain yield. The precision with which straw yields could be predicted and whether or not the relationship differed between conventional height and semidwarf cultivars were tested. Using "best fit" regressions based on least squares analysis, they derived equations to predict straw yield. They determined that prediction of hard red spring wheat straw yields from ratios derived from regression improved the accuracy over a constant ratio for all grain yields. However, the efficacy of this method for predicting straw yields depended on the limits of error acceptable to the user.

White (1987) showed that the partitioning of straw and grain dry matter of 22 cultivars varied both from cultivar to cultivar and from year to year. Similarly, Pendleton and Dungan (1960) report that for three variables, cultivar, seeding rate, and fertility, cultivar selection showed the greatest effect on grain yield, straw yield and straw to grain ratio.

Literature comparing genotypic differences in the amount of straw passing through the combine (combine throughput) is non-existent.

2.1.1 Wheat Cultivars

Wheat cultivars differ in many characteristics. One of the more recent significant changes is the development of short stature wheat (Briggle and Vogel, 1968). This trait, known as semidwarfism, is controlled by two recessive genes (Allan et al., 1968). Gale and Law (1976) located the genes on chromosomes 4A and 4D of *Triticum aestivum* L. and named them *Rht1* and *Rht2*. Semidwarf cultivars are frequently characterized by large grain yields and a comparatively short, stiff straw (Reitz and Salmon, 1968) that reduces the risk of lodging (Powell and Schlehuber, 1967; Vogel et al., 1960) and increases harvest index (Allan, 1983).

Much of the yield increases in wheat in the past few years can be attributed to the development of semidwarf cultivars. In areas of high yield potential, such as those with irrigation or high rainfall, semidwarf cultivars usually produce higher grain yields then conventional cultivars (Uddin and Marshall, 1989; Brandle and Knott, 1986; McNeal et al., 1972; Briggle and Vogel, 1968; Vogel et al., 1956). However, under stressful conditions such as drought, semidwarf yields have been variable. Many researchers have reported that when subjected to water stress during grain filling, grain production from many semidwarf cultivars is severely restricted (Power and Alessi, 1978; Briggle and Vogel, 1968; Porter et al., 1964).

Due to their inherently shorter culm length, semidwarf genotypes produce less straw residue per unit grain yield than conventional height genotypes (Clarke and DePauw, 1993). As a result, semidwarf wheats have lower straw to grain ratios (Gehl et al., 1990; Sharma and Smith, 1987; McNeal et al. 1972; Vogel et al., 1963, 1956). However, this does not necessarily mean that they have lower straw yields.

American hard red spring (HRS) semidwarf lines derived from the cultivar 'Norwin 10' exhibited larger grain yields than conventional height cultivars and had straw yields that were significantly smaller (Vogel et al., 1956). They found that the semidwarf selections #14 and #17 from a 'Norwin 10'/'Brevor' cross had higher grain yields but lower straw tonnage than Brevor. Similar results were obtained by McNeal et al. (1971) who examined tall, medium, and short selections from the cross 'Norwin 10'/Brevor 14'//6*'Centana'. They noted that 'Medium Centana' had significantly higher grain yields than either the 'Tall Centana' or 'Short Centana' and lower straw yields than 'Tall Centana'.

Canadian semidwarf wheat cultivars do not seem to follow the pattern set by older American semidwarf wheat cultivars. Clarke and DePauw (1993) reported that although HY-320 (a high-yielding semidwarf Canada prairie spring (CPS)) outyielded the tall HRS cultivar Neepawa, there was no significant differences in straw production. Research comparing residue production of Canadian and American bred semidwarf wheat cultivars is lacking.

Grain yield is the product of three yield components: number of spikes per unit area, number of kernels per spike, and individual kernel weight. The tillering capacity of semidwarf cultivars has been found to be similar to conventional height cultivars (Power and Alessi, 1978; McNeal et al., 1960) and in some cases significantly higher (Lupton et al., 1974) with slightly lower rates of tiller mortality (Thorne and Blacklock, 1971). The basis for higher yield potential in semidwarf cultivars is their greater number of kernels per spike (Cutforth et al., 1988; Brandle and Knott, 1986). This high potential may have arisen through a greater number of florets initiated, and/or better floret survival. Fischer and Stockman (1986) found no difference in the number of florets initiated by dwarf wheats and tall wheats, but floret survival was greater for the dwarf wheats. They argued that the greater number of kernels at harvest for dwarf wheats was related to reduced competition for assimilates by stems at anthesis, thus allowing for more assimilate movement to the spikes and increased floret survival. Brandle and Knott (1986) suggested that fluctuations in the number of kernels per spike determined whether or not semidwarf lines outyield conventional lines.

2.1.2 Barley Cultivars

Most studies have shown that yield increases from breeding efforts in spring barley are the result of greater partitioning of total dry matter into grain (greater HI) with little or no corresponding change in vegetative biomass (Jedel and Helm, 1994; Bulman et al., 1993; Boukerrou and Rasmusson, 1990; Wych and Rasmusson, 1983; Riggs et al., 1981).

A major objectives in barley breeding has been to develop cultivars with shorter, stiffer straw to lower yield losses associated with lodging under high input management systems. The semidwarf phenotype has provided a way of achieving a higher HI, which is itself associated with high grain yield in barley

(Wych and Rasmusson, 1983; Riggs et al., 1981). The *sdw* gene for reduced height can be traced to radiation induced mutations in the Norwegian cultivar 'Jotun' (Rasmusson et al., 1973). Germplasm from the *sdw* Jotun mutant stock has led to the development and release of the semidwarf cultivars Duke and Samson in Canada.

Boukerrou and Rasmusson (1990) reported that, as a group, six semidwarf barley genotypes grown in Minnesota produced 17% less straw and had a 3.3% higher HI than 36 tall genotypes. These results are consistent with those of Ali et al. (1978) who reported that American semidwarf barley lines produced 12% less straw dry matter than conventional height lines but yielded similarly with only a 3% difference noted in favour of the semidwarf cultivars. They also noted that American semidwarf cultivars produced more spikes and had higher HI than conventional height barley cultivars. In Canada, Jedel and Helm (1994) reported that Samson and Duke, produced less straw (approximately 11%) and had higher HI (approximately 4.8%) than 12 conventional height lines. Duke produced grain yields similar to the conventional height lines whereas Samson produced significantly less than the conventional height lines. In contrast to the American semidwarf lines examined by Ali et al. (1978), Samson and Duke partitioned yield into higher kernel numbers per spike and lower spike numbers per square meter rather than more spikes and similar kernel numbers.

A prominent characteristic of all semidwarf barleys is their high level of lodging resistance. In addition to reduced height, many semidwarf barley cultivars possess two other features that contribute to lodging resistance. One is a thick culm that is often about one-third larger than conventional height cultivars, and the other is a tendency to have a spreading and relatively procumbent crown. Because of this, when lodging of semidwarf barley does occur, it usually is associated with root lodging rather than stem lodging (Ali et al., 1978). Lodging reduces kernel weight, increases the percentage of thin kernels and ultimately reduces grain yield (Jedel and Helm, 1994). In barley, yield improvement appears to be directly related to improved lodging resistance. Enhanced lodging resistance permits high fertilization levels and irrigation which promotes high yield in barley (Powell and Schlehuber, 1967).

Jedel and Helm (1994), in an assessment of western Canadian barleys, found small genotypic differences for straw production among conventional height 6-row barley cultivars. Similar results were noted by Boukerrou and Rasmusson (1990) for 9 commercial barley cultivars in Minnesota. Bulman et al. (1993) also noted genotypic differences for straw production among 20 barley cultivars grown in eastern Canada and attributed them to the production of late tillers which were mostly non-fertile. However, Wych and Rasmusson (1983) found no significant differences in the amounts of straw produced among six 6-row malting cultivars.

In their assessment of western barley cultivars, Jedel and Helm (1994) noted that, as a group, the two-rowed cultivars had greater straw production than the six-rowed cultivars but not higher grain yields. The high straw yields of the two-rowed cultivars were attributed to the large number of culms per unit area. Yield differences were not observed because kernel numbers per spike for the two-rowed cultivars were much lower than six-rowed cultivars, nullifying the advantage of more spikes per unit area.

2.1.3 Oat Cultivars

The increase in grain yield of oats, as with the other cereal crops, has been attributed mainly to improved cultivars (Wych and Struthman, 1983). Data from field trials assessing oat cultivars released from 1923 to present indicates that increases in grain yield are greater than increases either in straw or biological yield. As a result, modern oat cultivars have a higher HI (Wych and Struthman, 1983).

Wych and Struthman (1983) reported significant straw production differences for 9 conventional height oat cultivars grown in Minnesota. Straw production ranged from 5.4 to 6.7 MT/ha and was not correlated with plant height. Lawes (1977) working with 14 conventional height oat cultivars in England also noted large differences in straw production among cultivars. Straw production ranged from a 3.35 to 5.27 t/ha.

Unlike wheat and barley, cultivars of semidwarf oats are not yet available for commercial production in Canada. In wheat and barley, the semidwarf phenotype has stronger, shorter straw, improved lodging resistance, higher HI, and higher grain yields than conventional height cultivars (Jedel and Helm, 1994; Boukerrou and Rasmusson, 1990; Wych and Rasmusson, 1983; Riggs et al., 1981). Meyers et al. (1985), in an agronomic comparison of semidwarf and conventional height oat genotypes, found that grain yield did not differ significantly among genotypes. As a group, the semidwarf genotypes did not differ consistently from the standard height lines for kernel number per panicle, kernel weight, or panicle number per unit area. Unlike semidwarf wheat and barley, Meyers and coworkers (1985) found that the HI of semidwarf oats was similar to that of conventional height lines. As a result, straw yields of the best grain yielding semidwarf cultivars tended to be 10% to 20% lower than that of the best conventional height cultivar. These differences were significant but not as large as expected. Meyers et al. (1985) suggested that thicker culms coupled with higher percent shoot survival may have partly compensated for the semidwarf's shorter stature.

2.2 Seeding Rate Effects on Residue Production and Grain Yield

For cereal crops, yield response over a wide range of seeding rates can be depicted as a curve that rises quickly to a maximum yield followed by a slow decline at high densities (Kirby, 1967; Donald, 1963; Holliday, 1960). There are several factors which can change the shape of the yield response curve. In general, the greater the environmental resources, the higher will be the optimal seeding rate (Donald, 1963; Holliday, 1960).

One of the most important of these environmental resources is soil moisture. When moisture supplies are adequate, best yields are usually obtained from high seeding rates (Wright et al., 1987; Ciha, 1983; Baker, 1982; Briggs, 1975; Guitard et al., 1961). However, when limited moisture is available, crops sown with low seeding rates have the highest yields (Reid and Warder, 1982; Pelton, 1969).

Another important environmental resource is soil fertility status. Much research has been conducted examining seeding rate by N interactions. In most cases there is an absence of seeding rate by N interaction (Read and Warder, 1981; Thorne and Blacklock, 1971; McFadden, 1970). However, others have shown that yield response to seeding rate can be changed by the degree of N fertilization (Wright et al., 1987; Roth et al., 1984). Wright et al. (1987) showed that with increasing seeding rate, the optimum fertilizer rate increased. They concluded that under the relatively humid production conditions of northeastern Saskatchewan, maximum yields will normally be achieved through a combination of high seeding and N fertilizer rates.

Seeding date can also have a profound influence on the effect of seeding rate. It has been well documented that delays in seeding date are accompanied by grain yield losses (Nass et al., 1975; Jessop and Ivins, 1970; Anderson and Hennig, 1964). Ciha (1983) examined the effect of seeding rate and seeding date on the agronomic performance of five spring barley cultivars in Washington State. Ciha found no significant seeding rate by seeding date interactions and concluded that increasing the seeding rate with later seeding dates was not beneficial in increasing grain yield. However, others have found significant seeding rate by seeding date interactions for grain yield (Briggs and Aytenfisu, 1979; McFadden, 1970). Briggs and Aytenfisu (1979) attribute the significant interaction between seeding rate and yield to the occurrence of spring frosts after each seeding date, which allowed the high seed rate plots to compensate for differential frost damage in each of the three seeding dates.

Many researchers have done extensive work examining the interaction of cultivar and seeding rate (Clarke and DePauw, 1993; Ciha, 1983; Baker, 1982; Faris and DePauw, 1981; Briggs and Aytenfisu, 1979; McFadden, 1970). Faris and DePauw (1981) evaluated three cultivars of spring wheat at five seeding rates in a series of seven tests in northwestern Alberta and concluded that each cultivar had a different optimum seeding rate for maximum grain and straw yield. Baker (1982) agreed with these findings but concluded that although cultivars responded differently to seeding rate the differences were not consistent between years and locations.

Baker (1982) in north central Saskatchewan, studied eight cultivars of spring wheat at three seeding rates and two dates of seeding over a two year period. Seeding rates ranged from 110 - 430 seeds m^{-2} and dates of seeding were designated as early (late April) and late (late May). Significant differences in straw and grain production among seeding rates and seeding dates were noted. Baker concluded that the average straw and grain yield for the eight cultivars increased with increasing seeding rate in each of the nine experiments. Similar results were also noted by others (Sharma and Smith 1987; Abd-El-Latif et al., 1986; Sprague and Farris, 1931). Baker (1982) also found that seeding later in the growing season (late May to early June) resulted in higher average straw and grain yields than earlier plantings. Unpublished data from H. M. Austenson cited by Baker indicates that later seeding (mid-May) is most advantageous as one proceeds in a northernly direction in the province of Saskatchewan but no further explanation as to why this occurred was given. Pendleton and Dungan (1960) in southern Illinois noted that straw yields peaked at a seeding density slightly higher than the density at which maximum yields were obtained and then began to decrease. Similar results from El-Gawad et al. (1986) in India and Gaffer and Shahidullah (1985) in Bangladesh have also been documented. Other research has indicated that seeding rate has little or no effect on residue production. Clarke and DePauw (1993) examined four genotypes of wheat under fallow, stubble, and irrigated conditions in southwestern Saskatchewan. Seeding rates ranged from 40 to 200 kg ha^{-1}. They concluded that seeding rate had a small and inconsistent effect on residue production. These results are in agreement with Marshall et al. (1987) who worked with one semidwarf and one conventional height oat cultivar and concluded that seeding rate did not affect straw yield for either cultivar.

2.3 Nitrogen Fertilizer Effects on Residue Production and Grain Yield

Nitrogen is the nutrient most limiting to crop production in the Canadian prairies (Grant et al., 1991). As a result, the effects of applied nitrogen on crop growth and development have been thoroughly studied. Plant responses to applied nitrogen are numerous and are profoundly affected by environmental conditions. Under normal growing conditions, typical results from applied nitrogen include taller, lusher plants with higher leaf area index (Brinkman and Rho, 1984; Green and Dawkins; 1986; Campbell and Davidson, 1979), increased leaf photosynthesis (Longstresh and Nobel, 1980), prolonged leaf area duration (Spiertz and DeVos, 1983; Campbell and Davidson, 1979; Thorne and Blacklock, 1971) and increased grain yield (Gauer et al., 1992; Gehl et al., 1990; Caldwell and Starratt, 1987; Power and Alessi, 1978; Pendleton and Dungan, 1960).

There are many undesirable effects of excessive nitrogen fertility. Increased vegetative biomass causes increased water use (Campbell and Davidson, 1979; Black and Siddoway, 1977; McNeal et al., 1971) and could cause moisture stress at anthesis reducing the plants ability to reach high yield levels (Campbell and Davidson, 1979). Also tall, lush plants are more prone to lodging (Brinkman and Rho, 1984; Holbrook and Bryne, 1983; Ohm, 1976) which predisposes them to disease infestations (Boquet and Johnson, 1987; Caldwell and Starratt, 1987).

It is well established that nitrogen application increases vegetative biomass and grain yield (Gauer et al., 1992; Gehl et al., 1990; Caldwell and

Starratt, 1987; Pendleton and Dungan, 1960). The grain yield response curve to N fertilizer is much the same as the yield response curve to seeding rate. Grain yield declines as nitrogen supply is increased and may decrease at high rates of application even when there is no lodging (Blackman et al., 1978).

Extensive studies of N fertility and crop growth indicate that the magnitude of response and the amount of N required for optimum grain yields are known to vary according to species, cultivar, available moisture, seeding date and time of N application (Lessells and Webber, 1965).

In the drier regions of the Canadian prairies, the relative efficiency of fertilizer N in increasing wheat grain yield is largely dependent on growing season moisture supply (Davidson and Campbell, 1984). Under low moisture conditions, yield responses vary depending upon the magnitude of water stress. In south western Manitoba, Grant et al. (1991) studied the response of six barley cultivars grown at six incremental levels of N fertilizer ranging from 0 to 200 kg ha^{-1}. Estimated moisture supply (EMS) was calculated and site years were grouped into moisture regimes based on EMS and grain yield potential. Under low moisture conditions, grain and straw yields increased with increasing N level, but the size of the response was small due to low moisture. Similarly, Gonzalez et al. (1993) showed that in a low rainfall, high grain-fill temperature year, N rate had little influence on grain yield, but increased straw yield. This reduced harvest index and increased the (R/G). However, Davidson and Campbell (1984) reported that when moisture was limited, excessive N fertilization actually reduced both grain and straw yields of Manitou spring wheat because the resultant vegetative growth depleted moisture reserves prematurely. However, under optimal (high) moisture conditions, grain and straw yields show large increases with each incremental addition of N fertilizer (Gonzalez et al., 1993; Grant et al., 1991).

Seeding date also has a significant effect on the efficiency in which N fertilizer increases grain yields. Black and Siddoway (1977) working in northeastern Montana, reported that yield increases due to N fertilization decreased as seeding date was delayed. Similar results were also noted by others (McFadden, 1970; Anderson and Hennig, 1964). As a result, early seeding of small grain cereals is extremely important to obtain maximum response to N fertilization for high yields.

Many studies have been conducted in which the N fertility response of different cereal crop cultivars have been compared in common environments (Grant et al. 1991; Gehl et al., 1990; Brinkman and Rho, 1984). Nitrogen fertilizer recommendations made by crop species are not normally altered due to crop cultivar. However, cultivar by N interactions are common for several traits, especially grain yield (Grant et al., 1991; Gehl et al., 1990; Blackman et al., 1978; Ohm, 1976; Knott, 1974). Although cultivars may respond differently to N fertilization, these differences often go unnoticed because responses are often masked by varying climatic conditions (Varvel and Seversen, 1987).

Grant et al. (1991) studied cultivar and nitrogen responses of six spring barley cultivars under varying moisture regimes in southern Manitoba. Under high moisture conditions, a higher level of N was found to benefit some varieties but not others. As a result, cultivar by N interactions were observed for both straw and grain yield. Under moderate moisture conditions no cultivar by N interaction occurred in grain yield, but there was an interaction in straw yield response. At low levels of N fertilizer the two semidwarf cultivars were similar in straw yield to the other conventional height cultivars. However, at the highest N level the two semidwarf cultivars produced less straw.

Gehl et al. (1990), working with six cultivars of spring wheat in southern Manitoba reported that differences in response to N fertilization among cultivars were most evident when yield potential was high. They found that the level of N fertility required to achieve maximum grain yield varied among cultivars, sites and years. Their results indicated that American semidwarf cultivars required higher rates of applied N than conventional height Canadian cultivars to reach maximum yield potential. Gehl et al. (1990) also found cultivar by N interactions for straw yield and concluded that straw production responded to N similarly to grain. However, Brinkman and Rho (1984) found significant cultivar by N interactions for grain yield but not for straw yield in three diverse cultivars of oats.

If moisture and other factors are adequate, the initial effect of applied N is to increase vegetative biomass production and grain yield (Terman, 1979). Vegetative biomass production increases because N increases leaf photosynthesis and water use efficiency. Plants grown under optimal N conditions are more productive and efficient resulting in taller, lusher plants with larger leaf area index than plants grown with insufficient N. The nature of grain yield increase is not clear. Power and Alessi (1978) conclude that the increased grain yield resulting from nitrogen fertilization was caused by the effects of N on tiller development and maturity. N fertilizer reduced tiller mortality providing more ears per hectare and subsequently greater grain yield. N fertilizer had much less effect upon kernels per ear or weight per kernel when compared to number of ears. In general kernel weight and kernels per ear decreased with increasing levels of N (McNeal et al., 1971; Nass et al., 1976; Power and Alessi, 1978). Thus grain production was more closely related to the number of high order tillers producing ears than either kernels per ear of weight per kernel.

III. CULTIVAR EFFECTS ON CROP RESIDUE AND GRAIN YIELD

3.1 Introduction

One approach to managing cereal residues that does not involve additional producer input could be to modify the amount of crop residues produced through plant breeding. Work conducted by White (1987) on spring barley cultivars in the United Kingdom showed that variation among cultivars in straw production was substantial, indicating that selection for more favourable partitioning of dry matter is possible.

Many producers believe that short-straw semidwarf cultivars produce less residue than conventional height cultivars. Research conducted in Minnesota by Ali et al. (1978) on semidwarf barley lines and by Meyers et al. (1985) on semidwarf oat lines indicated that vegetative yields of experimental semidwarf lines were smaller than normal conventional height lines. Similar findings were reported for semidwarf wheat cultivars by Vogel et al. (1956) in Montana. Vogel et al. (1956) found that semidwarf selections from the cross of 'Norwin 10' / 'Brevor' produced less straw residue than the conventional height cultivar Brevor. However, recent work by Clarke and DePauw (1993) in Saskatchewan has shown that straw production of high-yielding semidwarf Canada Prairie Spring (CPS) wheat cultivars were similar to that of conventional height Canada Western Red Spring (CWRS) wheat cultivars. It should be noted that only two conventional and two semidwarf cultivars were tested in their experiments.

