EFFECT OF SIMULATED EROSION ON CROP PRODUCTIVITY

by

Angela Kapoor Dozois

a thesis
presented to the University of Manitoba
in partial fulfilment of the
requirements for the degree of
Master of Science
in the
Department of Soil Science

Winnipeg, Manitoba

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ISBN 0-315-76796-0

ABSTRACT

Simulating soil erosion to assess its effects on productivity was the focus of this study conducted in south-western Manitoba. Six different soil types ranging from a Reinland loamy very fine sand to a Newdale clay loam were utilized. Experimental sites were designed as completely randomized split plots with the main plot treatment being topsoil removal and the subplot treatment being fertilizer application. Soil removal consisted of four levels; 0, 5, 10 and 20 cm of topsoil scraped off the surface. The subplot treatment included three fertility levels; (A) no fertilizer applied, (B) the recommended rate of fertilizer applied based on soil tests and (C) double the recommended rate of fertilizer applied. Wheat and canola, two crops common to the area, were seeded, grown, harvested and analyzed for nitrogen, phosphorus and potassium concentrations. Yield of the seed and straw was determined and nutrient uptake calculated. Data was statistically analyzed to determine the differences due to main and subplot treatments and to ascertain whether there were any significant interaction effects. Regression modelling was also done to evaluate which factors most influenced potential yields.

Nutrient concentrations at midseason were significantly (P=0.05) lower without fertilizer than with fertilizer applications. The most striking differences were noted for nitrogen concentrations. Topsoil removal effects on nitrogen concentrations were found at the Willowcrest

FS site where the 0 and 5 cm scraped plots had nitrogen concentrations significantly higher than the 10 and 20 cm scraped plots.

Seed and straw yields increased with fertilizer and decreased with an increase in topsoil removal. Topsoil removal was found to show significant differences at the Willowcrest FS site in 1987 where the 0 cm scraped plots yielded significantly higher than the 5, 10 and 20 cm scraped plot. Plots generally yielded significantly higher where fertilizer had been applied than without fertilizer additions. Nutrient concentrations of the seed and straw increased with fertilizer application but rarely were differences significant.

Nutrient uptake showed nitrogen, phosphorus and potassium to be significantly higher with than without fertilizer. Topsoil removal effects were also evident. The Willowcrest FS showed uptake for all nutrients in 1987 and phosphorus in 1988 to decrease as topsoil was removed. Similar differences were also found at other sites.

Regression equations developed for the data found fertilizer to have the greatest influence on yields with its effect reaching a maximum at high rates, thus inferring a diminishing effect. Topsoil removal had a negative effect on yields with the coarser textured soils having higher coefficients for the topsoil factor than the finer textured soils.

ACKNOWLEDGEMENTS

I wish to thank the following people who made the completion of this thesis an enlightening and enjoyable experience:

First and foremost, Dr. C.F. Shaykewich, Professor, Dept. of Soil Science, for his constant support, encouragement, kindness, patience and for having given me an opportunity all those years ago.

Dr. G.J. Racz, Department Head, Dept. of Soil Science, for serving on my examining committee and for providing vital advice for this project.

Dr. R. Sri Ranjan, Dept. of Agricultural Engineering, for serving on my examining committee.

Dr. C.M. Cho, Dr. O. Akinremi and Mr. G. Morden for answering my computer programming inquires and always coming to the rescue when my computer labour seemed to have disappeared.

Mr. V. Chan and Mr. M. Giesbrecht whose energetic and enthusiastic efforts made the collection and analysis of data possible.

Ms. V. Huzel, technician, for advising me in the art of plant and soil chemical analysis.

Mr. S. Glufka, technician, for assisting with the preparation of sites and preparing samples for chemical analysis.

Ms. H. Nemeth and Ms. P. Novotny, secretaries, for their constant help and high spirits.

Mr. B. Kenyon, for among other things, answering my never ending barrage of questions.

Mr. R. Balshaw, for his time and patience throughout our many statistics consultations.

Ms. A. Kaufmann, for her constant support and encouragement throughout my life and for teaching me the value of maintaining a youthful attitude, I am eternally grateful.

Mr. S. Kapoor, for his kind interest and support and for showing me the benefits hard work can bring.

Staff of the Manitoba Provincial Soil Testing Laboratory for their rapid and reliable soil analyses.

Agriculture Canada through the Economic and Regional Development agreement for providing the financial support for this project.

And finally, I would like to thank Lt. P. Dozois, my husband, best friend and true love, you are the secret of my smile and the twinkle in my eyes.

United we travel,
Neither dwelling on the past
Nor awaiting the future.
Today we realize Godot,
And savour the journey.

I love you Cherie.

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1. INTRODUCTION

As our population continues to increase, our dependency on the land increases, and so should our responsibility to the land. Although the world's potentially arable land is only 22% of the total land area (Lal, 1988), agriculture is the one indispensable industry that has been instrumental in establishing civilizations, and maintaining their existence. History tells that the downfall of many empires was due to the poor management of the agricultural practices employed at the time.

Productivity of a given area is largely dependent on the condition of the topsoil. Whether it is called surface soil, A horizon or epipedon, topsoil is the surface few centimetres of soil which is generally highest in organic matter and plant nutrients. This is the medium in which we grow the vital commodities that feed the world, therefore anything that threatens to degrade the soils also threatens our well-being.

Soil erosion is a process known to degrade soils. It involves the movement of surface materials; the transport, abrasion, sorting and deposition of the soil particles. This process causes many changes in physical, chemical and hydraulic properties and therefore changes in the productivity potential of the soil. Such changes include nutrient losses, organic matter losses, losses in actual volume of soil, a reduction in water holding capacity and available moisture to the plant, and physical changes that affect soil texture, soil structure and soil aeration. Eroded soils have a higher bulk density and are more inclined to form soil crusts. Surface seals develop and lead to a decrease in the infiltration rate and an increase in soil and water runoff. This increase in runoff also causes an increase in fertilizer and pesticide losses, reducing the amount of necessary components for good crop growth and posing a concern for environmental pollution. These changes are generally adverse changes that result in a reduction in productivity of a soil.

Although there has been much research conducted to assess the amount of soil lost due to soil erosion, little work has been done to determine the productivity losses that occur. Maintaining productivity at or near the maximum potential of a soil has always been the goal of farming. All our technological advances have occurred keeping this in mind. Soil erosion must be controlled if this philosophy is to be put into practice.

In today's agricultural society the fashionable term is sustainable agriculture. Although this concept is still undefined, one of its essential components is the control of agricultural soil erosion. There is no allowance for excessive erosion in a management system if the desire is sustainable agriculture and maintenance of good productivity.

It is a fact that soil erosion adversely affects productivity. This project set out to assess quantitatively the effects of soil erosion on crop productivity. Varying levels of simulated erosion were used to determine the changes in productivity of crops grown on different soil types. Modelling of the data was also done to estimate the effects of topsoil removal and fertilizer applications on yields.

2. LITERATURE REVIEW

2.1. Losses Due to Soil Erosion

2.1.1. Soil Losses

Soil is one of the earth's most important natural resources. It is the physical and biological environment in which we grow the necessary food, feed, and fibre to sustain life. There is no form of life that does not in some way, whether directly or indirectly, depend on the soil for it's existence.

The organism most dependent on the soil is man. Throughout history agriculture has been practised as a means for survival therefore the condition of the soil is of grave importance. As a source of nutrients and a supply of water, the soil is generally the limiting factor in the production of all agricultural crops.

One factor of current interest that can seriously change the soil of a given area is the process of soil erosion. Due to continuous cropping of agricultural lands, poor soil management, and other man-induced influences, natural erosion has become considerably accelerated.

Many tonnes of soil are annually moved off productive fields only to be deposited in ditches and waterways. Lal (1988) summarized many studies and concluded that natural world wide erosion amounted to 9.9 billion tons of soil a year, whereas human-induced accelerated erosion was 2.5 times higher at 26 billion tons per year. Brown (1984) estimated that globally, annual soil loss is as high as 23.4 billion tonnes over and above the amount of soil produced. After conducting much research on this subject, Bentley (1985) concluded that the American national average annual soil loss was about 11.2 t ha^{-1}.

2.1.2. Yield Losses

Although the loss of soil is an undesirable process, it is the resulting loss in productivity that is truly alarming. Unfortunately the process of soil erosion is not taken seriously until it becomes a direct threat to our supply of food. It is this threat that drives the fight toward implementation of conservation techniques.

Soil erosion has been found to be a threat due to the associated reduction in soil productivity. A high degree of correlation between the areas affected by severe soil erosion and those prone to large food deficits has been found (Lal, 1988). Africa, for instance, has the vicious cycle of erosion induced soil degradation resulting in a decline in land productivity.

Studying corn grown on artificially exposed subsoil and on unaltered surface soil, Engelstad and Shrader (1961) found that the subsoil yielded 3136 kg ha^{-1} less than the surface soil. Adams (1949) found yield reductions of 34-40% when comparing corn, cotton and oats grown on eroded and slightly eroded Piedmont soils. McDaniel and Hajek (1985) conducted a study of slightly and moderately eroded areas and found that 65% of the moderately eroded sites showed yield reductions.

A simulated erosion experiment was set up by Pettry et al. (1985). Treatments consisted of four levels of topsoil, 22.5 cm, 15 cm, 7.5 cm, and 0 cm of the Ah horizon. Two years of research under variable climatic conditions showed that yields decreased as the amount of topsoil decreased. Tanaka and Aase (1989) also found, using simulated erosion, a decrease in grain yields with an increase in topsoil removal. The 0.18 m soil removal treatment yielded only 45% of the control treatment of no topsoil removed. Thompson et al. (1989) also found yields to decrease with a decrease in the Ap horizon on Cecil soils in the Virginia Piedmont.

2.1.3. Dollar Losses

The best way to attract attention to a specific subject matter is to assess it in terms of economic loss. Having stated that soil erosion results in a loss of soil and losses in productivity, how does this equate in terms of the dollars lost due to soil erosion?

Battiston et al. (1985) found that conservative estimates of erosion-induced row crop yield reduction indicate that the annual cost of sheet and rill erosion to the agricultural production in the province of Ontario, Canada, which is directly attributed to yield losses alone is, about $27 million. Another $40 million are lost because of the nutrient and pesticide losses.

2.2. Changes to the Soil Due to Soil Erosion

There are many changes that occur to the soil due to the process of erosion. It is these changes that work together to result in a loss in crop productivity. There are changes to the available water holding capacity, the rooting depth, available nutrients, amount of organic matter and the general soil physical conditions. Soil erosion exposes subsoils to the surface that are generally less fertile and more restrictive to crop growth. Erosion also enhances other degrading processes such as leaching, acidification, compaction and biological degradation (Lal, 1988). The changes and ultimate destruction of these properties due to erosion causes a decrease in productivity (Pierce et al. 1983).

2.2.1. Root Zone Depletion and Exposure of Subsoils

Soil erosion results in an actual loss in depth of the profile. The volume of soil from which water and nutrients can be extracted by the roots is decreased, decreasing vital and necessary supplies to the plant. A root zone depletion also results in a decrease in the water holding capacity of a soil.

A decrease in the root zone is caused by surface removal of topsoil. The topsoil, usually the darkest part of the profile being removed means that the lower soils are exposed giving the soil a lighter color. This resulting lighter color of soil will cause a decrease in soil temperature. Subsoils may also contain excess salts, toxic substances, and layers that may be mechanically impervious to plant roots or water.

The subsequent effects of such changes are mentioned in the following sections.

2.2.2. Nutrient Losses

Nutrients can be lost from the soil in a number of ways. Soluble nutrients can be lost in the runoff waters or leached out of the soil profile. Nutrients are in close association with soil sediment and can be carried off while adsorbed to soil particles or soil organic matter. Nutrient loss due to soil erosion is one of the most degrading facets of soil erosion. This is the greatest cause of loss in fertility.

Many researches studying sediment losses have found that an increase in sediment loss results in an increase in organic nitrogen loss. Burwell et al. (1976) concluded that any practice that reduces the loss of sediment would reduce the loss of nitrogen associated with the sediment. Studying the eroded sediment Stoltenberg and White (1953) found it to contain more organic matter, nitrogen, available P and available K than the original soil. In another study, Hays et al. (1948) compared a moderately eroded and severely eroded soil with respect to their nutrient status. It was found that the moderately eroded soil had twice as much organic matter and nitrogen than the severely eroded soil in the top 15 cm, clearly illustrating the detrimental effects of erosion on topsoil.

2.2.3. Biocide Losses

With the ever increasing concern for the environment, the erosion of chemicals such as herbicides, fungicides and insecticides needs close surveillance. These chemicals, used to alleviate a variety of crop pests, are often applied directly to the soil surface. Many are applied prior to planting, a time when the soil has no cover and thus is particularly vulnerable to erosion. Most pesticides adhere to soil particles thus remaining at or very near the soil surface. Since there is a strong adsorption to soil particles they are easily lost as particles are carried away by erosion. Some chemicals are also soluble in water, making their loss as dissolved chemicals in the runoff water high.

The same holds true for fertilizers. They too are lost from the soil via sediment loss, and because of their solubility, via runoff loss.

Since many biocides and fertilizers are applied outside the growing season, they are easily carried or washed away due to a lack of crop cover. Zachar (1982) estimated that up to 40% of applied matter can be carried from the field and end up in the water systems.

2.2.4. Textural Changes

Textural changes that occur in the soil due to erosion are particularly damaging because the effects are irreversible. Generally wind erosion removes particles 0.1-0.15 mm in size, the silt fraction of the soil (Chepil, 1945). Frye et al. (1982) found, this selective separation to result in a higher clay content in eroded areas. Such a textural change leads to an increase in bulk density which can impede germination and root penetration. The increase in physical resistance to a plant can deter growth to depths necessary for water extraction by the roots. Clay soils also adsorb water strongly and decrease plant available water. This change in texture changes the total pore space and pore size distribution within the soil, altering its moisture regime and water transmissibility. The high clay content decreases the hydraulic conductivity thus decreasing the infiltration rate of water at the surface of the soil.

Soil erosion selectively removes soil particles changing the original texture of the soil permanently, an effect of erosion that can not be remedied by simply increasing fertilizer or irrigation.

2.2.5. Soil Crusting and Soil Sealing

Another result of soil erosion is the development of a soil crust due to losses of organic matter and soil aggregates from the surface soil. As the soil surface dries, components of the soil cement together forming a crust. The development of a soil crust can result in poor seedling emergence especially of a small seeded crop such as canola. Nuttall (1970) found that as the soil crust increased, the physical resistance to an emerging seedling increased, therefore reducing the number of plants emerging. Miller et al. (1988) studying the effects of erosion on crop emergence found lower seedling emergence and higher soil crust strength under simulated rainfall conditions on moderately and severely eroded soils than on slightly eroded soils.

Soil crusting also inhibits the rate of water infiltration, thereby increasing runoff. Soil crusts can eventually develop into soil seals that reduce aeration. Vital gaseous exchange between the soil and the atmosphere is reduced which can cause changes in the microbial population and also inhibit root growth because of an oxygen deficiency.

Soil crust strength was found by Hirch (1984) to increase as topsoil was removed. Such a condition will create an increase in runoff and a decrease in infiltration rate, all contributing to a degradation in soil conditions.

2.2.6. Infiltration Rate

Infiltration of necessary water is reduced due to erosion because of an increase in soil sealing which leads to an increase in runoff (Massee and Waggoner 1985). This reduced infiltration rate may also lead to water ponding which can delay seeding. Ponding can also saturate soils greatly inhibiting young seedling growth. The reduction in infiltration becomes a loss in available moisture to the crop.

2.2.7. Soil Temperature

Another soil characteristic that is altered by soil erosion is soil temperature. Many researches have found that as the soil surface, rich in organic matter and crop residue is removed the lighter colored subsurface layers are exposed. This change in color leads to a decrease in solar energy absorption and soil warming. Black and Greb (1968) found a marked change in dry soil color in each of their incremental soil removal treatments. Studying reflectance and temperature of different soil removal treatments, they found a gradual decrease in soil temperature with each increased soil removal increment. This change in soil temperature led them to conclude that nutrient uptake and other plant growth factors may be influenced by a change in soil color and the consequent change in soil temperature. A delay in plant maturity by 3-5 days was also observed due to the decrease in soil temperature.

Mackay and Barber (1984) found that a decrease in soil temperature resulted in a decrease in phosphorus uptake by corn. An intense investigation of their findings drew them to conclude that the most pronounced effect of temperature was on the root growth which increases root surface area for greater phosphorus absorption.

Power et al. (1964) using barley, also found that ion absorption, ion translocation and plant respiration decrease as soil temperature decreases.

2.2.8. Soil Erosion Effects on Crops

Hayes (1965), studying crop protection, found that moving soil could be extremely detrimental to crops. The abrasive action of moving soil can destroy a crop in a matter of minutes. A prairie sand storm occurring due to high winds and arid conditions can sand blast a young crop, perforating its leaves or in severe cases causing complete removal of the leaves.

Erosion causing soil displacement can expose plant roots and reduce plant stability. On the other hand the deposition of eroded soil can cause the burial of young plants. Plant diseases may also be spread by blowing soil from one place of epidemic to another.

Soil erosion usually occurs when the crop cover is relatively low, hence the direct physical damage due to soil erosion occurs when plants are in the most vulnerable seedling stage.

2.2.9. Effect of Soil Erosion on Available Water

Although soil erosion affects many aspects of the soil profile, it is currently thought that productivity is reduced mainly because of the reduction in available water holding capacity. Batchelder and Jones (1972) found that the most costly and difficult problem to rectify on subsoils is that of insufficient water.

The reduction is a result of a reduced root zone because of the removal of topsoil i.e. a reduction in the volume of soil from which plants can extract water. Soil erosion also causes textural changes. Eroded soils generally have a higher clay content than uneroded soils which makes water extraction by the plant more difficult. With the aid of irrigation it has been found that some yields of eroded fields can be increased over rainfed conditions. Eck (1968) found that on fields where varying increments of topsoil had been removed, additions of large amounts of nitrogen and phosphorus fertilizers could not restore yields. but when combined with supplemental irrigation yields could be restored. Massee and Waggoner (1985) in their experiments with simulated erosion found that the most productive plots extracted the most soil profile moisture demonstrating that loss of available moisture will have serious implications on the development of crops.

2.2.10. Changes in Organic Matter

Organic matter, found in greatest proportion at the top of the soil profile, is one of the vital soil components lost when soil is allowed to erode. Since it dictates to a large degree the condition of a soil, its loss causes many changes in soil properties such as soil porosity, soil aeration and soil stability.

Lyles and Tatarko (1986) studying the changes in soils eroding over a period of 36 years, found that in 8 out of 10 sites, organic matter declined. This decline averaged to 0.53% of the existing organic matter per year.

Organic matter also acts as a cementing agent thus aiding in good soil aggregation and making the soil less susceptible to erosion. Loss of organic matter can therefore perpetuate the process of soil erosion.

2.3. Off-Site Effects of Soil Erosion

Most of the studies on soil erosion focus on the agricultural aspect of erosion. Research has been done evaluating the costs of the effect of soil erosion of the field. The losses and changes that occur to a soil due to soil erosion have been closely studied with far less attention focusing on off-site effects and costs of soil erosion. The off-site damages of soil erosion are important in that they affect a far greater range of people and places, rural and urban and costs are believed to be two to three times higher than on site damages. With the decade of the 90's showing a great concern for environmental awareness, the effect of soil erosion on the environment is of top interest.

Some effects associated with soil movement include eutrophication of lakes and streams, sedimentation of waterways and reservoirs, filling in of ditches, and soil particulate pollution (Beasley et al., 1985). With the estimate of tons of soil being moved a year, the deposition of these soils into non-agricultural areas is inevitable. There is an increase in household interior and exterior cleaning, a reduction in recreational opportunities, an increase in machinery maintenance and adverse health impacts. Piper (1989) found that off-site damages from wind erosion appeared to be larger than on-site damages because of the extensive particulate pollution damage. Off-site household costs from wind erosion in Western United States were estimated to range from $4-12 billion annually (Piper 1989).

With this current high concern for the environment, nutrient pollution is also a cause for major concern. Due to nutrients dissolving in runoff waters, many lakes and streams have been polluted by high concentrations of nitrates and phosphates in the water (Waucope, 1978). Many of the sudden rampant algal infestations of recreational waters have been blamed on the additions of phosphates from agricultural fields to the water systems. Clark (1987) found that nutrient induced algal blooms can make a fish within a water body toxic.

The environment is of top priority in the minds of the agricultural society, the non-agricultural society and in all levels of government. Therefore, any threat of destruction of water systems will be carefully examined in the future.

2.4. Measurement of Soil Erosion

It has been established through research that soil erosion reduces yields and causes many off site damages. However, accurate measurement of actual soil erosion is relatively difficult. Erosion is a gradual process, the effects of which can not easily be deciphered.

