Effect of simulated soil erosion on wheat yields

by

Rose Morrison-Ives

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

Winnipeg, Manitoba

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ABSTRACT

Soil productivity usually declines when topsoil is lost to erosion. Extra fertilizer can often help mitigate the crop yield depressions seen under erosion conditions. In a soil-scalping experiment, yields of Benito wheat were measured under 4 levels of topsoil removal and 3 fertilizer regimes. Two experimental locations were selected in spring, 1983: a Reinland LVFS soil (described as a gleyed, carbonated rego black) and a Newdale CL (an orthic black chernozem). Both sites were seeded to 'Benito' wheat at a rate of 100 kg/ha. These sites were again seeded to 'Benito' wheat in 1984, as well as a newly- established third site on a somewhat degraded Pembina CL soil.

In year one, wheat yields at both experimental locations were significantly depressed where 20 cm of topsoil had been removed. On the Newdale CL soil, wheat yields decreased with each increasing amount of topsoil removal, while on the Reinland LVFS, only the plots where 20 cm of topsoil had been 'scalped' were substantially lower. Yield, even on severely 'scalped' plots, was not significantly affected by application of N and P fertlizers.

In the second year, wheat yields on both the Reinland LVFS and the Pembina CL were significantly lower than controls where 20 cm of topsoil had been removed. On the Newdale CL wheat yields among the soil removal treatments did not differ significantly at P = 0.05, although they were lower than controls, where topsoil had been removed.

In 1984, a significant fertilizer response was obtained; at all three experimental locations, the highest fertilizer application significantly increased grain yields where more than 5 cm of topsoil had been scalped. While extra fertilizer had a mitigating effect on the simulated erosion in 1984, it did not return the deeply scraped plots (where 10 or 20 cm of topsoil had been removed) to the soils' original (uneroded) productivity.

ACKNOWLEDGEMENTS

I wish to thank: Dr. C. F. Shaykewich, Professor, Department of Soil Science, under whose immediate supervision this investigation was conducted, for valuable advice, patience, unfailing good humour and, of course, helpful criticism of the manuscript.

Dr. G. J. Racz, Head, Department of Soil Science, for interest and advice during the course of the project and for serving on the examining committee.

Dr. L. E. Evans, Head, Department of Plant Science, for serving on the examining committee.

Mr. S. Glufka, Technician, Department of Soil Science, for skill in seeding and cultivating the experimental sites.

Ms. V. Huzel and Mr. G. Morden, Technicians, Department of Soil Science, for instruction in, and advice on, laboratory procedures.

Staff of the Provincial Soil Testing Laboratory, who always made time for 'just a few more' soil samples.

Ms. A. Kapoor and Ms. E. LaCroix, for assistance with field work.

George, for, among other things, digging holes on Sundays.

Agriculture Canada, for financial support which made this study possible.

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Chapter I

INTRODUCTION

Hamatreya

Bulkeley, Hunt, Willard, Hosmer, Meriam, Flint,
Possessed the land which rendered to their toil
Hay, corn, roots, hemp, flax, apples, wool and wood.
Each of these landlords walked amidst his farm,
Saying, 'T'is mine, my children's and my name's.
How sweet the west wind sounds in mine own trees!
How graceful climb those shadows on my hill!
I fancy these pure waters and the flags
Know me as does my dog: we sympathize;
And, I affirm, my actions smack of the soil.'

Where are these men? Asleep beneath their grounds:
And strangers, fond as they, their furrows plough.
Earth laughs in flowers, to see her boastful boys
Earth proud, proud of the earth that is not theirs;
Who steer the plough, but cannot steer their feet
Clear of the grave.
They added ridge to valley, brook to pond,
And sighed for all that bounded their domain;
'This suits me for a pasture, that's my park;
We must have clay, lime, gravel, granite-ledge,
And misty lowland where to go for peat.
The land is well - lies fairly to the south.
'T'is good, when you have crossed the sea and back,
To find the sitfast acres where you left them.'
Ah! The hot owner sees not Death, who adds
Him to his land, a lump of mould the more.
Hear what the earth says:

Earth-song

Mine and yours;
Mine, not yours.
Earth endures....

They called me theirs,
Who so controlled me;
Yet every one
Wished to stay, and is gone.
How am I theirs,
If they cannot hold me,
But I hold them?

When I heard the Earth-song,
I was no longer brave;
My avarice cooled
Like lust in the chill of the grave.

Ralph Waldo Emerson

Recently, in Manitoba, increased row crop production, monoculture cropping systems and the attendant use of large, soil-pulverizing tillage equipment, have made soil erosion a concern to many. Dryer than usual weather conditions in spring, when the soil is unprotected by vegetation, have caused dust storms reminiscent of times that some would rather forget.

A farmer who is faced with the threat of soil erosion wants to know whether crop yields will be adversely affected. Policy makers, too, lack information on productivity losses incurred by soil erosion. (It is acknowledged that the off-farm effects of soil erosion also need recogntion and clarification).

In Canada, little work has been done to identify the effects of soil erosion on soil productivity. The research that does exist is usually site and crop specific, as, indeed, is the present study. Most researchers have found that, dependant on soil profile characteristics, severe soil erosion will significantly reduce crop yields. Additional fertilizer imputs to eroded soil often have a mitigating effect, but unless the subsoil is unlimiting, fertilizer does not fully restore the original (uneroded) productivity of the soil.

The present study is a preliminary one. It investigates the effect of simulated soil erosion on yields of Benito wheat at three sites in Manitoba. Accelerated erosion is taking place in many parts of agricultural Manitoba. For this study, field sites were established in areas west of the Red River Valley, where the problem is more visible and where some communities are becoming concerned.

Chapter II

LITERATURE REVIEW

2.1 EROSION - AN HISTORICAL PERSPECTIVE

Natural (geological) erosion has been taking place throughout history. Accelerated erosion is also of ancient origin. Lowdermilk (1953) has related the downfall of several empires to soil erosion. Peattie (1936) reports that deforestation of the Apennines was serious in Roman times and even earlier denudation took place in Greece. Soils of the loess plateau in north-west China are among the most erodible in the world. In 1936, Eliassen estimated that the Yellow River annually transported enough sediment to raise an area of 640 square kilometres by 1.5 metres, even though Chinese farmers have long been cognizant of the problem and had probably done more on-the-farm erosion control work than farmers of any other nation (Thorp, 1936). The present-day enormity of the problem is confirmed by Lee (1984) who states that annual soil loss on 13 million hectares of Chinese farmland exceeds 302 t/ha/yr.

Despite long evidence of accelerated erosion in many parts of the world, it is only recently that any integrated remedial action has been taken. Jacks and Whyte (1938) record that check dams to slow flood waters were introduced into Japan in the year 1781; that, in Italy, the work of Ridolfi (1828-1830) forced the Royal University of Sienna to recognize the water erosion that was taking place in the area, and to recommend erosion control measures. In France, a government reforestation program was started in 1861 and, in Ceylon (Sri Lanka) where indiscriminate tree-felling had left slopes prey to severe water erosion, a forest ordinance was passed in 1885, to reserve forests for erosion protection. Meanwhile, Wollny (1888) investigated soil physical properties affecting erosion and runoff in Germany.

In North America, also, soil degradation was receiving notice, if nothing else. Pound and Clements (1898), two researchers in the United States, recognized the soil-degrading effects of both overgrazing and man's disturbance of the soil. Federal regulation of grazing land was suggested in 1901, but suppressed for several years. Some erosion plot work was started in 1917 at the Missouri Agriculture Experimental Station (Meyer, 1984). Bennett (1927) reported on the erosion problem to the First International Congress of Soil Science. In 1930 the United States Department of Agriculture began an investigative and educational program in soil erosion, leading, in 1933, to the establishment of the Soil Erosion Service, to demonstrate erosion control and rainfall conservation methods.

Bennett (1955) chillingly describes the dust bowl of 1934, when blowing soil from the parched Great Plains moved eastward, darkening the sun across two-thirds of the continent. The Soil Conservation Service was established in 1935, with Hugh H. Bennett as its head.

The Canadian experience parallels that of the United States. Severe soil drifting was recorded at Indianhead, as early as 1887 (Jacks and Whyte, 1938); in 1919 - a dry,windy year - it became a widespread Saskatchewan problem. Although a respite followed, by 1934, approximately 3.4 million hectares were affected by drought and wind erosion across the three prairie provinces. Ellis (1935) identified six affected areas in Manitoba. In 1935, Parliament passed the Prairie Farm Rehabilitation Act for the 'Rehabilitation of the drought and soil-drifting areas in Manitoba, Saskatchewan and Alberta.'

It is regrettable that, once the drought of the 1930's had passed, soil conservation measures lost their ardency and appeal, to a certain extent in the United States, and to a much greater degree in Canada. Carter (1977) reviews recent dust storms on the Great Plains - he concludes that conservation of the kind necessary to sustain agricultural productivity over the long term has not been achieved, and feels that despite the $15 billion spent on control measures since the dust bowl years, cropland erosion remains one of the biggest environmental problems faced by the United States.

On the Canadian Prairies, the Prairie Farm Rehabilitation Administration did not maintain its early soil conservation endeavours: over time, P.F.R.A. concentrated its efforts on water development and conservation activities were phased out.

Recently, P.F.R.A. has expressed concern over soil degradation problems on the Canadian prairies and is becoming involved in soil conservation once more (P.F.R.A., 1983). Since the mid 1970's, some dryer than average years on parts of the prairies, coupled with less than soil-conserving farming practices have made soil erosion very visible. Sparrow (1984) feels that soil degradation is the most serious agricultural crisis in Canadian history, and that action must be taken quickly.

2.2 TYPES OF SOIL EROSION

2.2.1 Defining the terms

Although the word 'erosion' was used in the nineteenth century, Zachar (1982) notes that the term 'soil erosion' did not come into general usage until the 1930's, and that it usually means the destruction of soil by wind or water. Bennett (1955) separates geological and accelerated erosion. The latter can further be divided into naturally-accelerated and anthropogenically-accelerated erosion.

The soil erosion problem currently apparent on the prairies is one of accelerated erosion; the 'natural' component is the part played by such factors as unusual weather conditions and pest infestations, while the 'man-made' component is the result of soil-degrading farming practices. Such practices are usually based on short-term farm economic considerations (Furtran and Van Kooten, 1983) and are beyond the scope of this thesis.

2.2.2 Wind erosion

Wind erosion is the result of strong winds blowing across a bare or sparsely-covered soil surface. In Canada, the hazard is greatest on the open prairies but, although wind erosion is more serious in arid and semi-arid regions, Lyles (1981) notes that it can be a problem wherever conducive conditions exist. Factors favouring wind erosion include a smooth soil surface with little or no vegetative cover, topsoil that is loose, dry and finely granulated, a lack of shelterbelts in the prevailing wind direction and wind of sufficient velocity to move the soil (Woodruff and Siddoway, 1965).

Wind erosion involves the detachment, movement and deposition of soil particles. Detachment is facilitated by any process causing a breakdown of soil aggregates. Such processes include freezing, wetting, the action of windblown rain and the abrasion of surface soil by wind-borne particles (P.F.R.A., 1983). Particle movement takes place by suspension, saltation and surface creep. Bagnold (1941) and others have concluded that saltation (the bouncing movement of a particle as it rebounds into the airflow after hitting the soil surface) is the most important of the transport processes, without which much suspension and surface creep would not occur.

Experiments conducted by Chepil (1945) demonstrated that soil particles larger than 1 mm in diameter are not often moved by wind, and that particles of diameter 0.1-0.15 mm are the most easily wind-eroded.

Most soils consist of aggregates; the stability of these aggregates largely determines the wind- erodibility of the soil (Chepil and Woodruff, 1963). When a soil is well structured, the number of unaggregated soil particles (those units which are small enough to be transported by wind) will be low, and thus, abrasion will be minimal. The number and stability of aggregates in a soil are principally determined by water, soil texture, organic cements and disaggregating processes (Wilson and Cooke 1981).

In a sandy soil, the water that binds soil grains together is easily removed by surface drying and the individual sand grains can then become airborne. In finer textured soils, more water is held against the high suctions of drying (Marshall and Holmes, 1979). Chepil (1956) found that, at tensions of less than 15 bars, soil erodibility decreased as the square of soil moisture content increased.

The effect of soil texture on the wind-erodibility of a soil is reflected in the soil's water-holding capacity and organic matter content. Chepil (1950) found soil aggregation to be directly related to the proportion of silt and clay-sized separates in the soils he investigated. Soils of high fine sand content are highly erodible. Silts and clayey soils generally have a higher organic matter content than sands; cements associated with the decomposition of organic matter also help in the aggregation process.

Wilson and Cooke (1981) characterize the force of the wind on the ground surface into two erosivity categories: those relating to the nature of the atmospheric flow itself and those that constrain the flow. The first category encompasses wind velocity and the conditions accompanying a certain wind. These researchers point out, for example, that if the prevailing wind brings rains, erosion may be the result of a dryer wind from another direction. Factors constraining windflow are those that affect surface roughness - vegetative cover, and its height and density, and the non-erodible soil fragments (clods and aggregates). Shelterbelts also reduce wind velocity, depending on their height and wind permeability. Wind velocity at the soil surface will also vary with the topography of the field (knolls are ususally preferentially eroded).

2.2.3 Water erosion

Although soils in some parts of Canada are frozen for several months of each year, and thus seasonally protected from water erosion, water erosion and flooding have occurred in every province of Canada within recent memory. Ripley et al. (1961) stated that erosive events such as rapid snowmelt or short, heavy rainfalls are likely to occur anywhere in the country.

Factors influencing water erosion include precipitation, soil erodibility, topography, and the cropping system and soil management practices used.

In a five-year study of 55 corn belt soils, Wischmeier and Mannering (1969) found that the inherent erodibility of a soil was related to its infiltration capacity and ability to resist the detachment and transport of soil particles by raindrops and runoff. They concluded that the erodibility of a soil is a measure of the total effect of a particular combination of soil properties. Significant soil variables were found to be per cent sand, per cent silt, clay ratio (per cent clay divided by per cent sand plus per cent silt), aggregation index, bulk density, organic matter content, per cent slope, soil reaction and structure, thickness of the granular soil layer, air-filled pore space, land use in the preceding three years, and the presence or absence of a loessial mantle and clay skins on ped surfaces. In short, soils high in silt content, low in clay and low in organic matter, were found to be the most water erodible.

The main erosive agents involved in water erosion of soil, are impacting raindrops and flowing runoff (Ellison, 1947 and Meyer, 1980). Gray and Leiser (1982) gave a simple yet descriptive definition of rainfall erosion; 'it begins with raindrop splash and ends with gullying...'

On cultivated fields, when factors other than rainfall are held constant, storm soil losses are proportional to two rainstorm characteristics: the total kinetic energy of the storm times its maximum 30 minute intensity (Wischmeier and Smith, 1965). The rate of soil erosion by water is affected by both slope length and gradient, by cropping factors (for instance, whether the field is in summerfallow or continuously cropped), and by the erosion control practices used (such as strip cropping and contour farming).

Three types of water erosion are normally recognized on farmland: sheet , rill, and gully erosion. Sheet erosion is the removal of soil from sloping land in thin layers or sheets. Rills are small cracks in the soil surface, along which runoff water preferentially travels downslope. Unchecked, rills usually further erode to become gullies - fissures too large to be destroyed by ordinary farm tillage equipment.

2.3 MEASUREMENT AND PREDICTION OF SOIL EROSION

2.3.1 Prediction of soil erosion

Many predictive soil erosion equations exist. Mitchell and Bubenzer (1980) refer to several such equations which are regional, being based on watershed parameters. The two most widely-applicable equations are the wind erosion equation and the universal soil loss equation, for the prediction of wind and water erosion, respectively.

1. The wind erosion equation, derived from the work of Chepil, is the result of nearly 30 years' research into the main factors influencing wind erosion (Woodruff and Siddoway, 1965).

   The equation is:

   $$E = f\{IKCLV\}$$

   Where E = average annual soil loss in mass/area
   I = soil erodibility index, measured in terms of soil aggregates greater than 0.84 mm in diameter
   K = soil ridge roughness factor
   C = climatic factor (considers wind velocity and soil moisture)
   L = unsheltered field width in the prevailing

wind direction
V = vegetative cover factor

The equation was designed to allow the determination of: a) the vulnerability of a particular field to wind erosion, and b) different field conditions needed to reduce potential soil loss to tolerable levels, under different climates. Slevinsky (1980) discusses the use of the wind erosion equation to calculate crop residues required to protect some Manitoba soils from springtime wind erosion.

2. The universal soil loss equation: The USLE was derived from many site-years' data gathered from cropland east of the Rocky Mountains in the United States. The present equation is the result of the combination of basic soil loss and runoff data collected since 1930, with improved techniques for evaluating the causative factors. The designation 'universal' was chosen to indicate that, unlike the earlier state- or soil-specific equations of Smith and Zingg, this model would be more adaptable to other regions (Wischmeier, 1984). Shaw (1981) advocates use of the USLE in Manitoba and suggests that soil survey maps should include such details as per cent slope, per cent fine sand and permeability measurements.