In Canada, differences among crop cultivars in terms of residue production have received little research attention. Information on the variation in residue production attributable to genotype would assist farmers in their choice of cultivar when yield and other characteristics have already been taken into consideration.

The objectives of the present study are (i) to determine the effect of cultivar selection on total residue production and the relative proportions of straw and chaff for wheat, barley, and oat cultivars, and (ii) to determine the effect of cultivar selection on estimated combine throughput and the weight of straw left in the field as standing stubble for cultivars of wheat, barley, and oats.

3.2 Materials and Methods

3.2.1 Description of Locations

Experiments were conducted at four locations in Manitoba over a 2-year period. In 1993, experiments were located at Oak Bluff and Arborg. The Oak Bluff location was situated at the corner of Hwy #3 (McGillvary Blvd.) and Hwy #1A (Perimeter Highway) on a Red River Clay soil. Precipitation was very heavy throughout most of the growing season, with prolonged flooding occurring on numerous occasions. Extensive flooding damage occurred and some experiments were discarded because of water, disease, and erosion damage. Because of flooding damage at the Oak Bluff location, the Arborg location of the Manitoba Crop Variety Evaluation Trials was added as a supplemental location in late July. The location was located 1 mile north and 1 mile east of Johnson Seeds of Arborg (SW 4 23 2E). The previous crops were flax (*Linum usitatissimum* L.) and summerfallow for the Oak Bluff and Arborg locations, respectively.

In 1994, the experiments were located at Winnipeg and Carman. The Winnipeg location was situated on a Red River clay 1 km west of the entrance to the University of Manitoba at the corner of Waverley Street and Markham Road. A very heavy rain storm occurred shortly after seeding and, as a result, all experiments, except one, were reseeded. The Carman location was located on a Denham loam soil, 1 km west of the Town of Carman at the University of Manitoba Field Station. Moisture conditions were poor at planting but timely rains encouraged excellent germination and emergence. Canola (*Brassica napus* L.) had been grown previously at both locations.

3.2.2 Description of Treatments and Experimental Design

Cultivar evaluation experiments were conducted with the three major cereal crops, wheat, barley, and oats. Cereal species were tested separately. Each experiment was conducted as a randomized complete block design with four replicates. The cultivars represented those commonly grown in the Red River Valley as well as some of the more recently released cultivars that are likely to gain favour with area producers. Cultivar descriptions for wheat, barley, and oats are outlined in Tables 3.1, 3.2, and 3.3, respectively.

Table 3.1. Description of wheat cultivars.

Year	Location	Cultivar	Type†	Height	Origin
1993	Oak Bluff	AC Domain	CWRS	standard	Canada
		AC Taber	CPS	semidwarf	Canada
		Bergen	DNRS	semidwarf	USA
		Glenlea	CWES	standard	Canada
		Grandin	DNRS	semidwarf	USA
		HY-612	CPS	semidwarf	Canada
		Katepwa	CWRS	standard	Canada
		Marshall	DNRS	semidwarf	USA
		Roblin	CWRS	standard	Canada
1993	Arborg	AC Domain	CWRS	standard	Canada
		AC Minto	CWRS	standard tall	Canada
		AC Taber	CPS	semidwarf	Canada
		CDC Teal	CWRS	standard	Canada
		Glenlea	CWES	standard	Canada
		Grandin	DNRS	semidwarf	USA
		Katepwa	CWRS	standard	Canada
		Roblin	CWRS	standard	Canada
1994	Winnipeg Carman	AC Domain	CWRS	standard	Canada
		AC Minto	CWRS	standard tall	Canada
		AC Taber	CPS	semidwarf	Canada
		Bergen	DNRS	semidwarf	USA
		CDC Teal	CWRS	standard	Canada
		Glenlea	CWES	standard	Canada
		Grandin	DNRS	semidwarf	USA
		HY-612	CPS	semidwarf	Canada
		Invader	CWRS	standard	Canada
		Katepwa	CWRS	standard	Canada
		Marshall	DNRS	semidwarf	USA
		Roblin	CWRS	standard	Canada

† CWRS, Canada Western Red Spring; CPS, Canada Prairie Spring; CWES, Canada Western Extra Strong; DNRS, Dark Northern Red Spring.

Table 3.2. Description of barley cultivars.

Year	Location	Cultivar	Type	Height	Origin
1993	Oak Bluff	Experiment discarded because of flood damage.			
1993	Arborg	Argyle	6-row malt	standard tall	Canada
		Duke	6-row feed	semidwarf	Canada
		Manley	2-row malt	standard	Canada
		Heartland	6-row feed	standard	Canada
1994	Winnipeg	Argyle	6-row malt	standard tall	Canada
	Carman	Duke	6-row feed	semidwarf	Canada
		Manley	2-row malt	standard	Canada
		Heartland	6-row feed	standard	Canada
		AC Lacombe	6-row feed	standard tall	Canada
		Bedford	6-row feed	standard tall	Canada
		Robust	6-row malt	standard tall	USA
		Excel	6-row malt	standard	USA

Table 3.3. Description of oat cultivars.

Year	Location	Cultivar	Caryopsis Type	Height	Origin
1993	Oak Bluff	Experiment discarded because of flood damage.			
1994	Winnipeg	AC Belmont	naked	standard	Canada
	Carman	AC Marie	covered	standard	Canada
		Dumont	covered	standard	Canada
		OT-257	covered	semidwarf	Canada
		Riel	covered	standard	Canada
		Robert	covered	standard	Canada

3.2.3 Experimental Procedure

3.2.3.1 Seeding and Maintenance

At the Oak Bluff, Carman, and Winnipeg locations, a Noble hoe-press drill (Noble Equipment Co., Nobleford, AB) adapted for plot work was used to seed plot areas 2 m wide by 8 m in length with a row spacing of 20 cm. At Oak Bluff, 100 kg N ha^{-1} and 25 kg P_2O_5 ha^{-1} were deep-band applied as a liquid formulation to the plot area 7 days prior to planting. Planting took place May 13, 1993. At Carman and Winnipeg, 7 kg N ha^{-1} and 28 kg P_2O_5 ha^{-1} were initially applied with the seed as monoammonium phosphate on May 10th and May 12th at each location, respectively. Additional N was broadcast as ammonium nitrate (34-0-0) one week after seedling emergence. The rates were 34 kg N ha^{-1} and 64 kg N ha^{-1} for Winnipeg and Carman, respectively. The amount of fertilizers applied each year was determined according to soil test results (NorWest Labs, Winnipeg, MB). A seeding rate of 300 viable seeds m^{-2} was used at Oak Bluff, Carman, and Winnipeg, the kernel weight and germination percentage of each variety having been previously determined.

The Arborg location was seeded on May 17, 1993 with a small plot seeder. The plot size was 1.6 m wide by 7 m in length with a row spacing of 18 cm. The plots received 50 kg P_2O_5 ha^{-1} at seeding as monoammonium phosphate and 100 kg N ha^{-1} was broadcast as ammonium nitrate (34-0-0) after seedling emergence. The seeding rate was 300 viable seeds m^{-2}.

Weed pressure was light at all locations and pesticides for each location were applied as required and are summarized in Table 3.4.

Table 3.4. Weed and disease control practices for cultivar experiments.

Date	Treatment	Application Method	Rate
Oak Bluff			
June 8	Refine Extra[1]	Post-emergent	20 g ha^{-1}
	MCPA amine 500	Post-emergent	1.1 L ha^{-1}
Arborg	MCPA amine 500	Post-emergent	1.1 L ha^{-1}
Winnipeg			
May 10	Vitaflow 280[2]	Seed treatment	
June 1	Roundup[3]	Pre-emergent (reseeded area only)	3.7 L ha^{-1}
June 8	Refine Extra	Post-emergent (wheat only)	20 g ha^{-1}
	Lontrel[4]	Post-emergent (spot spray)	1.5 L ha^{-1}
June 29	Tilt[5]	Post-emergent	125 g ha^{-1}
Carman			
May 10	Vitaflow 280	Seed treatment	
May 16	Roundup	Pre-emergent	3.7 L ha^{-1}
June 10	Refine Extra	Post-emergent	20 g ha^{-1}

1 Dupont Canada Inc.
2 Gustafson Canada Inc.
3 Monsanto Canada Inc.
4 Dow Elanco Canada Inc.
5 Ciba Crop Protection Inc.

3.2.3.2 Harvest and Sampling Measurements

At physiological maturity, subsamples totalling 0.5 m^2 were cut at ground level from the central rows of each plot with a hand-held sickle. The subsamples were tied into bundles and hung to dry in a greenhouse. Whole plots minus the two outside rows, were harvested from late-August to early September using a Wintersteiger (Wintersteiger, Nurserymaster Elite, Salt Lake City, UT) plot combine (Table 3.5)

Table 3.5. Date of seeding and harvest for wheat, barley, and oat cultivars.

Location	Crop	Seed Date †	Harvest Date
Oak Bluff	Wheat	May 13	September 18
	Barley		No harvest
Arborg	Wheat	May 17	October 1
	Barley		September 1
Carman	Wheat	May 10	August 26
	Barley		August 22
	Oats		August 26
Winnipeg	Wheat	May 12	September 3
	Barley	May 12 (28)	September 3
	Oats	May 12 (28)	September 10

† Date in parenthesis corresponds to the date of reseeding.

Whole plot grain samples were air-dried and cleaned before the mass was determined. Kernel water content was determined (Labtronic model 919, Winnipeg, MB) to correct yield to a 0% moisture basis.

For each subsample, spikes were separated and counted, and the total spike dry matter (DM) was taken. The straw and spikes were oven-dried at 65°C for three days to provide 0% moisture content dry weights, after which time the spikes were threshed with a belt thresher (Agriculex, model SPT-1, Guelph, ON), and total grain DM was measured. Chaff DM was measured as the difference between total head DM and grain DM. Straw length was determined by randomly measuring 15 stems. Total residue DM was calculated by adding together straw and chaff DM. Total dry matter (TDM) was calculated by adding total spike DM and total straw DM. Harvest index (HI) was calculated by dividing total grain DM by TDM. Weight culm^{-1} was determined by dividing total straw DM by the number of fertile spikes.

Measurements of estimated combine throughput, the amount of straw that passes through a combine, at different cutting heights were also estimated. The straw from each subsample was put into a specially designed cutting board, and the bottom 20 cm were cut and weighed. The total weight of straw minus the weight of the bottom 20 cm represented combine throughput at a 20-cm cutter bar height. Throughput for a 25-cm cutter bar height was accomplished by cutting and weighing an additional 5-cm length from the bottom of total straw, adding it to the weight of the previously cut 20-cm length and subtracting this value from the total straw weight. This procedure was repeated to give estimated combine throughput values for 30-and 35-cm cutting heights. Weight of straw left in the field as standing stubble was the actual weight of the straw cut from the bottom of the sample after each cutting.

3.2.4 Statistical Analysis

Statistical analyses were performed using SAS (SAS Institute, 1990). Treatments were analyzed using general linear models (GLM). When significant treatment effects were detected, means were separated using least significant difference (LSD) ($P<0.05$) procedure. Bartlett's test for homogeneity of variance was conducted to determine whether locations and years could be combined. Preplanned single degree-of-freedom contrasts were made to compare semidwarf to conventional cultivars and to compare taller and shorter conventional cultivars. Simple correlation analyses were performed to determine the strength of relationships between the different parameters.

3.3 Results and Discussion

3.3.1 General Productivity

In 1993, location differences in terms of residue and grain production were large. The large degree of variability for straw and grain production was attributed to differences in climate between locations. In general, straw and residue production were greater at Oak Bluff when compared to Arborg, but grain yield was not. The great amount of straw and total residue at the Oak Bluff location was attributed to the adverse climate experienced throughout the growing season. Cool, wet growing conditions caused excellent vegetative growth but allowed for the proliferation of diseases, such as fusarium head blight (*Fusarium spp.*) and septoria glume blotch (*Septoria nodorum*). Heavy disease pressure plus saturated soils encouraged lodging during the grain filling stage. This resulted in large straw volumes but drastically reduced grain yields.

In 1994, location differences were also observed but differences were not as large as in 1993. In general, cultivars at the Winnipeg location produced more straw and total residue than the same cultivars at Carman. Straw and residue production differences were attributed mostly to the amount of available moisture at each location. At Carman, 204 mm of precipitation (84% of normal) fell between seeding and harvest while 421 mm (145% of normal) fell at Winnipeg. Cultivar grain yields were quite similar between locations. In some cases, lower grain yields were noted for experiments at Winnipeg. When such differences were noted, the lower grain yields were attributed to yield losses due to lodging in the barley and oat cultivars.

3.3.2 Wheat Cultivars

Error variances were non-homogeneous for locations within years and between years, so that analyses of variance were performed separately for each location. There were significant differences in straw production among cultivars at the Arborg, Oak Bluff, and Carman locations, but not at Winnipeg (Tables 3.6 to 3.9). Of the four locations, straw production was the highest at Oak Bluff. Straw production was similar at Arborg, Carman and Winnipeg. Production in 1993 at Oak Bluff typified a worst case scenario for straw and grain yields. The cool wet climate caused lush vegetative growth which resulted in the production of large volumes of straw but very small grain yields.

Stem length and straw production were positively correlated at each location. High straw production was positively correlated with plant height (Table 3.10). Contrasts showed that as a group the conventional height cultivars produced more straw than the semidwarf cultivars at 3 of 4 locations (Table 3.11). However, individually, some semidwarf cultivars produced as much straw as some of the tall cultivars, while others produced substantially less. For example, straw production of AC Taber was equal to that of Katepwa, Roblin, AC Domain, and CDC Teal, while straw production of Marshall and Bergen was less than that of Katepwa and Glenlea at each of those locations in which the cultivars were grown together. Similar results were reported by Bauer and Zubrinski (1978) who found that some semidwarf cultivars produced more straw than conventional height cultivars, while other semidwarf cultivars yielded less or the same. Our results, as well as those reported by Bauer and

Table 3.6. Means of straw length, total residue, straw, chaff, grain yield, weight culm^{-1}, spikes m^{-2}, harvest index (HI), proportion of total residue that is chaff, and residue/grain (R/G) ratio for wheat cultivars (Oak Bluff, 1993).

Cultivar	Stem Length	Total Residue	Total Straw	Total Chaff	Grain Yield	Weight culm^{-1}	Spikes m^{-2}	HI	% Chaff	R/G Ratio
	(cm)	--------------------	($g\ m^{-2}$)		-----------------	(g)	(no.)			
Conventional										
AC Domain	84	633	516	117	261	0.81	645	0.291	18.4	2.51
Glenlea	92	693	556	137	195	1.25	453	0.220	19.7	3.58
Katepwa	92	643	522	121	196	0.83	635	0.229	18.9	3.40
Roblin	85	587	458	129	230	0.82	552	0.283	22.1	2.67
Semidwarf										
AC Taber	71	610	438	172	274	1.02	430	0.310	28.9	2.23
Bergen	68	580	433	147	249	0.70	623	0.300	25.3	2.33
Grandin	83	682	550	132	249	0.92	600	0.268	19.1	2.77
HY-612	74	596	439	157	294	0.87	505	0.330	26.7	2.03
Marshall	75	574	434	140	186	0.76	575	0.244	24.5	3.11
Significance	**	NS	*	*	**	**	**	**	**	**
$LSD_{(0.05)}$	6	119	97	31	61	0.16	122	0.049	3.4	0.66

NS, *, ** Not significant, and significant at the 5% and 1% levels of significance, respectively.

Table 3.7. Means of straw length, total residue, straw, chaff, grain yield, weight culm^{-1}, spikes m^{-2}, harvest index (HI), proportion of total residue that is chaff, and residue/grain (R/G) ratio for wheat cultivars (Arborg, 1993).

Cultivar	Stem Length	Total Residue	Total Straw	Total Chaff	Grain Yield	Weight culm^{-1}	Spikes m^{-2}	HI	% Chaff	R/G Ratio
	(cm)	-------------------	(g m^{-2})	-------------------		(g)	(no.)			
Conventional										
AC Domain	89	484	389	94	269	0.86	454	0.358	19.5	1.80
AC Minto	104	579	476	103	209	1.04	457	0.266	17.8	2.78
CDC Teal	89	486	385	101	260	0.86	449	0.347	20.8	1.89
Glenlea	103	541	439	102	267	1.40	315	0.330	18.9	2.03
Katepwa	100	494	385	109	214	0.90	424	0.302	21.9	2.31
Roblin	89	421	337	84	249	0.96	374	0.372	19.8	1.70
Semidwarf										
AC Taber	71	527	380	147	380	0.96	396	0.418	27.9	1.39
Grandin	81	489	369	121	250	0.90	409	0.338	24.7	1.97
Significance	**	NS	**	**	**	**	**	**	**	**
$LSD_{(0.05)}$	3	84	64	26	45	0.09	60	0.025	3.3	0.22

NS, ** Not significant, and significant at the 1% levels of significance, respectively.

Table 3.8. Means of straw length, total residue, straw, chaff, grain yield, weight $culm^{-1}$, spikes m^{-2}, harvest index (HI), proportion of total residue that is chaff, and residue/grain (R/G) ratio for wheat cultivars (Carman, 1994).

Cultivar	Stem Length	Total Residue	Total Straw	Total Chaff	Grain Yield	Weight $culm^{-1}$	Spikes m^{-2}	HI	% Chaff	R/G Ratio
	(cm)	---------- ($g\ m^{-2}$)	----------	----------	----------	(g)	(no.)			
Conventional										
AC Domain	87	516	402	114	357	0.72	557	0.409	22.1	1.44
AC Minto	106	654	529	125	391	0.88	603	0.375	19.2	1.67
CDC Teal	93	578	441	136	397	0.74	598	0.401	23.7	1.46
Glenlea	100	592	456	135	417	1.14	400	0.414	22.9	1.42
Invader	95	565	423	142	345	0.75	559	0.376	25.4	1.67
Katepwa	95	581	450	131	363	0.71	637	0.385	22.4	1.60
Roblin	87	546	413	133	303	0.68	604	0.356	24.5	1.82
Semidwarf										
AC Taber	79	627	435	192	500	0.86	504	0.444	30.6	1.25
Bergen	71	502	324	178	373	0.54	598	0.427	35.7	1.35
Grandin	80	568	401	167	299	0.68	597	0.343	29.4	1.92
HY-612	80	544	371	173	408	0.75	496	0.428	31.8	1.34
Marshall	75	571	387	184	439	0.54	722	0.434	32.3	1.30
Significance	**	NS	**	**	**	**	**	**	**	**
$LSD_{(0.05)}$	5	91	72	23	70	0.08	71	0.022	2.5	0.15

NS, *, ** Not significant, and significant at the 5% and 1% levels of significance, respectively.

Table 3.9. Means of straw length, total residue, straw, chaff, grain yield, weight culm^{-1}, spikes m^{-2}, harvest index (HI), proportion of total residue that is chaff and residue/grain (R/G) ratio for wheat cultivars (Winnipeg, 1994).

Cultivar	Stem Length	Total Residue	Total Straw	Total Chaff	Grain Yield	Weight culm^{-1}	Spikes m^{-2}	HI	% Chaff	R/G Ratio
	(cm)	------------------ (g m^{-2})			------------------	(g)	(no.)			
Conventional										
AC Domain	78	444	319	124	328	0.46	686	0.424	28.1	1.36
AC Minto	87	711	523	189	402	0.61	841	0.362	26.9	1.77
CDC Teal	87	555	386	169	400	0.49	785	0.419	30.5	1.39
Glenlea	92	635	459	176	431	0.91	511	0.404	27.7	1.48
Invader	88	697	470	226	389	0.65	726	0.358	32.5	1.80
Katepwa	86	666	473	193	396	0.56	852	0.373	29.0	1.69
Roblin	77	570	410	159	326	0.57	716	0.366	27.8	1.74
Semidwarf										
AC Taber	72	684	435	249	503	0.74	593	0.427	36.0	1.36
Bergen	66	519	324	195	356	0.48	674	0.405	37.9	1.47
Grandin	75	572	361	210	376	0.45	793	0.397	37.0	1.53
HY-612	79	601	389	213	481	0.63	619	0.444	35.5	1.26
Marshall	68	656	405	251	456	0.45	902	0.412	38.3	1.44
Significance	**	NS	NS	*	*	**	**	**	**	**
$LSD_{(0.05)}$	6	178	125	60	112	0.13	139	0.03	3.7	0.19

NS, *, ** Not significant, and significant at the 5% and 1% levels of significance, respectively.

Zubrinski, support the assertion by Blackman et al. (1978) and Thorne and Blacklock (1971) that short semidwarf varieties should not be considered as a homogeneous group clearly distinct from conventional height varieties.

Table 3.10. Correlation coefficients between stem length and total residue, straw, chaff, and grain yield.

	------------1993	------------	------------1994	------------
	ARBORG	OAK BLUFF	CARMAN	WINNIPEG
Total residue	0.34	0.59	0.55	0.32
Straw	0.65 *	0.77 *	0.87 **	0.62 *
Chaff	-0.61 *	-0.80 **	-0.80 **	-0.34
Grain yield	-0.78 *	-0.56	-0.14	-0.02

*, ** Significant at the 5% and 1% levels of significance, respectively.

One might expect tall cultivars to produce more total residue than semidwarf cultivars. However, total residue production did not differ among cultivars at any of the four locations (Tables 3.6 to 3.9). No relationship between plant height and total residue production was noted (Table 3.10). Contrasts of the semidwarf and conventional height cultivars showed that total residue production between the two groups was not significantly different at any of the locations (Table 3.11). Similar results were reported by Clarke and DePauw (1993) for common and durum wheat cultivars grown under dryland and irrigated conditions in southern Saskatchewan.