Since there is much variability in agricultural production, assessing the specific effects of soil erosion is very difficult. Crops are influenced by weather, moisture availability, disease, pests, farming procedures and of course, soil erosion. To determine the effects of each individual factor is virtually impossible. Also, technology is advancing at a rapid rate and may be masking the effects of soil erosion. Walker and Young (1986) found that ignoring technological progress in erosion damage assessment can lead to serious bias. Some areas may be very vulnerable to soil loss but have deep subsoils suitable for cultivation. This would result in a lack of appreciation of the magnitude of soil erosion since productivity may be unaffected by this loss in topsoil.

2.4.1. Methods of Measurement

One simple method of determining changes on soil movement is to transect the ground with a series of graduated pins (to a predetermined depth). Measuring the amount of exposed pin over time provides a rough estimate of the amount of soil moved (Gleason, 1957). Such a method has drawbacks in that the pin may enhance erosion by causing flow convergence that could result in the formations of rills.

Paint collars can be sprayed on to reference points such as large rocks or fence posts at the soil level (De Ploey and Gabriels, 1980). Changes in soil level relative to the collar indicate soil movement.

Catchment methods are also used to determine soil loss. This involves small bounded areas and is usually more expensive, more labour intensive and requires more elaborate equipment (Young and Onstad 1987). This could include small runoff plots and watersheds that measure runoff and soil loss. There are many problems inherent to such a system. One of the most important is the amount of time necessary to collect enough valid data. Several years are necessary to obtain data sufficiently reliable for research and conservation planning.

To reduce the amount of time required, erosion may be brought about artificially. Rainfall simulation has been developed to test soil loss of a given area (Meyer, 1988). This method allows control of the intensity and duration of a rainfall, as well as the location, timing and also the plot conditions at the time of the event. Studies that could take years of waiting for natural rainfall events can now be rapidly studied under controlled levels of all factors.

Similarly, simulated erosion has been used to test the effects of productivity losses due to soil erosion. Rather than waiting years for an area to erode before studies can proceed, simulating erosion allows us to study the effects of a process very similar to actual natural erosion.

For purposes of studying the effects of soil erosion on productivity, artificially removing topsoil is the best means of mimicking the natural process of topsoil removal. It is a rapid, simple and relatively inexpensive technique (Lal, 1988). There are obvious differences in the soils resulting from natural erosion and those resulting from simulated erosion but it is the best method to date. Although there are differences, simulated erosion used to determine reductions in yields is a means of demonstrating that soil erosion adversely effects productivity thus enhancing the awareness and encouraging implementation of conservation techniques to maintain soils and land productivity.

2.5. Models Used To Estimate Long Term Soil Erosion

Predicting effects of soil erosion in the future can aid us in making wise land management decisions today. This can be achieved by gathering enough data to predict the outcome of erosion events based on the influence of specific factors. The estimation of soil loss has been of particular interest to a number of researchers. Woodruff and Siddoway (1965) and Chepil and Woodruff (1963) developed equations to estimate soil loss due to wind erosion, while Wischmeier and Smith (1965) worked on equations that estimated soil erosion due to water erosion. Such equations predict soil loss. Also of interest, would be estimating the effect of soil loss on productivity.

In recent years, through the use of mathematics and computer programs, it has become more feasible to model the effects of erosion on productivity. Different factors that affect productivity in different ways are used with varying degrees of influence to assess how changes to soil profile characteristics cause changes to potential yields. These models help to estimate crop yields thereby allowing management decisions to be made that optimize crop productivity.

2.5.1. The Universal Soil Loss Equation (USLE)

One of the most widely used equations developed to predict soil loss is the USLE. This equation identifies the major factors that affect accelerated water erosion and uses them in an equation to predict the amount of soil lost. The equation is as follows

$$A = R\ K\ L\ S\ C\ P$$

where A is the predicted amount of soil lost in metric tonnes per hectare per year. It is the product of six factors that interact to result in a net soil loss from a given field. Briefly the factors are R, a rainfall and runoff factor; K, a soil erodibility factor; L, a slope length factor; S, a slope gradient factor; C, a cover and management factor; and P, an erosion control practice factor. The factors that have a role in determining the extent of erosion are the rainfall-runoff factor, the cover-management factor, and the erosion-control practice factor. A detailed description of each factor is given by Brady (1984) and an example of use of the equation is given by Peterson (1979). The USLE has proven to be one of the most efficient means used to estimate soil loss.

2.5.2. The Erosion-Productivity Impact Calculator Model (EPIC)

Although assessing soil loss is important, the affect of soil loss on productivity is more enlightening. Being able to predict the losses in productivity due to erosion can make clear to the producer that control measures are necessary if good productivity levels are desired and to be sustained. This is the role of prediction models. One such model, EPIC, allows for such predictions (Williams et al. 1985). It takes into consideration eight main factors; hydrology, weather, erosion, nutrients, soil temperature, crop growth, tillage and economics. This model considers physical components that determine erosion and plant growth, and economical components to assess the cost of erosion and the optimal management strategies. Such a model allows us to "see into the future", assess the adverse effects of soil erosion on productivity and provide a basis for recommending control measures to stop the ultimate degradation process.

2.5.3. Productivity Index Model (PI)

The PI model relates root growth to soil properties within a profile in which soil properties are the factors constraining crop growth and ultimately yields (Gantzer 1985). The PI equation is

$$PI = \Sigma\ (Ai\ Bi\ Ci\ RIi)$$

where PI is the soil productivity index, Ai is the sufficiency of potential available water holding capacity for the ith layer, Bi is the sufficiency of bulk density, Ci is the sufficiency of pH, RIi is the weighting factor for the ith soil layer and n is the number of soil layers. It is assumed that the suitability of crop growth is the summation of suitability of each individual horizon. Each of the factors in the PI equation is related to sufficiency for growth with values ranging from 0 to 1, 1 being the ideal medium. This model is relatively simple to use and productivity lies in the idea that yield is related to total root growth which is in turn related to soil conditions (Rijsberman and Wolman, 1985). Changes in soil conditions due to soil erosion can be used to calculate changes in the PI of soils.

2.5.4. The Nitrogen-Tillage-Residue Management Model (NTRM)

Being able to assess erosion-productivity relationships rapidly, as opposed to waiting for actual erosion to take place and then seeing its affects on productivity, is the basis behind developing models and equations for prediction. The NTRM model is such a model (Shaffer, 1985). It simulates the impact of soil erosion on crop productivity. The interactions of a growing crop with the physical, chemical, and biological properties of a soil is the basis of the model. Inputs to the model include climatic variables, dynamic soil variables such as soil water content, bulk density, and nutrient concentrations, static field properties such as percent slope, slope length, and aspect and management inputs. This model shows the relationship of erosion and productivity, therefore making possible the long and short term assessment of management practices.

2.5.5. The Potential Yield Index (PYI)

The PYI is a model that estimates soil productivity based on simulated root growth, potential nutrient uptake and potential water uptake of a crop through the growing season (Craft et al., 1985). It assumes that root growth is sensitive to the soil environment and that soil erosion causes a change to the root environment. Craft et al. (1985), using the PYI model, found that corn productivity on soils that had 6 cm of simulated soil erosion was reduced if there was no fertility restoration. With original fertility restored, the soils had PYI predictions similar to the uneroded PYI predictions.

Models such as these can predict the effects of erosion on productivity and also show that technological inputs such as fertilizers can mask the effects of erosion. Such evidence can help to make unbiased assessments of soil erosion and aid in developing conservation programs that maximize the productivity potential of our land and soils.

2.6. Summary

The literature shows that soil erosion results in soil loss, yield losses and ultimately dollar losses. The process changes profile characteristics, decreases the rooting zone of a crop and results in a reduction in the productivity potential of a given area. Soil erosion not only affects the agriculture industry but also has adverse off-site impacts. Methods of erosion measurement have been developed as have models to predict soil loss and consequent reductions in productivity.

3. MATERIALS AND METHODS

Research field sites were developed in south-western Manitoba. Soil types varied and included a Newdale CL, Pembina CL, Reinland LVFS, Ryerson FSL, Waskada VFSCL, and Willowcrest FS.

3.1. Field Design

Six field locations were used for the 1987 and 1988 field experiments. The Newdale CL and Pembina CL sites were developed in 1983 and 1984, respectively. The Willowcrest FS was developed in the fall of 1985 and the Ryerson FSL and the Waskada VFSCL were developed in the spring of 1986. The Reinland LVFS site was constructed in the fall of 1986. Table 3.1 gives a description of the experimental sites.

The Newdale CL and Pembina CL sites were 0.33 ha in total area and the Ryerson FSL, Reinland LVFS, Willowcrest FS, and Waskada VFSCL were 0.71 ha in total area. The smaller sites had plot dimensions of 9.6 m square with pathways of 6 m within and among four replicates and the larger site plot dimensions were 16.8 m square with 5.6 m pathways within and among four replicates. The topsoil treatments consisted of 0, 5, 10, and 20 cm of topsoil removed. This was achieved by using a local municipal standard road maintainer.

Topsoil treatments were divided into three subplots and three fertilizer treatments were applied. The fertilizer regimes were (A) no fertilizer applied, (B) recommended rate of fertilizer applied based on soil tests, and (C) approximately double the recommended rate.

Table 3.1. Description of experimental sites.

Site Name Legal Description	Soil Name and Surface Texture	Classification and 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)
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)
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)
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 overlay strongly calcareous glacial till. (Eilers et al., 1978)
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)

Each topsoil removal treatment was replicated four times resulting in 48 subplots from each site. The sites were set up on a completely randomized split plot design with topsoil removal being the main plot treatment and fertilizer application being the subplot treatment (Figure 3.1).

Soil sampling was done in the fall of 1986 and 1987 on the middle two replicates to a depth of 90 cm (Appendices 1 and 2). The samples were air dried, bulked according to treatment, analyzed for nutrient content and assessed for fertilizer recommendations. There were only small variations in nitrogen, phosphorus and potassium among the topsoil removal and fertilizer treatments, therefore an average soil test value for each nutrient was used to establish the fertilizer recommendations.

3.2. Field Experiment, 1987

Experimental sites were prepared using conventional farming methods where ever possible. In the spring, the Waskada VFSCL and the Newdale CL were disced twice and the other sites were disced once, using a three-point hitch tandem disc. All nitrogen, potassium and sulphur was hand broadcasted before seeding and sites were disced at right angles to the previous pass to incorporate the fertilizer. The recommended rate of phosphorus was drilled in with the seed. For the higher rate of phosphorus, half was seed placed and half was drilled in below the seed. Sources of fertilizer elements that were used included 34-0-0 (NH_4NO_3), 12-51-0 ($NH_4H_2PO_4$), and 0-0-60 (KCL).

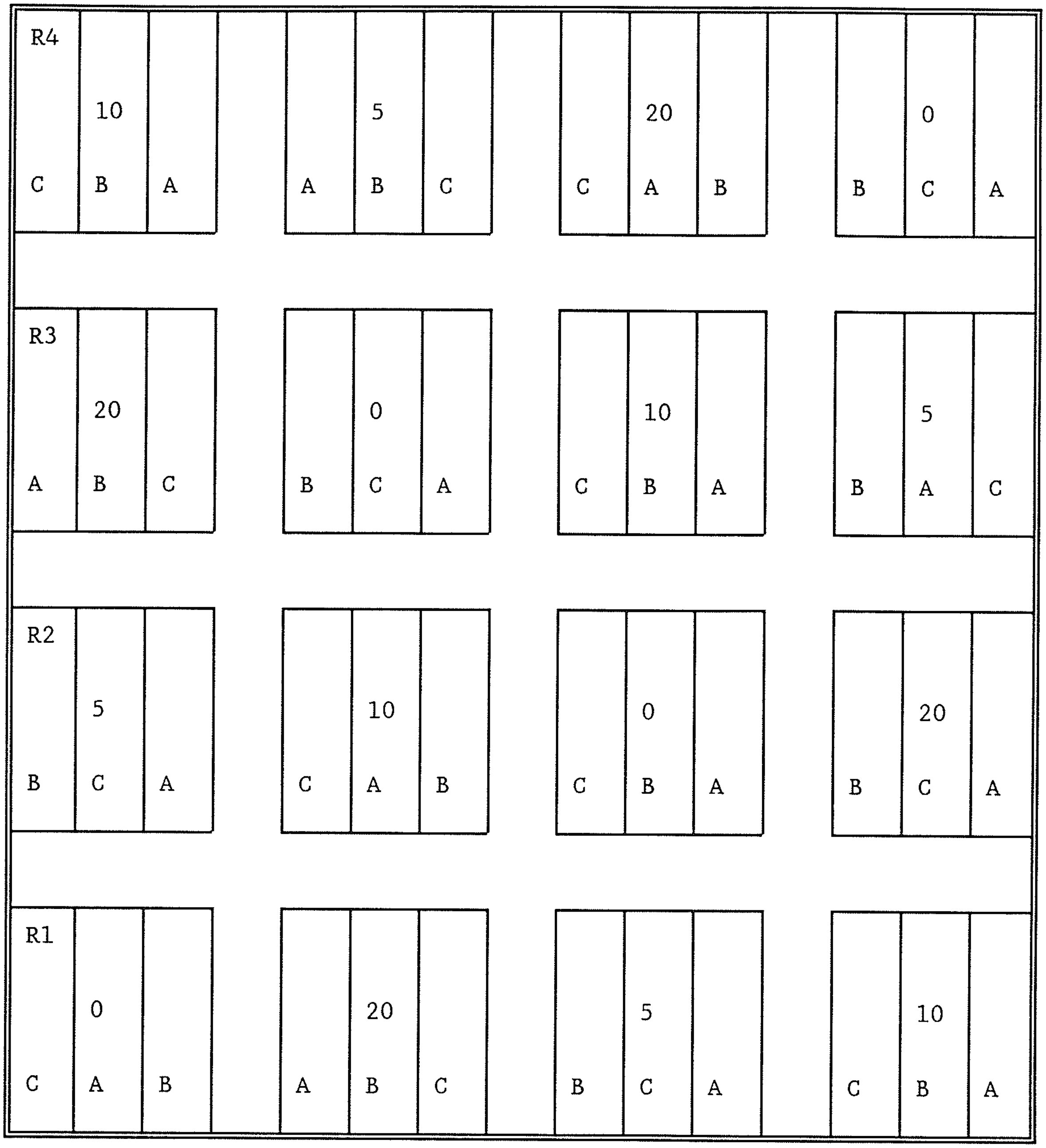

Figure 3.1. Plot diagram of the Newdale CL site.

Using a three-point hitch plot size seeder (144 cm in width with 18 cm row spacing), the sites were seeded to Columbus wheat (<u>Triticum aestivum</u>). Seeding rate was approximately 100 kg ha^{-1}. Table 3.2 shows seeding dates of experimental sites and rates of fertilizer used.

Table 3.2. Seeding dates and fertilizer rates of experimental sites, 1987.

Soil	Seeding Date	Fertilizer Rate	Fertilizer Element (kg ha^{-1}) N	P_2O_5	K_2O	S
Newdale CL	May 21	B	100	45	0	0
		C	200	90	0	0
Pembina CL	May 8	B	100	20	0	0
		C	200	40	0	0
Reinland LVFS	May 20	B	50	10	0	0
		C	100	20	0	0
Ryerson FSL	May 11	B	100	45	0	0
		C	200	90	0	0
Waskada VFSCL	May 11	B	100	45	0	0
		C	200	90	0	0
Willowcrest FS	May 7	B	100	45	15	0
		C	200	90	30	0

Many growth parameters were monitored throughout the season at each site. Emergence counts were made weekly along a one meter length on each topsoil treatment. Rainfall was recorded at the sites using recording and standard rain gauges. Where rainfall data was incomplete, missing information was obtained from Atmospheric Environment stations closest to the plots.

Herbicides were sprayed where necessary for appropriate weed control. All sites were sprayed with Bromox 720 at 0.78 l ha^{-1} for control of annual broadleaf weeds. Roundup was spot sprayed using a back pack sprayer for weed control on the periphery of the plots whenever necessary.

A midseason harvest was done approximately July 10, just prior to heading. Ten plants selected at random from each plot were dried, ground, and analyzed for nitrogen, phosphorus, and potassium content. The final harvest consisted of two representative square meters from each subplot. Samples were dried, and seed yields were determined. Averages of the two seed yields per subplot were calculated and taken as the final yield. Straw and seed samples were ground and nutrient analysis was conducted. Total nutrient uptake was calculated.

Data was statistically analyzed to determine the effects of the different treatments. Using a split plot design the effects of topsoil removal treatments and fertility treatments on yield and nutrient content were assessed. Analysis was also conducted to detect the presence of any interaction effect.

3.3. Field Experiment, 1988

In the spring, sites were disced to about 5 cm once, 'Treflan' was sprayed at 2.0 l ha^{-1} and the plots disced again to incorporate the herbicide. The herbicide was applied to control grassy and broadleaf weeds. All nitrogen, potassium, and sulphur were then hand broadcast on each subplot and the site was again disced to incorporate the fertilizer.

The recommended rate of phosphorus was drilled in with the seed and, for the higher rate of phosphorus, half was seed placed and half was drilled in below the seed to avoid any seed damage. Sources of fertilizer elements that were used included 34-0-0 (NH_4NO_3), 12-51-0 ($NH_4H_2PO_4$), 0-0-60 (KCL), and 21-0-0-24 ($(NH_4)_2SO_4$). Using a three-point hitch plot seeder, the sites were seeded to Westar canola (Brassica napus var. Westar). To help alleviate disease and insect problems the Westar canola was treated with Vitavex and Counter 5G. The seeding rate was 16 kg ha^{-1} (Table 3.3).

Table 3.3. Seeding dates and fertilizer rates of experimental sites, 1988.

Soil	Seeding Date	Fertilizer Rate	Fertilizer Element (kg ha^{-1}) N	P_2O_5	K_2O	S
Newdale CL	May 10	B	100	20	0	0
		C	200	40	0	0
Pembina CL	May 18	B	100	0	0	20
		C	200	0	0	40
Reinland LVFS	May 19	B	100	0	0	0
		C	150	20	0	0
Ryerson FSL	May 5	B	100	20	0	0
		C	200	40	0	0
Waskada VFSCL	May 5	B	50	0	0	0
		C	100	20	0	0
Willowcrest FS	May 13	B	100	20	35	20
		C	200	40	70	40

Field maintenance was the same as in 1987. Emergence counts were conducted weekly and rainfall was recorded. Weeds were controlled using a tank mix of 'Lontrel' and 'Poast'. Sites were sprayed to control Canada thistle (Cirsium arvensa), sow thistle (Sonchus spp.), green foxtail (Setaria viridis), volunteer barley (Hordeum vulgare) and quack grass (Agropyron repens). Tank mix rates were approximately 1.0 l ha^{-1} of 'Poast' and 1.6 l ha^{-1} 'Lontrel'. All sites received the tank mix application of herbicide with the exception of the Willowcrest FS site which received only a Poast application. Some hand rogging was done where spraying would have damaged the crop. A midseason harvest was done approximately June 30 when the plants were in full bloom and a final harvest was conducted approximately August 16. Midseason plant tissue and final harvest seed and straw tissue were analyzed for nitrogen, phosphorus and potassium content. Oil and protein content of the canola seed was also determined.

Data was statistically analyzed to determine the effects of the different treatments, by the same method used for the 1987 experiment.

3.4. Soil Analyses

The experimental soils were analyzed for many physical and chemical properties prior to topsoil removal. Physical analyses included bulk densities, field capacity, permanent wilting percentage, and available moisture (Appendix 3). Particle size analysis was also done for each soil (Appendix 4). Chemical analyses consisted of organic matter percentage, carbonate content, pH and conductivity (Appendix 5). Physical and chemical analyses of the soil were done by the methods described in Kenyon (1987).

3.5. Plant Analyses

Midseason plant samples, and final harvest straw and seed samples were analyzed for nitrogen, phosphorus, and potassium.

Total nitrogen was determined by digesting dried, ground samples in H_2SO_4 and Na_2SO_4-plus-catalyst digestion mix using a 1006 heating unit[1]. Distillation of the NH_3 into Boric acid and titration with HCl (Jackson 1958) were achieved using a Kjeltec Auto 1030 Analyzer[1].

To determine phosphorus and potassium a standard stock solution was prepared. 0.5 grams of plant sample, 2.5 ml of HNO_3 and 1.25 ml of $HCLO_4$ were put into digestion tubes and allowed to predigest for one hour. Samples were then further digested on a digestion block for 1.5 hours at 220°C. After samples cooled, solutions were vortexed and rinsed out of digestion tubes using deionized water into 25 ml volumetric flasks. This resulted in a stock solution with a dilution factor of 50.

A modified procedure by Murphy and Riley (1962) was used to determine the concentration of phosphorus in the solution. The PO_4^- ion was complexed with molybdenum causing the solution to turn a blue color. Absorbence of the solutions were then read at 885 nm on a 4050 UV/Visible spectrophotometer[2]. Further digestion of the sample was done according to the procedure of Chapman and Pratt (1961) and concentration of potassium was determined by atomic absorption using a model 560 absorption spectrophotometer[3]. $LiNO_3$ was used as an internal standard.

