Nitrogen and Phosphorus Losses in Surface Runoff Due to Rainfall in Manitoba

by

Andrew Peter Hargrave

A thesis presented to the
Faculty of Graduate Studies of the University of Manitoba
in partial fulfilment
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ABSTRACT

Four experimental field sites were monitored on the Gretna C, Leary SL, Ryerson SCL and Carroll CL for nitrogen and phosphorus losses in surface runoff in 1988 through 1990. At each site, 22.13 m x 4.6 m plots with a 9% slope with five continuous crop-management systems - 1) alfalfa, 2) corn, 3) wheat (minimum till), 4) wheat (conventional till) and 5) fallow were randomly assigned one plot per site. The minimum till wheat was not included in the Gretna C and the Leary SL. Coshocton samplers were used to collect 1% of the runoff and sediment. Samples were filtered through borosilicate microfiber filters to separate the sediment fraction from the dissolved fraction. The dissolved fraction was stored at 4° C if necessary before analysis. Nitrite and nitrate nitrogen and total phosphorus were analyzed colorimetrically and ammonium was measured by electrode. Sediment was air dried for total Kjeldahl digestible nitrogen and total perchloric acid digestible phosphorus.

Total nitrogen losses of up to 283 kg ha^{-1} were reported from the most severe storm on the Gretna C corn treatment. The alfalfa treatment were reduced to 1 kg ha^{-1} from the same storm and in most storms runoff was eliminated. Total nitrogen losses were more strongly influenced by a storm thirty minute intensity than by the rainfall amount, duration or erosivity index. Concentrations of total nitrogen in the sediment were higher in mid season than early or late season. Texture influenced both losses and concentration. The total nitrogen concentration was greatest in medium textured soils, but losses were greatest from fine textured soils. Coarse textured soils had both the lowest concentration and losses. Total nitrogen losses were highly correlated to soil loss. Total nitrogen concentration in runoff could be estimated using total rainfall, thirty minute intensity and soil loss.

Total phosphorus losses of up to 99 kg ha^{-1} were reported from the most severe storm on the Gretna C (corn treatment). Losses from the alfalfa treatment were only 0.3 kg ha^{-1} from the same event. Total phosphorus losses were influenced most by the thirty minute intensity. Total phosphorus concentration and losses were highest on the fine textured soils and lowest from the coarse textured soils. Total phosphorus losses were highly correlated to soil loss. Ammonium concentration in the dissolved fraction ranged from 0.03 to 3.69 $\mu g\ g^{-1}$, which exceeds the 0.03 $\mu g\ g^{-1}$ needed for accelerated algal growth. Concentrations of total phosphorus were as high as 2.15 $\mu g\ g^{-1}$, much higher than the 0.01 $\mu g\ g^{-1}$ needed to accelerate algal growth in standing waters. For the most part concentrations of nitrates were far below 8 $\mu g\ g^{-1}$ which is generally regarded as the maximum concentration acceptable for drinking water. All concentrations were lower with larger storms.

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1. INTRODUCTION

Over the last thirty years, plant nutrient losses in one form or another have been studied extensively, especially from agricultural as well as urban areas (Glandon et al. 1981, White and Gosz 1983), prairie (Timmons et al. 1973, Timmons and Holt 1977) and forest lands (Singer and Rust 1975, Persson et al. 1983). The studies have proven to be of both economic and ecological interest.

Rainfall and snowmelt are the major causes of erosion leading to nutrient losses from agricultural lands. Therefore, a discussion of nutrient losses would be incomplete without a discussion of sediment and water losses. Nutrient losses are associated with the two products of water erosion: 1) sediment and 2) water. By far, the largest portion of nutrients is associated with sediment and is therefore of the most economic importance. Nutrients such as ammonium, nitrates and soluble phosphorus are ecologically the most important since they are necessary for algal growth. These nutrients are primarily associated with water in runoff.

The objectives of this study were to:

1) study the magnitude of losses of total nitrogen and total phosphorus in the sediment fraction of runoff,

2) to identify the relationship of these losses to rainfall factors and soil factors,

3) to quantify concentrations of total phosphorus and total nitrogen in the sediment fraction of runoff,

4) to identify factors influencing concentrations of total nitrogen and total phosphorus,

5) to develop a predictive model for losses of total nitrogen and total phosphorus in runoff,

6) to examine nitrate, nitrite, ammonium and phosphorus concentrations in the dissolved phase of runoff and to discuss the ecological implications of these runoff products.

2. LITERATURE REVIEW

2.1 Sediment and water losses

Sediment and water losses by water erosion are influenced by naturally occurring phenomenon such as rainfall distribution and intensity, soil texture and antecedent conditions such as moisture content as well as anthropogenic factors such as conservation practices, fertilizer uses and cropping practices.

2.1.1 Effects of rainfall distribution and intensity

Temporal distribution of rainfall, which supplies the energy for water erosion, varies from year to year and from season to season. For example, in the Texas Blacklands, four storms were responsible for 70% of the sediment lost in 1973 and about 60% of the sediment lost during the entire 5 year study (Kissel et al. 1976). In Iowa and Missouri, over 80% of sediment losses during a 7 year period occurred in the months of April to June (Alberts et al. 1978). This coincided with a period of fertilizer applications, seeding and crop establishment. There were some intense thunderstorms during this period. However, this was not the case in all years and a much lower soil loss was associated with the drier years. Menzel et al. (1978) found that annual variations in sediment discharges in Oklahoma were extremely variable and were often greater than the effects of treatments designed to control erosion. On a Barnes loam in Minnesota (6% slope), sediment losses were greatest after seeding (Burwell et al. 1975). From continuous corn plots, 76% of the seasonal sediment lost was during the two month period following seeding, although only 23% of the runoff occurred during this period. In eastern South Dakota, runoff significantly increased with an increase in rainfall intensity, but the amount of rainfall and the length of time between storms had no significant effect (White et al. 1977).

2.1.2 Effects of conservation practices

Sediment losses have been found to be related to crop and residue cover. Baker and Laflen (1982), working with simulated rainfall on a Clarion SL in Iowa, noted that as residue cover increased, the time for runoff to begin was delayed and the runoff and erosion decreased. Studies in South Dakota showed that concentrations of sediment in runoff decreased as crop cover increased (White et al. 1977). In Minnesota, sediment losses were inversely proportional to the crop cover during the 2 month period following seeding (Burwell et al. 1975).

Surface runoff can be greatly reduced by good management practices such as returning residue to the soil and using a crop cover of biennials or perennials (Klausner et al. 1974). Wheat residues were far more effective than corn residues in reducing runoff (Abrahim and Rickson 1989, Table 2.1). The effectiveness of wheat residues compared to corn residues on reducing soil loss from the Evesham SCL in England was more pronounced on greater slopes. The reasons wheat straw performed so well were:

1) particles were not transported over the length of the plot,
2) wheat straw intercepted both rainfall and splash particles,
3) ponding from 'miniature dams' protected the soil surface,
4) roughness helped reduce runoff velocities,
5) increased infiltration due to incorporated straw,
6) no crusting and,
7) good contact between soil and straw.

Table 2.1 Relative effects of crop residue on runoff and soil loss at various slopes on an Evesham SCL in England (Abrahim and Rickson 1989).

Slope	Residue	Runoff	Soil loss
5%	fallow	100%	100%
	wheat	79%	29%
	corn	99%	83%
10%	fallow	100%	100%
	wheat	75%	62%
	corn	94%	83%
20%	fallow	100%	100%
	wheat	73%	54%
	corn	92%	83%
30%	fallow	100%	100%
	wheat	82%	54%
	corn	95%	81%

Corn residue performed poorly because it offered poor cover and because it was not easily incorporated.

More soil from corn plots was lost on conventional tillage systems (21.38 kg ha^{-1}) than from minimum tillage (1.60 kg ha^{-1}) on a Bedford silt loam in Indiana with slopes from 8.2 to 12.4% (Römkens et al. 1973). McDowell and McGregor (1980) found that no-till soybeans treatments yielded 1% of the soil loss of conventional tillage on a highly erodible loess soil in Mississippi.

2.1.3 Effects of fertilizer

Additions of fertilizer can decrease water and sediment losses on well drained soils because of an increased canopy cover which utilizes moisture and reduces the impact of the raindrop (Gambrel et al. 1975). Work on pasture lands in New Zealand also suggests a inverse correlation between runoff and fertilizer rates. When phosphorus was applied at two different rates; high (48 to 86 kg ha^{-1}) and low (0 to 19 kg ha^{-1}) in four successive years, the higher rates of fertilizer inputs increased legume growth and reduced runoff by as much as 25% (Lambert et al. 1985).

2.1.4 Effects of crop type

In Minnesota, average annual sediment losses due to rainfall ranged from 34.49 t ha^{-1}(fallow) to 0.02 t ha^{-1}(alfalfa) (Burwell et al. 1975). Sediment losses were 15.92 t ha^{-1} from continuous corn treatments. Similarly, in South Dakota, White and Williamson (1973) found sediment loss from plots followed the order:

fallow > corn > oats > alfalfa.

In Minnesota, water losses were highest from spring runoff, especially from alfalfa plots (Burwell et al. 1975). Over a period of ten years, water losses from rainfall, which accounted for between 4% (alfalfa) and 48% (rotation corn) of the seasonal runoff, was greatest from fallow plots (4.31 cm) while water loss from alfalfa was only 0.51 cm.

2.1.5 Effects of soil type and antecedent conditions

Hoyt et al. (1977) studied three soil textures; Toledo silty clay, Rossmoyne silt loam and Wausen sandy loam. Sediment discharge and runoff were influenced by texture. Soil losses and runoff increased from fine texture to coarse texture.

In Manitoba, high antecedent moisture conditions have been found to result in earlier initiation of runoff, slower infiltration rates, and therefore greater soil losses than from initially dry soils (Wahome 1989).

2.2 Nutrient losses

The various forms of phosphorus and nitrogen in runoff are found in both the dissolved fraction and the sediment fraction. Nutrients in the dissolved fraction are associated with particles in suspension after filtration. These particles are smaller than 0.45 μm. Total nitrogen and total phosphorus losses in the dissolved fraction have been found to be relatively insignificant (4%) compared to the sediment fraction (Burwell et al. 1975).

On a Barnes loam in Minnesota, nutrient losses were greater in the sediment fraction of runoff than in the dissolved fraction (except alfalfa) (Burwell et al. 1975). Sediment nitrogen accounted for 92% of the total nitrogen discharged in Iowa (Alberts et al. 1978). On a grass and legume pasture watershed in New Zealand, the majority of phosphorus and nitrogen losses were from the sediment fraction (Lambert et al. 1985).

Timmons and Holt (1977) studied nutrient losses from a native prairie situation on a Barnes loam dominated by little bluestem. Over 80% of the seasonal total N and total P losses from water erosion resulted from snowmelt. The runoff from snowmelt contained 65% of the total N and 33% of the total P in the dissolved fraction. Over 90% of the nutrient losses from rainfall were in the sediment fraction.

Nutrient concentrations varied greatly in an Oklahoma watershed study, average concentrations were reasonably predictable when runoff volume, sediment discharge, soil characteristics and fertilization history were considered (Menzel et al. 1978).

2.3 Nutrients in sediment fraction

Total nitrogen in sediment is composed of ammonium, nitrate, nitrite and organic fractions, with the latter being the most prevalent. Total phosphorus in sediment may be either organic, i.e. associated with the humic and fulvic acid complex in soil organic matter, or inorganic, i.e. associated with soil mineral particles such as Ca, Fe and Al phosphates. In the following, only total nitrogen and total phosphorus and not the individual fractions will be discussed.

2.3.1 Total nitrogen

Factors which affect total nitrogen losses in sediment include seasonal variations such as rainfall distribution and intensity, soil texture and fertility. Management practices such as residue management, tillage operations, cropping and fertilizer management also have an effect on total nitrogen losses in sediment.

2.3.1.1 Magnitude of losses

Total nitrogen losses vary among land uses. Burwell et al. (1975)

on a Barnes loam in Minnesota found that N transported in sediment accounted for 96% of average annual total nitrogen losses from fallow, continuous corn and rotation corn treatments. The average annual total nitrogen losses due to rainfall through a six year study period were highest from fallow plots (47.20 kg ha^{-1}) followed by continuous corn (21.21 kg ha^{-1}), rotation corn (13.12 kg ha^{-1}), rotation oats (1.91 kg ha^{-1}) and alfalfa plots (0.16 kg ha^{-1}). These researchers noted that the average annual precipitation was lower during the six year study than for the entire 10 year soil loss experiment. Estimated annual total nitrogen losses in sediment ranged from 0.09 kg ha^{-1} from alfalfa plots to 146.85 kg ha^{-1} from fallow plots for the entire ten year study. In western Nigeria, Lal (1976) reported the mean average total nitrogen loss to be 310 kg ha^{-1} in sediment from fallow plots with a 10% slope. This loss was reduced to 13.4 kg ha^{-1} under ploughed maize - cowpea rotation and to a negligible amount under no-till maize - cowpeas and maize - maize (mulch) rotations.

2.3.1.2 Effects of rainfall patterns

The influence of rainfall on nitrogen losses is two-fold: 1) an increase in rainfall increases total nitrogen losses; 2) increased duration of rainfall producing an increase in runoff results in a decrease in concentration of nitrogen in the sediment fraction of runoff (Chichester 1977).

Mean concentrations of nitrogen in sediment from a swelling clay in Texas were about 1200 $\mu g\ g^{-1}$ (Kissel et al. 1976). Total losses of nitrogen were 26.12 kg ha^{-1} in 5 years, of which 21.95 kg ha^{-1} were lost in one year which had four large and intense storms.

Kissel et al. (1976) found no relationship between total nitrogen concentration in sediment and the amount of sediment lost or rate of runoff.

Losses of total sediment nitrogen were highest early in the cropping season on a loess soil in Iowa (Schuman et al. 1973). The reasons for this may be progressive removal of nitrogen by crop use, leaching, immobilization and erosion. Gambrell et al. (1975) on nearly level corn plots in North Carolina also found that nitrogen losses were greatest in spring but peak losses may be delayed by a month on poorly drained soils.

2.3.1.3 Effects of management factors

In Iowa, Barisas et al. (1978) found that concentrations of total nitrogen in sediment did not change significantly with a change in residue cover. In Ohio, Chichester (1977) concluded that an increase in residue cover decreased nitrogen losses because of reduced runoff and therefore reduced sediment loss. Terracing reduced losses of total nitrogen in Iowa from 29.8 kg ha^{-1} to 2.62 kg ha^{-1} (Schuman et al., 1973). Sediment nitrogen losses increased as the area of cultivated soil in a watershed increased in central Canada (Neilson and MacKenzie 1977).

Nitrogen losses have been found to decrease with time after fertilizer application increases (Chichester 1977). Catchpoole (1975) in Queensland, Australia used ^{15}N studies on pasture to determine sinks for nitrogen. Findings revealed that, except where rain occurred shortly after broadcasting, only 5% of fertilizer N was lost in runoff. On one occasion, a rainfall 3 days after fertilization yielded a fertilizer - N loss of over 40%. Nitrogen losses from runoff in Ohio watersheds were less than the nitrogen inputs from rainfall when nitrogen fertilizer was worked in (Taylor et al. 1970).

Zero tillage can appreciably reduce the nitrogen losses in sediment from row crops. Nitrogen losses from no-till soybeans treatments were one-tenth of losses from conventional till soybeans treatments in Mississippi (McDowell and McGregor 1980). In Iowa, Laflen and Tabatabai (1984) and Barisas et al. (1978) concurred that reduced tillage reduced total nitrogen lost as a result of soil loss by controlling erosion.

In Indiana, concentrations of total nitrogen in sediment increased from conventional tillage to minimum tillage, and from unfertilized to fertilized plots (Römkens et al. 1973). The highest concentrations of nutrients were found in runoff water from fertilized minimum till corn plots. Losses of total nitrogen from conventional till and unfertilized plots were higher than from minimum till and fertilized plots. In New Zealand watersheds, Lambert et al. (1985) found that total nitrogen losses were not influenced by fertilizer treatment.

2.3.1.4 Effects of soil factors

Texture was found to influence nitrogen losses in sediment in Ohio (Hoyt et al. 1977). Fine textured soils lost the least nitrogen due to their low erosivity. Medium textured soils lost the most nitrogen due to higher erosivity and relatively high fertility. Coarse soils lost less nitrogen than medium soils because of their porosity and lower retention of nitrogen, but more than finer textured soils because of the higher erosivity.

In an Indiana study, total nitrogen lost in sediment increased as soil moisture increased, but concentrations were not different. Therefore, increased losses of total nitrogen were completely accounted for by increased sediment loss (Römkens et al. 1973)

2.3.2 Total phosphorus

Factors which affect total phosphorus losses in sediment include seasonal variations such as rainfall distribution and intensity, soil texture and fertility. Management practices such as residue management, tillage operations, cropping and fertilizer management also have an effect on total phosphorus losses in sediment.

2.3.2.1 Magnitude of losses

Total phosphorus (perchloric acid soluble) losses due to rainfall in sediment were observed from 1966 to 1971 in Minnesota (Table 2.2).

Table 2.2 Actual and estimated annual total phosphorus losses in sediment from a Barnes loam (Burwell et al. 1975).

Crop	Average 1966-71	Annual Total Phosphorus Lost 1962-71 (estimated)
	----------kg ha^{-1}---------	
alfalfa	0.04	0.02
oats - rotation	0.43	5.01
corn - rotation	2.96	8.43
corn - continuous	5.16	18.60
fallow	10.80	33.34

Estimated annual phosphorus losses over a ten year period range from 0.02 kg ha^{-1} (alfalfa) to 33.15 kg ha^{-1} (fallow). For all soil cover except alfalfa, phosphorus transported by sediment accounted for 95% or more of the annual phosphorus losses. White and Williamson (1973) in a three year study in South Dakota, found losses of phosphorus to be in decreasing order:

fallow > corn > oats > alfalfa.

The concentrations of phosphorus in sediment were in reverse order. Total phosphorus losses in sediment from runoff due to rainfall on a native prairie in Minnesota were 0.01 kg ha^{-1} per year (Timmons and Holt 1977). This was comparable to losses from alfalfa plots on the same soil type.

2.3.2.2 Effects of rainfall patterns

Using a series of artificial rainfalls on a Russell SiL in Indiana, Römkens and Nelson (1974) found the greatest phosphorus losses in sediment from the initial event, decreasing with each successive event due to preferential removal of colloidal particles in the erosion process. Sediment phosphorus concentrations were lowest in the summer months in New York (Klausner et al. 1974). Total phosphorus losses were greatest during the early growing season. Alberts et al. (1978) reported that 76% of the annual total phosphorus lost was during the months of April to June in Iowa. One event in April accounted for 55 to 78% of the total phosphorus lost in sediment during a two year study in a Great Lakes Basin watershed study (Hubbard et al. 1982).

2.3.2.3 Effects of management practices

Total phosphorus concentrations in sediment increased with an increase in residue cover in Iowa, but the total phosphorus loss was reduced due to decreased sediment loss (Barisas et al. 1978).

Total phosphorus losses from pasture increase with an increase in phosphorus fertilizer application. On a SiL pasture in New Zealand, Sharpley and Syers (1979) measured up to 5 fold increases in total phosphorus losses with a 50 kg P ha^{-1} application over no fertilizer even though sediment losses did not increase. Liquid application of fertilizers reduced these losses by 2 to 3 fold (Sharpley and Syers 1983). When fertilizer was incorporated by discing in Indiana, losses of total phosphorus were the same from plots when 56 or 113 kg ha^{-1} P were added (Römkens and Nelson 1974).

Phosphorus losses in sediment from row crop treatments can be reduced by reduction of tillage. Phosphorus losses from watersheds with no-till soybeans were one-sixth of the losses from watersheds with conventional till soybeans in Mississippi (McDowell and McGregor 1980). Total phosphorus losses were reduced from 20.3 kg ha^{-1} in fallow to 0.4 kg ha^{-1} from ploughed cowpeas - maize treatments to negligible from both no-till maize - cowpeas and maize - maize (mulch) treatments in western Nigeria (Lal 1976). In Iowa, Laflen and Tabatabai (1984) and Barisas et al. (1978) concurred that reduced tillage decreased total phosphorus lost from soil loss by controlling erosion. Terracing reduced phosphorus losses by as much as 75% from sloping lands (Alberts et al. 1978).

In Indiana, concentrations of total phosphorus in sediment increased from conventional tillage to minimum tillage, and from unfertilized to fertilized plots (Römkens et al. 1973). The highest concentrations of nutrients were found in runoff water from fertilized minimum till corn plots. Total nitrogen and phosphorus losses were not influenced by fertilizer treatment in a New Zealand watershed because increased legume growth nullified any increase in concentration from the broadcast fertilizer (Lambert et al. 1985).

2.4 Nutrients in the dissolved fraction

Nutrients in the dissolved fraction are those associated with particles less than 0.45 μm in filtrate. Total nitrogen is divided into ammonium - N, nitrate - N, and nitrite - N. Total phosphorus is treated as total dissolved phosphorus.

2.4.1 Total nitrogen

Klausner et al. (1974) found no significant correlation between volume of surface runoff and concentration of nitrogen in the runoff water, but theorized that soluble nitrogen concentrations may be a function of the time of year and the timing of fertilizer inputs. Other management factors are also important in the magnitude of losses of dissolved nitrogen.

2.4.1.1 Magnitude of losses

Timmons and Holt (1977) reported annual losses of 0.01 kg ha^{-1} of total nitrogen in runoff due to rainfall from a Barnes loam in a native Minnesota prairie state; 90% of the loss was in the dissolved fraction. Average total dissolved nitrogen lost from cropped plots in Minnesota were 3.43 kg ha^{-1} from fallow, 2.42 from continuous corn, 1.18 from rotation corn, 2.59 from oats and 4.01 from alfalfa (Burwell et al. 1975)

2.4.1.2 Seasonal effects

Snowmelt produced a greater proportion of nitrogen losses in the dissolved phase than rainfall for all cropping treatments in a study in Minnesota (Burwell et al. 1975). Nitrogen inputs from rainfall were greater than the total nitrogen losses in the dissolved phase for ten months of the year in New York (Klausner et al.1974).

Concentrations of dissolved nitrogen in runoff from a loess soil in Iowa declined throughout the growing season (Schuman et al. 1973). Concentrations of nitrogen prior to seeding were 5.6 $\mu g\ g^{-1}$, 2.2 $\mu g\ g^{-1}$ during seeding and establishment, and 1.5 $\mu g\ g^{-1}$ during reproduction and maturation. Soluble nitrogen lost was much greater from a storm in May than from a comparable storm in August. Average dissolved nitrogen concentrations were higher in 1969, a year which was characterized by several small rainfall events, than in other years which were characterized by larger events.

Concentration of total N in runoff from a barnlot in Coshocton, Ohio was found to be inversely related to temperature (Edwards et al. 1972). In January, average concentrations were 68.2 $\mu g\ g^{-1}$ with temperatures at -3°C, while at 22°C (August) concentrations were 8.6 $\mu g\ g^{-1}$. Long et al. (1975) on a Norfolk SL in the southeastern United States, found no difference in total nitrogen, ammonium or nitrates in runoff in a comparison of incorporated chemical fertilizers and incorporated manure.

2.4.1.3 Effects of management

Total nitrogen concentrations and total N losses in the dissolved fraction were significantly higher from a no till corn-soybean rotation treatment than from conventional till in Iowa (Laflen and Tabatabai 1984). Neilson and MacKenzie (1977) in a southwestern Quebec watershed study found that as the amount of land in corn production increased, soluble nitrogen lost increased. They attributed these losses to the increased tillage associated with corn production. Nutrient concentrations in the dissolved fraction increased as the residue cover increased in Iowa (Barisas et al. 1978).

2.4.1.4 Effects of fertilizers

The nitrate to ammonium ratio in runoff increased with an increase in phosphorus fertilizer on pasture in New Zealand (Lambert et al. 1985). It was suggested that increased legume growth allowed for a greater grazing population. This in turn increased urine return and increased herbage protein leading to higher nitrate losses. Schuman and Burwell (1974) used two rates (168 kg ha^{-1} and 448 kg ha^{-1}) of nitrogen fertilizer (anhydrous NH_3) knifed in to 25 to 30 cm in two Iowa watersheds. Nitrogen contributions from the fertilizer in runoff increased from 31% to 47% as the fertilizer rate increased. Differences in the form of nitrogen were also noted. The ratio of nitrate to ammonium from rainwater was 0.7:1.0. Nitrate in the streams from the watersheds increased with an increase in fertilizer added. The nitrate to ammonium ratio was 1.3:1.0 from the lower rate and was 1.64:1.0 from the higher rate.