Table 3.11. Single degree of freedom contrasts between semidwarf (SD) and conventional height (TALL) wheat cultivars at four Manitoba locations (1993-1994).

	1993						1994					
	ARBORG			OAK BLUFF			CARMAN			WINNIPEG		
	SD	TALL	Signif.	SD	TALL	Signif.	SD	TALL	Signif.	SD	TALL	Signif.
Grain yield (g m^{-2})	315	245	**	250	220	*	403	368	*	434	382	**
Total residue (g m^{-2})	508	501	NS	613	638	NS	562	576	NS	607	611	NS
Straw residue (g m^{-2})	374	402	NS	462	513	*	384	445	**	383	434	*
Chaff residue (g m^{-2})	134	99	**	152	126	**	179	131	**	224	177	**
Weight $culm^{-1}$ (g)	0.93	0.99	*	0.86	0.93	NS	0.67	0.80	**	0.55	0.61	*
Harvest index	0.38	0.33	**	0.29	0.26	**	0.42	0.39	**	0.42	0.39	**
% chaff	26.3	19.8	**	24.8	19.8	**	32.0	22.8	**	36.9	28.9	**
Residue/grain ratio	1.68	2.09	**	2.56	3.04	**	1.43	1.58	**	1.41	1.60	**

NS, *, ** Not significant and significant at the 5% and 1% levels of significance, respectively.

Similarity of total residue production was attributed to differences in chaff production among the cultivars. Chaff, being the collective term for the lemma, palea, rachis and awns (if present) varied greatly with cultivar and cultivar type. In our experiments, all semidwarf wheat cultivars produced awned infloresences while only one tall cultivar, Invader, exhibited the trait. In most studies, the chaff component of total residue is not measured and is included as "straw". Significant negative correlations between stem length and chaff production indicate that semidwarf cultivars produce more chaff residue than conventional height cultivars (Table 3.10). Contrasts comparing semidwarf and conventional height cultivar groups showed that as a group, the semidwarf cultivars consistently produced the most chaff (Table 3.11). Part of the reason semidwarf cultivars produced more chaff was due to the presence of awns. Our experiments indicate that awns account for approximately 5% of chaff dry matter or 1.5% of the total residue. Greater chaff production by semidwarf cultivars helped to mitigate the lower straw weights associated with short stature cultivars. As a result, total residue production differences amongst cultivars are small.

In this study, chaff accounted for 20-35% of total residue, depending on cultivar type. Since chaff production of the semidwarf cultivars is greater than that of the conventional height cultivars, a greater percentage of their total residue is comprised of chaff (Table 3.11). Averaged over 4 location-years, chaff accounted for 30% of the total residue of the semidwarf cultivars compared to only 23% for the conventional height cultivars. These values are consistent with those reported by Cutforth et al. (1988) who found that an average of 28% of the total residue of HY-320 (a semidwarf CPS cultivar) and 21% of that of Neepawa (a tall conventional height cultivar) was chaff. Because chaff management is often overlooked in the overall scheme of total residue management, special attention should be paid when growing semidwarf cultivars. Not only do semidwarf cultivars produce large quantities of chaff, the chaff itself accounts for a large percentage of the total residue.

Weight culm^{-1} and the number of culms per unit area determine overall straw production. Cultivars that produce many culms or very heavy culms have the potential of producing large amounts of straw. In our trials, culm weight appeared to have more influence on absolute straw production than culm number. Straw production was correlated to weight culm^{-1} but not to culms m^{-2} (Table 3.12). The conventional height cultivars AC Minto and Glenlea consistently produced the greatest amounts of straw residue while the semidwarf cultivar Bergen produced the least at Oak Bluff, Carman and Winnipeg. AC Minto and Glenlea both had heavy culms and were the tallest conventional height cultivars while Bergen had very light culms and was the shortest semidwarf cultivar (Tables 3.6 to Table 3.9). Of the semidwarf cultivars, AC Taber produced the most straw at three of the four locations. AC Taber produced fewer but heavier culms than other semidwarf cultivars causing it to be the highest straw producing semidwarf cultivar (Tables 3.6 to 3.9).

Table 3.12. Correlation coefficients between straw production and number of culms m^{-2}, weight $culm^{-1}$.

	1993		1994	
	ARBORG	OAK BLUFF	CARMAN	WINNIPEG
Culms m^{-2}	0.08	0.27	-0.12	0.15
Weight $culm^{-1}$	0.61 *	0.44	0.64 *	0.58 *

*, ** Significant at the 5% and 1% levels of significance, respectively.

Grain yields varied significantly among cultivars at all locations (Tables 3.6 to 3.9). Orthogonal contrasts showed that the semidwarf cultivars consistently outyielded the conventional height cultivars at each location (Table 3.11). The highest yielding cultivar was a CPS (AC Taber at 3 locations and HY-612 at the fourth location). Among the semidwarf cultivars there was a great degree of yield variation. Similar observations were made by Thorne and Blacklock (1971) who noted that semidwarf cultivars vary amongst themselves as much as they do from conventional height cultivars. In our experiments, contrasts comparing American-bred hard red spring (USA) semidwarf cultivars and Canada Prairie Spring (CPS) semidwarf cultivars revealed that the two groups differed in grain yield and HI. At each location, the semidwarf CPS cultivars produced more grain and had higher HI than the American semidwarf cultivars. Such results are not unexpected. A major objective in breeding American semidwarf wheats is to develop cultivars with high protein levels. High protein content has been shown to be linked to low grain yields. In

Canada, CPS wheat breeders are concentrating on high yields with less emphasis on high protein. Straw and total residue production did not differ between American and Canadian semidwarf cultivars (Table 3.13).

The residue to grain ratio (R/G) takes the variability of both residue production and grain yield into account simultaneously and is independent of their magnitudes. This allows for direct comparison of cultivars between locations and years. Large cultivar differences for R/G were noted at all locations (Tables 3.6 to 3.9) suggesting that the potential to select for more favourable DM partitioning exists in wheat. Bauer and Zubrinski (1978) found that R/G were largest and exhibited the most variability when actual grain yields did not meet potential grain yields. They also observed that R/G differences among cultivars were further magnified under adverse environmental conditions. In the good growing conditions of 1994, the average residue to grain ratios were 1.59 and 1.42, respectively, for the conventional height and semidwarf cultivars with average grain yields of 374 g m^{-2} and 419 g m^{-2}. The R/G were much higher and more variable in 1993 when compared to 1994 (Tables 3.6 and 3.7). Average ratios in 1993 were 2.57 and 2.09, respectively, for the semidwarf and conventional height cultivars. Average grain yields for the conventional and semidwarf cultivars were only 211 g m^{-2} and 250 g m^{-2}, respectively. Despite the degree of fluctuation from year to year, cultivars generally showed consistent R/G relative to each other. For example, AC Minto and Invader consistently had high R/G while AC Taber and HY-612 had low ones. The high R/G of Roblin at both locations in 1994 was attributed to the

Table 3.13. Single degree of freedom contrasts between Canadian semidwarf (CPS) and American semidwarf (USA) wheat cultivars at four Manitoba locations (1993-1994).

	1993						1994					
	ARBORG			OAK BLUFF			CARMAN			WINNIPEG		
	CPS	USA	Signif.	CPS	USA	Signif.	CPS	USA	Signif.	CPS	USA	Signif.
Grain yield (g m^{-2})	380	249	**	284	228	**	454	370	**	492	396	**
Total residue (g m^{-2})	527	490	NS	595	626	NS	585	547	NS	643	582	NS
Straw residue (g m^{-2})	380	369	NS	460	483	NS	403	371	NS	412	364	NS
Chaff residue (g m^{-2})	147	121	*	165	143	*	182	176	NS	231	219	NS
Weight/culm (g)	0.96	0.90	NS	0.93	0.81	*	0.81	0.58	**	0.68	0.46	**
Harvest index	0.42	0.34	**	0.32	0.27	**	0.44	0.40	**	0.44	0.41	**
% chaff	27.9	24.7	**	27.8	22.2	**	31.2	32.5	NS	35.8	37.7	NS

NS, *, ** Not significant and significant at the 5% and 1% levels of significance, respectively.

high incidence of fusarium head blight which lowered its grain yield. Single degree-of-freedom contrasts between the semidwarf and conventional height wheat cultivars for total R/G revealed that the semidwarf cultivars, as a whole produced less residue per unit of grain than the tall cultivars (Table 3.11). Of the conventional height cultivars, CDC Teal and AC Domain consistently produced the lowest R/G. The R/G of these cultivars were not significantly different than those of the semidwarf cultivars (Tables 3.6 to 3.9).

Analysis of cultivar means showed that grain yield and straw production were not correlated at any of the locations in 1993 or 1994 (Table 3.14). However, when semidwarf and conventional height cultivars were separated according to height groups, a relationship between grain yield and straw production became apparent (Figure 3.1). Among the semidwarf cultivars, grain yield and straw production were strongly positively correlated at both 1994 locations. The highest yielding semidwarf, AC Taber was the largest producer of straw within that group and produced amounts of straw comparable to some of the conventional height cultivars. For the conventional height cultivars, grain yield and straw production were not correlated indicating that the highest yielding cultivar did not necessarily produce the most straw. The large differences in straw production among similar yielding conventional cultivars shows that careful selection of conventional height wheat cultivars can help to minimize straw residue problems without sacrificing grain yield. For farmers wishing to reduce the amount of crop residues produced, we recommend that they plant AC Domain and refrain from planting Katepwa, AC Minto, and Glenlea.

Table 3.14. Correlation coefficients for grain yield with total residue and straw production.

	1993		1994	
	ARBORG	OAK BLUFF	CARMAN	WINNIPEG
Total residue	0.03	0.22	0.45	0.59
Straw	0.27	0.35	0.13	0.34

When large volumes of straw pass through the threshing area of a combine, combine performance and threshing speed is reduced. To reduce straw throughput, operators often raise the height of the cutter bar leaving more standing stubble in the field.

At all locations and cutting heights, significant varietal differences for estimated combine throughput were noted (Tables 3.15 and 3.16). However, cultivar differences for the mean amount of straw left as standing stubble after cutting at various heights were not significant (data not shown). Single degree-of-freedom contrasts showed that semidwarf cultivars had smaller estimated combine throughput than taller conventional height cultivars (Table 3.17).

Although height was correlated with estimated combine throughput, results from single degree-of-freedom contrasts comparing CWRS to CPS cultivars revealed that the CWRS cultivars had significantly larger estimated combine throughput only at Carman and Oak Bluff (Table 3.17) indicating that the semidwarf CPS cultivars can produce as much as or more straw than the considerably taller CWRS wheat cultivars.

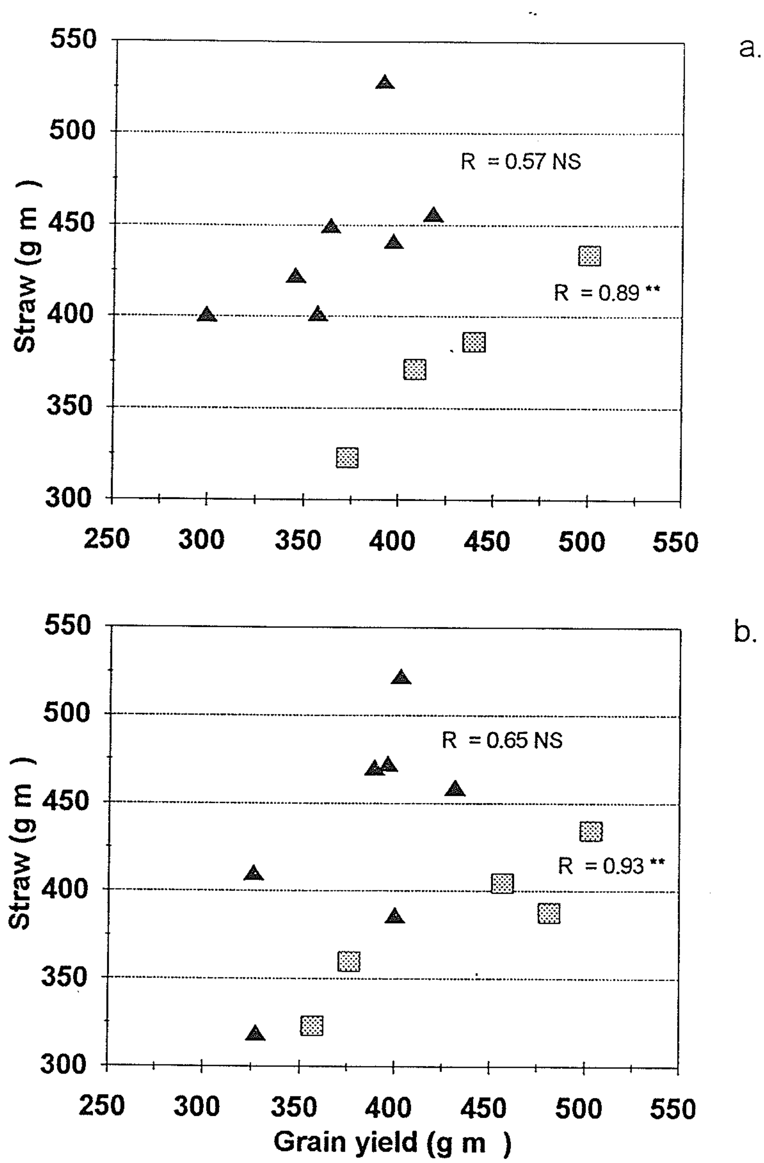

Figure 3.1. Relationship between grain yield and straw production for semidwarf (□) and conventional height (Δ) wheat cultivars at (a) Carman and (b) Winnipeg in 1994.

Table 3.15. Means of estimated combine throughput at 20-, 25-, 30-, and 35-cm cutting heights for wheat cultivars at Arborg and Oak Bluff, 1993.

	ARBORG --------- Cutting Height (cm) ---------				OAK BLUFF --------- Cutting Height (cm) ---------			
Cultivar	20	25	30	35	20	25	30	35
	---------- ($g\ m^{-2}$) ----------							
Conventional								
AC Domain	268	236	207	179	364	326	289	256
AC Minto	346	313	284	257	---	---	---	---
CDC Teal	267	237	208	182	---	---	---	---
Glenlea	320	288	259	234	388	349	311	275
Katepwa	276	251	227	205	362	326	291	258
Roblin	233	206	182	159	329	297	266	237
Semidwarf								
AC Taber	255	223	194	163	270	237	206	178
Bergen	---	---	---	---	310	326	289	256
Grandin	252	223	194	169	381	341	305	270
HY-612	---	---	---	---	289	252	218	184
Marshall	---	---	---	---	298	264	232	200
Significance	**	**	**	**	NS	NS	*	*
$LSD_{(0.05)}$	46	43	40	38	85	80	75	71

NS, *,** Not significant and significant at the 5% and 1% levels of significance, respectively.

Table 3.16. Means of estimated combine throughput at 20-, 25-, 30-, and 35-cm cutting heights for wheat cultivars at Carman and Winnipeg, 1994.

Cultivar	CARMAN --------- Cutting Height (cm) --------- 20	25	30	35	WINNIPEG --------- Cutting Height (cm) --------- 20	25	30	35
	($g\ m^{-2}$)							
Conventional								
AC Domain	245	203	175	145	166	125	88	57
AC Minto	341	301	262	224	287	233	182	134
CDC Teal	272	234	197	165	199	156	118	82
Glenlea	283	247	211	176	270	224	180	138
Invader	253	216	182	150	259	209	163	117
Katepwa	278	241	205	173	255	205	159	115
Roblin	233	193	158	126	210	163	121	82
Semidwarf								
AC Taber	225	186	150	117	225	172	124	81
Bergen	162	127	93	60	151	108	71	39
Grandin	214	176	139	105	187	144	103	68
HY-612	201	165	132	99	200	152	109	71
Marshall	198	161	125	89	191	141	93	55
Significance	**	**	**	**	*	*	**	**
$LSD_{(0.05)}$	57	54	50	47	84	74	64	55

*, ** Significant at the 5% and 1% levels of significance, respectively.

Table 3.17. Comparison of estimated combine throughput between semidwarf (SD) and conventional height (TALL) wheat cultivars and between Canada western red spring (CWRS) and Canada prairie spring (CPS) wheat cultivars at four Manitoba locations using single degree of freedom contrasts.

Cutting Height (cm)	ARBORG (1993)			OAK BLUFF (1993)			CARMAN (1994)			WINNIPEG (1994)		
	SD	TALL	Signif.	SD	TALL	Signif.	S.D.	TALL	Signif.	SD	TALL	Signif.
	(g m^{-2})											
20	254	285	*	309	361	*	200	272	**	191	235	**
25	223	255	*	273	324	*	163	234	**	142	188	**
30	194	228	**	239	289	**	128	199	**	100	144	**
35	166	203	**	206	257	**	94	167	**	63	101	**
	CWRS	CPS	Signif.	CWRS	CPS	Signif.	CWRS	CPS	Signif.	CWRS	CPS	Signif.
20	278	255	NS	352	279	*	274	213	**	223	213	NS
25	249	223	NS	316	245	**	234	175	**	177	162	NS
30	222	194	NS	282	212	**	200	141	**	133	117	NS
35	196	163	NS	251	181	**	167	108	**	94	76	NS

NS, *, ** Not significant and significant at the 5% and 1% levels of significance, respectively.

3.3.3 Barley Cultivars

Error variances between locations were not homogenous; consequently analyses of variance was conducted for each location separately. For the 10 traits examined in the barley experiments, all but grain yield were significantly affected by cultivar (Tables 3.18 to 3.20).

Plant height varied with the different growing conditions at each location. The height of conventional height cultivars between locations seemed to vary more than that of the semidwarf cultivar. For example, the stem length of Argyle measured 105 cm at Arborg, 97 cm at Winnipeg and only 84 cm at Carman, while Duke had a constant stem length of approximately 66 cm at each of the three locations. Other researchers have noted a similar pattern (Ali et al., 1978).

The straw yields of individual cultivars varied from location to location, with the lowest yields recorded mostly at Winnipeg. The magnitude of differences among location-years was substantial. For example, Argyle produced 385 g m^{-2} of straw at Winnipeg compared to 487 g m^{-2} at Carman, a difference of over 25%. Although absolute straw yields were affected by location, the relative yields of the cultivars were remarkably similar from location to location. Manley and Argyle consistently produced the most straw while Duke, Excel, and Heartland produced the least.

Unlike the semidwarf wheat cultivars, the semidwarf barley cultivar, Duke produced significantly less straw and total residue than the conventional height cultivars at all locations (Table 3.21). The straw production of Duke ranged

Table 3.18. Means of stem length, total residue, straw, chaff, grain yield, weight culm^{-1}, spikes m^{-2}, harvest index (HI), proportion of total residue that is chaff (% chaff), and residue/grain (R/G) ratio for barley cultivars (Arborg, 1993).

Cultivar	Stem Length	Total Residue	Total Straw	Total Chaff	Grain Yield	Weight culm^{-1}	Spikes m^{-2}	HI	% Chaff	R/G Ratio
	(cm)	(g m^{-2})				(g)	(no.)			
Conventional										
Argyle	105	527	474	53	480	1.30	365	0.476	10.1	1.10
Heartland	81	460	396	65	503	0.94	421	0.520	14.2	0.91
Manley	77	561	486	75	462	0.80	609	0.452	13.4	1.21
Semidwarf										
Duke	67	416	359	54	463	1.14	317	0.528	13.1	0.90
Significance	**	**	**	**	NS	**	**	**	**	**
$LSD_{(0.05)}$	6	69	63	8	70	0.10	85	0.013	1.3	0.06

NS, ** Not significant and significant at the 1% level of significance, respectively.

Table 3.19. Means of stem length, total residue, straw, chaff, grain yield, weight $culm^{-1}$, spikes m^{-2}, harvest index (HI), proportion of total residue that is chaff (% chaff), and residue/grain (R/G) ratio for barley cultivars (Carman, 1994).

Cultivar	Stem Length	Total Residue	Total Straw	Total Chaff	Grain Yield	Weight $culm^{-1}$	Spikes m^{-2}	HI	% Chaff	R/G Ratio
	(cm)	----------(g m^{-2})			----------	(g)	(no.)			
Conventional										
AC Lacombe	75	555	460	95	572	1.06	434	0.508	17.0	0.97
Argyle	84	587	487	100	541	1.33	366	0.479	17.3	1.09
Bedford	72	542	445	97	535	1.12	402	0.497	17.8	1.01
Excel	70	451	360	90	550	0.97	374	0.550	20.0	0.82
Heartland	65	481	388	92	560	0.82	484	0.537	19.0	0.87
Manley	73	610	484	125	521	0.82	594	0.461	20.8	1.17
Robust	75	519	426	92	549	1.20	357	0.514	17.8	0.95
Semidwarf										
Duke	65	459	369	89	518	1.14	325	0.530	19.5	0.89
Significance	**	**	**	**	NS	**	**	**	*	**
$LSD_{(0.05)}$	7	70	64	17	85	0.16	69	0.021	2.7	0.08

NS, *, ** Not significant and significant at the 5% and 1% levels of significance, respectively.

Table 3.20. Means of stem length, total residue, straw, chaff, grain yield, weight culm^{-1}, spikes m^{-2}, harvest index (HI), proportion of total residue that is chaff (% chaff), and residue/grain (R/G) ratio for barley cultivars (Winnipeg, 1994).

