Effect of simulated erosion on canola productivity

by

Brian Edward Kenyon

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ABSTRACT

Simulated soil erosion sites were developed on six soil types in Manitoba to assess the effect of topsoil removal on canola productivity. The soil types studied ranged from a Reinland loamy very fine sand to a Pembina clay loam. Plots were developed on a completely randomized split plot design with topsoil removal being the main plot treatment and fertilizer additions being the subplot treatment. Levels of topsoil removal were: 0 (control), 5, 10, and 20 cm. Each topsoil removal treatment was replicated 4 times. Each topsoil removal level was then treated with no fertilizer (control), recommended rate of fertilizer (based on soil test), and approximately twice the recommended rate of fertilizer.

Data from 1985 and 1986 indicated that, in general, canola yields decreased where 5, 10, and 20 cm of topsoil were removed and no fertilizer was added. For the fine textured soils, additions of fertilizer at the recommended rate usually mitigated the yield loss associated with topsoil removal in both years. Applications above the recommended rate of fertilizer did not significantly increase yields any further. Yield reduction where topsoil was removed was likely nitrogen related as the canola plants exhibited typical nitrogen deficiencies.

For the coarse textured soils, applications of fertilizer at the recommended rate, where 20 cm of topsoil had been removed, were not able to increase yields over those of the control (no topsoil removed, no fertilizer added). In some instances, even twice the recommended

rate of fertilizer did not increase yields over that of the control. For these soils, some other factor, other than fertility, was limiting crop growth. It is possible that the subsoil possessed some characteristics, either physical or chemical, which were limiting to crop growth.

For the Waskada VFSCL site, applications of the recommended rate and twice the recommended rate of fertilizer, where 10 and 20 cm of topsoil had been removed, did not increase yields over the control where no fertilizer had been added and no topsoil was removed. A layer consisting of gravel and coarse material existed approximately 20-30 cm below the soil surface. Exposure of this layer or increasing its proximity to the soil surface by the removal of topsoil likely restricted the root growth of canola and therefore limited yields on these subplots.

As the level of topsoil removed increased and no fertilizer was added, straw yields decreased. As well, nutrient concentration of the straw also decreased. Additions of fertilizer increased straw yield production and also increased the concentration of nutrients in the straw.

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1. INTRODUCTION

Canola has been produced on the Prairies for many years. It has proven to be a very good source of income for producers. There is concern then, that any factor which decreases the yield of canola will also decrease the return per hectare for the producers.

One factor which is likely to have serious effects on canola yield is soil erosion. There are several reasons for suspecting that soil erosion will reduce canola yields. Among these is the fact that soil erosion removes plant nutrients necessary for plant growth and reproduction. This effect will be more critical to canola than to a crop such as wheat because canola requires 25-30% more nitrogen and potassium, 50% more phosphorus, and 90% more sulfur (Ukrainetz, 1982). Erosion removes topsoil which contains significant amounts of these nutrients.

Soil erosion also removes organic matter from the soil surface. As well as being a potential source of plant available nutrients, organic matter helps to improve aeration, structure, and water holding capacity of soils. Therefore, loss of organic matter may have serious implications on canola growth.

Canola is a small seeded crop and its emergence may be seriously reduced on soils which tend to form soil crusts. Hirch (1984) found that crust strengths of eroded soils increased as the level of topsoil removal increased. The crusts formed impeded the emergence of canola. Therefore, the formation of soil crusts on eroded soil may make the establishment of an acceptable canola stand difficult.

Much research work has been conducted on the dynamics of soil erosion. Considerable amounts of research work have dealt with the influence of soil erosion on soil organic matter levels and on soil nutrient losses. Equations have been developed which predict soil loss from either wind or water erosion under different management systems. These equations are useful in predicting soil loss but they give little indication of how this soil loss affects crop productivity.

Qualitatively it is known that soil erosion reduces crop yields but quantitatively it is not known how much crop productivity is reduced by soil erosion. The purpose of this project, therefore, was to quantify the effect of several levels of simulated soil erosion on canola yields.

2. LITERATURE REVIEW

2.1. Problems, Costs, and Effects of Soil Erosion

Farmers today face increasing difficulties in producing agricultural commodities needed to feed the world's growing population. Agriculture is affected by many factors such as growing season precipitation, temperature, length of growing season, hail, insects, weeds, and soil erosion. All of these factors work congruently and eventually each has an affect on crop yields.

One factor that is beginning to receive considerable attention is soil erosion. Its importance lies in the fact that if it is not controlled, soil erosion could lead to the eventual destruction of our soils. Estimates of soil erosion globally are as high as 23.4 billion tonnes of soil loss per year in excess of soil that is being formed (Brown, 1984). Brown's estimates for the top four food producing countries of the world were (given in billion tonnes soil lost/year in excess of topsoil formation): United States - 1.5, Soviet Union - 2.3, India - 4.7, and China - 3.6. Together they represent just over half of the world's estimated soil loss.

Larson et al. (1983) predicted that in the United States 16.8 million hectares of land will be lost in the next 100 years if the current rate of soil erosion (currently 0.1% loss in crop production per year) continues. Pimentel et al. (1976) estimated that in the last 200 years, approximately 80.0 million hectares of farmland in the United States have been ruined or seriously impoverished for crop production through soil erosion. Sparrow (1984) concluded that Canada risks permanently losing a large portion of its agriculture capability if soil degradation is allowed to continue. This loss comes at a time when more land is needed or will be needed to feed the world's increasing population.

Soil erosion is costly in many ways. Huszar and Piper (1986) estimated the offsite cost of erosion to be in the order of $466 million annually in the United States. Senator Sparrow and his Standing Committee on Agriculture, Fisheries and Forestry (1984) estimated that soil degradation was costing Canadian farmers $1 billion per year in income. The committee estimated that it would cost $239 million (1982 prices) in increased fertilizer use to maintain crop production on eroded soil. Others (Willis and Evans, 1977) have reported that if as little as 2.5 mm of topsoil is lost each year through erosion, the cost of replacing the resulting loss of nutrients would be $28 billion per year. Bentley (1985) estimated that since the 1930's approximately $43 billion has been spent on conservation efforts in the United States. Yet the problem still persists and remains one of the biggest environmental concerns in the United States.

Why is the problem of soil erosion continuing to persist even though much time and money has been spent on it? Soil erosion is not usually a spectacular event that catches the interest of people. Unlike the famine of Northern Africa, soil erosion continues relatively unnoticed despite its potential effect on the world's food supply. The lack of recognition of the effect of soil erosion on the world's food supply stems from advances in agricultural technology. Generally, crop yields have been increasing due to improved crop varieties and the increased use of fertilizer. Also the use of pesticides, irrigation, and improved farming techniques and management have all led to an increase in crop yields. It is therefore difficult to see the effect of erosion because it is being masked by advances in technology. The questions that remain to be answered are: what would crop yields on eroded soil have been if technological advances had not been as great, and what would crop yields be with current technology and no erosion?

Other possible explanations for the persistance of soil erosion were offered by Bentley (1985). Bentley felt the persistance of soil erosion was due to the fact that farmers have no incentive for trying new conservation ideas. Conservation farming costs money to initiate. Unfortunately in today's poor economic times, most farmers are farming for short term goals, i.e. to make a living on their existing land, using their existing farming techniques, regardless of the longterm consequences. In order to get higher returns, agriculture producers are breaking more marginal land, which is susceptible to erosion. This is all a consequence of lower grain prices and higher input costs (Carter, 1977; Sparrow, 1984).

From the time and money spent it is apparent, then, that soil erosion is a serious problem. Soil erosion, as it applies to agriculture, is defined as the wearing away of the land surface by wind and water and the subsequent detachment and movement of the soil from its place of origin (Soil Science Society of America, 1984). Soil erosion is irreversible in the sense that, if most of the rooting depth is removed, plants will not have a favorable medium in which to grow. No level of current technology would be able to replace this lost soil.

However, soil erosion is reversible in the sense that loss of nutrients, associated with erosion, can be compensated for by the addition of fertilizer (Wolman, 1985). Also, the formation of new soil by natural erosion will eventually replace lost soil, but this process is slow and can be exceeded by accelerated erosion.

2.2. Types of Erosion

There are two main types of soil erosion- natural or geological erosion which is the normal erosion caused by geological processes acting over long periods of time; and accelerated erosion, which is the rapid erosion of soil brought about through the influence of man, usually through cultivation (Soil Science Society of America, 1984). Tillage exposes the soil to the actions of the climate and increases the possibility that the soil will erode through the greater opportunity for detachment and transport. Jones et al. (1985) found runoff from cultivated watersheds with 1.5% slope to be 5 times greater than losses from rangeland watersheds not exposed to cultivation. They found sediment loss from a 152 mm rainfall to be 6.5 t ha^{-1} from a fallow watershed, while sediment loss from a rangeland watershed was only 0.3 t ha^{-1}. Natural erosion is not necessarily harmful in that it can lead to the formation of soils over time through the weathering of parent material and has lead to our present day soils. Accelerated erosion is harmful in that it can lead to the destruction of our soils if not adequately controlled.

2.3. Effect of Erosion on Soil Productivity

Soil productivity is defined as the capacity of a soil, in its normal environment, to produce a particular plant or sequence of plants under a defined set of management practices (Soil Science Society of America Proceedings, 1965).

Accelerated erosion, referred to in the following text as simply soil erosion, can affect soil and its productivity in a number of ways. Soil erosion can decrease the water holding capacity of soils, remove plant nutrients, and lead to the loss of organic matter which results in the degradation of the soil surface structure (Nowak et al., 1985). Also, erosion exposes unproductive subsoils (Carter et al., 1985) and increases costs to farmers through loss of applied herbicides and pesticides which are bound to eroded soil particles (Moldenhauer and Onstad, 1975). Other harmful effects of soil erosion are eutrophication of lakes and streams (Taylor, 1967) and sedimentation of waterways and reservoirs.

There are isolated cases where soil erosion has actually increased the productivity of some soils, however these cases are rare and do not involve much area. Lal (1987) stated that soil erosion could be beneficial if it exposed fertile soil that had been buried under unfertile soil. Stoltenberg and White (1953) also agree that soil erosion is beneficial only if it removes unproductive topsoil and exposes a more fertile subsoil. Experiments in the Soviet Union (Byalyy and Azovtseva, 1964) found that the yields of some hay crops actually increased when grown on eroded rills. The increase in yield was attributed to an increase in moisture associated with the rills and colmatage or sedimentation of the rills which is the result of the hay reducing the transport capacity of the runoff. This allowed soil particles to settle out and increased fertility of the rills as a result of nutrients being leached down from higher elevations. These instances are rare, however, and are probably insignificant due to the small number of hectares involved.

Soil erosion has proven to be an area of soil science that is difficult to study and evaluate. This inherent problem stems from the fact that different soils are affected to varying degrees by wind and water erosion due to variations in texture, moisture status, topography, and profile characteristics (Meyer et al., 1985). Also, depending on the depth of the rooting zone and moisture status of the soil, erosion affects different crops to different extents. Crusting, which may occur on eroded soils, may affect the emergence of small seeded crops. Erosion also varies considerably from year to year and season to season. Also, the areal extent and amount of each erosion event will vary. Selective removal of plant nutrients and deposition of these nutrients elsewhere will also affect the way that soil erosion will affect the productivity of an eroded field (Meyer et al., 1985). Finally, variability of yield within a field can also lead to problems in estimating crop productivity changes. Lyles (1975) reported coefficients of variation for long term wheat yield averages to be 37% for Saskatchewan. Interaction of all these factors makes accurate assessments of soil erosion's effect on productivity difficult to assess.

2.3.1. Available Water Holding Capacity and Soil Erosion

Soil erosion can reduce soil productivity through its effect on soil water holding capacity. This can occur in two ways. First, soil erosion removes topsoil in which plants would normally root and therefore volume of soil from which the plant roots would extract moisture is reduced (Nowak et al., 1985). Secondly, soil erosion can change the texture of a soil depending on the texture of the exposed subsoil. Work conducted by Lyles and Tatarko (1986) in Western Kansas showed the silt fraction of soils decreased by 7.2 percent after 36 years of cropping and the sand fraction increased by 6.5 percent. They also found that the organic matter of the soils generally decreased with time. They felt that these changes may have been the result of erosion and would therefore influence the soil structure, water holding capacity, and nutrient status of a soil.

Eck (1968) showed the importance of available water on crop yields. Eck found that large applications of fertilizers could not restore lost sorghum dry matter yields where 10, 20, and 30 cm of topsoil had been removed. However, when supplemental irrigation was added, dry matter yields were restored. Any loss in available moisture will therefore have serious implications on the growth and development of crops.

2.3.2. Changes in Texture due to Soil Erosion

Comparing the physical and chemical characteristics between eroded and noneroded Typic Paleudalfs, Frye et al. (1982) found that the eroded soils had a higher clay content resulting in less available moisture in the top 30 cm of the soil. Frye et al. (1985) concluded that plant available moisture decreased as the clay content of the soil increased. Stone et al. (1985) found that the lower limit of available water increased as a result of an increase in clay content of an eroded Piedmont soil. Larson et al. (1985) studied the effect of erosion on the productivity index (PI) of several soils (PI used as described by Pierce et al., 1983). They found that, as the degree of erosion increased on a Seymour Series, the PI decreased. This was attributed to an increase in pH with depth of the profile and a decrease in available water holding capacity as the level of clay increased.

2.3.3. Nutrient Losses in Soil Erosion

2.3.3.1. Nutrient Content of Eroded Sediment

Soil erosion has been shown by many workers to affect the productivity of soils through its removal of nutrients, either associated with eroded sediment or dissolved in runoff water. Studies by Daniel and Langham (1936) compared the organic matter and nitrogen content of three different soils- virgin, cropped, and drifted. They found the organic matter of the drifted soil was reduced by 24.5% and the nitrogen content was reduced by 28% when compared to the virgin soil. They also found that the more the eroded soil was re-eroded the lower the organic matter and nitrogen contents became. Using simulated rainfall on a 13% sloping Zainsville silt loam, Moe et al. (1967) found that as the amount of sediment loss increased the loss of organic nitrogen also increased. Burwell et al. (1976) found similar results, adding that any practice which reduced the loss of sediment would reduce the loss of nitrogen associated with the sediment. Schuman et al. (1973) found that of all the nitrogen lost from contour planted corn watersheds with an average slope of about 15%, 92% was associated with sediment in the runoff. They found that the greatest loss of sediment, and therefore nitrogen, occurred at the time of seedbed preparation and establishment of a crop stand. Lal (1976a) also reported large losses of nutrients from plowed plots in Nigeria. Lal found that eroded sediment contained 2.4 times more organic matter, 1.6 times more total nitrogen, 5.8 times more available phosphorus, and higher amounts of other nutrients such as potassium, calcium, and magnesium than the soil from which the sediment originated. Stoltenberg and White (1953) found eroded soil to contain more organic matter, nitrogen, available P_2O_5, and available K_2O than the soil from which it came.

Alberts and Moldenhauer (1981) found that generally the smaller sized aggregates (0.21-0.05 mm) contained the greatest nutrient concentration of nitrogen and phosphorus. They found that as the runoff velocity was decreased the size of the particles that could be transported by the runoff also decreased. Even though the nutrient concentration of the larger sized particles was lower, their contribution to the loss of nutrients was significant because of the larger amounts that were removed under the different treatments. Enrichment of sediment can occur for all sizes of particles with the level of enrichment depending upon the transport capacity of the runoff (Alberts and Moldenhauer, 1981).

In other work, Alberts et al. (1981) determined the relationship between sediment size and nutrient content and found the very small fractions of sediment contained the lowest concentration of nitrogen and phosphorus. They concluded that "enrichment levels depend partly upon the ratio of the number of larger silt sized particles (0.05 to 0.020 mm) to the number of smaller silt-sized particles (0.020 to 0.002 mm) transported in the runoff". Massey et al. (1953) found losses of sediment as high as 20.2 t ha^{-1} $year^{-1}$ on an Almena silt loam with 3% slope. They found that in one year the eroded sediment was enriched with 854 kg ha^{-1} organic matter, 46 kg ha^{-1} total nitrogen, 1.6 kg ha^{-1} available phosphorus, and 5.7 kg ha^{-1} exchangeable potassium. In another report, Massey and Jackson (1952) found the following increasing order in which nutrients and organic matter are selectively removed: organic matter (2.1), organic nitrogen and ammonia nitrogen (2.7), available phosphorus (3.4), and exchangeable potassium (19.3), with enrichment ratios shown in brackets. Hays et al. (1948) compared the nutrient status of a moderately eroded and a severely eroded Fayette silt loam. They found that the moderately eroded soil contained over twice as much organic matter and nitrogen than the severely eroded soil in the top 15 cm. They also found that more nutrients and organic matter was lost from the moderately eroded soil than the severely eroded soil (Table 1). This was likely due to the higher amounts of these substances that were found in the moderately eroded soil.

Thus, it is clear that soil erosion can remove considerable amounts of sediment, nutrients, and organic matter depending on soil type and management practice used. This will in turn affect the productivity of soil and will determine the outcome of crop yields grown on that soil.

2.3.3.2. Nutrient Losses in Runoff Water

Dissolved nutrients in runoff water represents another way in which nutrients are lost from the soil. Kissel et al. (1976) found that losses of nitrogen in runoff were highest if a runoff producing event occurred shortly after fertilizer application when the soil was near field capacity. Such a condition results in less infiltration and more surface runoff. Neilsen and MacKenzie (1977) found losses of soluble nitrogen to be high where infiltration rates were low. Thus, it appears that the soil's ability to accept moisture will determine in part the amount of soluble nutrient losses that will occur.

Table 1. Total runoff losses of soil, organic matter, and nutrients during 1945 on an eroded Fayette SL. (Hays et al., 1948)

Crop & degree of erosion	Total Soil Loss t ha^{-1}	Total OM kg ha^{-1}	Total N kg ha^{-1}	Total P kg ha^{-1}	Total K kg ha^{-1}
Oats, moderate	52.00	1069	57.80	34.66	946
Oats, severe	53.06	751	36.10	39.20	974
Corn, moderate	2.31	78	3.89	1.91	43
Corn, severe	0.79	21	1.16	0.79	15

Not only does proper soil management improve or protect the soil from erosion and therefore nutrient losses, but proper management can reduce the amount of nutrient loss associated with runoff and percolate. Chichester (1977) found nitrogen losses to increase as soil cover decreased. As much as 10 kg ha^{-1} nitrogen was lost in runoff water from clean cultivated corn on 13% sloping land. By minimizing surface runoff and leaching losses, the author felt losses of nitrogen would be decreased. However, Burwell et al. (1975) found that less than 5% of the losses of nitrogen, phosphorus, and potassium were associated with the runoff water. They found that the majority of the nutrient loss was associated with the eroded sediment. Römkens et al. (1973) found that there was a curvilinear relationship between nitrogen and phosphorus in sediment removed by runoff and soil loss. They found that soil tillage systems which did not control the loss of sediment resulted in increased losses of nitrogen and phosphorus associated with the sediment. However, if soil loss was controlled through reduced tillage, they found more soluble forms of the nutrients, added through fertilization, were lost due to less mixing with the soil.