The equation is:

$$A = RKLSCP$$

Where A= average annual soil loss in mass/area
R = rainfall erosivity factor
K = soil erodibility
L = slope length factor
S = slope gradient factor
C = cropping management factor
P = erosion control practice

For a complete explanation of the wind erosion equation and the USLE, the reader is referred to Woodruff and Siddoway (1965) and Wischmeier and Smith (1965), respectively.

2.3.2 Measurement of soil erosion

Wipespread experimental use has been made of runoff plots to measure sediment yields from sloping land. In this method, runoff water is collected from bounded experimental plots, and sediment yield is measured. Erosion pins have also been inserted in the soil to measure changes in microrelief due to erosion (de Plooey and Gabriels, 1980). Wilson and Cooke (1980) describe the use of a 'catcher' to sample airborne particles and a relative soil height measurer to record small changes in the height of the soil surface due to wind erosion.

Several researchers (McCallan et al. 1980, and Beggs 1982) have investigated the use of Cesium-137 as an indicator of soil erosion and deposition. Cesium-137, produced by atmospheric nuclear explosions prior to 1963, reaches the earth's surface through precipitation and becomes strongly adsorbed to soil particles. Depth distribution activity patterns suggest that it is held in surface soils, making it potentially usable as an erosion tracer. Brown et al. (1981), in an Oregan experiment, found high total contents and thicker ^{137}Cs profiles in depositional soil sites. Jenkins et al. (1983) sampled several soils in Manitoba and believe that ^{137}Cs measurements can be useful in quantifying erosion that has happened since 1960.

2.4 EFFECTS OF SOIL EROSION ON CROP YIELDS

Soil erosion does not invariably reduce soil productivity. Battison et al. (1982) found that slight soil erosion increased corn yields on one of their field sites, by removing a 15 cm sand cap. Larsen et al. (1983) noted that some subsoils are able to support crop growth as well as the overlying top soils. These researchers use the example of a deep loess western Iowan soil which is eroding at a rate of 76 t/ha yearly; should this rate of erosion continue for the next 200 years, they estimate that soil productivity will only be reduced by 2 per cent. However, this is not the usual situation.

Lyles (1975) studied the possible effects of wind erosion on soil productivity. He attempted to determine erosional effects on production by relating topsoil thickness to crop yields for several areas of the Great Plains. Annual potential soil loss was calculated using the wind erosion equation, $\{E = f(IKCLV)\}$. Soils were classified into wind erodibility groups, 1 to 7. (Group 1 soils were the highest risk, being sandy, with less than one per cent dry soil aggregates greater than 0.84 mm in diameter. Group 7 soils were of the lowest risk). For the northern plains, Lyles estimated that wind erosion reduces wheat yields by 30 kg/ha annually in wind erodibility group 1 soils, and by 1.3 kg/ha in soils of group 7.

When topsoil is lost to erosion, plant nutrients are also lost. Olness et al. (1981) used 3 methods to measure available nitrogen in eroded sediment and in the soil from which the sediment originated. All 3 analytic methods showed available nitrogen to be significantly increased in the sediments from cropped soil. Alberts and Moldenhauer

(1981) applied simulated rainfall to plots on a silty loam soil in north central Indiana. They measured the nitrogen and phosphorus transported by eroded soil aggregates; nutrient enrichment occurred for all size fractions of eroded aggregates. In a further study, Alberts et al. (1981) found that a cornstalk residue strip providing 50 per cent ground cover could reduce nutrient discharge by about 70 per cent.

Several researchers have studied the effect of the lower fertility of eroded soils on crop yields. Some of their findings are summarized in Table 1.

Latham (1940), working with eroded sandy loams in South Carolina, planted cotton on the red clay subsoils that had become exposed. Low yields attained where both the B and C horizons were cropped, were attributed to lowered fertility. All plots received some inorganic fertilizer and, in the last year of the study, manure improved yields on the eroded soils.

Battison et al. (1982), although reporting one instance where a little soil erosion seemed to increase crop yields (mentioned above), generally found that, on eight Ontario field sites with a history of erosion, corn yields on the eroded soils were significantly lower than on the non-eroded plots at each site. The major cause of yield depression varied at each site; no single soil variable was found to be dominant. Yield reductions were due to reduced fertility or reduced water holding capacity in the eroded soils, or to a combination of both these factors. In coarse and fine textured soils, available soil moisture seemed to be the most limiting factor while, on a deep silt soil, decreased fertility appeared to be more important.

TABLE 1

Effect of soil erosion on crop yields

Researcher(s) & location	Soil type	Crop	Soil erosion (cm)	Fertilizer N (kg/ha)	Yield (t/ha)
Bradley (1970) Manitoba	Clay loam	Wheat	0	0	2.35
			0	111	2.96
			eroded	0	1.14
			"	111	1.81
Battison et al. (1982) Ontario	Various (7 sites)	Corn	0		5.94
			Eroded		4.27
Latham (1940) S.Carolina	sandy loam	Seed cotton	0	18 plus manure	1.05
			A horizon removed	"	0.34
			A and B horizons removed	"	0.09
Lindwall (1980) Alberta		Wheat	0	0	1.80
			0	45	1.87
			20	0	1.15
			20	45	1.62
Massee and Waggonner (1983) Idaho	silt loam	Wheat	0	0	1.80
				34	2.00
				67	2.37
			15	0	0.97
				34	1.55
				67	2.06
			30	0	0.71
				34	1.45
				67	1.88
Ripley et al. Ontario (1961)	loam	Barley			
			0	0	1.40
			0	9	2.10
			7.5	0	1.11
			7.5	9	1.70
			15.0	0	0.59
			15.0	9	1.14
			All topsoil lost	0	0.19
			"	9	0.54

Eck (1962) found that productivity of a clay subsoil, which did not have any physical limitations, could be restored to that of the original topsoil with the addition of macronutrients. In a later study on a silty clay loam soil (Eck, 1968) fertilizer N could only restore the productivity of the subsoil to that of topsoil when it was combined with irrigation. Reuss and Campbell (1961) conducted greenhouse and field studies, using oats and corn. Yields on eroded soils could be returned to the original (uneroded) levels with the application of fertilizer N, P and K. These researchers remarked that the subsoils they worked with were not limiting. Carlson et al. (1961) found that fertilizer N, P and Zn could restore the yields of corn grown on eroded soils. Batchelder and Jones (1972) grew corn for 4 years on an uneroded clay loam soil and an exposed clay subsoil. Lime was added for 2 years, and fertilizer N, P and Zn for 4 years. Top growth and grain yields increased each year of the study and, in the fourth year, yields from the irrigated and/or mulched subsoil plots were equivalent to those achieved on the irrigated topsoil and significantly greater than those on the non-irrigated topsoil. The authors felt that, once soil pH and fertility problems had been corrected, available soil water became the primary growth-limiting factor.

In Manitoba, Bradley (1970) investigated crop yields, soil nutrient levels, and the effect of fertilizers on eroded soils. Available N, P and K were found to be consistently lower in the eroded sites than in controls: fertilizers had more yield effect on eroded soils, but did not generally bring yields back to original (non-eroded) levels.

In order to investigate the effects of soil erosion on productivity, some researchers artificially erode soil by physically removing various amounts of topsoil from a level experimental site. In one such scalping experiment conducted on a silty clay loam soil, Olsen (1977) found that corn germination was often poor on the scraped plots, possibly due to soil crusting, and young corn plants were Zn deficient. Even with additions of macronutrients and Zn, grain and dry matter yields remained lower on the 'eroded' plots. Fertilizer compensated for some, but not all, of the loss in productivity due to soil erosion. Lindwall (1980), reporting on a long-term field experiment conducted in Alberta, similarly found that productivity on artificially-eroded soils could be improved but not fully restored.

In another scalping experiment (Massee and Waggoner, 1983) nitrogen additions partly mitigated the effect of topsoil removal when moisture was not limiting, however, a greater response was seen when nitrogen was applied to the non-eroded soils. These researchers concluded that, partly because of reduced fertility on eroded soils, there is incomplete soil profile moisture extraction by the consequently unthrifty crop.

Frye et al. (1982) studied the effects of moderate erosion on soil physical and chemical properties and on soil productivity. On both the silty soils investigated, corn yields were lower under erosion conditions. Despite the fact that one of these soils had been in sod for 60 years since the erosional event, Frye et al. were unable to restore the eroded soils to their original productivity. Eroded Ap horizons were higher in clay content and bulk density and lower in organic matter content and available water holding capacity, than were controls. The authors commented that neither optimum fertility nor low intensity use could completely restore these soils. Where erosion has damaged physical properties such as available water holding capacity, the effects may be both yield limiting and persistent.

Technology frequently masks the effects of soil erosion (Kraus and Allmaras, 1979). As crop technology advances, measurable increases in crop yields hide the slow but steady toll that erosion takes on soil productivity; often the problem is not detected until it is too late. Williams (1981) summarizes the ways in which soil erosion reduces productivity:

1. Loss of plant-available water holding capacity due to: a) a reduction in the depth of the rooting zone, or b) a change in the water holding characteristics of the rooting zone.
2. Loss of plant-available nutrients
3. Degradation of soil structure, leading to surface sealing and crusting.
4. Non-uniform removal of soil in a field, necessitating modifications to fertilizer and herbicide rates, and resulting in uneven tillage, crop germination and maturity.

EPIC is the acronym for a mathematical model developed to determine the relationship between soil erosion and soil productivity in the United States. When fully operational, the model will be applicable to a wide range of conditions and capable of simulating the effect of hundreds of years of erosion on soil productivity (Williams et al., 1984). Crosson and Stout (1983) reviewed some other determinative models: the Yield-Soil Loss Simulator developed by USDA, the University of Minnesota model, which related yield to soil layer characteristics and erosion data on specific soils, and a regression study which aimed to separate the effect of erosion on past growth of crop yields.

The Nitrogen-Tillage-Residue Management (NTRM) model has been recently described by Shaffer (1985). This model incorporates climate information, and soil physical, chemical and biological properties. It accepts existing and proposed soil management variables, and can simulate crop growth and yield over a short time or for a period of 100 years. The author feels that, besides its yield-determinative value, NTRM can be used to evaluate management options.

2.5 SOIL TOLERANCE LEVELS

How much soil erosion is tolerable on agricultural land? Soil loss tolerance is defined as the maximum rate of annual soil erosion that may occur and still permit a high level of crop productivity to be obtained economically and indefinitely (Wischmeier and Smith, 1965). Moldenhauer and Onstad (1975) suggest that tolerance levels should also consider the minimization of off-site damage from soil and chemical movement.

Young (1978) states that soil tolerance levels (T-values) should ensure maintenance of a rooting depth slightly above the level where productivity irreversibly declines. Using this criterion, tolerance levels could be larger on soils having an excess rooting depth. Logan (1979) is concerned that, if soils with the deepest topsoil are allowed to erode more rapidly, many of the best soils will be progressively deteriorated more quickly than less productive soils: rooting depth of the deepest soils will eventually approach that of shallower soils.

Most commonly used 'T-values' are in the range 0.2 - 1.0 mm/yr (Kirkby, 1980). The critical dividing line between harmful and harmless erosion is dependant upon the average intensity of soil formation by the weathering process (Zachar, 1982).

Soil renewal rates vary greatly, depending on the material being weathered, the climate, topography and organisms involved. Smith and Stamey (1965) calculated an average igneous rock weathering rate of 0.18 t/ha/yr, throughout earth's history. In one instance, Jenny (1941) found that weathering of limestone tombstones could produce 2.5 cm soil in 240-500 years (1.3-0.65 t/ha/yr) while, in another case, 30 cm soil weathered from limestone in 230 years (17.5 t/ha/yr). Under natural conditions soil is said to form at a rate of 2.5 cm in 300-1,000 years, although, under cultivation, the time may be reduced to 100 years (Schertz, 1983).

Kirkby (1980) and others (McCormack et al. 1979) have expressed concern over the current allocation of 'T-values'. These writers feel that rates of soil formation cannot compensate for some accepted 'T-values'. Kirkby notes that, as erosion increases, overland flow runoff usually also increases. This results in slightly less subsurface runoff, and ultimately, less bedrock weathering. Thus, any increase in erosion should reduce the tolerable level set by the rate of soil formation. Zachar (1982) writes that permissable erosion could be determined not only by the rate of soil formation, but also by the current state of the soil and by economic considerations.

Schumm and Harvey (1979) classify soils as predominantly non-renewable. This view is endorsed by Brown (1984): 'Because of the shortsighted way in which one-third to one-half of the world's cropland is being managed, the soils on this land have been converted from a renewable resource to a nonrenewable one.'

Chapter III

MATERIALS AND METHODS

The Walrus and the Carpenter
  Were walking close at hand;
They wept like anything to see
  Such quantities of sand:
'If this were only cleared away,'
  They said, 'it would be grand!'

'If seven maids with seven mops
  Swept it for half a year,
'Do you suppose,' the Walrus said,
  'That they could get it clear?'
'I doubt it,' said the Carpenter,
  And shed a bitter tear.

Lewis Carroll,
Through the Looking-glass
Chapter 4,
The Walrus and the Carpenter

3.1 FIELD EXPERIMENT

The problem of assessing the effect of soil erosion on soil productivity is a very difficult one. One's first instinct is to simply compare yields on eroded and non-eroded sites and equate the difference in yield to a loss of productivity due to soil erosion. Usually this kind of study involves an eroded site on a knoll and a non-eroded site in a depression. Critics say that the water regime between the two sites is bound to be different and thus, the results are confounded.

It is to eliminate these criticisms that the so-called 'scalping' experiments have been introduced. In this approach, erosion is simulated by physically removing various portions of the Ah horizon. Such experiments do have shortcomings. Natural erosion is a sorting process; aggregates of some size groups tend to be preferentially eroded. In a scalping experiment, the entire soil layer is removed. Despite this and other shortcomings, scalping experiments can help to give some indication of what the effects of soil erosion on soil productivity might be. For this reason, this method was chosen to be the subject of the present study.

In May 1983, two experimental sites were selected. The first was near Gladstone (legal description NE35-14-12W) on a Reinland loamy very fine sand. This soil has been classified as a gleyed, carbonated, rego black, developed on moderately coarse-textured deltaic, alluvial and lacustrine deposits (Ehrlich et al., 1957). At this particular site the Ah horizon was approximately 20 cm thick.

The second site was located near Minnedosa (legal description NW28-13-17W) on a smooth-phase Newdale clay loam. This is an orthic black soil, developed on boulder till of mixed materials derived from limestone, shale and granitic rock (Ehlrich et al., 1957). The Ah horizon at this site was also approximately 20 cm thick.

At each site, varying portions of the Ah horizon were removed. The four levels of topsoil removal were 0, 5, 10 and 20 cm. The experiment was built on a randomized complete block design. Each level of topsoil removal was replicated four times. Soil removal was accomplished using a standard road grader hired from the local municipality. Each plot was 9.6 m square with pathways of 6 m both within and among replicates.

Superimposed on the soil removal treatments were three levels of fertilizer application, A, B and C: a control, an intermediate and a higher rate (Table 2). These subplots were 3.2 m wide and 9.6 m long (Figure 1). The intermediate fertilizer rate reflected soil test recommendations for the uneroded soil. The objective of using a higher-than-recommended rate was to determine whether extra fertilizer would have a mitigating effect where soil had been 'eroded'.

Following scalping, both experimental sites were rototilled to a depth of 10 cm. Plots and pathways at each site were seeded to Benito wheat (Triticum aestivum var Benito) at a rate of 100 kg/ha. A three-point-hitch plot-size seeder (108 cm width with 18 cm row spacing) was used, and fertilizer placed with the seed. Since both sites were high in NO_3-N (the loamy sand site had received high applications of hog manure up to three years before this study and the Newdale soil had been summerfallowed) no N fertilizer was applied in 1983.

During the growing season, precipitation was measured at each site with a recording rain guage. Thermocouples were installed to measure soil temperature to a depth of 150 cm on a control plot and to 20 cm on plots where 10 and 20 cm of topsoil were removed. Aluminum access tubes were sunk to a depth of 150 cm in two replications of the four soil removal treatments, and volumetric soil moisture content was recorded using a Troxler[1] neutron meter. (Due to malfunctioning of the neutron meter, soil moisture data is incomplete).

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[1] Supplier: Troxler International Ltd, P. O. Box 12057,Research Triangle Park, N. C. 27709, U. S. A.