Cultivar	Stem Length	Total Residue	Total Straw	Total Chaff	Grain Yield	Weight culm^{-1}	Spikes m^{-2}	HI	% Chaff	R/G Ratio
	(cm)	---------- (g m^{-2})	----------	----------	----------	(g)	(no.)			
Conventional										
AC Lacombe	81	447	359	87	474	0.91	395	0.515	19.8	0.94
Argyle	97	473	385	88	381	1.29	298	0.447	18.3	1.24
Bedford	79	463	377	86	462	0.91	411	0.499	18.8	1.01
Excel	74	450	351	98	473	0.88	408	0.513	22.0	0.95
Heartland	77	443	345	98	450	0.82	419	0.504	22.0	0.99
Manley	79	623	479	144	467	0.92	521	0.429	23.0	1.34
Robust	85	473	392	80	447	1.10	358	0.485	17.0	1.06
Semidwarf										
Duke	66	410	309	101	484	0.99	311	0.542	25.0	0.85
Significance	**	**	**	**	NS	**	**	**	**	**
$LSD_{(0.05)}$	5	95	76	21	93	0.11	83	0.020	1.7	0.08

NS, *, ** Not significant and significant at the 5% and 1% levels of significance, respectively.

Table 3.21. Comparison of agronomic traits between semidwarf (SD) and conventional height (TALL) barley cultivars at three Manitoba locations (1993 -1994).

	------ ARBORG (1993) ------			------ CARMAN (1994) ------			---- WINNIPEG (1994) ----		
	SD	TALL	Signif.	SD	TALL	Signif.	SD	TALL	Signif.
Grain yield (g m^{-2})	463	482	NS	517	547	NS	484	451	NS
Total residue (g m^{-2})	413	516	**	459	535	**	410	481	*
Straw production (g m^{-2})	359	452	**	369	436	**	309	384	*
Chaff production (g m^{-2})	54	64	NS	89	98	NS	101	97	NS
Weight $culm^{-1}$ (g)	1.14	1.01	*	1.14	1.05	NS	0.99	0.98	NS
Spikes m^{-2}	317	465	**	325	430	**	311	401	**
Harvest index	0.53	0.48	**	0.53	0.51	**	0.54	0.48	**
% chaff	13.1	12.6	NS	19.5	18.5	NS	25.0	20.1	**
Residue/grain ratio	0.90	1.08	**	0.89	0.98	**	0.85	1.07	**

NS, *, ** Not significant and significant at the 5% and 1% levels of significance, respectively.

from 79% to 85% of the average weight of the conventional height cultivars at the three locations. Strong correlations between stem length and straw production indicated that plant height was a good indicator of straw production potential (Table 3.22).

Spike production was similar at each location. Single degree-of-freedom contrasts showed that at each location, Duke produced fewer spikes m^{-2} than the conventional height cultivars (Table 3.21). Similar observations were made by Jedel and Helm (1994). They reported that the Canadian semidwarf cultivars, Samson and Duke, produced fewer spikes per unit area than any of the other 6-row barley cultivars in their study. The individual culm weight of Duke was not lower than those of the tall cultivars at any of the locations (Table 3.21). The shorter culms of Duke were considerably thicker enabling Duke to produce culms with weights similar to those of taller cultivars. Research conducted by Ali et al. (1978) confirmed that semidwarf cultivars often had culms 1/3 thicker than those of the normal conventional height cultivars.

Unlike wheat, no clear correlations between straw production and number of culms m^{-2} or weight $culm^{-1}$ were evident (Table 3.22). This indicated that neither of culm weight nor culm number were overriding factors in determining absolute straw production.

Table 3.22. Correlation coefficients between straw production and stem length, harvest index (HI), number of culms, weight/culm, and grain yield of seven 6-row spring barley cultivars.

	ARBORG (1993)	CARMAN (1994)	WINNIPEG (1994)
Stem length (cm)	0.99 *	0.85 *	0.84 *
Harvest index	-0.97 **	-0.95 **	-0.81 *
culms m^{-2}	0.27	0.09	0.05
weight $culm^{-1}$	0.62	0.63	0.48
Grain yield	0.22	0.24	-0.61

*, ** Significant at the 5% and 1% levels of significance, respectively.

Overall, the 2-row cultivar Manley, produced the most straw with a three location average of 483 g m^{-2}, 28% greater than that of the lowest producer, Duke. Single degree-of-freedom contrasts comparing 2-row and 6-row barleys revealed that the 2-row cultivar produced considerably more straw, chaff, and total residue as well as larger R/G in all tests (Table 3.23). These results are consistent with the previous work of Jedel and Helm (1994). In our trials, the greater straw production of the 2-row cultivar was attributed to a 30% to 40% increase in culm number combined with only slightly thinner culms, compared to 6-row cultivars.

Grain yields were similar among cultivars at all locations (Table 3.18 to 3.21). Among locations, relative grain yields of the cultivars were much less consistent than straw yields. Yield losses due to lodging at the Winnipeg location may have further confounded the yield ranking differences. Single degree-of-freedom contrasts showed that Duke produced grain yields similar to the conventional height lines (Table 3.21). Contrasts also showed that the grain yield of the 2-row cultivar, Manley, was similar to the 6-row cultivars (Table 3.23). Cultivars that produced high yields of straw were rarely those which produced high grain yields. Among cultivars, no correlations were observed between grain yield and straw production (Table 3.22). White (1987) also reported that grain yield and straw production were not correlated and that grain yield was not a useful guide for estimating straw production.

Cultivar differences for R/G were significant for all locations (Tables 3.18 to 3.21). In our experiments, R/G and their rank among cultivars were very similar across location-years. Manley and Argyle consistently had the highest R/G while Duke and Excel always had the lowest. Consistent R/G among the cultivars between years indicated that the R/G has an important value for indicating the relative performance of cultivars. As with wheat, barley cultivars exhibited a wide range of R/G (0.82 to 1.34). This range suggests that potential to select for cultivars with more favourable patterns of dry matter partitioning exists.

HI values ranged from 0.42 to 0.55 in the barley experiments. These values were similar to those reported by Jedel and Helm (1994) in their assessment of western Canadian barley cultivars but slightly higher than those reported by Wych and Rasmusson (1983) for Minnesota barley cultivars. The HI of Duke was higher than the conventional height cultivars at each location (Table 3.21). This finding is consistent with reports by Ali et al. (1978) and Allan (1983) who both noted that short stature plants had higher HI than tall

Table 3.23. Comparison of agronomic traits between 6-row and 2-row barley cultivars at three Manitoba locations (1993 -1994).

	------ ARBORG (1993) ------			------ CARMAN (1994) ------			---- WINNIPEG (1994) ----		
	6-row	2-row	Signif.	6-row	2-row	Signif.	6-row	2-row	Signif.
Grain yield (g m^{-2})	482	462	NS	547	521	NS	453	467	NS
Total residue (g m^{-2})	467	561	**	513	610	**	451	623	**
Straw residue (g m^{-2})	409	486	**	419	484	**	360	479	*
Chaff residue (g m^{-2})	57	75	**	94	125	**	91	144	**
Weight $culm^{-1}$ (g)	1.13	0.80	**	1.09	0.82	**	0.99	0.92	NS
Spikes m^{-2}	368	609	**	391	594	**	371	521	**
Harvest index	0.51	0.45	**	0.52	0.46	**	0.50	0.43	**
% chaff	13.4	12.5	*	18.3	20.8	*	20.4	23.0	**
Residue/grain ratio	0.97	1.21	**	0.94	1.17	**	1.00	1.34	**

NS, *, ** Not significant and significant at the 5% and 1% levels of significance, respectively.

stature plants. Compared to the 6-row conventional height cultivars, Manley's similar grain yield and higher straw production compared to the 6-row cultivars, gave that cultivar a significantly lower HI value (Table 3.23). These results contradict those of Jedel and Helm (1994) who found no differences between 2-row and 6-row cultivars for HI or grain yield. At each of the locations, HI was negatively correlated with straw production (Table 3.22). This negative correlation indicates that high HI cultivars are very efficient at partitioning dry matter into grain yield and as a result have comparably lower straw production than low HI cultivars.

At all locations and cutting heights, significant varietal differences were noted for estimated combine throughput and weight of straw left as standing stubble after cutting at various heights (Tables 3.24 and 3.25). Statistical contrasts showed that at each location, the semidwarf cultivar Duke had less estimated combine throughput than conventional height cultivars although the weight of straw left as standing stubble was similar (Table 3.26). While Manley tended to have larger estimated combine throughput weights than the conventional height 6-row cultivars, statistical contrasts showed that the differences were only significant at the Winnipeg location (Table 3.27). Manley did, however, have significantly more straw left as standing stubble when compared to the conventional height 6-row cultivars. Statistical contrasts showed that Manley left more straw in the field at all cutting heights at both locations in 1994 and at the two highest cutting heights at the Arborg location in 1993 (Table 3.27).

Table 3.24. Means of estimated combine throughput at 20-, 25-, 30-, and 35-cm cutting heights for barley cultivars at Arborg, Carman, and Winnipeg (1993 -1994).

	ARBORG (1993) ------ Cutting Height (cm) ------				CARMAN (1994) ------ Cutting Height (cm) ------				WINNIPEG (1994) ------ Cutting Height (cm) ------			
Cultivar	20	25	30	35	20	25	30	35	20	25	30	35
	------ ($g\ m^{-2}$) ------											
Conventional												
AC Lacombe	---	---	---	---	291	256	219	186	225	193	163	136
Argyle	308	278	251	223	301	259	219	183	254	221	189	159
Bedford	---	---	---	---	275	237	200	166	234	204	173	144
Excel	---	---	---	---	220	185	153	121	211	178	148	119
Heartland	259	228	199	169	235	195	158	120	206	171	140	112
Manley	330	294	259	225	292	247	204	164	305	261	221	183
Robust	---	---	---	---	273	234	200	167	247	214	182	152
Semidwarf												
Duke	219	190	165	141	212	174	140	110	167	135	106	78
Significance	**	**	**	**	*	*	*	*	**	**	**	**
$LSD_{(0.05)}$	52	49	47	44	57	56	54	53	57	51	46	41

*, ** Significant at the 5% and 1% levels of significance, respectively.

Table 3.25. Mean weights of straw left in the field as standing stubble at cutting heights of 20-, 25-, 30-, and 35-cm for barley cultivars at three Manitoba locations (1993-1994).

	ARBORG (1993) ------ Cutting Height (cm) ------				CARMAN (1994) ------ Cutting Height (cm) ------				WINNIPEG (1994) ------ Cutting Height (cm) ------			
Cultivar	20	25	30	35	20	25	30	35	20	25	30	35
	($g\ m^{-2}$)											
Conventional												
AC Lacombe	---	---	---	---	169	204	240	274	134	166	196	223
Argyle	140	171	198	226	186	228	268	304	131	164	196	226
Bedford	---	---	---	---	169	208	245	279	143	173	204	232
Excel	---	---	---	---	141	175	207	239	141	173	204	233
Heartland	137	168	197	226	154	193	231	268	139	173	205	233
Manley	156	192	227	261	193	238	280	321	174	218	259	296
Robust	---	---	---	---	154	193	227	260	145	179	210	240
Semidwarf												
Duke	115	144	170	193	157	195	229	259	142	174	204	231
Significance	*	*	*	*	**	**	**	**	*	*	*	*
$LSD_{(0.05)}$	29	33	37	42	25	27	31	34	22	28	33	38

*, ** Significant at the 5% and 1% levels of significance, respectively.

Table 3.26. Comparison of estimated combine throughput between semidwarf (SD) and conventional height (TALL) barley cultivars and betweeen 6-row and 2-row barley cultivars at three Manitoba locations using single degree of freedom contrasts.

Cutting Height (cm)	----- ARBORG (1993) -----			----- CARMAN (1994) -----			----- WINNIPEG (1994) -----		
	SD	TALL	Signif.	SD	TALL	Signif.	SD	TALL	Signif.
	---------- ($g\ m^{-2}$) ----------								
20	219	299	**	213	269	*	167	240	**
25	190	267	**	174	230	*	135	206	**
30	165	236	**	140	193	*	106	174	**
35	141	206	**	110	158	*	78	144	**
	6-row	2-row	Signif.	6-row	2-row	Signif.	6-row	2-row	Signif.
20	283	330	NS	265	292	NS	230	305	**
25	253	294	NS	228	247	NS	197	261	**
30	225	259	NS	192	204	NS	166	221	**
35	196	225	NS	156	164	NS	136	183	**

NS, *, ** Not significant and significant at the 5% and 1% levels of significance, respectively.

Table 3.27. Comparison of the weight of standing stubble between semidwarf (SD) and conventional height (TALL) barley cultivars and between 6-row and 2-row barley cultivars at three Manitoba locations using single degree of freedom contrasts (1993-1994).

Cutting Height (cm)	----- ARBORG (1993) -----			---- CARMAN (1994) ----			---- WINNIPEG (1994) ----		
	SD	TALL	Signif.	SD	TALL	Signif.	SD	TALL	Signif.
	-----	-----	-----	-----	($g\ m^{-2}$)	-----	-----	-----	-----
20	115	138	NS	157	166	NS	142	144	NS
25	144	169	NS	195	206	NS	174	178	NS
30	170	198	NS	229	243	NS	204	211	NS
35	193	226	NS	259	278	NS	231	240	NS
	6-row	2-row	Signif.	6-row	2-row	Signif.	6-row	2-row	Signif.
20	139	156	NS	162	193	**	139	174	**
25	170	192	NS	200	238	**	171	218	**
30	198	227	*	236	280	**	203	259	**
35	226	261	*	271	321	**	231	296	**

NS, *, ** Not significant and significant at the 5% and 1% levels of significance, respectively.

3.3.4 Oat Cultivars

Because the error variances were heterogenous among locations, analyses of variance were conducted separately for each location. Significant cultivar differences were noted for all traits except straw and total residue at both locations and weight culm^{-1} at Carman (Tables 3.28 and 3.29).

Plants were 10 to 20 cm shorter at Carman compared to Winnipeg and the semidwarf cultivar, OT-257, was on average 27 cm shorter than the conventional height cultivars. Straw and total residue production of individual cultivars varied greatly from location to location, with lowest production values recorded mostly at Carman. Average straw production at Winnipeg was 609 g m^{-2}, 20% larger than the 512 g m^{-2} at Carman. A perceived reduction in straw production with semidwarf stature has dampened the enthusiasm for the development of semidwarf oats. In our trials, single degree of freedom contrasts comparing OT-257 with the conventional height hulled cultivars showed that OT-257 did not produce less straw or total residue at either location (Table 3.30). Straw yields of OT-257 ranged from 92% to 110% of the average conventional height hulled cultivar straw weight at the two 1994 locations. Meyers et al. (1985) reported that straw yields of Minnesota bred semidwarf oats also varied considerably and ranged from 73% to 125% of conventional height lines. They also reported that the straw yield of the best grain yielding semidwarf tended to be 10% to 20% less than that of the best conventional height line. Based solely on height differential, straw yield differences between OT-257 and the conventional height cultivars were not as

Table 3.28. Means of straw length, total residue, straw, chaff, grain, weight culm^{-1}, panicles m^{-2}, harvest index (HI), percent of total residue = chaff (% chaff), and residue/grain (R/G) ratio for oat cultivars (Carman, 1994).

Cultivar	Stem Length	Total Residue	Total Straw	Total Chaff	Grain Yield	Weight culm^{-1}	Panicles m^{-2}	HI	% Chaff	R/G Ratio
	(cm)	----------	----------	(g m^{-2})	----------	(g)	(no.)			
Conventional										
AC Belmont[1]	71	642	477	166	438	0.92	516	0.407	25.8	1.46
AC Marie	82	591	514	77	549	0.90	575	0.483	13.0	1.08
Dumont	79	595	515	80	610	0.88	594	0.508	13.3	0.97
Riel	74	635	557	78	579	0.73	771	0.476	12.3	1.10
Robert	77	611	526	85	576	0.84	636	0.486	14.0	1.06
Semidwarf										
OT-257	48	584	486	98	524	0.84	587	0.476	16.7	1.12
Significance	**	NS	NS	**	*	NS	*	**	**	**
LSD $_{(0.05)}$	8	158	131	28	105	0.20	134	0.034	1.3	0.16

[1] AC Belmont is a naked caryopsis type oat cultivar.

NS, *, ** Not significant, and significant at the 5% and 1% levels of significance, respectively.

Table 3.29. Means of straw length, total residue, straw, chaff, grain, weight $culm^{-1}$, panicles m^{-2}, harvest index (HI), percent of total residue = chaff (% chaff), and residue/grain (R/G) ratio for oat cultivars (Winnipeg, 1994).

Cultivar	Stem Length	Total Residue	Total Straw	Total Chaff	Grain Yield	Weight $culm^{-1}$	Panicles m^{-2}	HI	% Chaff	R/G Ratio
	(cm)	-------------------	($g\ m^{-2}$)	-------------------		(g)	(no.)			
Conventional										
AC Belmont[1]	93	754	616	137	436	1.66	371	0.366	18.3	1.73
AC Marie	93	680	579	101	553	1.40	414	0.448	14.9	1.24
Dumont	88	636	551	85	472	1.40	393	0.425	13.4	1.37
Riel	98	751	678	72	438	1.24	552	0.370	9.6	1.72
Robert	90	661	569	92	565	1.27	449	0.461	13.9	1.18
Semidwarf										
OT-257	65	802	658	144	582	1.28	513	0.421	18.1	1.38
Significance	**	NS	NS	**	**	**	**	**	**	**
$LSD_{(0.05)}$	6	120	114	15	82	0.18	82	0.042	2.3	0.26

[1] AC Belmont is a naked caryopsis type oat cultivar.
NS, ** Not significant, and significant at the 1% levels of significance.

great as might have been expected. Meyers et al. (1985) attributed smaller than expected straw production differences to thicker culms for the semidwarf cultivars, and possibly, coupled with higher shoot survival. In our trials, the individual culm weight of OT-257 was similar to those of the tall hulled cultivars at either locations (Table 3.30). This indicates that the shorter stems of OT-257 were thicker, thus reducing the advantage that short stems had on straw production.

In general, panicle production was greater at Carman compared to Winnipeg. Panicle production of OT-257 was not statistically different from the conventional height hulled cultivars at either location (Table 3.30). This observation agrees with those of Meyers et al. (1985) who found that although shoot survival tended to be higher for the semidwarf cultivars, panicle number did not differ consistently from the conventional height lines. Similar numbers of panicles produced per unit area coupled with shorter but thicker culms gave the semidwarf oat cultivar, OT-257, a straw production potential similar to taller conventional height cultivars.

Overall grain yields varied from location to location. Yield losses due to lodging caused generally lower grain yields at Winnipeg. For example, Riel which yielded 579 g m^{-2} at Carman lodged severely at Winnipeg and grain yields were 32% less or 438 g m^{-2}. Grain yield differences did not occur between OT-257 and the conventional height hulled cultivars at Carman, however at Winnipeg, OT-257 produced more grain (Table 3.30). The larger semidwarf grain yield at Winnipeg was attributed to superior lodging resistance.

Table 3.30. Comparison of agronomic traits between semidwarf (SD) and conventional height (TALL) oat cultivars at two Manitoba locations (1994).

	CARMAN (1994)			WINNIPEG (1994)		
	SD	TALL	Significance	SD	TALL	Significance
Grain yield (g m^{-2})	524	579	NS	582	507	*
Total residue (g m^{-2})	584	608	NS	802	682	*
Straw production (g m^{-2})	486	528	NS	658	594	NS
Chaff production (g m^{-2})	98	80	NS	144	88	**
Weight $culm^{-1}$ (g)	0.84	0.83	NS	1.28	1.33	NS
Panicles m^{-2}	587	643	NS	513	452	NS
Harvest Index	0.48	0.49	NS	0.42	0.43	NS
% of total residue = chaff	16.6	13.1	**	18.1	13.0	**
Residue/grain ratio	1.12	1.05	NS	1.38	1.37	NS

NS, *, ** Not significant and significant at the 5% and 1% levels of significance, respectively.

This clearly shows the type of grain yield "insurance" that the semidwarf stature provides under conditions conducive to lodging.

Chaff production, which is closely linked to grain yield, also varied between locations. At both locations, OT-257 produced the most chaff of the hulled cultivars, however differences were only significant at Carman. The percent of total residue comprised of chaff was larger for OT-257 than the rest of the hulled cultivars (Table 3.30). Chaff accounted for 17% of total residue of OT-257 at Carman and 18% at Winnipeg compared to only 13% for the conventional height hulled cultivars. Because chaff management is often overlooked in the overall scheme of total residue management, special attention will have to be paid to semidwarf cultivars which produce greater quantities of chaff and account for a larger percentage of their total residue.

HI was generally higher at Carman than at Winnipeg reflecting the higher grain yields and lower straw production noted at that location. The HI of OT-257 was similar to those of the conventional height hulled cultivars at both locations (Table 3.30). This result is in contrast with our findings for wheat and barley and with those of Ali et al. (1978) and Allan (1983) who noted that shortened plant stature often resulted in higher HI.

In our experiments, the R/G varied with both cultivar and location. R/G were higher at Winnipeg reflecting heavy straw production and poor grain yields caused by lodging. Residue to grain ratios of OT-257 and the conventional height lines did not differ significantly from each either at either location (Table 3.30). Although semidwarf plant stature was expected to favour higher HI and lower R/G it appears that this is not the case. However, the attainment of high grain yields through development of better semidwarf genotypes could move HI higher and lower the R/G.