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[1]Manufacturer Tecator, Inc., P.O. Box 405, 2875C Towerview Rd., Herndon, Virginia 22070

[2]Manufacturer LKB, P.O. Box 2173, Baltimore, Maryland 21203-2173

[3]Manufacturer Perkin-Elmer, 761 Main Ave., Norwalt, Connecticut 68590-0010

3.6. Seed Analyses

To determine oil content of the canola seed the seed was heated for about 16 hours at 110°C to get a uniform 0% moisture content. A known weight of the seed sample was analyzed for hydrogen content using a Newport Wide Line NMR analyzer. This was then calibrated against a standard of known oil content.

Protein content of the seed was obtained by analyzing the seed for total nitrogen (refer to plant analysis of total nitrogen) and multiplying that value by the 6.25 protein conversion factor.

4. RESULTS AND DISCUSSION

4.1. 1987 Wheat Experiment Results

4.1.1. Precipitation

Throughout the growing season, experimental plots received normal or above normal precipitation (Appendix 6). The Willowcrest FS site had normal amounts of precipitation with the other three sites showing above normal levels of precipitation. Generally, the greatest amount of precipitation fell in the months of July and August.

4.1.2. Emergence Counts

Emergence counts conducted weekly for four to five weeks after seedling emergence were statistically analyzed to determine the effects of topsoil removal on seedling emergence (Table 4.1). There were no trends in emergence and no evidence to suggest that topsoil removal affected seedling emergence either adversely or otherwise.

4.1.4. Midseason Harvest

Nitrogen, phosphorus and potassium nutrient concentrations at midseason were found to be at sufficient[4] levels in the plants for normal crop development (Appendix 9). An analysis of variance was preformed on each site to determine the affects of topsoil removal and fertilizer application and their possible interaction.

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[4]Adequacy of nutrients based on criteria established by the Manitoba Provincial Soil Testing Laboratory (Appendix 7).

Table 4.1 Wheat emergence counts (plants m^{-1}), 1987.

Soil Type	Topsoil Removal (cm)	Date 5/22	5/26	6/02	6/03	6/09	6/10	6/16	6/25
Newdale CL	0	-	-	-	50a†	50	-	46	-
	5	-	-	-	44b	47	-	47	-
	10	-	-	-	47ab	47	-	49	-
	20	-	-	-	43b	42	-	42	-
Pembina CL	0	-	-	61	-	-	68	64	58a
	5	-	-	48	-	-	48	54	38b
	10	-	-	68	-	-	72	74	63a
	20	-	-	70	-	-	78	70	63a
Reinland LVFS	0	-	-	-	55	53	-	48	-
	5	-	-	-	46	46	-	54	-
	10	-	-	-	48	46	-	49	-
	20	-	-	-	57	54	-	59	-
Ryerson FSL	0	-	55	-	64	65	-	62	-
	5	-	58	-	64	63	-	56	-
	10	-	68	-	75	76	-	39	-
	20	-	60	-	61	59	-	63	-
Waskada VFSCL	0	-	22	-	47	55	-	36	-
	5	-	29	-	38	52	-	30	-
	10	-	26	-	47	58	-	42	-
	20	-	36	-	46	52	-	43	-
Willowcrest FS	0	26	48	60	-	62		-	-
	5	18	43	64	-	70		-	-
	10	28	43	59	-	62		-	-
	20	43	40	45	-	48		-	-

†Within site and date means followed by the same letter are not significantly different at Duncan's 0.05 level.

The Willowcrest FS, Waskada VFSCL and the Newdale CL showed significant differences ($P<0.05$) due to the subplot fertilizer treatments. The subplots that received the highest rate of fertilizer showed mean concentrations of nitrogen over all topsoil removal treatments significantly higher than the subplots that received no fertilizer. The Willowcrest FS site also showed significant differences due to the topsoil removal treatments (Table 4.2). Further analysis of the nitrogen concentrations showed mean concentrations of the 0 and 5 cm scraped plots to be significantly higher than concentrations from the 10 and 20 cm scraped plots at Duncan's 0.05 level.

Table 4.2. Split plot analysis of variance for midseason wheat tissue nitrogen concentration of a Willowcrest FS soil, 1987.

Source of Variation	DF	SS	F Value	PR>F
Replicate	1	2.62	9.18	0.0563
Topsoil	3	32.47	37.93*	0.0069
T × R interaction	3	0.85	0.03	0.9927
Fertilizer	2	172.75	8.92*	0.0092
T × F interaction	6	47.84	0.82	0.5822
Error	8	77.49		

*Statistically significant at the 0.05 level.

Phosphorus concentrations were generally not affected by the topsoil removal and fertilizer treatments. Potassium concentration at the Newdale CL site were found to increase with an increase in fertilizer application. The Willowcrest FS showed an interaction response where concentrations decreased as topsoil removal increased and fertilizer application decreased.

4.1.5. Final Harvest

4.1.5.1. Seed Yield

Due to an uncontrollable weed infestation and premature harvesting by the farmer only four of the six sites were harvested. Experimental sites showed a decrease in yields with an increase in topsoil removal where fertilizer was not applied (Table 4.3). Table 4.4 shows relative yields as a percent of yield obtained with no topsoil removed and the recommended rate of fertilizer for each experimental site.

The Newdale CL site showed depressed yields on the subplots where topsoil was removed and no fertilizer was applied. Yield with 20 cm of topsoil removed was about one half that without any topsoil removed where no fertilizer had been applied. Applying the recommended rate of fertilizer was able to overcome the removal of topsoil and doubling the recommended rate of fertilizer continued to increase yields. Means from the three fertility treatments were found to be significantly different with the highest fertility treatment resulting in the highest yield.

The Pembina CL site showed a continuous decrease in yields with a continuous increase in topsoil removal where no fertilizer was added. Yields where no topsoil had been removed were approximately 40% higher than where 20 cm of topsoil had been removed. Applying the recommended rate of fertilizer increased yields significantly above yields where no fertilizer had been applied for all topsoil treatments. There were no significant differences in yields between the treatments that received fertilizer (Figure 4.1).

Table 4.3. Effect of topsoil removal and fertilizer application on wheat yields (kg ha^{-1}), 1987.

Site	Fertilizer	Topsoil Removal (cm)				
		0	5	10	20	means
Newdale CL	A	2030	1429.	979	1090	1382c†
	B	3325	3022	2940	2992	3070b
	C	3586	3215	3498	3480	3445a
means		2980	2555	2472	2521	
T × F interaction				*		
Pembina CL	A	1240	988	840	724	948b
	B	2106	2070	2154	2242	2143a
	C	2201	2142	2192	2185	2180a
means		1849	1733	1729	1717	
T × F interaction						
Waskada VFSCL	A	2268	1615	1672	1312	1716b
	B	1905	2150	2259	2049	2091ab
	C	2331	2310	2310	2301	2313a
means		2168	2025	2080	1888	
T × F interaction						
Willowcrest FS	A	1765	876	842	645	1051c
	B	2220	1329	1635	1184	1592b
	C	2706	1718	1919	1390	1933a
means		2230‡A	1308B	1490B	1073B	
T × F interaction						

†Within site, fertility means followed by the same letter are not significantly different at Duncan's 0.05 level.
‡Within site, topsoil means followed by the same letter are not significantly different at Duncan's 0.05 level.
*Interaction significant at the 0.05 level.

Table 4.4. Relative wheat yield, 1987 (% of control topsoil treatment and recommended rate of fertilizer).

Site	Fertilizer	Topsoil Removal (cm)			
		0	5	10	20
Newdale CL	A	61	43	29	32
	B	100	90	88	90
	C	107	96	105	104
Pembina CL	A	59	47	40	34
	B	100	98	102	106
	C	104	102	104	104
Waskada VFSCL	A	119	85	88	69
	B	100	113	119	108
	C	122	121	121	121
Willowcrest FS	A	80	40	38	29
	B	100	60	74	53
	C	122	77	86	63

At the Waskada VFSCL site yields at the 20 cm scraped plot were approximately 60% of the control topsoil treatment where no fertilizer had been applied. Where no fertilizer had been applied means were significantly lower than where double the recommended rate of fertilizer had been applied.

The Willowcrest FS showed yields to be severely depressed when topsoil was removed for all fertilizer levels. Where no fertilizer was applied, yields for the 5, 10, and 20 cm scraped plots were 50, 48, and 36% respectively of the no topsoil removed treatment, each significantly lower.

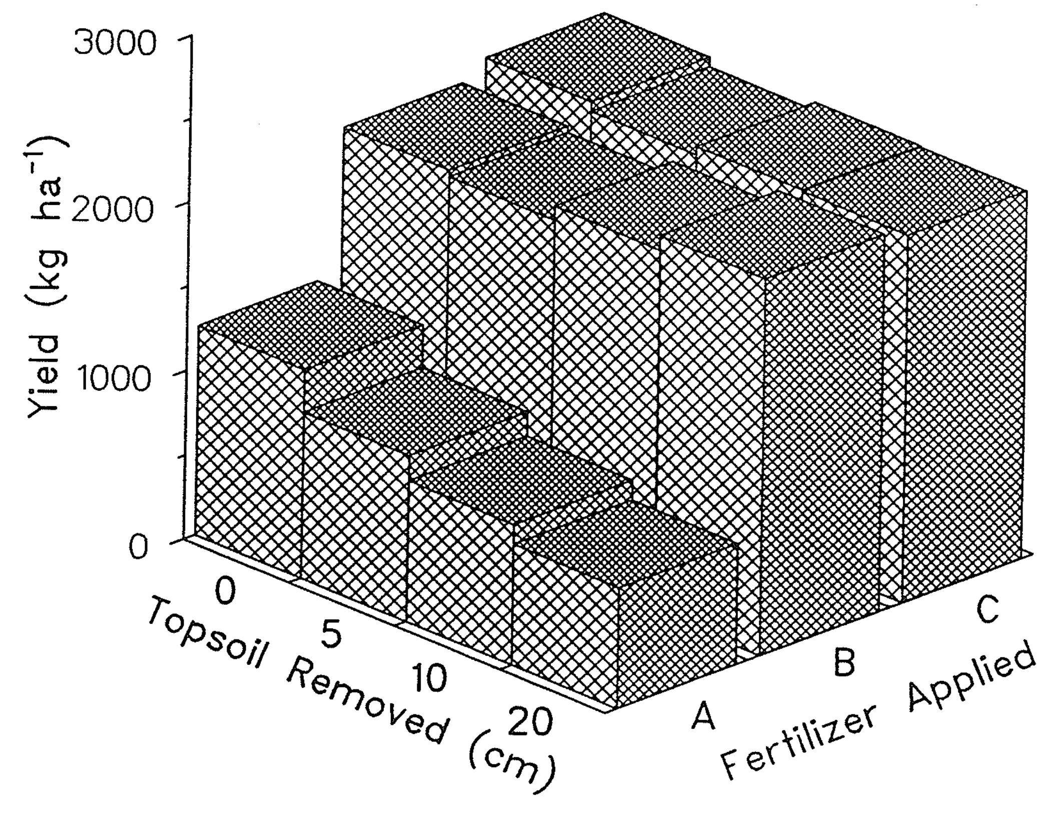

Figure 4.1. Effects of topsoil removal and fertilizer application on wheat yields of a Pembina CL soil, 1987.

The recommended rate of fertilizer raised yields but was not able to overcome the removal of topsoil indicative by the 20 cm scraped plot yielding only 53% of the control topsoil treatment at the recommended rate of fertilizer. Doubling the recommended rate showed an increase in yields but even this rate of fertilizer was not able to bring the yields back up to that of the control topsoil treatment. Where 20 cm of topsoil was removed and double the recommended rate of fertilizer was applied the yield was only 63% of the control topsoil treatment and the recommended rate of fertilizer. The subplot where no topsoil was removed and the highest rate of fertilizer applied yielded the highest. There were significant differences between the mean yields of all fertility treatments with yields increasing with an increase in fertilizer. Mean yields of the topsoil removal treatments showed the control topsoil treatment to be significantly higher than all the treatments where topsoil had been removed over all fertility treatments. Figure 4.2 shows the trends in yields due to the influence of topsoil removed and the rate of fertilizer applied.

4.1.5.2. Seed Nutrient Concentration

Nitrogen, phosphorus and potassium concentrations of the wheat grain were not affected by topsoil removal and fertilizer treatments (Appendix 10). Nitrogen tended to increase with an increase in fertilizer application at all sites but there were few significant differences. Phosphorus analysis showed virtually no differences and no trends between the various treatments of topsoil removal and fertilizer application. Similarly, potassium concentrations of the grain samples showed few differences and no trends due to applied treatments.

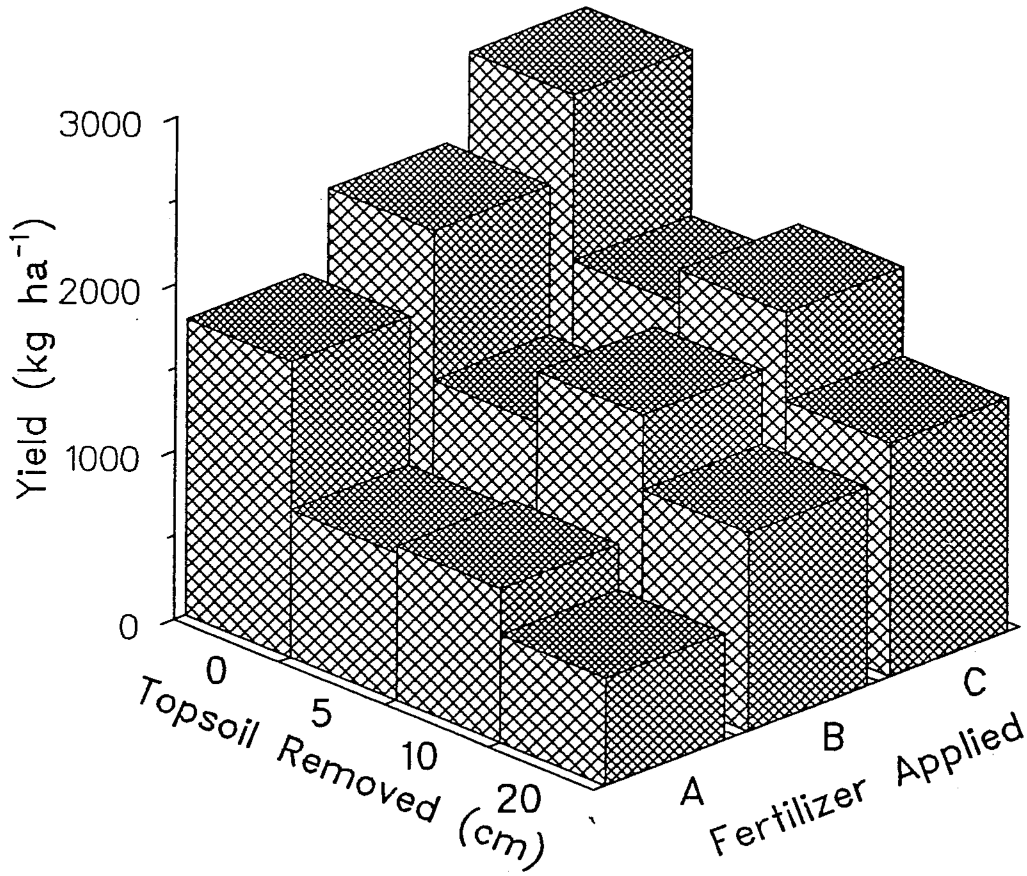

Figure 4.2. Effect of topsoil removal and fertilizer application on wheat yields of a Willowcrest FS soil, 1987.

4.1.5.3. Straw Yield

Straw yields were generally highest where no topsoil had been removed over all fertility levels and all experimental sites (Appendix 11). Yields were lowest where no fertilizer was added and greatest at the highest rate of fertilizer. There was no interaction response at any site. At the Newdale CL and Pembina CL sites where no fertilizer was added, means were significantly lower than means of the two levels of fertilizer applications at all topsoil removal treatments. Figure 4.3 shows the interaction of the different topsoil treatments and fertility levels at the Newdale CL site. The Waskada VFSCL site showed few trends of differences between any of the treatments.

Straw yields on the Willowcrest FS where no fertilizer was added were lowest. Where topsoil was removed mean yields were significantly lower than the control level of topsoil. Adding fertilizer increased yields over all topsoil removal treatments with the greatest yield obtained from the subplots that received double the recommended rate of fertilizer.

4.1.5.4. Straw Nutrient Concentration

There were few differences in the straw nutrient concentrations of the different topsoil removal and fertilizer treatments (Appendix 12). Nitrogen concentrations were lowest where no fertilizer had been applied, and increased with an increase in fertilizer application. Phosphorus concentrations showed no differences between the various topsoil and fertilizer treatments at any of the experimental sites.

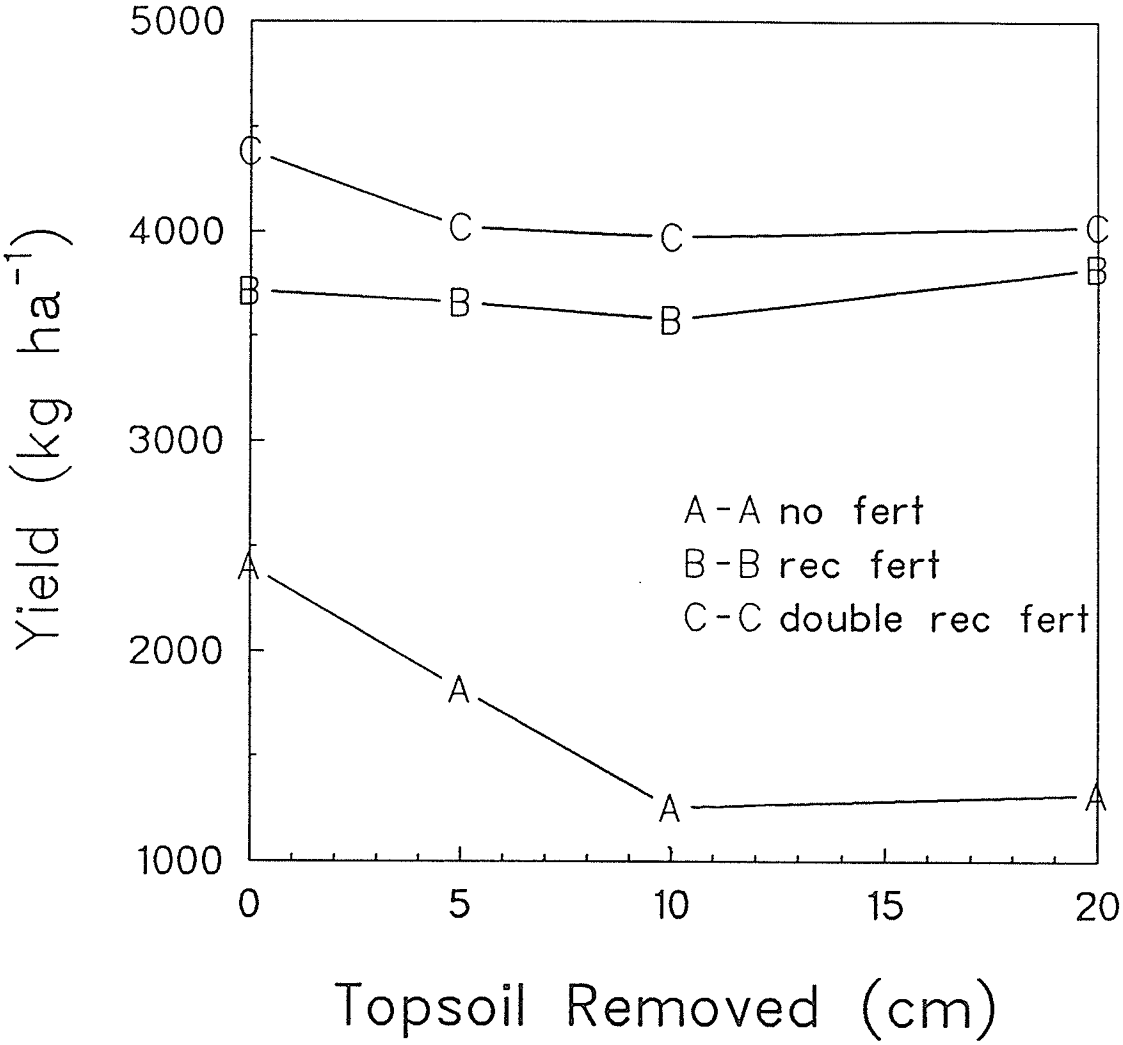

Figure 4.3. Interaction of topsoil and fertilizer treatments on wheat straw yields of a Newdale CL, 1987.

Potassium concentrations were greatest where double the recommended rate of fertilizer had been applied, but only slightly higher than concentrations from subplots that received the recommended rate of fertilizer. There was also a trend of decreasing concentrations with increasing topsoil removal.

4.1.5.5. Nutrient Uptake

Nutrient uptake by the plants was based on the seed and straw yields and nutrient content of the seed and straw. Uptake varied with fertilizer applications and topsoil removal (Appendix 13).

