Effect of simulated erosion on canola productivity

by

Brian Edward Kenyon

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ABSTRACT

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

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

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

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

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

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

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1. INTRODUCTION

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

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

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

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

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

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

2. LITERATURE REVIEW

2.1. Problems, Costs, and Effects of Soil Erosion

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

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

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

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

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

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

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

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

2.2. Types of Erosion

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

2.3. Effect of Erosion on Soil Productivity

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

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

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

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

2.3.1. Available Water Holding Capacity and Soil Erosion

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

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

2.3.2. Changes in Texture due to Soil Erosion

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

2.3.3. Nutrient Losses in Soil Erosion

2.3.3.1. Nutrient Content of Eroded Sediment

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

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

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

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

2.3.3.2. Nutrient Losses in Runoff Water

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

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

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

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

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

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

2.3.4. Effect of Soil Erosion on Soil Structure

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

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

2.4. Yield Losses due to Soil Erosion

Langdale et al. (1979) found that as the depth to the B_2 horizon decreased the clay content tended to increase. They found that on Southern Piedmont soils the loss of 15 cm of topsoil resulted in a 42% reduction in corn yield. Based on 1979 production levels, the loss of 147 kg of grain per hectare per year would occur for each centimeter of topsoil lost. In an experiment where topsoil was added to eroded areas to determine the effect on yield, Mielke and Schepers (1986) found that all crops responded to topsoil additions. They felt that the topsoil provided a good physical environment for development of plant roots