N

5 b	0 c	10 b	20 a	
5 c	0 a	10 a	20 b	Rep 1
5 a	0 b	10 c	20 c	
0 c	10 b	20 a	5 b	
0 a	10 a	20 b	5 c	Rep 2
0 b	10 c	20 c	5 a	
20 b	0 a	5 b	10 c	
20 a	0 b	5 c	10 a	Rep 3
20 c	0 c	5 a	10 b	
5 c	10 b	0 c	20 b	
5 b	10 c	0 a	20 a	Rep 4
5 a	10 a	0 b	20 c	

Figure 1: Plot diagram: Newdale CL site, NW28-13-17W

Digital designation on each plot indicates depth of topsoil (cm) removed.
Letter designation on each plot indicates fertilizer applied in which
a= control (no fertilizer)
b = soil test recommendations
c = higher fertilizer rate

TABLE 2

Fertilizer rates and seeding dates

	Seeding Date	Fertilizer Treatment A	B	C
Reinland LVFS				
	1983 May 21	0	20 kg/ha P_2O_5	45 kg/ha P_2O_5 30 kg/ha K_2O
	1984 May 10	0	10 kg/ha P_2O_5	90 kg/ha N 45 kg/ha P_2O_5
Newdale CL	1983 May 27	0	20 kg/ha P_2O_5	45 kg/ha P_2O_5
	1984 May 9	0	35 kg/ha P_2O_5	90 kg/ha N 45 kg/ha P_2O_5
Pembina CL	1984 May 11	15 kg/ha S	40 kg/ha N 10 kg/ha P_2O_5 15 kg/ha S	90 kg/ha N 45 kg/ha P_2O_5 30 kg/ha S

Sites were sprayed with 'Hoe-grass 284' at 2.49 l/ha and 'Buctril M' at 1.00 l/ha for control of broadleaved and grassy weeds. Midseason plant samples were collected when the crop was headed and final grain harvest was taken from an area of one square metre within each subplot at crop maturity. All plant samples were analysed for N, P and K content and some samples were analysed for micronutrient concentrations.

Since both 1983 sites are black chernozems and since many soils in the area of interest are luvisols, it was decided to establish a third site with somewhat different characteristics (Table 3). In October,

TABLE 3

Preliminary characterization of the uneroded soil at each field site

Location	Gladstone	Minnedosa	Altamont
Soil name	Reinland	Newdale	Pembina
surface texture	LVFS	CL	CL
pH			
0-15 cm	7.4	7.7	6.3
15-30	7.6	7.9	6.4
30-60	7.8	8.2	6.5
Salinity mS/cm			
0-15 cm	0.3	0.4	0.2
15-30	0.2	0.4	0.2
30-60	0.4	0.4	0.1
Carbonate content			
0-15 cm	Medium	Absent	Absent
15-30	High	Low	Absent
30-60	High	High	Absent
Nitrate nitrogen (kg/ha)			
0-15 cm	23.5	55.5	19.0
15-30	20.0	37.0	19.0
30-60	152.0	63.0	29.0
Available phosphorus (kg/ha)			
0-15 cm	84.0	35.0	93.0
15-30	56.0	9.0	50.0
30-60	6.0	9.0	50.0
Available potassium (kg/ha)			
0-15 cm	400.0	600.0	600.0
15-30	200.0	300.0	700.0
30-60	400.0	1000.0+	1000.0
Sulphate sulphur (kg/ha)			
0-15 cm	10.0	8.0	4.0
15-30	30.0	10.0	3.0
30-60	90.0	35.0	4.0
Organic matter (per cent)			
0-15 cm	3.0	7.0	3.0
15-30	2.0	3.4	2.0

1983, another site was prepared on a Pembina clay loam soil near Altamont. This soil is described as a Pembina grey-black (degrading black associate) (Ellis and Shafer, 1943). Site locations are shown in Figure 2.

In May, 1984, all three sites were seeded to Benito wheat. Sites at Altamont and Minnedosa were rototilled prior to seeding. (The site at Gladstone was not rototilled because the surface soil was extremely dry). As in the first year of the study, 3 rates of fertilizer were applied. In 1984 the 'C' rate included 90 kg/ha N at each site (Table 2). In 1984, soil moisture content to 90 cm was calculated from gravimetric soil samples, crop germination counts were taken when the wheat was in the two-leaf stage, and 'Hoe-grass 11' was used for weed control. Midseason tissue samples were analysed for N, P, K, S, Ca, Mg, Cu, Zn, Mn and Fe content. Grain samples were analysed for N, P, K, Cu, Zn and Mn. Other measurements and methods were the same as in the first year of the study.

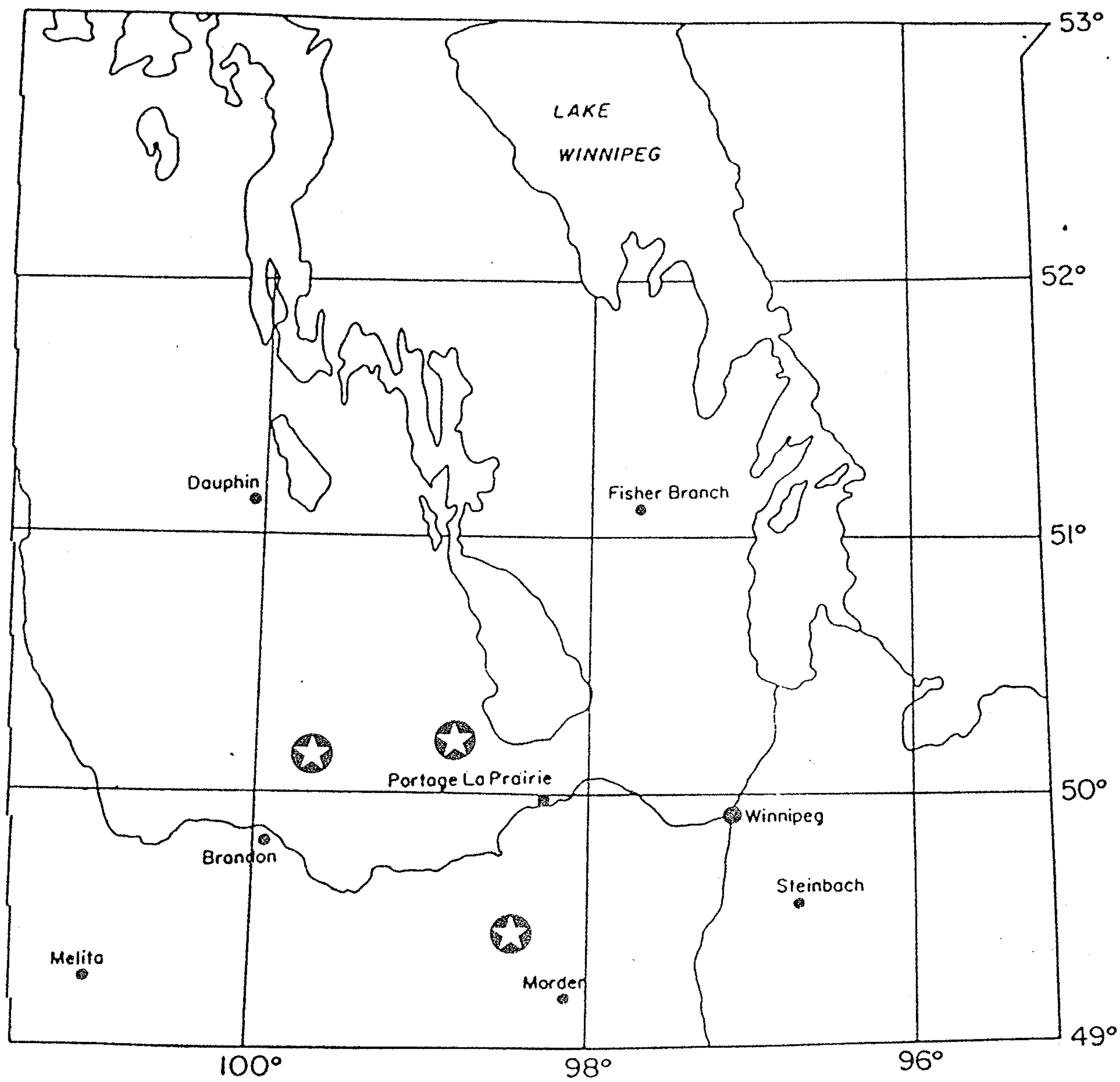

Figure 2: Location of field sites

3.2 SOIL ANALYSES

1. pH and Conductivity. Soil pH was determined on the supernatant of a 1:1 soil-water mixture, using a Beckman Zeromatic pH meter. Conductivity was measured on the same supernatant, using a Radiometer conductivity meter.

2. Inorganic Carbon (Carbonates). A one g soil sample was reacted with 0.1 M HCl for ten minutes and the evolved CO_2 collected on ascarite. Inorganic carbon content was calculated from the change in weight due to absorbed CO_2.

3. Nitrate-Nitrogen. Extraction was accomplished with 0.5 M $NaHCO_3$ at a pH of 8.5. NO_3-N was determined on a Technicon Auto Analyser,[2] using a modification of the automated colorimetric procedure of Kamphake et al. (1967).

4. Phosphorus. $NaHCO_3$ extractable phosphorus was also determined using the Technicon Auto Analyser. L-ascorbic acid was used as a reductant for the phosphomolybdate complex. Absorbance of the molybdophosphoric blue colour which develops on reduction was measured at 815 nm.

5. Potassium Extraction was accomplished with 1.0 N NH_4OAc. Potassium concentration was determined by flame photometry, using Li as an internal standard.

6. Sulphate-Sulphur. SO_4 was extracted with dilute $CaCl_2$ and determined colorimetrically on the Auto Analyser.

7. Calcium and Magnesium. Calcium and magnesium were extracted using 1.0 N NH_4OAc. Concentrations of Ca and Mg were then read on a Perkin-Elmer[3] atomic absorption spectrophotometer.

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[2] Supplier: Allied Fisher Scientific, 18 Plymouth St, Winnipeg, R2X 2V7.

8. Copper, Zinc, Manganese and Iron. Prepared soil was extracted using a 2:1 ratio of standard DTPA extracting solution to soil. Extracts were then analysed on the atomic absorption unit.

9. Particle size analysis was determined using the standard pipette sampling method described by Kilmer and Alexander (1949).

10. Organic matter The 1934 Walkley-Black method was used to determine soil organic matter. An automatic titrator was used to back titrate excess $K_2Cr_2O_7$ with $FeSO_4$.

11. Bulk density was determined by excavation. Four holes were augered at each site, using a flat-bottomed post hole auger. Holes were approximately 10 to 12 cm in diameter and each sample taken had a depth of 12 to 18 cm. Diameter and depth of each soil sample were carefully measured. All soil removed from each hole was weighed. From each sample, a representative subsample was weighed and then oven dried. The dry weight of the soil divided by the volume of the hole gave the bulk density.

12. Field capacity was determined by flooding a 1.5 square meter area with sufficient water to wet the soil to a depth of 120 cm. After infiltration, the area was covered with polyethylene to prevent evaporation. Two to three days later (depending on soil texture) four replicates of soil samples were taken from near the centre of each field capacity plot. Soil samples were weighed, oven dried at 105°C, and moisture content calculated on an oven-dry basis.

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[3] Supplier: Perkin-Elmer (Canada) Ltd, 8250 Mountain Sights Ave, Montreal, H4P 2B7.

13. Permanent wilting percentage Per cent moisture content at 15 atmospheres (FAP) was determined in the laboratory using the pressure membrane apparatus, as described by Richards (1947). Permanent wilting percentage was then determined using the following equation;

$$PWP = 0.0207 + 0.77468(FAP)$$ (Shaykewich, 1965).

14. Available moisture The per cent available moisture on a dry-weight basis was obtained by subtracting moisture content at permanent wilting percentage from that at field capacity. Using this value and bulk density for each soil layer, the available water (mm) for each layer and the sum for each profile were calculated. These data are given in Appendix M.

3.3 PLANT ANALYSIS

1. Total nitrogen was determined using a modified Kjeldahl method (Jackson, 1958). 0.5 g of plant material from each sample was weighed into digestion tubes. A catalyst (3.5 g K_2SO_4 plus 3.5 mg Se) and 10 ml concentrated H_2SO_4 were added. The mixture was digested for one hour at 400 - 430°C on a Tecator[4] 1006 digestor. Tubes were then cooled, and 25 ml distilled water added to each tube while vortexing. Distillation and titration was carried out using a Kjeltec 1030[5] analyser.

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[4] Supplier: Allied Fisher Scientific, 18 Plymouth St, Winnipeg, R2X 2V7.

[5] Supplier: Allied Fisher Scientific, 18 Plymouth St, Winnipeg, R2X 2V7.

One digestion procedure was used in preparation for analysis of all other nutrients of interest. One g of ground plant material from each field subplot was predigested at room temperature with 6 ml concentrated HNO_3. After three hours, 3 ml 70 per cent $HClO_4$ were added and the samples digested at 230^{0}C on a Tecator 1006 digestor. The digest was diluted to 25 ml with deionized water and shaken well. Ten to 15 ml was immediately transferred into centrifuge tubes. The remaining material was labelled solution 'A'. A 0.25 ml aliquot of 'A' was diluted with 4.75 ml deionized water and labelled solution 'B'.

2. Copper, Zinc, Manganese and Iron Material previously transferred to centrifuge tubes was allowed to stand overnight, then analysed for Cu, Zn, Mn and Fe content, using a Perkin-Elmer model 560 atomic absorption spectrophotometer.

3. Phosphorus An aliquot of 0.5 ml solution B was diluted with 9.5 ml deionized water. Two ml of complexing reagent was added to all samples for colour development, as described by Stainton et al. (1974). Phosphorus content was determined colorimetrically, using a Bausch and Lomb Spectronic 710 spectrophotometer set at 885 nm.

4. Potassium

   A 0.5 ml aliquot of solution B was diluted with 8.5 ml deionized water and 1.0 ml of a 2500 ppm $LiNO_3$ solution. K concentration was determined using a Perkin-Elmer model 560 atomic absorption spectrophotometer.

5. Calcium and Magnesium A 0.5 ml aliquot of solution B was mixed with 1.0 ml 10 per cent $LaCl_3$ and 8.5 ml deionized water. The resulting solution was analysed for Ca and Mg concentration by atomic absorption.

6. <u>Sulphate-sulphur</u> A 0.2 ml aliquot of solution A was diluted with 8 ml deionized water. The solution was analysed for SO_4 concentration using a Technicon Autoanalyser.

Chapter IV

RESULTS AND DISCUSSION

> My friend G. H. Hardy, who was professor of pure mathematics,...told me once that if he could find a proof that I was going to die in five minutes he would of course be very sorry to lose me, but this sorrow would be quite outweighed by pleasure in the proof. I entirely sympathized with him and was not at all offended.
>
> Bertrand Russell
> from, Clifton Fadiman,
> Any Number Can Play.

4.1 YEAR ONE

4.1.1 Grain yields

On the Newdale CL site, average grain yield declined with increasing amounts of topsoil removal, while on the Reinland LVFS, only the 20 cm soil removal treatment gave a substantially lower yield (Table 4). At both sites, only the 20 cm soil scalping treatment had a significantly lower yield than the control.

TABLE 4

Wheat yield obtained in 1983, averaged over soil removal treatments.

Depth of Topsoil removed	Wheat yield (tonne/ha)	
	Reinland LVFS	Newdale CL
0	1.603a*	2.768a
5	1.708a	2.231a
10	1.389a	2.040a
20	0.575b	1.633b
Coefficient of variation	28.1	23.6

* Tukey's w-procedure. Within location, means followed by the same letter are not significantly different at $P = 0.05$.

4.1.2 Effect of fertilizer

At neither site did fertility treatment have any significant effect on grain yields, either within or among topsoil removal treatments (Figures 3 and 4). On the Reinland LVFS the subplots that were fertilized to soil test recommendations yielded slightly less than those which received either no fertilizer or the heavier fertilizer application. On the Newdale CL, the soil test recommendation gave the highest yield, with the other two treatments slightly lower. (Table 5).

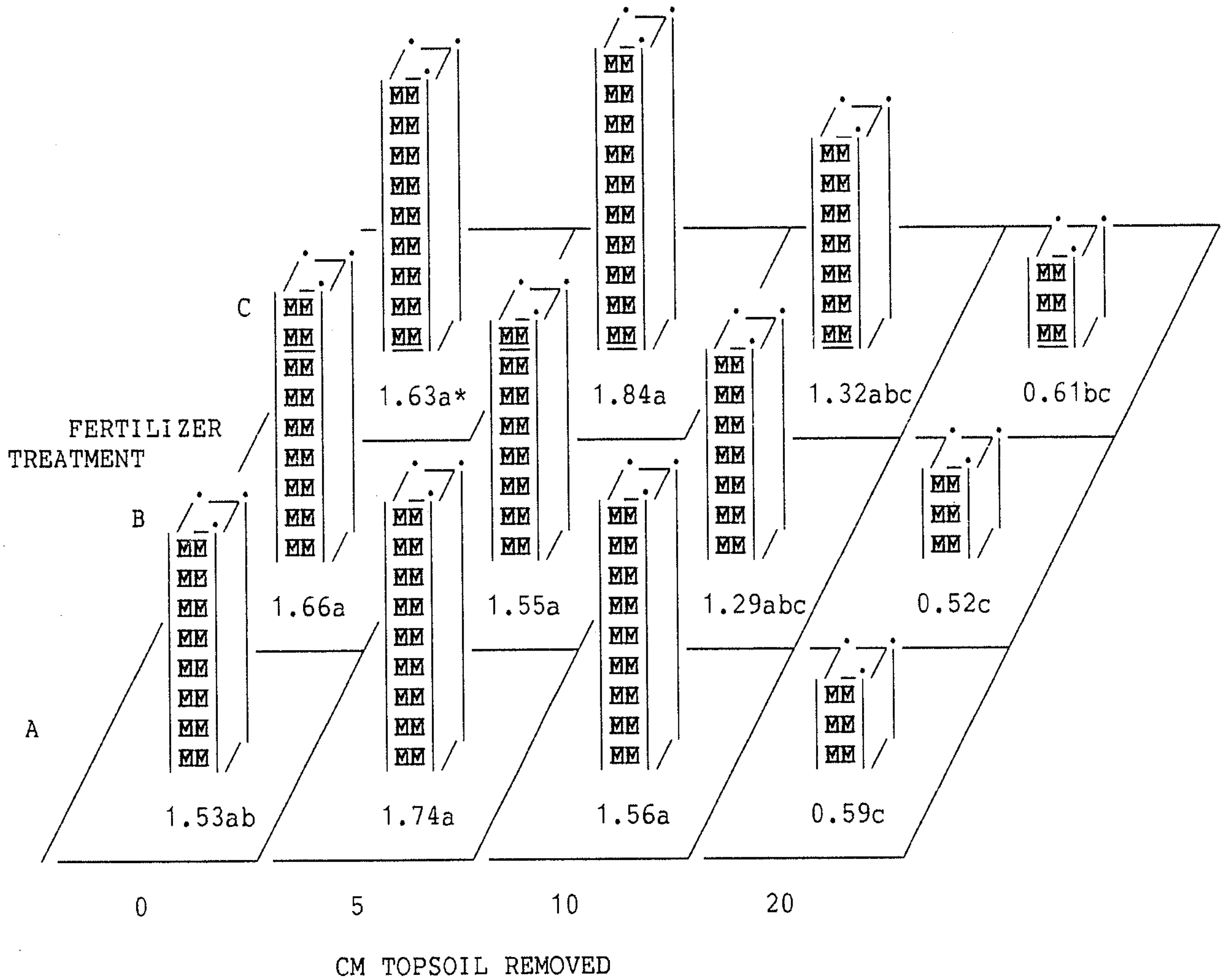

Figure 3: Wheat yields for each level of topsoil removal and fertilizer treatment, on Reinland LVFS soil in 1983.