Nitrogen uptake was found to be lowest where no fertilizer had been applied at all sites. Means were significantly lower where no fertilizer had been applied than where fertilizer was added. The Willowcrest FS and Waskada VFSCL also showed significant differences between the means of the different topsoil removal treatments. Both sites showed the control topsoil treatment to be significantly higher than the 5 and 10 cm scraped plots which appeared statistically the same, and the means of the 20 cm scraped plots were significantly lower. These two sites also showed a significant interaction response indicating uptake levels generally increased with an increase in fertilizer application and generally decreased with increasing topsoil removal (Figure 4.4).

For phosphorus uptake, fertilizer treatments were generally all significantly different from each other with the means of the C rate being highest and the means of the A rate being lowest (Appendix 13). Significant differences were also found due to topsoil removal. The Willowcrest FS showed means of the control topsoil removal treatment to be significantly higher than all the plots where topsoil had been removed. The Waskada VFSCL site showed the 20 cm scraped plot to be significantly lower than all the other topsoil removal treatments and showed an interaction response.

The Pembina CL site showed the same trend and also was found to have a significant interaction response. Phosphorus uptake interaction responses generally decreased with increasing topsoil removal and the A rate of fertilizer was less than the B rate which in turn was less than the C rate of fertilizer.

All sites showed potassium uptake levels to be significantly different at each fertilizer application rate with the C rate of fertilizer showing the highest uptake and the A rate showing the lowest. Only the Willowcrest FS site showed differences due to topsoil removal. Where topsoil had been removed, potassium uptake levels were significantly lower than where no topsoil had been removed. There was also a significant interaction response, showing uptake to generally decrease with an increase in topsoil removal.

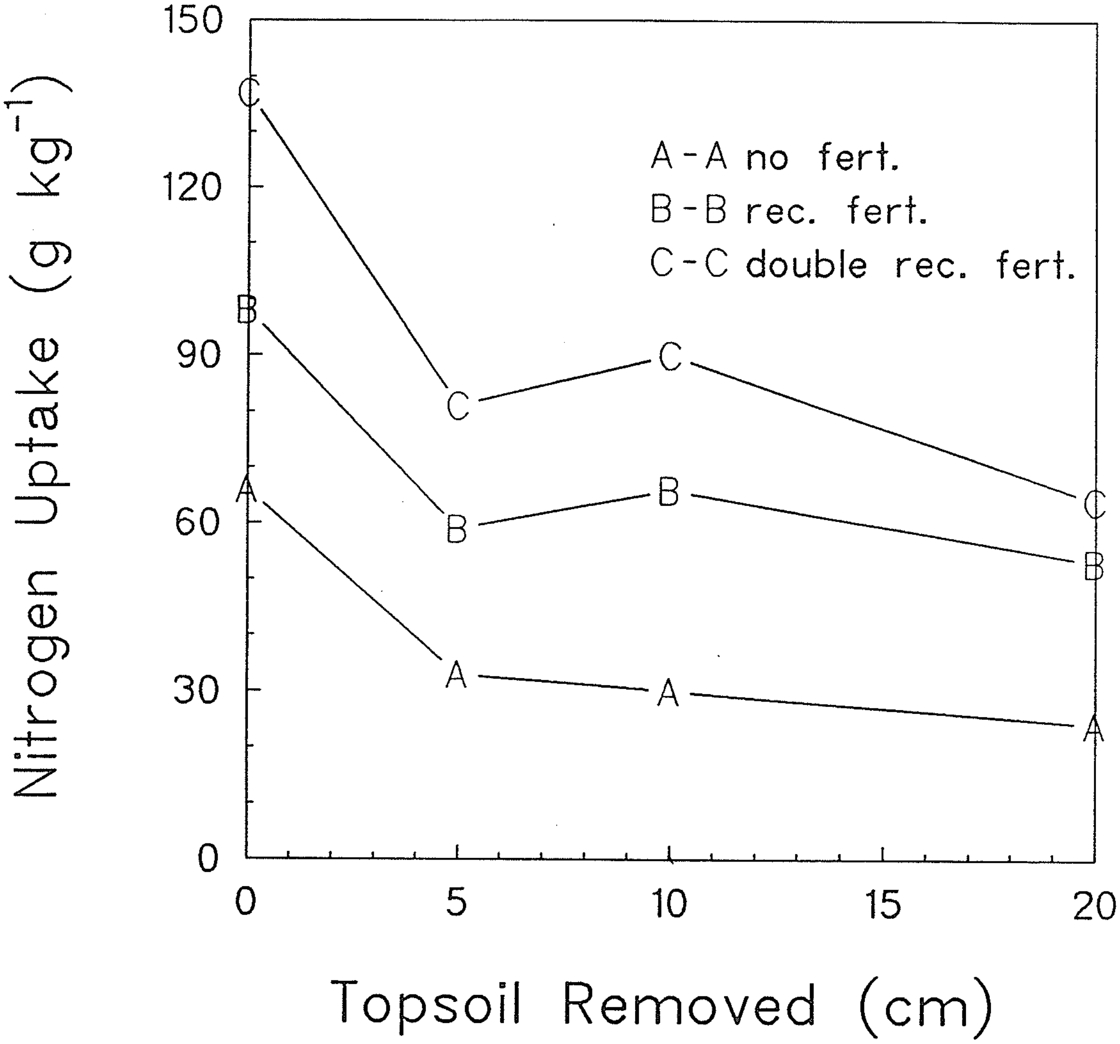

Figure 4.4. Interaction of topsoil and fertilizer treatments on the nitrogen uptake of a Willowcrest FS, 1987.

4.2. 1988 Canola Experiment Results

4.2.1. Precipitation

Precipitation throughout the growing season was considerably less than normal at all experimental sites (Appendix 6). The Pembina CL site received approximately half the moisture of a normal growing season with only 11 mm in June and a mere 0.4 mm in August. The Reinland LVFS and the Waskada VFSCL sites were also much below the normal seasonal precipitation.

4.2.2. Emergence Counts

There were no significant differences in crop emergence among the different topsoil removal treatments (Table 4.5) despite the fact that canola is a relatively small seeded crop and its emergence is often inhibited by soil crusts.

4.2.4. Midseason Harvest

Nutrient levels were sufficient[5] for normal crop development (Appendix 14) according to the midseason tissue analysis. Nitrogen concentrations were not affected by topsoil removal treatments but tended to increase with increases in fertilizer. The Willowcrest FS and Pembina CL showed nitrogen concentrations to significantly increase with an increase in fertilizer and the Reinland LVFS had a significant increase in nitrogen concentrations from where no fertilizer to where double recommended rate of fertilizer had been applied.

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[5]Adequacy of nutrients based on criteria established by the Manitoba Provincial Soil Testing Laboratory (Appendix 8).

Table 4.5. Canola emergence counts (plants m^{-1}), 1988.

Site	Topsoil Removal (cm)	5/24	5/30	Date 5/31	6/07	6/16
Newdale CL	0	-	-	34	41	40
	5	-	-	34	38	33
	10	-	-	26	55	34
	20	-	-	29	30	35
Pembina CL	0	-	26	-	26	25
	5	-	29	-	28	26
	10	-	29	-	28	30
	20	-	31	-	32	29
Reinland LVFS	0	-	-	41	40	36
	5	-	-	41	38	37
	10	-	-	37	37	33
	20	-	-	40	37	36
Ryerson FSL	0	48	44	-	44	-
	5	57	54	-	52	-
	10	60	60	-	56	-
	20	64	72	-	58	-
Waskada VFSCL	0	31	30	-	27	-
	5	34	31	-	21	-
	10	30	28	-	27	-
	20	37	34	-	33	-
Willowcrest FS	0	-	36	-	34	30
	5	-	32	-	30	29
	10	-	41	-	40	39
	20	-	39	-	38	36

†Within site and date, means with no letter notation or means followed by the same letter are not significantly different at Duncan's 0.05 level.

Although there was no significant interaction response, concentrations were generally found to increase as the fertilizer application increased and the topsoil removal treatment decreased.

Phosphorus concentrations were not affected by the topsoil removal treatments but the Willowcrest FS, the Reinland LVFS and the Ryerson FSL showed significant increases with increases in fertilizer. The first two sites showed an significant increase from the unfertilized treatment to the highest treatment of fertilizer whereas the third site showed a significant increase from the unfertilized treatment to the two fertilized treatments. There was no interaction response found.

There were no significant differences in potassium concentrations found at the Reinland LVFS or the Willowcrest FS sites but the Ryerson FSL showed the concentrations to be lowest where there was no fertilizer added. At the Pembina CL site concentrations were highest where double the recommended rate of fertilizer had been applied. There was no significant interaction response.

4.2.5. Final Harvest

4.2.5.1. Seed Yield

In 1988 two sites were lost due to the lack of precipitation. Canola yields on the four harvested sites decreased with increasing amounts of topsoil removed where no fertilizer was applied with a slight increase at the 10 cm scraped plots at three of the sites (Table 4.6). At all sites addition of fertilizer raised yields significantly above yields obtained from plots where no fertilizer had been added. There were no significant differences between means of different topsoil removal treatments at any of the sites.

The Ryerson FSL site showed increasing yields with increasing topsoil removal where fertilizer had been applied. Treatments that received no fertilizer were generally the same over all topsoil treatments. A significant interaction response occurred (Figure 4.5).

A significant interaction response was found at the Pembina CL site. Yields from the A and B fertilizer rates tended to decrease as topsoil removal increased with a slight increase at the 10 cm level of topsoil removal whereas the C rate of fertilizer showed a continuous increase in yields with an increase in topsoil removal.

An interaction response at the Willowcrest FS site showed yields to increase with an increase in topsoil removal for the recommended rate of fertilizer. Yields on A and C rates of fertilizer tended to decrease as topsoil removal increased (Figure 4.6). Table 4.7 shows relative canola yields as a percent of the control treatment.

4.2.5.2. Seed Nutrient Concentration

Nutrient analysis of the seed showed few variations among the different topsoil removal and fertilizer treatments (Appendix 15). Generally, nitrogen in the seed was found to increase with fertilizer application. Doubling the recommended rate of fertilizer on the field did not increase the nitrogen in the seed much above that found in the seeds that received the recommended rate of fertilizer.

Table 4.6. Effect of topsoil removal and fertilizer application on canola yields (kg ha^{-1}), 1988.

Site	Fertilizer	Topsoil Removal (cm)				
		0	5	10	20	means
Pembina CL	A	805	591	621	435	613b†
	B	1345	1344	1486	1309	1371a
	C	1096	1214	1372	1630	1328a
means		1082	1050	1160	1125	
T × F interaction				*		
Reinland LVFS	A	1874	1590	2077	1275	1704c
	B	2140	2091	2110	1868	2052b
	C	2055	2204	2628	2538	2356a
means		2023	1962	2272	1893	
T × F interaction						
Ryerson FSL	A	449	514	471	465	475b
	B	801	871	1016	1215	976a
	C	749	824	1130	1509	1053a
means		666	736	872	1063	
T × F interaction				*		
Willowcrest FS	A	1942	1301	1608	1239	1522b
	B	2500	2861	2908	2948	2804a
	C	2980	3354	2901	1948	2796a
means		2474	2505	2472	2044	
T × F interaction				*		

†Within site, fertility means followed by the same letter are not significantly different at Duncan's 0.05 level.
‡Within site, topsoil means with no letter notation or means followed by the same letter are not significantly different at Duncan's 0.05 level.
*Interaction significant at the 0.05 level.

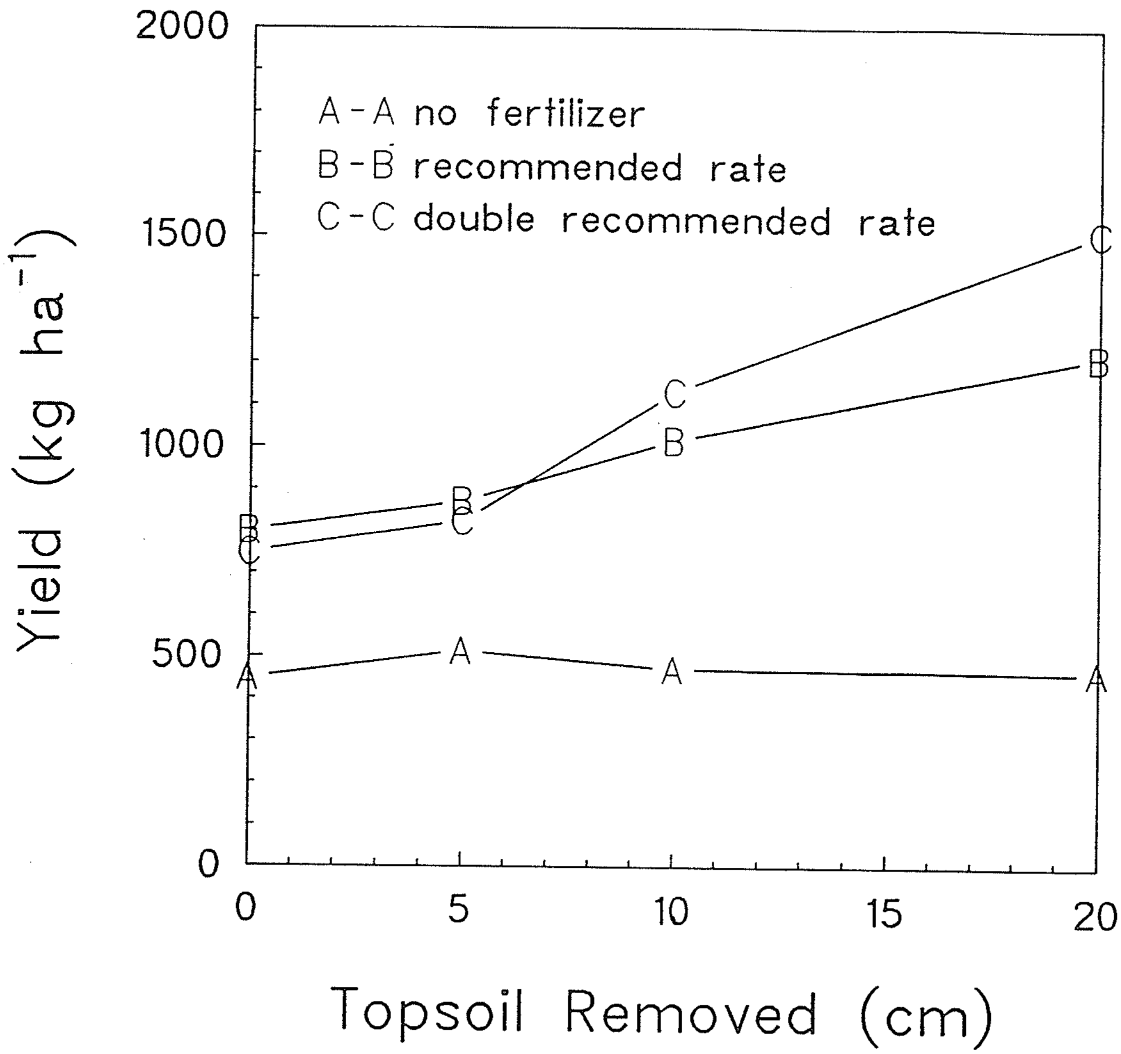

Figure 4.5. Interaction of the topsoil and fertilizer treatments on the canola yields of a Ryerson FSL, 1988.

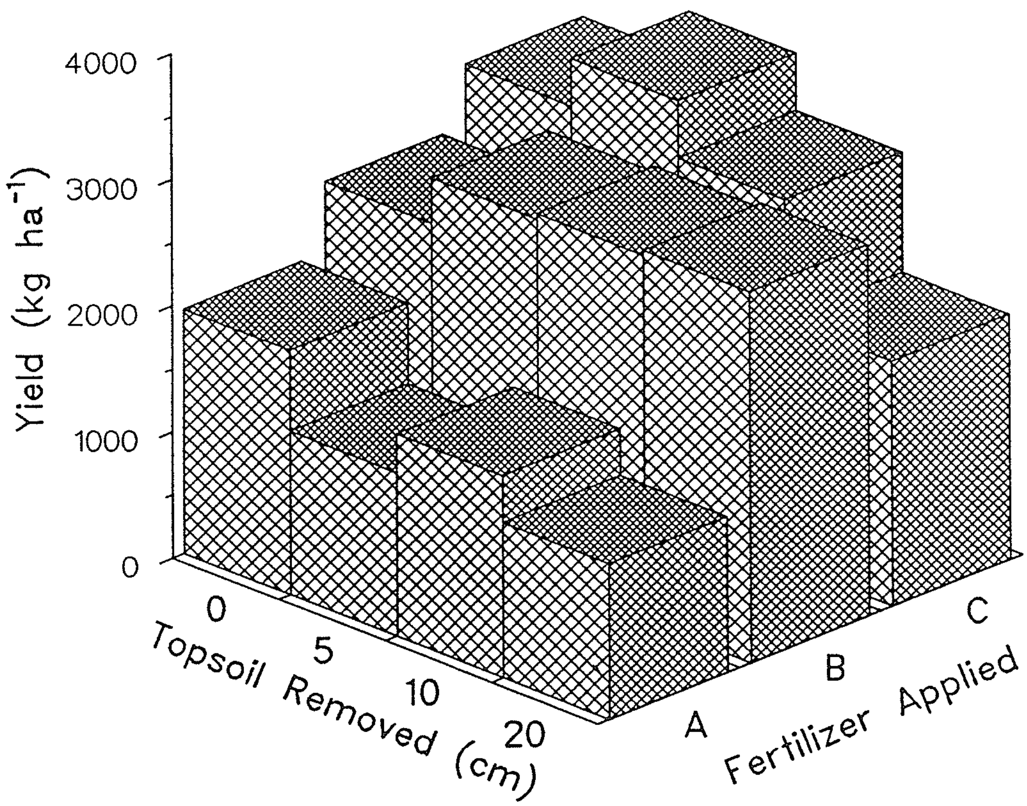

Figure 4.6. Effects of topsoil removal and fertilizer application on canola yields of a Willowcrest FS soil, 1988.

Table 4.7. Relative canola yield, 1988 (% of control topsoil removal treatment and recommended rate of fertilizer).

Soil	Fertilizer	Topsoil Removal (cm)			
		0	5	10	20
Pembina CL	A	60	44	46	32
	B	100	100	110	97
	C	82	90	102	121
Reinland LVFS	A	88	74	97	60
	B	100	98	99	87
	C	96	103	123	119
Ryerson FSL	A	56	64	59	58
	B	100	109	127	151
	C	93	103	141	188
Willowcrest FS	A	78	52	64	50
	B	100	114	116	118
	C	119	134	116	78

Phosphorus concentrations at the Willowcrest FS and Reinland LVFS showed means from the 5 cm scraped plots to be significantly higher than all other topsoil removal treatments. At Pembina CL site mean yields from the 10 and 20 cm scraped plots were higher than means from the 5 and 0 cm scraped plots.

There were no significant differences or interaction responses in potassium concentrations of the canola seed.

4.2.5.3. Seed Oil and Protein Content

Oil content of the seed varied little over the different topsoil treatments (Appendix 16). There was, however, a trend found at all sites based on the fertilizer applied. The oil content of the seed decreased with an increase in fertilizer application except at the Willowcrest FS site which showed no trends. Protein concentrations increased with fertilizer and decreased as topsoil removal increased. Again, differences were very slight.

4.2.5.4. Straw Yield

Straw yields were lowest where no fertilizer was added with the lowest yield at each site occurring where 20 cm of topsoil were removed (Appendix 17). All sites showed significant increases with fertility additions. On the Willowcrest FS and Pembina CL the C and B fertility treatments were significantly higher than the A rate of fertility. On the Reinland LVFS the C rate of fertilizer yielded significantly higher than the A and B rates. On the Ryerson FSL every increase in fertilizer significantly increased yield. The Reinland LVFS showed a significant interaction response with yields increasing with fertilizer and decreasing with topsoil removal.

4.2.5.5. Straw Nutrient Concentration

Nitrogen concentration in the straw varied due to fertilizer (Appendix 18). All sites showed the means of the A rate of fertilizer to be significantly lower than the means where fertilizer had been applied. The Willowcrest FS and Ryerson FSL showed the C rate of fertilizer means to be significantly higher than the means of the B rate of fertilizer. No interactions were observed.

Phosphorus concentrations in straw were significantly increased by fertilizer applications at the Ryerson FSL, the Willowcrest FS and the Pembina CL. Potassium concentration differences were found at the Pembina CL site where means of the B and C fertility treatments were significantly higher than means from the A fertility treatment.

4.2.5.6. Nutrient Uptake

Uptake was directly related to fertilizer applications at all sites for all nutrients (Appendix 19). The C rate of fertilizer showed uptake levels to be significantly higher and the A rate significantly lower than uptake levels recorded from the plots receiving the recommended rate of fertilizer. Uptake was also affected by topsoil removal.