Under simulated rainfall in Ohio, initial concentrations of nitrogen in runoff were found to be higher from fertilized plots with straw than from manure applied plots (Hoyt et al. 1977). Fertilized plots with the straw removed had the lowest concentrations. As time progressed, the nitrogen concentrations decreased to a level such that there was no difference in concentrations between treatments. All manure and fertilizer treatments were incorporated.

2.4.2 Ammonium nitrogen

Ammonium nitrogen adheres strongly to the soil and remains near the surface. Therefore, ammonium is likely to be an important component of total nitrogen lost during erosion (Baker and Laflen 1982).

Ammonium-N in runoff is dependent on a number of factors such as time of the season, discharge, management, tillage and moisture content.

2.4.2.1 Magnitude of losses

In Minnesota, annual nitrogen losses in the ammonium form from rainfall ranged from 0.01 kg ha^{-1} (alfalfa) to 0.09 kg ha^{-1} (continuous corn). Losses from fallow plots averaged 0.05 kg ha^{-1} (Burwell et al. 1975). On native prairie, less than 0.01 kg ha^{-1} y^{-1} of ammonium nitrogen was lost in runoff (Timmons and Holt 1977).

2.4.2.2 Seasonal effects

In Iowa, concentrations of ammonium were highest in spring runoff and snowmelt (Schuman et al. 1973). Ammonium concentrations were highest in the streamflow in winter when an Iowa watershed was dominantly residue cover (Alberts et al. 1978).

2.4.2.3 Effects of management

There was no significant increase in ammonium losses in Iowa from fertilized plots compared to unfertilized plots if fertilizers were injected at 5 cm or under residues (Baker and Laflen 1982). Ammonium losses did not increase with increased residue cover. Only fertilizer broadcast on top of the residue produced ammonium losses in runoff significantly greater than those from unfertilized plots.

2.4.3.4 Effects of discharge

Lewis (1986) studying a tropical watershed in Venezuela, found that the hydrograph of the concentration of ammonium-N had a similar pattern to that of total discharge but was delayed by several months.

2.4.3.5 Effects of tillage

Tillage of fallow just prior to a rainfall decreased ammonium nitrate losses in surface runoff in Indiana because of increased infiltration and ponding (Moe et al. 1967).

The incorporation of the fertilizer under conventional tillage accounted for the differences between tillage treatments in Indiana (Römkens et al. 1973, Table 2.3). Unfertilized minimum till plots had ammonium concentrations of only 0.23 $\mu g\ g^{-1}$ in runoff.

Table 2.3 Average [NH_4^+-N] concentration in runoff water and total NH_4^+-N for 2 successive events in Indiana (Römkens et al. 1973).

		Concentration		Total Mass	
Tillage		Dry	Wet	Dry	Wet
		-----$\mu g\ g^{-1}$------		------kg ha^{-1}-----	
minimum till	F[1]	51.24	6.94	15.84	3.11
(coulter)	U	0.23	0.01	0.07	<0.01
conventional till	F	0.26	0.17	0.11	0.10
	U	0.12	----	0.12	----

[1] F and U represent fertilized and unfertilized respectively.

2.4.2.6 Effects of antecedent moisture conditions

On an Indiana fragipan, as the moisture content at the time the fertilizer was applied increased, the total ammonium nitrogen lost in runoff water increased (Moe et al. 1967). However, the concentration of ammonium in the runoff water decreased with increasing moisture content.

Dry and wet (15 minutes following the first event) antecedent moisture conditions were compared using simulated rainfall in successive events following application of 170 kg ha^{-1} of N as ammonium nitrate broadcast. Ammonium concentration in runoff water and total ammonium lost decreased as moisture content increased (Römkens et al. 1973, Table 2.3). The difference between antecedent moisture conditions was probably due to undissolved ammonium at the surface being carried off in the runoff waters.

2.4.3 Nitrate and nitrite nitrogen

Nitrate nitrogen is very mobile and moves freely in solution. If infiltration is sufficient, there should be little nitrate lost to surface runoff. However, if the surface is only slowly permeable, there may be large nitrate losses in runoff.

Jones et al. (1977) claimed that nitrate concentration in runoff was a function of soil characteristics, discharge and year from a study of near level watersheds in Ohio. Other important factors include management, crop type and topography.

2.4.3.1 Magnitude of losses

Annual nitrate-N losses in the dissolved fraction were less than

0.01 kg ha^{-1} from alfalfa, 0.017 kg ha^{-1} from continuous corn and 0.44 kg ha^{-1} from fallow treatments (Burwell et al. 1975). Less than 0.01 kg ha^{-1} of nitrogen in runoff was in the form of nitrate or nitrite on a native prairie in Minnesota (Timmons and Holt 1977).

2.4.3.2 Seasonal effects

On a silty loam in Vermont most of the nitrate-N was lost in early spring when the soil was still frozen and impermeable (Benoit 1973). Rainfall yielded very little nitrate-N in runoff waters.

In New Zealand, large storms contributed up to 83% of the nitrate-N losses from forested and pasture watersheds yielding concentrations of up to 38.4 $\mu g\ g^{-1}$ from pasture (McColl et al. 1978). Lal (1976) also found that in Nigeria, the greatest loss of nitrate came during periods of heavy rainfall.

In Iowa, nitrate-N concentration from a loess soil was highest in snowmelt and spring runoff (Schuman et al. 1973). The highest concentrations of nitrate-N occurred in the fall when ammonium nitrate was fall broadcast prior to a wet season in New York (Klausner et al. 1974). Jones et al. (1977) also found that peak nitrate-N concentrations corresponded to periods of nitrogen fertilizer applications followed by rain. Three watersheds in Ohio were studied. Two were fertilized in spring and had concentrations above 10 $\mu g\ g^{-1}$, peaking at 31 $\mu g\ g^{-1}$ in spring runoff. During the remainder of the year concentrations were much lower. The other watershed was seeded to winter wheat with nitrogen fertilizer in the fall. The peak nitrate-N concentrations were in the period from November to January. In loess watersheds seeded to corn in

Iowa and Missouri, there were no significant seasonal variations in nitrate-N concentrations (Alberts et al. 1978). Ammonium nitrate was broadcast and incorporated prior to seeding. Nitrate-N concentrations in runoff from a barnlot were highest in the warm summer months (Edwards et al. 1972). Concentrations averaged 4.4 $\mu g\ g^{-1}$ in July and 5.8 $\mu g\ g^{-1}$ in August, while nine of the remaining ten months had concentrations of 2 $\mu g\ g^{-1}$ or less. The warm and drier aerobic conditions of the summer favoured nitrification of mineral nitrogen.

2.4.3.3 Effects of discharge

Research has been done on describing the hydrograph of a storm and the related concentrations of nitrate. In a tropical watershed in Venezuela, nitrate-N was at the lowest concentrations at the highest discharge and at the highest concentrations slightly after the discharge rate began to increase (Lewis 1986). Sharpley and Syers (1981) found a similar trend for nitrate-N from a New Zealand pasture, but noted that as the flow rate following a storm decreased, the nitrate-N concentration increased to a level higher than that in the initial discharge.

2.4.3.4 Effects of crop type

In Vermont, nitrate-N was found to be much higher in subsurface drains in corn plots than in alfalfa during the summer months, reflecting greater leaching of fertilizer nitrate-N in corn (Benoit 1973).

A comparison between a farmland and woodland in Ohio demonstrated that nitrate-N losses were more than four times higher from farmland than from a woodland watershed (Taylor et al. 1971). Nitrate concentrations were consistently higher from farmland in runoff waters, but on average only 1.28 $\mu g\ g^{-1}$ (from farmland). The authors did not consider these levels to be serious. However, in springtime nitrate levels reached 10 $\mu g\ g^{-1}$, which was above the critical level of 8.0 $\mu g\ g^{-1}$ for drinking water. Average nitrate-N concentrations in streams from a pasture dominated watershed in New Zealand were 9.29 $\mu g\ g^{-1}$ compared to 0.5 and 0.56 $\mu g\ g^{-1}$ from two individual forested watersheds during smaller storm events. During larger storms, the concentrations increased to 38.4, 1.43 and 1.41 $\mu g\ g^{-1}$, respectively (McColl et al. 1977). In Nigeria, the highest losses from fallow treatments were 9.6 kg ha^{-1}, appreciably higher than from the maize - maize (ploughed) rotation and the maize - cowpeas (no-till) rotation treatments (1.8 and 0.4 kg ha^{-1}, respectively) (Lal 1976). Lal found no significant difference among treatments in the concentration of nitrates in the runoff water. These ranged from 4 to 6 $\mu g\ g^{-1}$. This result indicated that the differences in losses were attributable entirely to differences in runoff among cropping treatments. However, it was noted that the seepage waters contained 3 times the concentration in runoff water, indicating leaching losses of fertilizer nitrogen in the form of nitrates.

2.4.3.5 Effects of topography

Nitrate and nitrite concentrations in runoff appear to be related to slope characteristics (Greenhill et al. 1983). Slopes with a smaller gradient tend to increase the time available for runoff to dissolve both nitrate-N and nitrite-N from the soil, yielding higher nitrate and nitrite concentrations. Lal (1976), on the other hand, found no significant variations in annual nitrate losses or concentrations among varied slopes in Nigeria.

2.4.3.6 Effects of antecedent conditions

Higher total nitrogen contents in the soil surface layer lead to mineralization of organic nitrogen, and therefore, higher nitrate and nitrite concentrations in runoff (Greenhill et al. 1983).

When fertilizer was broadcast on corn plots prior to tillage and simulated rainfall in Indiana, Römkens et al. (1973) found that concentrations of nitrate-N and the mass of nitrate-N lost decreased with an increase in moisture content (Table 2.4).

Table 2.4 Average [NO_3^-] and total NO_3^- lost from 2 successive events.*

		Concentration		Total Mass	
Tillage		Dry	Wet	Dry	Wet
		------$\mu g\ g^{-1}$ -----		-----$kg\ ha^{-1}$-----	
minimum till	F[1]	72.04	10.78	22.27	4.56
(coulter)	U	3.50	0.03	1.03	0.01
conventional till	F	1.45	0.65	0.59	0.95
	U	0.64	0.16	0.36	0.16

* Data taken from Römkens et al. (1973)

[1] F and U represent fertilized and unfertilized, respectively.

2.4.3.7 Effects of management

Losses of up to 29.2 kg ha^{-1} were reported from plots where stubble was removed from beans compared to 1.46 kg ha^{-1} when residue was returned (Klausner et al. 1974). Overall, losses of nitrate-N were significantly lower from well managed plots than from poorly managed plots.

2.4.4 Total dissolved phosphorus

Phosphorus behaves in much the same way as ammonium. It is immobile and is adsorbed to the soil colloids near the surface. Therefore, in order to reduce phosphorus losses, it is necessary to reduce sediment loss by increasing ground cover. To minimize losses of fertilizer phosphorus, it may be necessary to inject phosphorus below the surface.

There was no significant correlation between volume of surface runoff and phosphorus concentration in the runoff water in New York (Klausner et al. 1974). The authors theorized that soluble phosphorus concentrations may be a function of the time of year and the timing of fertilizer inputs.

In Wisconsin, phosphorus concentrations in runoff decreased with time after the start of runoff (Wendt and Corey 1980).

2.4.4.1 Magnitude of losses

In Minnesota, total dissolved phosphorus losses in runoff waters due to rainfall were 0.12 kg ha^{-1} from conventional till corn plots, 0.03 kg ha^{-1} from fallow plots and less than 0.01 kg ha^{-1} from alfalfa (Burwell et al. 1975). Less than 0.01 kg ha^{-1} of phosphorus in the dissolved phase was found in runoff due to rainfall on a native prairie (Timmons and Holt 1973). This was comparable to results found by Burwell et al. from alfalfa treatments.

2.4.4.2 Seasonal effects

The highest concentrations of phosphorus in runoff water were in the fall months from a barnlot in Ohio (Edwards et al. 1972). The lowest concentrations were in summer. Concentrations as high as 20 $\mu g\ g^{-1}$ were reported. In New York, the lowest concentrations of phosphorus were also in the summer (Klausner et al. 1974).

2.4.4.3 Effects of management

When fertilizers were banded at 5 cm or under residues, soluble phosphorus losses from fertilized plots were lower than from unfertilized plots (Baker and Laflen 1982). Phosphorus losses decreased as a result of increased residue cover. Only fertilizer broadcast on top of the residue significantly increased nutrient losses in runoff above the unfertilized plots.

In Nebraska, concentrations of phosphorus were higher in streams adjacent to legumes (Muir et al. 1973) which was possibly explained by the leaching of alfalfa residues during the period when the crop was dormant.

2.4.4.4 Effects of fertilizer

In Vermont, up to 2.0 $\mu g\ g^{-1}$ of phosphorus was found in surface runoff from corn and alfalfa treatments when phosphorus was surface broadcast (Benoit 1973). This was more than 100 times the phosphorus in subsurface drains, giving further evidence to the immobility of phosphorus.

On a Russell SiL in Indiana, increasing fertilizer rates increased the concentration of soluble phosphorus in runoff (Römkens and Nelson (1974). Using artificial rainfall at 6.35 cm h^{-1}, they found concentrations of phosphorus in runoff increased as the rate of phosphorus fertilizer increased (Table 2.5). Phosphorus fertilizer was broadcast and disced.

2.4.4.5 Effects of antecedent conditions

In New York, Klausner et al. (1974) found that most soluble phosphorus was lost from highly fertile soils that were poorly managed (residues removed or burned).

Table 2.5. Concentration of soluble P in runoff at three P fertilizer application rates.*

Rate P	PO_4
kg ha^{-1}	$\mu g\ g^{-1}$
0	0.07
55	0.24
113	0.44

* Data taken from Römkens and Nelson (1974)

The highest losses of soluble phosphorus occurred in watersheds with high fractions of organic or impermeable soils in southwestern Quebec (Neilson and Mackenzie 1977). Although losses were not of economic significance (1 kg ha^{-1} y^{-1}), average stream concentrations in these watersheds always exceeded 10 $\mu g\ g^{-1}$.

2.5 Eutrophication

Phosphorus carried in surface runoff from agricultural areas can be a major source of algal available phosphorus in surface waters (Wendt and Corey 1980). Greatest losses occur on recently tilled soils and on row crops.

The U.S. Environmental Protection Agency (1976) stated that soluble phosphorus levels in surface waters must be below 0.05 $\mu g\ g^{-1}$ for the body of water to maintain an ecological balance. Levels of .01 $\mu g\ g^{-1}$ have been found to accelerate algal growth in standing bodies of water in Minnesota (Holt et al. 1970). Soluble phosphorus concentrations as a percentage of total phosphorus were generally between 38 and 67%. Holt et al. suggested that 50% of total phosphorus could be assumed to be algal available.

Algal growth can be expected to bloom in ammonium concentrations of 0.03 $\mu g\ g^{-1}$ in surface waters (Sawyer et al. 1947).

Phosphorus inputs in streams from watersheds have been found to be greatest from runoff which flows directly from pasture to the stream (McColl 1978). A buffer strip of vegetation can greatly reduce the influx of phosphorus and therefore reduce eutrophication rates.

Nicholaichuk and Read (1978) found that concentrations of phosphorus in runoff from unfertilized as well as fertilized fallow plots exceeded 0.15 $\mu g\ g^{-1}$, the acceptable level in the Saskatchewan Water Quality Criteria (1970).

Lal (1976) found that in western Nigeria, concentrations of nitrates and phosphorus in streams draining agricultural lands were high enough to cause eutrophication of stream water and the phosphorus concentration was above 0.05 $\mu g\ g^{-1}$, the critical limit cited by Ryden et al. (1973). This was cause for some concern since in this part of the world more and more land is being transformed into farmland.

2.6 Summary

Nutrients associated with sediment in runoff are of primary economic importance. It is therefore necessary to reduce sediment losses in order to reduce nutrient losses. Good conservation practices such as increasing residue management, decreasing tillage, use of perennial grasses and forages on steep slopes and other practices intercept downward flow.

Although most rainfall events do not produce large economic losses of nitrogen and phosphorus (< 0.1 kg ha^{-1}), large events that occur every few years can lead to large nutrient losses (>5 kg ha^{-1}) as well as be damaging to soil structure.

Increases in moisture content can lead to greater soil losses and nutrient losses in both the sediment and dissolved fraction. It is possible to reduce the effects of moisture by increasing infiltration rates by maintaining residues.

Drilling or incorporating fertilizer reduces nutrient concentrations during the early cropping season when soil losses are the greatest.

Higher soil and nutrient losses can be expected from corn and fallow than from cereals. Forages yield the lowest total losses, but the highest concentrations in runoff water.

The dissolved fraction is important ecologically. Both dissolved phosphorus and ammonium are adsorbed to the soil colloids near the surface and are therefore associated with surface flow. Algal growth occurs at concentrations of 0.01 $\mu g\ g^{-1}$ of phosphorus and 0.03 $\mu g\ g^{-1}$ of ammonium in still water.

Nitrate losses are soluble and will move down into the profile. Nitrates are not important in surface flow although they are important in subsurface flow.

3. MATERIALS and METHODS

3.1 Field site locations and descriptions

Four Manitoba field sites of varying soil texture and uniform slope were selected. Two sites were located on the escarpment in south-central Manitoba and two sites in southwestern Manitoba (Figure 3.1).

The first site was established in the summer of 1984. It was located near Miami (legal description, NE 2-5-7W) on an imperfectly drained Gretna clay, developed on cretaceous clay outwash or outwash of weathered shale clay derived from escarpment ravines (Ellis and Shafer 1943). The site has a southerly exposure and a recent continuous cropping history.

The second site was established in the spring of 1985 near Roseisle (legal description, NW 18-6-7W) on an Agassiz beach formation. The soil is a well drained Leary sandy loam underlaid by sandy material (Ellis and Shafer 1943). The site has a westerly exposure and has a recent wheat-wheat-fallow rotation cropping history.

The third site, established in the summer of 1986, was located near Boissevain (legal description, SW of SE2-3-21W) on a Ryerson sandy clay loam in the Whitewater Lake basin, developed on deep strongly calcareous medium to moderately fine textured glacial till with coarse fragments

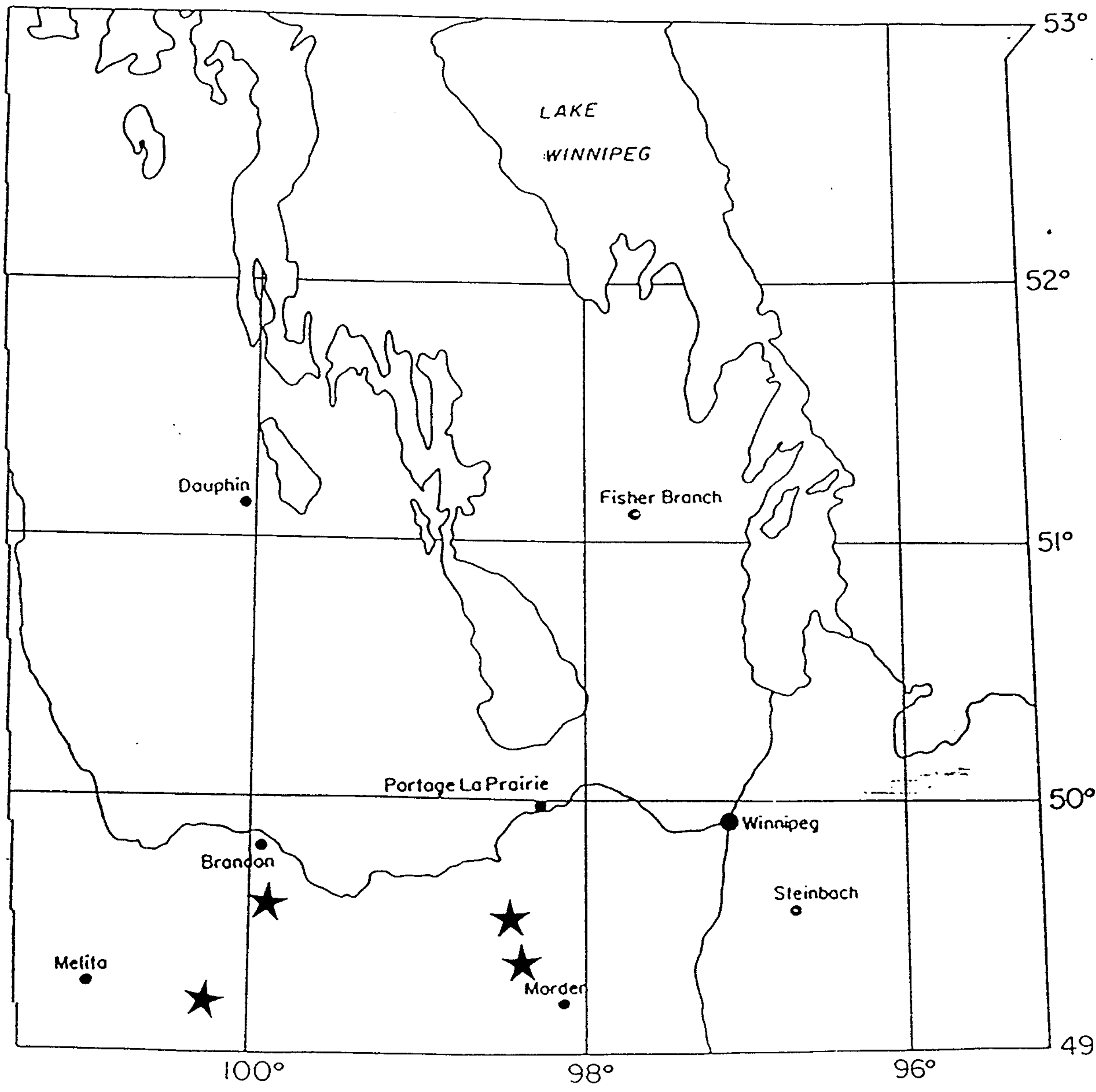

Figure 3.1 Location of experimental sites.

composed of shale, limestone and granitic rocks (Eilers et al. 1978). The site has an easterly exposure and has a recent cropping history of wheat-canola-fallow rotation.

The fourth site, located near Brandon (legal description, SW 29-8-19W), was established in the spring of 1987. In the basin of the glacial lakes Souris and Brandon, the well drained Carroll clay loam was developed on laucustrine sediment deposits, underlain at varying depths by a substrate of glacial till (Ehrlich et al. 1956). The site has a southwesterly exposure with a recent cropping history of wheat-canola-fallow rotation.

3.2 Experimental design and operations

At each site, a series of plots 0.01 ha in area with a slope length of 22.13 m, a width of 4.6 m and a uniform 9% slope were established. Five continuous crop-management systems - 1) alfalfa, 2) corn, 3) wheat - minimum tillage, 4) wheat - conventional tillage and 5) fallow were randomly assigned to one plot per site. The minimum till wheat treatment was not included on the Gretna clay and Leary sandy loam sites. Varieties used were Rambler alfalfa (Medicago sativa), Columbus wheat (Triticum aestivum) in the 1988-1989 crop years, Katepwa wheat (Triticum aestivum) was seeded in 1990. Pioneer 3995 corn (Zea mays L.) was seeded in the 1988-1990 crop years on Ryerson SCL and Carroll CL and the 1988-1989 crop years on the Gretna C and Leary SL. Pioneer 3979 corn (Zea mays L.) was seeded in 1990 on Gretna C and Leary SL.

Seeding rates used were as outlined in the "Field Crop Recommendations for Manitoba" (Manitoba Agriculture 1988). Wheat was seeded at 100 kg ha^{-1} with a 1.5 m double disc press drill with 18 cm row spacings. Fertilizer in the form of ammonium nitrate (34-0-0) and ammonium sulfate (21-0-0(24)) (if necessary) was broadcast prior to seedbed preparation. Ammonium phosphate (11-51-0) was side banded.

Corn was planted at 75000 seeds ha^{-1} using a hand planter with 15 cm spacings within rows and 61 cm row spacings. Fertilizer was hand broadcast prior to seedbed preparation. Ammonium phosphate, ammonium sulphate and potash (0-0-60) were applied at rates as recommended by soil testing (Appendix A).

Alfalfa was in the 4th year of establishment on the Gretna C and Leary SL and 3rd year on the Ryerson SCL and Carroll CL in 1988.

Conventional till wheat and corn received deep tillage treatments in the fall. Fallow was tilled every 4 to 6 weeks. Corn was cultivated once in the early growth stages.

Weed control was achieved by cultivation in fallow and in early stages in corn, hand weeding and chemical pesticides. The pesticides included Fusilade in alfalfa, Aatrex Plus or Aatrex + surfactant in corn, Hoegrass II and MCPA in wheat and spot spraying of Roundup. Details of rates and timing of herbicide application are in Appendix A.

Measurements were taken from all four sites in 1988 and 1990. Due to insufficient funding, the Carroll clay loam site was seeded and fertilized in 1989, but no measurements were taken.