Other workers (Dunigan et al., 1976) also found that incorporation of applied fertilizers reduced surface runoff losses of fertilizer elements. Alberts and Spomer (1985) found PO_4-P losses in surface runoff from till planted corn cropped watersheds to be quite high and exceeded water quality standards. They also found, as did Burwell et al. (1976), that large NO_3-N losses were associated with subsurface flow. They concluded that fertilizing according to crop needs, using slow release fertilizers, such as sulfur coated urea, and making better use of available water would all help to reduce nutrient losses. Menzel et al. (1978) found soluble nitrogen and phosphorus losses (fertilizer elements) in runoff from level cropped watersheds and rotational grazed watersheds with a 3% slope were low. On average, soluble losses of total nitrogen and phosphorus from cropped watersheds represented only 20% of the total nutrient losses. Soluble losses from rotational grazed watersheds were 20% of the total for nitrogen and 10% for phosphorus. These losses of nutrients represents a significant potential supply of plant nutrients and must therefore be protected.

The loss of nutrients causes a reduction in the productivity of eroded soils but the loss of these nutrients is also a concern to environmentalists. The increase in nutrient content of lakes and streams can lead to an increase in the eutrophication and a decrease in the quality of these bodies of water. Many authors have reported that the loss of soluble nutrients, although insignificant as it relates to agriculture, can lead to the eutrophication of surface waters (Burwell et al., 1975; Neilsen and MacKenzie, 1977). Taylor (1967) found that a concentration of phosphorus as low as 0.03 ppm was enough to initiate algal growth of lakes and streams. As a result, water treatment costs would increase and the value of the water for recreation purposes would decrease (Taylor, 1967). Greenhill et al. (1983) showed the importance of native pasture in reducing nutrient concentrations in runoff. They found that losses of applied superphosphate to pastures on sloping land were low and would not result in the pollution of lakes or streams.

2.3.4. Effect of Soil Erosion on Soil Structure

The loss of organic matter and the increase in clay content resulting from soil erosion has a detrimental effect on the structure of soils. Organic matter is not only a potential source of plant nutrients but it also plays a role in the structure of soils. Shaxson (1975) pointed out the importance of organic matter in improving soil structure and reducing impact of rainfall. Organic matter helps to improve aeration, soil porosity, and soil particle aggregation. As a result, organic matter ultimately affects the ability of plant roots to grow into soil. Therefore, a loss of organic matter will lead to a gradual deterioration of the soil. Soil organic matter also helps to increase the stability of soil aggregates and therefore, as the amount of organic matter decreases, the chance for erosion to occur increases (Wooldridge, 1964).

As was shown earlier, eroded soils tend to have higher clay contents which will also affect the soil structure. Frye et al. (1982) compared the physical characteristics of an eroded and noneroded soil and found the bulk densities to be higher in the top 15 cm of the eroded soil.

2.4. Yield Losses due to Soil Erosion

Langdale et al. (1979) found that as the depth to the B_2 horizon decreased the clay content tended to increase. They found that on Southern Piedmont soils the loss of 15 cm of topsoil resulted in a 42% reduction in corn yield. Based on 1979 production levels, the loss of 147 kg of grain per hectare per year would occur for each centimeter of topsoil lost. In an experiment where topsoil was added to eroded areas to determine the effect on yield, Mielke and Schepers (1986) found that all crops responded to topsoil additions. They felt that the topsoil provided a good physical environment for development of plant roots and that the additions of fertilizer could not overcome the deterioration of physical characteristics of the soil resulting from erosion. In a similar experiment Massee and Waggoner (1985) found that the removal of 15 cm of topsoil significantly reduced crop yields. Additions of fertilizer could not mitigate this yield loss entirely. This led them to conclude that "fertilizer nutrients cannot fully substitute for surface soil".

2.4.1. Subsoil Effect on Yields

Soil erosion removes topsoil which ultimately exposes subsoils that may or may not be productive. The final effect of soil erosion on crop yields will be determined by the quality of the subsoil in terms of its physical and chemical characteristics (Stoltenberg and White, 1953). Olson (1977) found that corn yields decreased when topsoil was removed and that additions of fertilizer could not overcome the negative effect of topsoil loss. However, the addition of topsoil to eroded soil overcame any yield loss and nutrient deficiency symptoms. The author noted that the eroded soil did not provide a good seedbed due to the higher clay content and crust formation impeded the emergence of corn seedlings.

In an effort to study the effect of added nutrients on the yield of subsoils, Carlson and Grunes (1958) determined the effect of added nitrogen, phosphorus, potassium, and minor elements on the yields of barley grown on subsoils. They found that barley yields on the subsoil did not equal the yields of barley grown on topsoil. This, they felt, may have been due to some growth limiting factor of the subsoil. Work conducted in Manitoba by Bradley in 1970 found that additions of fertilizer could not completely restore the yield loss associated with growing crops on eroded soils.

Other work in the United States showed that erosion of a Portney silt loam exposed an unproductive subsoil and resulted in reduction of crop yields (Carter et al., 1985). A calcareous hard pan of high silt content existed approximately 30-45 cm below the soil surface and when exposed by erosion provided a poor medium for crop development. High levels of fertilizer and irrigation could not improve the yields on this soil which represents a significant area of farmland (approximately 2 million hectares). It was concluded that only additions of topsoil to the eroded areas could improve crop yields grown on the eroded soil (Carter et al., 1985).

There are examples in the literature showing that it was possible to restore the productivity of exposed subsoils. Improving yields on exposed subsoils, however, can be quite involved. Batchelder and Jones (1972) found that the additions of fertilizer, lime, mulches, and some irrigation were needed to improve productivity of an exposed, relatively unproductive subsoil. Eck and Ford (1962) found that on the subsoils they studied, phosphorus was more limiting to crop growth than nitrogen. When phosphorus was applied alone, or with nitrogen, the subsoils outyielded the topsoil. This they attributed to a good subsoil texture which was higher in clay content than the coarse textured topsoil and provided a better medium in which the plants could grow. They noted that the subsoil was not deficient in micronutrients. In field experiments, Reuss and Campbell (1961) found corn responded well to nitrogen and phosphorus additions and to heavy rates of manure plowed down on exposed subsoils. They concluded that the subsoil of the Keiser soil they studied had no adverse physical properties which would affect crop growth.

Latham (1940) conducted an experiment in which topsoil, B, and C horizons of a Cecil sandy loam were added to excavated areas. Soil from the A horizon (topsoil) was brought in from 40 different sites, mixed, and then added on top of 30 cm of added B horizon. Soil from the B and C horizon was obtained from areas where those horizons had been exposed by erosion. Latham applied annual applications of 450 kg ha^{-1} fertilizer containing nitrogen, phosphorus, and potassium to the plots of the different horizons. Using the four year average seed yield for cotton grown on the plots, the author found the A horizon yielded three times more than the B horizon and twelve times more than the C horizon. To two plots of each horizon Latham applied 9 t ha^{-1} manure. There was a yield response to the added manure on all horizons. This led to the conclusion that through the use of manure and addition of sufficient plant nutrients the productivity of eroded Cecil soils could be improved.

2.4.2.1. Effect of Simulated Erosion on Productivity

Some studies of soil erosion have involved the use of simulated soil erosion to determine the effect of erosion on yield. Lal (1976b) artificially removed 12.5 cm of topsoil and found that maize yields were reduced to only 44% of the control plot (no soil removed). In Texas, Heilman and Thomas (1961) using a block of leveled land, cut half the block to a depth of 15 cm and filled the other half with topsoil. They then grew sorghum as a soil improvement crop. They found that even after applying 225 kg ha^{-1} NH_4SO_4 the yield of sorghum forage was 3916 kg ha^{-1} less on the cut area than on the fill area. They suggested that the reason for the lower yield was a result of organic matter removal which would have been a potential source of nitrogen. They estimated that it would require 388 kg ha^{-1} of nitrogen to restore the yield to that of the nonfertilized fill area. They did not, however, report the application of any phosphorus which had been shown to be low in soil test results. If they had added some phosphorus, the yield results may have been different.

Whitney et al. (1950) studied the effect of removing between 3.0 to 48.8 cm of topsoil on the yield of corn and sugar beets. Under this treatment they exposed subsoil that had a high lime content, had a very coarse columnar structure, and was low in total nitrogen and organic matter. They found that high application rates of fertilizer and manure and the use of irrigation could bring the eroded soil back to 'normal' production levels. However, they felt that unless the price of agriculture commodities were high, these treatments would not be economical.

2.4.2.2. Disadvantages of Simulated Erosion

Although the use of simulated erosion has been used to study the effect of erosion on the productivity of soils it does have its disadvantages. Natural erosion is a selective process whereby the finer, lighter particles are removed before the heavier particles

(Stoltenberg and White, 1953; Lyles and Tatarko, 1986). Natural erosion does not remove soil uniformly from all areas of a field and as a result there are areas that have more soil removed than others. This usually happens in the case of gullying and rilling which tends to remove large amounts of soil from small areas (Meyer et al., 1985).

Natural erosion does not remove all the topsoil at once. There is a possibility that, through cultivation, some subsoil may be mixed with topsoil (Meyer et al. 1985). If the subsoil has a different texture than the topsoil it may affect the amount of further erosion that takes place. For instance, mixing of a clay subsoil with coarse topsoil may help to increase aggregate stability and reduce the amount of sediment lost. Also, the process of natural erosion is slow and therefore there is a gradual change in the profile associated with the loss of soil. However, simulated erosion is rapid and would likely effect the productivity of soils to a greater extent (Burnett et al., 1985). Despite these drawbacks, simulated erosion is often the only practical means for evaluating the effect of erosion on productivity.

2.5. Assessing Long Term Effects of Soil Erosion

Although it is necessary to know the impact of soil erosion on crop productivity in the short term, in order to protect the soil, it is equally important to know the impact of soil erosion on crop yields decades or centuries from now. By making estimates of erosion on long term productivity, the evaluation of current land management techniques can be made. A number of equations have been developed to estimate soil loss either through wind erosion (Chepil and Woodruff, 1963;

Woodruff and Siddoway, 1965) or through water erosion (Wischmeier and Smith, 1965) under different management regimes. These equations can predict the loss of soil but are not able to make estimates of the long term effects of soil erosion on crop productivity.

2.5.1. The EPIC Model

In recent years, mathematical models have been introduced which try to predict the long term effects of soil erosion on productivity. Most of these models use the current rates of soil erosion and use this to predict productivity after a number of years. One such model, EPIC or Erosion Productivity Impact Calculator, was developed by a team of 14 researchers from across the United States to study the effect of soil erosion on productivity. The model is divided into eight main sections which include hydrology, weather, erosion, nutrients, plant growth, soil temperature, tillage, and economics. The model uses necessary inputs for determining erosion and crop growth, while the economic component is used for determining the cost of erosion and the most economical management options. The model uses a modified Manhattan, Kansas wind erosion equation (Woodruff and Siddoway, 1965) to predict wind erosion and a modified Universal Soil Loss Equation (Wischmeier and Smith, 1965) as developed by Onstad and Foster (1975) to predict water erosion.

The model predicts the effect of erosion on productivity for an area of about one hectare. The soil profile is divided into a maximum of ten layers with the top layer always having a thickness of 10 mm while the other nine can have varying thicknesses. As erosion proceeds the boundaries of the layers are moved down the profile with any changes in soil properties accounted for through interpolation (Williams, Dyke, and Jones, 1983).

Criteria used in testing the model included the ability of the model to accurately simulate erosion using necessary inputs; to be able to simulate erosion over a number of years; to be able to predict erosion for different soils, different climates, and different crops; to be efficient and easy to use; and to be able to assess the effect of different management practices on erosion and productivity (Williams et al., 1983). Williams et al. (1983) tested the model and found that it provided accurate and realistic results when predicted and measured sediment yields were compared. The model was inexpensive to run and was sensitive to soil erosion's effect on crop yields. The model predicted a 40% reduction in crop yields over a 50 year simulation period with high erosion rates and unfavorable subsoil characteristics.

2.5.2. Productivity Index Model

Another model was developed by Pierce et al. (1983) to assess the long term changes in productivity due to erosion. Their model used for predicting the effect of erosion on productivity was:

$$PI = \sum_{i=1}^{r} (A_i \times C_i \times D_i \times WF)$$

where PI is the productivity index, A_i is the sufficiency of available water capacity, C_i is the sufficiency of bulk density, D_i is the sufficiency of pH, WF is a weighting factor, and r is the number of horizons in which the roots can grow (Pierce et al., 1983). The weighting factor for any horizon is the normalized area under the curve between the upper and lower boundary of the horizon. It takes into account the fact that the soil layers nearest the soil surface play a more important role in crop rooting than those layers further down the profile. Readers are referred to the original paper by Pierce et al. (1983) for a complete description of the components of the model.

Data from the Soils-5 and National Resource Inventory data bases established in the United States was used to calculate productivity index and the changes in productivity with time. Their model predicted that erosion of productive soils with deep profiles could continue for indefinite periods of time as long as nutrients were replaced and the soil received proper management. However, the model predicted that productivity of soils would decline if the productivity of the exposed subsoil was less than that which was eroded.

Pierce et al. (1984) tested this model on the long term effect of erosion on the productivity of soil in the Corn Belt. The Corn Belt area consists of deep fertile soils on gently rolling terrain. The authors felt that this area would not suffer severe productivity changes assuming that the current rate of erosion did not change drastically in the next 100 years. They felt that "both the vulnerability of soils to productivity losses and the vulnerability of the landscape to erosion must be considered in assessing erosion's effects on soil productivity".

The model was also tested on a variety of different soil types and climatic conditions by Rijsberman and Wolman (1985). In their study they evaluated the use of the productivity index model for soils from the United States, India, Nigeria, and Mexico. They found that the model was useful in predicting the effect of soil erosion on crop productivity when certain modifications to the model were made. For example, penetrometer measurements were a better estimate of root penetration than bulk density for Hawaiian soils. For Nigerian and Indian soils a correction had to be made for the increased stoniness of these soils and its affect on the water holding capacity of the soil (Rijsberman and Wolman, 1985). They felt that once these corrections were made, the PI model would be useful globally in predicting longterm effects of erosion on productivity.

2.5.3. The NTRM Model

Another model known as the Nitrogen-Tillage-Residue Management or NTRM model was developed by Shaffer in 1985 and is useful in predicting the long and short term consequences of soil erosion on crop productivity. The NTRM model is useful because it "provides one means of quickly and economically assessing soil erosion-productivity relationships as influenced by existing and proposed management techniques" (Shaffer, 1985). Shaffer's model makes assessments on the effect of different management techniques, such as conservation tillage, multiple fertilizer applications, and irrigation, on erosion. The model is composed of many submodels such as tillage, soil temperature, surface residue, chemical equilibria, and root growth, as well as others, which are linked together to produce the total mathematical model. To show the effectiveness and accuracy of the model it was tested on a Dubuque silt loam which had 0.30 m of erosion. Shaffer (1985) found that irrigation, in addition to conservation tillage and multiple fertilizer applications, was needed to improve productivity of this soil.

2.6. Role of Models in Soil Conservation Programs

Models such as those described above will play an important role in the development of conservation programs. They will be useful in identifying land areas that should be taken out of production or are in danger of large decreases in production if current management does not change. They will provide a means whereby existing or proposed management systems can be evaluated. They will also be useful in deciding whether certain areas of land should be brought into production. Models such as these will also be able to provide a faster and more economical means for evaluating proposed or existing management systems. Shaffer (1985) felt that models must be able to account for climatic variability over short periods of time, account for differences in soil profiles, and account for different management techniques if the model is to be of any use. The final decision of whether a certain management technique should be used will be based on whether the benefits outway the costs of adopting the changes (Shaffer, 1985).

As the population of the world continues to increase the demand for food continues to rise. As a result, more pressure will be placed on agriculture producers to increase their crop production. This will involve more land being brought into production and more intensive farming on land already in production. These trends, if not properly managed, will add to the problem of soil erosion that already exists. Producers will have to be shown the costs and benefits of preventing soil erosion in both the short term and in the long term. Lovejoy and Napier (1986) felt that developing conservation practices in isolation would not help to overcome the soil erosion problem. Instead they felt that policies, such as incentive programs, must be developed so that erosion control programs are actually adopted by the producers. Perhaps increasing people's awareness about the extent of erosion in the world will help to preserve our soil for the future.

3. MATERIALS AND METHODS

Six field sites were developed in Manitoba on a Pembina clay loam, Ryerson fine sandy loam, Reinland loamy very fine sand, Newdale clay loam, Willowcrest fine sand, and a Waskada very fine sandy clay loam.

3.1. Field Experiment, 1985

Three field locations were used during the 1985 growing season. The three sites included a Pembina clay loam, a Reinland loamy very fine sand, and a Newdale clay loam. The Newdale clay loam and Reinland loamy very fine sand sites were developed in the spring of 1983 and the third site, Pembina clay loam, was developed in the fall of 1983. These three sites were planted to wheat in 1983 and 1984. Table 3.1 lists the site locations and descriptions of the experimental soils. For a detailed soil analysis and description of experimental sites see Ives (1985).

All sites were developed on a completely randomized split plot design. The three sites were 0.33 ha in total area with plot dimensions of 9.6 m square with pathways of 6 m both within and among replicates. All artificial erosion was done using a standard road maintainer hired from the local municipality. Topsoil removal consisted of 0 (control), 5, 10, and 20 cm. Each topsoil removal treatment was split into three subplots and treated with varying rates of fertilizer. Fertilizer treatments consisted of (A) no fertilizer-control, (B) recommended rate of fertilizer based on fall soil sampling, and (C) approximately twice the recommended rate of fertilizer.

Table 3.1. Description of experimental sites used in 1985.

Site Name & Legal Description	Soil name & Surface Texture	Classification/Description
Minnedosa NW 28-13-17W	Newdale CL	Orthic Black member of the smooth phase Newdale Association. Soil developed on medium textured, moderately calcareous boulder till of mixed materials. (Ehrlich et al., 1957)
Gladstone NE 35-14-12W	Reinland LVFS	Gleyed Rego Black member of the Almasippi Association. Carbonated soil which developed on moderately coarse textured deltaic, alluvial, and lacustrine deposits. (Ehrlich et al., 1957)
Altamont SW 11-5-8W	Pembina CL	Grey-Black member of the Pembina Association (degrading black associate) which developed on boulder till. (Ellis and Shafer, 1943)

The C rate of fertilizer was chosen so that fertilizer nutrients would not be limiting to crop growth. Each topsoil removal treatment was replicated four times to give a total of 48 observations from each site.