The conventional height naked caryopsis type oat cultivar, AC Belmont produced amounts of straw and total residue similar to the hulled cultivars at both locations. Compared to the hulled cultivars, AC Belmont produced more chaff but smaller grain yields (Table 3.31). Chaff accounted for 20% to 25% of the total residue of AC Belmont. These results are typical of hulless type cultivars. For hulled cultivars, the lemma and palea remain attached to the groat during threshing. However for hulless cultivars, the lemma and palea are dislodged during the threshing process and become part of the chaff instead of part of the overall grain yield.

Orthogonal contrasts showed that AC Belmont had a smaller HI and produced fewer panicles but had a higher R/G when compared to the hulled cultivars (Table 3.31).

Although estimated combine throughput was not affected by cultivar at either location, it seemed to decrease with plant height (Table 3.32). At Carman, significant correlation coefficients for throughput and height were observed at all cutting heights. Contrasts comparing the estimated combine throughput of OT-257 and the conventional height cultivars showed that at the higher cutting heights, OT-257 had smaller throughput (Table 3.32). At Winnipeg, estimated combine throughput was not correlated with plant height at any of the cutting heights. Contrasts also showed that at Winnipeg, OT-257

Table 3.31. Comparison of agronomic traits between hulless and hulled oat cultivars at two Manitoba locations (1994).

	CARMAN (1994)			WINNIPEG (1994)		
	Hulless	Hulled	Significance	Hulless	Hulled	Significance
Grain yield (g m^{-2})	438	568	**	436	522	*
Total residue (g m^{-2})	642	608	NS	754	706	NS
Straw production (g m^{-2})	477	528	NS	616	607	NS
Chaff production (g m^{-2})	166	80	**	137	99	**
Weight $culm^{-1}$ (g)	0.92	0.84	NS	1.66	1.33	**
Panicles m^{-2}	516	644	*	371	464	**
Harvest index	0.41	0.49	*	0.37	0.43	*
% of total residue = chaff	25.9	13.1	**	18.3	14.0	**
Residue/grain ratio	1.46	1.05	**	1.73	1.38	**

NS, *, ** Not significant and significant at the 5% and 1% levels of significance, respectively.

Table 3.32. Means of estimated combine throughput at 20-, 25-, 30, and 35-cm cutting heights for oat cultivars at Carman and Winnipeg (1994).

	CARMAN				WINNIPEG			
	--------- Cutting Height (cm) ---------				--------- Cutting Height (cm) ----------			
Cultivar	20	25	30	35	20	25	30	35
	($g\ m^{-2}$)							
Conventional								
AC Belmont[1]	289	241	198	158	444	403	364	327
AC Marie	331	288	249	212	404	362	323	287
Dumont	329	283	241	202	369	328	291	255
Riel	343	289	239	195	471	424	379	336
Robert	323	270	224	183	392	349	309	273
Semidwarf								
OT-257	253	192	138	92	413	357	298	239
Significance	NS	NS	NS	NS	NS	NS	NS	NS
$LSD_{(0.05)}$	112	104	95	86	82	79	74	70
Semidwarf vs Tall	NS	*	*	**	NS	NS	NS	NS

[1] AC Belmont is a naked caryopsis oat cultivar.
NS, *, ** Not significant and significant at the 5% and 1% levels of significance, respectively.

and the conventional height cultivars had similar estimated combine throughput.

Mean weight of straw standing as stubble was affected by cultivar at both locations. Contrast for stubble weight showed that at both locations for each cutting height, stubble weight of OT-257 was larger than the taller cultivars (Table 3.33).

Table 3.33. Mean weights of straw left in the field as standing stubble at cutting heights of 20-, 25-, 30-, and 35-cm for oat cultivars at Carman and Winnipeg (1994).

Cultivar	CARMAN Cutting Height (cm)				WINNIPEG Cutting Height (cm)			
	20	25	30	35	20	25	30	35
	($g\ m^{-2}$)							
Conventional								
AC Belmont[1]	188	234	279	318	172	213	252	289
AC Marie	183	226	265	302	175	217	255	292
Dumont	186	232	274	313	182	223	260	296
Riel	214	269	318	362	208	254	300	342
Robert	203	256	302	342	177	220	261	298
Semidwarf								
OT-257	233	294	348	394	245	301	360	419
Significance	**	**	**	*	**	**	**	**
$LSD_{(0.05)}$	26	33	42	51	41	48	57	64
Semidwarf vs Tall	**	**	**	**	**	**	**	**

[1] AC Belmont is a naked caryopsis oat cultivar.

*, ** Significant at the 5% and 1% levels of significance, respectively.

3.4 Summary and Conclusions

For wheat, the correlation between stem length and straw production indicated that taller plants produced more straw. However, no relationship existed between stem length and total residue production indicating that semidwarf wheat cultivars were able to produce as much total residue as tall wheat cultivars. Similarity of total residue production was due to chaff production differences among cultivars. Approximately 30% of the total residue of semidwarf wheat cultivars was chaff, compared to only 23% for conventional height wheat cultivars. Although all the semidwarf wheat cultivars produced awns they only accounted for approximately 1.5% of the total residue production. The percentage of total residue comprised of chaff became even larger when straw was cut above ground level and expressed in terms of the % of estimated combine throughput (Table 3.34).

Table 3.34. Percentage of total residue comprised of chaff going through the combine at different cutting heights for semidwarf and conventional height wheat cultivars averaged over locations (1993-1994).

	SEMIDWARF			CONVENTIONAL		
Cutting Height (cm)	1993 (%)	1994 (%)	Average (%)	1993 (%)	1994 (%)	Average (%)
0	25	34	30	20	26	23
20	33	51	42	26	38	32
25	36	57	46	28	42	35
30	39	64	51	30	47	39
35	43	72	57	33	54	43

Because semidwarf wheat cultivars produce greater quantities of chaff than conventional height cultivars, a greater potential for crop residue problems exists. Problems such as uneven seedling emergence and cold wet soils under the chaff layer would not be as serious if chaff residue was managed at harvest by chaff collection or chaff spreading.

For wheat, grain yield and straw production were positively correlated among semidwarf wheat cultivars only. As a result, the highest grain yielding semidwarf produced the most straw and total residue. Careful consideration must be made when choosing a semidwarf wheat cultivar with the intention of reducing straw production. Large differences in straw production among similar yielding conventional height wheat cultivars showed that selection of conventional height cultivars for reduced straw production was possible without sacrificing grain yield. For farmers wishing to reduce the amount of crop residues produced, we recommend that they plant AC Domain and refrain from planting cultivars such as Katepwa, AC Minto and Glenlea.

Estimated combine throughput varied greatly among wheat cultivars. Semidwarf wheat cultivars had smaller estimated combine throughput than conventional height cultivars. Because of lower estimated combine throughput, growing semidwarf wheat cultivars should help improve the speed and efficiency of harvest.

For barley cultivars, a strong correlation between stem length and straw production indicated that shorter cultivars produced less straw. No correlation between straw production and grain yield showed that for barley, grain yield was not a useful guide for estimating straw production. The semidwarf barley cultivar, Duke, produced less straw and total residue than conventional height barley cultivars but had similar grain yields. The large variation in straw production among similar yielding conventional height cultivars indicated that cultivar selection for low straw production without concurrent losses in grain yield was possible. Duke, Heartland, and Excel combined low straw production with high grain yield making these three cultivars attractive choices for producers wanting reduced residue production. The 2-row cultivar, Manley produced more straw, chaff, and total residue than the conventional height 6-row cultivars but had grain yields similar to the 6-rows. Larger straw and total residue production by 2-row cultivars should be considered when choosing the type and cultivar of barley to be grown. Duke, Heartland and Excel had low estimated combine throughput making them ideal choices for a faster more efficient harvest. Manley tended to have higher estimated combine throughput than conventional height 6-row cultivars. If the choice to grow 2-row barley cultivars is made, slower harvesting should be expected because of the increased amount of straw passing through the combine.

For oat cultivars, stem length and straw production were not correlated. Although there were significant differences among cultivars in stem length, differences in straw or total residue production among oat cultivars were not significant. However, AC Marie and Robert were the two cultivars that seemed to combine high grain yields with lower residue production. Farmers in the Red River valley wanting to avoid residue problems should choose either AC Marie or Robert as their favoured cultivars. Planting Riel should be avoided as this cultivar produces only average grain yields but has very high residue production capabilities. The semidwarf oat cultivar, OT-257, produced amounts of straw and total residue similar to conventional height cultivars. Similar to the semidwarf wheats, OT-257 produced more chaff than conventional height hulled cultivars. Chaff accounted for approximately 18% of the total residue of OT-257 but only 13% for the conventional height hulled cultivars. Due to similar straw production levels among the oat cultivars, estimated combine throughput was not affected by cultivar choice.

IV. SEEDING RATE EFFECT ON CROP RESIDUE AND GRAIN YIELD

4.1 Introduction

Rate of seeding affects a cereal plant's environment thereby altering the degree of interplant and intraplant competition. In general, research has shown that, although grain yields are reduced by excessively high or low planting densities, within a wide range of seeding rates grain yield is relatively unaffected by seeding density. Very little research has been conducted to determine the effect of seeding density on straw and total residue production.

Baker (1982) reported that the average grain and straw yields for eight spring wheat cultivars increased with increasingly higher seeding rate in each of nine experiments conducted in north central Saskatchewan. Similar results were found by Marshall et al. (1987) with oats in Pennsylvania and Pendleton and Dungan (1960) with winter wheat in Illinois. However, Clarke and DePauw (1993) reported that seeding rate had a small but inconsistent effect on residue production of spring wheat and durum under both rainfed and irrigated conditions in southern Saskatchewan.

Cultivar by seeding rate interactions for grain yield have been noted (Faris and DePauw, 1981; Baker, 1982). Although these interactions do exist, their magnitude and significance vary among locations and years. Information on cultivar by seeding rate interactions for straw and total residue production is non-existent, however, the possibility for a more stable interaction with residue production may arise since straw production has been reported to vary less than grain yield (Gehl et al., 1991). Gehl et al. (1991) found that the magnitude of difference between lowest-yielding and highest-yielding cultivars was much less for straw yield than for grain yield (12% as opposed to 30%). Smaller variations in straw production could be due to the productivity of a plant's tillers. Aguilar-Mariscal and Hunt (1991) reported that HI declined as the number of spikes per plant increased. In such a case, straw production would remain relatively constant while grain yield decreased as a plant filled the tiller spikes.

The objectives of the present study were (i) to examine the effect of seeding rate on total dry matter production and the relative proportions of straw, chaff and grain for different genotypes of spring wheat and barley under Manitoba conditions and, (ii) to determine the effect of seeding rate on combine throughput and the amount of straw left standing as stubble after cutting at a range of heights.

4.2 Materials and Methods

In 1994, field experiments were conducted at the University of Manitoba Field Station at Carman, MB and in Winnipeg, 1 km south of the main entrance to the University of Manitoba's Fort Garry campus at the corner of Markham Road and Waverley Street. The soils were a Denham loam and a Red River clay at the Carman and Winnipeg sites, respectively. At both locations, the experimental area had been seeded to canola (*Brassica napus* L.) the previous year.

Wheat and barley were tested in separate seeding rate trials. The wheat cultivars included two conventional height CWRS cultivars, Katepwa and Roblin, as well as a semidwarf CPS cultivar, AC Taber. The barley cultivars included Duke, (6-row, semidwarf feed type), Bedford, (6-row conventional height feed type) and Manley, (2-row conventional height malting type). Seeding rates of 100, 200, 300, and 400 viable seeds m^{-2} were used. The experiments were established as factorial randomized complete block designs with four replications.

4.2.1 Experimental Procedure

4.2.1.1 Seeding and Maintenance

Plots were seeded into standing canola stubble using a Noble hoe press drill (Noble Equipment Co., Nobleford AB) that had been adapted for plot work (Table 4.1). Each plot measured 7.5 m long and consisted of 10 rows, spaced 20 cm apart. Following a heavy storm, the plots in Winnipeg were flooded and were reseeded. Fertilization and weed control practices were the same as those described in Chapter III, section 3.2.3.1.

4.2.1.2 Harvest and Sampling Measurements

At physiological maturity, a 0.5 m^2 subsample was removed from the three centre rows of each plot. Entire plants were pulled out by the roots and the samples were tied in bundles and stored. Whole plots minus the two outside rows were harvested with a Wintersteiger small plot combine (Wintersteiger, Salt Lake City, UT) (Table 4.1).

Table 4.1. Dates of seeding and harvest for wheat and barley seeding rate experiments (1994).

Location	Crop	Seeding Date †	Harvest Date
Carman	Barley	May 10	August 22
	Wheat	May 10	August 26
Winnipeg	Barley	May 12, (28)	September 8
	Wheat	May 12, (28)	September 10

† Date in parenthesis corresponds to date of reseeding

Grain samples were cleaned and air-dried and the moisture contents were taken using a Labtronic model 919 grain tester (Labtronics, Winnipeg, MB). Plot yields were corrected to 0% moisture basis.

With the whole-plant subsample, plants were separated into main stems and tillers and the roots cut off at ground level and discarded. Main stem and tiller spikes were separated, counted, and threshed separately. Main stem and tiller straw and grain dry matter (DM) were oven dried at 65°C for three days after which time the spikes were threshed using a belt thresher (Agriculex, model STP-1, Guelph, ON). Main stem and tiller grain DM were weighed separately. Determination of main stem and tiller chaff, total residue and total dry matter, as well other parameters such as HI and residue to grain ratio (R/G), estimated combine throughput and the weight of straw left in the field as standing stubble were determined using the same procedures as outlined in Chapter III, section 3.2.3.

4.2.2 Statistical Analysis

Statistical analyses were performed using SAS (SAS Institute, 1990). The effects of seeding rate and cultivar were analyzed using the general linear models (GLM). When significant treatment effects were detected ($P<0.05$), means were separated using the Least Significant Difference (LSD) test. Orthogonal polynomial contrasts were used to determine whether the response to seeding rate was linear or quadratic. Bartlett's test for homogeneity of variance was conducted to determine whether locations could be combined. Preplanned single degree of freedom contrasts were used to compare low and high seeding rates and to compare semidwarf with conventional height cultivars. Simple correlation analyses were performed to determine the strength of relationships between the different parameters tested.

4.3 Results

4.3.1 Wheat Seeding Rate

Analyses of variance were conducted for each site separately since the error variance between locations was not homogenous. Except for total residue production at Carman, significant differences between cultivars were detected for the other parameters studied (Table 4.2). Significant differences between semidwarf and tall cultivars were noted for all traits except total residue (both sites) and straw residue at Winnipeg. Of the 3 cultivars examined, AC Taber produced more chaff and grain, had larger HI and weight culm^{-1} and produced fewer spikes than the conventional height cultivars Katepwa and Roblin. AC Taber also had a smaller residue to R/G, and at Carman it produced less straw residue than the other two cultivars.

Cultivar by seeding rate interactions were not significant at either site for all parameters studied. All traits except HI and R/G were significantly affected by seeding rate at Winnipeg. However, at Carman only spike number, HI and R/G were affected (Table 4.3). All of the traits that were affected by seeding rate could be best described by a linear function.

Average straw production, total residue production and grain yield were larger at Winnipeg compared to Carman. This may have been due to the heavier overall individual culm weights and greater culm production at Winnipeg compared to Carman (Table 4.3).

Table 4.2. Means of total residue, straw, chaff, grain yield, weight culm^{-1}, spikes m^{-2}, harvest index (HI), and total residue/grain ratio (R/G) for wheat cultivars averaged over seeding rates at Carman and Winnipeg, 1994.

Cultivar	Total Residue	Total Straw	Total Chaff	Grain Yield	Weight culm^{-1}	Spikes m^{-2}	HI	R/G Ratio
	(g m^{-2})				(g)	(no.)		
CARMAN								
AC Taber	534	368 b	166 a	430 a	0.86 a	425 c	0.445 a	1.25 c
Katepwa	587	464 a	124 b	378 b	0.77 b	603 a	0.391 b	1.56 b
Roblin	528	402 b	126 b	306 c	0.74 b	543 b	0.369 c	1.72 a
Significance	NS	**	**	**	**	**	**	**
Semidwarf vs Tall	NS	**	**	**	**	**	**	**
WINNIPEG								
AC Taber	790 a †	580 ab	210 a	594 a	1.26 a	459 c	0.430 a	1.34 b
Katepwa	796 a	631 a	166 b	427 b	0.90 b	705 a	0.349 b	1.87 a
Roblin	681 b	532 b	149 b	378 c	0.87 b	610 b	0.356 b	1.81 a
Significance	**	**	**	**	**	**	**	**
Semidwarf vs Tall	NS	NS	**	**	**	**	**	**

NS, ** Not significant and significant at the 1% level of significance.

† Means within the a column followed by the same letter are not significantly different according to a LSD $_{(0.05)}$ test.

Table 4.3. Seeding rate means averaged over wheat cultivars for total residue, straw, chaff, grain yield, weight culm^{-1}, spikes m^{-2}, harvest index (HI), and total residue/grain ratio (R/G) at Carman and Winnipeg, 1994.

Seeding Rate (seeds m^{-2})	Total Residue	Total Straw	Total Chaff	Grain Yield	Weight culm^{-1}	Spikes m^{-2}	HI	R/G Ratio
	---------- (g m^{-2})			----------	(g)	(no.)		
CARMAN								
100	507	371	136	358	0.80	461 c	0.413 a	1.43 a
200	556	416	142	376	0.79	527 b	0.401 ab	1.47 b
300	558	419	137	367	0.79	532 b	0.397 b	1.54 b
400	578	439	139	385	0.77	576 a	0.397 b	1.54 b
Significance	NS	NS	NS	NS	NS	**	*	**
Contrast ‡	NS	NS	NS	NS	NS	L	L	L
WINNIPEG								
100	855 a †	657 a	198 a	531 a	1.17 a	560 c	0.381	1.61
200	740 b	561 b	179 ab	467 b	0.99 b	569 bc	0.383	1.58
300	739 b	574 b	165 b	461 b	0.95 b	607 ab	0.382	1.60
400	690 b	532 b	158 b	406 c	0.85 c	629 a	0.369	1.70
Significance	**	**	**	**	**	**	NS	NS
Contrast	L	L	L	L	L	L	NS	NS

NS, *, ** Not significant and significant at the 5% and 1% levels of significance, respectively.
† Means within the a column followed by the same letter are not significantly different according to a LSD $_{(0.05)}$ test.
‡ Orthoganal contrasts signifcant at the 5% level (L = linear, Q = quadratic).

Table 4.4. Main and tiller stem seeding rate means averaged over wheat cultivars for spikes number, grain yield, straw residue and total residue at Carman and Winnipeg, 1994.

Seed Rate (seeds m^{-2})	CARMAN Spikes m^{-2}	Grain Yield	Straw Residue	Total Residue	WINNIPEG Spikes m^{-2}	Grain Yield	Straw Residue	Total Residue
	(no.)	(g m^{-2})			(no.)	(g m^{-2})		
Main Stem								
100	116 c †	123 c	109 c	151 c	113 d	141 c	158 b	209 c
200	169 b	162 b	154 b	210 b	159 c	176 b	184 b	260 b
300	213 a	187 ab	184 a	249 a	224 b	227 a	242 a	321 a
400	236 a	201 a	198 a	266 a	267 a	226 a	257 a	339 a
Significance	**	**	**	**	**	**	**	**
Contrast ‡	L	L	L	L	L	L	L	L
Tiller Stem								
100	345	235 a	262	356	455 a	391 a	497 a	652 a
200	358	214 a	262	348	401 b	290 b	377 b	494 b
300	319	180 b	235	307	383 b	234 c	332 bc	424 bc
400	339	184 b	241	312	362 b	180 d	276 c	352 c
Significance	NS	*	NS	NS	**	**	**	**
Contrast	NS	L	NS	NS	L	L	L	L

† Means within a column followed by the same letter are not significantly different according to a LSD $_{(0.05)}$ test.
‡ Orthoganal contrasts signifcant at the 5% level (L = linear, Q = quadratic).

Increased seeding rate resulted in a higher number of spikes m^{-2}, as spike number increased linearly at both sites (Table 4.3).

At Carman, although straw and total residue production were not significantly affected by seeding rate (Table 4.3), there appeared to be a trend toward larger straw and total residue production as seeding rate increased. Main stem residue production and grain yield increased linearly with seeding rate while tiller stem residue production remained unchanged and tiller grain yield decreased (Table 4.4). Increasingly greater main stem production and the associated similar tiller production resulted in total residue production and grain yield levels that tended to increase with seeding rate but were not significantly different across the range of seeding rates tested (Table 4.3). At Carman, straw and total residue were positively correlated with spike production and grain yield (Table 4.5).

Table 4.5. Correlation coefficients for straw and total residue production with grain yield, weight $culm^{-1}$, and spike number for wheat cultivars (Carman and Winnipeg, 1994).

	---------- STRAW ----------		----TOTAL RESIDUE ----	
	CARMAN	WINNIPEG	CARMAN	WINNIPEG
Spike number	0.99 **	-0.57	0.99 **	-0.66
Weight $culm^{-1}$	-0.84	0.95 **	-0.82	0.97 **
Grain yield (g m^{-2})	0.91 *	0.96 **	0.92 *	0.97 **

*, ** Significant at the 5% and 1% levels of significance, respectively.

At Winnipeg, seeding rate effects grain yield and straw and total residue production were contrary to the majority of previous reports. Largest straw and total residue production as well as grain yield were obtained at the lowest seeding rate and declined as seeding rate increased (Table 4.3). Similar to the trends noted from the data recorded from the Carman site, Winnipeg main stem residue production and grain yield increased linearly with seeding rate while tiller stem grain and residue production decreased linearly (Table 4.4). However, because tiller yields were so large, total residue production and grain yield actually decreased linearly as seeding rate increased. Extremely large tiller yields compensated for the low main stem production at the 100 seeds m^{-2} seeding rate causing the lowest seeding rate to out-produce the higher seeding rates in terms of total residue production and grain yield (Table 4.3).