Alfalfa was cut at 10% bloom to a height of about 20 cm. Corn was harvested at about 65% whole plant moisture. Wheat was harvested at head maturity. Stubble heights were about 15 cm. Whole plant samples from wheat, corn and alfalfa were randomly selected from three - one square meter areas prior to harvest representing the upper, middle and lower positions on the slope. Plant dry matter yields as well as seed yields from wheat were determined from each plot .

3.3 Soil characteristics

Soil characteristics were determined for each site using nine samples taken to a 15 cm depth using a grid pattern described by Wahome (1989). The soil properties determined from these samples were particle size analysis, percent organic matter, aggregate index and dispersion ratio. Bulk density was determined in the field as described in section 3.3.5. Structure code and permeability class were estimated using soil survey data. Montmorillonite clay content was determined using specific surfaces and soil texture data as described in Wahome (1989). Soil characteristics for each grid position are in Appendix F.

3.3.1 Particle size analysis

Percent sand, silt and clay were determined using the standard pipette sampling method (Gee and Bauder 1986). The components of the sand fractions were determined by dry sieving using a mechanical shaker. The size fractions were divided in accordance with the Canadian classification system (Canadian Soil Survey Committee 1978).

3.3.2 Organic matter content

Organic matter content was determined using the Walkley-Black (1934) chromic acid oxidation method. Organic carbon was oxidized with excess $K_2Cr_2O_7$ in concentrated H_2SO_4. An automatic titrator was used to back titrate with $FeSO_4$. The data were used to calculate organic carbon and multiplication by a conversion factor of 1.724 gave organic matter percentage.

3.3.3 Aggregate Index

A 200 g sample was passed through 9.5 mm and a 2.0 mm sieves using a mechanical shaker for 15 minutes. The aggregate index was determined as follows.

$$AI=\frac{X}{M-X} \tag{3.1}$$

AI = aggregate index

X = mass of soil aggregates between 2.0 mm and 9.5 mm

M = total mass of soil sample

3.3.4 Dispersion ratio

The procedure described by Middleton (1930) as modified by Pauls (1987) was used to determine the <.05 mm aggregate suspension percentage. The formula is as follows:

$$\text{Dispersion ratio} = \frac{\text{suspension percentage}}{\text{\% silt + \% clay}} \tag{3.2}$$

3.3.5 Bulk density

On each site, four locations outside the plots were chosen for the determination of bulk density. A 25 cm^3 core sampler was used at two depths (0-7.5 and 7.5-15 cm) with four replicates at each depth. Bulk density was determined by dividing the oven dry soil weight by the volume of the sampler. All replicates were averaged giving a single value for the site.

3.3.6 Structure and permeability

Soil structure and permeability were estimated based on soil survey maps, field observations by Pauls (1987) and Wahome (1989) in consultation with M. Langman (Manitoba Soil Survey).

3.3.7 Permanent wilting percentage

Permanent wilting percentage (PWP) was determined using a pressure membrane apparatus at a pressure of -1520 kPa. The samples were then weighed and gravimetric water content was determined. The following formula (Shaykewich 1965) was used to calculate PWP:

$$PWP = 0.0207 + 0.77468(FAP) \tag{3.3}$$

where FAP = moisture content at -1520 kPa (15 atmospheres).

3.3.8 Montmorillonite percentage

Percent montmorillonite was estimated using estimated specific unit area measurements and soil texture analysis. Specific area measurements were based on organic matter content and -1520 kPa soil moisture content (Young and Onstad 1976). The procedure is described in detail by Wahome (1989).

3.4 Field measurements

3.4.1 Cover measurements and crop stages

The percent canopy and mulch cover, which is the percentage of field area not directly hit by a falling vertical raindrop because of crop foliage or mulch interception was determined by a point line method (Wischmeier and Smith 1978) as modified by Pauls (1987). A 5 m length of 2.5 x 5.0 cm wood beam with 10 evenly placed double set screws used for sight lines was used. The beam was supported at either end by a bipod and its height was adjustable from 30 to 80 cm. Five positions on each plot were randomly selected. The beam was oriented 45 degrees to the long axis of the plot. When the crop height exceeded 80 cm, a horizontal bar with markings every 15 cm was suspended above the plot by two stands in the grassways between plots. A metal rod was suspended vertically from 20 successive markings 15 cm apart. The number of times the rod came into contact with a plant or residue determined the percent cover. This measurement was done on each plot at five positions.

Crop residue counts were done once each prior to seeding, before crop emergence, after harvest and after tillage. Crop cover counts were done weekly during the growing season, with the exception of the Ryerson SCL site in 1989, where they were done bi-weekly.

Crop stage periods given by Wischmeier and Smith (1978) were modified to account for a winter period and the absence of turn plough tillage. A comparison of the two systems is given below in Table 3.1.

Table 3.1 A comparison of two systems for the determination of crop stage.

Wischmeier and Smith (1978)	Modified System
Period F (rough fallow) -turn ploughing to secondary tillage.	Period W (winter) -last fall tillage to spring tillage.
Period SB (seedbed) -secondary tillage to 10% canopy cover.	Period SB (seedbed) - first spring tillage to 10% canopy cover
Period 1 (establishment) -10% to 50% canopy cover.	Period 1 (establishment) -10% to 50% canopy cover.
Period 2 (development) -50% to 75% canopy cover.	Period 2 (development) -50% to 75% canopy cover.
Period 3 (maturing crop) -75% canopy cover to harvest.	Period 3 (maturing crop -75% canopy cover to harvest.
Period 4 (residue or stubble) -harvest to ploughing or new seeding.	Period 4 (residue or stubble) -harvest to fall tillage.

3.4.2 Soil moisture

Weekly soil moisture samples (bi-weekly in 1989 on Ryerson SCL site) were taken. Samples were taken from three random locations on the plot representing the upper, middle and lower positions on the slope at two depths (0-7.5 cm and 7.5-15 cm). Moisture percentage was determined gravimetrically. Average plot soil moisture content for each depth was calculated by averaging the three replicates.

3.4.3 Rainfall measurements

A tipping bucket rain gauge linked to a datapod, and a standard rain gauge were located on each site. Information downloaded from the datapod gave total rainfall, total kinetic energy, storm duration, maximum 30 minute intensity and erosivity index for each storm. When the datapod failed, information was extracted from the recording rain gauge charts. In either case, the rainfall erosivity index was computed for each storm by a method described by Wischmeier and Smith (1978). The standard rain gauge was used as a check for the tipping bucket rain gauge. The tipping bucket gauge was routinely calibrated in the field to ensure accuracy.

3.4.4 Surface runoff

Surface runoff was collected using a Coshocton sampling system described in Pauls (1987) and shown in Figure 3.2. Runoff from the plots flowed down slope into a trough. The trough was sloped down to a 15 cm high flume located above a rotating Coshocton wheel with a diameter of 30 cm and an elevated aperture along its radius. The area of the aperture was 1% of the area of the wheel. The Gretna C and Leary SL sites had finned sampling wheels which were propelled by the runoff. The Ryerson SCL and Carroll CL had sampling wheels where rotated by an electric motor. The rotation of the wheels was initiated by a flotation device after 6 mm of rain had fallen.

3.4.4.1 Runoff volume measurement

A water level recorder was used to determine the rate of water loss from each plot. As the flux through the flume increased, the water height in an adjacent stilling well increased, raising a float, which in turn raised a pen on the water level recorder. As the flux decreased, the pen dropped by a reversal of events. The total volume of flow was found by

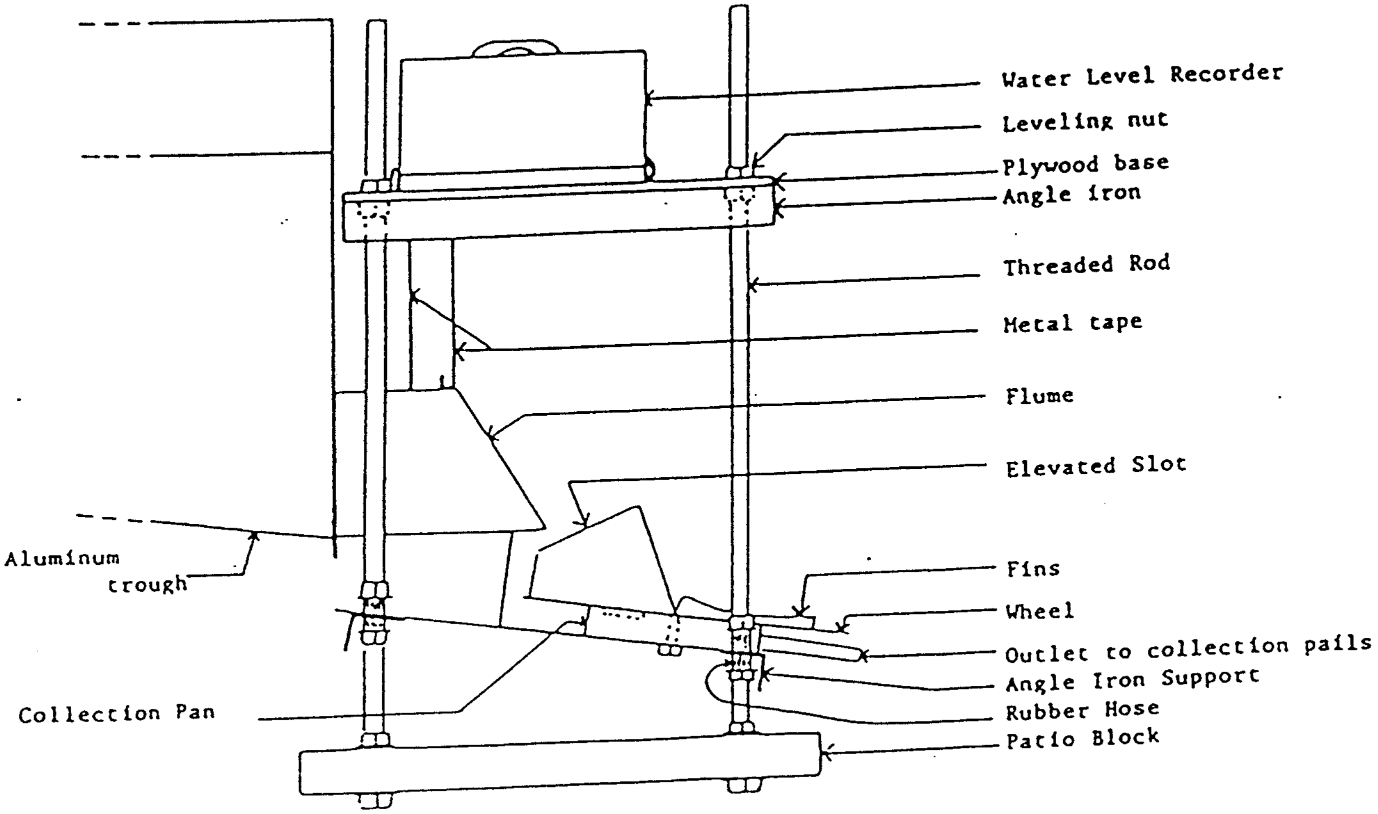

Figure 3.2 Side view of Coshocton sampler, water level recorder and lower trough end.

Source: Pauls 1987

measuring the area under the resultant curve. Each water level recorder was calibrated by relating flow rate in L s^{-1} to water level in the stilling well. Total water volume was calculated using the resultant calibration. Problems were encountered due to sedimentation in the stilling well giving artificially high runoff values. A detailed explanation of the method used to solve this problem is listed in Appendix E.

3.4.4.2 Soil loss measurement

Coshocton wheels in place below the flume were calibrated to determine the actual percentage of the total flow which entered through the apertures (Pauls 1987 and Wahome 1989). The portion which was sampled passed through a collection pan into a series of 20 L plastic containers.

When an event runoff occurred, the containers were collected and replaced and sediment in the trough was collected. The portion in the collection pail was filtered through borosilicate microfiber paper (Cole Parmer cat# GC5090MM)[1]. The sediment retained on the filter paper was then oven dried. The sediment collected from the trough was air dried, two 50 g portions were removed and the remainder was oven dried. One 50 g sample was used for nutrient analysis, while the other was oven dried. The latter sample was used to correct for sediment moisture content and subsequent calculation of the total oven dried weight.

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[1] Product name is included for the benefit of the reader and does not imply endorsement or preferential treatment of the product by the University of Manitoba, Department of Soil Science.

3.5 Nutrient analysis

Runoff was filtered through borosilicate microfiber paper (Cole Parmer cat# GC5090MM)[1] to separate the sediment fraction from the dissolved fraction. It was necessary to flocculate the runoff from the Gretna C with 2N KCl in order to satisfactorily clarify the dissolved sample for analysis. After filtration, the liquid portion was stored at 4°C until analysis.

3.5.1 Sediment total nitrogen

Nitrogen concentration in the soil was determined by distillation and titration with dilute sulfuric acid following the permanganate - reduced iron modification of the Kjeldahl digestion method as described by Bremner and Mulvaney (1982). Air dry moisture content information was used to convert the air dried mass of soil to oven dried mass. Total soil nitrogen losses in sediment were calculated by multiplying total soil loss by concentration.

3.5.2 Sediment total phosphorus

Phosphorus concentration was determined colorimetrically following soil preparation using the perchloric acid digestion method described by Olsen and Sommers (1982). Calculations were made to determine total phosphorus concentration as a fraction of oven dried mass. Total soil phosphorus losses in sediment were calculated by multiplying total soil loss by concentration.

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[1] Product name is included for the benefit of the reader and does not imply endorsement or preferential treatment of the product by the University of Manitoba, Department of Soil Science.

3.5.3 Dissolved nitrite nitrogen

Nitrite nitrogen concentration of the filtrate was determined by aqueous flow injection using the Technicon[1] FIAstar 5020 analyzer. An aqueous stream carrying nitrite was mixed with acidic sulphanilamide to form a diazo compound. By adding N-(1-naphthyl)-ethylenediamine dihydrochloride, a purple azo colour was formed, the intensity of which was related to the nitrite concentration. Absorbance of the resulting solution was measured at 540 nm (Keeney and Nelson 1982).

3.5.4 Dissolved nitrate nitrogen

Nitrate nitrogen concentration was determined by a aqueous flow injection method using the Technicon[1] FIAstar 5020 analyzer by measuring absorbance at a wavelength of 540 nm. This method is a modification of that described by Jackson et al. (1975), and involves a copperized Cd column for the reduction of nitrate to nitrite. The resultant concentration is that of the sum of nitrate and nitrite nitrogen. Subtraction of nitrite concentration yielded nitrate concentration.

3.5.5 Dissolved ammonium nitrogen

Ammonium nitrogen in runoff was converted to ammonia using 10 M NaOH. An Orion[1] Model 95-12 electrode was then used to determine the molarity of ammonia in solution as described by Keeney and Nelson (1982). Using a logarithmic scale calibration curve from standards, ammonium concentrations were determined.

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[1] Product name is included for the benefit of the reader and does not imply endorsement or preferential treatment of the product by the University of Manitoba, Department of Soil Science.

3.5.6 Dissolved phosphorus

The concentration of dissolved phosphorus was determined colorimetrically using ascorbic acid as a reductant for the phosphomolybdate complex. The development of a molybdophosphoric blue colour on reduction was measured at a wavelength of 885 nm (Olsen and Sommers 1982).

3.6 Statistical Procedures

Cropping treatments were laid out in a randomized complete block design. There was one replicate per site and four or five cropping treatments in each block.

Because of the complications which arise from differing soil types and rainfall patterns, each site was analyzed separately with the crop type being the treatment and the sampling events being the repetitions.

Comparison of means for rainfall events were done using a completely randomized ANOVA design to account for differing sample sizes. Duncan's mean comparison test were used at the 5% significance level to determine statistical significance.

Standard linear regression analyses with appropriate transformations were performed to determine the relationships between total nitrogen and total phosphorus losses to storm characteristics and antecedent conditions.

All analyses were done with the Cohort statistical package (1990) for IBM compatible microcomputers.

4. RESULTS and DISCUSSION

The scope of this discussion is based on data accumulated over the 1988, 1989 and 1990 growing seasons on the Gretna clay, Leary sandy loam, Ryerson sandy clay loam and the Carroll clay loam (1988 and 1990 only). Data from 1985 to 1987 is also used as a data base for extrapolation purposes. Data collected included rainfall and runoff characteristics, soil moisture levels, ground cover, soil loss, crop biomass and grain yields (Appendix B), nutrient content in runoff and soil physical properties.

4.1 Soil physical properties

Site characterization was done prior to plot construction. Included in the characterization was the determination of some soil physical properties which are believed to influence soil erodibility characteristics (Table 4.1 and Appendix C). When these soil characteristics were interpreted as suggested by Hoyt et al. (1977), expected soil losses were;

Gretna C < Carroll CL < Ryerson SCL < Leary SL.

Table 4.1 Some physical properties of field plot soils.

Soil	Sand	Silt	Clay	Saturation Moisture Content	Field Capacity	-1520 kPa Moisture Content	Bulk Density	Particle Density
	%			%w			g cc^{-1}	
Leary SL	74.5	14.5	11.1	28.7	11.4	6.7	1.54	2.62
Gretna C	23.0	28.6	50.4	33.6	26.2	20.6	1.44	2.64
Ryerson SCL	57.2	19.4	22.9	41.7	22.7	14.8	1.28	2.42
Carroll CL	40.6	25.1	34.3	36.3	27.4	16.1	1.30	2.45

4.2 Rainfall characteristics during the study period

Rainfall events which were significant under the criteria outlined by Wischmeier and Smith (1978) are given in Table 4.2. Erosivity of rainstorms can be divided into 4 categories:

Non-erosive	< 50 MJ mm ha^{-1} h^{-1}
Low	50 - 100 MJ mm ha^{-1} h^{-1}
Moderate	100 - 400 MJ mm ha^{-1} h^{-1}
High	400 + MJ mm ha^{-1} h^{-1}

Figure 4.1 shows the distribution of erosivity values for rainfall events classified according to erosivity for each site. Figure 4.2 breaks down the rainfall events by crop stage for corn and wheat.

A summary of annual total rainfall and erosivity for each site is reported in Table 4.3. The years 1988 and 1989 had below normal precipitation throughout southern Manitoba. There were few sampling events in these years. Most rainfall events in these years had low erosivity. There were only three storms from the Leary SL, Gretna C and Ryerson SCL sites that were moderately erosive events over the two years. There were two events in the Carroll CL site which were highly erosive. There were no seasonal patterns of rainfall observed in 1988 or 1989.

The year 1990 had average to above average rainfall. The year could

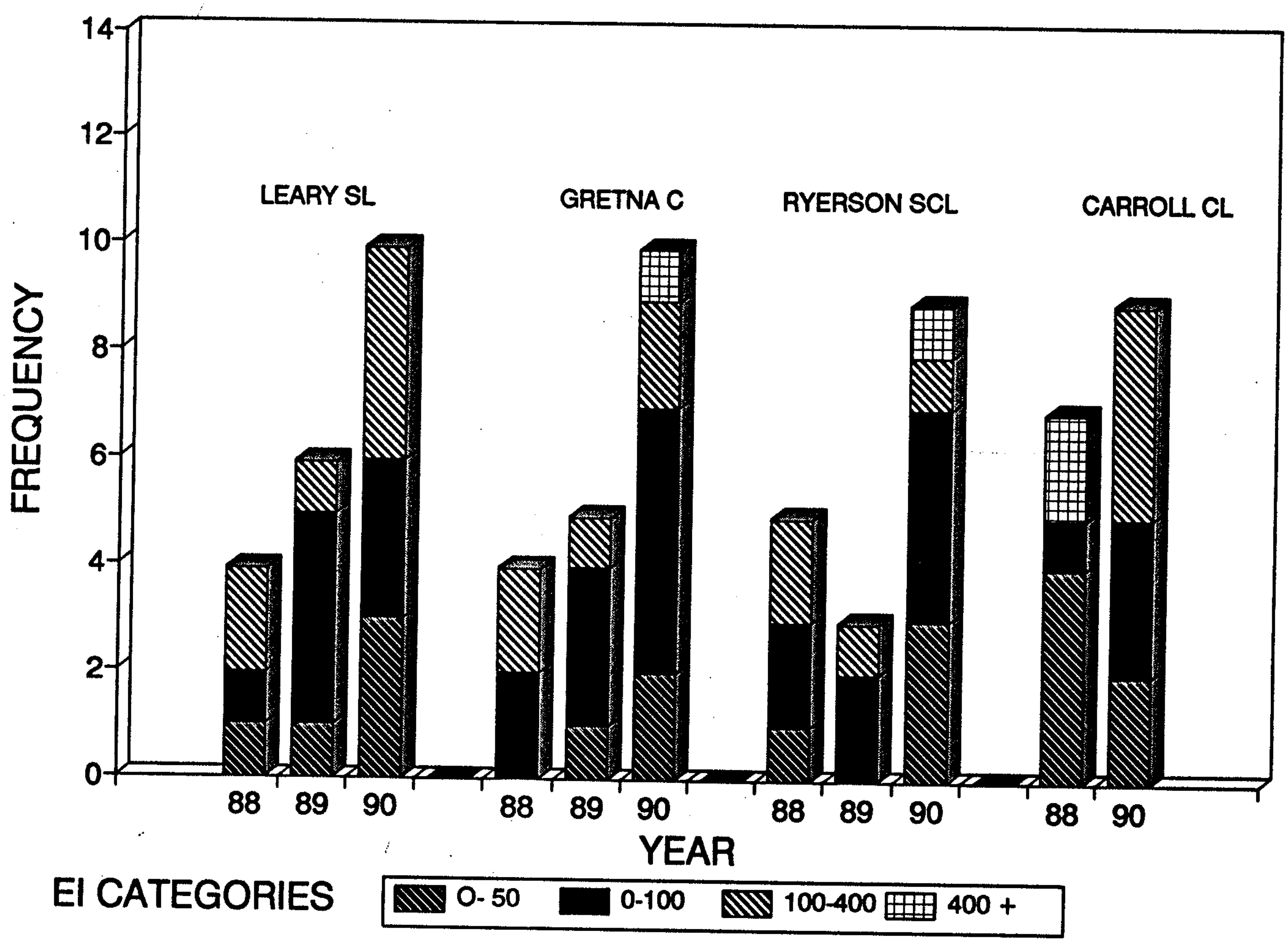

Figure 4.1 Distribution of rainfall events by erosivity for experimental sites.

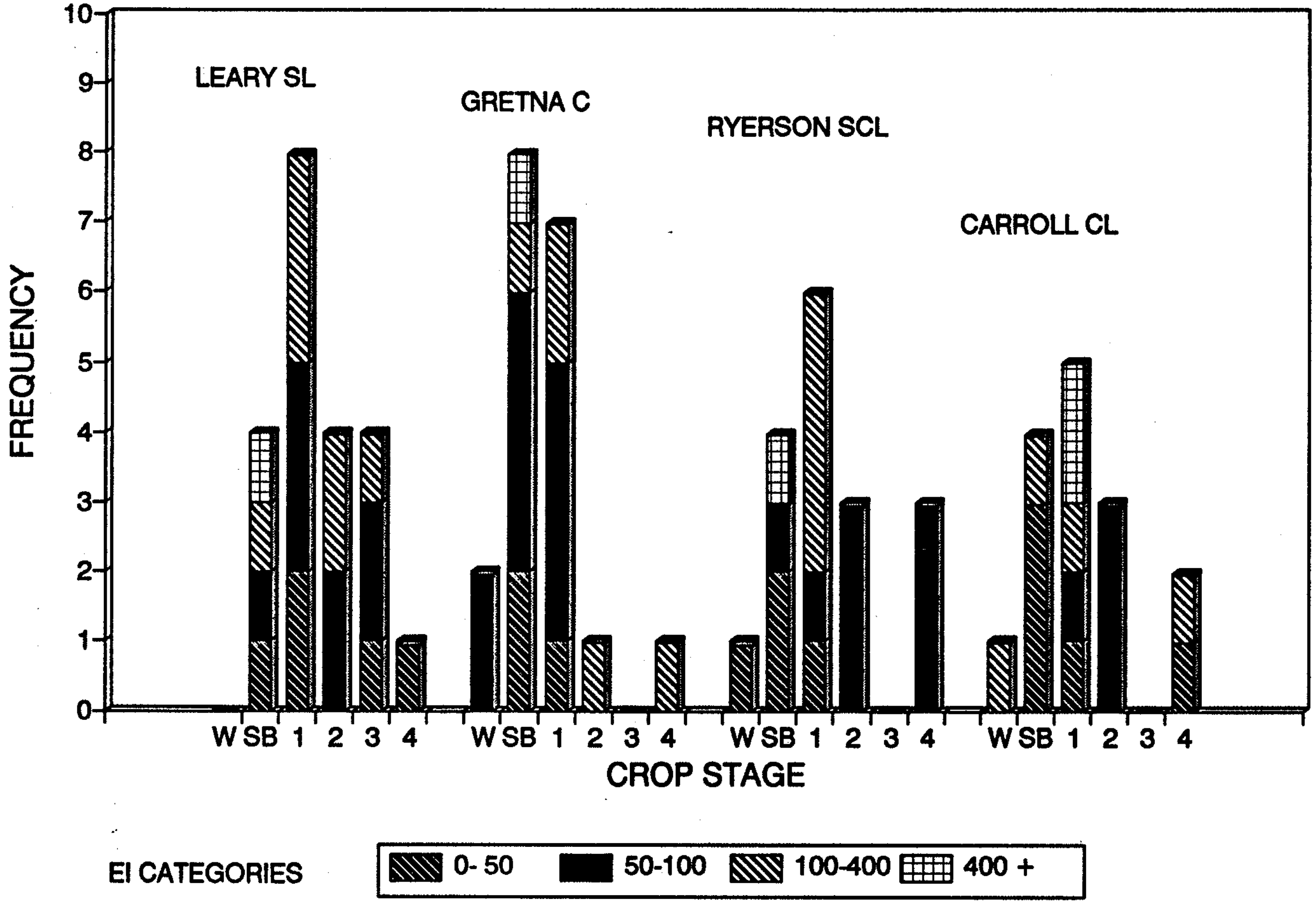

Figure 4.2a Erosivity of rainfall events by crop stage for corn.