All fertilizer recommendations were based on fall soil tests. Soil samples were collected in the fall of each year from the middle two replicates to a depth of 90 cm. The samples were air dried, bulked according to treatment, and then analyzed for the required nutrient content (Appendix 1). Analyses showed only small variations in nutrient levels among the various topsoil removal and fertilizer treatments. On this basis, an average soil test value for each nutrient was used in establishing the fertilizer recommendations.

In the spring, each site was disced once, using a three-point hitch tandem disc, and then sprayed with 'Treflan EC' at 2.0 l ha^{-1} for grassy and broadleaf weed control. The sites were then disced again to incorporate the 'Treflan'. Fertilizer was then added to each subplot with all nitrogen, sulfur, and potassium hand broadcasted before seeding. The sites were then disced one more time at right angles to the previous pass to thoroughly incorporate the fertilizer and the herbicide. The sites were then seeded using a three point hitch plot size seeder (144 cm in width with 18 cm row spacings) to Westar canola (Brassica napus var. Westar). Seeding rate was approximately 8 kg ha^{-1}. All required phosphorus was added with the seed at the B rate, and at the C rate, half the phosphorus was seed placed and the other half was drilled in below the seed. Table 3.2 shows the seeding dates and rates of fertilizer used at the experimental sites. Sources of the fertilizer elements used were 11-55-0, 34-0-0, and 0-0-0-16.

Table 3.2. Seeding dates and fertilizer rates† (kg/ha) used on experimental sites, 1985.

Site	Seeding Date	Fertilizer Rate	Fertilizer elements			
			N	P_2O_5	K_2O	S
Pembina CL	May 9	B	100	20	0	20
		C	150	40	0	40
Reinland LVFS	May 14	B	50	20	0	0
		C	100	40	0	0
Newdale CL	May 10	B	100	20	0	0
		C	150	40	0	0

†No fertilizer added at the A rate.

Throughout the growing season many growth parameters were monitored. All sites were monitored for weed growth and, depending on the spectrum of weeds present, appropriate post emergence herbicides were sprayed. 'Poast' herbicide was sprayed at the Reinland LVFS and the Newdale CL sites at a rate of 1.1 l ha^{-1} for control of grassy weeds. Crop emergence was tabulated each week and rainfall was recorded with recording rain gauges. Where rainfall data was not complete, due to equipment malfunction, the necessary information was obtained from Atmospheric Environment stations closest to the plots.

A harvest consisting of ten random plant samples (entire plant at flowering) from all subplots was conducted near midseason, approximately July 11. These samples were then analyzed for nutrient content (N,P,K,S). Final harvest consisted of representative square meter samples from each subplot. The plant samples were air dried and seed yield determined. Seed samples were analyzed for protein and oil content and the straw samples were analyzed for nutrient content.

3.2. Field Experiment, 1986

The same three sites used in 1985 were used again in 1986. Three new sites were added. After the various results had been analyzed from the 1985 season it was found that there were large differences between replicates. To overcome this it was felt that the size of the new sites should be increased to help reduce some of the error. The three newer sites were increased in total area to 0.71 ha with plot dimensions of 16.8 m square with 5.6 m pathways both within and among replicates. The three new sites were: a Ryerson fine sandy loam, developed in the spring of 1986, a Willowcrest fine sand, developed in the fall of 1985, and a Waskada very fine sandy clay loam, developed in the spring of 1986. The Ryerson fine sandy loam, the Willowcrest fine sand, and the Waskada very fine sandy clay loam soils had average Ah thicknesses of 23 cm, 27 cm, and 23 cm, respectively. Locations of the new sites and soil description are listed in Table 3.3.

Table 3.3. Description of new experimental sites used in 1986.

Site Name & Legal Description	Soil name & Surface Texture	Classification/Description
St. Claude NC 22-8-7W	Willowcrest FS	Gleyed Black member of the Almasippi Association which developed on weak to moderate calcareous, imperfectly drained sandy lacustrine deposits. (St. Jacques, 1984)
Boissevain SC 5-3-20W	Ryerson FSL	Orthic Black member of the Ryerson Association. Well drained soil underlain by deep, strongly calcareous, medium to moderately fine textured glacial till. (Eilers et al., 1978)
Waskada SH 12-2-25W	Waskada VFSCL	Orthic Black member of the Waskada Association. Developed on thin, medium textured, strongly calcareous aeolian and lacustrine deposits which overly strongly calcareous glacial till. (Eilers et al., 1978)

The Ryerson FSL and Waskada VFSCL sites were soil sampled in the spring of 1986 to 60 cm prior to removal of the topsoil, while the Willowcrest FS site was soil sampled in the fall of 1986, on the no topsoil removed treatment. Results of the analyses (Table 3.4) were used to determine the initial fertilizer recommendations. The same procedure used in 1985 to determine the fertilizer recommendations was used in 1986.

Table 3.4. Soil analyses of new experimental sites before site preparation.

Analysis	Depth (cm)	Sites: Ryerson FSL	Willowcrest FS	Waskada VFSCL
Organic Matter (%)	0-15	3.1	3.1	4.0
	15-30	2.2	1.4	2.3
	30-60	0.8	0.6	1.0
Carbonate Content	0-15	Very Low	Absent	Very Low
	15-30	Very Low	Absent	Very Low
	30-60	Low	Low	Medium
pH	0-15	7.8	7.5	7.6
	15-30	7.9	7.6	7.8
	30-60	7.9	7.9	7.9
Conductivity ($mS\ cm^{-1}$)	0-15	0.3	0.2	0.3
	15-30	0.2	0.2	0.3
	30-60	0.8	0.2	0.4
NO_3^--N† ($kg\ ha^{-1}$)	0-15	4.3	4.8	6.8
	15-30	5.6	7.6	6.7
	30-60	17.4	13.5	24.6
Avail. Phosphorus† ($kg\ ha^{-1}$)	0-15	6.1	3.8	60.5
	15-30	4.6	2.0	20.7
	30-60	6.2	2.6	19.4
Avail. Potassium‡ ($kg\ ha^{-1}$)	0-15	305.0	159.0	780.0
	15-30	262.0	167.0	689.0
	30-60	551.0	1543.0	980.0
Avail. SO_4^{2-}-S§ ($kg\ ha^{-1}$)	0-15	23.0	3.3	21.3
	15-30	26.0	5.0	23.2
	30-60	59.0	9.0	57.9

†Sodium bicarbonate extractable
‡Ammonium acetate exchangeable
§Water soluble

The original three sites were also soil sampled in the fall of 1985 to 60 cm. The samples were air dried and tested for the various nutrient contents. Results of the analysis (Appendix 2) where used to determine the 1986 fertilizer recommendations for these sites.

The same plot preparation procedures were used in 1986 as were used in 1985 with a few modifications. Since this was the second year that canola was to be grown on the sites, it was anticipated that disease and insect problems might develop. To help alleviate this problem the Westar canola was treated with Counter 5G for flea beetle control, and Vitavax for protection against seed and seedling rots/blights and blackleg. The seeding rate was doubled to 16 kg ha^{-1} to account for the Counter 5G in the mixture. Sources of the fertilizer nutrients used in 1986 included 11-51-0, 34-0-0, 0-0-60, and 21-0-0-24. Table 3.5 shows seeding dates and fertilizer rates used in 1986.

Weed control consisted of applications of 'Poast' herbicide to the Ryerson FSL, Reinland LVFS, and Newdale CL sites at 0.81 l ha^{-1} and to the Willowcrest FS site at 1.6 l ha^{-1} for control of green foxtail (Setaria viridis) and volunteer barley (Hordeum vulgare). The Waskada site had been planted to sunflowers the previous year and since there is no chemical control for volunteer sunflowers (Helianthus spp.) in canola, the site was hand rouged throughout the season. 'Round-Up' herbicide was sprayed with a hand held sprayer for spot control of quack grass (Agropyron repens) and Canada thistle (Cirsium arvense) at the Pembina CL and Newdale CL sites. 'Lontrel' herbicide was sprayed at the Reinland LVFS site in a tank-mix with 'Poast' at 1.0-1.5 l ha^{-1}

for control of Canada thistle and sow thistle (<u>Sonchus</u> <u>spp.</u>). 'Lontrel' was also sprayed at the Newdale CL site for control of Canada thistle and sow thistle.

Table 3.5. Seeding dates and fertilizer rates† (kg/ha) used on experimental sites, 1986.

Site	Seeding Date	Fertilizer Rate	Fertilizer elements			
			N	P_2O_5	K_2O	S
Pembina CL	May 22	B	100	0	0	20
		C	200	20	0	40
Ryerson FSL	May 21	B	100	20	0	0
		C	200	40	0	0
Reinland LVFS	May 23	B	100	20	0	0
		C	200	40	0	0
Newdale CL	May 26	B	100	20	0	0
		C	200	40	0	0
Willowcrest FS	May 13	B	100	20	35	20
		C	200	40	70	40
Waskada VFSCL	May 20	B	100	0	0	0
		C	200	20	0	0

†No fertilizer added at the A rate.

Soil moisture was monitored weekly at all six sites using a Troxler neutron meter[1]. Four aluminum access tubes were installed in the four middle plots at each site. However, failure to get enough good soil moisture data for calibration of the neutron meter resulted in the data not being used.

[1]Supplier: M & L Testing Equipment Co., 31 Dundas St. East, Hamilton, Ontario, L9J 1B1.

3.3. Soil Analyses

3.3.1. Physical Analyses

1. Bulk densities were determined in the field for each new experimental site. The process involved augering 4 holes to approximately 120 cm each. Samples were taken in approximately 15 cm layers (exact thickness measured) and the soil from each depth was weighed. A representative sample from each depth was selected, oven dried at 110^{o}C, and gravimetric water content determined. This allowed the calculation of amount of dry soil in each layer. Using the measured diameter and height of each hole, the volume was determined and the bulk density was calculated by dividing dry weight by the volume of each layer (Appendix 3).

2. Field capacity (FC) was determined in the field for each experimental site. The procedure involved flooding an area approximately 1.5 m x 1.5 m with enough water to completely saturate the soil to 120 cm. The area was then covered with plastic, to prevent evaporative losses, and left to 'equilibrate'. The 'equilibration time' varied from 2 days for the coarse textured soils to 4 days for the fine textured soils. From the middle of the flooded area, 4 replicates of soil samples in 15 cm layers to 120 cm were taken, and the gravimetric water content determined. Gravimetric water content at field capacity was multiplied by bulk density to determine water content at field capacity on a volume basis (Appendix 3).

3. Permanent wilting percentage (PWP) was determined in the laboratory using a pressure membrane apparatus. A pressure of approximately 1.6×10^6 Pa was applied until equilibrium was established. The samples were then weighed and gravimetric water content at fifteen bars determined. The following formula was used to estimate the permanent wilting percent:

$$PWP = 0.0207 + 0.77468(FAP) \quad \text{(Shaykewich, 1965)}$$

where FAP = gravimetric water content at 1.6×10^6 Pa (15 atmospheres) suction. Gravimetric PWP was multiplied by bulk density to determine water content at PWP on a volume basis (Appendix 3).

4. Available moisture was determined by subtracting the permanent wilting percent from the field capacity of each soil. The difference was then multiplied by the depth of each layer and then summed to determine the available water (mm) to 120 cm (Appendix 3).

5. Particle size analysis (pipette method as described by Kilmer and Alexander (1949)) was conducted at all new sites to 120 cm. The amount of each separate as a percentage of the total weight of mineral fraction was calculated. The sand fraction for each depth was sieved to determine the size distribution of the sand. Soil texture was then determined using a textural triangle (Appendix 4).

3.3.2. Chemical Analyses

1. The pH of the soils was determined on the slurry of a 1:1 mixture of soil and water. The conductivity was determined on the same slurry.

2. Nitrate-nitrogen was determined on a Technicon Auto Analyzer system using a modification of the automated colorimetric procedure of Kamphake et al. (1967).

3. Available phosphorus was extracted using sodium bicarbonate as described by Olsen et al. (1954). Concentration of phosphorus in solution was determined using ascorbic acid as a reductant for the phosphomolybdate complex. The development of a molybdophosphoric blue color due to reduction was measured at 815 nm (Murphy and Riley, 1962).

4. Exchangeable potassium was determined using flame photometry. Twenty five ml of 1N NH_4OAc plus 2.5 g of soil were shaken for 30 min, filtered, and a portion of filtrate was analyzed for K concentration. Lithium in the form of lithium nitrate, was used as the internal standard.

5. Sulphate-sulphur was determined using a dilute 0.001M $CaCl_2$ solution to extract the SO_4. The concentration in the extract was then determined colorimetrically using an Auto Analyzer II system (Lazrus et al., 1966).

6. Organic matter content was determined using the 1934 Walkley-Black procedure in which organic matter is oxidized by chromic acid and excess $K_2Cr_2O_7$ is back titrated with $FeSO_4$.

3.4.1. Plant Analyses

1. Total nitrogen was determined using a modified procedure by Jackson (1958). Distillation and titration were performed using a Tecator Kjeltec Auto 1030 Analyzer.

A standard stock solution was prepared by weighing 0.5 grams of plant material into digestion tubes. 2.5 ml of HNO_3 and 1.25 ml of $HClO_4$ were added to the samples. The tubes were then covered and the samples were then allowed to predigest for one hour. The samples were then digested for 1.5 hours at 220°C on a Tecator digestion block. After completion of digestion the tubes were removed and allowed to cool. All of the solution in the tubes was vortexed and then completely rinsed, using deionized water, into individual 25 ml volumetric flasks to give a dilution factor of 50. After shaking vigorously, a portion of the solution in the volumetric flasks was transferred to disposable borosillicate culture tubes. This was the stock solution from which all other tissue analysis (P,K,S) was determined.

2. Phosphorus concentration of the solution was determined by a modified procedure by Murphy and Riley (1962). The PO_4^- ion was

complexed with molybdenum, producing a blue color. Absorbance was read on a Bausch and Lomb spectrophotometer at 885 nm.

3. Potassium concentration was determined by atomic absorption on a Perkin-Elmer absorption spectrophotometer using $LiNO_3$ as an internal standard. Digestion of the plant samples was carried out according to the procedure of Chapman and Pratt (1961).

4. Sulfur concentration of diluted stock solution was determined colorimetrically by reading the SO_4^{2-}-S concentrations on a Technicon Auto Analyzer using the procedure of Lazrus et al. (1966).

3.5.1. Seed Analyses

1. Twenty grams of seed sample was tempered to 6-8% moisture and ground for 15 seconds using a Moulinex coffee grinder (impeller type). The oil and protein content were determined in an Instalab 800 NIR Product Analyzer (Williams, 1975).

4. RESULTS AND DISCUSSION

4.1. 1985 Results

4.1.1. Growing Season Precipitation

Total growing season precipitation was close to or above the long term average for all three sites (Appendix 5). Both the Reinland LVFS and Newdale CL sites had below average rainfall for the month of June, while the Pembina CL site had above average amounts. Precipitation in the month of July was well below the long term averages for all three sites. Heavy rainfall in early August before harvest increased the total precipitation for the growing season to long term average values. Thus, because of an uneven distribution of rainfall, yield may have been limited by moisture stress during July.

4.1.2. Crop Emergence

Topsoil removal did not appear to have any effect on canola emergence (Table 4.1). Topsoil removal did not significantly reduce canola emergence at any of the experimental sites and therefore did not adversely affect crop stand.

4.1.3. Midseason Tissue Analysis

Analysis of the canola tissue at midseason (entire plant at flowering) indicated that phosphorus concentrations in the plant were sufficient[1] to high at all sites with no significant differences

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[1]Adequacy of canola nutrients based on criteria established by the Manitoba Provincial Soil Testing Laboratory (Appendix 6).

existing between treatments (Appendix 7).

Table 4.1. Canola emergence counts (plants m^{-1}), 1985.

Site	Topsoil Removal (cm)	Date					
		May 24	May 31	June 6	June 13	June 20	June 27
Pembina CL	0	85†	107	103	96	100	-
	5	78	83	83	75	82	-
	10	93	116	113	103	108	-
	20	90	110	113	101	102	-
Reinland LVFS	0	45	56	83	48	56	49
	5	52	53	60	44	62	49
	10	52	64	77	58	55	45
	20	46	58	73	69	67	60
Newdale CL	0	104	111	112	109	106	-
	5	86	88	88	83	86	-
	10	89	96	96	94	93	-
	20	80	97	96	92	93	-

†Within site-date, unless otherwise noted, means followed by the same letter are not significantly different at Tukey's 0.05 level.

At the Pembina CL site, the nitrogen content of the tissue samples was low for all levels of topsoil removal where the A and the B rate of fertilizer had been added (Appendix 7). Twice the recommended rate of fertilizer (C rate) for all levels of topsoil removal had marginal concentrations of nitrogen. However, there were few significant differences among the treatments. Potassium concentrations in the tissue samples were marginal where 5, 10, and 20 cm of topsoil had been removed and no fertilizer had been added. The remaining treatments were sufficient in potassium. However, there were no significant differences among the treatments (Appendix 7). Sulfur concentrations were sufficient to high for most treatments with only the 10 cm topsoil removal, B rate of fertilizer treatment having low concentrations. Sulfur concentrations were highest where no fertilizer was added and decreased as increasing rates of fertilizer were added. Few significant differences existed (Appendix 7).

For the Newdale CL site, concentrations of nitrogen were marginal where 5, 10, and 20 cm of topsoil had been removed and no fertilizer had been added (Appendix 7). Ten centimeters of topsoil removal and the recommended rate of fertilizer treatment also resulted in marginal nitrogen concentrations. The remaining treatments were sufficient in nitrogen. There were no statistically significant differences among the treatments. Potassium concentrations were sufficient to high with no significant differences existing among the treatments (Appendix 7). Sulfur concentrations were sufficient to very high for all treatments (Appendix 7).

For the Reinland LVFS site, only the 5 cm topsoil removal, no fertilizer treatment and the 10 cm topsoil removal, recommended rate of fertilizer treatment were marginal in nitrogen (Appendix 7). The remaining treatments were sufficient with few significant differences existing among the treatments. Potassium concentrations were very high where no topsoil was removed and twice the rate of fertilizer was added (Appendix 7). The remaining treatments were sufficient to high in potassium with no significant differences existing between the treatments. All sulfur concentrations were high to very high with no significant differences existing among the treatments (Appendix 7).