* Tukey's w-procedure. Means followed by the same letter are not significantly different at P = 0.05.

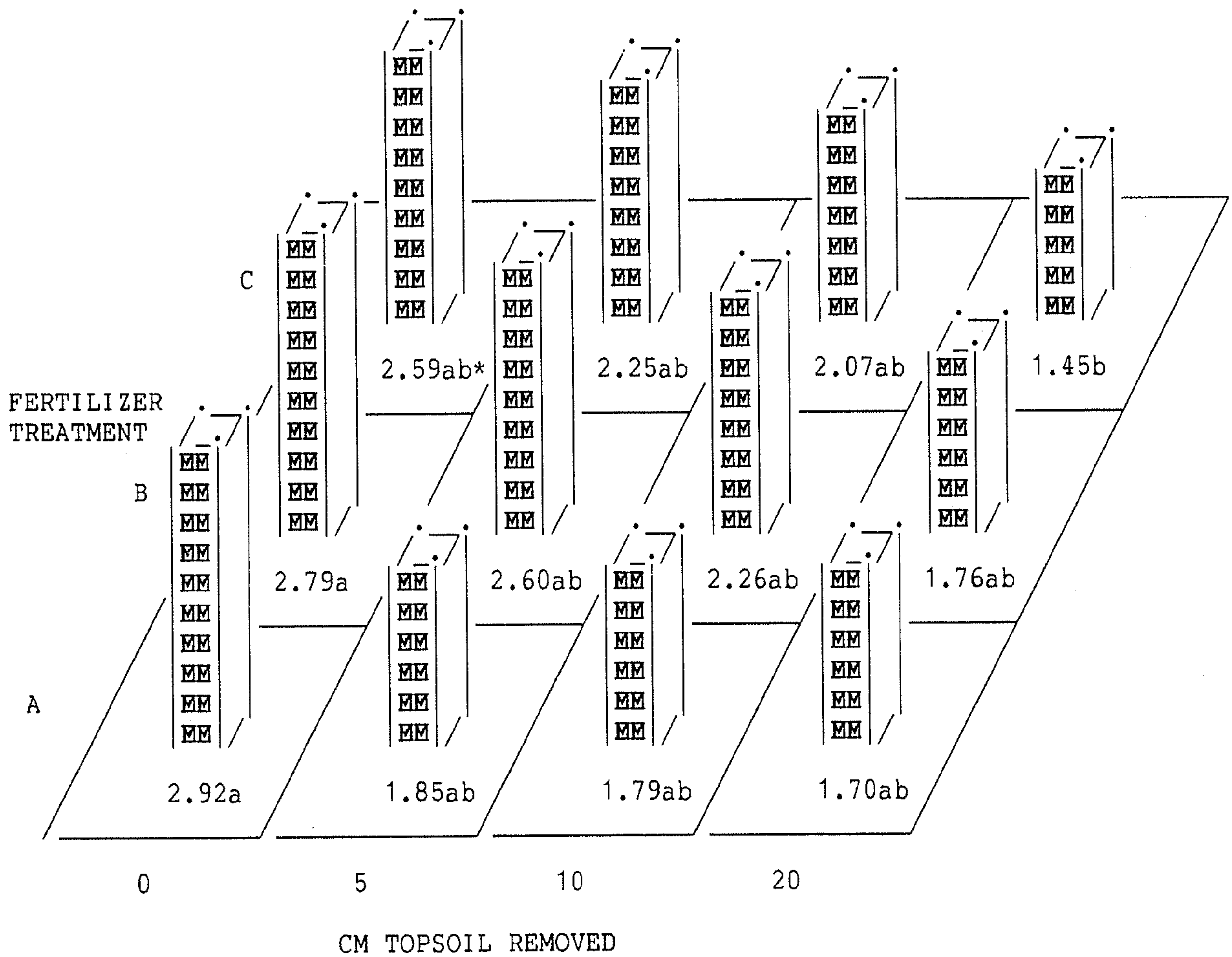

Figure 4: Wheat yields for each level of topsoil removal and fertilizer treatment on Newdale CL in 1983.

* Tukey's w-procedure. Means followed by the same letter are not significantly different at P = 0.05.

TABLE 5

Effect of fertilizer on wheat yields, averaged over soil removal treatments in 1983.

Fertilizer treatment	Number of observations	Yield (tonne/ha) Reinland LVFS	Newdale CL
A	16	1.356a*	2.065a
B	16	1.347a	2.353a
C	16	1.253a	2.087a

*Tukey's w-procedure. Within location, means followed by the same letter are not significantly different at P = 0.05.

4.1.3 Crop nutrient status

4.1.3.1 Midseason plant tissue

In 1983, plant tissue samples collected from individual subplots were bulked according to soil removal and fertilizer treatment. Topsoil removal and fertilizer treatment had little or no effect on nutrient concentrations in the crop at heading. (Appendix A).

4.1.3.2 Grain analysis

On the Reinland LVFS, per cent P and per cent K in the grain did not vary significantly for the various levels of topsoil removal; per cent N was significantly lower where 20 cm of topsoil had been removed. On the Newdale CL, a highly significant difference in per cent P was noted; as little as 5 cm of topsoil removed significantly decreased per cent P. Per cent P in the 20 cm soil removal treatment was, in turn, significantly lower than that in the 5 cm soil removal treatment (Table 6).

The nature of these differences has not been investigated. However, as indicated in the preliminary soil test results (Table 2) the Newdale CL had a high pH in the subsoil and lower available P prior to seeding.

TABLE 6

Concentrations of N, P, and K in grain at final harvest.

Site	Depth of Topsoil removed (cm)	%N	%P	%K
Reinland LVFS	0	2.598a*	0.493a	0.475a
	5	2.538a	0.497a	0.463a
	10	2.543a	0.483a	0.447a
	20	2.482b	0.477a	0.466a
Newdale CL	0	2.668a	0.418a	0.380a
	5	2.507a	0.344b	0.367a
	10	2.590a	0.344b	0.388a
	20	2.507a	0.313c	0.388a

* Tukey's w-procedure. Within location, means followed by the same letter are not significantly different at P = 0.05.

Within soil removal treatments, the wheat grown on the 20 cm plots of the Reinland LVFS had higher protein content on the C-fertilized subplots (Appendix D).

4.1.4 Growing season conditions in 1983

4.1.4.1 Soil moisture

Both soils were at field capacity at seeding (May 21 1983 on the LVFS and May 27 1983 on the Newdale CL). At the Newdale site, the newly exposed B horizon, where 20 cm of topsoil had been removed, developed a blocky structure as surface moisture evaporated in the week following seeding. Soil moisture data from late June to harvest (Appendix G) showed that to a depth of 100 cm, the soil at both sites was wetter where 10 or 20 cm of topsoil had been removed than on other treatments.

4.1.4.2 Precipitation

During the growing season of 1983, precipitation was well below the long-term average at both sites (Appendix J). On the Reinland LVFS, moisture stress from heading to maturity may have accelerated crop maturity. On the Newdale CL, no signs of moisture stress were observed.

4.2 YEAR TWO

4.2.1 Grain yields

In 1984, wheat yields, averaged over all fertilizer treatments, on the Reinland LVFS soil decreased with each increase in topsoil removal (Table 7). Where 10 or 20 cm of topsoil had been removed, yields were significantly lower than the control ($P = 0.05$). This year, this trend was not seen on the Newdale CL. There were no significant differences among wheat yields where 5, 10 or 20 cm of topsoil was removed, although these were significantly lower than the average wheat yields obtained from control plots at $P = 0.1$. On the Pembina CL soil, wheat yields between control plots and those where 5 or 10 cm of topsoil had been scalped were not significantly different, but average wheat yields from the deeply scraped plots (20 cm) were significantly depressed when compared to controls.

TABLE 7

Wheat yields obtained in 1984, averaged over soil removal treatments.

Depth of Topsoil removed	Wheat yield (tonne/ha)		
	Reinland LVFS	Newdale CL	Pembina CL
0	2.297a*	2.785a	2.986a
5	1.911ab	2.306a	3.043a
10	1.551bc	2.269a	2.876a
20	1.073c	2.263a	1.498b
Coefficient of variation	17.9	17.5	21.7

* Tukey's w-procedure. Within location, means followed by the same letter are not significantly different at P = 0.05.

4.2.2 Effect of fertilizer

In 1984, significant fertilizer effects were seen. At all three locations, grain yields (averaged over soil removal treatments) were significantly higher in the subplots that had received the heaviest fertilizer application (Figures 5, 6 and 7).

Within soil removal treatment, fertilizer had no significant effect on grain yield where either no topsoil or 5 cm of topsoil had been removed (Table 8). However, the higher-than-recommended rate of fertilizer significantly improved yields on the Reinland LVFS and Pembina CL soils where 10 cm of topsoil were removed, and on all three soils where 20 cm had been removed.

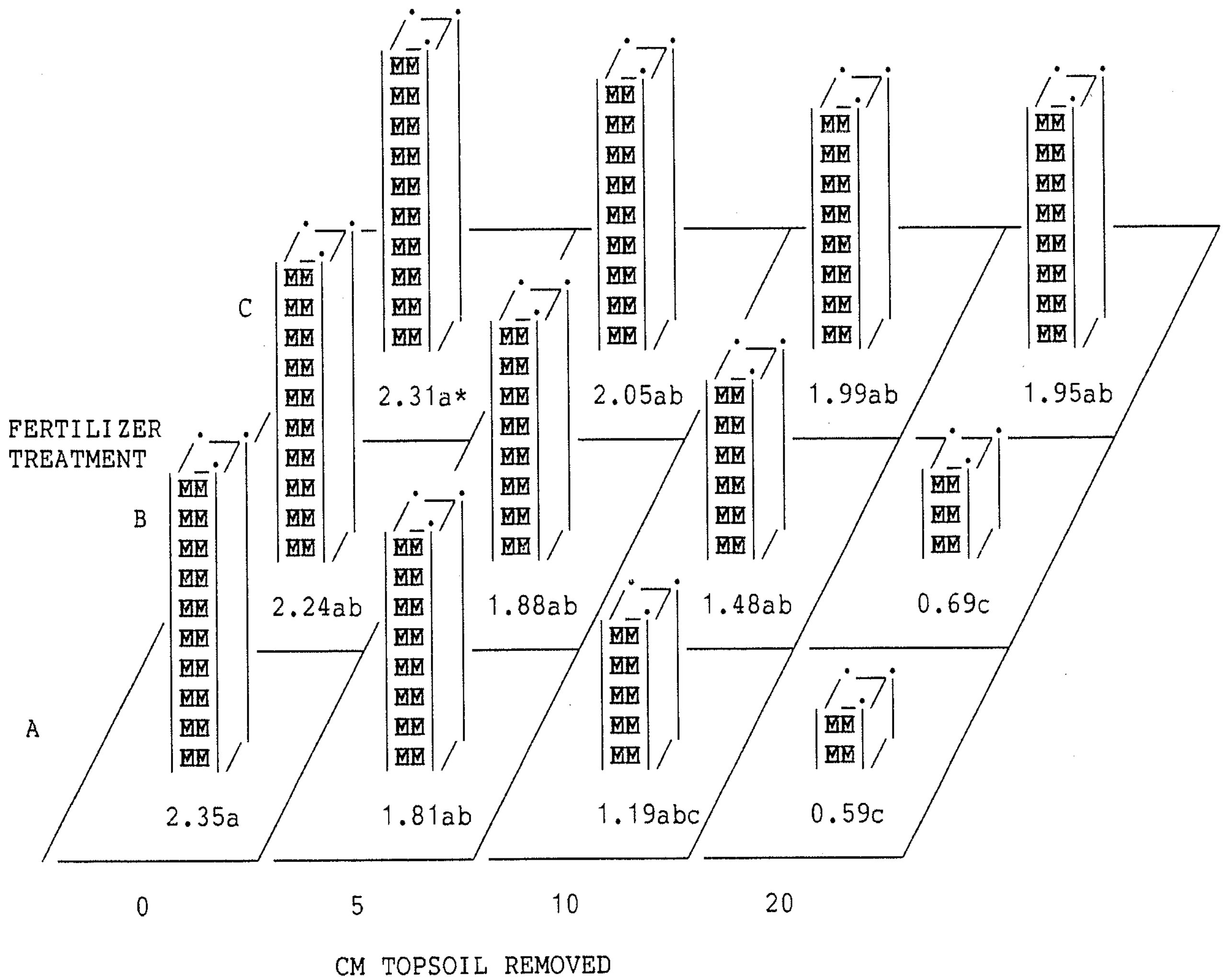

Figure 5: Wheat yields for each level of topsoil removal and fertilizer treatment, on Reinland LVFS in 1984.

* Tukey's w-procedure. Means followed by the same letter are not significantly different at P = 0.05.

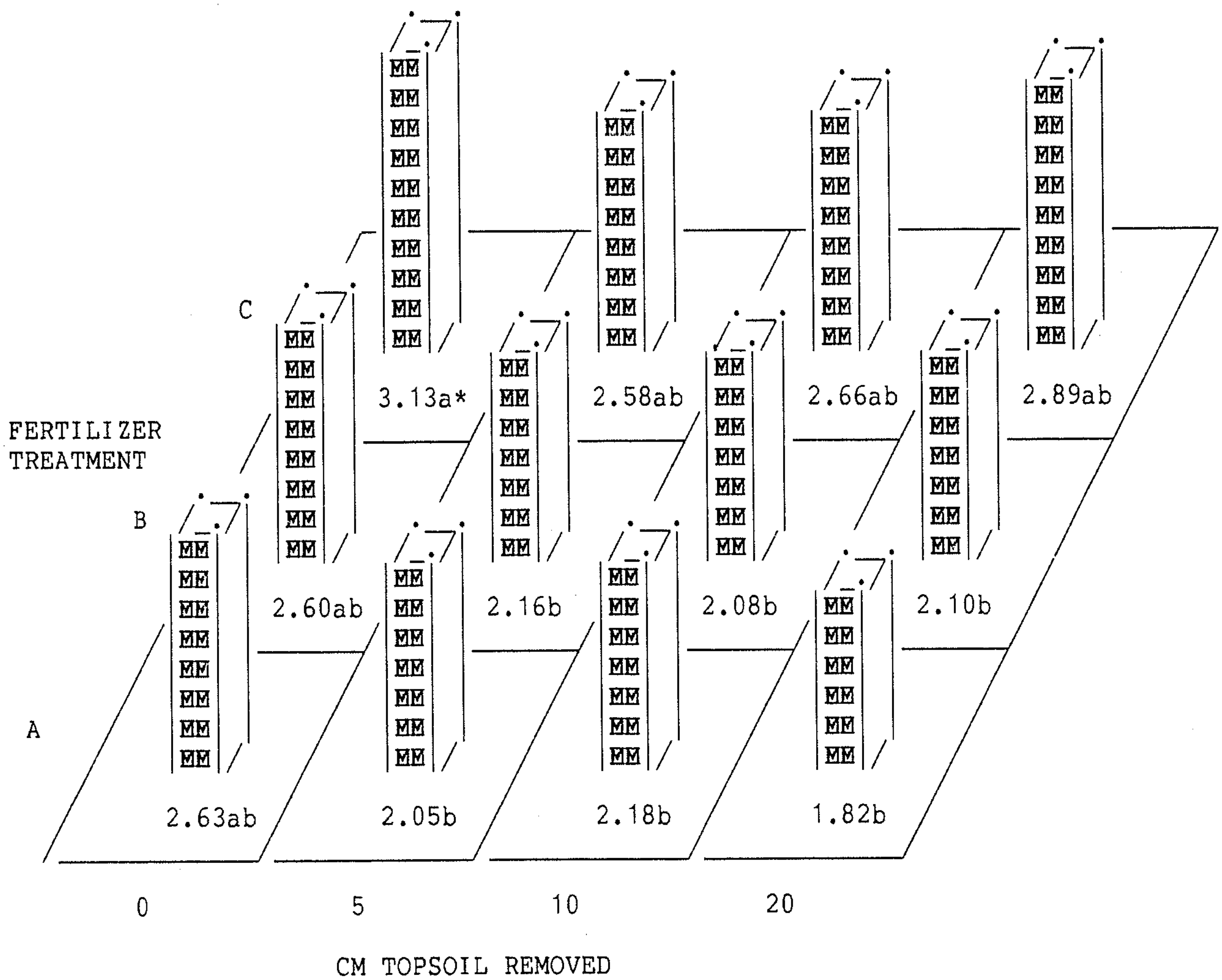

Figure 6: Wheat yields for each level of topsoil removal and fertilizer treatment, on Newdale CL in 1984.