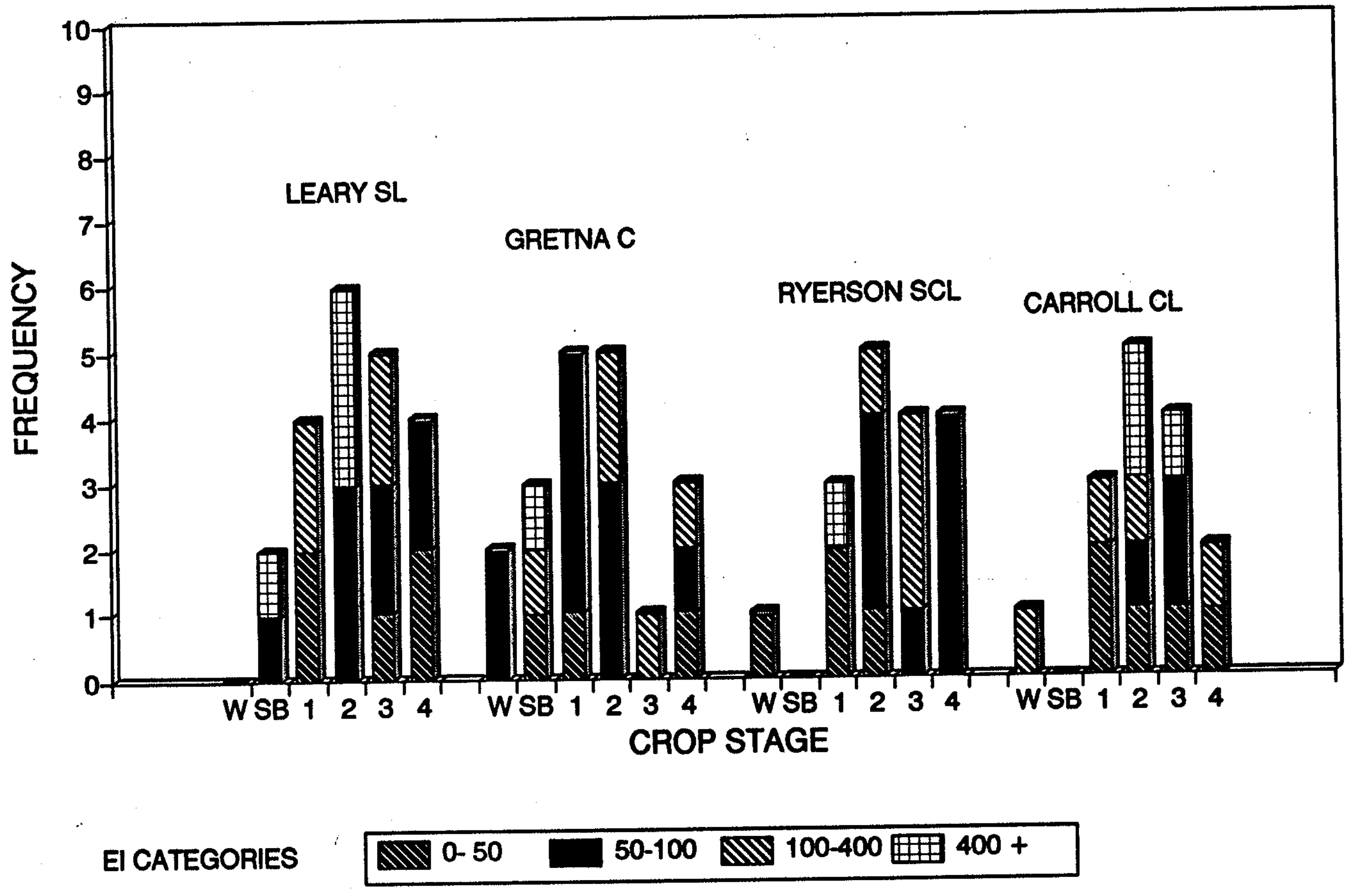

Figure 4.2b Erosivity of rainfall events by crop stage for wheat.

Table 4.2 Rainstorm characteristics for experimental sites in 1988-1990.

Date of Storm	Total Rainfall	Maximum 30 minute Intensity	Duration	Rainfall Erosivity
	mm	mm h^{-1}	min	MJ mm ha^{-1} h^{-1}
Leary sandy loam:				
1988.06.01	26.6	28.4	95	162
1988.07.05	21.4	18.4	285	99
1988.07.12	28.8	36.8	189	250
1988.09.11	23.2	8.4	610	43
1989.06.06	29.8	11.2	824	73
1989.06.12	46.2	6.0	1600	60
1989.07.14	7.4	14.8	23	23
1989.08.03	37.2	39.6	115	325
1989.08.17	16.0	16.8	254	66
1989.09.10	45.2	6.0	1186	59
1990.06.01	69.8	39.2	1660	606
1990.06.08	30.4	12.4	1167	83
1990.06.11	12.6	16.8	244	36
1990.06.18	27.6	31.2	689	181
1990.06.19	11.6	22.4	80	41
1990.07.02	33.2	36.4	175	209
1990.07.06	28.0	47.2	131	336
1990.07.28	14.4	25.6	111	74
1990.08.01	25.8	29.6	643	163
1990.08.22	15.8	25.6	116	90
1990.09.17	20.4	8.4	428	38
Gretna clay:				
1988.05.07	22.4	10.8	968	50
1988.07.05	16.8	15.2	290	64
1988.07.06	22.2	44.4	28	192
1988.09.11	40.0	17.6	1504	159
1989.06.12	43.4	8.8	1560	83
1989.08.03	23.8	41.6	101	132
1989.08.25	10.8	15.2	72	41
1989.09.10	60.4	6.4	1222	84
1990.05.14	38.2	8.0	2340	67
1990.05.20	16.2	13.6	481	54
1990.06.01	93.6	72.8	1675	950
1990.06.08	20.8	6.4	1052	29
1990.06.11	32.8	59.2	56	280
1990.06.17	13.4	16.0	421	51
1990.06.19	10.6	9.6	83	23
1990.07.02	14.6	27.6	56	92
1990.07.06	15.0	24.4	130	92
1990.08.22	22.8	37.6	133	204
1990.09.17	13.6	3.2	455	9

Table 4.2 cont. Rainstorm characteristics for experimental sites in 1988-1990.

Date of Storm	Total Rainfall	Maximum 30 minute Intensity	Duration	Rainfall Erosivity
	mm	mm h^{-1}	min	MJ mm ha^{-1} h^{-1}
Ryerson sandy clay loam:				
1988.06.15	31.8	4.0	1222	28
1988.07.06	40.6	40.0	574	199
1988.07.12	23.4	29.6	361	138
1988.09.10	38.4	10.4	148	78
1988.09.18	26.8	8.8	658	51
1989.06.28	42.5	17.4	960	148
1989.08.11	22.9	14.5	95	73
1989.09.03	22.0	12.4	283	62
1990.05.15	39.6	5.6	2019	48
1990.06.01	17.0	4.0	1161	15
1990.06.07	11.8	9.2	388	24
1990.06.16	81.6	55.2	526	1002
1990.06.19	13.0	18.8	83	57
1990.07.01	15.6	17.6	112	66
1990.07.03	21.2	25.6	148	125
1990.08.22	15.0	18.0	370	53
1990.09.17	23.6	15.2	750	80
Carroll clay loam:				
1988.05.07	16.2	7.4	620	20
1988.06.14	26.7	5.9	840	25
1988.07.06	95.8	65.0	280	1660
1988.07.13	45.7	45.2	245	504
1988.08.18	16.4	7.2	299	22
1988.09.10	47.9	7.5	771	58
1988.09.18	20.3	7.0	343	24
1990.05.15	94.8	10.8	1784	223
1990.06.07	17.4	5.6	866	318
1990.06.17	40.4	32.8	922	189
1990.06.19	11.4	4.8	609	12
1990.07.03	43.4	68.8	190	189
1990.07.06	15.2	13.6	210	46
1990.08.01	21.2	36.8	317	73
1990.08.18	25.0	15.6	1002	87
1990.08.27	19.0	37.2	251	59

Table 4.3 Summary of rainfall characteristics for experimental sites in 1988-1990.

Year	Total Rainfall from Events	Rainfall Erosivity
	mm	MJ mm ha-1 h^{-1}
Leary sandy loam:		
1988	100.0	554
1989	181.8	606
1990	331.2	1857
Total	613.0	3017
Gretna clay:		
1988	101.4	465
1989	138.4	340
1990	291.6	1851
Total	531.4	2656
Ryerson sandy clay loam:		
1988	161.0	494
1989	87.4	283
1990	238.4	1470
Total	486.8	2247
Carroll clay loam:		
1988	269.0	2313
1990	287.8	1196
Total	556.8	3509

be divided into two distinct rainfall seasons. The period between June 1 and July 6 was a period of frequent rainstorms including a highly erosive event on all but the Carroll CL site. The latter period was drier with a few low or moderate erosivity events from each site scattered through the three months. Crops were under moisture stress through this period.

Four rainfall events over the three experiment years accounted for 50% of the rainfall erosivity but only 27% of the rainfall on the Leary SL. Thirteen of the 21 events were of low erosivity and accounted for 53% of the rainfall.

At the Leary site, the rainfall event on June 1, 1990 accounted for

51% and 32% of the seasonal erosivity and rainfall, respectively. For the entire length of the study, this event accounted for 36% and 18% of the erosivity and rainfall, respectively. During the study, 56% of the rainfall fell as low erosive rainfall, accounting for 28% of the total erosivity, less than the June 1, 1990 event.

At the Ryerson site, one storm event on June 16, 1990 had an erosivity value of 1002 MJ mm ha^{-1} h^{-1}. This compares with the estimated seasonal average of 1160 MJ mm ha^{-1} h^{-1} for southern Manitoba (Wall et al 1983). This event accounted for 34% of the rainfall in 1990 and 17% of the rainfall over the three years. Also, 68% of the seasonal erosivity and 45% of the total study period was observed in this one event. Twelve of the 17 events were low erosive events accounting for 57% of the total rainfall and 28% of the rainfall erosivity.

Unlike the other three sites, the most erosive rainfall events on the Carroll CL were in 1988. There were 2 rainfall events one week apart: on July 6 (95.8 mm) and July 13 (45.7 mm) with erosivity values of 1660 MJ mm ha^{-1} h^{-1} and 504 MJ mm ha^{-1} h^{-1}, respectively. These events contributed 53% of the seasonal rainfall and 25% of the total rainfall for the two years (1988 and 1990). The erosivity of these two events accounted for 94% of the total for the season and 62% of the study period total. There was an event on May 15, 1990 with total rainfall (94.8 mm) comparable to the July 6, 1988 event, but the rain was spread over a period more than six times as long. As a result, erosivity of the event was only 223 MJ mm ha^{-1} h^{-1}.

4.3 Surface runoff and soil loss

The maximum flow rates and total runoff volumes for each event sampled are reported in Tables 4.4a and 4.4b. The antecedent moisture content, crop cover percentage and soil loss for each sampling event are found in Table 4.5.

4.3.1 Effects of rainfall intensity

Runoff and soil loss from two rainfall events with equal amounts of rainfall were greater when the rainfall was more intense.

Two events on the Leary SL of 26.6 mm on June 1, 1988 and 29.8 mm on June 6, 1989 had similar antecedent moisture conditions. The maximum 30 minute intensity and erosivity index for the events were 28.4 mm h^{-1} and 162 MJ mm ha^{-1} h^{-1} on June 1; and 11.2 mm h^{-1} and 73 MJ mm ha^{-1} h^{-1} on June 6. Surface runoff was greater from the June 1 event from the wheat (308 L compared to 16 L), corn (115 L compared to 13 L) and fallow plots (102 L compared to 20 L). The intensity of the June 1 event was about 2.5 times that of the June 8 event but it produced 20 times as much soil loss from the fallow treatment. Substantial differences were also noted from the wheat (23 fold) and corn (2 fold) treatments.

Similarly, on the Ryerson SCL, surface runoff and soil loss from a July 6, 1988 (40.6 mm, I_{30} (maximum 30 minute intensity) = 40 mm h^{-1}, EI (erosivity index) = 199 MJ mm ha^{-1} h^{-1}) was greater than from a June 28, 1989 event (42.5 mm, I_{30} = 17.4 mm h^{-1}, EI = 148). Surface runoff losses

Table 4.4a Runoff data from Leary SL and Gretna C 1988-1990.

Date of Rainfall	Alfalfa		Wheat (Con.Till)		Corn		Summerfallow	
	Max Flow Rate	Tot Runoff Volume	Max Flow Rate	Tot Runoff Volume	Max Flow Rate	Tot Runoff Volume	Max Flow Rate	Tot Runoff Volume
	L s^{-1}	L	L s^{-1}	L	L s^{-1}	L	L s^{-1}	L
Leary sandy loam:								
1988.06.01	0.00	0.00	1.19	308.00	0.40	115.26	0.09	101.73
1988.07.05	0.03	19.38	1.68	566.53	0.09	19.41	0.03	20.65
1988.07.12	0.03	19.38	1.68	649.95	0.36	372.87	0.51	362.10
1988.09.11	0.00	0.00	0.02	37.91	0.02	15.76	0.03	13.77
1989.06.06	0.03	19.88	0.02	16.24	0.02	12.96	0.02	20.14
1989.06.12	0.00	0.00	0.02	16.05	0.02	27.79	0.02	81.39
1989.07.14	0.07	41.99	0.49	103.63	0.05	19.61	0.02	20.86
1989.08.03	0.69	152.11	1.80	827.76	2.23	1135.07	0.96	463.56
1989.08.17	0.00	0.00	0.49	150.91	0.88	368.72	0.23	111.99
1989.09.10	0.00	0.00	0.02	17.40	0.03	185.93	0.03	163.98
1990.06.01	0.17	167.32	2.73	2359.25	3.01	2160.22	0.32	672.93
1990.06.08	0.04	31.38	0.24	513.95	0.46	463.11	0.00	0.00
1990.06.11	0.12	100.73	3.08	1022.20	2.75	863.60	2.54	1013.73
1990.06.18	0.04	21.19	0.14	41.39	2.25	275.72	1.08	159.20
1990.06.19	0.08	56.03	4.67	2796.93	8.57	2974.58	3.24	2957.61
1990.07.02	0.12	63.26	3.03	1543.78	17.45	7180.73	3.14	1575.31
1990.07.06	0.13	125.99	3.67	1968.14	17.17	7971.98	3.38	1709.12
1990.07.28	0.11	33.73	2.89	556.49	2.87	513.81	3.61	781.58
1990.08.01	0.09	98.75	3.99	1410.71	2.98	1200.66	4.64	2316.50
1990.08.22	0.05	36.35	2.53	489.25	1.63	309.20	0.00	0.00
1990.09.17	0.00	0.00	0.14	80.90	0.28	90.81	0.00	0.00
Gretna clay:								
1988.05.07	0.02	13.41	0.29	235.43	0.03	57.71	0.61	534.25
1988.07.05	0.03	23.46	0.04	9.25	0.03	20.20	0.02	10.31
1988.07.06	0.05	112.87	0.14	472.71	0.36	935.89	1.73	1697.15
1988.09.11	0.02	88.02	0.04	89.08	0.14	203.51	0.03	238.07
1989.06.06	0.00	0.00	0.03	31.96	0.02	69.01	0.00	0.00
1989.06.12	0.00	0.00	0.05	112.00	0.04	81.87	0.04	29.39
1989.08.03	0.02	20.12	0.03	47.15	0.12	93.63	0.32	181.76
1989.08.25	0.00	0.00	0.00	0.00	0.19	63.13	0.17	68.98
1989.09.10	0.00	0.00	0.03	29.72	0.12	448.72	0.17	460.15
1990.05.15	0.02	11.90	0.02	52.79	0.02	173.62	0.02	163.21
1990.05.21	0.05	39.24	0.30	385.41	0.89	739.64	1.46	491.94
1990.06.01	0.00	0.00	4.63	9691.54	3.62	2685.29	5.43	3141.10
1990.06.08	0.02	13.41	0.10	108.75	0.06	112.85	0.07	88.15
1990.06.11	0.06	346.83	4.74	3918.66	1.04	1459.30	4.86	3160.89
1990.06.17	0.00	0.00	0.36	373.68	0.59	386.14	0.48	257.15
1990.06.19	0.03	101.13	1.00	529.26	0.56	712.72	0.50	899.89
1990.07.02	0.00	0.00	0.30	133.61	2.05	882.30	1.29	906.13
1990.07.06	0.00	0.00	0.94	513.14	0.25	123.85	0.50	216.00
1990.08.22	0.00	0.00	0.01	6.34	0.02	13.77	0.02	71.03

Table 4.4b Runoff Data from Ryerson SCL and Carroll CL in 1988-1990.

Date of Rainfall	Alfalfa		Wheat (Con.Till)		Corn		Summerfallow		Wheat (Min.Till)	
	Max Flow Rate	Tot Runoff Volume	Max Flow Rate	Tot Runoff Volume	Max Flow Rate	Tot Runoff Volume	Max Flow Rate	Tot Runoff Volume	Max Flow Rate	Tot Runoff Volume
	$L\ s^{-1}$	L	$L\ s^{-1}$	L	$L\ s^{-1}$	L	$L\ s^{-1}$	L	$L\ s^{-1}$	L
Ryerson sandy clay loam:										
1988.06.15	0.01	23.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988.07.06	0.16	55.92	3.36	1299.31	2.17	699.56	3.00	662.25	6.16	1410.31
1988.07.12	0.03	7.08	1.31	215.56	1.04	374.01	1.71	672.75	0.66	146.47
1988.09.10	0.01	3.26	0.01	18.96	0.46	403.86	0.00	0.00	0.00	0.00
1988.09.18	0.01	10.22	0.00	0.00	0.14	583.88	0.00	0.00	0.00	0.00
1989.06.28	0.16	46.64	0.49	201.08	0.41	282.42	0.36	308.45	0.27	145.26
1989.08.11	0.06	19.30	0.74	159.13	0.61	379.13	0.58	255.76	0.62	234.33
1989.09.03	0.02	15.18	0.01	14.22	0.23	163.85	0.00	0.00	0.00	0.00
1990.05.15	0.02	6.47	0.11	30.41	0.14	35.14	0.10	38.12	0.12	44.20
1990.06.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990.06.07	0.00	0.00	0.00	0.00	0.19	62.31	0.00	0.00	0.00	0.00
1990.06.16	0.00	0.81	3.22	3451.35	2.66	3749.23	0.76	1250.39	3.37	2822.00
1990.06.19	0.00	0.00	0.32	97.63	0.01	3.38	0.02	6.15	0.01	0.00
1990.07.01	0.00	0.00	0.00	0.00	0.57	198.54	0.17	92.34	0.00	0.00
1990.07.03	0.00	0.00	1.93	1276.71	1.98	1064.92	2.50	1217.23	2.25	1105.11
1990.08.22	0.00	0.00	0.13	45.45	0.71	198.04	0.00	0.00	0.08	30.96
1990.09.17	0.00	0.00	0.01	6.48	0.04	16.01	0.00	0.00	0.03	13.70
Carroll clay loam:										
1988.05.07	4.72	729.09	2.24	360.93	2.24	244.03	2.49	381.57	0.43	64.58
1988.06.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988.07.06	1.11	735.40	2.18	3121.56	4.03	3951.29	2.83	2753.73	2.11	2656.15
1988.07.13	0.82	580.31	2.17	1911.16	5.26	2332.02	3.80	2974.16	2.69	1834.43
1988.08.18	0.00	0.00	0.06	12.43	0.13	88.60	0.00	0.00	0.00	0.00
1988.09.10	0.00	0.00	0.00	0.00	0.05	72.32	0.00	0.00	0.00	0.00
1988.09.18	0.00	0.00	0.00	0.00	0.05	105.60	0.00	0.00	0.00	0.00
1990.05.15	0.12	96.25	0.02	17.37	0.24	215.47	0.00	0.00	0.00	0.00
1990.06.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1990.06.17	0.00	0.00	0.26	150.42	0.54	413.19	0.02	5.05	0.41	278.38
1990.06.19	0.00	0.00	0.00	0.00	0.11	42.70	0.01	0.94	0.00	0.00
1990.07.03	0.06	40.41	3.61	960.71	10.68	1738.90	2.94	898.73	2.98	805.28
1990.07.06	0.12	45.27	2.77	664.22	0.07	24.99	0.22	51.20	2.61	533.06
1990.08.01	0.05	24.84	0.20	54.09	0.40	130.37	0.36	86.47	0.00	0.00
1990.08.18	0.02	78.48	0.00	3.59	0.05	15.93	0.00	0.00	0.00	0.00

Table 4.5 Antecedent conditions and soil loss in 1988-1990.

Date of Storm	Antecedent moisture (by mass)				Ground cover			Soil loss			
	Alfalfa	Corn	Wheat	Fallow	Alfalfa	Corn	Wheat	Alfalfa	Corn	Wheat	Fallow
	%							t ha^{-1}			
Leary sandy loam:											
1988.06.01	4.4	10.6	9.0	9.7	97	4	41	0.00	0.12	0.46	0.20
1988.07.05	3.0	7.2	3.6	10.2	97	43	70	0.00	0.02	0.52	0.05
1988.07.12	10.4	13.4	11.1	13.6	98	46	70	0.00	0.37	0.72	3.70
1988.09.11	2.1	3.7	2.9	6.3	96	59	49	0.00	0.06	0.02	0.01
						1988 Total		0.00	0.57	1.72	3.96
1989.06.06	4.5	8.2	7.8	10.1	100	17	59	0.00	0.04	0.04	0.03
1989.06.12	11.9	14.1	14.0	14.2	98	16	62	0.00	0.02	0.01	0.01
1989.07.14	5.1	8.0	5.9	9.6	99	47	81	0.02	0.05	0.08	0.05
1989.08.03	3.8	4.4	3.0	11.2	91	55	77	0.12	1.38	0.45	4.27
1989.08.17	6.3	8.2	9.7	9.2	94	64	67	0.00	0.37	0.21	0.49
1989.09.10	6.7	9.1	11.4	11.4	96	53	67	0.00	0.12	0.03	0.49
						1989 Total		0.14	1.98	2.54	9.30
1990.06.01	6.4	11.9	10.3	10.5	96	6	1	0.03	5.62	2.71	0.45
1990.06.08	11.1	13.2	12.0	12.2	96	4	6	0.01	4.21	0.91	0.47
1990.06.11	13.5	14.0	13.5	13.7	97	6	26	0.00	8.86	3.34	1.07
1990.06.18	11.1	12.0	11.4	11.8	99	12	34	0.00	2.11	0.65	6.10
1990.06.19	13.5	14.0	13.5	13.7	99	12	34	0.00	32.81	9.62	23.67
1990.07.02	9.6	10.7	8.1	10.6	97	45	68	0.00	----^{1}	14.11	5.89^{2}
1990.07.06	13.4	11.6	9.6	11.7	97	51	64	0.00	----^{1}	16.19	----^{1}
1990.07.28	5.6	7.4	5.0	9.6	99	78	78	0.00	4.39	2.90	2.39
1990.08.01	7.6	7.3	6.1	9.7	98	79	78	0.00	8.20	6.22	17.94
1990.08.22	5.0	7.3	5.7	10.4	99	78	78	0.00	1.70	1.32	0.03
1990.09.17	4.9	4.7	6.4	9.1	92	79	43	0.00	0.11	0.06	0.02
						1990 Total		0.18	69.99	60.57	67.33
Gretna clay:											
1988.05.07	18.2	22.3	24.9	26.5	42	5	28	0.00	0.26	0.70	1.49
1988.07.05	9.9	12.9	14.2	20.4	66	30	58	0.01	0.06	0.01	0.07
1988.07.06	25.5	24.5	20.9	27.0	66	30	54	0.08	10.27	10.76	13.68
1988.09.11	10.9	12.7	13.3	14.6	56	8	32	0.01	0.13	0.05	0.09
						1988 Total		0.10	10.72	11.52	15.33
1989.06.12	19.8	27.4	28.5	27.0	74	6	17	0.00	0.15	0.13	0.16
1989.08.03	10.1	15.1	11.2	20.5	74	27	50	0.00	0.57	0.57	5.98
1989.08.25	13.5	16.8	15.6	19.0	76	27	37	0.00	0.25	0.00	0.18
1989.09.10	15.4	18.4	16.0	22.1	60	26	37	0.00	0.18	0.13	5.97
						1989 Total		0.00	1.15	0.83	12.29
1990.05.14	24.0	25.6	26.2	24.6	56	-	--	0.00	0.06	0.04	0.06
1990.05.20	30.6	31.2	34.5	29.4	66	-	--	0.00	11.69	0.77	15.48
1990.06.01	25.9	24.8	26.7	24.3	89	0	0	0.32	98.88	21.33	51.31
1990.06.08	25.9	26.8	26.6	25.0	90	2	2	0.00	0.72	0.08	0.31
1990.06.11	25.9	26.8	26.6	25.0	91	2	9	0.42	58.66	67.80	100.29
1990.06.17	27.4	26.7	26.0	25.5	92	2	14	0.00	8.24	0.91	6.84
1990.06.19	27.4	26.7	26.0	25.5	95	2	17	0.00	8.54	5.30	9.27
1990.07.02	18.4	21.8	23.6	19.0	99	21	62	0.00	4.83	0.64	13.94
1990.07.06	21.4	23.1	21.0	22.7	99	23	62	0.00	3.51	4.99	0.28
1990.08.22	11.6	13.4	12.3	16.8	98	54	85	0.00	0.25	0.00	0.03
						1990 Total		0.74	195.38	101.86	197.81

1. Sample lost because of lack of drainage in sampler.
2. Entire event not sampled because of inadequate drainage from sampling area.