4.1.4. Final Harvest

4.1.4.1. Seed Yield

In general, canola yields decreased as the level of topsoil removal increased when no fertilizer was added (Table 4.2). For the Pembina CL site, where no topsoil was removed and no fertilizer was added, yields were over 3.5 times higher than where 20 cm of topsoil had been removed and no fertilizer was added. Similarly, without fertilizer at the Reinland LVFS and the Newdale CL sites, yields were 2.1 times higher where no topsoil had been removed than where 20 cm of topsoil had been removed.

In most cases for the fine textured soils, the addition of fertilizer was able to overcome the yield loss associated with the removal of topsoil. Generally, addition of fertilizer at the recommended rate increased the yield of canola over that of the control. Applications of twice the recommended rate of fertilizer did not significantly increase yields over those obtained with the recommended rate of fertilizer. Table 4.3 shows the relative yields of canola as a percent of the control for the various sites. The table indicates that for the Pembina CL site, canola yields were reduced to 27.6% of the control where 20 cm of topsoil was removed and no fertilizer was added. For the Reinland LVFS and for the Newdale CL sites, yields were reduced to 47.8% of the control where 20 cm of topsoil was removed and no fertilizer was added. Canola at both the Pembina CL and the Newdale CL sites responded to the application of fertilizer. Yields were always higher than the control when either the B or the C rates of fertilizer were added. Canola yields at the

Reinland LVFS site were still lower than the control where 20 cm of topsoil had been removed and the B and C rates of fertilizer had been added. Figure 4.1, using the Pembina CL site as an example, shows the overall trends that occurred as topsoil was removed and fertilizer was added.

Table 4.2. Effect of topsoil removal on canola yields (kg ha^{-1}), 1985.

Site	Fertilizer	Topsoil Removal (cm)			
		0	5	10	20
Pembina CL	A	1315.0cd†	740.0de	720.0de	362.5e
	B	2047.5abc	2605.0ab	1932.5bc	1992.5abc
	C	2430.0ab	2177.5ab	2222.5ab	2805.0a
Reinland LVFS	A	1485.0ab	1427.5ab	1380.0ab	710.0b
	B	1757.5ab	1935.0ab	1752.5ab	1450.0ab
	C	2680.0a	1947.5ab	2020.0ab	1362.5ab
Newdale CL	A	1652.5abc	972.5cb	1592.5abc	790.0c
	B	1942.5abc	2105.0abc	2000.0abc	2270.0abc
	C	2392.5ab	2062.5abc	2770.0a	2570.0a

†Within site, means followed by the same letter are not significantly different at Tukey's 0.05 level.

The canola yields were close to or slightly below the average yield of canola reported for the various crop zones in Manitoba. The average yield of Westar canola for the Minnedosa area was 2114 kg ha^{-1} (Field Crop Variety Recommendations for Manitoba, 1986). The average Westar canola yield for the Altamont and Gladstone areas was reported as 2021 kg ha^{-1} (Field Crop Variety Recommendations for Manitoba, 1986).

Table 4.3. Relative canola yield, 1985 (% of control).

Site	Fertilizer	Topsoil Removal (cm)			
		0	5	10	20
Pembina CL	A	100.0	56.3	54.8	27.6
	B	155.7	198.1	147.0	151.5
	C	184.8	165.6	169.0	213.3
Reinland LVFS	A	100.0	96.1	92.9	47.8
	B	118.4	130.3	118.0	97.6
	C	180.5	131.1	136.0	91.8
Newdale CL	A	100.0	58.9	96.4	47.8
	B	117.5	127.4	121.0	137.4
	C	144.8	124.8	167.6	155.5

4.1.4.2. Seed Protein and Oil

Analysis of the seed for protein concentration indicated that, in general, the protein concentration of the seed was usually lowest where no fertilizer was added and 20 cm of topsoil was removed, although few significant differences existed (Appendix 8). Conversely, there was a small trend towards higher oil concentration where no fertilizer was added and 20 cm of topsoil was removed (Appendix 8). Few significant differences were found among the treatments. In general, as fertilizer was added the oil concentration decreased in the seed and the protein concentration increased.

4.1.4.3. Straw Yield

For Pembina CL site, straw yield on all topsoil removal treatments that did not receive fertilizer was significantly different from those that did receive fertilizer (Appendix 9). Within fertilizer treatment,

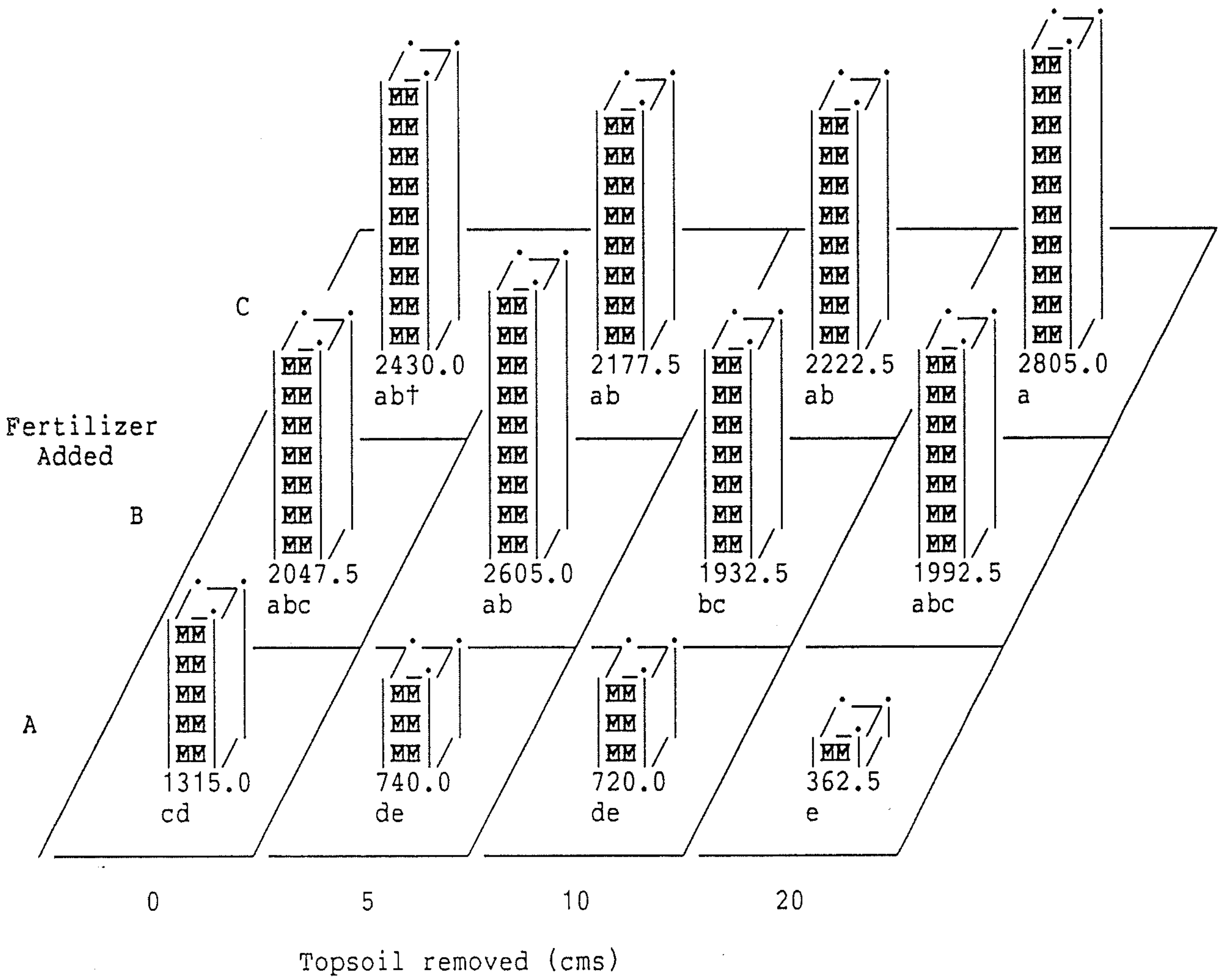

Figure 4.1. Canola yields (kg/ha) for each level of topsoil removal and fertilizer treatment, on Pembina CL soil in 1985.

†Means followed by the same letter are not significantly different at Tukey's 0.05 level.

no significant differences were found. There existed a trend towards lower straw yields as the amount of topsoil removed increased and fertilizer rate decreased.

For the Reinland LVFS and Newdale CL sites, few significant differences existed among the treatments (Appendix 9). Straw yields were lower where topsoil was removed and no fertilizer was added than where fertilizer was added. Once fertilizer was added, straw yields on the eroded and noneroded soils were similar.

4.1.4.4. Straw Nutrient Concentration

Nitrogen concentrations in the straw generally decreased as the amount of topsoil removal increased within the no fertilizer added treatment (Appendix 10). The concentration of nitrogen in the straw usually increased as fertilizer rate increased. The same effect occurred for phosphorus, potassium, and sulfur. Usually the C rate of fertilizer had higher concentrations of nutrients in the straw than the A or B rate, with the B rate being higher than the A rate. Quite often the 20 cm topsoil removal treatment had the lowest concentrations of nutrients within a given fertilizer treatment. For some nutrients and in some instances, for the 20 cm topsoil removal treatment, the recommended rate of fertilizer did not increase the concentration of nutrients above that of the control.

4.2. 1986 Results

4.2.1. Growing Season Precipitation

Total growing season precipitation was close to the long-term average for the Ryerson FSL and the Reinland LVFS sites (Appendix 5). The Pembina CL site had below average precipitation levels for the growing season. The other three sites had precipitation above the long term average for their respective areas. However, precipitation was variable throughout the growing season. As Appendix 5 indicates, precipitation after seeding for all six sites was very low. The Ryerson FSL, the Reinland LVFS, and the Waskada VFSCL all had below average rainfall for the month of June. All six sites experienced well above average amounts of precipitation for the month of July and below average precipitation levels for the month of August.

4.2.2. Crop Emergence

As in 1985, topsoil removal did not appear to have any affect on canola emergence (Table 4.4). With only a few exceptions, topsoil removal did not significantly reduce canola emergence at any of the experimental sites and therefore did not appear to have any effect on the final crop stand.

4.2.3. Midseason Tissue Analysis

Midseason tissue analysis in 1986 indicated that, in general, nitrogen concentrations were sufficient with a few sites showing low to marginal concentrations (Appendix 11). Low to marginal concentrations of nitrogen occurred at the Pembina CL site where 0, 5, 10, and 20 cm of topsoil had been removed and no fertilizer had been added. The 20 cm topsoil removal, recommended rate of fertilizer treatment was also marginal in nitrogen at this site. For the Reinland LVFS site,

Table 4.4. Canola emergence counts (plants m^{-1}), 1986.

Site	Topsoil Removal (cm)	Date					
		May 22	June 2	June 9	June 19	June 25	July 2
Pembina CL	0	-	-	20†	29	-	-
	5	-	-	18	31	-	-
	10	-	-	26	33	-	-
	20	-	-	27	31	-	-
Ryerson FSL	0	-	28	29	35	39	-
	5	-	13	12	17	32	-
	10	-	17	23	27	43	-
	20	-	13	15	22	34	-
Reinland LVFS	0	-	23	28	27	25	23
	5	-	8	18	19	18	9
	10	-	24	32	32	28	26
	20	-	26	32	28	25	24
Newdale CL	0	-	-	-	-	56	40
	5	-	-	-	-	40	41
	10	-	-	-	-	68	66
	20	-	-	-	-	54	43
Willowcrest FS	0	26	35	35	33	34	-
	5	18	8	7	11	13	-
	10	29	19	19	33	35	-
	20	35	18	18	30	31	-
Waskada VFSCL	0	-	20a	43	44	37b	-
	5	-	10ab	29	39	37b	-
	10	-	6ab	32	48	44ab	-
	20	-	0b	44	56	60a	-

†Within site-date, unless otherwise noted, means followed by the same letter are not significantly different at Tukey's 0.05 level.

marginal to low concentrations of nitrogen occurred on all but the 0 cm topsoil removal, B rate of fertilizer treatment and the 5 and 10 cm topsoil removal, twice the recommended rate of fertilizer treatments. For the Willowcrest FS site, nitrogen concentrations were marginal where 0, 5, 10, and 20 cm of topsoil had been removed and no fertilizer had been added. Nitrogen concentrations in the tissue for the no topsoil removal, twice the recommended rate of fertilizer treatment were also marginal while canola grown on the no topsoil removal, recommended rate of fertilizer treatment was low in nitrogen. Canola grown on the rest of the sites were usually sufficient in nitrogen. However, for all sites, no significant differences existed among the treatments.

Phosphorus concentrations were sufficient to high with few significant differences among the treatments (Appendix 11). Potassium concentrations in the canola tissue were sufficient to high with few to no significant differences existing among the treatments (Appendix 11). Sulfur concentrations were usually sufficient to high with some treatments showing very high concentrations of sulfur. For each site, no significant differences existed among treatments for sulfur concentrations in the canola tissue (Appendix 11).

Trends in the nutrient concentrations of the tissue with increases in fertilizer rate were small. Nitrogen, potassium, and sulfur exhibited no trends at all while phosphorus concentrations were usually lowest where no fertilizer was added. The B rate of fertilizer usually increased the concentration of phosphorus in the tissue, while the C rate usually increased the concentration even further. All concentrations of phosphorus were sufficient in the canola tissue and few to no significant differences existed among the treatments. Within each fertilizer treatment, removal of topsoil did not appear to have any affect on the concentration of phosphorus in the canola tissue.

4.2.4. Final Harvest

4.2.4.1. Seed Yield

In general, canola yields were reduced where topsoil was removed and no fertilizer was added (Table 4.5). There was a trend towards lower yields as the level of topsoil removed increased and no fertilizer was added. In most cases for the fine textured soils, application of the recommended rate of fertilizer overcame any yield loss associated with the loss of topsoil. Application of twice the recommended rate of fertilizer did not significantly increase yields over those obtained with the recommended rate of fertilizer. Even at twice the recommended rate of fertilizer, yields on the 20 cm topsoil removal treatment were usually lower than those on the no topsoil removal, twice the recommended rate of fertilizer treatment. However, few significant differences were found.

Table 4.6 shows the relative yield of canola as a percentage of the control for each site for 1986. It indicates that in some cases, canola yields were reduced to 32.7% of the control. With a few exceptions, application of fertilizer increased canola yields above that of the control.

Table 4.5. Effect of topsoil removal on canola yields (kg/ha), 1986.

Site	Fertilizer	Topsoil Removal(cm)			
		0	5	10	20
Pembina CL	A	855.0bcd†	680.0bcd	527.5cd	280.0d
	B	1700.0ab	2290.0a	1312.5abcd	1480.0abc
	C	1682.5ab	1792.5ab	2252.5a	1542.5abc
Ryerson FSL	A	2090.0abcd	1660.0bcd	1402.5cd	1132.5d
	B	3047.5abc	3267.5ab	3902.5a	2637.5abcd
	C	3077.5abc	3045.0abc	3725.0a	3310.0ab
Reinland LVFS	A	1287.5abc	1187.5abc	765.0bc	645.0c
	B	1817.5abc	1762.5abc	1667.5abc	1272.5abc
	C	2047.5ab	2227.5a	1815.0abc	1582.5abc
Newdale CL	A	1382.5abc	685.0bc	397.5c	687.5bc
	B	1867.5ab	2172.5a	1277.5abc	1507.5abc
	C	2142.5a	1877.5ab	2325.0a	1775.0ab
Willowcrest FS	A	2427.5abc	1010.0c	1355.0bc	1025.0c
	B	2587.5ab	2122.5abc	2605.0ab	1607.5bc
	C	3417.5a	2577.5ab	2482.5abc	2322.5abc
Waskada VFSCL	A	2177.5abc	1835.0abc	1277.5bc	1085.0c
	B	2587.5ab	2220.0abc	2145.0abc	1340.0abc
	C	2735.0a	1807.5abc	2082.5abc	1980.0abc

†Within site, means followed by the same letter are not significantly different at Tukey's .05 level.

At both the Waskada VFSCL and the Willowcrest FS sites, yields on the 20 cm topsoil removal, recommended rate of fertilizer treatment were lower than the no topsoil removal, no fertilizer added treatment. Even twice the recommended rate of fertilizer did not increase yields above the control, although there were no statistically significant differences between the control and these treatments. At the Waskada site, yields were not restored where 10 cm of topsoil had been removed and the recommended rate of fertilizer applied. As with 20 cm of topsoil removed, twice the recommended rate of fertilizer was not able to improve yield over that of the control. However, these two treatments were not significantly different from the control. At these sites, fertilizer was not able to overcome the loss of yield where 20 cm of topsoil had been removed.

Table 4.6. Relative canola yield, 1986 (% of control).

Site	Fertilizer	Topsoil Removal (cm)			
		0	5	10	20
Pembina CL	A	100.0	79.5	61.7	32.7
	B	198.8	267.8	153.5	173.1
	C	196.8	209.6	263.5	180.4
Ryerson FSL	A	100.0	79.4	67.1	54.2
	B	145.8	156.3	186.7	126.2
	C	147.2	145.7	178.2	158.4
Reinland LVFS	A	100.0	92.2	59.4	50.1
	B	141.2	136.9	129.5	98.8
	C	159.0	173.0	141.0	122.9
Newdale CL	A	100.0	49.5	28.8	49.7
	B	135.1	157.1	92.4	109.0
	C	155.0	135.8	168.2	128.4
Willowcrest FS	A	100.0	41.6	55.8	42.2
	B	106.6	87.4	107.3	62.2
	C	140.8	106.2	102.3	95.7
Waskada VFSCL	A	100.0	84.3	58.7	49.8
	B	118.8	102.0	98.5	61.5
	C	125.6	83.0	95.6	90.9

At all other sites, the canola responded to the application of fertilizer. In most cases, the recommended rate of fertilizer was able to increase yields above that of the control. Figures 4.2 and 4.3, using the Ryerson FSL and the Willowcrest FS sites as examples, shows the overall trends that occurred under the various treatments.

Canola yield at the Ryerson FSL site was above the average canola yield reported for its crop zone. The average Westar canola yield for this zone was 2474 kg ha^{-1} (Field Crop Variety Recommendations for Manitoba, 1987). Canola yields at the Waskada VFSCL site and the Willowcrest FS sites were close to the average yields of 2474 kg ha^{-1} and 2495 kg ha^{-1} reported for their crop zones respectively (Field Crop Variety Recommendations for Manitoba, 1987). However, canola yields at the Pembina CL, Newdale CL, and the Reinland LVFS sites were well below the average canola yields reported for their areas. The average Westar canola yield for the Altamont and Gladstone areas was 2495 kg ha^{-1}, while the average yield for the Minnedosa area was reported as 2457 kg ha^{-1} (Field Crop Variety Recommendations for Manitoba, 1987).