Nitrogen uptake at the Ryerson FSL 10 and 20 cm scraped plots showed levels to be statistically higher than means from the 0 and 5 cm scraped plots whereas the Pembina CL site showed the 0 and 5 cm scraped plots to be significantly higher than the 10 and 20 cm scraped plots. These two sites showed significant interaction responses where nitrogen uptake increased with an increase in topsoil removal where fertilizer had been added at the Ryerson FSL and where double the recommended rate of fertilizer was applied at the Pembina CL site. The Willowcrest FS also showed an interaction response where uptake levels decreased with an increase in topsoil removal.

The Willowcrest FS site showed significant differences in phosphorus uptake due to topsoil removal. Where 20 cm of soil had been removed, mean uptake levels were significantly lower than all the other topsoil removal treatments. A significant interaction response (Figure 4.7) verified that uptake levels increased with increasing fertilizer application and were relatively stable along topsoil removal treatments until 20 cm of topsoil were removed. The Pembina CL site also showed a significant interaction response where increasing fertilizer increased uptake levels but levels were about the same for all topsoil removal treatments.

Potassium uptake differences due to topsoil treatments were few with only the Pembina CL site showing significant differences between means. All sites showed mean differences due to fertility treatments. In all cases, means from the A rate of fertility were significantly lower than means from the B and C rates of fertility.

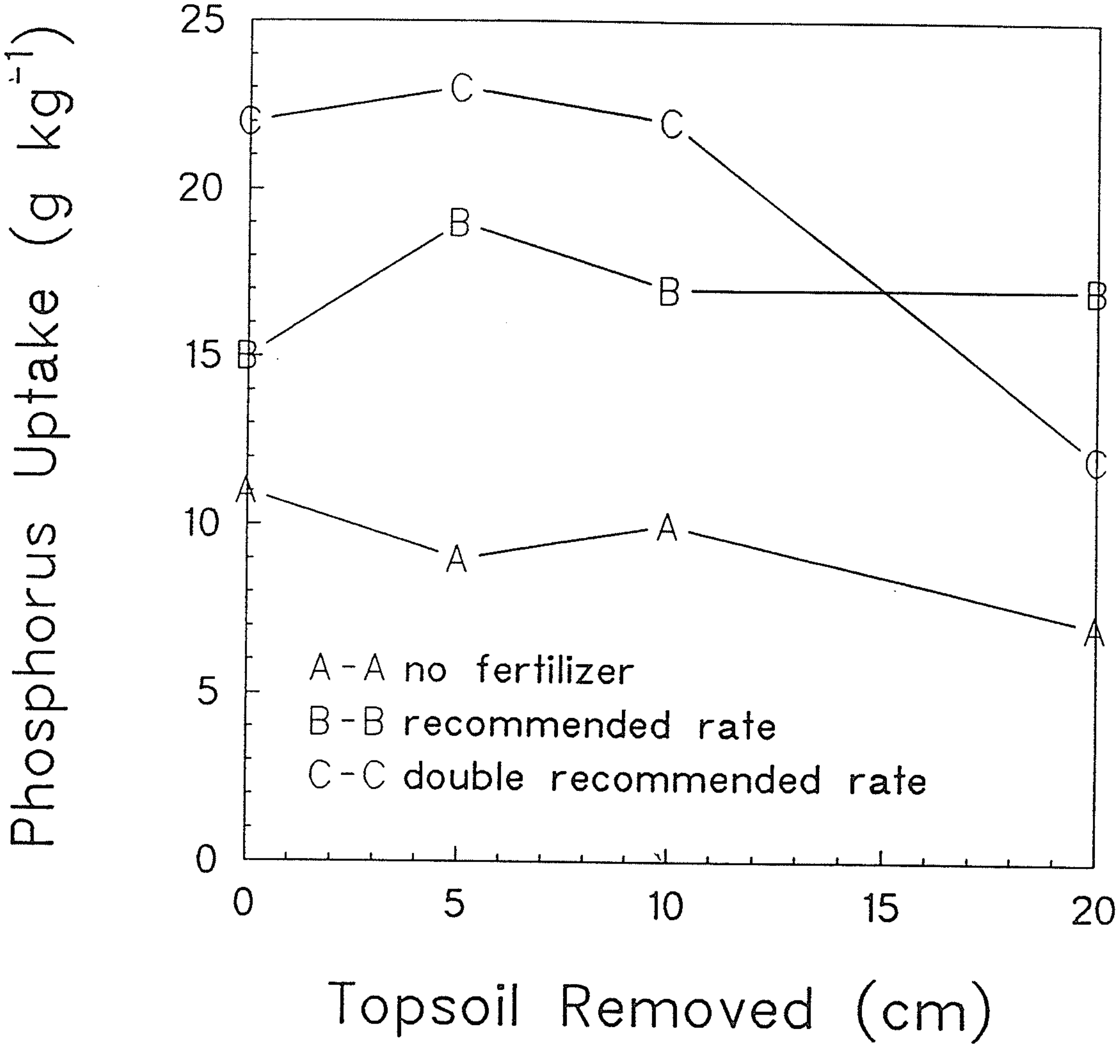

Figure 4.7. Interaction of the topsoil and fertilizer treatments on the phosphorus uptake by canola on a Willowcrest FS soil, 1988.

4.3. Discussion

4.3.1. Growing Season Events

For the 1987 growing season, crop germination and emergence were uniform under all experimental treatments. Wheat seedlings development was the same until approximately the third leaf stage. At this point fertilizer treatments became apparent. Where no fertilizer had been added for all topsoil removal treatments plants were smaller, thinner stemmed, and lighter colored than plants that received fertilizer applications. Plants that received the recommended rate of fertilizer appeared healthy and developed well throughout the growing season. The plants treated with the greatest amount of fertilizer were slightly taller than the plants fertilized with the recommended rate of fertilizer.

Final harvest was done approximately seventeen weeks after seeding and yield data was obtained from the Newdale CL, Pembina CL, Waskada VFSCL and the Willowcrest FS sites.

In 1988 canola emergence was the same under all topsoil removal treatments although appeared spotty and staggered. Seedlings at the cotyledon stage showed the effect of the fertilizer treatments. Where no fertilizer was added, plants were a pale green color, shorter and thinner than where fertilizer had been added. There were little differences between the plants under the two fertilizer addition treatments.

In the sixth week after seeding moisture stress became very evident. Plants started paling in color and curling around the stem. Blooming occurred in the seventh week when the plants were approximately 15 cm tall. At this time new germination was also occurring. The Newdale CL site seemed to suffer the greatest from the moisture stress showing very spotty growth and a hard, dry cracking soil surface.

Despite previously having bloomed, the Waskada VFSCL site bloomed again in the tenth week after seeding although still a mere 15 cm in height. Plants were pale and very weak.

In week twelve it became evident that the Newdale CL site would not produce a harvestable crop. The canola growth was very spotty and plants were short, pale and withering. The thistle was rampant and the ground hard and dry. Round Up was sprayed to kill off the crop and weeds and at the end of the growing season the area was deep tilled to break up the thistle root network.

In the fifteenth week the Waskada VFSCL site showed little hope of developing into an experimentally viable crop. Although pod development had occurred on the undersized plants, seed development was very poor. Many pods were empty and those containing seeds were very small and limp. Seeds were shapeless or flat. It was decided that this site was not useful for experimental analysis.

Final harvest was done at the Pembina CL, Reinland LVFS, Ryerson FSL, and Willowcrest FS sites in the sixteenth week after seeding.

4.3.2. Precipitation

For the 1987 growing season precipitation was normal or above normal for all experimental sites. Most of the precipitation in May occurred after seeding had taken place and this resulted in the development of a moist, rich seed bed allowing for good uniform germination and emergence. Moisture was abundant throughout the growing season and rainfall in the month of August prior to harvest resulted in a healthy good yielding crop.

In 1988, all sites showed precipitation to be well below the long term average. Most of the precipitation in the month of May occurred prior to seeding. Throughout the growing season precipitation occurred rarely and in small amounts. Moisture was lacking at the crucial stages of crop development. Seedlings were deprived of moisture resulting in slowed crop development from the start of the growing season. Plants at the reproductive stage at some sites were a mere 15 cm tall. Shortly after blooming moisture stress became very apparent and plants began to wilt and curl around their stems.

Precipitation proved to be a limiting factor reducing yields at all experimental sites. The unexpected behaviour of the crop yielding highest at the highest level of topsoil removal could have been caused by the moisture stress. Plants on the highly scraped plots may have been able to obtain moisture deeper in the soil profile than those of less eroded plots because their roots were closer to the water table. Plots may also have developed seals at the soil surface because of the lack of organic matter thus not allowing what little precipitation there was to penetrate the soil and pass into the profile. Yields at all sites were reduced, most likely due to a lack of precipitation.

4.3.3. Seedling Emergence

The literature shows that eroded soils are more likely to form crusts than uneroded soils (Hirch 1984, Nuttal 1970). Under simulated rainfall, Miller et al. (1988) found lower seedling emergence and higher soil crust strengths on moderately and severely eroded soils when compared to slightly eroded soils. Crust strengths are directly related to the silt content of a soil and generally, eroded soils have a higher silt and clay content. Due to rapid wetting and drying and this change in soil texture, eroded soils are more susceptible to soil crusting.

When erosion occurs naturally the process of topsoil removal is very selective. There is an enhancement in silt and clay content which leads to soil crusting. Artificially eroding soils, however, is not a selective process but rather removes all fractions of an horizon. There is no enhancement of silt and clay content.

To determine whether crusts were developing and impeding seedling emergence on the simulated erosion plots, weekly emergence counts were conducted. Neither the wheat or the small seeded canola showed any evidence of inhibited growth due to soil crusting or topsoil removal.

4.3.4. Soil Nutrient Content

Soil nutrient content before fertilizer application may have been a limiting factor to the growth of the crops (Appendix 1). In 1987 nitrogen was found to be generally low at all experimental sites where no fertilizer or the recommended rate of fertilizer had been applied the previous years. Only on the subplots where double the recommended rate of fertilizer had been applied the years before was nitrogen considered to be at a high enough level for good crop development. Phosphorus levels were found to be low or very low at all sites except the Pembina CL site where it was very high. Previous fertilizer application did not seem to have an effect on the levels of phosphorus in the soil. Topsoil removal on the other hand seemed to affect the amount of phosphorus found in the soil. As the amount of soil removal increased, phosphorus levels decreased.

Potassium in the soil was very high at all sites except the Willowcrest FS where it was low. There were no apparent trends in potassium levels due to previous fertilizer applications or topsoil removal treatments.

Since crop growth is directly related to the amount of available nutrients in the soil, this lack of vital nutrients on the A subplots could have been a factor responsible for the decrease in yields noted at these subplots in 1987. Although soil nutrient content was the same at the B rate of fertilizer subplots, the application of the recommended rate of fertilizer to these subplots was able to overcome this apparent lack of nutrients at all sites except the Willowcrest FS. At this site even where double the recommended rate of fertilizer had been applied, yields were not bought up to that of the control.

For the 1988 growing season nitrogen in the soil was low on the A rate of fertilizer subplots and high to very high where fertilizer had been applied the years before (Appendix 2). Phosphorus was found to be high at the Pembina CL. At the Reinland LVFS phosphorus levels were high where 0 and 5 cm of topsoil had been removed and low where 10 and 20 cm of topsoil had been removed. The Ryerson FSL and the Willowcrest FS both showed low levels of phosphorus on all subplots. Potassium levels were high to very high at all sites except the Willowcrest FS. That site had low levels of potassium over all treatments. All sites showed reduced yields on the A subplots which could be related in part to the fact that nutrients in the soil were not at sufficient levels for good crop development.

4.3.4. Midseason Tissue Analysis

Midseason nutrient concentration reflects the current status of the plant. According to the criteria used by the Manitoba Soil Testing Laboratory (Appendix 7), nitrogen, phosphorus and potassium were at sufficient levels in the plants at midseason in 1987. The general trend however at all experimental sites was that as fertilizer application increased, nutrient concentration increased (Appendix 9). The subplots that received no fertilizer were almost always the ones that showed the lowest midseason nutrient content. Although concentrations were sufficient at this time, nutrients in the soil may have been depleted after the midseason harvest resulting in yield decreases at these subplots.

In the 1988 canola experiment, nitrogen and phosphorus concentrations at midseason were sufficient (Appendix 8) at all sites under all treatments (Appendix 14). Again, the general trend was an increase in nutrient concentration with an increase in fertilizer application. Potassium was found to be low at all sites under all experimental treatments. This midseason indicator of potassium deficiency may have been a factor that resulted in a low yielding crop.

Nutrient deficiency may have had a significant influence on crop growth, development and yield. Plants that showed low nutrient concentrations were also the ones that exhibited typical nutrient deficiency characteristics of Brassica crops. They were pale in color, had relatively thin stems and were slow to develop. These were the lowest yielding plants.

4.3.4. Seed Yields

Yields were affected by both topsoil removal and fertilizer treatments. Often effects of topsoil removal where no fertilizer had been applied were not found to be significantly different when statistically analyzed. A separate analysis of yields without fertilizer may have resulted in more significant differences due to topsoil removal but since fertilizer application is a part of every good soil management program having the complete data set analyzed was the desire of the author.

In 1987 wheat grain yields on the Newdale CL, Pembina CL and Waskada VFSCL reacted similarly to applied treatments. Where no fertilizer had been applied, yields decreased as topsoil removal increased. The 20 cm scraped plots with no fertilizer yielded approximately 56% of the 0 cm scraped plots. When the recommended rate of fertilizer was applied, yields over all topsoil removal treatments were increased. The difference between the A and B fertility rate at the Waskada VFSCL was not significant. This lack of significant difference between fertility treatments may have been due to the fact that this site was more recently established and fertilizer had been applied to the A subplots more recently than at the other two sites. There were no real differences between the yields from different topsoil removal treatments at this fertility level. Doubling the fertilizer raised yields slightly above those from the recommended rate of fertilizer. These soils seemed able to compensate for the removal of topsoil with the application of the recommended rate of fertilizer. Where fertilizer had been applied, topsoil removal had little effect on wheat yields on those soils.

On the Willowcrest FS, on the other hand, yields were significantly decreased where topsoil had been removed for all fertility treatments. There was also a significant difference between all the fertilizer treatments. The A rate of fertilizer yielded lowest and the C rate yielded the highest. Addition of fertilizer at this site did raise yields but was not able to bring them up to the yields of the control topsoil treatment at any of the fertility levels. In this case addition of fertilizer was not able to compensate for the removal of topsoil.

At all sites in 1988, canola seed yields where no fertilizer had been applied were significantly lower than where the recommended rate of fertilizer had been applied. There were few differences between the latter and where double the recommended rate of fertilizer had been applied. No site showed significant differences between the different topsoil removal treatments but trends were noted. Where fertilizer had been applied, yields were generally highest at the 10 and 20 cm scraped plots. Since this was very unexpected behaviour for the yields and it was common at all sites, it was concluded that the unusually low precipitation may have been responsible.

4.3.5. Straw Production

Straw production was directly related to seed production. Any subplot that yielded low in seed also had less straw residue returned to the soil. Straw decomposition adds to the soil nutrient base thus a reduction in straw could lower the nutrients and organic matter being returned to the field as well as decrease the protective soil cover that develops when residue is returned to the soil. Hence anything that reduces the residue that would be returned to the soil, also reduces the nutrient content in the soil, the organic matter returned to the soil and the erosion retarding crop cover.

4.3.6. Factors Contributing to Productivity Losses Due to Soil Removal

There were many factors that influenced final crop yields. As mentioned, soil nutrient content was likely an important contributing factor to the outcome of the final yields. Topsoil removal effects were clearly evident where the fertility level of the soil was low. Removing topsoil had the effect of decreasing wheat and canola yields. Adding nutrients in some cases was able to bring yields up to the levels of the control topsoil treatment thus eliminating the effects of topsoil removal. This was not the case on the coarsest textured soil in the present study. Adding even double the recommended rate of fertilizer on the Willowcrest FS was not able to raise yield to that of the control topsoil treatment when precipitation was normal. This eliminated macronutrient fertility as a factor that is responsible for the low yield. There may, however, have been deficiencies in micronutrients such as zinc and copper. Massee and Waggoner (1985) found that on artificially eroded sites, reduced soil fertility caused crops to be unthrifty and to extract less of the available soil profile moisture. Mielke and Schepers (1986) found that there are characteristics of topsoil beneficial to plant growth that, once lost, are not replaced simply by adding fertilizer. Miller et al. (1988) found infiltration rates to be lower on moderately eroded soils than on slightly eroded soils. Textural changes also occur when soil is allowed to erode (Lyles and Tatarko, 1986). This leads to potentially detrimental effects on soil structure and stability.

Ability to use available moisture is another factor that may have influenced final yields. Higher yields seemed to be correlated to higher clay contents in the different subplot soils under normal and low precipitation. In 1988 within sites where fertilizer had been applied and the highest simulated erosion had occurred, yields were found to be highest. These subplots generally had higher clay contents. Perhaps the higher moisture holding capacities of the clay soils enabled the crops to take advantage of the available moisture more readily.

5. EFFECTS OF SIMULATED EROSION OVER TIME

Soil erosion is an ongoing process that has differential effects on different soil profiles. Soil degradation leads to productivity losses which in turn, accelerate soil erosion. It's severity depends on the interaction of the soil characteristics, soil properties, soil uses, prevailing climate, management systems and soil conservation practices. Quantifying a process with such inherent variability is no easy task.

This long term study sought to assess the effects of erosion by simulating the natural process. Experimental sites were set up on different soil types in south-western Manitoba. Soil surfaces were scraped resulting in varying depths of topsoil. Different rates of fertilizer were applied to the scraped plots. Wheat and canola, popular crops for that area, were used to determine the effects of simulated erosion.

Two site-years of data were obtained in 1983, three in 1984, three in 1985, six in 1986, four in 1987 and four in 1988. Wheat was grown in 1983, 1984 and 1987 and canola was seeded in 1985, 1986 and 1988. The trend for both crops in all experimental years was similar to the results discussed in the previous chapter. Yields decreased with an increase in topsoil removal where no fertilizer had been applied and coarser textured soils were less able to recover from topsoil removal by fertilizer application. Examples of effects of topsoil removal and fertilizer applications on yields from previous years can be found in Figures 5.1 to 5.4.

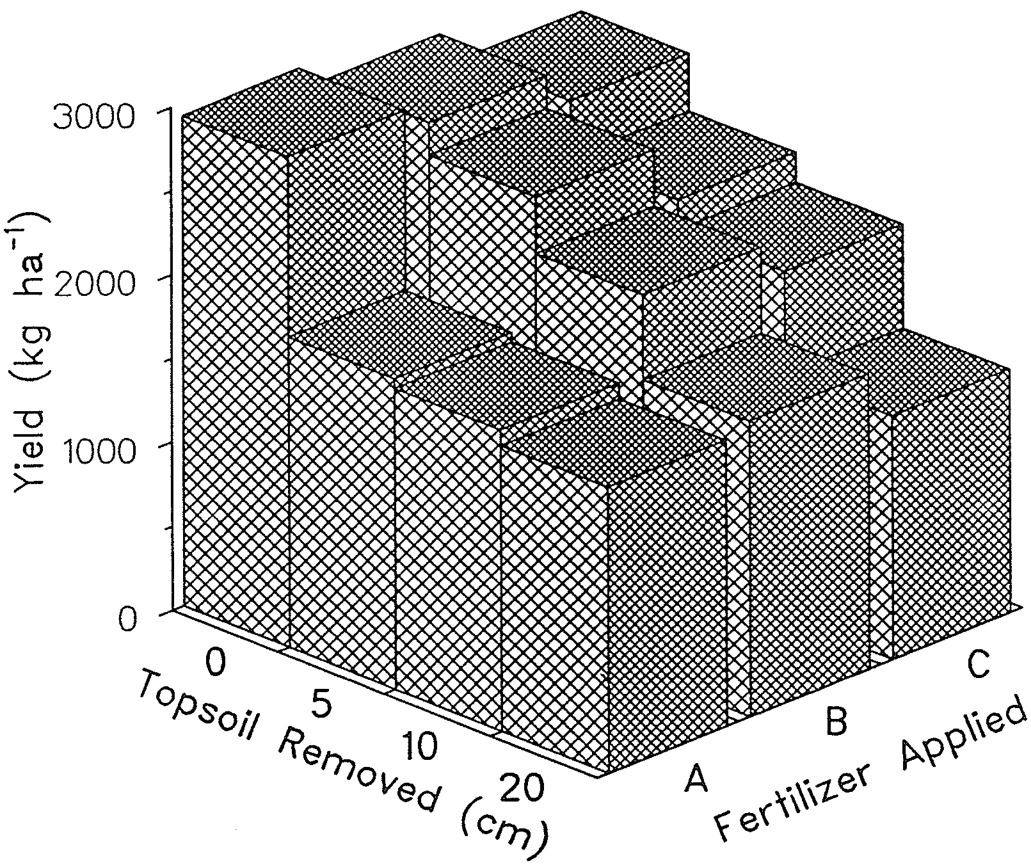

Figure 5.1. Effect of topsoil removal and fertilizer application on wheat yields, Newdale CL, 1983.