Table 4.5 continued. Antecedent conditions and soil loss in 1988-1990.

Date of Storm	Antecedent moisture (by mass)					Ground cover				Soil loss				
	Alfalfa	Corn	Wheat CT	Fallow	Wheat MT	Alfalfa	Corn	Wheat CT	Wheat MT	Alfalfa	Corn	Wheat CT	Fallow	Wheat MT
	%									t ha^{-1}				
Ryerson sandy clay loam:														
1988.06.15	9.5	16.5	11.5	15.8	10.6	94	23	55	51	0.01	0.07	0.06	0.06	0.06
1988.07.06	7.3	9.8	12.0	16.9	8.8	98	39	76	66	0.12	5.16	1.82	4.17	3.02
1988.07.12	10.9	12.5	11.1	18.8	11.0	96	42	76	72	0.02	2.68	0.34	0.95[1]	0.53
1988.09.10	7.6	8.5	6.5	7.7	8.8	95	8	51	35	0.00	0.69	0.01	0.06	0.01
1988.09.18	20.4	19.4	20.1	20.7	20.2	95	8	51	35	0.00	0.81	0.01	0.01	0.01
						1988 Total				0.15	9.49	2.24	5.25	3.63
1989.06.28	11.1	20.4	15.0	21.8	14.5	98	18	60	69	0.02	1.46	0.21	1.89	0.14
1989.08.11	7.9	10.7	7.9	16.3	8.5	97	55	64	60	0.00	4.00	0.35	1.21	0.18
1989.09.03	12.1	15.0	15.4	17.0	17.0	98	41	48	52	0.04	0.32	0.02	0.03	0.02
						1989 Total				0.06	5.78	0.58	3.13	0.34
1990.05.15	----	----	----	----	----	--	--	--	--	0.01	0.03	0.02	0.02	0.01
1990.06.01	22.1	21.5	19.6	19.9	24.7	98	5	20	30	0.01	0.03	0.04	0.02	0.04
1990.06.07	20.3	22.9	22.7	23.6	27.1	98	5	26	36	0.00	0.05	0.03	0.03	0.03
1990.06.16	15.5	22.4	20.4	22.5	22.5	98	7	37	61	0.04	12.54	4.67	4.55	5.52
1990.06.19	27.0	27.2	25.0	27.0	29.9	98	9	58	74	0.01	1.41	0.53	0.23	0.16
1990.07.01	17.4	22.2	18.7	21.6	20.2	99	16	71	82	0.00	1.39	0.68	0.47	0.16
1990.07.03	28.3	26.6	23.0	26.2	26.2	99	20	77	85	0.00	4.44	1.15	4.10	1.09
1990.08.22	13.7	12.6	13.2	20.4	13.2	99	64	88	90	0.00	0.73	0.24	0.10	0.05
1990.09.17	9.5	13.1	15.3	16.6	17.1	90	61	36	51	0.00	0.07	0.03	0.06	0.04
						1990 Total				0.07	20.66	7.39	9.58	7.10
Carroll clay loam:														
1988.05.07	27.0	24.6	24.4	25.6	23.5	68	6	23	34	0.02	0.09	0.07	0.07	0.07
1988.06.14	10.4	19.8	13.1	19.2	13.5	92	6	38	36	0.00	0.00	0.00	0.00	0.00
1988.07.06[2]	16.7	22.0	16.4	17.4	17.0	93	20	63	70	----	----	----	----	----
1988.07.13	27.9	26.4	24.1	25.8	26.0	87	21	60	70	0.64	22.50	0.45	6.59	0.13
1988.08.12	12.5	16.6	12.4	20.1	16.4	97	47	73	75	0.06	0.46	0.12	0.15	0.08
1988.09.10	10.9	14.6	12.8	20.7	12.8	95	28	31	42	0.02	0.12	0.05	0.07	0.04
1988.09.18	24.7	25.2	24.6	27.4	23.1	92	22	31	42	0.01	0.27	0.02	0.04	0.03
						1988 Total				0.75	23.44	0.71	6.92	0.35
1990.05.15	----	----	----	----	----	--	--	--	--	0.09	0.12	0.09	0.11	0.06
1990.06.07	18.3	27.2	26.2	27.5	25.2	98	8	24	36	0.01	0.01	0.01	0.01	0.01
1990.06.17	16.7	24.4	22.6	25.2	24.4	99	6	44	50	0.10	3.88	0.57	0.06	0.29
1990.06.19	27.4	27.4	27.4	27.4	27.4	99	8	50	56	0.01	0.02	0.01	0.01	0.01
1990.07.03	14.5	23.4	19.5	23.7	18.0	98	19	72	77	0.05	13.16	2.06	10.37	1.81
1990.07.06	27.4	27.4	27.4	27.4	27.4	98	24	75	77	0.01	1.51	0.19	0.17	0.28
1990.08.01	13.8	18.0	13.8	21.8	12.7	95	63	80	77	0.02	2.36	0.13	0.19	0.08
1990.08.18	14.1	16.3	15.1	24.3	14.5	96	66	83	84	0.02	0.31	0.10	0.12	0.04
						1990 Total				0.31	21.37	3.16	11.04	2.58

1. System failed to sample complete event for fallow.
2. System failed because of lightening strike at the beginning of storm.

(L) from each treatment were as follows:

	July 6	June 28
alfalfa	56	47
corn	700	282
fallow	662	308
wheat (conventional till)	1299	201
wheat (minimum till)	1410	145

Soil losses (t ha^{-1}) from these events for each treatment were as follows:

	July 6	June 28
alfalfa	0.12	0.02
corn	5.16	1.46
fallow	4.17	1.89
wheat (conventional till)	1.82	0.21
wheat (minimum till)	3.02	0.14

At the Carroll site, there were two large rainstorms, on July 6, 1988 (95.8 mm, I_{30} = 65 mm h^{-1}) and on May 15, 1990 (94.8 mm, I_{30} = 11.2 MJ mm h^{-1}). The higher intensity rainfall yielded runoff volumes which surpassed by far the lower intensity event even though the ground cover was more substantial on the wheat and corn plots during the July 6th storm. There was no runoff from fallow and MT wheat plots in the May 15, 1990 event, while runoff from the July 6, 1988 event were 2754 L and 2656 L, respectively. Runoff from the alfalfa, wheat and corn treatments increased from 96 L, 17 L and 215 L to 735 L, 3122 L and 3951 L, respectively. A lightning strike inactivated the sampling system on the July 6 1988 event, so a comparison of soil loss could not be made. Comparing the May 15 1990 event to a smaller event with more intense rainfall on July 3 1990 (43.4 mm, I_{30} = 68.8 mm h^{-1}, EI = 189), soil loss from the fallow plot from the latter event was nearly 2 orders of magnitude greater.

4.3.2 Effects of soil antecedent moisture

The soil antecedent moisture content affected the amount of surface water which ran off the plots. The higher the antecedent moisture at the time of a rainfall event the greater was the volume of runoff. Also, soil loss from soil with higher antecedent moisture was greater than from a soil with lower moisture content.

As an example, on the Leary SL, a 27.6 mm storm on June 18, 1990 with an EI of 181 MJ mm ha^{-1} h^{-1} produced runoff of only 159 L from fallow. The next day moisture levels were 2% by mass higher in the upper 15 cm, and an 11.6 mm event with an erosivity value of 41 MJ mm ha^{-1} h^{-1} produced much greater runoff (2958 L). A similar trend was noted in wheat, corn and alfalfa treatments from these events. Soil loss from the fallow plot on the June 18 event was 6.10 t ha^{-1}, which is equivalent to 0.03 t ha^{-1} per erosivity unit. The soil loss from the fallow plot during the June 19 event was 23.67 t ha^{-1} or 0.57 t ha^{-1} per erosive unit. The difference was even more dramatic on the wheat and corn treatments. Losses from these plots increased from 0.65 and 2.11 t ha^{-1} to 9.62 and 32.81 t ha^{-1}, respectively. This was equivalent to a 66 fold increase on a per erosive unit basis.

When moisture levels were near saturation, surface runoff and soil loss occurred from storms which would normally be considered "non-erosive". Two events which did not meet the "erosive storm" criteria set by Wischmeier and Smith (1978) were sampled from the Gretna site. The first was on August 25, 1988. This rainfall event was 10.8 mm with an EI of 41 MJ mm ha^{-1} h^{-1}. The antecedent moisture level was 57% of saturation, and runoff from fallow was 69 L. Soil losses from both corn (0.25 t ha^{-1})

and fallow (0.18 t ha^{-1}) occurred. By comparison, on June 19 1990, rainfall was 10.6 mm and the EI was 23 MJ mm ha^{-1} h^{-1}. The antecedent moisture was 76% of saturation and surface runoff from the fallow plot was 900 L. Soil losses were observed from wheat (5.30 t ha^{-1}), corn (8.54 t ha^{-1}) and fallow (9.27 t ha^{-1}) treatments. The losses per erosive unit from the fallow treatment were 0.40 t ha^{-1}.

Conversely, if antecedent moisture levels were very low, rainfall events which would be expected to produce substantial runoff produced none. An example of this was on August 22, 1990 on the Gretna C. Moisture content on fallow was 50% of saturation. The rainfall was 22.8 mm with an erosivity index of 204 MJ mm ha^{-1} h^{-1}. The runoff from the fallow plot was only 71 L and soil loss was 0.03 t ha^{-1} or 0.0001 t ha^{-1} per erosive unit.

When antecedent soil moisture content is low, infiltration rate is high and the soil is more capable of accepting rainfall without yielding runoff. As the pore spaces fill up with water and approach saturation, the infiltration rate decreases, ponding increases and runoff is initiated. With larger rainfall events, runoff is delayed until the water content in the surface layer approaches saturation and the rainfall intensity surpasses the infiltration rate. Two large events demonstrate this on the Carroll CL. On July 6, 1988, antecedent moisture on fallow was 47% of saturation. The rainfall event was very large (95.8 mm) and intense (I_{30} = 65 mm h^{-1}). Runoff from the fallow plot was 2753 L. On July 13, 1988, one week later, a considerably smaller rainfall event took place (45.7 mm, I_{30} = 45.2 mm h^{-1}). Antecedent moisture was 71% of saturation and runoff from the fallow plot was 2974 L. A greater proportion of the rainfall was taken into the soil from the first storm even though it was more intense than the second storm. This indicates that the infiltration rate was substantially reduced in the latter event because of higher initial moisture content.

4.3.3 Effects of crop cover

As the crop canopy develops, the potential for soil loss should diminish because of a reduction in the erosive impact of the raindrops. This is difficult to illustrate since the effects of cropping stages tend to be confounded by differences in moisture contents. A comparison of average soil loss per erosive unit at various cropping stages is given in Table 4.6.

On the Gretna C there were no significant differences in mean soil loss per erosive unit (K^* value) among the different crop stages on either corn or wheat treatments. However, both crops show a trend of decreasing K^* as the crop cover increased from seed bed to maturity.

The Leary SL did not show any significant differences in mean soil loss per erosive unit in the corn treatment. In the wheat treatment, the lowest occurred were when the crop was in stage 4. The highest losses were during the seedbed and early growth stages. The K^* value was significantly lower in seedbed and stage 4 than stage 1. The relatively low soil loss in the seedbed stage is contrary to that expected from the literature, e.g. Burwell et al (1975), who suggest that the most erosive period is after seeding.

Table 4.6 Comparison of mean soil loss per erosive unit for crop stages 1988 - 1990.

[1]Crop Stage		Soil Type			
		Leary SL	Gretna C	Ryerson SCL	Carroll CL
		t h MJ^{-1} mm^{-1}			
Corn					
	W	-----	0.1087a	0.0006 b	0.0005 b
	SB	0.0767a[2]	0.1255a	0.0103ab	0.0047ab
	1	0.1167a	0.0225a	0.0190ab	0.0311a
	2	0.0023a	-----	0.0231a	0.0120ab
	3	0.0329a	0.0012a	-----	-----
	4	0.0014a	0.0008a	0.0100ab	0.0035ab
LSD		0.2348	0.1181	0.0188	0.0278
Wheat					
	W	-----	0.0074a	0.0004 b	0.0004a
	SB	0.0077 b	0.0891a	-----	-----
	1	0.0835a	0.0660a	0.0029ab	0.0019a
	2	0.0219ab	0.0243a	0.0056a	0.0030a
	3	0.0194ab	0.0000a	0.0063a	0.0024a
	4	0.0014 b	0.0009a	0.0002 b	0.0005a
LSD		0.0623	0.1148	0.0041	0.0045
MT wheat					
	W			0.0002a	0.0003a
	SB			-----	-----
	1			0.0020a	0.0005a
	2			0.0047a	0.0011a
	3			0.0040a	0.0031a
	4			0.0003a	0.0005a
LSD				0.0045	0.0037

1. Crop stages are described under the modified system in Table 3.1.
2. Means followed by the same letter did not significantly differ (p=0.05).

On the Ryerson SCL, the K^* value was significantly lower prior to seeding than at stage 2 in both conventional till wheat and corn treatments on the Ryerson SCL. K^* at stage 4 was also significantly lower and at stage 3 was significantly higher in the conventional till wheat treatment. There was no significantly difference in K^* value among growth stages in minimum till wheat treatment although the trend was similar to conventional till wheat and corn treatments.

The K^* value prior to seeding was significantly lower than in stage 1 in the corn treatment on the Carroll CL. There were no significant differences among stages on either wheat plot.

There did not appear to be any consistent trends in K^* value to indicate that increased canopy cover in row crops or cereal crops under the tillage systems used reduced erosion.

4.3.4 Effects of crop type

On the Gretna C and Leary SL, sediment losses followed the order:

fallow > corn > wheat > alfalfa.

This is the same order as White and Williamson (1973) found in South Dakota. Three year averages (t ha^{-1} yr^{-1}) for these two sites were as follows:

	Leary SL	Gretna C
alfalfa	0.1	0.3
wheat	21.6	38.1
corn	24.2	69.1
fallow	26.8	75.1

All average losses from treatments were greater than the tolerable soil loss limit of 11 t ha^{-1} yr^{-1} except for both alfalfa plots which were well below this limit. Two of the three years were drier than normal. Also, the averages for fallow and corn on the Leary SL were underestimated because 2 major events were lost from each.

Both the Carroll CL and Ryerson SCL produced results different from those at the sites above. Soil losses from corn exceeded that from fallow. Differences between minimum till wheat and conventional till wheat were very small. Average soil losses (t ha^{-1} yr^{-1}) from these sites for each cropping treatment were:

	Ryerson SCL	Carroll CL
alfalfa	0.1	0.5
MT wheat	3.7	1.5
CT wheat	3.4	1.9
fallow	6.0	9.0
corn	12.0	22.4

The average annual erosivity on the Ryerson SCL was 749 MJ mm ha^{-1} h^{-1} which is below average and 1070 MJ mm ha^{-1} h^{-1} on the Carroll CL, average for southern Manitoba. Losses from corn treatments on both sites were above the tolerable limit of 11 t ha^{-1} yr^{-1}. Due to equipment failure, the losses on the Carroll CL did not include the largest event over the 2 years. The loss from the fallow treatment would have in all probability exceeded the tolerable loss limit had the July 6, 1988 event been sampled.

On all sites, alfalfa was effective in reducing and almost eliminating erosion. The relatively large loss from the alfalfa plot on the Carroll CL may have been a result of ground squirrel activity. Row crops did very little to reduce erosion and even enhanced erosion in some cases by providing channels for surface runoff. Cereal crops reduced erosion compared to row crops and fallow, but did not always reduce erosion below the tolerable limit.

4.3.5 Effects of soil texture

Over the three year period of 1988 to 1990 soil losses from the fallow treatment on the four experimental sites show that the finer textured Gretna C was the most erosive soil type and was significantly more erosive than the Ryerson SCL and Carroll CL (Table 4.7). This agrees with results reported by Hoyt et al. (1977), who found that increasing fineness of texture increased soil losses. The Leary SL did not fall into this pattern since it had the coarsest texture and was the second most erosive.

Table 4.7 Comparison of mean soil loss (t ha^{-1}) per erosive unit (MJ mm ha^{-1} h^{-1}) (K value) among soil textures for fallow (1988 - 1990).

Soil Type	K value
	t h MJ^{-1} mm^{-1}
Gretna C	0.090a[1]
Leary SL	0.044ab
Ryerson SCL	0.007 b
Carroll CL	0.006 b

1. Means followed by the same letter did not significantly differ.

4.4 Total nitrogen in the sediment fraction

The sediment fraction accounted for greater than 99% of total nitrogen losses in surface runoff on all sites and on all crop types from 1988 - 1990. The influence of rainfall characteristics, management inputs, crop cover and type and soil texture are discussed with respect to nitrogen concentration and losses in sediment.

4.4.1 Magnitude of losses

Total nitrogen concentrations in the sediment fraction of runoff for each sampling event are found in Table 4.8. Table 4.9 contains total nitrogen losses for each sampling event. Average annual losses of total nitrogen losses for each sampling event. Average annual losses of total nitrogen (kg ha^{-1}) were as follows:

	Leary SL	Gretna C	Ryerson SCL	Carroll CL
Alfalfa	0.0	0.8	0.3	1.8
Corn	7.8	159.5	27.9	58.8
CT Wheat	5.3	100.3	8.7	5.2
Fallow	7.2	162.0	15.4	23.9
MT Wheat	---	---	10.1	3.9

4.4.2 Effects of rainfall intensity and patterns

Total losses of total nitrogen vary from year to year. On the Ryerson SCL, Gretna C and Leary SL, total nitrogen losses were greatest in 1990, the year of greatest rainfall on these sites. Total nitrogen losses on the Gretna C in 1990 were 95% (corn), 86% (fallow), 90% (wheat) and 87% (alfalfa) of the total three year loss. A similar pattern was observed on the Leary SL. Losses in 1990 accounted for 96% (corn), 83% (fallow) and 95% (wheat) of the three year totals.

A few of rainfall events were responsible for a large proportion of total nitrogen losses on all the sites. Two large rainfall events on the Gretna C on June 1 (93.6 mm) and June 11 (32.8 mm) accounted for 83% of the total nitrogen losses from the corn treatment in 1990 and 79% of the total losses over three years. Similarly, these events accounted for 75% of the seasonal losses from wheat and fallow treatments.

On the Carroll CL in each year, there was one event which accounted for most of the total nitrogen losses in the respective years. Losses of

Table 4.8 Total nitrogen concentrations in runoff sediment 1988 - 1990.

Date	Alfalfa	Corn	Fallow	Wheat
	$\mu g\ g^{-1}$			
Leary sandy loam:				
1988.06.01	----	466	422	369
1988.07.05	----	571	478	337
1988.07.12	----	425	369	225
1988.09.11	----	710	638	638
1989.06.06	----	699	597	585
1989.06.12	----	969	641	547
1989.07.14	1036	307	278	565
1989.08.03	628	425	431	303
1989.08.17	----	459	332	386
1989.09.10	----	436	426	556
1990.06.01	786	553	762	398
1990.06.08	435	600	855	249
1990.06.11	----	302	354	287
1990.06.18	----	304	394	300
1990.06.19	----	262	246	277
1990.07.02	----	---[1]	277	215
1990.07.06	----	---[1]	335	232
1990.07.28	----	415	354	330
1990.08.01	----	294	338	270
1990.08.22	----	333	586	325
1990.09.17	----	529	510	408
Gretna clay:				
1988.05.07	----	2214	2448	2731
1988.07.05	3884	2719	2684	2930
1988.07.06	3122	1869	2186	2283
1988.09.11	3954	2809	2597	2842
1989.06.12	----	2381	2702	2662
1989.08.03	----	2156	2563	2204
1989.08.25	----	2622	2141	----
1989.09.10	----	3299	2959	2515
1990.05.14	----	2853	2501	2356
1990.05.20	----	2004	2038	2997
1990.06.01	3550	2862	2233	1975
1990.06.08	2534	2571	2053	2681
1990.06.11	----	1633	1998	2384
1990.06.17	----	2228	2734	3300
1990.06.19	----	1840	2210	2592
1990.07.02	----	1759	2227	2944
1990.07.06	----	2292	2302	3754
1990.08.22	----	2337	2241	----

1. No sample due to a drainage problem.

Table 4.8 continued. Total nitrogen concentrations in runoff sediment 1988 - 1990.

Date	Alfalfa	Corn	Fallow	Wheat	
				Con-till	Min-till
			$\mu g\ g^{-1}$		
Ryerson sandy clay loam:					
1988.06.15	4004	3043	3001	3648	3633
1988.07.06	3433	2271	2445	2517	2708
1988.07.12	3227	2650	2304	3692	3041
1988.09.10	----	2793	3227	3527	3927
1988.09.18	----	2677	3213	3457	4033
1989.06.28	4586	2782	2519	3324	3129
1989.08.11	----	2445	1938	3457	3675
1989.09.03	3466	3015	3421	3692	3971
1990.05.15	3496	2171	3037	3485	3991
1990.06.01	3444	2482	3018	3713	3826
1990.06.07	----	2225	2942	3550	3978
1990.06.16	3236	1989	2202	2248	2547
1990.06.19	2524	2500	3263	3126	3052
1990.07.01	----	2449	2889	3056	3695
1990.07.03	----	2679	3288	2395	3055
1990.08.22	----	2300	2637	2655	3293
1990.09.17	----	2456	3355	3871	3429
Carroll clay loam:					
1988.05.07	3171	3075	3135	2991	2820
1988.06.14	----	----	----	----	----
1988.07.06[1]	----	----	----	----	----
1988.07.13	3289	2782	2717	2704	3342
1988.08.18	3401	2693	2899	2750	2913
1988.09.10	3432	3250	3159	3029	3594
1988.09.18	3393	3172	3246	3185	3095
1990.05.15	4012	2683	2982	2801	2768
1990.06.07	4098	3601	3023	3237	3055
1990.06.17	3593	2365	3014	2853	2777
1990.06.19	3985	2709	3025	2750	2961
1990.07.03	3355	2373	2597	2605	2741
1990.07.06	3736	2645	2858	2685	2756
1990.08.01	3351	2759	2827	2783	3165
1990.08.18	3978	2938	2706	3248	2750
1990.08.27	----	----	----	----	----

1. System failed because of lightening strike prior to rainfall.

Table 4.9 Total nitrogen losses in runoff sediment 1988 - 1990.