4.2.4.2. Seed Protein and Oil

Overall, protein concentration decreased as the level of topsoil removal increased and no fertilizer was added. Application of fertilizer increased the protein concentration in the canola seed but few significant differences existed among the treatments (Appendix 12). The opposite effect was seen for the oil concentration of the seed. As the level of topsoil removal increased the oil concentration usually increased when no fertilizer was added. Applications of fertilizer reduced the oil concentration of the seed and again, few significant differences existed among the treatments for the various sites (Appendix 12).

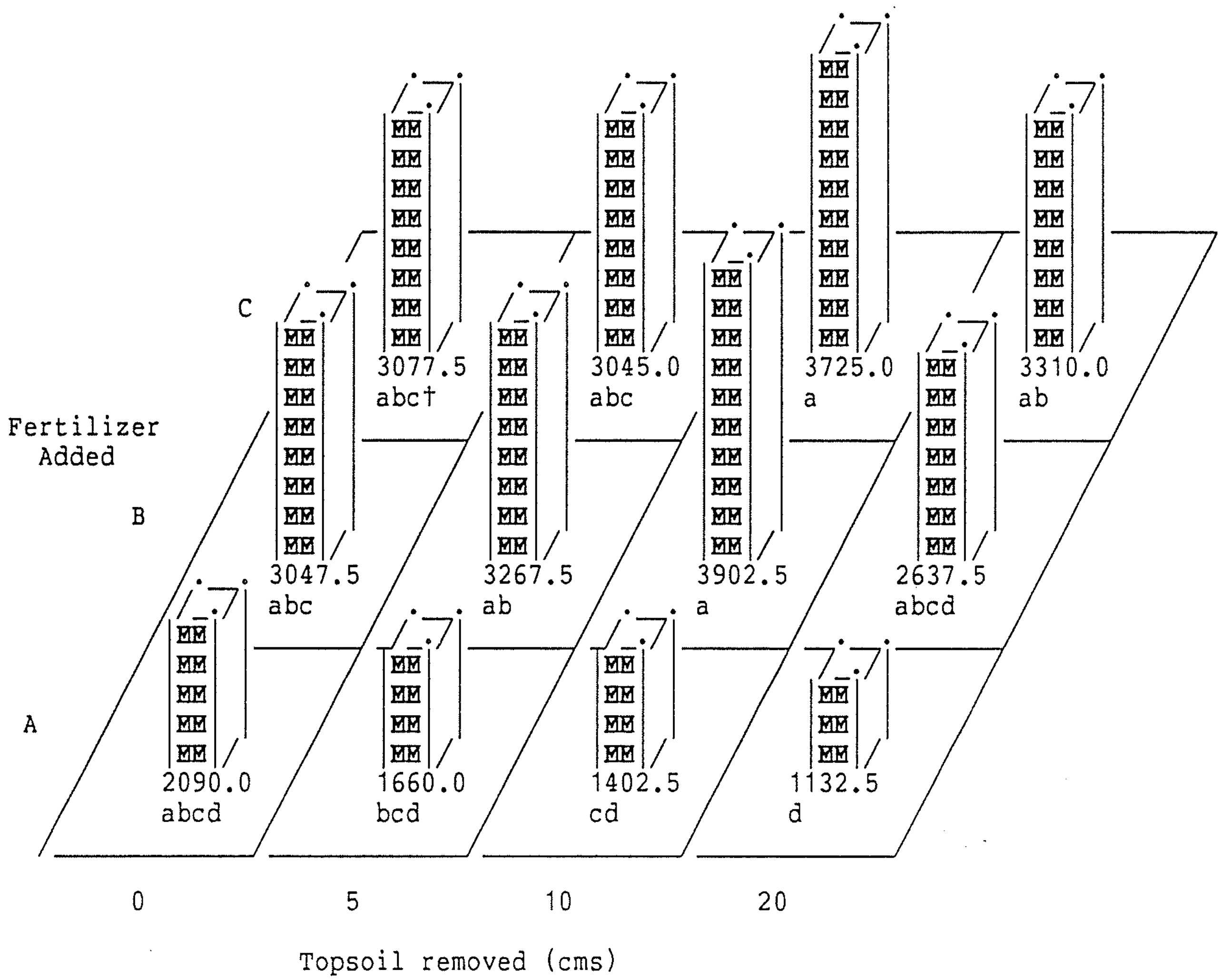

Figure 4.2. Canola yields (kg/ha) for each level of topsoil removal and fertilizer treatment, on Ryerson FSL soil in 1986.

†Means followed by the same letter are not significantly different at Tukey's 0.05 level.

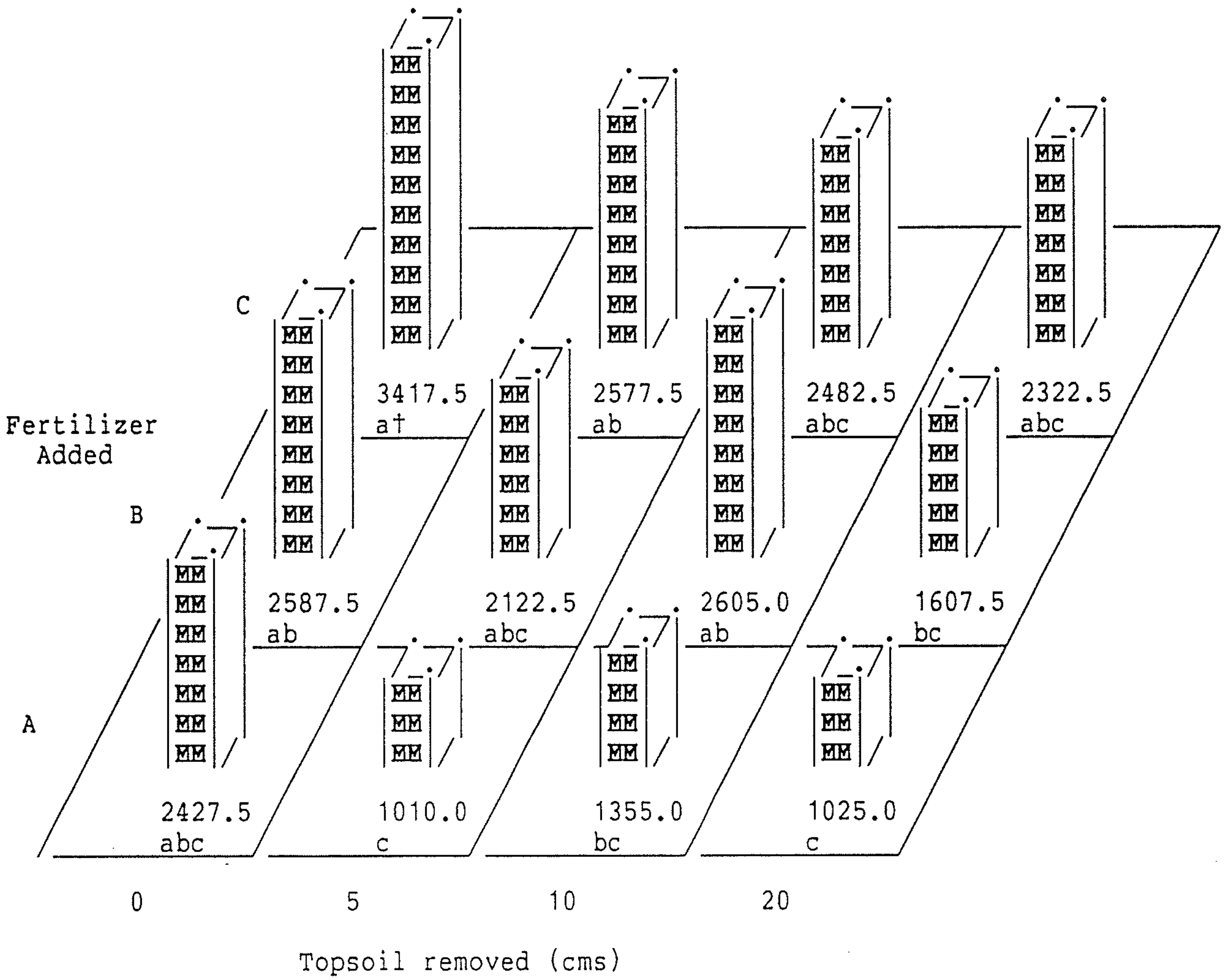

Figure 4.3. Canola yields (kg/ha) for each level of topsoil removal and fertilizer treatment, on Willowcrest FS soil in 1986.

†Means followed by the same letter are not significantly different at Tukey's 0.05 level.

4.2.4.3. Straw Yield

In general, straw yields decreased as the level of topsoil removal increased and no fertilizer was added (Appendix 13). Applications of the recommended rate of fertilizer increased straw yields over those where no fertilizer had been added. Twice the recommended rate of fertilizer did not significantly increase straw yields over the recommended rate of fertilizer. Few significant differences existed among the treatments for the various sites.

4.2.4.4. Straw Nutrient Concentration

Nitrogen concentration of the straw decreased as the level of topsoil removed increased and no fertilizer was added (Appendix 14). Application of the recommended rate of fertilizer increased the concentration of nitrogen in the straw samples while twice the recommended rate of fertilizer increased the concentration of nitrogen even further. In general, within fertilizer treatment, nitrogen concentrations decreased as the level of topsoil removed increased, although few significant differences occurred. The Reinland LVFS, the Willowcrest FS, and the Waskada VFSCL nitrogen concentrations for the 20 cm topsoil removal, recommended rate of fertilizer treatment were lower than the nitrogen concentration in the control. Twice the recommended rate of fertilizer increased the nitrogen concentrations above that of the control. At the other three sites, nitrogen concentrations were usually higher than the control for both the recommended and twice the recommended rates of fertilizer.

Phosphorus concentrations in the straw also tended to decrease as the level of topsoil removed increased and no fertilizer was added. Concentrations in the straw increased as fertilizer was added, with the C rate of fertilizer increasing the concentration more than the B rate of fertilizer. There was a small trend towards lower concentrations of phosphorus in the straw as topsoil was removed and fertilizer was added. Few significant differences were found between the treatments. Phosphorus concentrations at the Reinland LVFS, the Willowcrest FS, and the Waskada VFSCL sites were below the concentration of the control where 20 cm of topsoil had been removed and the recommended rate of fertilizer had been added. The phosphorus concentrations at the other three sites were higher than the control for this treatment. Twice the recommended rate of fertilizer usually increased the phosphorus concentrations above that of the control (Appendix 14).

Trends in potassium and sulfur concentration in the straw were similar to nitrogen and phosphorus. The concentrations of potassium and sulfur in the straw usually decreased as the level of topsoil removal increased and no fertilizer was added. Application of fertilizer increased the concentrations of potassium and sulfur in the straw with the B rate of fertilizer having slightly lower concentrations than the C rate. A slight trend towards lower concentrations of the two nutrients in the straw existed as the level of topsoil removal increased and the B or the C rates of fertilizer were added, although few significant differences existed (Appendix 14). Potassium concentrations in the straw at the Newdale Cl, Willowcrest FS, and Waskada VFSCL sites were below the control concentration of potassium for the 20 cm topsoil removal, recommended rate of fertilizer added treatment. Sulfur concentrations for the 20 cm topsoil removal, recommended rate of fertilizer treatment were also below the control concentration at the Newdale CL and Waskada VFSCL sites.

4.3. Discussion

4.3.1. Growing Season Conditions

In 1985, the sites received adequate rainfall after seeding. As a result, crop emergence was uniform. Soon after emergence of the crop distinct differences in growth stages could be recognized. The subplots that received no fertilizer had slower growth than the fertilized subplots. The canola plants on the non-fertilized subplots were approximately 2 leaf stages in development behind the fertilized subplots. The fertilized canola plants were usually thicker stemmed and exhibited more vigorous growth than the unfertilized canola plants. This effect was noticed for all subplots and for all topsoil removal treatments. As a general rule, there was no visual difference in plant growth between the recommended and twice the recommended rates of fertilizer.

Between June 6 and June 10, 1985, a wind storm caused severe damage to the canola seedlings at the Reinland LVFS site. Most of the canola plants suffered wind blast damage to the leaves. Despite the damage to the seedlings it was decided to give the canola an opportunity to recover before any reseeding decisions were made. Approximately 13 days later the crop appeared to be making a recovery. As a result, the crop was allowed to develop but there was some spotty growth of canola due to the wind damage.

Rainfall during the month of July, 1985 was well below the long term average at all three sites. By the beginning of July, the canola at all three sites had reached the flowering stage. Richards and Thurling (1978) found that seed yield of canola was reduced if a drought condition (soils had reached permanent wilting point) occurred during the reproductive stage of development. Rainfall during the months of May and June for the Pembina CL site had been above the long term average for that area. Rainfall at the Reinland LVFS and the Newdale CL sites was close to or below the long term average for May and June. As a result, soil moisture levels were adequate going into the month of July. Thomas (1984) reported that the rooting depth of canola by flowering can be as deep as 1 to 2 meters. The canola plants never appeared wilted as they were able to draw on soil moisture lower down in the profile. Therefore, it was suspected that the low rainfall in July did not significantly affect final yield. Rainfall in August, 1985 was significantly higher than the long term average for all three sites. A significant amount of rain fell in the first week of August. It is probable that this rain helped contribute to the final yield.

Canola exhibits indeterminate growth and is therefore able to compensate for a drought period if conditions after the droughty period become favorable for further growth. Canola can compensate for a period of reduced growth by reflowering and by setting new pods which can restore the final yield[2]. Rainfall in the month of August likely contributed to the final yield by increasing the weight of the canola

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[2]Scarth, R. 1987. Personal communication.

seeds as they filled. As a result, final yield was likely not affected to any great extent by the limited rainfall in July.

Rainfall during July, 1986 was significantly higher than the long term average for all six sites. Therefore, it is likely that rainfall would not have been a limiting factor to the final yield of canola in 1986.

In 1986, seedbed preparation was a problem. Rainfall occurred just before site preparation, and when disced, the sites were left with many large clods. The tillage operations that were needed to prepare the seedbed and to incorporate the fertilizer and herbicide tended to dry out the soil surface. No rain fell for approximately 2-3 weeks after seeding and as a result canola emergence was very poor and was delayed by about 2-3 weeks. This delay in rainfall likely explains the smaller canola stand in 1986 as compared to that in 1985.

The canola at the three sites used in 1985 suffered the most under these conditions. The combination of poor seedbed quality and low moisture, plus the fact that canola had been grown on these sites the year before, all combined to reduce the vigor of the canola. Delayed swathing and combining of the unharvested canola in the fall of 1985 led to shattering of the canola pods. Significant seed loss occurred resulting in considerable amounts of volunteer canola growing on these three sites in 1986. These three sites were generally disease free for most of the growing season. Late in the season these sites developed Black spot (<u>Alternaria</u> <u>brassicae</u>). The major symptom of the disease is the development of black spots on the stems and pods which results in early splitting of pods and shrinkage of seed (McDonald, 1980). Plots where the plants were infected were harvested early to help reduce seed loss from shattering. Early harvest and harvesting by hand helped to reduce any significant yield loss. The influence of these factors contributed to the lower yields found at these sites. The remaining experimental sites were generally disease free.

Weed control was adequate at all sites for both years. At all sites, application of herbicides satisfactorily controlled the growth of weeds. The Waskada VFSCL site was hand rouged for volunteer sunflowers as there existed no in crop chemical control of this weed.

4.3.2. Canola Emergence

Canola is a small seeded crop and therefore it's emergence may be impeded by soil crust formation. Soil crusts usually form when a wet soil dries rapidly. Nuttall (1982) found that crust strengths as low as 20 mb could impede the emergence of canola. Nuttall reported that soil crust strength increased as the silt content of the surface soil increased. Recent work studying the effect of soil erosion on canola emergence indicated that soil crust strength increased as the level of topsoil removal increased (Hirch, 1984). Hirch found that soil crust formation impeded the emergence of canola grown on the eroded soils.

Soil crusting did not appear to be a problem on the experimental sites. Emergence counts were taken weekly to determine if the eroded topsoil formed crusts which could impede the emergence of canola. For the experimental soils examined, canola emergence was not affected by the removal of topsoil. It was therefore assumed that, for the two years of the experiment, conditions (wet soil drying rapidly) did not develop that would lead to the formation of soil crusts.

4.3.3. Midseason Tissue Analysis

The reduction in yield that occurred on the scraped subplots where no fertilizer was added could be attributed to low nutrient content of the soil. Tissue nutrient concentration at midseason is a good predictor of final yield. It indicates the concentration of nutrients in the crop which reflects the supply of available nutrients in the soil. The supply of available nutrients will determine crop growth and will therefore have an effect on final yield (McGill, 1981). McGill reported that the concentration of some nutrients in the plant may be low even though the amount in the soil is sufficient. This can occur when the low concentration of one nutrient limits the uptake of another nutrient. A further description of the effect of topsoil removal on soil fertility and the subsequent effect on crop yield will be presented in a later section after midseason nutrient concentrations and final yields are presented.

Soil test results for the Pembina CL site in the fall of 1984 and 1985 indicated that the nitrate nitrogen amounts were low[3] to very low as the level of topsoil removal increased. Nitrogen concentrations in the tissue at midseason, 1985, were low where no fertilizer was added. Where the recommended rate of fertilizer was added, nitrogen concentrations were still low. Additions of twice the recommended rate of fertilizer resulted in marginal concentrations of nitrogen in the

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[3]Sufficiency of soil nutrients was determined from Guidelines to the Interpretation of Soil Analysis as formulated and approved for use in Manitoba by the Manitoba Soil Fertility Advisory Committee.

tissue. For 1986, nitrogen concentrations in the tissue were marginal for the no topsoil, 10 cm, and 20 cm of topsoil removal, no fertilizer added treatments. The 20 cm topsoil removal, recommended rate of fertilizer treatment was also marginal in nitrogen. The remaining treatments were sufficient in nitrogen. Phosphorus concentrations in the plant tissue were high to sufficient for all treatments, for both years. Phosphorus amounts in the soil were generally very high for this site. Potassium concentrations, midseason 1985, were found to be marginal where 5, 10, and 20 cm of topsoil were removed and no fertilizer was added even though available potassium in the soil was very high. Potassium concentrations in the tissue, midseason 1986, were sufficient. Potassium amounts in the soil were very high. Sulfur concentrations were generally sufficient to high in the plant samples for both years, even though sulfur amounts in the soil were medium to low.

At the Newdale CL site in 1985, nitrogen concentrations in the canola were marginal where 5, 10, and 20 cm of topsoil had been removed and no fertilizer had been added. Soil test results indicated that the amount of nitrogen was low. For 1986, nitrogen concentrations in the plant were generally sufficient, even though the amount of nitrate nitrogen in the soil was found to be medium to low at this site. The concentration of the other nutrients at this site were sufficient in the plant tissue. For both years, the soil test results indicated that available phosphorus was generally quite low for this site with the amount decreasing as topsoil removal increased and no fertilizer was added. This may also have led to the reduced yields where no fertilizer was added, although the plant tissue test indicated that the phosphorus concentrations in the tissue at midseason were sufficient.