At Winnipeg, although straw and total residue production were not correlated with spike production as they had been at the Carman site, straw and total residue were still stongly correlated with grain yield (Table 4.5).

Seeding rate had no effect on weight $culm^{-1}$ at Carman; however, at Winnipeg, culm weights decreased with increasingly higher seeding rates. Seeding rate had no effect on HI or R/G at Winnipeg; however, at Carman, HI decreased and R/G increased with higher seeding rates. Even though seeding rate effects for R/G were only significant at Carman, there was a trend toward higher R/Gs with increasingly higher seeding rates. The 400 seeds m^{-2} rate had the highest R/G at both locations. Straw production at this rate was the highest at Carman and although it was not the highest at Winnipeg, the 400 seed m^{-2} rate combined a low straw yield with the lowest grain yield to give the highest R/G.

Estimated combine throughput and straw left as stubble after cutting at the various heights were affected by seeding rate at Winnipeg, but not at Carman (Tables 4.6 and 4.7). At both sites, estimated combine throughput was strongly correlated with straw production at all cutting heights. At the 20-cm cutting height between 61% and 65% of total straw passed through the combine. By raising the cutting height 5-cm to 25-cm, the estimated combine throughput dropped 9%. As a result, only 54% of total straw production would have passed through the combine. Raising the cutting height another 5-cm to 30-cm decreased estimated combine throughput a further 7% to 47% and raising the cutting height a final time to 35-cm reduced the estimated combine throughput to only 41% of total straw production.

Table 4.6. Means of estimated combine throughput at 20-, 25-, 30, and 35-cm cutting heights averaged over wheat cultivars at Carman and Winnipeg, 1994.

Seeding Rate (seeds m^{-2})	CARMAN Cutting Height (cm) 20	25	30	35	WINNIPEG Cutting Height (cm) 20	25	30	35
	($g\ m^{-2}$)				($g\ m^{-2}$)			
100	223	192	165	139	434 a †	383 a	335 a	288 a
200	252	219	189	162	360 b	313 b	271 b	232 b
300	258	223	193	165	370 b	324 b	281 b	241 b
400	259	224	191	165	340 b	296 b	257 b	218 b
Significance	NS	NS	NS	NS	**	**	**	**

NS, ** Not significant and significant at the 1% level of significance.

† Means within a column followed by the same letter are not significantly different according to a LSD $_{(0.05)}$ test.

Table 4.7. Mean weight of straw left in the field as standing stubble at cutting heights of 20-, 25-, 30, and 35-cm averaged over wheat cultivars. (Carman and Winnipeg, 1994).

Seeding Rate (seeds m^{-2})	CARMAN				WINNIPEG			
	Cutting Height				Cutting Height			
	20 cm	25 cm	30 cm	35 cm	20 cm	25 cm	30 cm	35 cm
	($g\ m^{-2}$)				($g\ m^{-2}$)			
100	147	179	206	231	223 a †	274 a	322 a	369 a
200	164	197	227	254	201 b	247 b	289 b	329 b
300	160	195	226	254	203 b	249 b	292 b	333 b
400	179	215	247	274	192 b	236 b	275 b	314 b
Significance	NS	NS	NS	NS	*	*	*	*

NS, * Not significant and significant at the 5% level of significance.

† Means within a column followed by the same letter are not significantly different according to a $LSD_{(0.05)}$ test.

4.3.2 Barley Seeding Rate

Error variances were heterogeneous between sites so that individual analyses of variance were conducted for each location separately. Significant cultivar differences were noted at both locations for all traits except grain yield and weight $culm^{-1}$ at Winnipeg (Table 4.8). Single degree of freedom contrasts comparing the 6-row semidwarf cultivar, Duke, and the 6-row conventional height cultivar, Bedford, showed no significant differences in total residue, straw, or grain yield at both Carman and Winnipeg as well as weight $culm^{-1}$ at Winnipeg (Table 4.8). Duke produced fewer spikes and more chaff and had a higher HI and a lower R/G than Bedford. The 2-row cultivar, Manley, produced the greatest number of spikes and the most straw, chaff, and total residue. Manley also had the lowest HI and weight $culm^{-1}$ and the highest R/G of the three cultivars.

At both sites, as seeding rate increased, culm weight decreased and spike number increased (Table 4.9). However, similar to the wheat seeding rate trials, higher spike numbers did not result in higher grain yields (Table 4.9).

At Carman, total residue, chaff and grain yield decreased as seeding rate increased. Decreases associated with the higher seeding rates could be best described by a quadratic function. Straw residue also decreased slightly with higher seeding rates but differences were not significant (Table 4.9). At Carman, main stem residue production and grain yield increased linearly with seeding rate while tiller stem residue production and grain yield decreased quadratically (Table 4.10). As a result, total plant residue production and grain

Table 4.8. Means of total residue, straw, chaff, grain yield, weight $culm^{-1}$, spikes m^{-2}, harvest index (HI), and total residue/grain ratio (R/G) for barley cultivars averaged over seeding rates at Carman and Winnipeg, 1994.

Cultivar	Total Residue	Total Straw	Total Chaff	Grain Yield	Weight $culm^{-1}$	Spikes m^{-2}	HI	R/G Ratio
	---------- ($g\ m^{-2}$)	----------	----------	----------	(g)	(no.)		
CARMAN								
Bedford	424 b †	334 b	79 c	482	0.86 b	358 c	0.52 b	0.93 b
Duke	445 b	366 b	90 b	510	0.95 a	428 b	0.55 a	0.83 c
Manley	596 a	440 a	129 a	488	0.72 c	611 a	0.46 c	1.17 a
Significance	**	**	**	NS	**	**	**	**
Duke vs Bedford	NS	NS	**	NS	**	**	**	**
WINNIPEG								
Bedford	525 b	457 b	68 c	537	1.02	452 b	0.50 b	0.99 b
Duke	502 b	408 b	94 b	586	1.04	394 c	0.54 a	0.86 c
Manley	680 a	563 a	118 a	527	0.99	569 a	0.44 c	1.29 a
Significance	**	**	**	NS	NS	**	**	**
Duke vs Bedford	NS	NS	**	NS	NS	**	**	**

NS, ** Not significant and significant at the 1% level of significance.

† Means within the a column followed by the same letter are not significantly different according to a $LSD_{(0.05)}$ test.

Table 4.9. Seeding rate means averaged over barley cultivars for total residue, straw, chaff, grain yield, weight culm^{-1}, spikes m^{-2}, harvest index (HI), and total residue/grain ratio (R/G) at Carman and Winnipeg, 1994.

Seeding Rate (seeds m^{-2})	Total Residue	Total Straw	Total Chaff	Grain Yield	Weight culm^{-1}	Spikes m^{-2}	HI	R/G Ratio
	------------------------ (g m^{-2})			------------------------	(g)	(no.)		
CARMAN								
100	526 a †	410	116 a	543 a	0.94 a	432 b	0.51	0.97
200	466 b	367	99 b	464 b	0.86 ab	454 ab	0.50	1.01
300	456 b	365	92 b	486 b	0.80 b	466 ab	0.52	0.94
400	469 b	378	91 b	480 b	0.80 b	473 a	0.51	0.99
Significance	*	NS	*	*	**	*	NS	NS
Contrast ‡	Q	NS	Q	Q	L	L	NS	NS
WINNIPEG								
100	590	489	100 a	589 a	1.16 a	425 b	0.50	1.02
200	568	475	92 ab	557 a	1.07 b	444 b	0.50	1.03
300	602	507	95 ab	569 a	0.99 c	508 a	0.49	1.06
400	519	434	85 b	485 b	0.85 d	508 a	0.49	1.07
Significance	NS	NS	*	*	**	**	NS	NS
Contrast	NS	NS	L	L	L	L	NS	NS

NS, *, ** Not significant and significant at the 5% and 1% levels of significance, respectively.

† Means within the a column followed by the same letter are not significantly different according to a LSD $_{(0.05)}$ test.

‡ Orthoganal contrasts signifcant at the 5% level (L = linear, Q = quadratic).

Table 4.10. Main and tiller stem seeding rate means averaged over barley cultivars for spikes number, grain yield, straw residue and total residue at Carman and Winnipeg, 1994.

Seed Rate (seeds m^{-2})	CARMAN Spikes m^{-2}	CARMAN Grain Yield	CARMAN Straw Residue	CARMAN Total Residue	WINNIPEG Spikes m^{-2}	WINNIPEG Grain Yield	WINNIPEG Straw Residue	WINNIPEG Total Residue
	(no.)	(g m^{-2})			(no.)	(g m^{-2})		
Main Stem								
100	93 c †	181 c	116 c	148 c	94 d	168 c	123 c	149 d
200	168 b	238 b	152 b	192 b	153 c	233 b	180 b	216 c
300	208 a	269 ab	171 ab	217 ab	203 b	277 a	219 a	263 b
400	232 a	286 a	188 a	239 a	257 a	299 a	237 a	287 a
Significance	**	**	**	**	**	**	**	**
Contrast ‡	L	L	L	L	L	L	L	L
Tiller Stem								
100	339 a	362 a	294 a	378 a	331 a	421 a	367 a	441 a
200	286 b	227 b	215 b	274 b	291 ab	324 b	295 b	351 b
300	259 c	216 b	193 b	239 b	306 a	292 b	288 b	339 b
400	241 c	194 b	190 b	230 b	251 b	186 c	197 c	232 c
Significance	**	**	**	**	**	**	**	**
Contrast	L	Q	Q	Q	L	L	L	L

† Means within the a column followed by the same letter are not significantly different according to a LSD $_{(0.05)}$ test.
‡ Orthoganal contrasts signifcant at the 5% level (L = linear, Q = quadratic).

yield decreased in a quadratic fashion because of the influence of the large tiller component at the low seeding rate. At Carman, straw and total residue production were correlated with grain yield but not with spike number or weight culm^{-1} (Table 4.11).

At Winnipeg, total residue and straw production were not affected by seeding rate. However, grain yield and chaff DM decreased as seeding rate increased (Table 4.9). Main stem total residue production and grain yield increased linearly with seeding rate while tiller grain yield and residue decreased in the same fashion (Table 4.10). As a result, total plant residue production was similar at all seeding rates while grain yield decreased slightly so that smallest grain yields came from the highest seeding rate (Table 4.9). At Winnipeg, straw and total residue production were correlated with grain yield but not to spike number or weight culm^{-1} (Table 4.11).

Table 4.11. Correlation coefficients for straw and total residue production with grain yield, weight culm^{-1}, and spike number for barley cultivars (Carman and Winnipeg, 1994).

	---------- STRAW ----------		----TOTAL RESIDUE ----	
	CARMAN	WINNIPEG	CARMAN	WINNIPEG
Spike number	0.12	-0.25	-0.03	-0.33
Weight culm^{-1}	0.79	0.66	0.88	0.72
Grain yield (g m^{-2})	0.93 *	0.91 *	0.93 *	0.94 **

*, ** Significant at the 5% and 1% levels of significance, respectively.

Harvest index and R/G were not affected by seeding rate at Carman or Winnipeg (Table 4.9).

Estimated combine throughput and estimated standing stubble at the various heights were not affected by seeding rate at either site (Tables 4.12 and 4.13). Estimated combine throughput varied from site to site but not to as great an extent as found in wheat (Table 4.6). At Winnipeg and Carman, estimated combine throughput was strongly correlated with straw production at each cutting height. At the 20-cm cutting height, 54% to 58% of the total straw passed through the combine. By raising the cutting height 5-cm to 25-cm, estimated combine throughput was reduced by 10% to 46% of total straw. Increasing the cutting height another 5-cm to 30-cm reduced estimated combine throughput a further 9% to 37% and increasing the cutting height to 35-cm reduced the estimated combine throughput to only 29% of the total straw production. Straw left as standing stubble was less affected by location than estimated combine throughput. Standing stubble measuring 20-cm high weighed 200 g m^{-2} at Winnipeg (or 42% of total straw production) and 175 g m^{-2} (or 46% of total straw production) at Carman.

Table 4.12. Means of estimated combine throughput at 20-, 25-, 30, and 35-cm cutting heights averaged over barley cultivars at Carman and Winnipeg, 1994.

Seeding Rate (seeds m^{-2})	CARMAN Cutting Height 20 cm	25 cm	30 cm	35 cm	WINNIPEG Cutting Height 20 cm	25 cm	30 cm	35 cm
	($g\ m^{-2}$)				($g\ m^{-2}$)			
100	222	183	147	113	278	230	185	145
200	192	153	117	84	277	233	192	155
300	196	157	122	89	302	255	212	170
400	205	166	129	96	249	206	167	131
Significance	NS	NS	NS	NS	NS	NS	NS	NS

NS Not significant at the 5% level of significance.

Table 4.13. Mean weights of straw left in the field as standing stubble at cutting heights of 20-, 25-, 30, and 35-cm averaged over barley cultivars. (Carman and Winnipeg, 1994).

Seeding Rate (seeds m^{-2})	CARMAN – Cutting Height				WINNIPEG – Cutting Height			
	20 cm	25 cm	30 cm	35 cm	20 cm	25 cm	30 cm	35 cm
	($g\ m^{-2}$)				($g\ m^{-2}$)			
100	188	227	263	297	211	259	304	344
200	175	215	251	283	198	242	283	320
300	168	207	242	275	204	251	295	336
400	172	212	249	282	185	228	267	302
Significance	NS	NS	NS	NS	NS	NS	NS	NS

NS Not significant at the 5% level of significance.

4.4 Discussion

Although the Winnipeg site had to be reseeded at the end of May, the length of the growing season and differential crop maturity was not a concern at either site. At both sites, the recommended days to maturity for each cultivar tested was exceeded which allowed for sufficient time for both mainstems and tillers to mature.

Intuitively, one might expect total residue and straw production to increase with seeding rate. Greater culm production per unit area should result in greater straw and total residue production. In our experiments, although culm number increased with seeding rate, culm weight decreased resulting in similar absolute straw weight over all seeding rates. Clarke and DePauw (1993) working in southwestern Saskatchewan reported similar results. They observed that seeding rate had a small and inconsistent effect on the straw and total residue production of spring and durum wheat under both dryland and irrigated production regimes. In contrast, Baker (1982) found that straw production of eight spring wheat cultivars increased with seeding rate in each of nine experiments in north central Saskatchewan. In northern areas similar to Baker's study, early frosts can be a problem and the length of the growing season may be limited. Under these conditions, with low seeding rates the tillering phase is extended and maturity is often delayed. Compared to higher seeding rates where maturity is often enhanced, lower seeding rates may have lower residue production and grain yield because of delayed maturity.

In our experiments, grain yield and chaff production were affected by seeding rate in 3 of the 4 wheat and barley experiments. Although spike number increased with seeding rate, grain and chaff yields did not. In each of the trials in which seeding rate had a significant effect, grain yields were the highest at the low seeding rate. These results contradict many previous findings (Faris and DePauw, 1987; Baker 1982; Kirby 1967) but agree with those of Pelton (1969). In Pelton's study, however, the highest grain yields from lowest seeding rate were attributed to poor moisture resources. With limited moisture available for plant growth, plants grown with a high seeding rate ran out of moisture before grain filling could be fully completed. Such a scenario may have occurred at Carman which received only 204 mm of precipitation between seeding and harvest. However, at Winnipeg ample precipitation was available for proper grain filling. In our trials, the low seeding rates had a higher percent emergence rate and the final percent plant stand was higher than the high seeding rates. Also, because seeding rates only varied slightly from recommended rates, it may have been possible for the plants at the low seeding rate to compensate for smaller spike numbers by altering the number and size of kernels produced. Such observations have been made previously by Read and Warder (1982) and Thorne and Blacklock (1971). The assertion by Jessop and Ivins (1970), that the effect of seeding date on yield of spring wheat is related mainly to differences in weather at particular stages of development could also help to explain the yield advantage noted by the low seeding rate.

Information and discussion of the effects of seeding rate on R/G is unavailable. However, R/G calculations can be made if grain yield and harvest index are given. Data taken from numerous sources (El-Gawad, 1986; Baker, 1982; Pendleton and Dungan, 1960) reveals that straw yields will increase more quickly and decrease more slowly than grain yields as seeding rates are increased (Figure 4.1). As a result, R/G increase with seeding rate whether grain yield increases or decreases. Calculations from data taken from Baker (1982) indicate that R/G are larger and more significantly affected by later seeding.

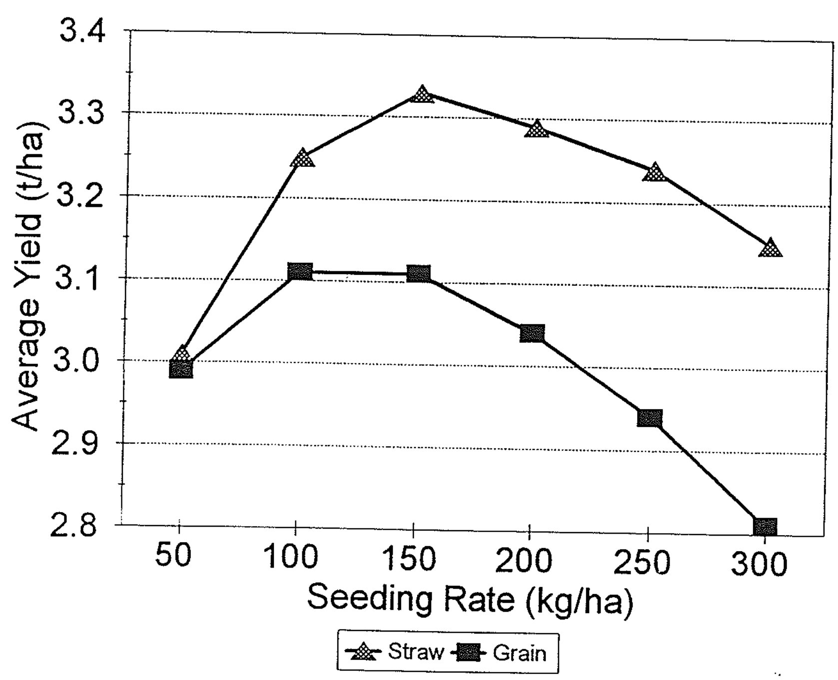

Figure 4.1. Residue production and grain yield of four spring wheat cultivars in relation to seeding rate in Illinois (adapted from Pendleton and Dungan, 1960).

Inconsistent results between locations on the effect of seeding rate on straw, total residue production and grain yield do not allow for clear conclusions to be drawn about an "optimum" seeding rate. In these trials, the seeding rates which produced small volumes of straw also produced low grain yields and the seeding rates which produced high grain yields were associated with large straw volumes. At both sites strong correlations between straw and grain yield and total residue and grain yield indicated that a seeding rate which would minimize straw production without compromising grain yield is not likely possible.

Estimated combine throughput was not affected by seeding rate in 3 of the 4 experiments involving wheat and barley cultivars. At both sites, estimated combine throughput was correlated with straw production at all cutting heights. In the one experiment in which significant differences were noted among seeding rates, the lowest seeding rate produced the most straw and had the largest estimated combine throughput. Like estimated combine throughput, weight of standing stubble was also not affected by seeding rate. The weight of wheat and barley stubble cut at equal heights was very similar at each location.

V. NITROGEN FERTILITY EFFECT ON CROP RESIDUE AND GRAIN YIELD

5.1 Introduction

Nitrogen fertility is a major factor influencing cereal crop production on the Canadian Prairies. Research has generally shown that N fertilizer increases vegetative plant growth and grain yield (Ohm, 1976; Blackman et al., 1978; McNeal et al., 1971). However, high rates of N commonly increase the incidence and severity of foliar diseases (Caldwell and Starratt, 1987; Jenkyn et al., 1983) and lodging (Johnston and MacLeod, 1987) which unless controlled can reduce or limit yield. High rates of N have also been observed to decrease yields even in the absence of diseases or lodging by inducing late-season moisture deficits (Campbell and Davidson, 1979; Stark and Brown, 1987).

Moisture conditions dramatically affect a plant's response to N fertility. Numerous researchers have reported that yield and production differences in response to N fertilization among cultivars are most evident when yield potential (moisture) is high (Grant et al., 1991; Gehl et al., 1990; Kroentajer and Berliner, 1988).

Cultivar by N interactions for grain yield (Grant et al., 1991; Gehl et al., 1990; Blackman et al., 1978; Ohm, 1976) and straw production (Grant et al., 1991; Gehl et al., 1990) have been noted. Although these interactions do exist they often go unnoticed because they are masked by varying climatic conditions. Grant et al. (1990) observed cultivar by N interactions for grain yield and straw production when moisture conditions were abundant but not under moisture deficit conditions. Under moderate moisture conditions, cultivar by N interactions were noted for straw production but not grain yield. Based on this study, moisture affected cultivar by N interactions for grain yield more than cultivar by N interactions for straw production. As a result, cultivar by N interactions for straw production are more likely than cultivar by N interaction for grain yield under poor to moderate moisture conditions.

Numerous studies have been conducted to determine how individual cultivars respond to N fertility while others have contrasted the N fertility responses of different cereal cultivars (Grant et al., 1991; Gehl et al., 1990; Blackman et al., 1978; Ohm, 1976; McNeal et al., 1971; Pendleton and Dungan, 1953). In these studies, the primary subject of interest was grain yield or yield component analysis. Seldom have these studies examined straw and total residue production and related them to grain yield at different N fertility levels.