Date	Alfalfa	Corn	Fallow	Wheat
	$kg\ ha^{-1}$			
Leary sandy loam:				
1988.06.01	----	0.06	0.08	0.17
1988.07.05	----	0.01	0.02	0.18
1988.07.12	----	0.16	1.37	0.16
1988.09.11	----	0.04	0.01	0.01
Total 1988	0.00	0.27	1.48	0.52
1989.06.06	----	0.03	0.02	0.02
1989.06.12	----	0.02	0.01	0.01
1989.07.14	0.02	0.02	0.01	0.05
1989.08.03	0.08	0.59	1.84	0.14
1989.08.17	----	0.02	0.16	0.08
1989.09.10	----	0.05	0.21	0.02
Total 1989	0.10	0.73	2.25	0.32
1990.06.01	0.02	3.11	0.34	1.08
1990.06.08	0.00	2.53	0.40	0.23
1990.06.11	----	2.68	0.38	0.96
1990.06.18	----	0.64	2.40	0.20
1990.06.19	----	8.60	5.82	2.66
1990.07.02	----	----[1]	1.63[1]	3.03
1990.07.06	----	----[1]	----[1]	3.76
1990.07.28	----	1.82	0.85	0.96
1990.08.01	----	2.41	6.06	1.68
1990.08.22	----	0.57	0.02	0.43
1990.09.17	----	0.06	0.01	0.02
Total 1990	0.02	22.42	17.91	15.01
Total 1988-90	0.12	23.42	21.64	15.85
Gretna clay:				
1988.05.07	----	0.58	3.65	1.91
1988.07.05	0.04	0.16	0.19	0.03
1988.07.06	0.25	19.19	29.90	24.57
1988.09.11	0.04	0.37	0.23	0.14
Total 1988	0.33	20.30	33.97	26.65
1989.06.12	----	0.36	0.43	0.35
1989.08.03	----	1.23	15.33	1.26
1989.08.25	----	0.66	0.39	----
1989.09.10	----	0.59	17.67	0.33
Total 1989	0.00	2.84	33.82	1.94
1990.05.14	----	0.17	0.15	0.09
1990.05.20	----	23.43	31.55	2.31
1990.06.01	1.14	282.99	114.58	42.13
1990.06.08	1.06	1.85	0.64	0.21
1990.06.11	----	95.79	200.38	161.64
1990.06.17	----	18.36	18.70	3.00
1990.06.19	----	15.71	20.49	13.74
1990.07.02	----	8.50	31.04	1.88
1990.07.06	----	8.04	0.64	18.73
1990.08.22	----	0.58	0.07	0.00
Total 1990	2.20	455.42	418.24	272.32
Total 1988-90	2.53	478.56	486.03	300.91

1. No sample due to a drainage problem.

Table 4.9 continued. Total nitrogen in runoff sediment 1988 - 1990.

Date	Alfalfa	Corn	Fallow	Wheat	
				Con-till	Min-till
	kg ha^{-1}				
Ryerson sandy clay loam:					
1988.06.15	0.04	0.21	0.18	0.22	0.22
1988.07.06	0.41	11.72	10.20	4.58	8.18
1988.07.12	0.06	7.10	2.19[1]	1.26	1.61
1988.09.10	----	1.93	0.19	0.04	0.04
1988.09.18	----	2.17	0.03	0.03	0.04
Total 1988	0.51	23.13	12.79	6.13	10.09
1989.06.28	0.09	4.06	4.75	0.70	0.44
1989.08.11	----	9.78	2.34	1.21	0.66
1989.09.03	0.14	0.96	0.10	0.07	0.08
Total 1989	0.23	14.80	7.19	1.98	1.18
1990.05.15	0.03	0.07	0.06	0.07	0.04
1990.06.01	0.03	0.07	0.06	0.15	0.15
1990.06.07	----	0.11	0.09	0.11	0.12
1990.06.16	0.13	24.94	10.02	10.50	14.23
1990.06.19	0.03	3.53	0.75	1.66	0.54
1990.07.01	----	3.40	1.36	2.08	0.57
1990.07.03	----	11.89	13.48	2.75	2.94
1990.08.22	----	1.70	0.26	0.64	0.20
1990.09.17	----	0.17	0.20	0.12	0.15
Total 1990	0.22	45.88	26.28	18.08	18.94
Total 1988-90	0.96	83.81	46.26	26.19	30.21
Carroll clay loam:					
1988.05.07	0.06	0.28	0.22	0.21	0.20
1988.06.14	----	----	----	----	----
1988.07.06[2]	----	----	----	----	----
1988.07.13	2.10	62.60	17.91	1.22	0.43
1988.08.18	0.20	1.24	0.43	0.33	0.23
1988.09.10	0.07	0.39	0.22	0.15	0.14
1988.09.18	0.03	0.86	0.13	0.06	0.09
Total 1988	2.46	65.37	18.91	1.97	1.09
1990.05.15	0.36	0.32	0.33	0.25	0.17
1990.06.07	0.04	0.04	0.03	0.03	0.03
1990.06.17	0.36	9.18	0.18	1.62	0.81
1990.06.19	0.04	0.05	0.03	0.03	0.03
1990.07.03	0.17	31.23	26.93	5.37	4.96
1990.07.06	0.04	3.99	0.49	0.51	0.77
1990.08.01	0.07	6.59	0.54	0.36	0.25
1990.08.18	0.08	0.91	0.32	0.32	0.11
1990.08.27	----	----	----	----	----
Total 1990	1.16	52.31	28.85	8.49	7.13
Total 1988,90	3.52	117.68	47.76	10.46	8.22

1. System failed to sample complete event because of silting on sampler.
2. System failed because of lightening strike prior to rainfall.

total nitrogen from an event on July 13, 1988 were 62.6 kg ha^{-1} (96% of the annual total) from the corn plot and 17.9 kg ha^{-1} (95%) from the fallow plot. Total nitrogen losses from an event on July 3, 1990 were 31.2 kg ha^{-1} (60%) from the corn treatment and 26.9 kg ha^{-1} (93%) from the fallow plot. Combined, these two events accounted for 80% of the total nitrogen lost from the corn treatment and 94% from fallow over the duration of the study.

Table 4.10 shows concentration of nitrogen in surface runoff sediment by time within the growing season. Rainfall events were divided into three periods, 1) before June 16, 2) June 16 to August 15 and 3) August 16 and later. Corn, wheat and fallow treatments showed trends of lower concentrations of nitrogen in runoff sediment in the period mid June to mid August than in either spring or late summer / fall. There were no significant variations in nitrogen concentration with respect to the time of year from alfalfa plots. This result may be due to the small number of samplings. The mid season period was significantly lower than the later season from the corn treatment on all soil types except the Ryerson SCL and lower than the earliest period on the Carroll CL and Leary SL. The Ryerson SCL also showed a trend toward higher mean concentrations in the period 3. Mean concentrations of nitrogen on fallow were significantly lower in period 2 than periods 1 and 3 on the Leary SL and period 3 on the Ryerson SCL. The conventional till wheat treatment showed significantly reduced concentrations in the middle period on all soils but the Gretna C. The minimum till wheat treatment on the Ryerson SCL had significantly higher concentrations of nitrogen in period 1 than in period 2.

The significance of the effects of total rainfall, the duration, 30

Table 4.10 Effect of time of season on concentration of total nitrogen in sediment (1988 - 1990).

Crop/Period[1]	Leary SL	Gretna C	Ryerson SCL	Carroll CL
	$\mu g\ g^{-1}$			
Alfalfa				
1	611a[2]	3042a	3648a	3760a
2	832a	3503a	3401a	3552a
3	---	3954a	3466a	3551a
LSD 0.05	316	1460	778	434
Corn				
1	598a	2360ab	2480a	3120a
2	375 b	2123 b	2471a	2606 b
3	493a	2767a	2648a	3013a
LSD 0.05	151	454	319	362
Fallow				
1	605a	2282a	3000ab	3047a
2	350 b	2415a	2606 b	2840a
3	498a	2485a	3171a	3003a
LSD 0.05	119	322	416	235
CT wheat				
1	406ab	2541a	3599a	3010a
2	305 b	2858a	2977 b	2730 b
3	463a	2679a	3440ab	3053a
LSD 0.05	111	512	486	215
MT wheat				
1			3857a	2881a
2			3113 b	2957a
3			3731ab	3088a
LSD 0.05			374	3540

1. Period 1 = start to June 15.
Period 2 = June 16 to August 15.
Period 3 = August 16 and later.
2. Means within crop for each location followed by the same letter did not differ significantly ($p<0.05$).

minute intensity and erosivity of the rainfall on nitrogen concentration is shown in Table 4.11. There was no significant effect of duration or intensity of rainfall on total nitrogen concentration on alfalfa on any site. Only corn treatments on the Gretna C and Leary SL, conventional

Table 4.11 Correlation coefficients between total nitrogen concentration in sediment and rainfall factors (1988 - 1990).

	I_{30}	Duration	Rainfall Amount	Erosivity Index
		Leary SL		
Alfalfa	0.99	0.77	0.84	0.31
Corn	0.39**	0.41**	0.29*	0.04
Wheat	0.56***	0.16	0.03	0.37*
Fallow	0.21	0.50***	0.28*	0.18
		Gretna C		
Alfalfa	0.80	0.80	0.05	0.72
Corn	0.30*	0.48**	0.33*	0.14
Wheat	0.39*	0.15	0.35*	0.29*
Fallow	0.15	0.19	0.21	0.04
		Ryerson SCL		
Alfalfa	0.18	0.02	0.28	0.11
Corn	0.27	0.06	0.33*	0.23
Wheat	0.56***	0.17	0.29	0.43*
Fallow	0.28*	0.29*	0.17	0.26
MT Wheat	0.62***	0.30*	0.31*	0.76***
		Carroll CL		
Alfalfa	0.27	0.26	0.27	0.07
Corn	0.28	0.22	0.05	0.24
Wheat	0.36*	0.62**	0.04	0.15
Fallow	0.54**	0.31	0.09	0.16
MT Wheat	0.03	0.02	0.17	0.15

1. Denotes level of significance (* = P=0.05), (** = P=0.01), (*** = P=0.001).

till wheat treatment on the Carroll CL and the fallow and minimum till wheat treatments on the Ryerson SCL were nitrogen concentrations significantly influenced by the duration of the rainfall. Chichester (1977) indicated that as the duration of the rainfall event lengthened, the concentration of total nitrogen in sediment decreased. Although this result was observed in this experiment at times, the effect of the duration of rainfall was not statistically significant for most treatments. The total rainfall also significantly influenced total nitrogen concentrations in sediment from corn treatments on all but the Carroll CL. The 30 minute intensity of the rainfall significantly influenced the concentration of nitrogen in runoff on the conventional till wheat treatments on all sites. The erosivity of the event also influenced total nitrogen concentrations on conventional till wheat treatments on all but the Carroll CL. Of all the rainfall characteristics considered, the 30 minute intensity appeared to have the most influence on total nitrogen concentration in sediment.

4.4.3 Effects of management practices

Fertilizer in the form of ammonium nitrate and ammonium sulfate (when needed) was broadcast and incorporated on corn and wheat plots. Ammonium sulfate was broadcast on alfalfa plots.

The nitrogen concentration in sediment following fertilizer application was significantly higher than in the subsequent two months on the Carroll CL, and Leary SL on wheat and corn treatments, on the Gretna C corn treatment and on the Ryerson SCL wheat treatment (Table 4.8). This was in agreement with results reported by Chichester (1977).

Rainfall sampling events on the Leary SL following fertilizer application (9 days after) occurred in 1990 only. The concentration of nitrogen from the wheat plot in the first event was 398 $\mu g\ g^{-1}$ compared to a mean of 260 $\mu g\ g^{-1}$ for the following 6 events. Similarly, in the first two events following fertilizer application from the corn plot, mean concentrations were 577 $\mu g\ g^{-1}$ compared to 327 $\mu g\ g^{-1}$ in the subsequent 4 events. There were only two sampling events from the alfalfa treatment in 1990. For the June 1 event nitrogen concentration was 786 $\mu g\ g^{-1}$, 81%

higher than the June 8 event. It must also be noted that concentrations in sediment from the fallow treatment were higher in the June 1 (762 μg g^{-1}) and June 8 (855 μg g^{-1}) events than the mean concentration of the next seven events (328 μg g^{-1}) even though no fertilizer was applied.

The Gretna C had two years in which a sampling event followed fertilizer application (1988 and 1990). The mean concentration of total nitrogen following application was 2538 μg g^{-1} compared to 2102 μg g^{-1} for the next two months. Concentration of nitrogen from the alfalfa treatment was 40% higher in the June 1 1990 event than the following event. Wheat and fallow treatments showed no statistically significant difference.

On the Ryerson SCL, 1990 was the only year in which an erosion event followed closely fertilizer application (June 1). All treatments showed higher concentrations than subsequent events except fallow treatments, although only the two wheat treatments were statistically significantly higher. The mean concentration of nitrogen in the two sampling events following application was 3632 μg g^{-1} from the conventional till wheat treatment and 3902 μg g^{-1} from the minimum till wheat treatment compared to 2706 μg g^{-1} and 3087 μg g^{-1}, respectively, from subsequent events.

On the Carroll CL both 1988 and 1990 had rainfall events closely following fertilizer application. Concentrations of nitrogen on all treatments except fallow had higher concentrations than those from prior and subsequent events, although only corn and conventional till wheat were significantly higher. Mean sediment concentration following fertilizer application was 3338 μg g^{-1} from the corn treatment and 3114 μg g^{-1} from the wheat treatment compared to a mean of 2575 μg g^{-1} and 2719 μg g^{-1}, respectively, from the subsequent erosion event.

There was only one sampling event on both the Ryerson SCL and the Carroll CL in 1990 on stubble prior to seeding. There were no residue counts available, but deep tillage on the conventional till wheat treatment reduced the residue compared to minimum till wheat treatment. On the Ryerson SCL, concentration of total nitrogen was higher on minimum till wheat treatment than on conventional till wheat treatment (3991 $\mu g\ g^{-1}$ compared to 3485 $\mu g\ g^{-1}$). This was similar to results found by Barisas et al. (1978). The Carroll CL produced a different result. Concentrations from conventional tillage and minimum till wheat treatments were nearly equal. There are too few sampling events to establish a conclusion on the effects of residue on concentration of nitrogen in sediment.

Total nitrogen losses from the sampling events on May 15 1990 on wheat stubble prior to seeding were higher on conventional till wheat treatments than minimum till wheat treatments on both the Ryerson SCL and the Carroll CL. The total nitrogen losses (kg ha^{-1}) were as follows:

	Carroll CL	Ryerson SCL
Conventional till	0.25	0.07
Minimum till	0.17	0.04

These results were as expected (Chichester 1977), but there were not enough sampling events to draw conclusions.

4.4.4 Effects of crop cover

Total nitrogen concentration and total nitrogen loss per erosive unit are shown in Table 4.12. The highest concentrations of nitrogen on both corn and wheat treatments on the Leary SL occurred after harvest and prior to fall tillage. These concentrations were significantly higher

Table 4.12 Comparison of mean total nitrogen concentration in sediment [TN] and total nitrogen loss per erosive unit (TN*) during 6 canopy cover stages.

Crop Stage	Soil Type							
	Leary SL		Gretna C		Ryerson SCL		Carroll CL	
	[TN]	TN*	[TN]	TN*	[TN]	TN*	[TN]	TN*
	$\mu g\ g^{-1}$	$kg\ h\ MJ^{-1}\ mm^{-1}$	$\mu g\ g^{-1}$	$kg\ h\ MJ^{-1}\ mm^{-1}$	$\mu g\ g^{-1}$	$kg\ h\ MJ^{-1}\ mm^{-1}$	$\mu g\ g^{-1}$	$kg\ h\ MJ^{-1}\ mm^{-1}$
Corn								
W	---	------	2429a	0.2182ab	2171 c	0.0014 b	2683a	0.0014 b
SB	480 b[1]	0.0276a	2247a	0.2518a	2299 c	0.0241ab	2849a	0.0122ab
1	505ab	0.0308a	2388a	0.0450ab	2646ab	0.0487ab	----	------
2	440 b	0.0010a	2337a	0.0029 b	2400 bc	0.0559a	2713a	0.0797a
3	393 b	0.0118a	----	------	----	------	2849a	0.0498ab
4	710a	0.0010a	2809a	0.0023 b	2828a	0.0276ab	3211a	0.0111ab
LSD	214	0.0621	566	0.2191	283	0.0467	503	0.0718
Wheat								
W	---	------	2677a	0.0221a	3485ab	0.0015 b	2801ab	0.0011a
SB	324 b	0.0023 b	2347a	0.2097a	----	------	----	------
1	308 b	0.0234a	2821a	0.1746a	3170ab	0.0083ab	3027ab	0.0057a
2	357ab	0.0048 b	2823a	0.0724a	3322ab	0.0179a	2702 b	0.0097a
3	359ab	0.0061 b	----	0.0000a	2815 b	0.0165a	2905ab	0.0066a
4	497a	0.0006 b	2679a	0.0016a	3637a	0.0009 b	3107a	0.0014a
LSD	155	0.0169	649	0.2745	652	0.0109	307	0.0134
MT wheat								
W					3991a	0.0008 b	2768 b	0.0007a
SB					----	------	----	------
1					3902ab	0.0076ab	2938 b	0.0057a
2					3155 c	0.0137a	3027ab	0.0020a
3					3413 bc	0.0120ab	2865 b	0.0104a
4					3890ab	0.0011 b	3345a	0.0017a
LSD					487	0.0115	346	0.0115

[1] Means followed by the same letter within each column and for each crop treatment did not differ significantly (P<0.05)

than concentrations of total nitrogen in sediment lost from erosive storms on the seed bed. There were no significant differences of total nitrogen concentration in sediment between crop stages on the Gretna C although concentrations from the corn treatment in crop were lower than on stubble or tilled soil. Concentrations of nitrogen were highest after harvest and prior to fall tillage (period 4) on the Ryerson SCL corn and conventional till wheat treatments and on all three plots on the Carroll CL. On the Ryerson SCL corn, concentrations prior to planting and during seedling establishment were significantly lower than during period 2 (50-75% canopy cover) and period 4, while on the conventional till wheat treatment concentrations from the mature crop (period 3) were lower than period 4. Both wheat plots on the Carroll CL had significantly lower concentrations in crop when there was a canopy cover than either stubble after harvest or prior to seeding. In most cases, concentrations of nitrogen were high after harvest, low in the mid to late growing season and variable in the early season.

Total nitrogen losses per erosive unit were lower in the mid to late growing season and after harvest than in the early growing season on wheat and corn treatments on both the Gretna C and Leary SL. Losses from corn treatments were also high in the prior to seeding and seedling establishment period. Total nitrogen losses per erosive unit on the Carroll CL and Ryerson SCL wheat were highest in the early to mid growing season. On corn treatments, losses prior to spring tillage were significantly lower than during the mid growing season.

4.4.5 Effects of crop type

Average annual erosivity over the period of 1988 to 1990 was below the southern Manitoba average of 1160 MJ mm ha^{-1} h^{-1} yr^{-1} on the Leary SL (1006 MJ mm ha^{-1} h^{-1} yr^{-1}), Gretna C (885 MJ mm ha^{-1} h^{-1} yr^{-1}) and the Ryerson SCL (749 MJ mm ha^{-1} h^{-1} yr^{-1}). Rainfall erosivity on the Carroll CL was average over the period of 1988 and 1990. Therefore, it is reasonable to assume that the total nitrogen losses reported in this study represent a below average to average loss.

Total nitrogen losses in sediment were lowest from alfalfa plots on all sites with annual losses ranging from 0 kg ha^{-1} (Leary 1989) to 2.46 kg N ha^{-1} (Carroll CL 1988). Losses from cereals (wheat treatments) were greater than alfalfa every year but less than from fallow and corn treatments. From wheat plots, annual losses ranged from 0.32 kg ha^{-1} (Leary SL 1989) to 272 kg ha^{-1} (Gretna C 1990). From corn plots, annual losses ranged from 0.27 kg ha^{-1} (Leary SL 1988) to 455 kg ha^{-1} (Gretna C 1990) and fallow plots from 1.48 kg ha^{-1} (Leary SL 1988) to 418 kg ha^{-1} (Gretna C 1990).

Annual average annual total nitrogen losses from the Gretna C and Leary SL followed the order:

fallow ≈ corn > wheat > alfalfa

The three year averages (kg N ha^{-1} yr^{-1}) were as follows:

	Leary SL	Gretna C
alfalfa	0.0	0.8
wheat	5.3	100.3
corn	7.8	159.5
fallow	7.2	162.0

On the Ryerson SCL and Carroll CL, losses of total nitrogen from the corn plot was greater than from fallow. Losses from the two wheat treatments were approximately equal. Average annual total nitrogen losses (kg N ha^{-1} yr^{-1}) were as follows:

	Ryerson SCL	Carroll CL
alfalfa	0.3	1.8
CT wheat	8.7	5.2
MT wheat	10.1	4.1
fallow	15.4	23.9
corn	27.9	58.8

Table 4.13 compares average concentrations of total nitrogen by crop for each site. At each location, concentrations of nitrogen were higher from alfalfa than all other treatments. Only the wheat treatments on the Ryerson SCL were not significantly lower. Concentrations from corn and fallow were significantly lower than from wheat on both the Gretna C and

Table 4.13 Average total nitrogen concentrations by crop 1988 - 1990.

	Leary SL	Gretna C	Ryerson SCL	Carroll CL
	$\mu g\ g^{-1}$			
Alfalfa	721a[1]	3409a	3480a	3600a
Corn	477 b	2358 c	2525 c	2850 b
Fallow	458 b	2379 c	2865 b	2937 b
CT wheat	372 b	2697 b	3260a	2894 b
MT wheat			3470a	2980 b
LSD 0.05	101	276	313	217

1. Means followed by the same letter within each column did not differ significantly ($p<0.05$)

the Ryerson SCL. This may be due to the higher soil loss in some events from these plots and erosion cutting deeper into the less fertile profile.

4.4.6 Effects of texture

Antecedent total nitrogen concentrations were taken to a depth of 7.5 cm in the fall of 1987 (Table 4.14, Appendix C). As expected from results obtained by Hoyt et al. (1977), the medium textured soils (Carroll CL and Ryerson SCL) were the most fertile followed by the fine textured Gretna C and the Leary SL. This was consistent with differences in mean concentration of nitrogen in runoff sediment where:

Carroll CL ≈ Ryerson SCL > Gretna C >Leary SL.

The mean concentrations in the runoff sediment were larger than in the sampling because in most events, the sediment was from a depth shallower than the sampling depth.

Average seasonal total nitrogen losses from the Gretna C were much higher than from the medium textured and coarse textured soils (Table 4.14 column (1)). This was also the case when the seasonal averages were standardized for the total rainfall (column (2)) or rainfall erosivity (column (3)). Both total nitrogen loss per mm of rainfall and per erosivity unit were significantly higher on the Gretna C than the other soils. The Leary SL was the lowest because of its low fertility level, but was not significantly different from the Ryerson SCL or the Carroll CL.

Table 4.14 Effects of soil texture on total nitrogen losses and concentration on fallow (1988 - 1990)

Site	Total Nitrogen Concentration				
	Antecedent	Sediment	(1)	(2)	(3)
	-------$\mu g\ g^{-1}$------		$kg\ ha^{-1}\ yr^{-1}$	$kg\ ha^{-1}\ mm^{-1}$	$kg\ h\ MJ^{-1}\ mm^{-1}$
Gretna C	1630	2379 b[#]	162.0	0.96a	0.201a
Carroll CL	2374	2938a	23.9	0.08 b	0.016 b
Ryerson SCL	2216	2865a	15.4	0.09 b	0.018 b
Leary SL	408	458 c	7.2	0.05 b	0.012 b
LSD 0.05		179		0.48	0.088

1. Average annual total nitrogen losses.
2. Total nitrogen losses per mm of rainfall.
3. Total nitrogen losses per erosive unit.

#. Means followed by the same letter within each column did not significantly differ ($p<0.05$)

4.4.7 Predictability of total nitrogen losses in sediment

Although total nitrogen concentration in the sediment fraction of runoff was found to be quite variable and influenced by many factors in all treatments, total nitrogen losses were found to be linearly related to total soil loss (Table 4.15). All regression lines pass through the origin because of the difference in magnitude between soil loss and nitrogen concentration. The regression coefficient in each equation very closely resembles the mean total nitrogen concentration for each treatment.

Table 4.15 Regression equations estimating total nitrogen loss (y) (kg ha^{-1}) from total soil loss (x) (t ha^{-1}).