For the Reinland LVFS site in 1985, most of the nutrients were sufficient with only the 5 cm topsoil removal, no fertilizer added (A) treatment and the 10 cm topsoil removal, recommended rate of fertilizer (B) treatment having marginal nitrogen concentrations in the canola tissue. Soil test results at this site indicated that, in general, most of the soil nutrients tested for were high to very high. However, nitrogen amounts were low where 10 cm of topsoil was removed and no fertilizer was added. Nitrogen amounts were also medium where 20 cm of topsoil was removed and no fertilizer was added. Available soil phosphorus in the 20 cm topsoil removal, no fertilizer added treatment was very low. This may have caused the yield reduction that occurred for this treatment. For 1986, the concentration of nitrogen in the tissue at midseason was found to be marginal to low where no fertilizer had been added and increasing amounts of topsoil had been removed. Soil test results from the fall of 1985 indicated that the amount of nitrate nitrogen in the soil was low. The concentration of the other nutrients were generally sufficient in the tissue. The soil test results indicated that the other nutrients were generally quite sufficient where no fertilizer had been added. Where 20 cm of topsoil was removed and no fertilizer was added, soil phosphorus amounts were low and soil potassium amounts were medium.

The three new sites were soil sampled before site preparation. As a result, the removal of topsoil would have also removed some plant available nutrients. Only the canola at the Willowcrest FS site was found to be marginal in nitrogen where 0, 5, 10, and 20 cm of topsoil had been removed and no fertilizer was added. The no topsoil removal, C rate of fertilizer treatment was also marginal in nitrogen while the no topsoil removal, B rate of fertilizer treatment was low in nitrogen. Soil nitrate levels at the Willowcrest FS site were low in the top 60 cm of soil. For the other two sites, tissue analysis indicated that nitrogen concentrations were generally sufficient. The concentration of the other plant nutrients were sufficient to high at these sites. The removal of topsoil at these sites would have removed some available plant nutrients which may have caused the reduction in yield where no fertilizer was added.

It appears that the lower canola yields, where no fertilizer was added, could be the result of nitrogen and in some cases phosphorus deficiencies in the soil. Generally, the canola plants grown on the eroded soil where no fertilizer was added were a pale green color. They usually exhibited slower growth and had thin weak stems. These are common symptoms of nitrogen and phosphorus deficiencies in Brassica crops (Bould et al. 1984).

4.3.4. Canola Yields

In general, the yield of canola was reduced as the level of topsoil removed increased in the no fertilizer added treatment. Canola yields were reduced to as little as 28 to 50% of the control. Similar findings were reported by Ives (1985) for wheat. The author found that wheat yields were usually lowest where 20 cm of topsoil was removed and no fertilizer was added. Within topsoil removal treatment, applications of twice the recommended rate of fertilizer did not always increase the wheat yields above that of the control. By contrast, canola responded differently to the application of fertilizer. Usually on the fine textured soils, the recommended rate of fertilizer was able to increase canola yields above that of the control. Twice the recommended rate of fertilizer did not significantly increase yields further. Similar findings to that of wheat were found for the coarse textured soils. Sometimes even twice the recommended rate of fertilizer was not able to increase canola yields above that of the control. A more comprehensive comparison will be better supported with further research data collected from the same sites.

Due to the higher amounts of nutrients in the soil at the Waskada VFSCL site, it was expected that a large response to the application of fertilizer would not occur. Where fertilizer was not added and no topsoil was removed, canola yields were close to the average yield reported for that crop zone. Where fertilizer was added and no topsoil was removed, yields were not significantly higher than the yields of the control.

Where canola yields were not restored by the application of fertilizer, it was suspected that some other factor or factors may have been limiting crop growth. A further detailed analysis of the subsoil at these sites may indicate what factor, either physical or chemical, was limiting crop growth. At the Waskada VFSCL site, a layer of gravel and coarse material was found approximately 20 to 30 cm below the soil surface. Exposure of this layer or increasing its proximity to the soil surface by the removal of topsoil may have affected the productivity of canola by restricting the root growth of the canola.

Usually canola yields were not restored by the application of fertilizer on the coarse textured soils where 20 cm of topsoil was removed. Lack of yield recovery may have been the result of an increase in clay content of these soils as the topsoil was removed. Some workers have reported that the increase in clay content of exposed subsoils reduces available soil moisture (Frye et al. 1982; Frye et al. 1985; Larson et al. 1985; Stone et al. 1985). A more detailed analysis of the subsoil at these sites would be required in order to verify that the clay content increased as topsoil was removed and that the available moisture decreased.

For practical purposes, one would like to know what kind of yield losses one might expect under 'normal' management. In this case, it would seem the appropriate reference point would be yield on the no topsoil removed, recommended fertilizer rate treatment. Table 4.7 shows the relative yield of canola as a percent of the no topsoil removal, recommended rate of fertilizer added treatment. It indicates that for most sites, at the low levels of topsoil removal, yields were maintained by the application of the recommended rate of fertilizer. However, where 20 cm of topsoil was removed and the recommended rate of fertilizer was added, yields were reduced approximately 10-50% depending on the soil type. For some soil types, usually the coarse textured soils, application of fertilizer at the recommended rate was generally not able to maintain canola yields as increasing amounts of topsoil were removed. This was likely due to the presence of some subsoil characteristic which limited crop growth. For these soil types, the loss of topsoil results in the loss of yield which fertilizer additions at the recommended rate cannot restore.

Table 4.7. Relative canola yield for the recommended rate of fertilizer treatment as affected by topsoil removal.

Site	Topsoil removal (cm)			
	0	5	10	20
1985				
Pembina CL	100	127.2	94.4	97.3
Reinland LVFS	100	110.1	99.7	82.5
Newdale CL	100	108.4	103.0	116.9
1986				
Pembina CL	100	134.7	77.2	87.1
Ryerson FSL	100	107.2	128.1	86.5
Reinland LVFS	100	97.0	91.7	70.0
Newdale CL	100	116.3	68.4	80.7
Willowcrest FS	100	82.0	100.7	62.1
Waskada VFSCL	100	85.8	82.9	51.8

4.3.5. Seed Quality

The effect of topsoil removal on canola seed quality was small. In general the oil concentration of the seed increased and the protein concentration decreased as the level of topsoil removed increased and no fertilizer was added. Application of fertilizer increased protein concentration and decreased oil concentration of the seed. However, since total seed yield also decreased when no fertilizer was added, on a per unit area basis the overall affect was a decrease in the yield of protein and oil. Where the application of fertilizer increased canola seed yield it also increased the yield of protein and oil.

4.3.6. Soil Fertility and Effect on Yield

All three sites used in 1985 had been planted to wheat the previous year. The Reinland LVFS and the Newdale CL sites were established in the spring of 1983 and were also planted to wheat that year. As a result, the plots that did not receive any fertilizer (A rate) had not received fertilizer since 1983 for these two sites. The Pembina CL site had not received any fertilizer on the A subplots since 1984.

Soil test results from the fall of 1984 (Appendix 1) show that, for the Pembina CL site, as the level of topsoil removal increased, nitrate nitrogen amounts in the top 60 cm of soil decreased. Within topsoil removal treatment, for the Reinland LVFS and for the Newdale CL sites, nitrate nitrogen amounts were usually lowest where no fertilizer was added.

For the Pembina CL site, available soil phosphorus also showed a slight decline where no fertilizer was added and the level of topsoil removed increased, but the amounts were still high. At the Reinland site, within fertilizer treatment, phosphorus amounts were very low where 20 cm of topsoil was removed. For the Newdale CL, phosphorus amounts were generally quite low with the amounts decreasing with increasing levels of topsoil removed (Appendix 1).

Soil potassium amounts generally remained very high over the various treatments. The amount of sulfur in the soil was variable over the various treatments. Sulphate sulfur amounts were very high for the Reinland LVFS and for the Newdale CL sites, while they ranged from very high to low for the Pembina CL site (Appendix 1).

For the three new sites that were developed for the 1986 season, this was the first year that the A subplots had not had any fertilizer added. As a result the A subplots may have benefitted from residual fertilizer added the previous year. Both the Ryerson FSL and the Willowcrest FS sites had low amounts of nitrate nitrogen in the top 60 cm of topsoil when they were initially sampled. The Waskada VFSCL site had very high amounts of nitrate nitrogen. The amount of phosphorus in the top 15 cm of topsoil was very low for the Ryerson FSL and for the Willowcrest FS sites while the amount for the Waskada VFSCL site was very high. Amounts of potassium in the top 15 cm of topsoil were low for the Willowcrest FS site, high for the Ryerson FSL site and very high for the Waskada VFSCL site. The amount of sulfur in the top 60 cm of topsoil was low for the Willowcrest FS site and very high for both the Ryerson FSL and the Waskada VFSCL site.

It would appear that the high yields that were reported for the Waskada VFSCL site, where no fertilizer was added, could be explained by the higher amounts of residual nutrients that were found in the soil. The higher yields reported for the Ryerson FSL site could be explained in part by the higher amounts of sulfur and potassium in the soil, although the amounts of nitrogen and phosphorus were considered low. The reduction in yield that occurred where topsoil was removed was probably due to the removal of plant available nutrients, especially nitrogen. The extent of the yield reduction would therefore depend on the amount of plant available nutrients that was left in the soil after topsoil removal.

The three sites that were used in 1985 were again planted to canola in 1986. The canola growth at these sites, especially on the A subplots, was very poor. When compared to the three newer sites, the canola growth was less vigorous and the plants were considerably smaller. Canola yields on the A subplots within the topsoil removal treatments was very poor. This may have been due to the low amounts of nutrients in the soil for these subplots.

At the Pembina CL, Reinland LVFS, and Newdale CL sites nitrate nitrogen amounts were usually low to very low. For the A subplots, the nitrogen amounts usually decreased as the level of topsoil removed increased. Phosphorus amounts were very high for the Pembina CL site. At the Reinland LVFS site, for all fertilizer treatments, phosphorus amounts were very high for the 0, 5, and 10 cm topsoil removal treatments. The 20 cm topsoil removal treatment was low in phosphorus where the A and C rates of fertilizer were added. At the Newdale CL site, phosphorus amounts were generally low to very low and the amount usually decreased as the level of topsoil removal increased and no fertilizer was added. In general, potassium amounts were very high at all sites. The amount of sulphate-sulfur was generally high to very high for both the Reinland LVFS and the Newdale CL sites for all treatments. At the Pembina CL site, the sulfur amounts were medium to low. For the A subplots at this site, the concentration tended to decrease as the level of topsoil removed increased (Appendix 2).

The lower yields that were reported for the A subplots at the three older sites could be partially explained by the low amounts of nitrogen and in some cases the low amounts of phosphorus and sulfur found in the A subplots.

4.3.7. Straw (Residue) Production

The reduction in straw yield caused by the removal of topsoil resulted in less straw being returned to the soil. This result has two implications. Straw is a valuable source of plant nutrients which become available as the straw is decomposed. The less straw that is returned to the soil the less the organic matter is built up and the less nutrients become available through organic matter decomposition. Straw returned to the soil surface also helps to protect the soil from further erosion (Anderson, 1982). Generally, canola crops do not return much trash to the soil surface. Any factor that reduces the amount of trash that is returned to the soil surface will reduce the ability of the trash to protect the soil from further erosion. Reduction in straw yield leaves the soil vulnerable to further erosion.

Not only does soil erosion reduce the amount of straw that is returned to the soil, it also causes a reduction in the concentration of nutrients in the straw where no fertilizer is added. As a result, smaller amounts of nutrients are returned to the soil. Application of fertilizer on eroded soil improves straw production and increases the concentration of nutrients in the straw.

5. CONCLUSION

Simulated soil erosion had an adverse affect on canola yields. As the level of topsoil removed increased, canola yields decreased. Depending on the soil type, yields where 20 cm of topsoil had been removed were reduced to 27-50% of the control. Generally for the fine textured soils, fertilizer applications at the recommended rate were able to increase canola yields over that of the control. Applications of twice the recommended rate of fertilizer did not significantly increase yields over the recommended rate of fertilizer.

For some soil types, fertilizer applications did not always increase canola yields where 20 cm of topsoil had been removed. This effect was seen for the coarser textured Reinland LVFS and Willowcrest FS sites. For these sites, factors other than fertility were limiting crop yields. A complete detailed analysis of the subsoils at these sites may reveal that the subsoil possesses some characteristics, either chemical or physical, that may limit crop growth.

For the Waskada VFSCL site, yields were not restored where 10 and 20 cm of topsoil had been removed. Applications of the recommended rate and twice the recommended rate of fertilizer did not increase yields over the control where no fertilizer had been added and no topsoil was removed. A layer consisting of gravel and coarse material existed approximately 20-30 cm below the soil surface. Exposure of this layer or increasing its proximity to the soil surface by the removal of topsoil likely restricted the root growth of canola and therefore limited yields on these subplots.

For some soil types, applications of the recommended rate of fertilizer were not able to restore canola yields as the level of topsoil removal increased. Where 20 cm of topsoil was removed and the recommended rate of fertilizer was added, yields were reduced by approximately 10-50% depending on the soil type. It is hoped that from data such as this and a knowledge of the soil profile, prediction of yield loss will be made possible.

The application of fertilizer on the artificially eroded soil increased straw production. As the level of topsoil removal increased and no fertilizer was added, straw production decreased. Not only did fertilizer applications increase the amount of straw that was produced, but it also increased the nutrient concentration of the straw. Fertilizer applications to eroded soils will therefore increase protection of the soil from further erosion by increasing the amount of straw that is returned to the soil surface. As well, fertilizer use on eroded soils will increase the nutrient content of the surface soil by increasing the nutrient concentration in the straw. Upon decomposition of the straw, available plant nutrients will be released to the surface soil.

The data generated by this project can be used in making economic analysis of canola grown on eroded or eroding soils. The best data for this analysis would be from treatments using otherwise good management practices i.e. application of the recommended rate of fertilizer. If the actual amount of yield reduction from erosion is known, agriculture producers will be able to calculate the returns derived from the use of conservation farming. They will also be better able to evaluate their choice of conservation practice if they know how much soil erosion is reduced using a particular conservation technique. Data from this project could also be used to determine the cost of erosion. This would be done by determining the amount of fertilizer needed to bring an eroded soil to the same production level as one that is not eroded. Where crop yields can not be restored through the application of fertilizer, the additional cost of erosion is the loss in potential productivity of the soil.

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Appendix 1. Soil nutrient content of experimental sites, October 1984.

Site	Treatment[1]	Depth (cm)	NO_3^--N† ($kg\ ha^{-1}$)	Avail. P† ($kg\ ha^{-1}$)	Avail. K‡ ($kg\ ha^{-1}$)	SO_4^{2-}-S§ ($kg\ ha^{-1}$)
Pembina CL	T1A	0-15	11.8	53.3	666	9.7
		15-30	6.5	31.7	644	13.0
		30-60	7.9	63.4	1628	6.2
		60-90	7.9	70.4	1782	13.2
	T1B	0-15	13.4	61.3	741	6.3
		15-30	4.7	40.7	594	3.2
		30-60	8.8	86.2	1584	6.2
		60-90	8.8	75.7	1650	10.6
	T1C	0-15	12.6	71.4	708	5.5
		15-30	5.4	51.8	621	6.1
		30-60	8.8	103.8	1835	7.0
		60-90	12.3	57.2	1835	5.3
	T2A	0-15	7.1	50.4	638	6.3
		15-30	3.6	35.3	540	2.9
		30-60	11.4	88.0	1628	10.6
		60-90	3.5	59.8	1474	10.6
	T2B	0-15	7.1	63.0	743	7.1
		15-30	4.0	45.4	630	8.3
		30-60	5.3	77.4	1769	8.8
		60-90	3.5	68.6	1769	8.8
	T2C	0-15	13.0	77.3	683	16.8
		15-30	11.2	52.6	563	31.7
		30-60	20.2	84.5	1443	15.0
		60-90	27.3	81.0	1593	8.8
	T3A	0-15	6.7	50.0	725	7.6
		15-30	4.0	35.6	702	7.6
		30-60	6.2	77.4	2024	15.0
		60-90	3.5	44.0	1575	7.0
	T3B	0-15	4.2	39.1	609	3.4
		15-30	3.6	41.0	603	3.2
		30-60	7.0	64.2	1694	5.3
		60-90	4.4	41.4	1474	6.2
	T3C	0-15	5.9	45.4	659	10.9
		15-30	3.2	32.0	648	11.5
		30-60	4.4	48.4	1672	8.8
		60-90	3.5	33.4	1518	5.3
	T4A	0-15	2.9	42.0	781	7.1
		15-30	2.1	31.7	688	4.0
		30-60	3.5	26.9	2130	6.2
		60-90	2.6	62.5	1892	10.6
	T4B	0-15	2.5	34.9	641	4.6
		15-30	4.0	22.7	549	5.4
		30-60	7.9	24.5	1333	6.2
		60-90	4.4	46.6	1580	34.3
	T4C	0-15	2.9	39.1	540	19.7
		15-30	1.1	31.7	792	13.3
		30-60	0.9	54.6	1672	15.0
		60-90	0.9	41.4	1399	10.6

[1]T1= 0 cm topsoil removal T2= 5 cm topsoil removal
T3= 10 cm topsoil removal T4= 20 cm topsoil removal

Appendix 1 (cont'd)