* Tukey's w-procedure. Means followed by the same letter are not significantly different at P = 0.05.

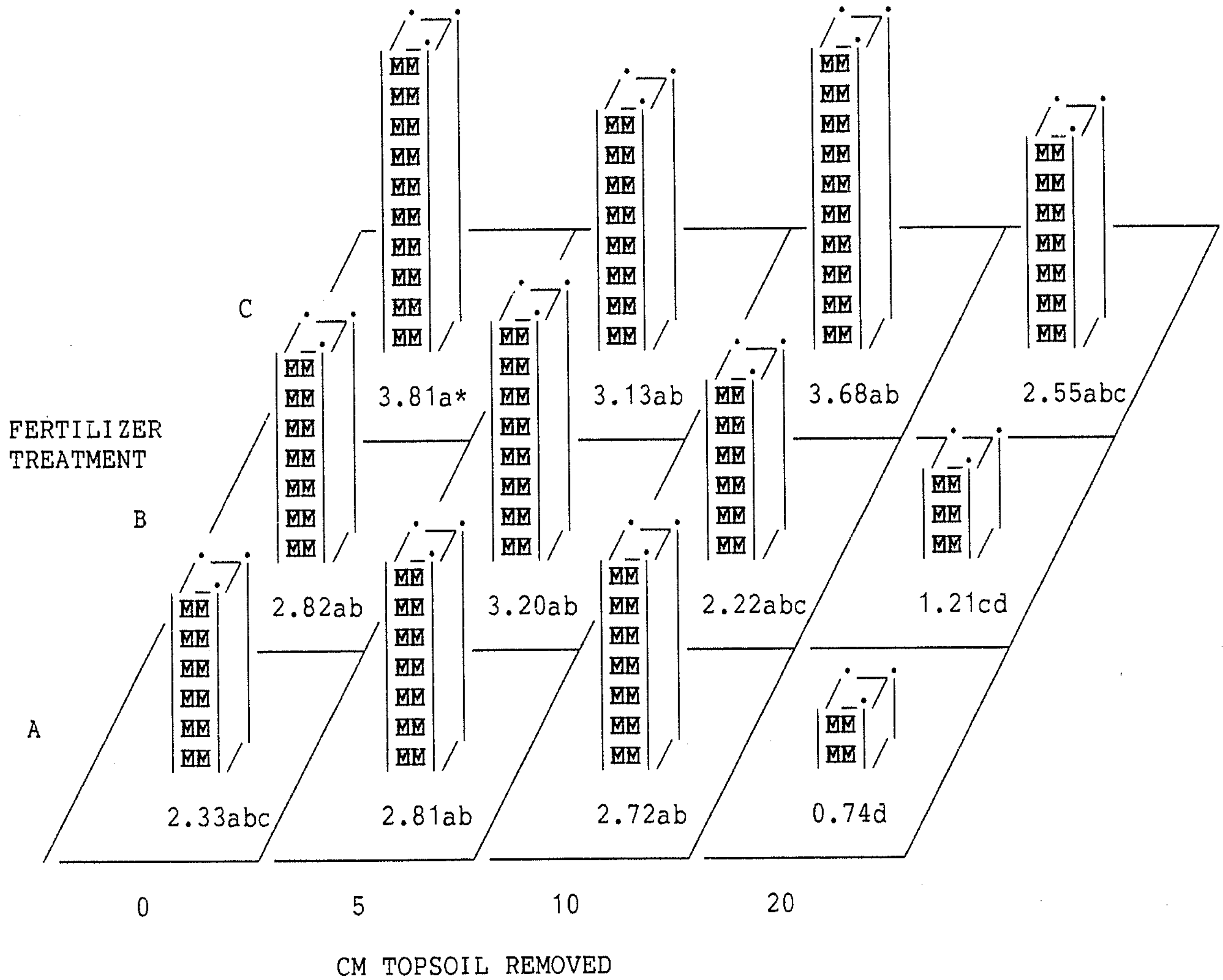

Figure 7: Wheat yields for each level of topsoil removal and fertilizer treatment, on Pembina CL soil in 1984.

* Tukey's w-procedure. Means followed by the same letter are not significantly different at P = 0.05.

TABLE 8

The effect of fertilizer on grain yields, within soil removal treatments in 1984.

Depth of topsoil removed (cm)	Fertilizer treatment	Wheat yield (tonne/ha) Reinland LVFS	Newdale CL	Pembina CL
0	A	2.348a*	2.633a	2.330a
	B	2.238a	2.595a	2.823a
	C	2.305a	3.128a	3.805b
5	A	1.805a	2.050a	2.805a
	B	1.883a	2.158a	3.200a
	C	2.045a	2.580a	3.125a
10	A	1.185a	2.183a	2.723a
	B	1.475ab	2.078a	2.223a
	C	1.993b	2.658a	3.683b
20	A	0.585a	1.823a	0.735a
	B	0.690a	2.095ab	1.205ab
	C	1.945b	2.890b	2.553b

* Tukey's w-procedure. Within location and soil treatment, means followed by the same letter are not significantly different at P = 0.05.

4.2.3 Crop nutrient status

4.2.3.1 Midseason tissue

Results of midseason tissue analysis are given in Appendix C. Significant differences in nutrient concentrations, among soil removal treatments and fertilizer treatments are shown in Tables 9 and 10.

Midseason plant samples from the Pembina CL site were significantly lower in per cent N, P and K where 20 cm of topsoil had been scalped. Samples from the Reinland LVFS also showed decreasing N content with increasing amounts of topsoil removal. Per cent P in midseason samples grown on the Newdale CL were significantly lower where 20 cm of topsoil

TABLE 9

Midseason tissue concentrations averaged over soil removal treatments.

Site	Soil removal treatment	N (%)	P (%)	K (%)	Cu (ppm)	Zn (ppm)
Reinland LVFS	0 cm	2.06a*				18.13ab
	5 cm	2.15a				18.42a
	10 cm	2.10a				16.25b
	20 cm	1.82b				11.92c
Newdale CL	0 cm		0.28a		4.90a	14.63a
	5 cm		0.25a		4.02b	15.96a
	10 cm		0.26a		4.50ab	14.43ab
	20 cm		0.23b		5.00a	12.73b
Pembina CL	0 cm	2.01a	0.42a	2.10a	3.02a	13.98a
	5 cm	1.80a	0.34a	2.29a	2.48b	12.75ab
	10 cm	1.75a	0.36a	2.06a	2.94a	11.33bc
	20 cm	1.57b	0.25b	1.78b	3.08a	10.88c

* Tukey's w-procedure. Within location, means followed by the same letter are not significantly different at P = 0.05.

TABLE 10

Midseason tissue concentrations averaged over fertilizer treatments.

Site	Fertilizer treatment	N (%)	P (%)	K (%)	Cu (ppm)	Zn (ppm)
Reinland LVFS	A	1.95a*	0.27ab			15.41a
	B	1.94a	0.28a			15.41a
	C	2.21b	0.25b			17.72b
Newdale CL	A					15.47a
	B					13.92b
	C					13.92b
Pembina CL	A	1.49a		1.96a	3.30a	11.69a
	B	1.56a		2.01ab	2.61b	11.38a
	C	2.30b		2.21b	2.73b	13.64b

* Tukey's w-procedure. Within location, means followed by the same letter are not significantly different at P = 0.05.

had been removed. At all three sites, Cu content of the tissue samples was depressed on the 20 cm soil removal treatments. On the Reinland and Pembina soils, per cent N in the midseason plant samples was significantly higher where the highest rate of N fertilizer had been used.

4.2.3.2 Grain analysis

1. Reinland LVFS: As in the first year of the study, per cent nitrogen in the final grain harvest was lower where 20 cm of topsoil had been removed (Table 11). P content in the grain was significantly higher in the grain from control soil plots.
2. Newdale CL: Per cent P in the grain was significantly lower where 20 cm of topsoil was removed. When compared to control soil plots, per cent K was significantly depressed where either 10 or 20 cm of topsoil had been scalped.
3. Pembina CL: Soil removal treatment did not significantly affect N, P or K content of the grain.

On both the Reinland LVFS and the Newdale CL sites, Cu content of the grain increased with increasing levels of topsoil removal: the opposite trend was seen on the Pembina CL. Grain sampled from 20 cm soil plots on the Pembina CL and the Reinland LVFS contained significantly less Zn than that from controls (Appendix E).

TABLE 11

Concentrations of N, P and K in grain at final harvest, in 1984.

Site	Depth of topsoil removed (cm)	%N	%P	%K
Reinland LVFS	0	2.907a*	0.467a	0.345a
	5	2.774ab	0.535b	0.349a
	10	2.721ab	0.548b	0.316a
	20	2.558b	0.582b	0.305a
Newdale CL	0	2.500a	0.410a	0.496a
	5	2.298a	0.381ab	0.489a
	10	2.261a	0.427a	0.259c
	20	2.435a	0.333b	0.377b
Pembina CL	0	2.369a	0.568a	0.568a
	5	2.376a	0.577a	0.479a
	10	2.285a	0.529a	0.446a
	20	2.228a	0.516a	0.528a

* Tukey's w-procedure. Within location and column, means followed by the same letter are not significantly different at P = 0.05.

4.2.4 Growing season conditions in 1984

4.2.4.1 Soil moisture

Soil moisture was at less than field capacity when the three sites were seeded on May 9-11, 1984 (Appendix H). Both CL soils were rototilled prior to seeding. The LVFS was not spring-cultivated, because of the extremely low water content in the surface soil. Gravimetric soil samples, taken throughout the growing season, showed that the deeply scraped plots usually contained more moisture than control plots (Appendix H).

4.2.4.2 Precipitation

As in the first year of this study, growing season precipitation was well below the long-term averages at both the Reinland LVFS and Newdale

CL sites (Appendix J). On the Pembina soil, precipitation was only slightly below normal.

4.3 DISCUSSION

4.3.1 Crop growth and development

At the time of site preparation in May 1983, the Newdale CL site was wet. This resulted in considerable compaction of those plots from which topsoil was scraped. The period following soil removal and seeding was quite dry, producing a poor seed bed. Consequently, germination of the wheat was uneven and the plant stand less than optimum on some of the scraped plots (Figure 8). Wheat germination and emergence on the Reinland LVFS site were even.

In 1983, weed control was satisfactory on the Reinland LVFS, but some hand weeding was necessary on the Newdale CL because of uneven wild mustard emergence on scraped plots. The Pembina CL site was scalped in late October, 1983, in the hope of avoiding the springtime problem of compaction. In the second year of the study, although no significant germination differences were found at any of the sites, (Appendix I) 'scalped' plots on the Newdale CL showed signs of tractor tire compaction well into the season, and in these places, crop growth was somewhat slow.

In 1984, weed control was excellent at all three sites until late in the growing season, when a few weeds appeared on the Reinland LVFS site which had not been spring cultivated.

In year one, visual differences between the crop grown on the deeply scraped plots (10 or 20 cm soil removed) compared to the others became

Figure 8: Uneven wheat germination on a 20 cm soil plot, Newdale CL, 1983.

apparent in late June. This was most noticeable on the Reinland LVFS site although crop emergence here had been even. Wheat growing on the deeply scraped plots was shorter stemmed, produced fewer tillers and less fertile florets per spike (Figure 9).

Figure 9: Wheat in the foreground is growing where 20 cm of topsoil has been removed: Reinland LVFS, 1983.

In 1984, at all three field sites, the effect of the highest fertilizer treatment was noticeable (Figure 10). At the Pembina CL site, where no topsoil was removed, wheat grown under the highest fertilizer regime started to lodge two weeks before harvest. At all experimental sites, wheat grown where 20 cm of topsoil had been scalped, took approximately four days longer to head than wheat grown on other soil treatments. In 1983, this effect was apparent for all fertilizer treatments. In 1984, it was more noticeable on the 'A' (no fertilizer added) subplots.

Figure 10: Wheat growing where 20 cm of topsoil has been removed, Pembina CL, 1984. From left to right, A, B and C fertilizer treatments.

4.3.2 Crop nutrient status

In the first year of the study, midseason tissue samples were bulked, and thus results were not analysed statistically. Plant tissue analyses from 1984 show that, on the Pembina CL soil, the differences seen in N, P and K content among midseason plant samples from the four soil removal treatments were not found in the grain samples. Grain from the 'C' fertilized subplots had higher protein content than the grain grown under the other fertilizer regimes.

4.3.3 Effect of organic matter

When topsoil is lost to erosion, soil organic matter is also lost. At all three field sites, in the top 15 cm of soil, the fall 1984 organic matter content of the most deeply scraped plots was less than fifty per cent of that found in the controls (Appendix L). Since soil organic matter helps protect soil from erosion, by aiding aggregation and providing ground cover, the decreased organic matter content of eroded soils can leave them more vulnerable to further erosion. Slevinsky (1980) using textural data from North Dakota, categorized soils in the Gladstone-Minnedosa area as to Wind Erodibility Group. According to these classifications, a wheat stubble residue of 616 Kg/ha in the spring is necessary to prevent erosion on a LVFS. On the test site of this texture, many of the plots on which 20 cm of topsoil had been removed could not provide this amount of residue under conventional management.

The relationships expressed in Table 12 indicate that organic matter content of the plough layer may have had an effect on 1984 grain yields obtained from control subplots. On the Newdale and Pembina soils, the relationship loses significance as fertilizer is added.

TABLE 12

Regression equations describing the effect of soil organic matter on wheat yields.

Site	Number of observations	Fertilizer treatment	Regression equation**	
Reinland LVFS	8	A	Y = −0.767 + 1.473 O.M.	R^2 = .895*
Newdale CL	8	A	Y = 0.899 + 0.226 O.M.	R^2 = .726*
Pembina CL	8	A	Y = 0.610 + 0.756 O.M.	R^2 = .749*
Reinland LVFS	8	B	Y = −0.380 + 1.151 O.M.	R^2 = .750*
Newdale CL	8	B	Y = 1.454 + 0.117 O.M.	R^2 = .483
Pembina CL	8	B	Y = 0.0723 + 1.134 O.M.	R^2 = .570
Reinland LVFS	8	C	Y = 0.108 + 0.837 O.M.	R^2 = .756*
Newdale CL	8	C	Y = 2.866 − 0.051 O.M.	R^2 = −.210
Pembina CL	8	C	Y = 2.037 + 0.725 O.M.	R^2 = .647

**(Y = wheat yield (t/ha); O.M. = per cent organic matter in plough layer)
* significant at P = 0.05.

4.3.4 Soil temperatures

Soil temperature readings (Appendix F) indicate that differences in Ap horizon temperatures among the four soil removal treatments were not sufficient to affect crop germination or early growth. At a depth of 150 cm the highest temperature recorded on the Reinland LVFS was 14.8 ^{0}C on August 15, 1983 and 15.2 ^{0}C on July 9, 1984. On the CL soils, maximum recorded temperatures at 150 cm were lower: 11.9 ^{0}C on 29 August, 1983 and 10 ^{0}C on 4 August, 1984 on the Newdale soil and 11.4 ^{0}C on 7 August, 1984 on the Pembina CL.

4.3.5 Crop water use

Although growing season precipitation was well below the long-term average at both the Reinland LVFS and the Newdale CL sites in both years of the study, grain yields were higher in 1984. As has been noted, fertilizer additions in 1984 significantly increased yields. It is also worthy of note that, although rainfall was less than optimum, in the second year of the study, at least 30 mm of precipitation was recorded at each site during the last two weeks of June. Lehane and Staple (1962) in a study on the effect of soil moisture tensions on growth of wheat, found that moisture stress at heading had the most deleterious effect on yield. In 1983, precipitation was adequate early in the season, but not during the period from heading to harvest. By contrast in 1984, the crop was not moisture stressed during the critical heading stage.

In both study years, soil moisture content was greater in the deeply scraped plots. (All moisture sampling was done on 'C'-fertilized subplots). While it might be anticipated that the less vigourous crop, growing on the deeply eroded soil, would extract less moisture from the soil, the relationship is not simple. Drainage on the Pembina CL is described as moderate. Both the Reinland LVFS and the Newdale CL are imperfectly drained: removing topsoil at these two sites in particular, places the crop in a wetter environment.