Plot	Equation	se(b)	r^2
Leary SL			
Alfalfa	y=0.671x	0.076	0.988
Corn	y=0.281x	0.015	0.954
Fallow	y=0.289x	0.014	0.966
Wheat	y=0.240x	0.008	0.984
Gretna C			
Alfalfa	y=2.911x	0.395	0.972
Corn	y=2.525x	0.146	0.956
Fallow	y=2.058x	0.030	0.997
Wheat	y=2.354x	0.043	0.996
Ryerson SCL			
Alfalfa	y=3.420x	0.098	0.997
Corn	y=2.150x	0.069	0.987
Fallow	y=2.591x	0.145	0.970
CT Wheat	y=2.326x	0.046	0.993
MT Wheat	y=2.616x	0.018	0.999
Carroll CL			
Alfalfa	y=3.304x	0.033	0.999
Corn	y=2.672x	0.061	0.995
Fallow	y=2.632x	0.018	0.999
CT Wheat	y=2.631x	0.019	0.999
MT Wheat	y=2.746x	0.013	0.999

At each site, the slope of total nitrogen lost per unit soil loss was highest from the alfalfa treatments. There was no difference in slope between corn and wheat treatments at any site. On the Gretna C, the fallow treatment had a smaller slope than corn and wheat treatments, while on the Leary SL, fallow had a larger slope.

4.4.8 Factors influencing concentration of total nitrogen concentration in sediment

Total sediment concentration in a given storm was determined to be an exponential function of rainfall factors and soil loss. Table 4.16 shows the regression coefficients of the exponential correlations of total nitrogen concentration with rainfall factors and soil loss on the fallow treatment for the four experimental sites. There were only weak correlations between nitrogen concentration and rainfall factors, but in a multi linear regression with soil loss, a fairly good fit can be obtained on all soil types except the Gretna C (Table 4.17). Total rainfall and the 30 minute intensity were used as variables on three soil types. The duration of the rainfall was utilized as a variable on the Leary SL and the Ryerson SCL. The variable soil loss as a quadratic was used for the Ryerson SCL to improve the fit of the curve. More observations and possibly a controlled system using artificial rainfall may improve these curves, but would be very costly. Other variables, viz. antecedent moisture by itself and as its ratio to permanent wilting percentage, field capacity and saturation, produced very inconsistent, complex and unrealistic equations.

4.4.9 Estimated total nitrogen losses 1985 to 1987

Total annual nitrogen losses in runoff from previous years was estimated using the equations in Table 4.15. Measured soil loss from these experimental sites were taken from Pauls (1987) and Shaykewich et al. (1991). Total annual soil loss and the estimated total nitrogen losses are found in Table 4.18.

On the Leary SL and the Gretna C, the estimated total nitrogen loss from alfalfa treatments were much higher than from 1988 to 1990, yet

Table 4.16 Correlation coefficients between the Natural Log of total nitrogen concentration on fallow treatments and soil loss and rainfall characteristics (1988 - 1990).

Site	I_{30}	Duration	Rainfall Amount	Erosivity Index	Soil loss
Leary SL	.231	.476**[1]	.290*	.140	.337*
Gretna C	.172	.336*	.463**	.248	.120
Ryerson SCL	.281*	.287*	.168	.284	.680***
Carroll CL	.552**	.304	.103	.164	.473*

1. Denotes level of significance (* = p=.05), (** = p=.01), (*** = p=.001).

Table 4.17 Multilinear dependence of total nitrogen concentration ($\mu g\ g^{-1}$), total soil loss (SL) ($t\ ha^{-1}$) and total rainfall (mm) or 30 minute intensity (I_{30}) ($mm\ hr^{-1}$).

Site	Equation	r^2
Leary SL	$\ln(z) = 5.8505 + 0.0005 * (\text{min}) - 0.0006 * (\text{mm})$	0.47
	$\ln(z) = 5.9482 - 0.0013 * (\text{mm}) + 0.0004 * (\text{min}) - 0.0229 * (\text{SL})$	0.64
Gretna C	$\ln(z) = 7.6888 + 0.0051 * (\text{mm}) - 0.0020 * (I_{30})$	0.53
	$\ln(z) = 7.6616 + 0.0052 * (\text{mm}) + 0.0002 * (I_{30}) - 0.0025 * (\text{SL})$	0.64
Ryerson SCL	$\ln(z) = 7.9528 - 0.0064 * (\text{mm}) + 0.0028 * (I_{30}) + 0.0002 (\text{min})$	0.50
	$\ln(z) = 8.1233 - 0.0021 * (\text{mm}) - 0.3160 * (\text{SL}) + 0.0610 * (\text{SL})^2$	0.71
Carroll CL	$\ln(z) = 8.0409 - 0.0025 * (I_{30})$	0.55
	$\ln(z) = 8.0330 - 0.0019 * (I_{30}) - 0.0044 * (\text{SL})$	0.57

losses from fallow treatments were similar. The reasons for these high losses may have been a result of seasonal timing and crop establishment. Total nitrogen losses from fallow treatments for the three years was much higher from the Gretna C (108 kg ha^{-1}) than from the Leary SL (25.5 kg ha^{-1}). This was consistent with the 1988 to 1990 results. On the Gretna C, losses from the wheat treatment were a little higher than from the corn treatment in 1985 and 1986, but in 1987, the corn treatment lost more than the wheat treatment, a result which was observed for the next three years.

Average annual total nitrogen losses from 1985 to 1990 based on estimated and observed losses are found in Table 4.18. Average total

Table 4.18 Total seasonal soil loss and estimated total nitrogen loss 1985-1987 for four experimental sites and actual seasonal losses from 1988-1990.

	Leary SL		Gretna C		Ryerson SCL		Carroll CL	
Year	Soil Loss	TN Loss	Soil Loss	TN Loss	Soil Loss	TN Loss	Soil Loss	TN Loss
	t ha^{-1}	kg ha^{-1}	t ha^{-1}	kg ha^{-1}	t ha^{-1}	kg ha^{-1}	t ha^{-1}	kg ha^{-1}
Alfalfa								
1985	2.7	1.7	5.5	16.0				
1986	8.4	5.4	12.4	36.1				
1987	0.0	0.0	0.2	0.6	0.3	1.0	0.2	0.6
Average	3.7	2.4	6.0	17.6				
1988	0.0	0.0	0.1	0.3	0.2	0.5	0.8	2.5
1989	0.1	0.1	0.0	0.0	0.0	0.2		
1990	0.2	0.0	0.7	2.2	0.0	0.2	0.3	1.2
Total average	1.9	1.2	3.2	9.1	0.1	0.3	0.4	1.4
Corn								
1985	22.3	6.3	14.9	37.6				
1986	22.3	6.3	48.8	123.2				
1987	4.4	1.2	4.6	11.6	13.1	28.2	0.7	1.9
Average	16.3	4.6	22.8	57.6				
1988	0.6	0.3	10.7	20.3	9.5	23.1	23.4	65.4
1989	2.0	0.7	1.1	2.8	5.8	14.8		
1990	70.0	22.4	195.4	455.4	20.7	45.9	21.4	52.3
Total average	20.2	6.2	45.9	108.5	12.3	28.0	15.2	40.0
Fallow								
1985	52.1	25.9	31.7	65.2				
1986	17.7	8.8	69.6	143.2				
1987	83.7	41.7	56.5	116.3	15.3	35.1	0.6	1.6
Average	51.2	25.5	52.6	108.3				
1988	4.0	1.5	15.3	34.0	5.3	12.8	6.9	18.9
1989	9.3	2.3	12.3	33.8	3.1	7.2		
1990	67.3	17.9	197.8	418.2	9.6	26.3	11.0	28.9
Total average	39.0	16.4	63.9	135.1	8.3	20.4	6.2	16.5
CT Wheat								
1985	19.4	4.7	21.5	56.3				
1986	26.5	6.4	52.6	137.8				
1987	0.8	0.2	0.9	2.4	3.3	7.7	0.6	1.6
Average	15.6	3.8	25.0	65.5				
1988	1.7	0.5	11.5	26.7	2.2	6.1	0.7	2.0
1989	2.5	0.3	0.8	1.9	0.6	2.0		
1990	60.6	15.0	101.9	272.3	7.4	18.1	3.2	8.5
Total average	18.6	4.5	31.5	82.9	3.4	8.5	1.5	4.0
MT Wheat								
1987					1.3	2.8	0.3	0.8
1988					3.6	10.1	0.4	1.1
1989					0.3	1.2		
1990					7.1	18.9	2.6	7.1
Total average					3.1	8.3	1.1	3.0

nitrogen losses from the Gretna C were 108 kg ha^{-1} from corn treatment, 135.1 kg ha^{-1} from the fallow treatment and 82.9 kg ha^{-1} from the wheat treatment. Both soil losses and total nitrogen losses were much higher from the Gretna C than from the other soil types.

4.5 Total phosphorus in the sediment fraction

Concentration of total phosphorus and magnitude of these losses in sediment will be discussed in this section. The effects of rainfall, management inputs, canopy cover, crop type and soil texture will be examined for influences on total phosphorus losses.

The predictability of total phosphorus losses will be assessed and the resulting equations used to estimate losses resulting from rainfall events in the years 1985 to 1987.

4.5.1 Magnitude of total phosphorus losses in the sediment fraction of runoff

The total phosphorus concentrations in the sediment fraction of the runoff for each rainfall event are shown in Table 4.19. From the concentration and total soil loss, total phosphorus lost in the sediment was calculated. Total phosphorus lost in sediment is shown in Table 4.20.

Average annual losses of total phosphorus (kg ha^{-1}) were as follows:

	Leary SL	Gretna C	Ryerson SCL	Carroll CL
Alfalfa	0.0	0.3	0.1	0.5
Corn	9.9	68.3	8.0	17.2
CT Wheat	8.3	41.2	2.6	1.6
Fallow	10.9	72.0	5.4	7.2
MT Wheat	---	---	3.1	1.3

Table 4.19 Total phosphorus concentrations in runoff sediment 1988 - 1990.

Date	Alfalfa	Corn	Fallow	Wheat
	μg g^{-1}			
Leary sandy loam:				
1988.06.01	----	432	395	380
1988.07.05	----	488	417	616
1988.07.12	----	459	411	658
1988.09.11	----	549	601	459
1989.06.06	----	418	493	518
1989.06.12	----	455	460	465
1989.07.14	523	605	455	415
1989.08.03	408	400	563	413
1989.08.17	----	415	448	518
1989.09.10	----	315	340	375
1990.06.01	478	590	489	471
1990.06.08	351	532	624	628
1990.06.11	----	616	405	425
1990.06.18	----	433	355	524
1990.06.19	----	328	607	391
1990.07.02	----	----[1]	475	440
1990.07.06	----	----[1]	470	339
1990.07.28	----	441	498	385
1990.08.01	----	391	375	382
1990.08.22	----	434	592	556
1990.09.17	----	500	383	393
Gretna clay:				
1988.05.07	----	1082	1295	984
1988.07.05	1068	993	833	988
1988.07.06	933	973	904	960
1988.09.11	1088	980	875	1075
1989.06.12	----	925	880	913
1989.08.03	----	908	805	953
1989.08.25	----	1120	935	----
1989.09.10	----	955	853	1055
1990.05.14	----	1016	975	1133
1990.05.20	----	1073	979	1303
1990.06.01	895	997	1070	1141
1990.06.08	952	927	792	1298
1990.06.11	----	902	915	1062
1990.06.17	----	1123	1070	1490
1990.06.19	----	1152	910	1326
1990.07.02	----	1104	934	1268
1990.07.06	----	1090	961	1248
1990.08.22	----	1099	912	984

---

1. No sample due to a drainage problem.

Table 4.19 continued. Total phosphorus concentrations in runoff sediment 1988 - 1990.

Date	Alfalfa	Corn	Fallow	Wheat	
				Con-till	Min-till
	$\mu g\ g^{-1}$				
Ryerson sandy clay loam:					
1988.06.15	1468	1124	1087	1045	715
1988.07.06	864	593	943	785	850
1988.07.12	1134	943	923	796	1028
1988.09.10	----	667	626	791	657
1988.09.18	----	864	667	703	672
1989.06.28	988	835	940	773	790
1989.08.11	----	670	958	920	993
1989.09.03	825	790	903	793	858
1990.05.15	823	854	840	821	907
1990.06.01	966	814	1013	1000	1017
1990.06.07	----	674	872	793	889
1990.06.16	765	803	885	797	917
1990.06.19	768	794	869	704	969
1990.07.01	----	613	833	782	742
1990.07.03	----	721	823	605	653
1990.08.22	----	865	937	914	1244
1990.09.17	----	801	879	856	1124
Carroll clay loam:					
1988.05.07	761	784	852	812	764
1988.06.14	----	----	----	----	----
1988.07.06[1]	----	----	----	----	833
1988.07.13	875	703	690	745	775
1988.08.18	824	813	775	784	657
1988.09.10	758	775	653	733	950
1988.09.18	832	1025	668	793	963
1990.05.15	664	849	846	885	831
1990.06.07	740	857	861	883	817
1990.06.17	683	805	858	825	823
1990.06.19	905	835	843	956	904
1990.07.03	748	827	860	851	867
1990.07.06	763	905	851	802	931
1990.08.01	711	853	860	902	871
1990.08.18	863	962	729	931	862
1990.08.27	---	---	---	---	---

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[1] System failed because of lightening strike prior to rainfall.

Table 4.20 Total phosphorus losses in runoff sediment 1988 - 1990.

Date	Alfalfa	Corn	Fallow	Wheat
		$kg\ ha^{-1}$		
Leary sandy loam:				
1988.06.01	----	0.05	0.08	0.17
1988.07.05	----	0.01	0.02	0.32
1988.07.12	----	0.17	1.52	0.47
1988.09.11	----	0.03	0.01	0.01
Total 1988	0.00	0.26	1.63	0.97
1989.06.06	----	0.02	0.01	0.02
1989.06.12	----	0.01	0.00	0.00
1989.07.14	0.01	0.03	0.02	0.03
1989.08.03	0.05	0.55	2.40	0.19
1989.08.17	----	0.02	0.22	0.11
1989.09.10	----	0.04	0.17	0.01
Total 1989	0.06	0.67	2.82	0.36
1990.06.01	0.01	3.32	0.22	1.28
1990.06.08	0.00	2.24	0.29	0.57
1990.06.11	----	5.46	0.43	1.42
1990.06.18	----	0.91	2.17	0.34
1990.06.19	----	10.76	14.37	3.76
1990.07.02	----	----[1]	2.80[1]	6.21
1990.07.06	----	----[1]	----[1]	5.49
1990.07.28	----	1.94	1.19	1.12
1990.08.01	----	3.21	6.73	2.38
1990.08.22	----	0.74	0.02	0.73
1990.09.17	----	0.06	0.01	0.02
Total 1990	0.01	28.62	28.23	23.66
Total 1988-90	0.07	29.55	32.68	24.99
Gretna clay:				
1988.05.07	----	0.28	1.93	0.69
1988.07.05	0.01	0.06	0.06	0.01
1988.07.06	0.07	9.99	12.37	10.33
1988.09.11	0.01	0.13	0.08	0.05
Total 1988	0.09	10.46	14.44	11.08
1989.06.12	----	0.14	0.14	0.05
1989.08.03	----	0.52	4.81	0.12
1989.08.25	----	0.28	0.17	----
1989.09.10	----	0.17	5.09	0.14
Total 1989	0.00	1.11	10.21	0.31
1990.05.14	----	0.06	0.06	0.05
1990.05.20	----	12.54	15.15	1.00
1990.06.01	0.29	98.58	54.90	24.34
1990.06.08	0.40	0.67	0.25	0.10
1990.06.11	----	52.91	91.77	72.00
1990.06.17	----	9.25	7.32	1.36
1990.06.19	----	9.84	8.44	7.03
1990.07.02	----	5.33	13.02	0.00
1990.07.06	----	3.83	0.27	6.23
1990.08.22	----	0.27	0.03	0.00
Total 1990	0.69	193.28	191.21	112.11
Total 1988-90	0.78	204.85	215.86	123.50

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[1] No sample due to a drainage problem.

Table 4.20 continued. Total phosphorus in runoff sediment 1988 - 1990.

Date	Alfalfa	Corn	Fallow	Wheat	
				Con-till	Min-till
			kg ha^{-1}		
Ryerson sandy clay loam:					
1988.06.15	0.01	0.08	0.07	0.06	0.06
1988.07.06	0.10	3.06	3.94	1.43	2.37
1988.07.12	0.02	2.53	0.88[1]	0.27	0.42
1988.09.10	----	0.46	0.04	0.01	0.01
1988.09.18	----	0.70	0.01	0.01	0.01
Total 1988	0.13	6.83	4.94	1.78	2.87
1989.06.28	0.02	1.22	1.78	0.16	0.11
1989.08.11	----	2.68	1.16	0.32	0.17
1989.09.03	0.03	0.25	0.03	0.02	0.02
Total 1989	0.05	4.15	2.97	0.50	0.30
1990.05.15	0.01	0.03	0.02	0.02	0.01
1990.06.01	0.01	0.02	0.02	0.04	0.04
1990.06.07	----	0.03	0.03	0.02	0.03
1990.06.16	0.03	10.07	4.03	3.72	5.06
1990.06.19	0.01	1.12	0.20	0.37	0.16
1990.07.01	----	0.85	0.39	0.53	0.12
1990.07.03	----	0.32	3.37	0.70	0.71
1990.08.22	----	0.63	0.09	0.22	0.06
1990.09.17	----	0.06	0.05	0.03	0.04
Total 1990	0.06	13.13	8.20	5.65	6.23
Total 1988-90	0.24	24.11	16.11	7.93	9.40
Carroll clay loam:					
1988.05.07	0.02	0.07	0.06	0.06	0.05
1988.06.14	----	----	----	----	----
1988.07.06[2]	----	----	----	----	----
1988.07.13	0.56	15.82	4.55	0.34	0.10
1988.08.18	0.05	0.37	0.12	0.09	0.05
1988.09.10	0.02	0.09	0.05	0.04	0.04
1988.09.18	0.01	0.28	0.03	0.02	0.03
Total 1988	0.69	16.67	4.84	0.56	0.28
1990.05.15	0.06	0.10	0.09	0.08	0.05
1990.06.07	0.01	0.01	0.01	0.01	0.01
1990.06.17	0.07	0.05	0.47	0.24	
1990.06.19	0.01	0.02	0.01	0.01	0.01
1990.07.03	0.04	10.88	8.92	1.75	1.57
1990.07.06	0.01	1.37	0.14	0.15	0.26
1990.08.01	0.01	2.01	0.16	0.12	0.07
1990.08.18	0.02	0.30	0.09	0.09	0.03
1990.08.27	----	----	----	----	----
Total 1990	0.23	17.81	9.47	2.67	2.24
Total 1988,90	0.92	34.48	14.31	3.23	2.52

1. System failed to sample complete event because of silting on sampler.
2. System failed because of lightening strike prior to rainfall.

4.5.2 Effects of rainfall intensity and seasonal patterns

Romkens and Nelson (1974) found that with consecutive simulation rainfall events, the concentration of total phosphorus in the sediment decreased with each successive event. This was not the case in this study. There were slight fluctuations in total phosphorus concentrations, but there were no consistent decreasing or increasing trends. For example, on the Gretna C fallow treatment, 5 rainfall events were sampled in a period of 19 days in 1990 on June 1, June 8, June 11, June 17 and June 19. Total phosphorus concentrations were 1070, 792, 915, 1070 and 910 $\mu g\ g^{-1}$, respectively. Thus there was no clear decreasing trend. Also on the Gretna C in 1988, there were two successive events on July 5 and 6. Total phosphorus concentration increased slightly from 833 $\mu g\ g^{-1}$ to 904 $\mu g\ g^{-1}$. On the cropped plots, concentrations of total phosphorus decreased slightly with time in the 1988 events but increased slightly in the 1990 events.

There were 2 pairs of successive events in 1990 on the Carroll CL. The first on June 17 and 19 showed increases of 10% or more in concentration of total phosphorus in the alfalfa, minimum till wheat and conventional till wheat treatments. The second on July 3 and 6 produced no such differences and in fact, total phosphorus concentration from the conventional till wheat treatment decreased by 6%.

On the Ryerson SCL, there was a decrease in concentration of total phosphorus on both wheat treatments from July 1 to July 3 but there was an increase from the corn treatment. On June 16 and June 19, there was a decrease in total phosphorus concentration in the conventional till wheat treatment. Although there were differences of more than 10% in the total phosphorus concentration in sediment produced by successive events, this was not always the case, nor was it consistently increasing or decreasing under conditions of this study.

Klausner et al. (1974) found that sediment phosphorus concentrations were lowest during the summer months. Table 4.21 gives the total phosphorus concentrations divided into three time periods. Period 1 was the early season (before June 16). Period 2 was the mid-growing season (June 16 to August 15). Period 3 was the late season (August 16 and later). There were no significant seasonal differences on the Gretna C or the Leary SL. On the Ryerson SCL, there were significant differences on the conventional till wheat and fallow treatments. The concentration of phosphorus after mid August was significantly lower than before mid-June in both treatments. On conventional till wheat the concentration of phosphorus in mid-summer was also significantly lower than before mid-June. The concentration of phosphorus was significantly lower after mid-August on the Carroll CL fallow treatment than the other two periods of the season. On the alfalfa treatment, the period before mid-June was significantly lower than after mid-August. From the three of years data it was not possible to conclude that concentrations of total phosphorus in sediment was lowest in the mid-summer months.

Total phosphorus losses were found to vary greatly from year to year. Over the three years on the Gretna C, losses from the corn, fallow and wheat treatments were 205, 216 and 112 kg ha^{-1}, respectively. Losses from 1990 accounted for 94% of the losses from the corn treatment, 89% from the fallow treatment and 91% from the wheat treatment. The greatest proportion of total phosphorus losses on the Leary SL were also found in

Table 4.21 Effect of time of season on concentration of total phosphorus (1988 - 1990).

Crop/Period[1]	Leary SL	Gretna C	Ryerson SCL	Carroll CL
	μg g^{-1}			
Alfalfa				
1	415a[#]	924a	1086a	722 b
2	466a	1001a	904a	794ab
3	---	1088a	825a	819a
LSD 0.05	76	169	286	86
Corn				
1	507a	989a	867a	830a
2	443a	1049a	797a	840a
3	443a	1039a	747a	894a
LSD 0.05	80	94	138	102
Fallow				
1	478a	987a	953a	853a
2	463a	917a	897ab	819a
3	473a	894a	802 b	706 b
LSD 0.05	85	134	108	67
CT wheat				
1	481a	1119a	915a	860a
2	456a	1176a	770 b	833a
3	460a	1038a	811 b	810a
LSD 0.05	90	194	103	87
MT wheat				
1			882a	804a
2			853a	858a
3			911a	858a
LSD 0.05			199	100

1. Period 1 = start to June 15.
   Period 2 = June 16 to August 15.
   Period 3 = August 16 and later.

#. Means followed by the same letter did not differ significantly ($p<0.05$).

1990 in spite of the fact that two major events on the fallow and corn plots during the year were not sampled. Losses in 1990 were 29 kg ha^{-1} from the corn treatment, 28 kg ha^{-1} from the fallow treatment and 24 kg ha^{-1} from the wheat treatment, accounting for 97%, 86% and 95% of the total 3 year losses, respectively.

Losses from individual rainfall events varied greatly and most of the large losses of total phosphorus occurred from one or two events. On the Gretna C, rainfall events on June 1 and June 11, 1990 accounted for losses of 99 and 53 kg P ha^{-1} from the corn treatment, 55 and 92 kg P ha^{-1} from the fallow treatment and 24 and 72 kg ha^{-1} from the wheat treatment. These two events had 43% of the growing season rainfall but accounted for 78% of the seasonal losses from the corn treatment, 77% from the fallow treatment and 86% from the wheat treatment. Of the 18 sampling events over the 3 year study, these two events accounted for 74% of the total phosphorus losses from the corn treatment, 68% from the fallow treatment and 78% the from wheat treatment, but only had 24% of the total rainfall.

Individual rainfall events dominated total phosphorus losses on the Carroll CL. On July 13, 1988, 16 kg P ha^{-1} were lost from the corn plot, accounting for 95% of the growing season losses. On July 3, 1990, 11 kg P ha^{-1} were lost from the corn plot, 61% of the losses for that growing season. These two events combined accounted for 77% of the losses for all 13 events over the duration of the study. Losses of total phosphorus from fallow, conventional till wheat and minimum till wheat treatments from these two events accounted for 94%, 65% and 66% of the total losses, respectively.

Various characteristics of rainfall affect total phosphorus losses. Table 4.22 shows correlations between total phosphorus losses and maximum 30 minute intensity (I_{30}), the duration of the rainfall, the total rainfall (mm) and erosivity index (EI) on each treatment at each site.

Total phosphorus losses was influenced more by maximum 30 minute

Table 4.22 Correlation coefficients between total phosphorus losses in sediment and rainfall factors (1988 - 1990).