Site	Treatment	Depth (cm)	NO_3^--N† (kg ha^{-1})	Avail. P† (kg ha^{-1})	Avail. K‡ (kg ha^{-1})	SO_4^{2-}-S§ (kg ha^{-1})
Reinland LVFS	T1A	0-15	13.0	71.5	625	8.0
		15-30	22.0	6.5	455	23.5
		30-60	31.2	9.4	541	37.4
		60-90	12.5	3.1	572	19.8
	T1B	0-15	5.0	86.1	500	5.0
		15-30	18.5	41.5	375	50+
		30-60	43.7	36.4	442	104+
		60-90	33.3	3.1	281	104+
	T1C	0-15	12.0	96.5	550	9.0
		15-30	19.8	34.0	386	17.5
		30-60	109.1	8.2	510	102+
		60-90	31.2	9.4	416	104+
	T2A	0-15	5.5	52.0	388	7.5
		15-30	5.1	5.1	306	13.3
		30-60	73.4	1.0	219	102+
		60-90	69.7	1.0	156	104+
	T2B	0-15	7.1	61.7	309	12.2
		15-30	19.8	35.0	258	46+
		30-60	66.3	8.2	230	102+
		60-90	30.2	1.0	172	104+
	T2C	0-15	8.8	86.1	378	8.8
		15-30	10.1	16.1	184	20.2
		30-60	69.4	3.1	230	102+
		60-90	43.7	1.0	172	104+
	T3A	0-15	3.4	37.0	315	6.3
		15-30	3.2	6.9	437	20.2
		30-60	20.8	5.2	494	104+
		60-90	12.5	1.0	333	104+
	T3B	0-15	5.0	35.3	445	42+
		15-30	4.0	7.5	538	50+
		30-60	38.5	2.0	796	104+
		60-90	22.9	1.0	614	104+
	T3C	0-15	8.0	69.7	368	14.7
		15-30	20.7	20.2	170	46+
		30-60	80.1	10.4	208	104+
		60-90	31.2	1.0	260	104+
	T4A	0-15	2.9	9.7	246	5.0
		15-30	3.2	1.4	212	11.5
		30-60	30.0	0.9	345	92+
		60-90	15.5	1.0	458	104+
	T4B	0-15	2.9	10.9	221	5.5
		15-30	4.1	2.3	131	46+
		30-60	61.2	1.0	255	102+
		60-90	49.0	1.0	296	102+
	T4C	0-15	3.8	10.5	260	9.2
		15-30	5.5	3.2	357	102+
		30-60	85.7	1.0	255	102+
		60-90	146.9	1.0	296	102+

Appendix 1 (cont'd)

Site	Treatment	Depth (cm)	NO_3^--N† (kg ha^{-1})	Avail. P† (kg ha^{-1})	Avail. K‡ (kg ha^{-1})	SO_4^{2-}-S§ (kg ha^{-1})
Newdale CL	T1A	0-15	8.3	18.7	779	17.6
		15-30	11.5	13.0	635	36+
		30-60	20.2	9.7	1351	88+
		60-90	12.5	3.9	1014	78+
	T1B	0-15	9.7	29.9	783	36+
		15-30	14.4	6.1	626	36+
		30-60	23.8	32.6	1448	88+
		60-90	10.6	11.4	1311	88+
	T1C	0-15	14.0	27.0	630	12.6
		15-30	18.7	13.3	601	36+
		30-60	23.8	16.7	1373	88+
		60-90	10.6	10.6	1294	88+
	T2A	0-15	2.5	6.1	599	18+
		15-30	3.6	2.2	511	16.9
		30-60	8.6	3.9	1034	78+
		60-90	8.6	4.7	936	78+
	T2B	0-15	3.6	16.9	612	36+
		15-30	5.3	4.6	494	38+
		30-60	8.6	7.0	831	78+
		60-90	10.9	5.5	722	78+
	T2C	0-15	15.1	8.3	545	18+
		15-30	13.3	2.9	441	14.8
		30-60	17.9	3.9	780	78+
		60-90	9.4	7.8	780	78+
	T3A	0-15	5.4	4.3	549	16.9
		15-30	9.7	1.8	452	36+
		30-60	11.7	2.3	800	78+
		60-90	3.9	2.3	616	78+
	T3B	0-15	4.3	5.8	554	36+
		15-30	4.0	2.2	553	36+
		30-60	9.4	5.5	1170	35.1
		60-90	5.5	3.9	835	78+
	T3C	0-15	11.5	11.5	626	14.4
		15-30	11.9	4.6	504	12.5
		30-60	13.3	1.6	858	78+
		60-90	3.1	1.6	885	78+
	T4A	0-15	9.4	2.9	445	15.1
		15-30	9.0	1.8	324	36+
		30-60	17.6	1.8	572	88+
		60-90	8.8	0.9	537	88+
	T4B	0-15	2.2	3.2	356	12.6
		15-30	4.6	3.0	376	13.7
		30-60	9.4	6.2	800	78+
		60-90	4.7	1.6	815	78+
	T4C	0-15	7.9	6.1	428	36+
		15-30	10.1	4.3	441	36+
		30-60	31.2	9.4	718	78+
		60-90	31.2	2.3	624	78+

†Sodium bicarbonate extractable
‡Ammonium acetate exchangeable
§Water soluble

Appendix 2. Soil nutrient content of experimental sites, October 1985.

Site	Treatment[1]	Depth (cm)	NO_3^--N† (kg ha^{-1})	Avail. P† (kg ha^{-1})	Avail. K‡ (kg ha^{-1})	SO_4^{2-}-S§ (kg ha^{-1})
Pembina CL	T1A	0-15	2.5	56.5	608	4.3
		15-30	2.9	38.9	612	3.6
		30-60	10.6	45.8	1945	14.1
	T1B	0-15	3.2	64.8	738	4.0
		15-30	1.8	56.5	635	4.0
		30-60	5.3	77.4	1531	15.0
	T1C	0-15	2.9	68.4	733	7.2
		15-30	2.2	52.6	589	5.4
		30-60	7.0	23.8	1474	14.1
	T2A	0-15	2.9	57.2	706	5.8
		15-30	2.5	45.7	646	4.3
		30-60	5.3	72.2	1835	8.8
	T2B	0-15	2.9	53.3	693	5.8
		15-30	2.5	45.0	756	4.3
		30-60	8.8	44.0	1782	7.9
	T2C	0-15	4.3	68.0	715	10.8
		15-30	2.9	42.1	657	8.3
		30-60	4.4	74.8	1461	8.8
	T3A	0-15	2.9	58.7	657	5.0
		15-30	1.8	36.4	652	2.2
		30-60	3.5	63.4	1870	5.3
	T3B	0-15	1.8	58.0	725	3.2
		15-30	2.5	34.6	725	4.0
		30-60	5.3	50.2	2244	13.2
	T3C	0-15	7.6	55.8	563	6.8
		15-30	4.7	50.0	729	6.5
		30-60	13.2	98.6	1813	14.1
	T4A	0-15	2.5	47.5	617	4.3
		15-30	2.9	44.3	693	3.6
		30-60	7.9	84.5	1602	4.4
	T4B	0-15	2.9	46.8	720	4.7
		15-30	5.8	44.6	747	4.7
		30-60	7.9	61.6	1672	7.0
	T4C	0-15	2.9	47.9	572	10.1
		15-30	3.2	34.9	720	5.8
		30-60	15.0	59.0	1773	13.2

[1]T1= 0 cm topsoil removal T2= 5 cm topsoil removal
T3= 10 cm topsoil removal T4= 20 cm topsoil removal

Appendix 2 (cont'd)

Site	Treatment	Depth (cm)	NO_3^--N† (kg ha^{-1})	Avail. P† (kg ha^{-1})	Avail. K‡ (kg ha^{-1})	SO_4^{2-}-S§ (kg ha^{-1})
Reinland LVFS	T1A	0-15	6.3	122.6	515	15.1
		15-30	6.9	65.3	407	12.9
		30-60	8.2	31.6	893	33.7
	T1B	0-15	5.0	116.3	470	8.4
		15-30	4.6	34.0	391	10.1
		30-60	6.1	18.4	811	15.3
	T1C	0-15	12.2	120.5	557	42+
		15-30	8.3	35.4	453	11.5
		30-60	10.2	17.3	648	102+
	T2A	0-15	6.3	75.6	281	7.6
		15-30	7.4	17.9	242	46+
		30-60	10.2	12.2	357	28.6
	T2B	0-15	9.2	117.2	378	13.4
		15-30	6.0	28.5	345	23+
		30-60	9.2	20.4	969	31.6
	T2C	0-15	11.3	121.4	445	21+
		15-30	12.4	20.2	329	23+
		30-60	15.3	11.2	413	39.8
	T3A	0-15	6.7	44.9	452	21+
		15-30	7.4	10.1	564	23+
		30-60	7.1	11.2	903	16.3
	T3B	0-15	8.8	81.9	473	42+
		15-30	5.5	13.3	511	9.7
		30-60	7.1	7.1	928	20.4
	T3C	0-15	6.3	52.1	338	32+
		15-30	5.5	9.7	196	11.5
		30-60	2.0	9.2	576	17.3
	T4A	0-15	2.9	14.3	221	8.4
		15-30	2.8	4.1	161	8.7
		30-60	4.1	4.1	255	26.5
	T4B	0-15	3.8	32.3	277	12.2
		15-30	3.7	6.0	136	17.5
		30-60	6.1	7.1	168	28.6
	T4C	0-15	2.9	15.1	277	8.0
		15-30	4.6	6.9	189	14.3
		30-60	6.1	5.1	230	37.7

Appendix 2 (cont'd)

Site	Treatment	Depth (cm)	NO_3^--N† (kg ha^{-1})	Avail. P† (kg ha^{-1})	Avail. K‡ (kg ha^{-1})	SO_4^{2-}-S§ (kg ha^{-1})
Newdale CL	T1A	0-15	16.9	16.9	878	13.0
		15-30	12.2	7.6	60	10.4
		30-60	15.0	9.7	1254	88+
	T1B	0-15	7.9	33.1	828	9.4
		15-30	5.4	13.7	630	7.6
		30-60	14.1	19.4	1386	22.0
	T1C	0-15	9.7	26.6	860	11.9
		15-30	4.7	5.8	639	11.2
		30-60	11.4	7.9	1461	88+
	T2A	0-15	5.0	6.1	563	7.2
		15-30	6.1	3.2	463	7.6
		30-60	7.0	10.6	1276	26.4
	T2B	0-15	9.7	11.2	630	11.5
		15-30	6.5	5.4	526	10.8
		30-60	11.4	5.3	946	20.2
	T2C	0-15	7.6	9.7	531	6.8
		15-30	8.3	3.6	486	10.4
		30-60	21.1	4.4	946	88+
	T3A	0-15	6.5	5.8	832	13.3
		15-30	5.0	2.2	583	14.0
		30-60	7.0	3.5	1166	88+
	T3B	0-15	7.6	14.4	772	36+
		15-30	6.5	5.8	628	12.6
		30-60	7.0	6.2	1210	44+
	T3C	0-15	10.1	10.8	761	18+
		15-30	4.0	6.1	517	11.5
		30-60	7.0	4.4	1131	88+
	T4A	0-15	4.7	5.8	538	9.0
		15-30	5.0	2.5	450	18+
		30-60	5.3	2.6	884	88+
	T4B	0-15	4.3	5.4	547	36+
		15-30	2.9	2.5	436	12.2
		30-60	6.2	3.5	999	88+
	T4C	0-15	6.5	11.5	616	7.2
		15-30	9.4	4.7	617	14.0
		30-60	6.2	4.4	1192	15.0

†Sodium bicarbonate extractable
‡Ammonium acetate exchangeable
§Water soluble

Appendix 3. Physical properties of experimental sites.

Site	Depth (cm)	Bulk Density (g cm^{-3})	Water content (% volume) FC	PWP	Available Moisture (mm)
Ryerson FSL	0-15	1.28	23.88	14.39	14.24
	15-30	1.56	26.96	19.53	11.15
	30-60	1.64	28.28	16.37	35.73
	60-90	1.72	32.67	21.33	34.02
	90-120	1.82	46.89	18.24	85.95
Willowcrest FS	0-15	1.28	19.44	8.19	16.88
	15-30	1.52	19.68	8.18	17.25
	30-60	1.49	17.49	10.21	21.84
	60-90	1.52	16.49	9.77	20.16
	90-120	1.63	26.89	14.07	38.46
Waskada VFSCL	0-15	1.37	29.58	17.95	17.45
	15-30	1.45	34.57	22.21	18.54
	30-60	1.38	35.33	21.24	42.27
	60-90	1.48	41.15	18.02	69.39
	90-120	1.54	35.36	16.90	55.38

Appendix 4. Particle size analysis of experimental sites.

Site	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture
Ryerson FSL	0-15	66.71	15.24	18.05	FSL
	15-30	70.12	9.46	20.43	FSCL
	30-60	68.95	9.85	21.20	FSCL
	60-90	71.52	12.86	15.62	FSL
	90-120	69.39	15.23	15.39	VFSL
Willowcrest FS	0-15	89.56	3.97	6.47	FS
	15-30	88.73	3.71	7.56	FLS
	30-60	77.17	9.85	12.97	VFSL
	60-90	83.35	5.93	10.72	VFLS
	90-120	80.98	9.73	9.29	VFLS
Waskada VFSCL	0-15	46.84	24.76	28.40	VFSCL
	15-30	41.28	26.44	32.27	CL
	30-60	39.92	24.04	36.04	CL
	60-90	41.96	23.71	34.34	CL
	90-120	48.13	21.36	30.51	VFSCL

Appendix 5. Growing season precipitation (mm).

Year	Site	May	June	July	August	Total
1985	Pembina CL	76.7 (58.4)†	95.0	31.0	240.8 (219.7)	443.5
1986	Pembina CL	63.6 (1.2)	76.7	95.4	17.8 (0.0)	253.5
Normal‡		69.0	87.7	80.7	65.6	303.0
1986	Ryerson FSL	74.6 (0.0)	46.8	123.6	30.4 (0.0)	275.4
Normal		61.7	85.1	63.3	77.0	287.1
1985	Reinland LVFS	32.7 (32.7)	79.0	20.3	173.3 (173.3)	305.3
1986	Reinland LVFS	71.0 (0.0)	56.1	97.9	33.2 (0.0)	258.2
Normal		45.4	95.4	60.3	68.7	269.8
1985	Newdale CL	56.0 (40.1)	66.4	12.7	162.9 (161.9)	298.0
1986	Newdale CL	57.4 (0.0)	79.0	141.0	19.0 (0.0)	296.4
Normal		51.9	81.3	73.4	62.5	269.1
1986	Willowcrest FS	53.0 (2.6)	78.7	147.9	30.8 (0.0)	310.4
Normal		56.8	80.7	73.2	63.8	274.5
1986	Waskada VFSCL	81.6 (0.0)	60.2	107.4	21.2 (0.0)	270.4
Normal		46.2	82.9	64.3	63.1	256.5

†Data in () represents rainfall after seeding and before final harvest.
‡Source: Canadian Climate Normals, 1951-1980. Vol. 3. Precipitation. Environment Canada, Downsview, Ontario.

Appendix 6. Interpretive criteria for canola tissue analysis[1].

Nutrient	Low	Marginal	Sufficient	High	Excess
Nitrogen (g kg^{-1})	20.0	20.0 - 25.0	25.0 - 40.0	40.0 - 50.0	50.0
Phosphorus (g kg^{-1})	1.5	1.5 - 2.5	2.5 - 5.0	5.0 - 8.0	8.0
Potassium (g kg^{-1})	12.0	12.0 - 15.0	15.0 - 25.0	25.0 - 40.0	40.0
Sulfur (g kg^{-1})	2.0	2.0 - 2.5	2.5 - 5.0	5.0 - 10.0	10.0

[1]Source: Manitoba Provincial Soil Testing Laboratory.

Appendix 7. Midseason tissue analysis, 1985.

Site	Topsoil Removal (cms)	Fertilizer Rate	N g kg^{-1}	P g kg^{-1}	K g kg^{-1}	S g kg^{-1}
Pembina CL	0	A	17.58ab†	3.86a	16.93a	7.23ab
		B	19.48ab	3.39a	21.05a	2.98cde
		C	21.88ab	3.36a	17.65a	3.15bcde
	5	A	16.28b	3.95a	14.43a	5.58abcd
		B	19.10ab	3.34a	19.78a	3.55bcde
		C	23.08ab	3.41a	20.10a	3.23bcde
	10	A	18.50ab	3.74a	13.03a	5.70abc
		B	18.90ab	3.27a	15.98a	1.43e
		C	23.85ab	3.36a	17.38a	3.33bcde
	20	A	16.83b	4.06a	14.33a	9.2a
		B	17.50ab	3.30a	20.58a	4.08bcde
		C	24.90a	3.84a	19.98a	3.80bcde
Reinland LVFS	0	A	28.75abc	3.93a	25.20a	7.47a
		B	34.08abc	3.67a	33.35a	7.80a
		C	36.58ab	3.81a	40.53a	9.73a
	5	A	24.25c	4.07a	26.75a	9.93a
		B	31.53abc	3.57a	25.90a	10.87a
		C	37.95a	3.57a	32.75a	11.27a
	10	A	26.15abc	3.40a	27.18a	10.95a
		B	24.85bc	3.63a	23.90a	8.53a
		C	35.28abc	3.41a	34.03a	5.90a
	20	A	25.55bc	3.62a	23.48a	9.70a
		B	27.98abc	2.89a	28.45a	5.90a
		C	34.53abc	3.45a	30.33a	8.80a
Newdale CL	0	A	25.53a	3.40a	24.83a	16.90‡
		B	26.70a	3.34a	22.05a	4.80
		C	31.48a	3.13a	23.08a	10.80
	5	A	24.45a	2.76a	18.98a	7.10
		B	25.85a	2.74a	25.18a	7.30
		C	28.90a	3.07a	23.35a	6.30
	10	A	23.70a	2.50a	18.88a	12.70
		B	24.90a	2.64a	21.23a	13.40
		C	28.50a	2.66a	19.93a	8.50
	20	A	23.38a	2.62a	18.93a	21.10
		B	25.15a	3.02a	18.73a	16.10
		C	28.70a	3.22a	24.50a	15.30

†Within site-nutrient, means followed by the same letter are not significantly different at Tukey's 0.05 level.
‡No statistical analysis performed, data from 1 replicate only.

Appendix 8. Canola seed protein and oil concentration (%), 1985.

Site	Topsoil Removal (cms)	Fertilizer Rate	Protein (%)	Oil (%)
Pembina CL	0	A	15.1abc†	50.4ab
		B	15.4abc	49.2abc
		C	18.7a	46.4c
	5	A	14.7abc	52.2a
		B	17.5ab	47.9bc
		C	15.9abc	48.8abc
	10	A	14.3bc	50.1ab
		B	13.7bc	49.7abc
		C	15.6abc	48.5abc
	20	A	13.1c	51.2ab
		B	14.4abc	49.5abc
		C	16.4abc	47.5bc
Reinland LVFS	0	A	18.6a	47.8a
		B	20.5a	45.9a
		C	20.8a	45.9a
	5	A	18.8a	47.2a
		B	21.0a	45.3a
		C	21.4a	44.9a
	10	A	18.0a	47.5a
		B	20.3a	45.1a
		C	20.4a	44.3a
	20	A	17.2a	48.3a
		B	18.4a	47.6a
		C	19.4a	45.3a
Newdale CL	0	A	17.5ab	49.5abc
		B	18.2ab	48.4abcd
		C	22.2a	44.3d
	5	A	14.8b	51.2a
		B	18.4ab	48.0abcd
		C	20.6ab	45.9cd
	10	A	18.1ab	48.6abcd
		B	16.9ab	49.7abc
		C	20.7ab	46.7bcd
	20	A	16.8ab	50.3ab
		B	17.7ab	49.3abc
		C	20.4ab	47.2abcd

†Within site-nutrient, means followed by the same letter are not significantly different at Tukey's 0.05 level.