Frye et al. (1982) described several characteristics of the Ap horizon of eroded soils. These researchers found that a decrease in available water holding capacity (due to increased clay content in the Ap horizon) was the most important yield-limiting effect seen in the eroded soils they studied. In the present study, a slight decrease in available water holding capacity was seen on the Pembina CL soil. Other characteristics of the Ap horizon of eroded soils, such as higher bulk density, lower organic matter content and lower fertility status, were seen at all three experimental locations.

4.3.6 Soil analysis: fall 1984

Results of soil analyses (Appendix K) show that NO_3-N and available P (from 0 - 60 cm) decrease in all three soils as topsoil is removed. On the Pembina CL, available P tests as 'high' for all soil removal treatments and SO_4-S is low. Available P is generally low on the calcareous Newdale CL soil. On both this site and the Reinland LVFS, NO_3-N is much higher than on the Pembina CL. In several soil samples from the Reinland LVFS, DTPA-extractable Cu is below the critical level mentioned by McGill.[6]

[6] McGill, K. 1985. Personal Communication.

Chapter V

SUMMARY AND CONCLUSIONS

Nunc lento sonito dicunt, morieris.

No man is an island, entire of itself,
every man is a piece of the continent,
a part of the main.
If a clod be washed away by the sea,
Europe is the less, as well as if a promontory were ....
Any man's death diminishes me,
because I am involved in mankind,
and therefore, never send to know for whom the bell tolls:
it tolls for thee.

from Meditation XV11
John Donne.

In this study, the effect of simulated soil erosion on wheat yields was investigated at three sites in southern Manitoba. In year one, fertilizer applications had no significant effect on wheat yields, even where 20 cm of topsoil had been removed.. In the second year, however, the highest fertilizer rate significantly increased yields wherever more than 5 cm of topsoil had been removed. Results indicate that neither soil temperature nor total soil moisture content adversely affected grain yields on the 'eroded' plots. Where no N, P or K fertilizer was used, a relationship was found between per cent organic matter in the plough layer and wheat yield. Soil samples taken from 'eroded' plots contained less available N and P than those taken from control plots. In 1984, fertilizer application compensated for some of the loss in soil productivity due to soil erosion.

This study provides only 5 site-years' data. During both 1983 and 1984, precipitation was below normal at both the Reinland LVFS and the Newdale CL site. Different weather conditions would possibly have produced different soil erosion - soil productivity relationships. On well drained soils, it is probable that the effects of simulated soil erosion would have depressed wheat yields even further during the two years of the study.

On the Pembina CL soil, where growing season precipitation was near normal, wheat yield on the uneroded soil, which received the highest fertilizer application, was 3.81 t/ha. Where 20 cm of topsoil had been removed, wheat yields were 0.74 t/ha on 'A' subplots (no N, P or K fertilizer) 1.21 t/ha from 'B' subplots and 2.55 t/ha on 'C' subplots which received the highest fertilizer application. Clearly, in 1984, it was economically feasible to add extra fertilizer to the deeply eroded soil. It is also clear that the extra fertilizer did not restore this soil to its original productivity.

Many site-years' data would be needed to fully evaluate the effect of soil erosion on a soil's productivity. Results of the present study indicate that soil erosion reduces crop yields, that extra inputs can often improve the productivity of eroded soils, and that, depending on soil characteristics and management practices, the original (uneroded) productivity of the soil may not be completely regained.

It is conceivable that a future study could combine many site-years' data and utilize several crops. It is also conceivable that economic analysis of yield results could be included in such a study.

The different soil erosion-crop yield relationships seen in this study, from site to site and from year to year, emphasize the site specificity of such work and the need for long-term studies. Predictive soil erosion-productivity models could be put to good use in Manitoba, for farm management decision-making and for conservation planning, if there existed a sufficient data base of relevant soil parameters.

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Appendix A

CEREAL TISSUE ANALYSIS: INTERPRETIVE CRITERIA USED BY MANITOBA PROVINCIAL SOIL TESTING LABORATORY (WHOLE PLANT PRIOR TO FILLING)

Nutrient		Low	Marginal	Sufficient	High	Excess
Nitrogen (N) %	Spring	1.50	1.50-2.00	2.00-3.00	3.00-4.00	4.00
	Winter	1.25	1.25-1.75	1.75-3.00	3.00-4.00	4.00
Phosphorus (P) %		0.15	0.15-0.25	0.26-0.50	0.50-0.80	0.80
Potassium (K) %		1.00	1.00-1.50	1.50-3.00	3.00-5.00	5.00
Sulphur (S) %		0.10	0.10-0.15	0.15-0.40	0.40-0.80	0.80
Calcium (Ca) %	Other	0.10	0.10-0.20	0.20-1.00	1.00-1.50	1.50
	Barley	0.20	0.20-0.30	0.30-2.00	2.00-2.50	2.50
Magnesium (Mg) %		0.10	0.10-0.15	0.15-0.50	0.50-1.00	1.00
Zinc (Zn) ppm		10	10-15	15-70	70- 150	150
Copper (Cu) ppm	Barley	2.3	2.3-3.7	3.7-25	25- 50	50
	Wheat	3.0	3.0-4.5	4.5-25	25- 50	50
	Oats	1.7	1.7-2.5	2.5-25	25- 50	50
Iron (Fe) ppm		15	15-20	20-250	250- 500	500
Manganese (Mn) ppm		10	10-15	15-100	100- 250	250

Appendix B

CHEMICAL COMPOSITION OF WHEAT AT HEADING, 1983.

Soil removal treatment	Fertilizer treatment	N	P	K (%)	S	Ca	Mg	Cu (ppm)	Zn	Mn	Fe
Reinland LVFS. Sampling date 830704											
0 cm	A	2.20	0.29	3.54	0.28	0.71	0.31	4.50	17.75	18.00	56.75
	B	2.15	0.30	3.35	0.34	0.74	0.34	4.75	21.00	16.50	71.00
	C	2.29	0.31	3.26	0.21	0.80	0.34	3.75	18.50	22.50	59.25
5 cm	A	2.31	0.32	3.76	0.35	0.79	0.32	4.75	15.75	19.25	69.00
	B	2.40	0.30	3.46	0.39	0.79	0.35	5.75	23.25	18.25	59.75
	C	2.11	0.27	3.81	0.28	0.73	0.32	6.00	12.75	22.00	64.50
10 cm	A	2.31	0.34	3.50	0.31	0.59	0.39	5.50	18.25	20.00	59.00
	B	2.09	0.34	3.67	0.38	0.68	0.29	4.25	17.25	17.75	75.00
	C	2.19	0.35	3.61	0.30	0.71	0.34	4.25	18.50	16.50	64.25
20 cm	A	2.29	0.38	3.49	0.31	0.73	0.30	4.50	17.75	22.25	63.50
	B	2.35	0.32	3.71	0.33	0.76	0.35	5.25	19.00	21.25	80.25
	C	2.21	0.35	3.89	0.37	0.82	0.33	5.75	20.75	18.00	76.25
Newdale CL Sampling date 830712											
0 cm	A	2.31	0.35	3.81	0.32	0.85	0.23	5.75	14.75	42.25	57.00
	B	2.24	0.26	3.58	0.33	0.61	0.22	5.50	14.75	34.75	55.50
	C	1.99	0.29	3.69	0.28	0.62	0.19	5.25	16.75	37.00	61.25
5 cm	A	2.01	0.24	3.68	0.39	0.77	0.21	4.50	17.00	41.00	69.25
	B	2.11	0.23	3.54	0.28	0.86	0.23	4.75	13.50	33.25	66.00
	C	1.90	0.34	3.29	0.31	0.90	0.19	6.00	18.00	51.25	81.25
10 cm	A	2.06	0.28	3.99	0.35	0.74	0.19	5.50	19.25	34.25	71.50
	B	1.91	0.37	3.66	0.24	0.61	0.24	5.75	18.50	43.00	67.25
	C	1.95	0.33	3.28	0.33	0.78	0.22	4.75	16.00	33.00	54.00
20 cm	A	2.09	0.30	3.77	0.41	0.68	0.25	6.25	18.25	36.50	78.00
	B	2.14	0.32	3.19	0.40	0.78	0.23	5.75	19.75	38.25	89.00
	C	2.00	0.31	3.61	0.33	0.71	0.19	5.50	18.50	39.25	56.50

Appendix C

CHEMICAL COMPOSITION OF WHEAT AT HEADING, 1984.

Soil removal treatment	Fertilizer treatment	N (%)	P (%)	K (%)	S (%)	Ca (%)	Mg (%)	Cu (ppm)	Zn (ppm)	Mn (ppm)	Fe (ppm)
Reinland LVFS. Sampling date 840706											
0 cm	A	2.01	0.26	3.23	0.26	0.74	0.29	3.25	16.75	15.00	51.00
	B	1.90	0.26	3.32	0.26	0.81	0.25	3.34	16.75	16.00	49.25
	C	2.23	0.28	3.29	0.26	0.78	0.27	3.75	20.88	17.00	52.25
5 cm	A	2.13	0.28	3.40	0.28	0.89	0.28	3.63	16.25	17.25	51.75
	B	1.94	0.29	3.32	0.31	0.86	0.25	3.38	17.00	16.13	56.00
	C	2.37	0.27	3.29	0.30	0.76	0.29	3.38	22.00	15.25	49.75
10 cm	A	1.90	0.29	3.34	0.32	0.71	0.27	3.25	16.25	14.00	53.25
	B	2.25	0.28	3.50	0.27	0.75	0.29	3.25	15.38	15.63	59.00
	C	2.15	0.26	3.39	0.31	0.72	0.30	3.50	17.13	15.38	56.25
20 cm	A	1.72	0.28	3.41	0.32	0.81	0.32	3.50	12.38	14.75	59.00
	B	1.67	0.30	3.31	0.28	0.75	0.26	3.63	12.50	13.25	53.25
	C	2.08	0.24	3.28	0.30	0.73	0.28	3.50	10.90	13.88	54.75
Newdale CL Sampling date 840707											
0 cm	A	1.88	0.28	3.84	0.31	0.64	0.19	5.13	14.50	47.00	45.25
	B	2.16	0.29	3.84	0.29	0.70	0.23	5.13	13.63	55.00	57.25
	C	2.39	0.28	3.58	0.32	0.77	0.23	4.44	13.63	37.75	45.50
5 cm	A	2.08	0.24	3.76	0.28	0.77	0.24	3.75	17.56	41.00	55.25
	B	2.03	0.26	3.77	0.30	0.79	0.23	4.00	15.94	46.50	66.00
	C	2.15	0.24	3.75	0.32	0.68	0.22	4.31	14.38	47.50	50.75
10 cm	A	1.99	0.23	3.83	0.32	0.69	0.19	4.75	16.75	38.75	56.25
	B	1.99	0.29	3.85	0.34	0.80	0.24	4.25	14.38	47.25	57.25
	C	2.06	0.27	3.80	0.30	0.74	0.26	4.50	12.18	41.75	54.00
20 cm	A	2.12	0.20	3.88	0.27	0.79	0.22	4.75	13.00	45.00	51.25
	B	2.14	0.25	3.86	0.31	0.70	0.22	4.88	11.75	48.00	57.50
	C	2.44	0.25	3.86	0.31	0.75	0.19	5.38	13.38	49.25	59.00
Pembina Cl Sampling date 840711											
0 cm	A	1.68	0.45	2.13	0.29	0.34	0.21	3.75	14.00	17.75	50.50
	B	1.79	0.42	2.13	0.29	0.24	0.21	2.94	13.44	16.75	39.75
	C	2.57	0.38	2.05	0.28	0.29	0.19	2.36	14.50	17.75	41.25
5 cm	A	1.44	0.35	2.13	0.28	0.29	0.24	2.69	11.50	18.00	40.25
	B	1.68	0.33	2.30	0.27	0.31	0.20	2.06	11.44	19.75	50.00
	C	2.29	0.33	2.45	0.27	0.33	0.19	2.69	15.31	19.25	49.00
10 cm	A	1.59	0.35	2.20	0.27	0.22	0.24	3.25	11.00	17.25	32.50
	B	1.25	0.34	1.80	0.29	0.35	0.24	2.94	9.63	15.75	49.25
	C	2.42	0.40	2.18	0.29	0.38	0.21	2.63	13.34	14.75	39.75
20 cm	A	1.27	0.23	1.37	0.26	0.33	0.24	3.50	10.25	18.25	42.25
	B	1.55	0.25	1.80	0.28	0.39	0.22	2.50	11.38	18.75	43.50
	C	1.94	0.28	2.15	0.28	0.30	0.19	3.25	11.38	16.75	51.75

Appendix D

NUTRIENT ANALYSIS OF GRAIN: FINAL HARVEST, 1983.

Site	Soil removal treatment	Fertilizer treatment	N	% P	K
Reinland LVFS	0 cm	A	2.63a*	0.52a	0.50a
		B	2.57a	0.48a	0.47a
		C	2.60a	0.48a	0.46a
	5 cm	A	2.57a	0.49a	0.44a
		B	2.53a	0.49a	0.46a
		C	2.52a	0.51a	0.49a
	10 cm	A	2.53a	0.48a	0.43a
		B	2.59a	0.46b	0.43a
		C	2.52a	0.52a	0.49a
	20 cm	A	2.43a	0.47a	0.45a
		B	2.50ab	0.48a	0.47a
		C	2.52a	0.48a	0.49a

Site	Soil removal treatment	Fertilizer treatment	N	% P	K
Newdale CL	0 cm	A	2.73a*	0.43a	0.38a
		B	2.66a	0.41a	0.38a
		C	2.61a	0.41a	0.38a
	5 cm	A	2.60a	0.32a	0.37a
		B	2.43a	0.38a	0.40a
		C	2.49a	0.33a	0.34a
	10 cm	A	2.57a	0.34a	0.37a
		B	2.67a	0.36a	0.42a
		C	2.54a	0.31a	0.38a
	20 cm	A	2.62a	0.33a	0.38a
		B	2.41a	0.29a	0.35a
		C	2.67a	0.33a	0.43b

* Tukey's w-procedure. Within location and soil treatment, means followed by the same letter are not significantly different at P = 0.05.

Appendix E

NUTRIENT ANALYSIS OF GRAIN: FINAL HARVEST, 1984.

Site	Soil removal treatment	Fertilizer treatment	N	% P	K	Cu	ppm Zn
Reinland LVFS	0 cm	A	2.88a*	0.45a	0.34a	2.88a	30.56a
		B	2.75a	0.49a	0.39a	2.81a	33.25a
		C	3.09b	0.47a	0.32a	3.44a	41.63a
	5 cm	A	2.81a	0.51a	0.37a	4.60a	32.10a
		B	2.86a	0.58a	0.36a	3.80a	35.80ab
		C	2.67a	0.52a	0.32a	4.00a	45.30b
	10 cm	A	2.48a	0.58a	0.37a	6.75a	41.75a
		B	2.68a	0.56a	0.30ab	5.00b	26.69b
		C	3.00a	0.51a	0.25b	4.00b	33.50ab
	20 cm	A	2.64a	0.67a	0.32a	7.25a	36.60a
		B	2.43a	0.57ab	0.37a	6.25a	26.00a
		C	2.61a	0.51b	0.26a	5.32a	22.00a

Site	Soil removal treatment	Fertilizer treatment	N	% P	K	Cu	ppm Zn
Newdale CL	0 cm	A	2.43ab	0.45a	0.54a	3.94a	27.20a
		B	2.30a	0.40a	0.44a	3.13a	20.50a
		C	2.78a	0.38a	0.51a	4.63a	25.60a
	5 cm	A	2.06a	0.41ab	0.49a	5.13a	34.75a
		B	2.32a	0.42a	0.55a	4.67a	26.88a
		C	2.52a	0.32b	0.43a	4.63a	23.82a
	10 cm	A	2.00a	0.35a	0.20a	6.70a	38.60a
		B	2.30ab	0.52b	0.27ab	5.40a	32.60a
		C	2.49b	0.41ab	0.32b	6.70a	29.10a
	20 cm	A	2.34a	0.31a	0.36a	6.56a	31.10a
		B	2.33a	0.35a	0.42a	6.44a	25.40a
		C	2.64a	0.34a	0.35a	6.63a	22.80a

* Tukey's w-procedure. Within location and soil treatment, means followed by the same letter are not significantly different at P = 0.05.

Appendix E (cont'd)

Site	Soil removal treatment	Fertilizer treatment	N	% P	K	ppm Cu	Zn
Pembina CL	0 cm	A	2.17a	0.56a	0.49a	6.88a	38.70a
		B	2.28a	0.61a	0.675a	6.50a	34.90a
		C	2.66a	0.54a	0.54a	4.75a	35.00a
	5 cm	A	2.10a	0.59a	0.55a	6.94a	32.63a
		B	2.16a	0.53a	0.46a	4.50a	29.06a
		C	2.82b	0.61a	0.43a	4.50a	32.13a
	10 cm	A	2.11a	0.54a	0.46a	5.19a	27.69a
		B	1.97a	0.55a	0.48a	5.50a	28.31a
		C	2.78b	0.50a	0.40a	4.19a	26.81a
	20 cm	A	2.08a	0.55a	0.55a	3.00a	29.31a
		B	2.11a	0.53a	0.54a	2.44a	32.06a
		C	2.50a	0.47a	0.50a	2.38a	26.63a

* Tukey's w-procedure. Within location and soil treatment, means followed by the same letter are not significantly different at P = 0.05.