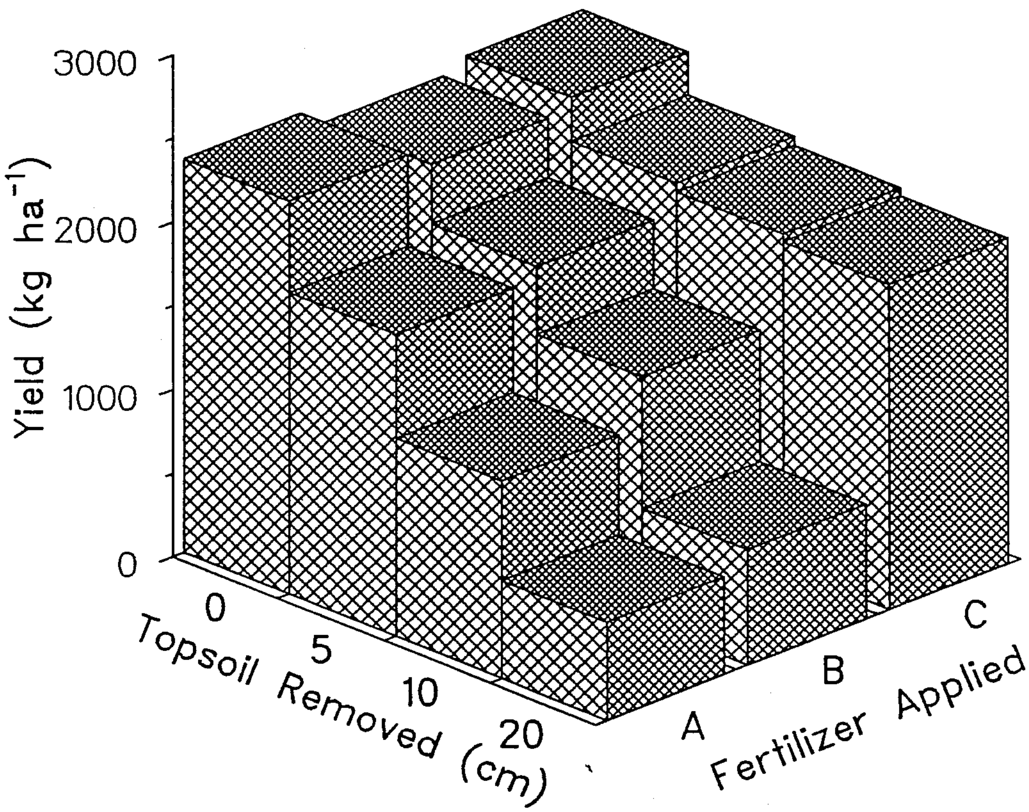

Figure 5.2. Effect of topsoil removal and fertilizer application on wheat yields, Reinland LVFS, 1984.

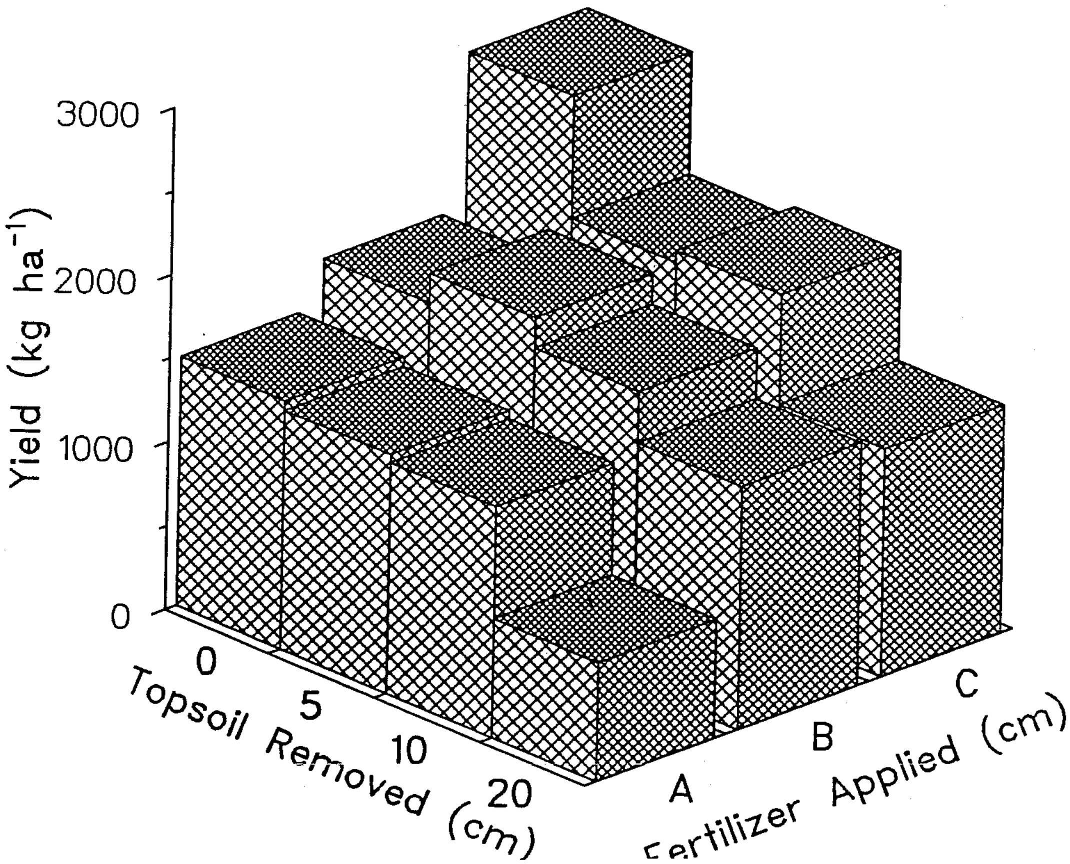

Figure 5.3. Effect of topsoil removal and fertilizer application on canola yields, Reinland LVFS, 1985.

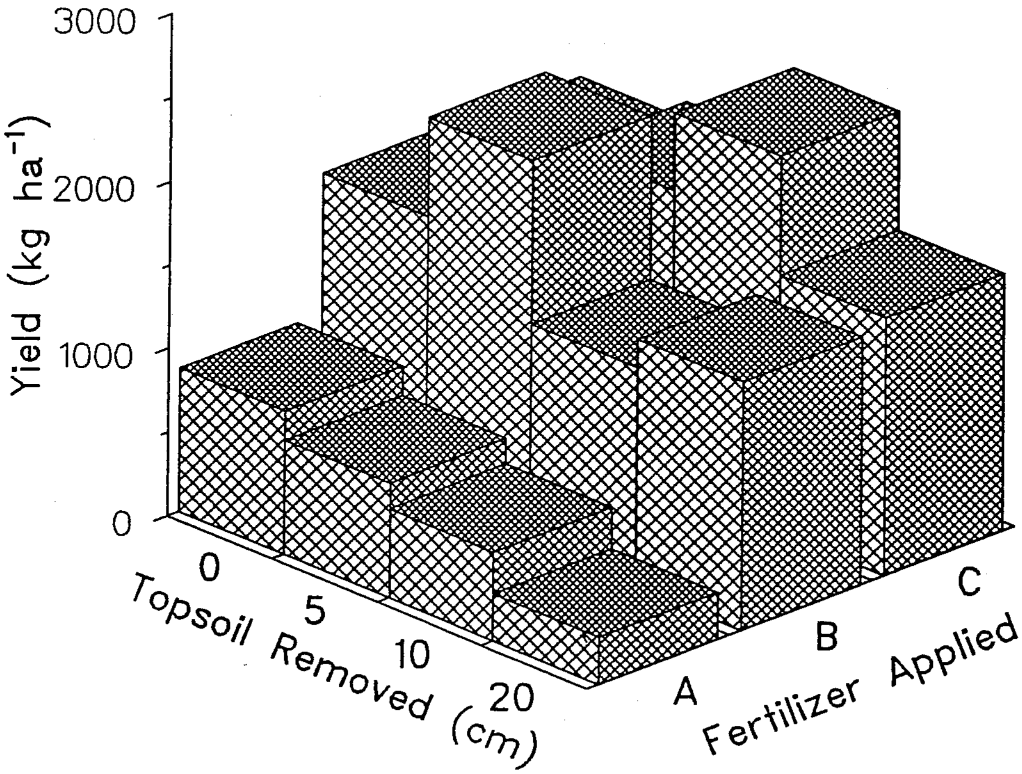

Figure 5.4. Effect of topsoil removal and fertilizer application on canola yields, Pembina CL, 1986.

The next logical step after accumulating such data is to explore the factors that affect crop yield and attempt to create models that may fit the data. Yield results of the different years showed a direct relationship between yield and fertilizer application. Topsoil removal and precipitation seemed to play a lesser role in influencing yields. It was thought that these factors along with their various interactions may lead to models that could explain the resulting yields. Fertility data for the first two years of the study was not available therefore no regression analysis was done on the wheat data. Multiple regression analysis was preformed on all the canola yield data. The Pembina CL and Reinland LVFS sites had three years of data and the Newdale CL, Ryerson FSL and Willowcrest FS had two years of data for the regression analysis. A second order equation was sought using the relative yield (calculated using the control treatment of no topsoil removed and the recommended rate of fertilizer as the 100% treatment) as a function of fertility, topsoil removal and precipitation, and their three interactions as well as their squared terms. Initial analysis of variance were run on the data to determine the factors that were significant. Subsequently factors were tested in different permutations with each other until a plausible equation was achieved with an acceptable R-square value. Table 5.1 shows the results of the regression analysis for the Pembina CL.

Table 5.1. Regression analysis of the Pembina CL canola yields.

Source	DF	Coefficient	F Value	PR>F
Intercept	1	30.55	16.83	0.0003
Fertilizer	1	1.11	91.45	0.0001
Topsoil	1	-0.35	0.71	0.4047
Fert*Fert	1	-0.003	55.76	0.0001

For each site such a procedure was done to determine the factors that most influenced the yield and to determine the equation that best fit the data. Table 5.2 lists the regression equations that were developed and their R-square values.

Table 5.2. Regression equations for canola data.

Site	Regression Equation*	R^2
Pembina CL	$Y = 30.55 + 1.11F - 0.35T - 0.003F^2$	.76
Newdale CL	$Y = 14.58 + 1.78F - 0.23T - 0.01F^2$	.76
Reinland LVFS	$Y = 56.94 + 0.59F - 1.12T - 0.001F^2$	.78
Ryerson FSL	$Y = 29.53 + 0.77F - 0.69T - 0.001F^2$	.61
Willowcrest FS	$Y = 41.37 + 1.18F - 1.14T - 0.004F^2$	.67

*Where Y is relative yield, F is the available fertilizer (soil NH_3-N in the first 60 cm + 1/2 applied N) and T is the topsoil removed in cms.

In all cases, fertilizer had the greatest influence on yields. The fertilizer squared term showed that the relationship was not a straight line relationship but rather one that reached a maximum at high rates of fertilizer thus inferring a diminishing effect of this factor. Topsoil removal was found to have a negative affect on yields at all sites. Also noteworthy is the fact that the coarser textured soils showed higher coefficients for the topsoil factor than the clay loam soils.

The result of modelling this data was information gained about the factors that affect yields and the degree to which these factors affect yields. Although some of the data sets are not as large as one would like for the purposes of modelling, a basic relationship can be seen on all soil types.

6. CONCLUSIONS

Wheat and canola yields were found to be adversely affected by the removal of topsoil. Where no fertilizer was added on all soil types, yields generally decreased with an increase in topsoil removal. Depending on the soil type and degree of simulated erosion, productivity losses could be reduced by the addition of fertilizer.

Adding fertilizer at the recommended rate to the finer textured soils considerably diminished the effect of the topsoil removal. On the Pembina CL soil in 1987 where no fertilizer had been applied and no topsoil had been removed, yields were approximately 50% of those achieved by adding the recommended rate of fertilizer to the eroded plots, clearly indicating the importance of fertilizer application. Doubling the recommended rate of fertilizer in these cases raised yields slightly above than those achieved by applying the recommended rate of fertilizer.

On the other hand, on the coarsest textured soil of the study, even the highest rate of fertilizer was not able to overcome the effects of topsoil removal. The Willowcrest FS showed a continuous decrease in yields with each increase in topsoil removal for all fertility levels. Since fertility was not a factor in reducing yields, it was concluded that characteristics native to the soil were responsible for the reduction in yields. Examination of the soil showed it to be lowest in soil nutrients, highest in sand content, lowest in organic matter content and lowest in available moisture at 114.59 mm in the first 120 cm. The average available moisture for the other soils of the study was 198.44 mm. These are characteristics common to coarse textured soils thus leading one to conclude that productivity of such soils may be affected to a greater extent by erosion.

Straw production was directly related to yield. It increased with an increase in fertilizer application and decreased with an increase in topsoil removal.

Nutrient concentrations of the seed and straw tended to increase with fertilizer applications at midseason and final harvest. Topsoil removal did not influence concentrations to any great extent. Nutrient uptake was affected by fertilizer applications as well as topsoil removal. Generally uptake was greatest where fertilizer was highest and topsoil removal was lowest.

Regression analysis of the data collected over several years showed fertility to have the greatest influence on yields and topsoil removal to have a lesser and negative influence on yields. Coefficients for topsoil removal were highest for the coarser textured soils, reinforcing the conclusion that these soils are adversely affected to a greater extent by topsoil removal than finer textured soils. It must be remembered that all the soils used in this study had an A horizon of greater than 20 cm. Soils eroded down to the B horizon would presumably show considerably different results.

Research information obtained from this study clearly elucidated the influence of erosion on productivity. The realization that maintenance of fertility is of greater importance than loss of topsoil may result in management practices that focus on fertility as opposed to soil loss in areas of high soil erosion. Obviously some highly eroded soils can still be productive with the proper fertility program but the balance of inputs and potential gains must be considered and found to be economically beneficial. Data from this project can also be used to illustrate the losses in productivity of a soil based on the amount of soil eroded and the fertilizer available. The regression equations developed can give approximations for relative yields based on the amount of soil that has been lost and the amount of nutrients that are available. Such research also clarifies that need for soil nutrient enhancing practices and soil conservation implementation.

Knowing all this, the question arises: What can be done to reduce or halt this degradative process? The answer lies in the implementation of conservation practices and programs. First the farmer must be aware of the adverse effects of soil erosion. This is the function of research and the focus of this study. Conducting experiments that clearly depict what can result from uncontrolled soil erosion is the first step. The second and equally important step is then setting up a forum to transfer this knowledge to the people that are most likely to benefit from it. Making clear the adverse effects of erosion to the right people will encourage the implementation of conservation techniques into good production systems. Technology and technology transfer are the key factors that ultimately result in an intelligent land management system.

Further studies of naturally eroded soil and similar uneroded soils may give a more real analysis of the effects of erosion on soil productivity.

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Appendix 1. Soil nutrient content of experimental sites, October 1986.

Site	Topsoil Removal	Fert	Depth (cm)	NO_3^--N† (kg ha^{-1})	Avail. P† (kg ha^{-1})	Avail. K‡ (kg ha^{-1})
Newdale CL	0	A	0-15	9.3	16.0	970
			15-30	10.0	10.0	676
			30-60	4.2	6.7	949
			60-90	5.0	5.0	1029
			90-120	9.2	7.6	1029
	0	B	0-15	13.0	20.6	741
			15-30	8.0	5.5	573
			30-60	3.3	6.7	1142
			60-90	3.3	6.7	987
			90-120	2.5	3.3	1063
	0	C	0-15	30.2	16.8	638
			15-30	36.5	10.0	571
			30-60	27.8	13.4	1050
			60-90	14.2	5.8	882
			90-120	12.6	5.0	911
	5	A	0-15	8.8	12.6	882
			15-30	4.6	6.7	766
			30-60	1.7	5.9	1554
			60-90	0.8	5.0	1058
			90-120	0.8	6.7	974
	5	B	0-15	13.4	12.6	848
			15-30	8.8	5.4	785
			30-60	4.2	6.7	1340
			60-90	1.7	3.3	995
			90-120	2.5	3.3	1067
	5	C	0-15	30.2	13.9	865
			15-30	18.5	6.7	766
			30-60	6.7	5.0	1184
			60-90	0.8	5.0	1063
			90-120	3.3	8.4	1037

Appendix 1. (cont'd)

Site	Topsoil Removal	Fert	Depth (cm)	NO_3^--N (kg ha^{-1})	Avail. P (kg ha^{-1})	Avail. K (kg ha^{-1})
Newdale CL	10	A	0-15	5.0	5.4	693
			15-30	4.2	5.4	735
			30-60	5.0	5.0	1197
			60-90	5.0	4.2	1025
			90-120	4.2	4.2	966
	10	B	0-15	11.0	10.0	735
			15-30	10.0	5.0	611
			30-60	7.6	7.6	1025
			60-90	0.8	4.2	924
			90-120	2.5	4.2	890
	10	C	0-15	12.6	15.1	773
			15-30	14.7	8.8	724
			30-60	12.6	5.9	1113
			60-90	6.7	2.5	1008
			90-120	10.9	5.0	999
	20	A	0-15	4.6	3.8	615
			15-30	2.9	2.9	529
			30-60	3.3	3.3	974
			60-90	0.8	2.5	945
			90-120	8.4	2.5	882
	20	B	0-15	4.6	6.3	638
			15-30	2.5	3.8	533
			30-60	4.2	4.2	978
			60-90	3.3	2.5	974
			90-120	4.2	2.5	1105
	20	C	0-15	16.3	9.2	661
			15-30	23.0	4.2	588
			30-60	4.2	4.2	882
			60-90	5.4	2.5	1021
			90-120	2.5	2.5	1050

Appendix 1. (cont'd)

	Topsoil Removal	Fert	Depth (cm)	NO_3^--N (kg ha^{-1})	Avail. P (kg ha^{-1})	Avail. K (kg ha^{-1})
Pembina CL	0	A	0-15	3.8	39.9	672
			15-30	5.9	65.1	760
			30-60	9.2	26.0	1134
			60-90	7.6	57.1	1310
			90-120	25.2	126.0	1365
	0	B	0-15	16.4	70.6	893
			15-30	10.1	58.0	846
			30-60	8.4	89.0	1583
			60-90	7.6	71.4	1655
			90-120	10.1	126.0	1625
	0	C	0-15	178.5	79.8	760
			15-30	113.0	75.6	773
			30-60	53.8	83.2	1499
			60-90	49.6	55.4	1550
			90-120	14.7	38.6	1575
	5	A	0-15	7.1	58.4	735
			15-30	5.5	41.6	798
			30-60	4.2	71.4	1743
			60-90	4.2	38.6	1617
			90-120	8.4	21.8	1486
	5	B	0-15	11.3	74.8	785
			15-30	7.6	59.2	756
			30-60	7.6	79.8	1571
			60-90	7.6	47.9	1491
			90-120	8.4	33.6	1407
	5	C	0-15	86.1	60.5	680
			15-30	45.0	48.7	770
			30-60	23.5	66.3	1717
			60-90	15.1	52.9	1331
			90-120	8.4	32.7	1323

Appendix 1. (cont'd)

Site	Topsoil Removal	Fert	Depth (cm)	NO_3^--N (kg ha^{-1})	Avail. P (kg ha^{-1})	Avail. K (kg ha^{-1})
Pembina CL	10	A	0-15	6.3	45.0	815
			15-30	3.3	36.5	829
			30-60	4.2	56.2	1974
			60-90	2.5	47.0	1533
			90-120	1.6	20.1	1403
	10	B	0-15	5.5	44.5	813
			15-30	3.3	37.0	924
			30-60	1.7	60.5	1886
			60-90	9.2	38.7	1672
			90-120	9.2	34.4	1470
	10	C	0-15	13.4	60.5	685
			15-30	7.6	47.0	756
			30-60	8.4	61.3	1907
			60-90	2.5	73.9	1966
			90-120	3.3	49.5	1394
	20	A	0-15	4.2	34.9	693
			15-30	5.5	36.1	792
			30-60	8.4	62.2	1789
			60-90	6.7	47.0	1638
			90-120	5.9	43.7	1533
	20	B	0-15	7.1	54.2	767
			15-30	5.5	39.1	719
			30-60	6.7	62.2	1617
			60-90	5.9	51.2	1756
			90-120	7.6	36.1	1575
	20	C	0-15	14.7	52.5	544
			15-30	10.5	49.1	689
			30-60	8.4	79.0	1512
			60-90	7.6	49.6	1655
			90-120	7.6	31.1	1407

Appendix 1. (cont'd)