The objectives of the present study were (i) to examine the effect of N fertilization on total dry matter production and the relative proportions of straw, chaff, and grain yield for a commonly grown wheat cultivar (Katepwa) and commonly grown barley cultivar (Argyle) under Manitoba conditions and (ii) to determine the effect of N fertilization on combine throughput and the amount of standing stubble left in the field after harvesting at a range of cutting heights.

5.2 Materials and Methods

In 1993, field experiments were conducted at Oak Bluff, MB at the corner of Hwy #3 (McGilvary Blvd.) and Hwy 1A (Perimeter Highway). The soil was classified as a Red River clay and the previous crop was flax (*Linum usitatissimum* L.). In 1994, field experiments were conducted at the University of Manitoba Field Station at Carman, MB and at a location 1 km south of the University of Manitoba at the corner of Markham road and Waverley street. The soils were classified as a Denham loam and Red River clay at the Carman and Winnipeg locations, respectively. The previous crop at each location was canola (*Brassica napus* L.).

Katepwa wheat and Argyle barley were grown in separate experiments under different N regimes. Nitrogen treatments were broadcast applied as ammonium nitrate (34-0-0) at rates of 27, 54, and 107 kg N ha^{-1} two weeks after emergence. A check treatment with 0 kg N ha^{-1} was included in the 1994 trials. The experiments were established as randomized complete block designs with four replications.

5.2.1 Experimental Procedure

5.2.1.1 Seeding and Maintenance

Plots were seeded into standing canola stubble with a Noble hoe-press drill (Noble Equipment Co., Nobleford AB) adapted for plot work (Table 5.1). Plots were 7.5 m in length and consisted of 10 rows spaced 20-cm apart. The barley experiment was discarded at Oak Bluff in 1993 because of repeated flood damage. In 1994, the plots in Winnipeg were reseeded after flooding from a thunderstorm caused emergence problems. Seeding rate, pest control practices, and phosphate fertilization were the same as those described in Chapter III.

5.2.1.2 Harvest and Sampling Measurements

At physiological maturity, a 0.5 m^2 subsample was removed from three centre rows of each plot. The plants were cut with a hand-held sickle at ground level, tied into bundles, and stored. Whole plots minus the two outside rows were combined (Table 5.1) with a Wintersteiger (Wintersteiger, Nurserymaster Elite, Salt Lake City UT) combine. Grain samples were air dried and moisture contents were taken (Labtronic model 919, Winnipeg, MB). The grain was cleaned, and plot yields were measured and corrected to 0% moisture basis.

Table 5.1. Dates of seeding and harvest for wheat and barley N fertility experiments (1993-1994).

Location	Crop	Seeding Date †	Harvest Date
Oak Bluff (1993)	Wheat	May 13	September 19
	Barley	May 13	No Harvest
Carman (1994)	Wheat	May 10	August 26
	Barley	May 10	August 22
Winnipeg (1994)	Wheat	May 12, (28)	September 8
	Barley	May 12, (28)	September 3

† Date in parenthesis corresponds to the date of reseeding.

For each subsample, fertile spikes were counted and removed, and total head dry matter (DM) was weighed. The straw and head DM were oven-dried at 65°C for three days after which time the spikes were threshed using a belt thresher (Agriculex, model STP-1, Guelph, ON). Total grain DM and straw DM were recorded. Chaff, total residue, straw length, weight $culm^{-1}$, HI, residue to grain ratio, estimated combine throughput, and weight of straw left standing in the field as stubble were determined following the same procedures outlined in Chapter III, section 3.2.3.

5.2.2 Statistical Analysis

Statistical analyses were performed using SAS (SAS Institute, 1990). A 5% level of probability or less for a greater F-value was considered to be statistically significant. When significant treatment effects were detected ($P<0.05$), means were separated using the Least Significant Difference (LSD) test. Data were also subjected to analyses using orthogonal polynomial contrasts to determine whether the response to increasingly higher rates of N fertilizer were significantly linear, quadratic, or cubic. Bartlett's test for homogeneity of variances was conducted to determine whether locations could be combined. Preplanned single degree of freedom contrasts were made to compare low and high N rates. Simple correlation analyses were performed to determine the strength of relationships between the different parameters measured.

5.3 Results

5.3.1 Katepwa Wheat

Individual analyses of variance were performed for each location since error variances were heterogeneous. In 1993 at Oak Bluff, significant differences attributable to applied N were not noted for any of the parameters measured. The lack of response was attributed to flooding and disease. Data from this location (Appendix Table 1) and will not be discussed.

In 1994, total residue, straw, and chaff production as well as spikes m^{-2} and weight $culm^{-1}$ were greater in Winnipeg than in Carman (Table 5.2). The grain yields from each N treatment were similar at both locations. Lower HI and higher R/G were measured at Winnipeg compared to Carman.

Straw, chaff, and total residue production responded significantly to applied N at both locations (Table 5.2). At both locations, orthogonal polynomial contrasts showed that the response of total residue, straw, and chaff production to N fertilizer could be described by a quadratic function. Grain yield responded significantly to increasing levels of N fertilization at Winnipeg only. Plant height increased with applied N at both locations. At Carman, the tallest plants were grown at the highest level of applied N. At Winnipeg, plant height increased with the first addition of N and no further height differences were noted with additional N (Table 5.2).

The number of fertile spikes m^{-2} increased with N rate at Carman; however, at Winnipeg, although the response was similar in nature, no significant differences were noted between N levels. Weight $culm^{-1}$ was not

Table 5.2. Mean total residue, straw, and chaff production, grain yield, stem length, weight $culm^{-1}$, spikes m^{-2}, harvest index (HI), and residue/grain ratio (R/G) for Katepwa wheat as affected by N fertilizer (Carman and Winnipeg, 1994).

Nitrogen Rate (kg N ha^{-1})	Stem Length	Total Residue	Total Straw	Total Chaff	Grain Yield	Weight $culm^{-1}$	Spikes m^{-2}	HI	R/G Ratio
	(cm)	----------------------	($g\ m^{-2}$)		----------------------	(g)	(no.)		
CARMAN									
0	77 c †	352 c	270 c	82 c	262	0.57	469 b	0.40	1.34
27	78 bc	384 bc	295 bc	89 bc	310	0.59	503 b	0.45	1.25
54	88 ab	515 a	405 a	110 a	350	0.68	596 a	0.41	1.49
107	89 a	474 ab	369 ab	105 ab	330	0.60	613 a	0.41	1.45
Significance	*	*	*	*	NS	NS	**	NS	NS
Contrast ‡	L	Q	Q	Q	Q	NS	L	NS	NS
WINNIPEG									
0	87 b	476 b	370 b	106 b	277 b	0.73	515	0.37 a	1.72 b
27	98 a	617 a	495 a	135 a	358 a	0.80	617	0.36 a	1.77 b
54	101 a	741 a	587 a	154 a	399 a	0.89	664	0.35 a	1.82 b
107	101 a	711 a	570 a	141 a	349 a	0.87	659	0.33 b	2.05 a
Significance	**	**	**	*	*	NS	NS	**	*
Contrast	Q	Q	Q	Q	Q	L	L	L	L

NS, *, ** Not significant and significant at the 5% and 1% levels of significance, respectively.

† For each location, means within a column followed by the same letter are not significantly different according to a $LSD_{(0.05)}$ test.

‡ Orthogonal polynomial contrasts that are significant at the 5% level (L = linear, Q = quadratic).

affected by applied N at either location but, there was a trend toward heavier culms at the higher N rates (Table 5.2).

Straw and total residue production were correlated with spike number, weight $culm^{-1}$, stem length, and grain yield at both locations (Table 5.3).

At Winnipeg, HI declined and the R/G rose as the N application rate increased. Orthogonal polynomial contrasts showed that the responses of HI and R/G to N fertilizer could be best described by a linear function. The lowest HI and highest R/G came from the highest N rate and were significantly different from the other N levels; however, among the three lower N treatments, no significant differences were noted. At Carman, HI and R/G were not significantly affected by the N fertilizer level applied (Table 5.2).

Table 5.3. Correlation coefficients for straw and residue production with spike number, weight $culm^{-1}$, stem length and grain yield for spring wheat.

	--------- STRAW ----------		----TOTAL RESIDUE ----	
	Carman	Winnipeg	Carman	Winnipeg
Spike number	0.83 **	0.92 **	0.84 **	0.92 **
Weight $culm^{-1}$	0.66 **	0.82 **	0.65 **	0.82 **
Stem length (cm)	0.54 *	0.72 **	0.55 *	0.72 **
Grain yield (g m^{-2})	0.89 **	0.61 *	0.91 **	0.61 *

*, ** Significant at the 5% and 1% levels of significance, respectively.

At both locations, the estimated combine throughput and the straw left as standing stubble after cutting at various heights were affected by applied N (Tables 5.4 and 5.5). Estimated combine throughput was correlated with total straw production at both locations (r = 0.98 ** at Winnipeg and r = 0.99 ** at Carman). Throughput response to applied N could be described by a curvilinear equation and followed the same pattern as straw production. Maximum throughput was obtained with 54 kg N ha^{-1} with 258 g m^{-2} at Carman, and 384 g m^{-2} at Winnipeg. In general, weight of standing stubble increased with cutting height and N rate. The stubble weight response to applied N could be described by a linear function at Carman and a curvilinear function at Winnipeg.

Table 5.4. Means of estimated combine throughput at 20-, 25-, 30-, and 35-cm cutting heights for Katepwa wheat at Carman and Winnipeg, 1994.

Nitrogen Rate	CARMAN				WINNIPEG			
	Cutting Height				Cutting Height			
(kg N ha^{-1})	20 cm	25 cm	30 cm	35 cm	20 cm	25 cm	30 cm	35 cm
	($g\ m^{-2}$)				($g\ m^{-2}$)			
0	153 c †	126 c	104 c	83 c	225 b	194 b	165 b	138 b
27	172 bc	143 bc	122 bc	94 bc	325 a	286 a	250 a	217 a
54	258 a	224 a	192 a	163 a	384 a	342 a	301 a	263 a
107	225 ab	192 ab	161 ab	135 ab	372 a	332 a	293 a	257 a
Significance	*	*	*	*	**	**	**	**
Contrast ‡	Q	Q	Q	Q	Q	Q	Q	Q

*, ** Significant at the 5% and 1% levels of significance, respectively.
† Means within a column followed by the same letter are not significantly different according to a $LSD_{(0.05)}$ test.
‡ Orthogonal polynomial contrasts that are significant at the 5% level (L = linear, Q = quadratic).

Table 5.5. Mean weight of Katepwa wheat straw left in the field as standing stubble at cuttings heights of 20-, 25-, 30-, and 35-cm (Carman and Winnipeg, 1994).

	CARMAN				WINNIPEG			
	Cutting Height				Cutting Height			
Nitrogen Rate (kg N ha^{-1})	20 cm	25 cm	30 cm	35 cm	20 cm	25 cm	30 cm	35 cm
	(g m^{-2})				(g m^{-2})			
0	116 c †	143 c	166 b	186 c	144 c	176 b	205 b	232 b
27	123 bc	152 bc	173 b	201 bc	170 bc	209 ab	244 ab	278 ab
54	147 a	182 a	214 a	242 a	204 a	246 a	287 a	324 a
107	144 ab	177 ab	208 a	235 ab	198 ab	238 a	277 a	313 a
Significance	*	*	**	*	**	**	*	*
Contrast ‡	L	L	L	L	Q	Q	Q	Q

*, ** Significant at the 5% and 1% levels of significance, respectively.

† Means within a column followed by the same letter are not significantly different according to a $LSD_{(0.05)}$ test.

‡ Orthogonal polynomial contrasts that are significant at the 5% level (L = linear, Q = quadratic).

5.3.2 Argyle Barley

Total residue production, straw production, stem length and weight culm^{-1} were greater at the Winnipeg location compared to Carman (Table 5.6). The higher production response at Winnipeg was attributed to better moisture conditions. Lower grain yields and HI as well as higher R/G were noted at the Winnipeg location compared to Carman.

Individual analyses of variance were conducted for Carman and Winnipeg because of heterogenous error variances. At both locations, total residue and straw production increased with increasing amounts of applied N. Orthogonal polynomial contrasts showed that the response of straw and total residue production to applied N could be described by a linear function. Grain yields were not significantly affected by N treatment, though there was a tendency for yields to improve slightly with progressively higher levels of N (Table 5.6). Orthogonal polynomial contrasts showed that the yield response to applied N could be described by a linear function at Winnipeg but not at Carman. At both locations differences in spike number and chaff production were not significant and varied considerably with N level. In general, plant height increased as higher levels of N were applied. Plant height increased approximately 10 cm with each increment of N up to the 54 kg ha^{-1} rate at Winnipeg. At Carman, plant height increases with increasing N application rate were small and could be described by a linear function (Table 5.6)

Straw and total residue production were correlated with spike number, weight culm^{-1}, stem length, and grain yield at both locations (Table 5.7).

Table 5.6. Mean total residue, straw, chaff, and grain yield, stem length, weight culm^{-1}, spikes m^{-2}, harvest index (HI), and residue/grain ratio (R/G) for Argyle barley as affected by N fertilizer rate (Carman and Waverley, 1994).

Nitrogen Rate (kg N ha^{-1})	Stem Length	Total Residue	Total Straw	Total Chaff	Grain Yield	Weight culm^{-1}	Spikes m^{-2}	HI	R/G Ratio
	(cm)	---------- (g m^{-2})			----------	(g)	(no.)		
<u>CARMAN</u>									
0	73 b †	382 b	316 b	66	432	0.85	378	0.53 a	0.88 b
27	75 b	433 ab	360 ab	73	472	0.97	373	0.52 ab	0.92 ab
54	77 ab	465 a	385 a	80	503	0.91	422	0.52 ab	0.93 ab
107	82 a	487 a	413 a	74	503	1.06	392	0.51 b	0.97 a
Significance	*	*	*	NS	NS	NS	NS	*	*
Contrast ‡	L	L	L	NS	NS	L	NS	L	L
<u>WINNIPEG</u>									
0	77 c	376 b	319 b	57	329	1.10 d	289	0.47 a	1.14 c
27	89 b	504 a	434 a	70	383	1.33 c	326	0.43 b	1.31 b
54	103 a	556 a	495 a	61	405	1.46 b	340	0.42 c	1.37 a
107	99 a	586 a	519 a	67	415	1.56 a	337	0.41 c	1.41 a
Significance	**	*	**	NS	NS	**	NS	*	*
Contrast	Q	L	L	NS	L	L	NS	L	L

NS, *, ** Not significant and significant at the 5% and 1% levels of significance, respectively.

† Within a location, means within a column followed by the same letter are not significantly different according to a $LSD_{(0.05)}$ test.

‡ Orthogonal polynomial contrasts that are significant at the 5% level (L = linear, Q = quadratic).

Table 5.7. Correlation coefficients for straw and total residue production, stem length, weight culm^{-1}, spike number, and grain yield for spring barley.

	STRAW		TOTAL RESIDUE	
	Carman	Winnipeg	Carman	Winnipeg
Spike number	0.50 *	0.72 **	0.53 *	0.77 **
Weight culm^{-1} (g)	0.55 *	0.82 **	0.52 *	0.76 **
Stem length (cm)	0.65 **	0.85 **	0.62 **	0.83 **
Grain yield (g m^{-2})	0.91 **	0.86 **	0.93 **	0.88 **

*, ** Significant at the 5% and 1% levels of significance, respectively.

At both locations, HI decreased and R/G increased as the level of applied N increased. Orthogonal polynomial contrasts revealed that the response to applied N was best described by a linear function (Table 5.6).

Estimated combine throughput was significantly affected by N fertilizer only at the Winnipeg location. At Carman, although N fertilizer significantly increased straw production and tended to increase estimated combine throughput, differences were not large enough to be significant (Table 5.8). At Carman, the maximum throughput weighed 263 g m^{-2} while at Winnipeg, the largest throughput weighed 290 g m^{-2}. Maximum throughput came from the combination of 20-cm cutting height and 107 kg N ha^{-1} at both locations. Weight of straw left standing as stubble tended to be slightly larger at the higher N levels; however, weight differences were not significant at either location (Table 5.9).

Table 5.8. Means of estimated combine throughput at 20-, 25-, 30-, and 35-cm cutting heights for Argyle barley at Carman and Winnipeg, 1994.

Nitrogen Rate	CARMAN Cutting Height				WINNIPEG Cutting Height			
(kg N ha^{-1})	20 cm	25 cm	30 cm	35 cm	20 cm	25 cm	30 cm	35 cm
	($g\ m^{-2}$)				($g\ m^{-2}$)			
0	191	161	133	106	154 b †	123 c	95 c	71 c
27	224	191	159	128	229 a	191 b	155 b	120 b
54	237	204	173	143	263 a	226 ab	191 ab	159 ab
107	263	228	196	163	290 a	253 a	216 a	180 a
Significance	NS	NS	NS	NS	**	**	**	**
Contrast ‡	L	L	L	L	L	L	L	L

NS, ** Not significant and significant at the 1% level of significance.

† Means within a column followed by the same letter are not significantly different according to a $LSD_{(0.05)}$ test.

‡ Orthogonal polynomial contrasts that are significant at the 5% level (L = linear, Q = quadratic).

Table 5.9. Mean weight of Argyle barley straw left in the field as standing stubble at cuttings heights of 20-, 25-, 30-, and 35-cm (Carman and Winnipeg, 1994).

	CARMAN				WINNIPEG			
Nitrogen Rate	Cutting Height				Cutting Height			
(kg N ha^{-1})	20 cm	25 cm	30 cm	35 cm	20 cm	25 cm	30 cm	35 cm
	($g\ m^{-2}$)				($g\ m^{-2}$)			
0	125	155	184	211	134	165	194	217
27	136	169	201	232	157	194	230	262
54	148	181	212	242	163	201	238	272
107	149	184	217	249	179	217	254	290
Significance	NS	NS	NS	NS	NS	NS	NS	NS
Contrast ‡	L	L	L	L	L	L	L	L

NS Not significant at the 5% level of significance.
‡ Orthogonal polynomial contrasts that are significant at the 5% level (L = linear, Q = quadratic).

5.4 Discussion

The increases in total residue and straw production at both locations can be attributed to the tall, lush plants produced at the high levels of applied N. In both the wheat and barley fertility experiments, the combination of tall plants, heavy culms, and the highest number of culms per unit area resulted in greatest straw and total residue production with the highest application rates of applied N (Tables 5.2 and 5.6). Other researchers have found similar patterns. McNeal et al. (1971) found that applied N increased plant height and straw yield under normal moisture conditions while Campbell et al. (1981) and Power and Alessi (1978) found that the number of tillers surviving to maturity was directly related to the level of N available. Lower absolute straw and total residue production and smaller responses to N treatments at Carman compared to Winnipeg (Figure 5.1 and Figure 5.2) were postulated to be the result of the drier conditions experienced at the Carman location. Carman received only 84% of normal precipitation compared to 145% of normal at Winnipeg. Grant et al. (1991), working in southern Manitoba, found that increases in straw production from N fertilization were much smaller when moisture was limited compared to when it was were abundant. Similarly, Gehl et al. (1990) found differences in response to N fertilization among wheat cultivars to be most evident when yield potential (moisture conditions) was high.

A lack of a significant grain yield response to high rates of N fertilizer has also been reported for spring cereals (Cooper and Blakeney; 1990) and can be explained by the effects of previous cropping practices. Soil test results from

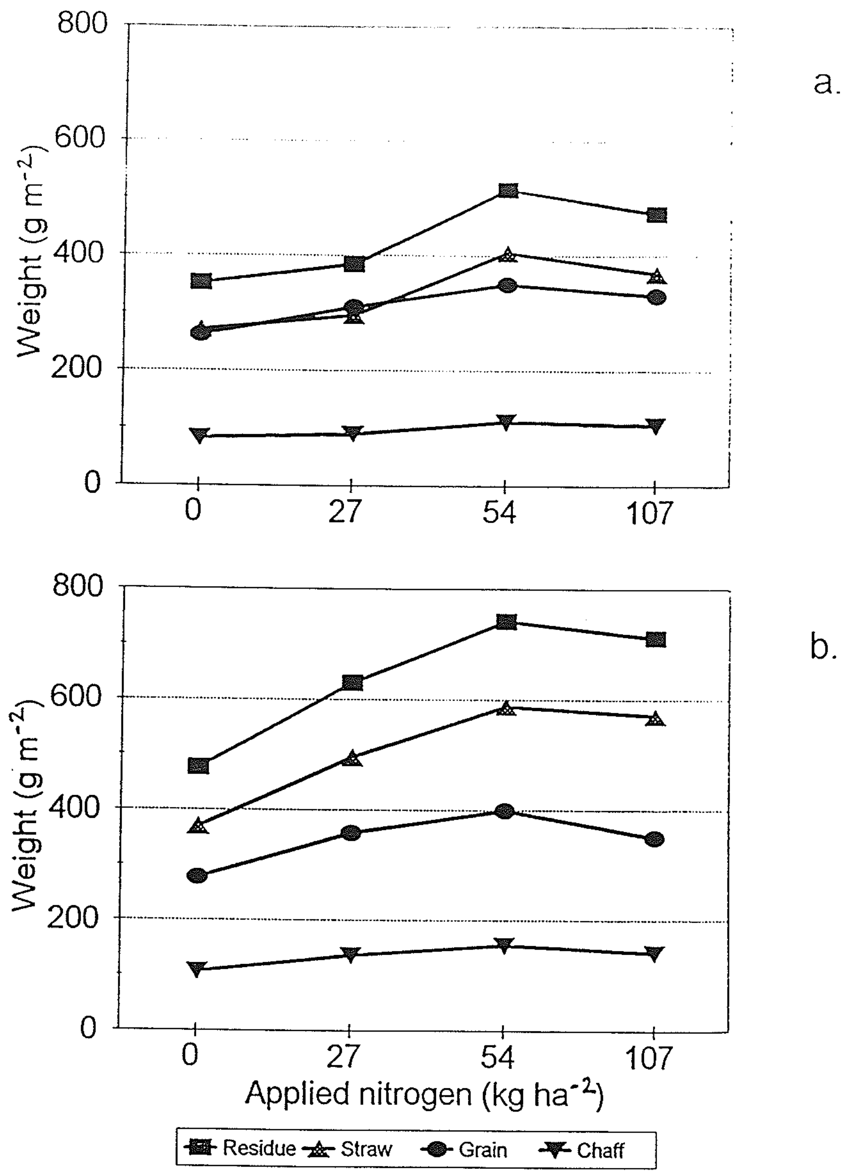

Figure 5.1. Residue production and grain yield of Katepwa wheat in relation to applied fertilizer nitrogen at (a) Carman (b) Winnipeg (1994).