Appendix F

SOIL TEMPERATURES.

Site	Date Year, Month, Day	Air temp °C	Soil removal treatment (cm)	Soil temp °C(at cm depth) 2.5	5.0	10.0	20.0	50.0	100.0	150.0
Reinland LVFS										
	830531	19.0	0	20.0	15.0	11.6	8.9			
			20	22.0	21.0	16.2	12.5			
	830606	19.0	0	15.6	14.8	13.4	10.9			
			20	17.0	15.0	13.6	11.0			
	830612	27.0	0	26.0	22.2	19.2	16.0	12.1	7.1	3.8
			20	24.3	23.9	21.0	18.0			
	830616	25.0	0	25.0	21.5	16.4	12.0	11.0	8.1	5.1
	830626	25.0	0	30.0	25.6	21.3	17.4	14.7	12.7	9.2
			20	26.6	23.9	19.4	17.7			
	830711	19.0	0	23.3	21.0	19.2	18.3	17.2	14.3	9.1
			20	19.2	18.4	17.8	17.8			
	830720	30.0	0	28.4	26.4	23.2	20.4	18.3	15.1	13.0
			20	36.6	33.8	28.0	25.4			
	830727	29.0	0	26.8	23.8	21.4	20.1	18.6	15.8	13.4
			20	30.5	28.2	24.6	23.2			
	830802	25.0	0	23.4	20.5	20.0	19.4	19.1	15.4	13.6
			20	30.0	21.1	21.1	20.6			
	830815	29.0	0	32.0	28.8	24.0	20.5	19.8	16.0	14.8
			20	32.4	29.1	24.5	22.3			
	840515	15.0	0	19.2	17.2	14.1	10.5	6.5	2.1	2.1
			20	19.0	16.8	14.5	11.0			
	840528	22.0	0	14.6	12.5	9.4	8.8	7.8	4.7	3.0
			20	22.0	18.7	13.5	12.8			
	840605	20.0	0	16.9	16.0	15.1	14.7	12.7	8.4	5.8
			20	21.3	18.9	16.8	14.7			
	840709	27.0	0	35.4	32.2	27.0	23.2	21.0	18.5	15.2
			20	28.4	21.4	16.9	16.3			
	840716	23.0	0	29.5	27.4	25.0	24.6			
	840731	25.0	0	23.2	22.0	20.6	19.6	17.7	13.5	11.0
			20	22.5	21.8	20.5	20.5			
	840804	32.0	0	34.5	32.0	23.5	20.5	18.0	14.7	11.6
			20	33.0	29.6	25.0	22.2			
	840808	22.0	0	20.4	20.4	20.0	20.0	19.4	15.6	13.0
			20	20.0	20.0	19.8	19.8			

Appendix F (cont'd)

Site	Date Year, Month, Day	Air temp ^{0}C	Soil removal treatment (cm)	Soil temp ^{0}C(at cm depth) 2.5	5.0	10.0	20.0	50.0	100.0	150.0
Newdale CL										
	830531	23.0	0	26.0	15.0	11.6	8.9			
			20	25.5	21.6	16.2	12.5			
	830606	22.0	0	25.4	18.6	11.1	7.2			
			20	25.5	23.2	10.4	7.5			
	830616	25.0	0	25.1	23.8	18.0	12.9	10.1	5.4	1.8
			20	24.6	19.7	15.1	9.5			
	830625	27.0	0	29.0	26.6	20.9	14.8	8.1	3.1	1.9
	830713	25.0	0	22.0	20.8	18.6	16.8	13.9	10.0	7.3
			20	24.6	22.0	19.9	18.6			
	830719	31.0	0	26.0	23.0	21.2	18.6	15.5	12.1	9.7
			20	26.6	25.6	22.9	19.3			
	830725	28.0	0	25.1	22.9	20.2	17.9	16.4	13.1	10.5
			20	26.6	24.0	22.4	18.6			
	830801	21.0	0	23.0	15.5	15.2	15.5	13.8	10.9	10.0
			20	16.3	16.2	16.4	16.9			
	830808	26.0	0	28.2	24.6	20.1	17.6	16.0	12.3	10.3
			20	24.0	22.4	20.8	20.4			
	830815	23.0	0	21.2	19.6	17.3	16.6	14.9	12.2	10.2
			20	20.4	19.7	18.7	17.0			
	830823	20.0	0	19.2	17.9	16.4	15.5	14.8	12.8	11.0
			20	17.8	16.3	16.0	15.6			
	830829	26.0	0	25.8	23.4	21.0	18.8	16.4	14.7	11.9
			20	23.2	21.4	19.9	17.7			
	840522	12.0	0	14.1	13.0	11.8	9.2	6.7	3.3	1.0
			20	16.1	14.3	12.2	9.6			
	840828	20.0	0	19.4	17.8	12.8	9.2	6.2	2.6	0.2
	8406o5	20.0	0	23.4	21.1	17.9	16.1	12.9	8.4	5.6
			20	21.3	17.9	16.8	14.7			
	840710	28.0	0	25.6	23.4	18.8	16.0	14.8	11.2	9.0
			20	30.6	26.0	21.0	16.8			
	840716	26.0	0	29.1	23.4	20.2	18.4	16.1	11.9	9.4
			20	32.9	25.8	22.5	19.1			
	840804	25.0	0	26.0	26.2	22.0	20.2	18.0	12.5	10.0
			20	26.5	22.5	22.5	22.0			
	840813	22.0	0	24.9	22.3	19.9	17.8	14.4	10.1	8.0

Appendix F (cont'd)

Site	Date Year, Month, Day	Air temp ^0C	Soil removal treatment (cm)	Soil temp ^0C(at cm depth) 2.5	5.0	10.0	20.0	50.0	100.0	150.0
Pembina CL										
	840529	21.0	0	18.4	16.8	15.1	12.5	8.8	5.1	3.0
			20	20.0	18.5	16.4	12.8			
	840606	20.0	0	22.4	20.8	18.9	15.9	12.4	7.1	4.5
			20	23.6	21.3	19.0	16.3			
	840711	27.0	0	24.0	21.8	19.9	18.3	16.4	14.4	10.8
			20	24.4	22.0	20.2	19.8			
	840730	25.0	0	24.5	23.5	22.0	19.2	16.0	12.5	9.8
			20	24.7	23.2	21.5	19.6	16.3		
	840807	23.0	0	23.9	22.6	21.9	21.5	18.8	13.3	11.4
			20	22.7	21.9	21.8	21.1			
	840814	27.0	0	25.7	23.9	22.1	20.6	17.4	13.3	10.5
			20	23.3	22.5	21.3	17.5			

Appendix G

SOIL MOISTURE (MM) TO A DEPTH OF 100 CM, DURING GROWING SEASON OF 1983

Site	Date Year, Month, Day	Soil removal treatment (cm) 0	5	10	20
Reinland LVFS					
	830521	210.6	224.6	262.0	278.8
	830630	140.0	150.9	185.4	160.0
	830815	101.4	104.0	110.3	112.4
Newdale CL					
	830527	382.3	400.8	430.1	438.0
	830630	152.1	164.4	178.9	220.7
	830831	113.7	121.0	124.0	132.1

Appendix H

SOIL MOISTURE (MM) TO A DEPTH OF 100 CM, DURING GROWING SEASON OF 1984.

Site	Date Year, Month, Day	Soil removal treatment (cm) 0	5	10	20
Reinland LVFS					
	840509	132.5	154.7	196.3	133.2
	840528	92.1	126.0	169.0	96.9
	840611	140.7	152.4	171.3	177.5
	840625	116.9	194.9	103.6	148.0
	840709	73.4	108.3	141.3	91.8
	840716	124.9	188.2	140.7	163.6
	840727	53.8	107.0	89.5	84.0
	840804	83.9	89.0	97.0	99.9
	840808	115.6	124.6	122.4	128.7
Newdale CL					
	840510	213.1	296.8	293.3	239.3
	840528	217.0	244.0	273.1	298.2
	840611	190.4	241.4	261.3	208.8
	840625	173.0	222.9	210.2	240.0
	840710	143.9	207.5	184.7	206.8
	840716	176.7	145.1	190.2	229.9
	840724	131.1	140.0	170.3	174.4
	840813	120.1	156.7	197.6	164.9
Pembina CL					
	840511	315.4	338.6	281.8	282.1
	840523	320.0	333.2	349.0	334.7
	840612	369.5	349.5	336.4	293.0
	840627	298.9	294.1	315.4	319.2
	840711	291.0	312.0	323.6	309.9
	840718	233.2	238.1	249.0	264.2
	840805	154.6	168.9	191.0	168.1

Appendix I

GERMINATION OF WHEAT, 1984

Site	Number of Observations	Fertilizer Treatment	Seedlings emerged/M Soil Removal Treatment (cm) 0	5	10	20
Reinland LVFS						
	4	A	65	62	68	65
	4	B	61	67	61	62
	4	C	60	63	64	67
Newdale CL						
	4	A	56	58	56	60
	4	B	54	62	54	52
	4	C	55	64	54	55
Pembina CL						
	4	A	70	71	68	74
	4	B	64	69	69	71
	4	C	67	73	70	72

Appendix J

GROWING SEASON PRECIPITATION

Site	Year	Precipitation (mm) May	June	July	August	Total
Reinland LVFS						
	1983	59.6	49.5	48.0	5.0	162.1
	1984	27.5	67.0	65.0	49.0	208.5
	normal*	45.4	95.4	60.3	68.7	269.8
Newdale CL						
	1983	53.0	29.0	66.0	34.0	182.0
	1984	27.0	73.5	33.5	16.0	150.0
	normal*	51.9	81.3	73.4	62.5	269.1
Pembina CL						
	1984	35.0	102.0	74.0	58.0	269.0
	normal*	69.0	87.7	80.7	65.6	303.0

* Obtained from Canadian Climate Normals 1951-1980. Temperature and Precipitation. Prairie Provinces. Environment Canada, Downsview, Ontario.

Appendix K

CHEMICAL ANALYSIS OF SOILS, FALL 1984

MANITOBA PROVINCIAL SOIL TESTING LABORATORY
ELLIS BUILDING ☐ UNIVERSITY OF MANITOBA
WINNIPEG, MANITOBA R3T 2N2
TELEPHONE: 474-8166

ROUTINE SOIL ANALYSIS REPORT

Date Sample Received	Date Report Prepared
November 6 1984	December 11 1984

LABORATORY TEST RESULTS

Laboratory Number	Soil and Treatment Reinland LVFS	Depth	Texture	Carbonate Content	pH	Salinity mmhos/cm	Nitrate-Nitrogen* ppm	Nitrate-Nitrogen* kg/ha	Available Phosphorus* ppm	Available Phosphorus* kg/ha	Available Potassium** ppm	Available Potassium** kg/ha	Sulphate-Sulphur*** ppm	Sulphate-Sulphur*** kg/ha
R 2890 A	T1A	0-15	VFS	M			5.2	13.0	28.6	71.5	250	625	3.2	8.0
B		15-30	VFS	M			8.8	22.0	2.6	6.5	182	455	9.4	23.5
C		30-60	VFS	VH			6.0	31.2	1.8	9.4	104	541	7.2	37.4
D		60-90	VFS	M			2.4	12.5	0.6	3.1	110	572	3.8	19.8
R 2891 A	T1B	0-15	LVFS	M			2.4	5.0	41.0	86.1	238	500	2.4	5.0
B		15-30	VVFS	M			7.4	18.5	16.6	41.5	150	375	20+	50+
C		30-60	VVFS	VH			8.4	43.7	7.0	36.4	85	442	20+	104+
D		60-90	VFS	H			6.4	33.3	0.6	3.1	54	281	20+	104+
R 2892 A	T1C	0-15	VFS	L			4.8	12.0	38.6	96.5	220	550	3.6	9.0
B		15-30	LVFS	M			8.6	19.8	14.8	34.0	168	386	7.6	17.5
R 2892 C		30-60	LVFS	H			21.4	109.1	1.6	8.2	100	510	20+	102+
D		60-90	VFS	H			6.0	31.2	1.8	9.4	80	416	20+	104+
R 2893 A	T2A	0-15	VFS	M			2.2	5.5	20.8	52.0	155	388	3.0	7.5
B		15-30	LVFS	M			2.2	5.1	2.2	5.1	60	306	2.6	13.3
C		30-60	LVFS	M			14.4	73.4	0.2	1.0	43	219	20+	102+
D		60-90	VFS	M			13.4	69.7	0.2	1.0	30	156	20+	104+
R 2894 A	T2B	0-15	LVFS	H			3.4	7.1	29.4	61.7	147	309	5.8	12.2
B		15-30	LVFS	H			8.6	19.8	15.2	35.0	112	258	20+	46+
C		30-60	LVFS	H			13.0	66.3	1.6	8.2	45	230	20+	102+
D		60-90	VFS	M			5.8	30.2	0.2	1.0	33	172	20+	104+
R 2895 A	T2C	0-15	LVFS	M			4.2	8.8	41.0	86.1	180	378	4.2	8.8
B		15-30	LVFS	H			4.4	10.1	7.0	16.1	80	184	8.8	20.2
C		30-60	LVFS	H			13.6	69.4	0.6	3.1	45	230	20+	102+
D		60-90	VFS	M			8.4	43.7	0.2	1.0	33	172	20+	104+
R 2896 A	T3A	0-15	LVFS	H			1.6	3.4	17.6	37.0	150	315	3.0	6.3
B		15-30	LVFS	H			1.4	3.2	3.0	6.9	190	437	8.8	20.2
C		30-60	VFS	M			4.0	20.8	1.0	5.2	95	494	20+	104+
D		60-90	VFS	M			2.4	12.5	0.2	1.0	64	333	20+	104+
R 2897 A	T3B	0-15	LVFS	M			2.4	5.0	16.8	35.3	212	445	20+	42+
B		15-30	VFS	M			1.6	4.0	3.0	7.5	215	538	20+	50+

*Sodium Bicarbonate Extractable
**Ammonium Acetate Exchangeable
***Water Soluble

INTERPRETIVE COMMENTS

C.C.

T = Soil removal treatment, where 1 = 0 cm removed
2 = 5 cm removed
3 = 10 cm removed
4 = 20 cm removed

A,B,C = fertilizer treatment applied in previous growing season.

MANITOBA PROVINCIAL SOIL TESTING LABORATORY

ELLIS BUILDING ◻ UNIVERSITY OF MANITOBA
WINNIPEG, MANITOBA R3T 2N2
TELEPHONE: 474-8155

ROUTINE SOIL ANALYSIS REPORT

LABORATORY TEST RESULTS

Laboratory Number	Soil and Treatment Reinland LVFS	Depth	Texture	Carbonate Content	pH	Salinity	Nitrate-Nitrogen ppm	Nitrate-Nitrogen kg/ha	Available Phosphorus ppm	Available Phosphorus kg/ha	Available Potassium ppm	Available Potassium kg/ha	Sulphate-Sulphur ppm	Sulphate-Sulphur kg/ha
R 2897 C	T3B	30-60	VFS	M			7.4	38.5	0.8	2.0	153	796	20+	104+
D		60-90	VFS	M			4.4	22.9	0.2	1.0	118	614	20+	104+
R 2898 A	T3C	0-15	LVFS	VH			3.8	8.0	33.2	69.7	175	368	7.0	14.7
B		15-30	LVFS	H			9.0	20.7	8.8	20.2	74	170	20+	46+
C		30-60	VFS	M			15.4	80.1	2.0	10.4	40	208	20+	104+
D		60-90	VFS	L			6.0	31.2	0.2	1.0	50	260	20+	104+
R 2899 A	T4A	0-15	LVFS	M			1.4	2.9	4.6	9.7	117	246	2.4	5.0
B		15-30	LVFS	H			1.4	3.2	0.6	1.4	92	212	5.0	11.5
C		30-60	VFSL	H			7.4	30.0	0.2	0.9	75	345	20+	82+
D		60-90	VFS	M			6.2	15.5	0.2	1.0	88	458	20+	104+
R 2900 A	T4B	0-15	LVFS	H			1.4	2.9	5.2	10.9	105	221	2.6	5.5
B		15-30	LVFS	H			1.8	4.1	1.0	2.3	57	131	20+	46+
C		30-60	LVFS	H			12.0	61.2	0.2	1.0	50	255	20+	102+
D		60-90	LVFS	M			9.6	49.0	0.2	1.0	58	296	20+	102+
R 2901 A	T4C	0-15	LVFS	H			1.8	3.8	5.0	10.5	124	260	4.4	9.2
B		15-30	LVFS	H			2.4	5.5	1.4	3.2	70	357	20+	102+
C		30-60	LVFS	H			26.8	85.7	0.2	1.0	50	255	20+	102+
D		60-90	LVFS	H			28.8	146.9	0.2	1.0	58	296	20+	102+
R 2902 A	Pembina CL T1A	0-15	CL	A	6.3	0.2	5.6	11.8	25.4	53.3	317	666	4.6	9.7
B		15-30	C	VL	6.3	0.2	3.6	6.5	17.6	31.7	358	644	7.2	13.0
R 2902 C		30-60	C	A	6.1	0.1	1.8	7.9	14.4	63.4	370	1628	1.4	6.2
D		60-90	C	A	6.3	0.1	1.8	7.9	16.0	70.4	405	1782	3.0	13.2
R 2903 A	T 1B	0-15	CL	A	6.4	0.2	6.4	13.4	29.2	61.3	353	741	3.0	6.3
B		15-30	C	A	6.5	0.2	2.6	4.7	22.6	40.7	330	594	1.8	3.2
C		30-60	C	VL	6.3	0.1	2.0	8.8	19.6	86.2	360	1584	1.4	6.2
D		60-90	C	A	6.5	0.4	2.0	8.8	17.2	75.7	375	1650	2.4	10.6
R 2904 A	T1C	0-15	CL	A	6.4	0.2	6.0	12.6	34.0	71.4	337	708	2.6	5.5
B		15-30	C	A	6.5	0.2	3.0	5.4	28.8	51.8	345	621	3.4	6.1
C		30-60	C	A	6.5	0.2	2.0	8.8	23.6	103.8	417	1835	1.6	7.0
D		60-90	C	A	6.4	0.2	2.8	12.3	13.0	57.2	417	1835	1.2	5.3

C.C.