Site	Topsoil Removal	Fert	Depth (cm)	NO_3^--N (kg ha^{-1})	Avail. P (kg ha^{-1})	Avail. K (kg ha^{-1})
Waskada VFSCL	0	A	0-15	14.4	16.7	556
			15-30	18.4	25.5	1210
			30-60	25.6	5.0	428
			60-90	61.6	7.0	880
			90-120	45.7	6.1	1043
	0	B	0-15	13.6	20.5	756
			15-30	5.4	8.0	504
			30-60	61.6	8.8	897
			60-90	88.0	7.9	884
			90-120	38.7	7.0	985
	0	C	0-15	31.5	37.6	530
			15-30	34.0	25.6	519
			30-60	65.1	21.1	836
			60-90	71.2	8.8	770
			90-120	45.7	9.7	893
	5	A	0-15	9.5	17.1	722
			15-30	4.2	10.0	630
			30-60	4.4	12.3	968
			60-90	4.4	7.9	1021
			90-120	17.6	7.9	1034
	5	B	0-15	11.4	13.6	703
			15-30	7.1	7.9	577
			30-60	5.2	7.9	933
			60-90	6.1	7.0	999
			90-120	17.6	6.1	1122
	5	C	0-15	14.8	12.1	646
			15-30	13.4	8.8	584
			30-60	55.4	8.8	1184
			60-90	41.3	6.1	919
			90-120	27.2	13.2	880

Appendix 1. (cont'd)

Site	Topsoil Removal	Fert	Depth (cm)	NO_3^--N (kg ha^{-1})	Avail. P (kg ha^{-1})	Avail. K (kg ha^{-1})
Waskada VFSCL	10	A	0-15	6.8	19.7	579
			15-30	3.7	9.7	397
			30-60	28.1	9.6	814
			60-90	22.9	7.9	902
			90-120	15.8	6.1	1003
	10	B	0-15	8.3	8.7	541
			15-30	4.6	6.3	445
			30-60	12.3	16.2	814
			60-90	25.5	7.0	774
			90-120	17.6	5.3	814
	10	C	0-15	17.8	9.1	513
			15-30	10.0	8.0	451
			30-60	11.4	7.9	902
			60-90	13.2	8.8	876
			90-120	29.0	9.7	924
	20	A	0-15	6.0	8.0	456
			15-30	6.3	4.6	409
			30-60	8.8	7.9	726
			60-90	66	10.5	871
			90-120	83.6	17.6	968
	20	B	0-15	7.6	3.0	443
			15-30	15.1	2.9	430
			30-60	8.8	5.3	814
			60-90	98.5	4.4	1034
			90-120	105	3.5	968
	20	C	0-15	45.2	16.7	429
			15-30	182.7	8.0	388
			30-60	181.2	7.0	748
			60-90	187.4	4.4	735
			90-120	151.3	4.4	893

Appendix 1. (cont'd)

Site	Topsoil Removal	Fert	Depth (cm)	NO_3^--N (kg ha^{-1})	Avail. P (kg ha^{-1})	Avail. K (kg ha^{-1})
Willowcrest FS	0	A	0-15	7.5	23.3	218
			15-30	4.8	4.8	154
			30-60	9.2	4.6	368
			60-90	5.5	3.7	276
			90-120	4.6	2.8	248
	0	B	0-15	8.4	5.7	154
			15-30	17.2	2.2	176
			30-60	25.8	1.8	437
			60-90	12.0	1.8	363
			90-120	12.9	0.9	322
	0	C	0-15	8.4	10.6	154
			15-30	12.8	7.5	143
			30-60	37.7	5.5	354
			60-90	29.4	4.6	276
			90-120	22.1	3.7	271
	5	A	0-15	4.0	5.3	143
			15-30	4.0	3.1	165
			30-60	12.0	4.6	299
			60-90	9.2	2.8	230
			90-120	4.6	0.9	299
	5	B	0-15	5.7	4.8	161
			15-30	4.8	3.1	176
			30-60	10.1	2.8	322
			60-90	8.3	1.8	276
			90-120	11.0	1.8	276
	5	C	0-15	4.0	3.5	165
			15-30	6.6	4.0	165
			30-60	18.4	2.8	285
			60-90	13.8	3.7	248
			90-120	22.1	1.8	469

Appendix 1. (cont'd)

Site	Topsoil Removal	Fert	Depth (cm)	NO_3^--N (kg ha^{-1})	Avail. P (kg ha^{-1})	Avail. K (kg ha^{-1})
Willowcrest FS	10	A	0-15	4.0	1.3	145
			15-30	1.8	0.9	165
			30-60	9.2	1.8	363
			60-90	3.7	1.8	276
			90-120	2.8	1.8	276
	10	B	0-15	7.0	2.6	174
			15-30	5.7	1.8	194
			30-60	9.2	1.8	345
			60-90	5.5	1.8	271
			90-120	5.5	1.8	239
	10	C	0-15	15.0	4.4	128
			15-30	29.0	1.8	165
			30-60	54.3	1.8	377
			60-90	32.2	1.8	262
			90-120	8.3	1.8	299
	20	A	0-15	3.5	0.9	183
			15-30	2.2	0.9	205
			30-60	12.0	1.8	437
			60-90	6.4	2.8	382
			90-120	13.8	2.8	446
	20	B	0-15	6.6	1.8	209
			15-30	4.4	1.8	209
			30-60	9.2	2.8	414
			60-90	8.3	9.2	308
			90-120	12.0	6.4	446
	20	C	0-15	2.6	0.9	176
			15-30	4.0	1.3	194
			30-60	8.3	2.8	414
			60-90	11.0	1.8	317
			90-120	11.0	1.8	506

†Sodium bicarbonate extractable
‡Ammonium acetate exchangeable

Appendix 2. Soil nutrient content of experimental site, October 1987.

Site	Topsoil Removal	Fert	Depth (cm)	NO_3^--N† (kg ha^{-1})	Avail. P† (kg ha^{-1})	Avail. K‡ (kg ha^{-1})
Pembina CL	0	A	0-15	9.3	77.7	735
			15-30	6.3	66.4	704
			30-60	4.2	113.4	1785
	0	B	0-15	18.9	51.7	651
			15-30	31.5	83.2	662
			30-60	18.5	84.0	1743
	0	C	0-15	68.0	73.4	693
			15-30	112.1	51.7	630
			30-60	68.9	52.9	1302
	5	A	0-15	8.4	81.9	790
			15-30	7.1	77.7	788
			30-60	5.9	1075	1680
	5	B	0-15	13.4	70.6	735
			15-30	17.6	35.7	903
			30-60	31.1	63.0	1743
	5	C	0-15	23.9	66.4	714
			15-30	26.0	46.2	819
			30-60	33.6	86.5	1743
	10	A	0-15	8.4	52.5	714
			15-30	4.2	55.4	767
			30-60	5.9	75.6	1785
	10	B	0-15	6.3	44.1	767
			15-30	8.4	39.9	819
			30-60	14.3	65.5	1743
	10	C	0-15	7.1	62.2	693
			15-30	11.3	46.2	924
			30-60	33.6	84.0	1953
	20	A	0-15	2.9	49.6	956
			15-30	3.4	49.6	956
			30-60	5.9	63.0	1743
	20	B	0-15	8.4	58.0	830
			15-30	5.5	42.0	882
			30-60	10.9	69.7	1701
	20	C	0-15	14.7	58.8	798
			15-30	14.7	62.2	861
			30-60	47.9	90.7	1743

Appendix 2. (cont'd)

Site	Topsoil Removal	Fert	Depth (cm)	NO_3^--N (kg ha^{-1})	Avail. P (kg ha^{-1})	Avail. K (kg ha^{-1})
Reinland LVFS	0	A	0-15	13.6	87.1	352
			15-30	19.4	29.0	242
			30-60	101.2	10.1	322
	0	B	0-15	15.8	100.3	308
			15-30	5.7	14.5	198
			30-60	26.7	7.4	322
	0	C	0-15	14.5	92.8	341
			15-30	22.4	23.3	187
			30-60	96.6	10.1	322
	5	A	0-15	14.5	54.1	209
			15-30	7.9	11.4	176
			30-60	53.4	7.4	299
	5	B	0-15	9.2	21.1	176
			15-30	5.7	12.3	143
			30-60	28.5	5.5	253
	5	C	0-15	10.1	47.5	198
			15-30	5.7	15.8	176
			30-60	39.6	7.4	276
	10	A	0-15	29.0	15.8	220
			15-30	78.3	7.9	154
			30-60	186.8	4.6	345
	10	B	0-15	32.1	25.5	220
			15-30	31.2	9.2	220
			30-60	88.3	7.4	436
	10	C	0-15	68.6	38.7	264
			15-30	48.8	21.1	220
			30-60	65.3	7.4	276
	20	A	0-15	4.8	7.0	429
			15-30	3.5	4.8	352
			30-60	14.7	5.5	966
	20	B	0-15	4.8	13.6	495
			15-30	5.7	3.5	495
			30-60	54.3	5.5	1357
	20	C	0-15	5.7	4.8	341
			15-30	15.8	3.5	440
			30-60	200.6	2.8	874

Appendix 2. (cont'd)

Site	Topsoil Removal	Fert	Depth (cm)	NO_3^--N (kg ha^{-1})	Avail. P (kg ha^{-1})	Avail. K (kg ha^{-1})
Ryerson FSL	0	A	0-15	12.2	4.9	465
			15-30	11.3	1.3	389
			30-60	35.2	2.6	748
	0	B	0-15	14.1	4.9	437
			15-30	27.3	3.4	410
			30-60	17.6	2.6	660
	0	C	0-15	38.8	8.7	389
			15-30	120.5	6.3	357
			30-60	193.6	7.9	638
	5	A	0-15	9.5	3.4	323
			15-30	5.0	1.3	273
			30-60	7.0	0.9	704
	5	B	0-15	21.7	4.2	332
			15-30	17.6	1.3	294
			30-60	32.6	2.6	594
	5	C	0-15	8.4	8.0	352
			15-30	14.7	6.7	326
			30-60	6.2	2.6	528
	10	A	0-15	11.4	1.9	371
			15-30	11.3	0.4	326
			30-60	44.0	0.9	594
	10	B	0-15	7.6	1.1	294
			15-30	18.9	4.6	336
			30-60	23.8	0.9	616
	10	C	0-15	38.7	4.9	294
			15-30	66.4	5.5	315
			30-60	133.8	0.9	594
	20	A	0-15	4.6	3.0	276
			15-30	3.8	0.4	305
			30-60	4.4	0.9	594
	20	B	0-15	9.9	4.9	304
			15-30	9.7	2.5	305
			30-60	10.6	7.0	572
	20	C	0-15	21.7	12.5	285
			15-30	18.9	5.5	315
			30-60	28.2	2.6	572

Appendix 2. (cont'd)

Site	Topsoil Removal	Fert	Depth (cm)	NO_3^--N (kg ha^{-1})	Avail. P (kg ha^{-1})	Avail. K (kg ha^{-1})
Willowcrest FS	0	A	0-15	11.0	7.9	165
			15-30	6.6	2.6	165
			30-60	7.4	0.9	368
	0	B	0-15	13.2	5.8	143
			15-30	7.5	2.2	154
			30-60	41.4	2.8	345
	0	C	0-15	14.1	5.8	154
			15-30	6.6	2.2	154
			30-60	9.2	0.9	322
	5	A	0-15	16.3	10.1	143
			15-30	9.2	1.8	187
			30-60	15.6	0.9	345
	5	B	0-15	17.6	9.2	143
			15-30	18.5	5.7	176
			30-60	23.0	0.9	391
	5	C	0-15	16.3	4.8	132
			15-30	13.6	2.2	176
			30-60	20.2	0.9	322
	10	A	0-15	8.8	3.5	154
			15-30	5.3	2.2	154
			30-60	9.2	5.5	345
	10	B	0-15	9.2	3.5	198
			15-30	5.3	1.3	176
			30-60	6.4	2.8	368
	10	C	0-15	10.1	1.8	165
			15-30	6.6	0.4	154
			30-60	15.6	0.9	322
	20	A	0-15	11.9	11.4	132
			15-30	5.3	1.6	165
			30-60	9.2	0.9	345
	20	B	0-15	13.2	2.6	143
			15-30	6.2	1.3	165
			30-60	6.4	0.9	322
	20	C	0-15	16.3	3.5	176
			15-30	6.6	0.4	176
			30-60	57.0	0.9	368

†Sodium bicarbonate extractable
‡Ammonium acetate exchangeable

Appendix 3. Physical properties of experimental sites.

Site	Depth (cm)	Bulk Density (g cm^{-3})	Water Content (% volume) FC	Water Content (% volume) PWP	Available Moisture (mm)
Newdale CL	0-20	1.27	31.5	14.8	42.4
	20-45	1.34	28.4	12.9	51.8
	45-85	1.47	25.0	11.9	77.2
	85-120	1.52	18.4	8.8	51.1
Profile Total					222.5
Pembina CL	0-25	1.17	34.3	18.6	46.0
	25-62	1.22	31.1	17.9	59.6
	62-120	1.30	32.0	20.3	88.2
Profile Total					193.8
Reinland LVFS	0-20	1.33	17.7	5.9	31.4
	20-40	1.62	13.8	4.1	31.4
	40-70	1.52	12.6	2.5	46.2
	70-110	1.59	11.8	2.4	59.6
	110-120	1.55	21.9	6.8	23.4
Profile Total					192.0
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
Profile Total					181.1
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
Profile Total					203.0
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
Profile Total					114.6

Appendix 4. Particle size analysis of experimental sites.

Site	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture
Newdale CL	0-20	37	25	38	CL
	20-45	35	30	35	CL
	45-85	41	28	31	CL
	85-120	43	33	24	L
Pembina CL	0-25	37	25	38	CL
	25-62	31	29	40	C
	62-120	31	23	46	C
Reinland LVFS	0-20	81	9	10	LVFS
	20-40	86	8	6	LFS
	40-70	94	4	2	LFS
	70-110	89	9	2	VFS
	110-120	44	33	23	L
Ryerson FSL	0-15	67	15	18	FSL
	15-30	70	10	20	FSCL
	30-60	69	10	21	FSCL
	60-90	71	13	16	FSL
	90-120	69	15	16	VFSL
Waskada VFSCL	0-15	47	25	28	VFSCL
	15-30	41	27	32	CL
	30-60	40	24	36	CL
	60-90	42	24	34	CL
	90-120	48	21	31	VFSCL
Willowcrest FS	0-15	90	4	6	FS
	15-30	88	4	8	FLS
	30-60	77	10	13	VFSL
	60-90	83	6	11	VFLS
	90-120	81	10	9	VFLS

Appendix 5. Chemical properties of experimental sites.

Site	Depth (cm)	Organic Matter (%)	Carbonate Content	pH	Conductivity (mS cm^{-1})
Newdale CL	0-15	7.0	Absent	7.7	0.4
	15-30	3.4	Low	7.9	0.4
	30-60	NA	High	8.2	0.4
Pembina CL	0-15	3.0	Absent	6.3	0.2
	15-30	2.0	Absent	6.4	0.2
	30-60	NA	Absent	6.5	0.1
Reinland LVFS	0-15	3.0	Medium	7.4	0.3
	15-30	2.0	High	7.6	0.2
	30-60	NA	High	7.8	0.4
Ryerson FSL	0-15	3.1	Very Low	7.8	0.3
	15-30	2.2	Very Low	7.9	0.2
	30-60	0.8	Low	7.9	0.8
Waskada VFSCL	0-15	4.0	Very Low	7.6	0.3
	15-30	2.3	Very Low	7.8	0.3
	30-60	1.0	Medium	7.9	0.4
Willowcrest FS	0-15	3.1	Absent	7.5	0.2
	15-30	1.4	Absent	7.6	0.2
	30-60	0.6	Low	7.9	0.2

Appendix 6. Growing season precipitation (mm).

Year	Site	May	June	July	August	September	Total
1987	Pembina	59 (57)†	67	141	106	54 (38)	426
1988	CL	55	11	86	0.4 (0.4)		153
Normal‡		69	88	81			303
1988	Ryerson	49 (16)	79	84	13 (6)		225
Normal	FSL	62	85	63	77		287
1988	Reinland	64 (2)	20	68	8 (7)		161
Normal	LVFS	45	95	60	69		270
1987	Newdale	41 (35)	73	112	50	38 (4)	348
Normal	CL	52	81	73	62		269
1987	Willowcrest	49 (47)	36	45	145 (142)		274
1988	FS	49	66	64	32 (12)		211
Normal		57	81	73	64		274
1987	Waskada	48 (44)	64	121	84 (80)		316.9
Normal	VFSCL	46	83	64	63		256

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

Appendix 7. Interpretive criteria for wheat tissue analysis.†

Nutrient	Low	Marginal	Sufficient	High	Excess
Nitrogen (g kg^{-1})	12.5	12.5-17.5	17.5-30.0	30.0-40.0	40.0
Phosphorus (g kg^{-1})	1.5	1.5-2.5	2.6-5.0	5.0-8.0	8.0
Potassium (g kg^{-1})	10.0	10.0-15.0	15.0-30.0	30.0-50.0	50.0

†Source: Manitoba Provincial Soil Testing Laboratory.

Appendix 8. Interpretive criteria for canola tissue analysis.†

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

†Source: Manitoba Soil Testing Laboratory.

Appendix 9. Midseason tissue analysis of wheat, 1987.

Site	Topsoil Removal (cm)	Fertilizer Treatment	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
Newdale CL	0	A	22.77	2.57	20.20
		B	26.40	2.89	22.85
		C	31.20	3.26	25.95
	5	A	15.06	2.62	19.70
		B	25.08	2.62	24.60
		C	26.72	3.00	24.85
	10	A	20.58	2.64	17.85
		B	26.46	2.78	20.80
		C	32.21	2.64	24.50
	20	A	15.72	2.61	19.45
		B	28.43	2.38	20.20
		C	34.82	2.60	28.05
Topsoil					
Fertilizer			*		*
T × F interaction					
Pembina CL	0	A	32.68	2.85	29.90
		B	34.94	3.06	29.55
		C	26.88	2.84	24.05
	5	A	20.75	3.02	21.65
		B	31.66	2.60	23.45
		C	37.78	3.22	30.65
	10	A	27.68	3.21	18.80
		B	23.64	2.60	23.35
		C	36.08	3.35	30.45
	20	A	21.57	2.99	23.70
		B	31.50	2.68	29.55
		C	33.28	2.86	31.65
Topsoil					
Fertilizer				*	
T × F interaction					

Appendix 9 (con't)

Site	Topsoil Removal (cm)	Fertilizer Treatment	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
Waskada VFSC	0	A	37.54	2.93	19.35
		B	41.80	3.12	24.05
		C	38.28	3.12	22.70
	5	A	26.92	3.04	19.20
		B	31.26	2.60	19.10
		C	39.18	3.38	19.02
	10	A	29.68	2.75	16.35
		B	29.11	3.05	20.35
		C	39.80	3.06	21.90
	20	A	36.23	2.32	13.48
		B	33.00	2.61	20.70
		C	37.96	3.53	21.20
Topsoil					
Fertilizer			*		
T × F interaction					
Willowcrest FS	0	A	28.31	2.72	25.30
		B	31.72	2.58	27.50
		C	36.55	3.20	28.85
	5	A	29.26	3.19	21.65
		B	29.42	2.67	21.90
		C	35.57	3.34	20.65
	10	A	26.04	2.81	22.10
		B	27.52	2.39	15.50
		C	34.92	2.94	21.75
	20	A	27.84	2.95	29.90
		B	30.84	2.39	19.90
		C	30.11	2.58	18.05
Topsoil			*		
Fertilizer			*		
T × F interaction					*

*Within site and nutrient, treatment or interaction significant at the 0.05 level.

Appendix 10. Grain nutrient content, 1987.

Site	Topsoil Removal (cm)	Fertilizer Treatment	N ($g\ kg^{-1}$)	P ($g\ kg^{-1}$)	K ($g\ kg^{-1}$)
Newdale CL	0	A	26.10	2.68	2.2
		B	26.25	2.64	2.2
		C	27.65	2.58	2.3
	5	A	22.78	2.74	2.1
		B	27.12	2.50	2.7
		C	27.31	2.46	2.8
	10	A	21.94	2.32	2.5
		B	25.92	2.43	2.8
		C	28.81	2.81	2.6
	20	A	24.08	2.52	2.3
		B	28.28	2.80	2.6
		C	27.54	2.62	2.6
Topsoil					
Fertilizer			*		
T × F interaction					
Pembina CL	0	A	29.21	3.02	2.8
		B	27.85	3.92	2.6
		C	29.35	2.88	2.7
	5	A	25.21	2.66	2.7
		B	28.72	2.90	2.8
		C	30.58	3.48	2.8
	10	A	26.31	2.42	2.8
		B	28.02	1.74	2.6
		C	31.14	2.57	2.8
	20	A	24.76	3.06	2.7
		B	27.54	1.49	2.4
		C	29.71	2.12	2.5
Topsoil					
Fertilizer			*		
T × F interaction					

Appendix 10. (cont'd)

Site	Topsoil Removal (cm)	Fertilizer Treatment	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
Waskada VFSC	0	A	31.05	3.01	2.5
		B	32.12	2.78	2.0
		C	34.05	2.70	2.1
	5	A	26.18	2.96	2.1
		B	30.83	3.21	2.0
		C	31.20	3.22	2.0
	10	A	29.16	2.78	2.0
		B	30.92	3.11	1.9
		C	31.39	3.01	1.9
	20	A	26.70	2.30	1.9
		B	28.76	2.91	2.3
		C	31.52	2.59	2.0
Topsoil			*		*
Fertilizer					
T × F interaction					
Willowcrest FS	0	A	29.92	2.68	3.2
		B	31.20	2.53	3.1
		C	33.34	2.60	3.1
	5	A	28.94	2.78	3.6
		B	31.55	2.65	3.0
		C	33.13	2.36	3.1
	10	A	28.20	2.68	3.4
		B	30.42	2.58	3.2
		C	32.32	2.42	3.4
	20	A	28.04	2.52	3.4
		B	34.29	2.44	3.6
		C	32.46	2.34	3.0
Topsoil					
Fertilizer			*		
T × F interaction					

*Within site and nutrient, treatment or interaction significant at the 0.05 level.