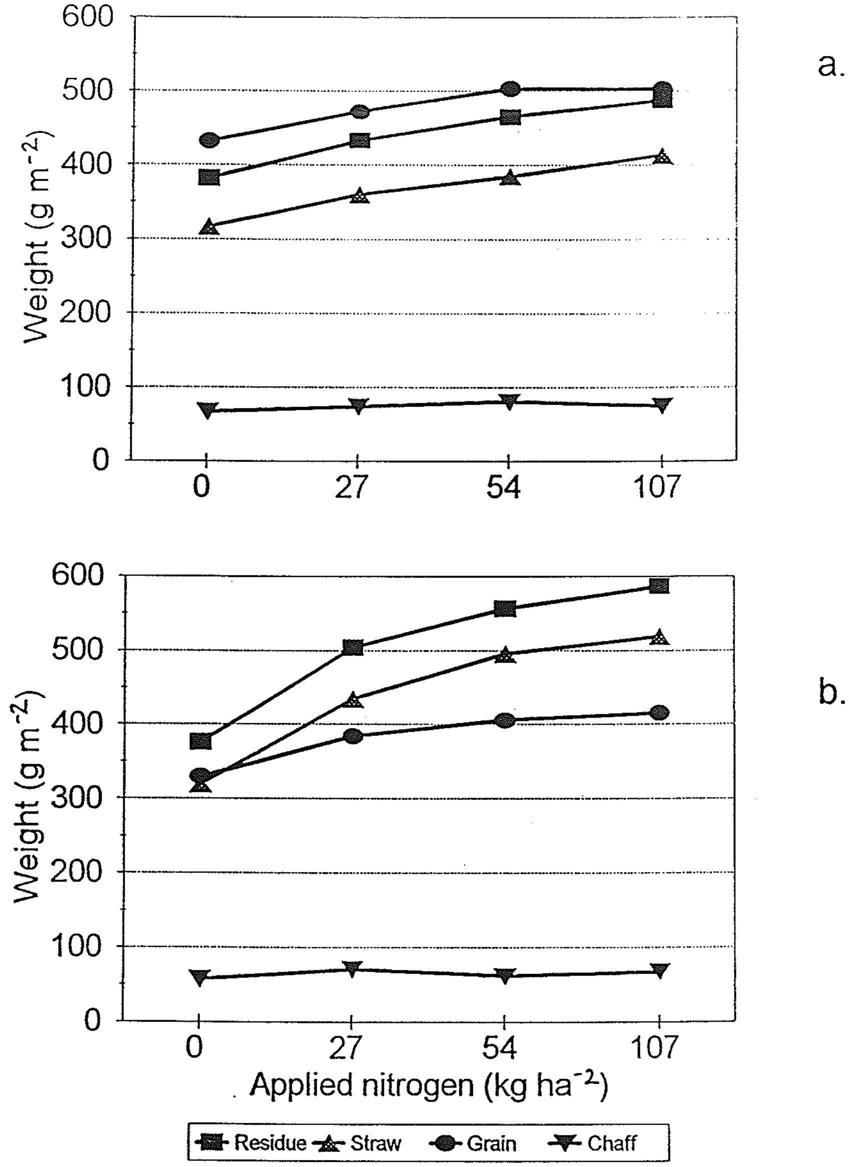

Figure 5.2. Residue production and grain yield of Argyle barley in relation to applied fertilizer nitrogen at (a) Carman (b) Winnipeg (1994).

soil cores taken in the spring of 1994 indicated that residual soil N was high at both locations (95 kg actual N ha^{-1} at Carman and 126 kg actual N ha^{-1} at Winnipeg). These initially high levels of residual soil N may have contributed to the low response noted for 3 of our 4 experiments. The absence of significant differences between N treatments for spikes per unit area suggests that the formation of yield components was not limited by N. In general, however, small increases in grain yield still occurred with increasing N application levels before tapering off at the highest N level (Figure 5.1 and Figure 5.2). The smaller grain yield increases at Carman compared to those of Winnipeg were attributed to low moisture levels and higher levels of disease at the Carman location. The small grain yield increases at both locations were probably the result of N effects on the development and maturation of tillers. Similar observations were made by Power and Alessi (1978) who concluded that N fertilizer reduced high order tiller mortality which provided more ears per unit area and subsequently greater grain yield.

Strong correlations between grain yield and straw and total residue production at both locations for wheat and barley indicated that the largest plants appeared to produce the highest grain yields. Having a quadratic function capable of describing the grain yield responses to fertilizer N agrees with the assertion by Blackman et al. (1978) that grain yield response to N declines as N supply is increased and may fall at high rates of application even when there is no lodging. Lodging did not pose a problem for the wheat at either location or the barley at Carman; however, at Winnipeg, barley lodged at the two highest rates of applied N and may have further contributed to the non-significant yield differences noted among N levels at that location.

Changes in grain yield relative to straw yield are not equal for all environments. Modifying an environment by altering its fertility level will affect how grain and straw yields respond to that environment. As a result, R/G change with incremental applications of N fertilizer (Reitz, 1976). Calculations from numerous data sources (Bulman and Smith, 1993; Grant et al., 1991; Gehl et al., 1990; Pendleton and Dungan, 1960) reveal that in general, with each incremental addition of N, straw yields increase more quickly and decrease more slowly than grain yields. As a result, R/G increase with each additional incremental of N, whether or not grain yield is increasing (Figure 5.3).

In our trials, the tendency for straw production to continue increasing at higher N rates while grain yields levelled off or began decreasing resulted in a reduction in HI and an increase in the R/G. Others researchers have reported similar observations (Brinkman and Rho, 1984; Gehl et al., 1990). Continued straw production increases without subsequent increases in grain yield indicated that applying too much N causes unfavourable patterns of dry matter distribution. Excessive N applications increases the potential for residue management problems and might have reduced grain yields more in the event of severe lodging. Yield losses could have been further accentuated because lodging often encourages the development of yield-reducing diseases.

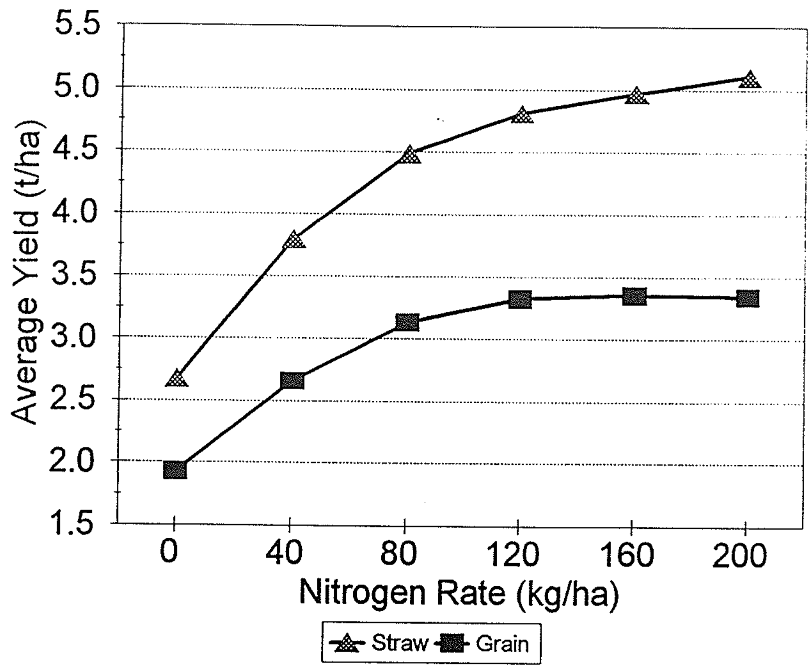

Figure 5.3. Residue production and grain yield of six spring wheat cultivars in relation to applied N in Manitoba (adapted from Gehl et al., 1990).

Nitrogen fertilization seemed to cause greater location-to-location variation for straw production than for grain yield. The mean straw weight of Katepwa wheat at Winnipeg was 51% larger than at Carman while grain yield was only 11% larger. Calculations from data taken from Grant et al. (1991) showed a similar pattern to the one we observed. In their experiments, mean straw weight of 6 barley cultivars at the highest-producing location was 115% larger than the mean straw weight of the lowest-producing location. Grain yield differences were smaller with the highest-yielding location producing only 54% more grain than the lowest-yielding location. In our barley experiments, lodging increased the location-to-location variability of grain yield so that grain yield variability from location-to-location was actually slightly larger than straw production. However, under conditions not conducive to yield losses, straw production seems to be more variable.

The magnitude of the difference between the highest-yielding and lowest-yielding N application rate within a location was also greater for straw production than for grain yield. The highest-yielding N rate yielded on average 55% more straw than the lowest-yielding N rate for Katepwa wheat and 47% more straw for Argyle barley. The average grain yield difference between the highest-yielding and lowest-yielding N rate was 38% for Katepwa and only 20% for Argyle. Similarly, calculation made from data taken from Grant et al. (1991), working with spring barley and Gehl et al. (1990), working with spring wheat, indicated that in 5 of 6 different environments, straw production differences between the highest-yielding and lowest-yielding N rate were greater than grain yield differences.

Larger variations in straw production compared to grain yield within a location coupled with the earlier fact that N affects the location-to-location variability of straw production more than the location-to-location variability of grain yield indicates that straw production could be manipulated by varying N rates without sacrificing grain yields; however, the environmental conditions must be optimal for this to occur. Because we have little control over the environment, the chance of successfully manipulating N rates with the goal of reducing straw and total residue production without concurrent grain yield losses is unlikely.

Estimated combine throughputs at 20-, 25-, 30-, and 35-cm cutting heights were affected by N fertility in 3 of 4 experiments involving wheat and barley. At both locations, estimated combine throughput was strongly correlated with straw production at each cutting height. As the level of applied N increased, estimated combine throughput became larger. Largest throughputs were always associated with the N rate producing the largest amounts of straw residue. In the experiment in which significant differences were not noted among N rates, estimated combine throughput still increased with each incremental addition of N. At the 20-cm cutting height, approximately 62% of the total straw passed through the combine. By raising the cutting height 5-cm to 25-cm, estimated combine throughput was reduced by 8% to 54% of total straw. Increasing the cutting height another 5-cm to 30-cm reduced estimated combine throughput a further 8% to 46% and increasing the cutting height to 35-cm reduced the estimated combine throughput to only 39% of the total straw production. Weight of standing wheat stubble was affected by N rate at both locations; however, weight of standing barley stubble was not. If spike production had increased with increasing N level, differences in the weight of standing stubble would have been noted.

5.5 Summary and Conclusions

Our studies with N fertilizer showed that straw production continued to increase past the N levels at which no further grain yield increases occurred. This indicated that with N fertilizer, over-fertilization could lead to excessive residue production without the benefit of gaining any extra grain yield. This was especially evident when initial levels of residual soil N were high. Our studies also showed that the most productive N level in terms of grain yield also was the most productive in terms of straw, chaff and total residue production.

Under conditions where yield response to applied N is high, although higher rates of N may give economically significant yield increases, the yield advantage may be outweighed by the proportionately greater residue produced from that extra increment of N fertility. Farmers should pay particular attention to their fertility levels. Regular soil testing to ensure N fertility levels are not inadequate or excessive will ensure high yields without the problems associated with excessive crop residues.

Because straw and total residue production increased with applied N, estimated combine throughput increased as well. Because straw production was correlated with grain yield, it would appear that using N fertility to reduce combine throughput would not be feasible since lower straw production would result in lower grain yields.

VI. GENERAL DISCUSSION AND CONCLUSIONS

Information on the variation in straw, chaff, and total residue production attributable to genotype gathered in these studies has clearly shown that cultivar selection is an important tool that can be used to minimize crop residue production. This information should assist farmers in cultivar selection when grain yield and other characteristics have already been taken into consideration. It is recommended that straw yield be measured in variety trials and included as an additional characteristic on variety recommendation lists. Cultivar recommendations made in this chapter are applicable only to producers in the Red River Valley area. However, the data could be applied to make different recommendation for other areas with different climates.

Results from the present study showed that while the variation in total residue production among cultivars of wheat and oats was small, the variation in the amounts of straw and chaff produced by all three cereal crops was substantial. In general, within a species, the semidwarf cultivars produced less straw than conventional height cultivars. However, some cultivars such as AC Taber (wheat) and OT-257 (oats) could produce as much as or more straw than much taller cultivars indicating that semidwarf cultivars have the potential to produce as much straw as taller conventional height cultivars. Cultivars exhibiting the semidwarf trait should not be considered as belonging to a homogeneous group of cultivars and careful consideration should be made when choosing such a cultivar with the intention of reducing straw production.

Our studies also showed that straw production varied considerably among the taller cereal cultivars. The large differences in straw production among similar yielding conventional height cultivars indicated that it would be possible while maintaining high grain yields to choose high or low straw yielding cultivars to fit in with the method of disposal of straw from a crop. For farmers in the Red River valley wishing to reduce the amount of crop residues produced, we recommend for HRS wheat that they plant AC Domain or Roblin and refrain from planting cultivars such as Katepwa, AC Minto and Glenlea. For barley, Duke, Heartland, and Excel combined low straw production with high grain yield making these three cultivars attractive choices for producers wanting reduced residue production. The 2-row cultivar, Manley produced more straw, chaff, and total residue than the conventional height 6-row cultivars but had grain yields similar to the 6-rows. Larger straw and total residue production by 2-row cultivars should be considered when choosing the type and cultivar of barley to be grown. For oat growers in the Red River valley, AC Marie and Robert were the two cultivars that seemed to combine high grain yields with lower residue production. Farmers wanting to avoid the problems associated with large volumes of crop residue should choose either AC Marie or Robert as their favoured cultivars. Planting Riel should be avoided as this cultivar produces only average grain yields but has very high residue production capabilities. The semidwarf oat cultivar, OT-257, produced amounts of straw and total residue similar to conventional height cultivars.

Our studies showed that although total residue production of semidwarf wheat and oats was quite similar to conventional height cultivars, chaff accounted for a larger percentage of a semidwarf cultivar's total residue. For semidwarf wheat cultivars, approximately 30% of the total residue was chaff. For semidwarf oats, chaff accounted for approximately 18%. These values compared with 23% and 13% for conventional height cultivars of wheat and oat, respectively. Because chaff management is often neglected in the overall scheme of total residue management, special attention will have to be paid to semidwarf cultivars. Not only do these cultivars produce greater quantities of chaff but the chaff itself accounts for a larger percentage of the total residue. As a result, a greater potential for crop residue problems exist, especially if chaff residue is not spread properly at harvest. Typical problems that may be encountered are poor uneven seedling emergence due to the thick layer of chaff residue left behind a combine not utilizing a chaff spreader and slower growth because of cold soils underneath the chaff layer.

With the exception of semidwarf wheat cultivars, the lack of significant correlations between grain yield and total residue production indicated that using grain yields as an indicator of total residue production was not an accurate evaluation method.

The R/G takes the variability of both residue production and grain yield into account simultaneously and is independent of their magnitudes. Because of this, it can be used for direct comparison of cultivars between sites and years making it a useful measurement to guide farmers in cultivar selection. Large differences for R/G noted among cultivars within a species suggests that the potential to select cultivars with a more favourable pattern of residue and grain dry matter partitioning exists.

Within the range of seeding rates tested in our studies, it would appear that straw and total residue production are not easily altered by changing plant density. Inconsistent results between experimental sites demonstrated that the environment has a large impact on the size and nature of the effect that seeding rate has on a plant population. In general, the results of our studies showed that seeding rate had a small effect on straw and total residue production. Seeding rate had a significant positive effect on the number of culms produced per unit area; however, the individual culm weights decreased with increasingly higher seeding rates mitigating the effect of greater culm numbers. As a result, straw production did not increase with seeding rate.

Although spikes m^{-2} increased with increasingly higher seeding rates grain yield did not increase indicating that yield compensation occurred nullifying the disadvantage of fewer spikes m^{-2}. In each experiment where seeding rate had a significant effect on grain yield, largest yields were produced at the lowest seeding rate.

Our studies with N fertility on wheat and barley showed that straw and total residue production increased with increasingly higher rates of N fertilizer. The small differences obtained for grain yield were attributed to the high levels of residual soil N from the previous year. The tendency for residue production to continue increasing at higher N rates while grain yields levelled off or began decreasing showed that over-fertilization increased the potential for residue management problems by shifting the patterns of dry matter distribution. Higher N rates resulted in larger R/G indicating that as N rate increased, more residue per unit of grain yield was produced. Under conditions where yield response to applied N is high, although higher rates of N may give economically significant yield increases, the yield advantage may be outweighed by the proportionately greater residue produced from that extra increment of N fertility. Farmers should pay particular attention to their fertility levels. Regular soil testing to ensure N fertility levels are not inadequate or excessive will ensure high yields without the problems associated with excessive crop residues.

Estimated combine throughput was affected by cultivar in the wheat and barley experiments but not in the oat experiments. The highly significant correlations between estimated combine throughput and straw production indicated that selecting a cultivar with low straw production will reduce combine throughput and improve the combine's threshing capacity. Semidwarf wheat and barley cultivars had smaller estimated combine throughputs at all cutting heights when compared to the conventional height cultivars; however, the semidwarf oat cultivar tended to have estimated combine throughput weights similar to the conventional height cultivars. AC Domain and Roblin (conventional height wheat cultivars) and Heartland and Excel (conventional height barley cultivars) had low estimated combine throughput making them good choices for a faster more efficient harvest. The 2-row barley cultivar, Manley tended to have higher estimated combine throughput than conventional height 6-row cultivars. If the choice to grow 2-row barley cultivars is made, slower harvesting should be expected because of the increased amount of straw passing through the combine. Estimated combine throughput increased with increasingly higher rates of N fertilizer for both wheat and barley but was not affected by seeding rate.

VII. RESEARCH OPPORTUNITIES

7.1 Ongoing Research

As well as differing in the amounts of crop residues produced, cultivars have also been shown to differ in their proportions of chemical constituents (cellulose, hemicellulose, lignin and N) and in their rates of decomposition. Ongoing research is being carried out at the University of Manitoba Research Station at Glenlea to measure decomposition rates and to determine differences in residue decomposition for numerous cultivars of wheat, barley and oats.

N concentration and the C/N ratio of plant residues can influence microbial decompostion of crop residues. Fertilizer N added to the soil or straw can occasionally affect decomposition. Ongoing work at the Glenlea research station is examining the decomposition rates of wheat and barley residues of differing N concentrations.

Other factors that can also influence the microbial decomposition of crop residues include particle size, loading rate, and straw placement (above or below the soil surface). Continuing research is monitoring the effects that these factors have on residue decomposition.

7.2 Future Research

Research in the area of crop residue management is far from complete. Another pre-seeding management decision that should be examined is the effect of row width on residue production. Narrow row spacings less than 18-23 cm have generally caused consistent increases in yield over wider row spacings in spring cereals (Holliday, 1960; Finlay et al., 1971; Briggs, 1975). However, in past studies only grain yields were reported with no mention about row spacing effects on straw production.

Work on seeding rate should be investigated further. The inconsistent results from the two sites in 1994 made interpretation of the data difficult. Data from new trials should help to draw more definite conclusions about seeding rate effects of residue production and grain yield.

One of the very interesting findings of our studies dealt with chaff production. Depending on cultivar type, wheat chaff accounted for 25-35% of total residue production. Since many producers still do not spread their chaff, research examining the emergence and development of a subsequent crop under unspread vs spread chaff rows would be useful for extension work with farmers.

Another area of research that could be explored deals with post-harvest decisions. Large high capacity combines are capable to using wide swaths but are often poorly equipped when it comes to chopping and redistributing the straw. Different pieces of residue management equipment such as better straw choppers and heavy harrows could be tested for the effectiveness in breaking up and redistributing crop residues during and after harvest.

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Appendix Table 1. Mean total residue, straw, and chaff production, grain yield, stem length, weight culm^{-1}, spikes m^{-2}, harvest index (HI), and residue/grain ratio (R/G) for Katepwa wheat as affected by N fertilizer (Oak Bluff, 1993).

Nitrogen Rate (kg N ha^{-1})	Stem Length	Total Residue	Total Straw	Total Chaff	Grain Yield	Weight culm^{-1}	Spikes m^{-2}	HI	R/G Ratio
	(cm)	------------ (g m^{-2}) ------------				(g)	(no.)		
OAK BLUFF									
27	82	561	483	79	204	0.98	524	0.27	2.83
54	84	584	496	87	189	0.88	565	0.24	3.21
107	81	599	511	88	206	0.99	530	0.26	2.91
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS Not significant at the 5% level of significance.