INTERPRETIVE COMMENTS

T = Soil removal treatment, where 1 = 0 cm removed
2 = 5 cm removed
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4 = 20 cm removed

A,B,C = fertilizer treatment applied in previous growing season.

MANITOBA PROVINCIAL SOIL TESTING LABORATORY

ELLIS BUILDING ☐ UNIVERSITY OF MANITOBA
WINNIPEG, MANITOBA R3T 2N2
TELEPHONE: 474-8166

ROUTINE SOIL ANALYSIS REPORT

DATE SAMPLES RECEIVED	DATE REPORT PREPARED

LABORATORY TEST RESULTS

LABORATORY NUMBER	Soil and Treatment	DEPTH	TEXTURE	CARBONATE CONTENT	pH	SALINITY mS/cm	NITRATE - NITROGEN*		AVAILABLE PHOSPHORUS*		AVAILABLE POTASSIUM**		SULPHATE - SULPHUR***	
	Pembina CL						ppm	kg/ha	ppm	kg/ha	ppm	kg/ha	ppm	kg/ha
R 2905 A	T2A	0-15	CL	A	6.4	0.2	3.4	7.1	24.0	50.4	304	638	3.0	6.3
B		15-30	C	A	6.6	0.1	2.0	3.6	19.6	35.3	300	540	1.6	2.9
C		30-60	C	A	6.5	0.1	2.6	11.4	20.0	88.0	370	1628	2.4	10.6
D		60-90	C	A	6.0	0.1	0.8	3.5	13.6	59.8	335	1474	2.4	10.6
R 2906 A	T2B	0-15	CL	A	6.6	0.1	3.4	7.1	30.0	63.0	354	743	3.4	7.1
B		15-30	C	A	6.5	0.1	2.2	4.0	25.2	45.4	350	630	4.6	8.3
C		30-60	C	A	6.5	0.1	1.2	5.3	17.6	77.4	402	1769	2.0	8.8
D		60-90	C	A	6.4	0.1	0.8	3.5	15.6	68.6	402	1769	2.0	8.8
R 2907 A	T2C	0-15	CL	A	6.5	0.2	6.2	13.0	36.8	77.3	325	683	8.0	16.8
B		15-30	C	A	6.6	0.2	6.2	11.2	29.2	52.6	313	563	7.2	31.7
R 2907 C	T2C	30-60	C	A	6.4	0.1	4.6	20.2	19.2	84.5	328	1443	3.4	15.0
D		60-90	C	A	5.7	0.1	6.2	27.3	18.4	81.0	362	1593	2.0	8.8
R 2908 A	T3A	0-15	CL	A	6.5	0.1	3.2	6.7	23.8	50.0	345	725	4.2	7.6
B		15-30	C	A	6.7	0.1	2.2	4.0	19.8	35.6	390	702	4.2	7.6
C		30-60	C	A	6.6	0.2	1.4	6.2	17.6	77.4	460	2024	3.4	15.0
D		60-90	C	A	6.5	0.1	0.8	3.5	10.0	44.0	358	1575	1.6	7.0
R 2909 A	T3B	0-15	CL	A	6.6	0.1	2.0	4.2	18.6	39.1	290	609	1.6	3.4
B		15-30	C	A	6.6	0.1	2.0	3.6	22.8	41.0	335	603	1.8	3.2
C		30-60	C	A	6.4	0.1	1.6	7.0	14.6	64.2	385	1694	1.2	5.3
D		60-90	C	A	6.3	0.1	1.0	4.4	9.4	41.4	335	1474	1.4	6.2
R 2910 A	T3C	0-15	CL	A	6.4	0.2	2.8	5.9	21.6	45.4	314	659	5.2	10.9
B		15-30	C	A	6.4	0.2	1.8	3.2	18.0	32.0	360	648	6.4	11.5
C		30-60	C	A	6.0	0.1	1.0	4.4	11.0	48.4	380	1672	2.0	8.8
D		60-90	C	A	6.2	0.1	0.8	3.5	7.6	33.4	345	1518	1.2	5.3
R 2911 A	T4A	0-15	CL	A	6.3	0.1	1.4	2.9	20.0	42.0	372	781	3.4	7.1
B		15-30	C	A	6.4	0.1	1.0	2.1	17.6	31.7	382	688	2.2	4.0
C		30-60	C	A	6.5	0.2	0.8	3.5	12.8	26.9	484	2130	1.4	6.2
D		60-90	C	A	6.9	0.4	0.6	2.6	14.2	62.5	430	1892	2.4	10.6
R 2912 A	T4B	0-15	CL	A	6.8	0.3	1.2	2.5	16.6	34.9	305	641	2.2	4.6
B		15-30	C	A	6.4	0.2	2.2	4.0	12.6	22.7	305	549	3.0	5.4

*Sodium Bicarbonate Extractable
**Ammonium Acetate Exchangeable
***Water Soluble

INTERPRETIVE COMMENTS

C.C.

T = Soil removal treatment, where 1 = 0 cm removed
2 = 5 cm removed
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A,B,C = fertilizer treatment applied in previous growing season.

MANITOBA PROVINCIAL SOIL TESTING LABORATORY
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WINNIPEG, MANITOBA R3T 2N2
TELEPHONE: 474-8156

ROUTINE SOIL ANALYSIS REPORT

DATE SAMPLES RECEIVED	DATE REPORT PREPARED

LABORATORY TEST RESULTS

LABORATORY NUMBER	Soil and Treatment	DEPTH	TEXTURE	CARBONATE CONTENT	pH	SALINITY mmhos/cm	NITRATE-NITROGEN* ppm	NITRATE-NITROGEN* kg/ha	AVAILABLE PHOSPHORUS** ppm	AVAILABLE PHOSPHORUS** kg/ha	AVAILABLE POTASSIUM** ppm	AVAILABLE POTASSIUM** kg/ha	SULPHATE-SULPHUR*** ppm	SULPHATE-SULPHUR*** kg/ha
	Pembina CL													
R 2912 C	T4D	30-60	C	A	6.2	0.1	1.8	7.9	13.6	24.5	303	1333	1.4	6.2
D		60-90	C	A	6.5	0.3	1.0	4.4	10.6	46.6	359	1580	7.8	34.3
R 2913 A	T4C	0-15	CL	A	6.6	0.2	1.4	2.9	18.6	39.1	257	540	9.4	19.7
B		15-30	C	A	6.8	0.2	0.6	1.1	17.6	31.7	440	792	7.4	13.3
C		30-60	C	A	6.5	0.2	0.2	0.9	12.4	54.6	380	1672	3.4	15.0
D		60-90	C	A	6.4	0.1	0.2	0.9	9.4	41.4	318	1399	2.4	10.6
R 2914 A	Newdale CL T 1A	0-15	CL	VL	7.3	0.4	4.6	8.3	10.4	18.7	433	779	9.8	17.6
B		15-30	CL	A	7.4	0.5	6.4	11.5	7.2	13.0	353	635	20+	36+
C		30-60	CL	M	7.3	1.4	4.6	20.2	2.2	9.7	307	1351	20+	88+
D		60-90	SIC	VH	7.7	3.0	3.2	12.5	1.0	3.9	260	1014	20+	78+
R 2915 A	T1B	0-15	CL	VL	7.5	0.4	5.4	9.7	16.6	29.9	435	783	20+	36+
B		15-30	CL	M	7.6	0.4	8.0	14.4	3.4	6.1	348	626	20+	36+
C		30-60	C	L	7.6	0.4	5.4	23.8	7.4	32.6	329	1448	20+	88+
D		60-90	C	L	7.6	0.7	2.4	10.6	2.6	11.4	298	1311	20+	88+
R 2916 A	T1C	0-15	CL	A	7.4	0.4	7.8	14.0	15.0	27.0	350	630	7.0	12.6
B		15-30	CL	A	7.4	0.5	10.4	18.7	7.4	13.3	334	601	20+	36+
C		30-60	CL	A	7.7	0.6	5.4	23.8	3.8	16.7	312	1373	20+	88+
D		60-90	C	VL	7.6	1.4	2.4	10.6	2.4	10.6	294	1294	20+	88+
R 2917 A	R3T2A	0-15	CL	VL	7.6	0.4	1.4	2.5	3.4	6.1	333	599	10+	18+
B		15-30	CL	L	7.6	0.4	2.0	3.6	1.2	2.2	284	511	9.4	16.9
R 2917 C	T2A	30-60	SIC	H	7.8	0.5	2.2	8.6	1.0	3.9	265	1034	20+	78+
D		60-90	SIC	VH	7.8	1.5	2.2	8.6	1.2	4.7	240	936	20+	78+
R 2918 A	T2B	0-15	SIC	VH	7.9	0.5	2.0	3.6	9.4	16.9	340	612	20+	36+
B		15-30	SIC	VH	7.8	0.7	2.8	5.3	2.4	4.6	260	494	20+	38+
C		30-60	SIC	VH	7.8	1.5	2.2	8.6	1.8	7.0	213	831	20+	78+
D		60-90	SIC	VH	7.8	1.7	2.8	10.9	1.4	5.5	185	722	20+	78+
R 2919 A	T2C	0-15	CL	M	7.9	0.5	8.4	15.1	4.6	8.3	303	545	10+	18+
B		15-30	CL	M	7.9	0.5	7.4	13.3	1.6	2.9	245	441	8.2	14.8
C		30-60	SIC	VH	8.1	0.5	4.6	17.9	1.0	3.9	200	780	20+	78+
D		60-90	SIC	VH	8.1	0.6	2.4	9.4	2.0	7.8	200	780	20+	78+

*Sodium Bicarbonate Extractable
**Ammonium Acetate Exchangeable
***Water Soluble

C.C.

INTERPRETIVE COMMENTS

T = Soil removal treatment, where 1 = 0 cm removed
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4 = 20 cm removed

A,B,C = fertilizer treatment applied in previous growing season.

MANITOBA PROVINCIAL SOIL TESTING LABORATORY

ELLIS BUILDING □ UNIVERSITY OF MANITOBA
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TELEPHONE: 474-8166

ROUTINE SOIL ANALYSIS REPORT

DATE SAMPLES RECEIVED	DATE REPORT PREPARED

LABORATORY TEST RESULTS

LABORATORY NUMBER	Soil and Treatment	DEPTH	TEXTURE	CARBONATE CONTENT	pH	SALINITY mmho/cm	NITRATE - NITROGEN*		AVAILABLE PHOSPHORUS*		AVAILABLE POTASSIUM**		SULPHATE - SULPHUR***	
	Newdale CL						ppm	kg/ha	ppm	kg/ha	ppm	kg/ha	ppm	kg/ha
R 2920 A	T3A	0-15	CL	VL	7.8	0.4	3.0	5.4	2.4	4.3	305	549	9.4	16.9
B		15-30	CL	M	7.9	0.4	5.4	9.7	1.0	1.8	251	452	20+	36+
C		30-60	SiC	H	8.0	0.9	3.0	11.7	0.6	2.3	205	800	20+	78+
D		60-90	SiC	M	8.0	1.2	1.0	3.9	0.6	2.3	158	616	20+	78+
R 2921 A	T3B	0-15	CL	VL	7.7	0.4	2.4	4.3	3.2	5.8	308	554	20+	36+
B		15-30	CL	A	7.5	0.4	2.2	4.0	1.2	2.2	307	553	20+	36+
C		30-60	SiC	VL	7.7	0.4	2.4	9.4	1.4	5.5	300	1170	9.0	35.1
D		60-90	SiC	M	7.9	1.6	1.4	5.5	1.0	3.9	214	835	20+	78+
R 2922 A	T3C	0-15	CL	VL	7.8	0.5	6.4	11.5	6.4	11.5	348	626	8.0	14.4
B		15-30	SiC	H	7.7	0.5	6.6	11.9	2.4	4.6	265	504	6.6	12.5
R 2922 C	T3C	30-60	SiC	VH	7.6	1.6	3.4	13.3	0.4	1.6	220	858	20+	78+
D		60-90	SiC	VH	8.1	3.0	0.8	3.1	0.4	1.6	227	885	20+	78+
R 2923 A	T4A	0-15	CL	VH	8.0	0.4	5.2	9.4	1.6	2.9	248	445	8.4	15.1
B		15-30	CL	VH	7.8	0.4	5.0	9.0	1.0	1.8	180	324	20+	36+
C		30-60	CL	VH	8.0	0.8	4.0	17.6	0.4	1.8	130	572	20+	78+
D		60-90	C	VH	8.0	0.8	2.0	8.8	0.2	0.9	122	537	20+	88+
R 2924 A	T4B	0-15	SiC	VH	7.9	0.4	1.2	2.2	1.8	3.2	198	356	7.0	12.6
B		15-30	SiC	VH	7.9	0.4	2.4	4.6	1.6	3.0	198	376	7.2	13.7
C		30-60	SiC	VH	7.9	0.6	2.4	9.4	1.6	6.2	205	800	20+	78+
D		60-90	SiC	VH	7.9	1.6	1.2	4.7	0.4	1.6	209	815	20+	78+
R 2925 A	T4C	0-15	CL	M	7.9	0.5	4.4	7.9	3.4	6.1	238	428	20+	36+
B		15-30	CL	H	7.9	0.5	5.6	10.1	2.4	4.3	245	441	20+	36+
C		30-60	SiC	H	7.9	0.5	8.0	31.2	2.4	9.4	184	718	20+	78+
D		60-90	SiC	H	8.0	0.9	8.0	31.2	0.6	2.3	160	624	20+	78+

*Sodium Bicarbonate Extractable
**Ammonium Acetate Exchangeable
***Water Soluble

C.C.

INTERPRETIVE COMMENTS

T = Soil removal treatment, where 1 = 0 cm removed
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A,B,C = fertilizer treatment applied in previous growing season.

Appendix L

ORGANIC MATTER CONTENT OF THE EXPERIMENTAL SOILS, FALL 1984

Soil removal treatment (cm)	Fertilizer treatment	Per cent organic matter in 0-15 cm soil depth		
		Reinland LVFS	Newdale CL	Pembina CL
0	A	2.3	6.6	3.1
	B	2.1	6.9	2.8
	C	1.9	6.4	2.9
5	A	1.2	2.6	2.1
	B	2.1	3.1	2.6
	C	1.7	3.4	2.3
10	A	1.6	2.8	2.1
	B	1.3	2.9	1.4
	C	1.7	4.4	1.9
20	A	1.1	3.4	0.5
	B	1.2	2.8	1.8
	C	1.1	3.5	1.0

Appendix M

SOME PHYSICAL PROPERTIES OF THE EXPERIMENTAL SOILS

Site Horizon	Particle size distribution %S	%Si	%C	Textural class	Bulk density (g/cc)	Water content (% by weight) FC	PWP	Available moisture (mm)
Reinland LVFS								
0- 20 cm Ap	81	9	10	LVFS	1.33	17.7	5.9	31.4
20- 40 cm Ac	86	8	6	LFS	1.62	13.8	4.1	31.4
40- 70 cm Ckg1	94	4	2	LFS	1.52	12.6	2.5	46.2
70-110 cm Ckg2	89	9	2	VFS	1.59	11.8	2.4	59.6
110-120cm 2Ckg	44	33	23	L	1.55	21.9	6.8	23.4
Newdale CL								
0- 20 cm Ah	37	25	38	CL	1.27	31.5	14.8	42.4
20- 45 cm Bm	35	30	35	CL	1.34	28.4	12.9	51.8
45- 85 cm Cca	41	28	31	CL	1.47	25.0	11.9	77.2
85-120 cm Ck	43	33	24	L	1.52	18.4	8.8	51.1
Pembina CL								
0- 25 cm Ap	37	25	38	CL	1.17	34.3	18.6	46.0
25- 62 cm Btj	31	29	40	C	1.22	31.1	17.9	59.6
62-120 cm C	31	23	46	C	1.30	32.0	20.3	88.2