Appendix 11. Effect of topsoil removal and fertilizer application on wheat straw yields (kg ha^{-1}), 1987.

Site	Fertilizer	Topsoil Removal (cm)				
		0	5	10	20	means
Newdale CL	A	2402.5	1818.8	1255.0	1315.0	1697.8b†
	B	3715.0	3660.0	3577.5	3823.8	3694.1a
	C	4385.0	4022.5	3975.0	4023.8	4101.6a
means		3500.8	3167.1	2935.8	3054.2	
T × F interaction						
Pembina CL	A	2212.5	1631.2	1451.2	1371.2	1666.6c
	B	3741.2	3993.8	3865.0	4177.5	3944.4b
	C	4398.8	4128.8	4500.0	4396.2	4355.9a
means		3450.8	3251.3	3272.1	3315.0	
T × F interaction						
Waskada VFSCL	A	2268.8	1605.0	1640.0	1403.8	1729.4b
	B	1521.2	2097.5	2221.2	2113.8	2081.6ab
	C	2461.2	2475.0	2212.5	2571.2	2430.6a
means		2208.8	2059.2	2024.6	2029.6	
T × F interaction						
Willowcrest FS	A	2465.0	1328.8	1406.2	1043.8	1518.7c
	B	3230.0	1922.5	1985.0	1600.0	2184.4b
	C	3832.5	2368.8	2586.2	1832.5	2655.0a
means		3265.0‡A	1873.3B	1992.5B	1492.1B	
T × F interaction						

†Within site, fertility means followed by the same letter are not significantly different at Duncan's 0.05 level.
‡Within site, topsoil means followed by the same letter are not significantly different at Duncan's 0.05 level.
*Interaction significant at the 0.05 level.

Appendix 12. Wheat straw nutrient content, 1987.

Site	Topsoil Removal (cm)	Fertilizer Treatment	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
Newdale CL	0	A	4.69	0.87	17.3
		B	6.57	1.06	14.9
		C	8.36	1.08	18.0
	5	A	3.11	1.26	19.1
		B	5.31	0.94	15.2
		C	5.14	0.92	14.0
	10	A	3.35	0.84	10.2
		B	4.20	1.01	13.4
		C	6.71	0.84	18.0
	20	A	3.23	0.92	10.2
		B	5.50	0.80	15.6
		C	6.26	0.94	16.5
Topsoil					
Fertilizer			*		
T × F interaction					
Pembina CL	0	A	6.54	1.46	12.0
		B	10.29	1.44	15.6
		C	11.16	1.27	19.4
	5	A	4.30	1.18	9.7
		B	9.58	1.18	16.0
		C	12.00	1.51	19.1
	10	A	5.29	1.38	8.4
		B	7.40	1.44	14.6
		C	11.10	1.66	19.6
	20	A	5.28	1.62	10.90
		B	7.58	1.14	16.3
		C	25.56	1.20	18.8
Topsoil					
Fertilizer			*		*
T × F interaction				*	

Appendix 12. (cont'd)

Site	Topsoil Removal (cm)	Fertilizer Treatment	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
Waskada VFSCL	0	A	5.48	0.96	12.9
		B	6.48	0.83	18.2
		C	8.08	0.90	18.4
	5	A	4.08	0.94	12.7
		B	5.86	0.93	14.1
		C	6.56	0.88	14.4
	10	A	4.72	0.84	9.15
		B	6.91	0.70	12.3
		C	8.16	0.66	16.1
	20	A	4.67	0.62	14.1
		B	4.61	0.49	12.8
		C	7.32	0.84	15.4
Topsoil				*	
Fertilizer			*	*	
T × F interaction				*	
Willowcrest FS	0	A	5.38	0.71	4.2
		B	9.12	0.63	4.8
		C	12.09	0.60	6.8
	5	A	5.80	1.31	2.0
		B	8.90	0.66	2.7
		C	10.13	0.60	4.8
	10	A	4.64	0.78	3.0
		B	8.22	0.53	2.8
		C	11.02	0.84	4.8
	20	A	5.93	0.96	5.4
		B	7.62	0.88	2.8
		C	10.38	0.90	5.0
Topsoil					*
Fertilizer			*		*
T × F interaction					

*Within site and nutrient, treatment or interaction significant at the 0.05 level.

Appendix 13. Nutrient uptake by wheat, 1987.

Site	Topsoil Removal (cm)	Fertilizer Treatment	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
Newdale CL	0	A	64.26	7.53	46.03
		B	111.68	12.68	62.65
		C	135.88	13.96	87.40
	5	A	38.20	6.19	37.74
		B	101.40	11.0	63.61
		C	108.46	11.61	64.95
	10	A	25.68	3.33	15.18
		B	91.20	10.76	56.20
		C	127.43	13.19	80.44
	20	A	30.49	3.96	15.86
		B	105.66	11.46	67.28
		C	121.03	12.9	75.44
Topsoil					
Fertilizer			*	*	*
T × F interaction					
Pembina CL	0	A	50.70	6.98	30.02
		B	97.16	13.66	63.73
		C	111.70	11.51	92.82
	5	A	31.92	4.56	18.49
		B	97.72	10.70	69.70
		C	115.22	13.58	83.93
	10	A	29.78	4.03	14.54
		B	88.93	9.30	62.11
		C	118.24	13.10	94.56
	20	A	25.16	4.45	16.86
		B	93.44	8.10	73.36
		C	111.32	9.87	88.33
Topsoil				*	
Fertilizer			*	*	*
T × F interaction				*	

Appendix 13. (cont'd)

Site	Topsoil Removal (cm)	Fertilizer Treatment	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
Waskada VFSCL	0	A	83.86	8.49	34.94
		B	71.05	6.56	31.59
		C	99.25	8.52	50.06
	5	A	48.82	6.30	23.78
		B	78.56	8.86	33.88
		C	99.22	9.62	40.14
	10	A	56.50	6.01	18.44
		B	85.20	8.58	31.50
		C	90.56	8.42	40.01
	20	A	41.60	3.89	15.27
		B	68.67	7.00	31.76
		C	91.33	8.14	44.18
Topsoil			*	*	
Fertilizer			*	*	*
T × F interaction			*	*	
Willowcrest FS	0	A	66.10	6.49	15.83
		B	98.49	7.65	22.44
		C	136.54	9.32	34.45
	5	A	33.06	3.51	5.81
		B	59.02	4.78	9.41
		C	80.90	5.48	16.82
	10	A	30.28	3.34	7.18
		B	66.06	5.26	10.65
		C	90.53	6.82	18.98
	20	A	24.27	2.63	7.78
		B	52.80	4.30	8.72
		C	64.14	4.90	13.24
Topsoil			*	*	*
Fertilizer			*	*	*
T × F interaction			*		*

*Within site and nutrient, treatment or interaction significant at the 0.05 level.

Appendix 14. Midseason tissue analysis of canola, 1988.

Site	Topsoil Removal (cm)	Fertilizer Treatment	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
Pembina CL	0	A	20.76	3.13	2.20
		B	27.91	2.60	2.25
		C	36.26	2.54	2.30
	5	A	26.10	3.20	2.10
		B	25.62	2.70	2.70
		C	33.43	2.94	2.75
	10	A	21.08	3.04	2.50
		B	24.42	2.66	2.75
		C	33.00	2.49	2.62
	20	A	13.09	2.90	2.30
		B	22.40	2.77	2.55
		C	29.89	3.60	2.60
Topsoil					
Fertilizer			*		*
T × F interaction					
Reinland LVFS	0	A	29.86	2.52	2.80
		B	30.20	2.55	2.55
		C	27.21	2.81	2.70
	5	A	21.68	2.20	2.70
		B	26.82	2.94	2.80
		C	24.29	2.88	2.75
	10	A	31.58	2.44	2.80
		B	21.68	2.36	2.55
		C	27.60	2.92	2.80
	20	A	22.20	2.09	2.65
		B	22.59	2.15	2.35
		C	27.80	2.48	2.50
Topsoil					
Fertilizer					
T × F interaction					

Appendix 14. (cont'd)

Site	Topsoil Removal (cm)	Fertilizer Treatment	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
Ryerson FSL	0	A	31.86	2.48	2.50
		B	35.30	3.34	2.05
		C	39.06	4.70	2.10
	5	A	29.70	2.35	2.10
		B	33.80	3.96	2.00
		C	37.32	4.09	2.00
	10	A	26.06	2.83	2.05
		B	32.94	4.38	1.90
		C	37.68	4.32	1.90
	20	A	30.00	2.55	1.90
		B	32.68	3.13	2.30
		C	35.92	3.92	2.05
Topsoil					
Fertilizer			*	*	*
T × F interaction					
Willowcrest FS	0	A	35.06	2.42	3.18
		B	27.86	3.10	3.12
		C	39.56	3.62	3.10
	5	A	29.10	2.16	3.60
		B	20.20	2.83	3.18
		C	41.44	3.58	3.10
	10	A	24.67	1.96	3.42
		B	34.20	2.99	3.18
		C	35.82	3.83	3.35
	20	A	29.91a	2.92	3.40
		B	34.66	3.75	3.58
		C	37.54	3.80	3.00
Topsoil					
Fertilizer			*	*	
T × F interaction					

*Within site and nutrient, treatment or interaction significant at the 0.05 level.

Appendix 15. Canola seed nutrient content, 1988.

Site	Topsoil Removal (cm)	Fertilizer Treatment	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
Pembina CL	0	A	37.28	5.28	3.8
		B	47.92	6.74	5.4
		C	49.60	6.88	5.6
	5	A	37.36	7.60	6.2
		B	46.56	7.37	7.6
		C	51.04	6.66	6.8
	10	A	33.20	8.18	6.6
		B	44.16	7.02	8.5
		C	51.68	7.12	8.4
	20	A	31.04	7.13	8.9
		B	42.96	7.02	9.4
		C	47.12	7.66	10.9
Topsoil				*	*
Fertilizer			*		*
T × F interaction				*	
Reinland LVFS	0	A	45.68	4.60	7.6
		B	46.88	6.86	7.1
		C	47.36	5.37	7.8
	5	A	41.60	6.12	6.8
		B	47.36	5.35	6.8
		C	46.64	7.30	7.2
	10	A	43.92	4.38	7.0
		B	45.60	4.68	7.2
		C	48.40	5.22	7.9
	20	A	42.48	4.32	6.2
		B	46.96	6.28	6.9
		C	44.56	6.00	7.1
Topsoil				*	
Fertilizer				*	
T × F interaction				*	

Appendix 15. (cont'd)

Site	Topsoil Removal (cm)	Fertilizer Treatment	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
Ryerson FSL	0	A	44.64	5.24	7.4
		B	49.28	6.54	7.1
		C	49.12	6.32	7.9
	5	A	37.92	5.84	7.8
		B	46.64	5.40	6.4
		C	47.92	9.21	7.3
	10	A	40.96	4.32	7.8
		B	44.40	5.06	6.8
		C	46.32	5.96	7.2
	20	A	33.92	6.20	6.6
		B	40.24	5.37	9.2
		C	44.88	5.14	8.0
Topsoil					
Fertilizer			*		
T × F interaction					
Willowcrest FS	0	A	36.00	4.76	5.0
		B	39.44	4.84	4.4
		C	44.08	6.17	5.1
	5	A	34.56	5.97	6.8
		B	40.08	5.62	6.3
		C	42.16	5.40	10.8
	10	A	35.68	4.69	13.5
		B	38.48	4.84	10.8
		C	41.20	5.99	11.8
	20	A	37.52	4.30	10.8
		B	41.68	4.52	8.2
		C	43.04	4.75	8.7
Topsoil				*	*
Fertilizer			*	*	*
T × F interaction				*	

*Within site and nutrient, treatment or interaction significant at the 0.05 level.

Appendix 16. Canola seed protein and oil content, 1988

Site	Topsoil Removal (cm)	Fertilizer Treatment	Protein (%)	Oil (%)
Pembina CL	0	A	23.3	43.5
		B	30.1	38.2
		C	31.0	36.0
	5	A	23.4	43.5
		B	29.1	38.2
		C	31.9	36.4
	10	A	20.8	45.1
		B	27.6	40.0
		C	32.3	36.0
	20	A	19.4	46.4
		B	26.8	39.5
		C	29.4	37.3
Topsoil			*	
Fertilizer			*	*
T × F interaction				
Reinland LVFS	0	A	28.6	40.8
		B	29.3	40.1
		C	29.6	40.4
	5	A	26.0	42.0
		B	29.6	42.9
		C	29.2	41.4
	10	A	27.8	42.0
		B	28.5	42.7
		C	30.2	40.2
	20	A	26.6	44.0
		B	29.6	41.0
		C	27.8	41.4
Topsoil				
Fertilizer				
T × F interaction				

Appendix 16. (cont'd)

Site	Topsoil Removal (cm)	Fertilizer Treatment	Protein (%)	Oil (%)
Ryerson FSL	0	A	27.9	42.6
		B	30.8	38.8
		C	30.7	37.4
	5	A	23.7	45.7
		B	29.2	40.2
		C	30.0	37.9
	10	A	25.6	43.4
		B	26.6	41.8
		C	29.0	40.2
	20	A	21.2	45.9
		B	25.2	43.2
		C	28.0	41.2
Topsoil				*
Fertilizer			*	*
T × F interaction				
Willowcrest FS	0	A	22.5	46.7
		B	24.4	45.5
		C	27.6	45.0
	5	A	21.6	43.2
		B	25.0	44.9
		C	26.4	44.6
	10	A	22.3	45.6
		B	24.0	47.4
		C	25.8	45.2
	20	A	23.4	45.3
		B	26.0	46.6
		C	26.9	45.3
Topsoil			*	
Fertilizer				*
T × F interaction				

*Within site and nutrient, treatment or interaction significant at the 0.05 level.

Appendix 17. Effect of topsoil removal and fertilizer application on canola straw yields (kg ha^{-1}), 1988.

Site	Fertilizer	Topsoil Removal (cm)				
		0	5	10	20	means
Pembina CL	A	2318.8	2061.2	1917.5	1410.0	1926.9†b
	B	3367.5	3347.5	3480.0	3156.2	3147.1a
	C	3428.8	3188.8	3413.8	4148.8	3545.0a
means		2784.1	2865.8	2937.1	2905.0	
T × F interaction						
Reinland LVFS	A	4478.8	3847.5	4380.0	2685.0	3847.8b
	B	4857.5	4551.2	4355.0	4148.8	4252.0b
	C	4926.2	4816.2	5675.0	5462.5	5220.0a
means		4754.2	4405.0	4501.8	4098.8	
T × F interaction				*		
Ryerson FSL	A	1465.0	1307.5	1420.0	1287.5	1370.0c
	B	2245.0	2081.2	2353.8	2343.8	2255.9b
	C	2273.8	2296.2	2796.2	2813.8	2545.0a
means		1994.6	1895.0	2190.0	2148.3	
T × F interaction						
Willowcrest FS	A	3662.5	3333.8	4335.0	2452.5	3013.4b
	B	4898.8	5468.8	5802.5	5378.8	5387.2a
	C	6340.0	6146.2	6127.5	4862.5	5869.1a
means		4967.1	4982.9	4844.9	4231.3	
T × F interaction						

†Within site, fertility means followed by the same letter are not significantly different at Duncan's 0.05 level.
‡Within site, topsoil means followed by the same letter are not significantly different at Duncan's 0.05 level.
*Interaction significant at the 0.05 level.

Appendix 18. Canola straw nutrient content, 1988.

Site	Topsoil Removal (cm)	Fertilizer Treatment	N ($g\ kg^{-1}$)	P ($g\ kg^{-1}$)	K ($g\ kg^{-1}$)
Pembina CL	0	A	3.64	1.20	17.8
		B	10.64	1.08	22.2
		C	14.48	1.68	24.6
	5	A	3.54	1.15	16.7
		B	11.90	1.11	18.2
		C	15.24	1.24	25.5
	10	A	4.65	1.28	16.8
		B	5.45	0.82	19.3
		C	10.78	1.26	21.0
	20	A	3.78	1.26	16.8
		B	6.66	1.13	23.0
		C	11.44	0.95	23.4
Topsoil					
Fertilizer			*	*	*
T × F interaction				*	
Reinland LVFS	0	A	5.77	0.57	14.7
		B	14.13	1.09	15.6
		C	15.65	1.25	15.6
	5	A	5.29	0.51	12.4
		B	10.70	0.88	14.6
		C	17.68	1.68	14.2
	10	A	5.82	0.76	14.4
		B	13.64	0.95	13.1
		C	14.38	1.08	13.0
	20	A	5.02	0.54	11.4
		B	11.40	0.74	11.3
		C	12.62	0.84	12.3
Topsoil					
Fertilizer			*		
T × F interaction					

Appendix 18. (cont'd)

Site	Topsoil Removal (cm)	Fertilizer Treatment	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
Ryerson FSL	0	A	8.20	0.62	12.0
		B	10.82	0.84	15.6
		C	14.30	1.20	12.4
	5	A	5.23	0.56	12.6
		B	10.74	0.74	12.2
		C	12.26	0.99	13.2
	10	A	7.29	0.65	10.6
		B	10.38	0.66	12.7
		C	16.16	0.98	10.0
	20	A	4.48	0.64	10.3
		B	10.38	0.79	12.9
		C	10.08	0.76	10.4
Topsoil					
Fertilizer			*	*	
T × F interaction				*	
Willowcrest FS	0	A	5.63	0.52	12.5
		B	8.80	0.67	13.0
		C	9.38	0.64	12.8
	5	A	4.14	0.50	11.0
		B	9.82	0.53	11.8
		C	9.10	0.74	15.4
	10	A	4.71	0.46	11.6
		B	8.16	0.57	11.7
		C	10.24	0.84	14.2
	20	A	5.91	0.63	12.3
		B	8.60	0.65	12.6
		C	8.58	0.63	11.5
Topsoil					
Fertilizer			*	*	
T × F interaction				*	

*Within site and nutrient, treatment or interaction significant at the 0.05 level.

Appendix 19. Nutrient uptake by canola, 1988.

Site	Topsoil Removal (cm)	Fertilizer Treatment	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
Pembina CL	0	A	38.46	7.02	44.34
		B	11.26	12.68	82.26
		C	104.04	13.28	90.71
	5	A	29.38	6.86	38.12
		B	102.38	13.62	71.03
		C	110.54	12.02	89.63
	10	A	29.54	7.54	36.25
		B	84.61	13.28	79.80
		C	107.75	14.08	83.28
	20	A	18.92	4.88	27.63
		B	77.26	12.74	84.74
		C	124.28	16.42	115.06
Topsoil			*		*
Fertilizer			*	*	*
T × F interaction			*	*	
Reinland LVFS	0	A	111.44	11.18	80.0
		B	168.96	19.96	90.0
		C	174.42	17.18	92.9
	5	A	86.50	11.68	58.8
		B	147.74	15.17	81.0
		C	187.94	24.22	84.4
	10	A	116.68	12.42	77.7
		B	155.64	14.01	72.1
		C	208.78	19.84	94.2
	20	A	68.54	6.95	38.6
		B	135.00	14.80	59.8
		C	182.01	19.80	85.2
Topsoil					
Fertilizer			*	*	*
T × F interaction					

Appendix 19. (cont'd)

Site	Topsoil Removal (cm)	Fertilizer Treatment	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
Ryerson FSL	0	A	32.04	3.26	21.0
		B	63.76	6.62	40.8
		C	69.30	7.45	34.0
	5	A	26.32	3.74	20.5
		B	62.98	6.24	30.9
		C	67.62	9.86	36.2
	10	A	29.65	2.96	18.6
		B	67.59	5.65	35.6
		C	97.53	9.48	36.2
	20	A	21.54	3.84	16.3
		B	73.20	8.37	41.4
		C	96.08	9.90	41.2
Topsoil			*		
Fertilizer			*	*	*
T × F interaction			*		
Willowcrest FS	0	A	90.55	11.16	55.4
		B	141.70	15.37	75.0
		C	191.77	22.23	87.2
	5	A	58.76	9.42	12.6
		B	168.38	18.96	82.8
		C	197.32	23.02	130.4
	10	A	77.78	9.54	72.2
		B	159.23	17.36	99.4
		C	182.30	22.56	121.6
	20	A	60.97	6.86	105.5
		B	169.11	16.83	91.5
		C	125.54	12.33	72.9
Topsoil				*	
Fertilizer			*	*	
T × F interaction			*	*	

*Within site and nutrient, treatment or interaction significant at the 0.05 level.