Appendix 9. Straw yields (kg ha^{-1}), 1985.

Site	Fertilizer	Topsoil Removal (cm) 0	5	10	20
Pembina CL	A	2915.0b†	1607.5b	1507.5b	1132.5b
	B	4877.5a	6780.0a	5375.0a	5565.0a
	C	6407.5a	5660.0a	5817.5a	6735.0a
Reinland LVFS	A	2925.0ab	2852.5ab	2825.0ab	1540.0b
	B	3397.5ab	4032.5a	3747.5ab	3277.5ab
	C	4675.0a	4167.5a	4247.5a	3000.0ab
Newdale CL	A	3320.0bcde	2100.0de	2917.5cde	1520.0e
	B	4127.5abcd	5087.5abc	3967.5abcd	4472.5abc
	C	5790.0a	5195.0abc	5642.5ab	5145.0abc

†Within site, means followed by the same letter are not significantly different at Tukey's .05 level.

Appendix 10. Final harvest- straw nutrient concentration, 1985.

Site	Topsoil Removal (cms)	Fertilizer Rate	N kg ha^{-1}	P kg ha^{-1}	K kg ha^{-1}	S kg ha^{-1}
Pembina CL	0	A	10.4cde†	4.0cd	49.2ef	13.4ab
		B	18.2bcde	6.2abcd	96.3bcd	10.8ab
		C	35.9a	11.2a	149.4a	24.2ab
	5	A	6.4de	2.4d	28.1f	8.1ab
		B	35.0ab	9.3ab	130.6abc	31.6a
		C	22.6abcd	7.8abc	111.4abcd	24.7ab
	10	A	7.2de	2.1d	25.3f	7.4ab
		B	18.5bcde	5.7bcd	85.7de	14.3ab
		C	25.9abc	9.2ab	124.6abcd	20.9ab
	20	A	4.9e	1.5d	15.7f	4.6b
		B	19.0abcde	5.6bcd	89.2cde	13.3ab
		C	31.8ab	8.3abc	136.9ab	16.9ab
Reinland LVFS	0	A	16.7ab	3.1ab	53.5ab	9.5a
		B	24.2ab	3.7ab	70.8ab	9.9a
		C	38.2ab	4.0ab	101.8a	18.1a
	5	A	16.9ab	2.6ab	44.0b	9.7a
		B	31.4ab	4.7a	66.2ab	12.8a
		C	42.4a	5.1a	74.4ab	21.2a
	10	A	20.0ab	2.6ab	48.5ab	11.1a
		B	30.2ab	3.2ab	66.9ab	15.9a
		C	36.3ab	4.0ab	78.5ab	21.0a
	20	A	9.8b	1.1b	24.1b	7.4a
		B	22.1ab	2.2ab	49.0ab	8.3a
		C	26.8ab	2.7ab	51.1ab	9.8a
Newdale CL	0	A	20.0bc	1.7bcde	64.6bcde	18.7ab
		B	21.7bc	2.7bcde	69.3abcd	26.0ab
		C	70.7a	5.7a	119.1a	33.4ab
	5	A	8.1c	0.7de	29.3de	10.3b
		B	30.0bc	3.1bc	91.1abc	28.6ab
		C	40.3b	3.6ab	97.1abc	33.4ab
	10	A	16.8bc	1.1cde	54.6cde	13.7ab
		B	16.3bc	1.4bcde	68.1bcde	26.7ab
		C	42.0b	3.0bcd	113.1ab	38.1a
	20	A	6.6c	0.4e	18.8e	8.5b
		B	19.3bc	1.6bcde	87.5abc	26.6ab
		C	40.0b	3.1bc	89.1abc	33.7ab

†Within site-nutrient, means followed by the same letter are not significantly different at Tukey's 0.05 level.

Appendix 11. Midseason tissue analysis, 1986.

Site	Topsoil Removal (cms)	Fertilizer Rate	N $g\ kg^{-1}$	P $g\ kg^{-1}$	K $g\ kg^{-1}$	S $g\ kg^{-1}$
Pembina CL	0	A	20.13a†	4.41a	19.68b	7.75a
		B	26.00a	4.21a	23.63ab	6.85a
		C	30.75a	4.21a	28.13a	7.30a
	5	A	25.63a	4.64a	22.55ab	7.85a
		B	26.45a	3.83a	22.35ab	7.38a
		C	30.08a	4.08a	24.20ab	7.90a
	10	A	22.60a	4.66a	20.65ab	8.78a
		B	29.10a	3.97a	21.95ab	6.23a
		C	33.95a	4.27a	25.55ab	8.08a
	20	A	23.73a	4.44a	17.88b	7.97a
		B	24.38a	3.52a	20.98ab	6.53a
		C	29.50a	3.77a	23.45ab	8.50a
Ryerson FSL	0	A	25.15a	2.68d	21.70a	12.85a
		B	29.25a	2.95cd	23.10a	12.68a
		C	23.43a	3.81abcd	26.13a	9.58a
	5	A	33.93a	3.18bcd	22.93a	13.73a
		B	31.95a	3.91abcd	25.70a	13.88a
		C	27.68a	4.68a	22.33a	12.35a
	10	A	30.08a	3.18bcd	24.70a	13.30a
		B	35.20a	4.16abc	25.50a	11.20a
		C	27.46a	4.51ab	21.73a	10.95a
	20	A	32.13a	2.66d	22.20a	13.05a
		B	27.20a	3.90abcd	24.65a	11.73a
		C	37.68a	4.39abc	20.48a	12.78a
Reinland LVFS	0	A	21.63a	4.07a	20.10a	6.43a
		B	26.00a	4.52a	25.40a	3.65a
		C	22.53a	4.65a	26.43a	3.95a
	5	A	16.13a	4.21a	19.15a	6.58a
		B	22.43a	4.40a	22.50a	6.45a
		C	31.33a	4.83a	25.40a	5.13a
	10	A	16.33a	4.03a	18.67a	2.37a
		B	24.65a	4.34a	24.40a	3.78a
		C	25.80a	4.70a	23.95a	2.70a
	20	A	20.65a	4.13a	24.13a	4.90a
		B	24.35a	4.16a	24.43a	3.90a
		C	23.73a	4.36a	25.20a	3.68a

Appendix 11 (cont'd)

Site	Topsoil Removal (cms)	Fertilizer Rate	N $g\ kg^{-1}$	P $g\ kg^{-1}$	K $g\ kg^{-1}$	S $g\ kg^{-1}$
Newdale CL	0	A	29.58a	4.27abc	31.95a	9.33a
		B	36.28a	4.54ab	30.98a	6.50a
		C	38.45a	5.09a	36.85a	5.60a
	5	A	28.95a	3.55bcd	28.95a	8.40a
		B	38.20a	4.09abcd	34.33a	5.03a
		C	38.95a	4.52abc	31.08a	5.38a
	10	A	28.93a	3.16cd	28.45a	8.17a
		B	33.95a	3.97abcd	30.60a	6.78a
		C	39.58a	4.82ab	33.43a	6.98a
	20	A	26.30a	2.88d	26.55a	8.73a
		B	30.23a	3.74abcd	30.50a	7.00a
		C	23.93a	4.42abc	27.23a	4.83a
Willowcrest FS	0	A	20.43a	3.51ab	18.03a	4.83a
		B	16.68a	3.53ab	20.15a	5.55a
		C	20.33a	4.18ab	17.80a	5.35a
	5	A	20.90a	3.23b	17.90a	3.25a
		B	28.08a	3.63ab	16.03a	5.00a
		C	34.18a	5.01a	20.35a	5.58a
	10	A	24.13a	3.34b	18.60a	3.40a
		B	30.93a	4.09ab	17.73a	4.48a
		C	36.18a	4.77ab	16.95a	5.28a
	20	A	24.43a	3.29b	19.63a	3.08a
		B	26.20a	3.67ab	16.65a	4.80a
		C	33.48a	4.13ab	18.28a	5.50a
Waskada VFSCL	0	A	32.25a	3.89a	19.90a	9.55a
		B	27.53a	3.90a	21.78a	9.28a
		C	27.48a	3.82a	22.53a	8.25a
	5	A	23.75a	3.60a	20.50a	9.88a
		B	26.95a	3.50a	22.13a	7.10a
		C	30.93a	3.86a	24.98a	6.68a
	10	A	29.28a	4.25a	23.13a	9.80a
		B	27.23a	3.79a	23.25a	8.23a
		C	27.93a	3.45a	21.73a	8.45a
	20	A	31.80a	3.25a	22.18a	10.95a
		B	33.73a	3.39a	24.23a	12.13a
		C	34.23a	4.42a	23.98a	11.03a

†Within site-nutrient, means followed by the same letter are not significantly different at Tukey's 0.05 level.

Appendix 12. Canola seed protein and oil concentration (%), 1986.

Site	Topsoil Removal (cms)	Fertilizer Rate	Protein (%)	Oil (%)
Pembina CL	0	A	19.1abcd†	47.0abc
		B	20.1abcd	45.7bcd
		C	22.9a	43.1d
	5	A	17.0d	48.8ab
		B	19.0bcd	47.2abc
		C	22.3ab	43.8d
	10	A	17.0d	48.7ab
		B	17.9cd	47.6abc
		C	21.2abc	45.0cd
	20	A	16.9d	49.0a
		B	18.2cd	47.8abc
		C	22.3ab	43.6d
Ryerson FSL	0	A	22.0a	46.9a
		B	23.4a	45.2a
		C	23.5a	44.9a
	5	A	20.4a	48.3a
		B	22.3a	46.5a
		C	24.3a	43.9a
	10	A	20.2a	48.3a
		B	22.4a	46.1a
		C	23.7a	45.2a
	20	A	21.4a	46.8a
		B	22.2a	46.5a
		C	22.4a	46.3a
Reinland LVFS	0	A	21.2ab	44.1a
		B	21.7ab	43.5a
		C	23.0a	42.8a
	5	A	21.5ab	44.0a
		B	22.0ab	43.6a
		C	22.1ab	44.2a
	10	A	19.8b	45.2a
		B	19.8b	45.7a
		C	21.5ab	44.2a
	20	A	20.0b	45.4a
		B	19.5b	45.4a
		C	20.0b	44.6a

Appendix 12 (cont'd)

Site	Topsoil Removal (cms)	Fertilizer Rate	Protein (%)	Oil (%)
Newdale CL	0	A	16.5cde	49.7abc
		B	19.5abcde	47.6abcd
		C	24.0a	42.6d
	5	A	14.6e	50.8a
		B	20.7abcd	46.8abcd
		C	23.0ab	44.0cd
	10	A	15.0e	49.6abc
		B	17.8bcde	47.6abcd
		C	21.9abc	44.7bcd
	20	A	16.0de	50.0abc
		B	16.4cde	50.5ab
		C	22.6ab	44.2cd
Willowcrest FS	0	A	22.6abc	45.9abc
		B	22.7abc	45.3cd
		C	24.0a	44.4d
	5	A	20.2c	47.9a
		B	21.8abc	46.1abcd
		C	23.0ab	45.0d
	10	A	21.3bc	47.0abc
		B	22.2abc	45.4bcd
		C	23.0ab	44.6d
	20	A	20.2c	47.4ab
		B	20.3bc	47.9a
		C	22.6abc	45.3cd
Waskada VFSCL	0	A	25.1a	42.4a
		B	24.4ab	42.8a
		C	25.0ab	42.5a
	5	A	22.7ab	44.4a
		B	22.8ab	44.3a
		C	23.9ab	43.5a
	10	A	20.8ab	45.1a
		B	23.7ab	43.2a
		C	22.4ab	44.4a
	20	A	19.7b	47.2a
		B	21.0ab	46.1a
		C	24.0ab	43.0a

†Within site-nutrient, means followed by the same letter are not significantly different at Tukey's 0.05 level.

Appendix 13. Straw yields (kg ha^{-1}), 1986.

Site	Fertilizer	Topsoil Removal (cm) 0	5	10	20
Pembina CL	A	2047.5bcd†	1925.0bcd	1427.5cd	732.5d
	B	4452.5a	4707.5a	3780.0ab	3547.5abc
	C	4637.5a	4695.0a	4922.5a	3652.5abc
Ryerson FSL	A	3540.0bcd	2900.0cd	2777.5cd	2435.0d
	B	5310.0abc	5432.5abc	6472.5a	4692.5abcd
	C	5600.0ab	5307.5abc	6392.5a	5590.0ab
Reinland LVFS	A	3012.5abc	2852.5abc	1922.5bc	1570.0c
	B	4505.0a	4612.5a	3852.5abc	3200.0abc
	C	5170.0a	5302.5a	4600.0a	4137.5ab
Newdale CL	A	3690.0cd	2332.5d	1557.5d	2060.0d
	B	5110.0abc	5750.0abc	4062.5abcd	3960.0bcd
	C	6390.0ab	5665.0abc	6512.5a	5112.5abc
Willowcrest FS	A	3787.5bcde	1712.5e	2452.5cde	2282.5de
	B	4800.0ab	3990.0bcd	4910.0ab	3347.5bcde
	C	6295.0a	4632.5abc	4680.0abc	4207.5abcd
Waskada VFSCL	A	4252.5ab	3427.5ab	3645.0ab	2912.5b
	B	4780.0a	4225.0ab	4932.5a	3312.5ab
	C	4502.5ab	4382.5ab	4805.0a	4917.5a

†Within site, means followed by the same letter are not significantly different at Tukey's .05 level.

Appendix 14. Final Harvest- straw nutrient concentration, 1986.

Site	Topsoil Removal (cms)	Fertilizer Rate	N kg ha^{-1}	P kg ha^{-1}	K kg ha^{-1}	S kg ha^{-1}
Pembina CL	0	A	13.1cd†	4.1abc	30.7bcd	15.9ab
		B	30.9abc	8.4a	79.7ab	18.5ab
		C	42.6a	7.8a	103.0a	30.7ab
	5	A	12.1cd	3.9abc	30.3cd	14.2ab
		B	23.1abcd	5.0abc	88.9a	29.8ab
		C	37.9ab	7.0ab	94.8a	31.5ab
	10	A	7.8d	2.4bc	20.8cd	11.1ab
		B	21.0bcd	6.6abc	60.7abc	20.5ab
		C	38.8ab	7.7ab	96.2a	33.5a
	20	A	4.5d	1.2c	11.4d	6.1b
		B	19.7bcd	5.7abc	60.3abcd	16.0ab
		C	33.1abc	6.0abc	67.8abc	27.1ab
Ryerson FSL	0	A	19.5ab	1.2a	44.9ab	34.6ab
		B	35.2ab	2.2a	94.8a	52.8ab
		C	40.0ab	1.8a	74.8ab	81.4a
	5	A	18.2ab	0.7a	29.5b	44.8ab
		B	28.0ab	1.1a	74.2ab	67.7ab
		C	38.4ab	2.3a	68.7ab	52.9ab
	10	A	15.8b	1.2a	31.8b	30.6b
		B	46.0a	2.0a	89.2a	72.0ab
		C	43.1ab	2.0a	96.9a	64.5ab
	20	A	18.4ab	1.1a	21.8b	29.0b
		B	29.5ab	1.3a	61.0ab	39.3ab
		C	36.3ab	1.5a	58.8ab	47.1ab
Reinland LVFS	0	A	19.8cde	4.3abc	55.7abc	4.3‡
		B	35.3abc	5.2abc	78.7abc	6.8
		C	42.4ab	6.8a	113.4a	6.5
	5	A	18.9cde	3.7abc	52.0bc	48.3
		B	33.5abc	5.4abc	90.2abc	20.8
		C	46.4a	6.0ab	99.1ab	6.0
	10	A	11.6de	2.1bc	35.0c	2.3
		B	20.9bcde	3.4abc	76.9abc	-
		C	40.3abc	5.3abc	81.6abc	38.8
	20	A	10.0e	1.9c	33.3c	13.3
		B	19.3cde	3.0abc	64.7abc	3.9
		C	32.6abcd	4.3abc	87.5abc	-

Appendix 14 (cont'd)

Site	Topsoil Removal (cms)	Fertilizer Rate	N kg ha^{-1}	P kg ha^{-1}	K kg ha^{-1}	S kg ha^{-1}
Newdale CL	0	A	18.2cd	2.0cd	67.3bcde	41.3ab
		B	34.1bcd	3.4abcd	100.4abc	58.3ab
		C	80.7a	6.5a	144.3a	87.4a
	5	A	11.1d	1.5cd	33.4de	16.1b
		B	40.4abcd	3.4abcd	112.5abc	64.1ab
		C	63.6ab	4.9abc	111.9abc	71.2ab
	10	A	8.4d	1.0d	22.8e	15.2b
		B	21.7cd	2.5bcd	65.8bcde	36.0ab
		C	67.9ab	5.8ab	128.1ab	66.8ab
	20	A	11.3d	1.3cd	30.8de	15.4b
		B	18.2cd	2.1bcd	62.8cde	34.8ab
		C	54.9abc	3.6abcd	88.6abcd	64.2ab
Willowcrest FS	0	A	24.4cdef	2.0bc	69.3abcd	17.1a
		B	37.7bc	3.4b	88.2ab	21.5a
		C	60.2a	5.2a	102.9a	23.6a
	5	A	10.7f	0.9c	24.3e	4.3a
		B	26.5cde	2.0bc	52.6bcde	9.2a
		C	38.3bc	3.3b	66.1abcde	20.8a
	10	A	17.2ef	1.6c	37.6cde	11.0a
		B	35.5bc	3.4b	75.2abc	19.1a
		C	41.2ab	3.4b	69.9abcd	18.5a
	20	A	13.5ef	1.2c	31.7de	5.6a
		B	19.8def	1.4c	42.0cde	36.1a
		C	32.4bcd	2.3bc	58.3bcde	19.2a
Waskada VFSCL	0	A	36.6ab	4.2a	79.5ab	33.1a
		B	34.7ab	3.2a	86.6a	31.6ab
		C	38.7ab	4.5a	80.3ab	32.1ab
	5	A	25.1ab	2.8a	58.1ab	22.3ab
		B	30.0ab	3.1a	71.1ab	21.6ab
		C	46.3a	4.2a	80.6ab	21.1ab
	10	A	26.6ab	3.5a	45.5b	17.6ab
		B	39.4ab	3.2a	83.5ab	24.5ab
		C	34.0ab	3.6a	68.4ab	26.5ab
	20	A	17.9b	1.9a	45.3b	13.5b
		B	25.2ab	1.6a	47.7ab	19.3ab
		C	45.7a	3.9a	83.3ab	31.4ab

†Within site-nutrient, means followed by the same letter are not significantly different at Tukey's 0.05 level.
‡No statistical analysis performed, data from 1 replicate only.