	I_{30}	Duration	Rainfall Amount	Erosivity Index
		Leary SL		
Alfalfa	0.52	0.26	0.23	0.79
Corn	0.14	0.05	0.21	0.08
Wheat	0.34**[1]	0.10	0.02	0.16
Fallow	0.15	0.05	0.05	0.01
		Gretna C		
Alfalfa	0.74	0.45	0.25	0.71
Corn	0.90***	0.02	0.68**	0.84***
Wheat	0.47**	0.07	0.06	0.42*
Fallow	0.65***	0.02	0.18	0.49**
		Ryerson SCL		
Alfalfa	0.36	0.11	0.17	0.52
Corn	0.89***	0.08	0.84***	0.92***
Wheat	0.95***	0.08	0.87***	0.92***
Fallow	0.76***	0.12	0.56***	0.78***
MT Wheat	0.98***	0.07	0.84***	0.90***
		Carroll CL		
Alfalfa	0.16	0.06	0.23	0.04
Corn	0.31*	0.16	0.43*	0.60**
Wheat	0.47*	0.13	0.31	0.17
Fallow	0.50**	0.18	0.33*	0.25
MT Wheat	0.48*	0.12	0.20	0.08

1. Denotes level of significance (* = P=0.05), (** = P=0.01), (*** = P=0.001).

intensity than by any other factor examined in this study. All treatments except the Leary SL corn and fallow treatments and all the alfalfa treatments, showed some statistically significant correlations ($p<0.05$).

There was no significant correlation between rainfall duration and total phosphorus lost in sediment on any site or treatment. The correlation between total amount of rainfall and total phosphorus losses were highly significant on the Ryerson SCL on all treatments except alfalfa. On the Gretna C, this correlation was only moderately significant on the corn treatment. There was a significant relationship for the Carroll CL fallow and corn treatments. All other treatments showed no statistically significant correlation ($p<0.05$).

All treatments except alfalfa show a statistically significant relationship between erosivity index and total phosphorus losses on the Gretna C and Ryerson SCL. The Carroll CL corn treatment also showed significant correlations. All other treatments, in particular all treatments from the Leary SL, show no significant correlation.

Losses from alfalfa treatments were very low, even under highly erosive rainfall events. This may be the reason for no correlation between total phosphorus losses and rainfall characteristics.

4.5.3 Effects of management practices

Fertilizer in the form of ammonium phosphate was side banded on wheat plots, banded prior to seeding on corn plots and broadcast on alfalfa plots.

Total phosphorus concentrations from storm events shortly after fertilizer application were statistically compared to the mean of the remaining observations to detect any differences as a result of fertilizer additions.

On the Gretna C, total phosphorus concentration in the wheat treatment was not higher on an event one day after seeding (May 7, 1988) (984 $\mu g\ g^{-1}$) or seven days after seeding on June 1, 1990 (1141 $\mu g\ g^{-1}$) than subsequent observations, and was not significantly higher than the mean concentration of the remaining observations (1137 $\mu g\ g^{-1}$). Concentration of total phosphorus was 1082 $\mu g\ g^{-1}$ from the corn plot on the May 7 event.

This was higher by 10.2% than the mean of the remaining 1988 observations (982 μg g^{-1}), but not significantly higher than the three year mean concentration (1021 μg g^{-1}). The total phosphorus concentration on June 1. 1990 (997 μg g^{-1}) was lower than the mean concentration. On the fallow plot, which had no fertilizer inputs, total phosphorus concentration from the May 7, 1988 event was 1295 μg g^{-1}, a 42.6% increase over the three mean (908 μg g^{-1}) and 1070 μg g^{-1} on June 1, 1990. These increases were statistically significant.

There was only one rainfall event closely following a seeding event on the Leary SL. The event was on June 1 1990, nine days after seeding. There were no significant increases in total phosphorus concentration over the seasonal mean from any treatment.

The Carroll CL had a rainfall event on May 7 1988, one to two days after seeding. There were no statistical increases in total phosphorus concentration over the mean of the balance of observations.

Two events were examined on the Ryerson SCL, June 15 1988 (41 days after seeding) and June 1 1990 (nine days after seeding). Concentrations of total phosphorus from all plots except the minimum till wheat plot were statistically higher than the other observations on June 15, even though the time between seeding and sampling was 41 days. On June 1, 1990, only the conventional till wheat treatment showed a statistically significant increase in total phosphorus concentration.

Even though some sampling dates were only one or two days after seeding, the three sites failed to show a significant loading of total phosphorus concentration over the growing season average. This was even true for the alfalfa treatments, on which the ammonium phosphate was surface broadcast. The significant increase in phosphorus concentration on the Ryerson SCL 41 days following seeding must have resulted from sources other than fertilizer. Furthermore, a significant increase in phosphorus concentration at this time from the fallow treatment, which did not receive any fertilizer, had no apparent explanation.

Increased residue on minimum tillage wheat produced only a modest difference in mean total phosphorus concentration on the Ryerson SCL and the Carroll CL. Mean concentrations on the Ryerson SCL were 886 $\mu g\ g^{-1}$ (s = 157) on the minimum till wheat treatment compared to 816 $\mu g\ g^{-1}$ (s = 107) from the conventional tillage treatment. On the Carroll CL, mean concentrations were 849 $\mu g\ g^{-1}$ (s = 79) on the minimum till wheat treatment and 833 $\mu g\ g^{-1}$ (s = 71) on the conventional tillage treatment. Neither of these differences were statistically significant.

Average seasonal losses were higher on the minimum till wheat treatment (3.1 kg $ha^{-1}\ yr^{-1}$) than the conventional till wheat treatment (2.6 kg $ha^{-1}\ yr^{-1}$) on the Ryerson SCL. On the Carroll CL, the reverse was found on, the minimum till wheat treatment lost 1.3 kg $ha^{-1}\ yr^{-1}$ and the conventional till wheat treatment lost 1.6 kg $ha^{-1}\ yr^{-1}$.

4.5.4 Effects of crop cover

Total phosphorus concentrations in runoff sediment for various crop stages are given in Table 4.23.

On the Leary SL, concentrations of total phosphorus in corn was significantly higher before crop establishment and after harvest than from crop establishment to harvest.

Table 4.23 Mean total phosphorus concentration in sediment during 6 canopy cover stages (1988 - 1990).

Crop Stage	Soil Type			
	Leary SL	Gretna C	Ryerson SCL	Carroll CL
	$\mu g\ g^{-1}$			
Corn				
W[#]	---	1045ab	854a	849a
SB	543a[1]	1015ab	771a	828a
1	455 b	1020ab	805a	840a
2	377 b	----	779a	908a
3	442 b	1099a	---	---
4	549a	980 b	774a	900a
LSD	83	105	186	125
Wheat				
W	---	1218a	821a	885a
SB	550a	1167a	---	---
1	430a	1178a	863a	840ab
2	506a	1037a	845a	818ab
3	430a	984a	775a	878a
4	436a	1065a	786a	763 b
LSD	109	256	161	101
MT wheat				
W			907a	831 b
SB			---	---
1			953a	850 b
2			886a	820 b
3			880a	838 b
4			853a	957a
LSD			207	98

1. Means followed by the same letter within each column and for each crop treatment did not differ significantly ($P<0.05$)

#. Definitions for crop stages are found in Table 3.1 - Modified System.

On the Gretna C, total phosphorus concentration from the corn treatment was significantly higher in the mature crop (period 3) than in post harvest residues (period 4).

On the Carroll CL, the conventional till wheat treatment had significantly lower concentrations on post harvest residues than in the mature crop (period 3) or prior to spring tillage (period W). Conversely, higher concentrations of phosphorus were reported in the minimum till wheat treatment from post harvest residues than all other periods.

No other treatments showed any significant variations over the growing season. Crop cover did not appear to consistently influence total phosphorus concentration.

4.5.5 Effects of crop type

Annual total phosphorus losses from the Gretna C and Leary SL followed the order:

fallow > corn > wheat > alfalfa

This was consistent with the effects of crop type found by White and Williamson (1973) and Burwell et al (1975). The three year averages (kg P ha^{-1} yr^{-1}) were as follows:

	Leary SL	Gretna C
alfalfa	0.0	0.3
wheat	8.3	41.2
corn	9.9	68.3
fallow	10.9	72.0

Losses of total phosphorus from the corn treatment surpassed those from the fallow treatment on the Ryerson SCL and Carroll CL. This was contrary to results reported in the literature. There was little difference between the two wheat treatments. Average annual total phosphorus losses (kg P ha^{-1} yr^{-1}) were as follows:

	Ryerson SCL	Carroll CL
alfalfa	0.1	0.5
CT wheat	2.6	1.6
MT wheat	3.1	1.3
fallow	5.4	7.2
corn	8.0	17.2

Table 4.24 compares concentrations of total phosphorus by crop for each site. There were significant differences on all sites except on the

Leary SL, but no consistent trends. On the Ryerson SCL, concentrations of total phosphorus were significantly higher from the alfalfa treatment than for corn or conventional till wheat treatments. The Carroll CL, however, had significantly higher concentrations from the corn treatment than the alfalfa treatment, and concentrations from the wheat treatment on the Gretna C were significantly higher than all other treatments.

Table 4.24 Average total phosphorus concentrations in sediment by crop 1988 - 1990.

	Leary SL	Gretna C	Ryerson SCL	Carroll CL
	$\mu g\ g^{-1}$			
Alfalfa	440a[1]	987 b	956a	786 b
Corn	463a	1023 b	790 b	853a
Fallow	469a	939 b	882ab	794ab
CT wheat	464a	1128a	816 b	833ab
MT wheat			896ab	846ab
LSD 0.05	54	82	100	58

1. Means followed by the same letter within each column did not differ significantly ($p<0.05$)

4.5.6 Effects of soil type

The Gretna C and the Ryerson SCL had significantly higher concentrations of total phosphorus in runoff from the fallow treatments than did the Carroll CL or Leary SL (Table 4.25). The Carroll CL had significantly higher concentrations than the Leary SL. This was not consistent with the antecedent concentration of soil phosphorus. The discrepancy is probably due to the depth of sample being 7.5 cm while most of the runoff sediment was derived from a shallower depth.

Total phosphorus losses from the clay soil were much higher than the coarser textured soils. The order of annual total phosphorus losses from sediment was as follows:

Clay > Sandy Loam > Clay Loam > Sandy Clay Loam.

When these losses were expressed on a unit rainfall basis (Table 4.25 column (2)), the Gretna clay had significantly higher losses than the other soils. The same result was found when losses were standardized for differences in erosivity (Table 4.25 column (3)).

From data gathered over three years in this experiment it appears that soil phosphorus losses were greater from fine textured soils followed by coarse textured soils and medium textured soils.

Table 4.25 Comparisons of total phosphorus losses from fallow by soil texture.

Site	Total Nitrogen Concentration				
	Antecedent	Sediment	(1)	(2)	(3)
	$\mu g\ g^{-1}$		$kg\ ha^{-1}\ yr^{-1}$	$kg\ ha^{-1}\ mm^{-1}$	$kg\ h\ MJ^{-1}\ mm^{-1}$
Gretna C	788	939a[#]	72.0	0.42a	0.085a
Ryerson SCL	677	882a	5.4	0.03 b	0.006 b
Carroll CL	757	794 b	7.2	0.02 b	0.005 b
Leary SL	514	469 c	10.9	0.09 b	0.022 b
LSD 0.05		62		0.23	0.046

1. Average annual total phosphorus losses (kg P $ha^{-1}\ yr^{-1}$)
2. Total phosphorus losses per mm of rainfall (kg P $ha^{-1}\ mm^{-1}$)
3. Total phosphorus losses per erosive unit (kg P h $MJ^{-1}\ mm^{-1}$)

[#] Means followed by the same letter within each column did not significantly differ ($p<0.05$)

4.5.7 Predictability of total phosphorus losses in runoff sediment

Total phosphorus in the sediment fraction of runoff was found to be closely related to soil loss in all treatments but the nature of the relationship varied greatly from site to site (Table 4.26). Total phosphorus losses were linearly related to total soil loss. The strong relationship between total phosphorus and soil loss suggests the consistency of total phosphorus concentration in sediment over the three year period. This was implied earlier where no correlations between total phosphorus concentration and seasonal factors, management factors or rainfall factors were found. It appears, therefore, to be possible to estimate the total phosphorus lost if soil loss is known.

Table 4.26 Regression equation estimating total phosphorus loss (y) from total soil loss (x).

Plot	Equation	se(b)	r^2
Leary SL			
Alfalfa	y=0.411x	0.034	0.990
Corn	y=0.360x	0.021	0.951
Fallow	y=0.515x	0.030	0.954
Wheat	y=0.387x	0.012	0.985
Gretna C			
Alfalfa	y=0.934x	0.019	0.999
Corn	y=0.976x	0.015	0.997
Fallow	y=0.947x	0.017	0.996
Wheat	y=1.069x	0.011	0.999
Ryerson SCL			
Alfalfa	y=0.830x	0.025	0.996
Corn	y=0.758x	0.070	0.921
Fallow	y=0.890x	0.016	0.997
CT Wheat	y=0.756x	0.012	0.997
MT Wheat	y=0.879x	0.019	0.994
Carroll CL			
Alfalfa	y=0.866x	0.013	0.998
Corn	y=0.721x	0.040	0.974
Fallow	y=0.812x	0.028	0.989
CT Wheat	y=0.817x	0.036	0.983
MT Wheat	y=0.868x	0.006	0.999

For each site, the slope of total phosphorus losses per unit soil loss was the smallest in the corn treatment in three of four sites. There were no other trends.

4.5.8 Estimated total phosphorus losses 1985 to 1987

The equations in Table 4.26 were applied to data collected from 1985 to 1987 on these experimental sites. Table 4.27 gives the measured seasonal soil loss from the experimental sites for the years 1985 to 1987 (Pauls 1987 and Shaykewich et al. 1991) and the estimated total phosphorus losses.

The three year average of estimated total phosphorus losses were highest from the fallow treatment on the Leary SL (20.5 kg ha^{-1}), Gretna C (49.8 kg ha^{-1}), and Ryerson SCL (14.0 kg ha^{-1}). This is in agreement with the results accumulated from 1988 to 1990. Losses were much higher from the Gretna C than the Leary SL for all treatments.

4.6 Nutrients in the dissolved fraction of runoff water

Concentrations of ammonium, nitrate, nitrite and total phosphorus in the dissolved fraction from the years 1988 and 1989 are given in Table 4.28. Some rainfall events were not sampled because of an insufficient quantity of sample.

Nutrient losses in the dissolved fraction of runoff accounted for less a than 0.5% of total phosphorus and total nitrogen losses from all treatments (Table 4.29). The greatest losses of total nitrogen (two year total) in the dissolved fraction was 2 g N ha^{-1} from the fallow treatment on the Carroll CL. The largest losses of total phosphorus were on the

Table 4.27 Total seasonal soil loss and estimated total phosphorus loss 1985-1987 for four experimental sites.

	Leary SL		Gretna C		Ryerson SCL		Carroll CL	
Year	Soil Loss	TP Loss	Soil Loss	TP Loss	Soil Loss	TP Loss	Soil Loss	TP Loss
	t ha^{-1}	kg ha^{-1}	t ha^{-1}	kg ha^{-1}	t ha^{-1}	kg ha^{-1}	t ha^{-1}	kg ha^{-1}
Alfalfa								
1985	2.7	1.1	5.5	5.1				
1986	8.4	3.5	12.4	11.5				
1987	0.0	0.0	0.2	0.2	0.3	0.3	0.2	0.2
Average	3.7	1.5	6.0	5.6				
Total Average	1.9	0.8	3.2	2.9	0.1	0.1	0.4	0.4
Corn								
1985	22.3	8.0	14.9	14.5				
1986	22.3	8.0	48.8	47.6				
1987	4.4	1.6	4.6	4.5	13.1	10.1	0.7	0.5
Average	16.3	5.9	22.8	22.2				
Total average	20.2	7.9	45.9	45.2	12.3	8.6	15.2	11.7
Fallow								
1985	52.1	20.8	31.7	30.0				
1986	17.7	7.1	69.6	65.9				
1987	83.7	33.5	56.5	53.5	15.3	14.0	0.6	0.5
Average	51.2	20.5	52.6	49.8				
Total Average	39.0	15.7	63.9	60.9	8.3	7.5	6.2	4.9
CT Wheat								
1985	19.4	7.5	21.5	23.0				
1986	26.5	10.3	52.6	56.2				
1987	0.8	0.3	0.9	1.0	3.3	2.6	0.6	0.5
Average	15.6	6.0	25.0	26.7				
Total Average	18.6	7.2	31.5	34.0	3.4	2.6	1.5	1.2
MT Wheat								
1987					1.3	1.1	0.3	0.3
Total Average					3.1	2.6	1.1	0.9

Leary SL where corn and alfalfa treatments each lost 0.2 g P ha^{-1}.

4.6.1 Total dissolved nitrogen in surface runoff

Lambert et al. (1985) found that the ratio nitrate to ammonium ratio in runoff was higher when growth of forage was vigorous. Although, in the present study, the number of samplings was not large enough for a statistical comparison, 4 of the 5 samplings in July and early August had nitrate to ammonium ratios ranging from 3.55 to 1 on the Carroll CL, to 66.5 to 1 on the Leary SL. This compares to 2 samplings in May on the

Table 4.28 Dissolved nutrient concentration in runoff from experimental sites 1988-1989.

Date of Storm	Alfalfa				Corn				Fallow				CT Wheat				MT Wheat			
	NH_4^+	NO_3^-	NO_2^-	PO_4	NH_4^+	NO_3^-	NO_2^-	PO_4	NH_4^+	NO_3^-	NO_2^-	PO_4	NH_4^+	NO_3^-	NO_2^-	PO_4	NH_4^+	NO_3^-	NO_2^-	PO_4
	$\mu g\ g^{-1}$																			
Leary sandy loam:																				
1988.06.01	----	----	----	----	0.19	0.41	0.24	0.43	0.92	0.20	0.49	0.23	3.69	2.57	0.54	1.06				
1988.07.05	----	----	----	----	----	----	----	----	----	----	----	----	2.15	0.51	0.02	0.38				
1988.07.12	----	----	----	----	1.38	0.58	0.06	0.51	0.65	0.16	0.53	0.28	1.27	2.89	0.21	0.54				
1988.09.11	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----				
1989.06.06	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----				
1989.06.12	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----				
1989.07.14	2.57	1.42	0.15	0.98	----	----	----	----	----	----	----	----	2.12	3.41	0.34	1.01				
1989.08.03	0.04	2.66	0.80	1.49	0.03	0.36	0.19	1.03	0.03	0.61	0.13	0.65	3.18	0.38	0.04	0.74				
1989.08.17	----	----	----	----	0.07	0.56	0.27	0.85	0.12	0.59	0.17	0.98	0.03	1.03	0.10	0.65				
1989.09.10	----	----	----	----	0.16	0.44	0.23	0.61	3.06	1.32	0.27	2.15	----	----	----	----				
Gretna clay:																				
1988.05.07	----	----	----	----	----	----	----	----	1.59	1.97	0.03	0.10	0.91	1.48	0.21	0.19				
1988.07.05	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----				
1988.07.06	0.25	2.40	0.01	0.27	1.00	1.22	0.32	0.17	0.55	0.56	0.57	0.06	0.11	0.59	0.34	0.06				
1988.09.11	----	----	----	----	1.44	1.95	0.00	0.07	2.01	2.21	0.00	0.10	----	----	----	----				
1989.06.12	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----				
1989.08.03	----	----	----	----	----	----	----	----	1.55	2.00	0.00	0.09	0.81	2.32	0.00	0.76				
1989.08.25	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----				
1989.09.10	----	----	----	----	2.15	1.05	0.00	0.09	2.81	2.49	0.00	0.10	----	----	----	----				
Ryerson sandy clay																				
1988.06.15	2.25	2.83	0.06	0.61	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
1988.07.06	0.33	1.40	0.01	1.30	0.60	0.77	0.16	0.60	0.26	0.56	0.01	0.38	0.29	0.65	0.02	0.22	0.51	0.68	0.06	0.45
1988.07.12	----	----	----	----	0.59	1.04	0.46	0.68	----[3]	----	----	----	1.00	0.58	0.05	0.34	0.48	0.94	0.24	0.53
1988.09.10	----	----	----	----	0.28	0.61	0.46	0.57	----	----	----	----	----	----	----	----	----	----	----	----
1988.09.18	----	----	----	----	0.10	0.50	0.05	0.51	----	----	----	----	----	----	----	----	----	----	----	----
1989.06.28	0.22	0.08	0.03	0.80	0.12	0.19	0.05	0.35	0.13	0.34	0.08	0.14	0.52	0.24	0.14	0.09	0.16	1.04	0.04	0.29
1989.08.11	----	----	----	----	1.00	0.43	0.09	0.46	0.71	1.27	0.34	0.71	2.09	1.49	0.24	0.39	2.72	0.43	0.02	0.87
1989.09.03	----	----	----	----	0.27	0.34	0.17	0.31	----	----	----	----	----	----	----	----	----	----	----	----
Carroll clay loam:																				
1988.05.07	1.61	0.75	0.02	0.06	0.15	0.93	0.49	0.30	0.15	1.97	0.46	0.82	0.21	1.54	0.42	0.20	----	----	----	----
1988.06.14	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
1988.07.06[2]	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
1988.07.13	0.20	0.71	0.01	0.20	0.23	0.52	0.02	0.10	0.28	5.69	0.47	0.52	0.10	0.65	0.02	0.10	0.15	1.16	0.03	0.43
1988.08.18	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
1988.09.10	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
1988.09.18	----	----	----	----	0.22	1.49	0.04	0.25	----	----	----	----	----	----	----	----	----	----	----	----

1. No sample due to a drainage problem.
2. System failed because of lightening strike prior to rainfall.
3. Fallow not sampled because of silting on the Coshocton sampler.

Table 4.29 Dissolved nutrient losses in runoff from experimental sites 1988-1989.

Date of	Alfalfa				Corn				Fallow				CT Wheat				MT Wheat			
Storm	NH_4^+	NO_3^-	NO_2^-	PO_4	NH_4^+	NO_3^-	NO_2^-	PO_4	NH_4^+	NO_3^-	NO_2^-	PO_4	NH_4^+	NO_3^-	NO_2^-	PO_4	NH_4^+	NO_3^-	NO_2^-	PO_4
	$g\ ha^{-1}$																			
Leary sandy loam:																				
1988.06.01	----	----	----	----	0.02	0.05	0.03	0.05	0.01	0.00	0.01	0.00	0.11	0.08	0.02	0.03				
1988.07.05	----	----	----	----	----	----	----	----	----	----	----	----	0.12	0.03	0.00	0.02				
1988.07.12	----	----	----	----	0.05	0.02	0.00	0.02	0.02	0.01	0.02	0.01	0.02	0.19	0.01	0.04				
1988.09.11	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----				
1989.06.06	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----				
1989.06.12	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----				
1989.07.14	0.01	0.01	0.00	0.00	----	----	----	----	----	----	----	----	0.02	0.04	0.00	0.01				
1989.08.03	0.01	0.40	0.12	0.23	0.00	0.04	0.02	0.12	0.00	0.03	0.01	0.03	0.26	0.03	0.00	0.06				
1989.08.17	----	----	----	----	0.00	0.02	0.01	0.03	0.00	0.01	0.00	0.01	0.00	0.02	0.00	0.01				
1989.09.10	----	----	----	----	0.00	0.01	0.00	0.01	0.05	0.02	0.00	0.04	----	----	----	----				
Gretna clay:																				
1988.05.07	----	----	----	----	----	----	----	----	0.08	0.11	0.00	0.01	0.02	0.03	0.01	0.00				
1988.07.05	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----				
1988.07.06	0.00	0.03	0.00	0.00	0.09	0.11	0.03	0.02	0.09	0.10	0.10	0.01	0.01	0.03	0.02	0.00				
1988.09.11	----	----	----	----	0.03	0.04	0.00	0.00	0.05	0.05	0.00	0.00	----	----	----	----				
1989.06.12	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----				
1989.08.03	----	----	----	----	----	----	----	----	0.03	0.04	0.00	0.00	0.01	0.03	0.00	0.01				
1989.08.25	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----				
1989.09.10	----	----	----	----	0.10	0.05	0.00	0.00	0.13	0.11	0.00	0.00	----	----	----	----				
Ryerson sandy clay																				
1988.06.15	0.01	0.01	0.00	0.00	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
1988.07.06	0.00	0.01	0.00	0.01	0.04	0.05	0.01	0.04	0.02	0.04	0.00	0.03	0.04	0.08	0.00	0.03	0.07	0.10	0.01	0.06
1988.07.12	----	----	----	----	0.02	0.04	0.02	0.03	----[3]	----	----	----	0.02	0.01	0.00	0.01	0.01	0.01	0.00	0.01
1988.09.10	----	----	----	----	0.01	0.02	0.02	0.02	----	----	----	----	----	----	----	----	----	----	----	----
1988.09.18	----	----	----	----	0.01	0.03	0.00	0.03	----	----	----	----	----	----	----	----	----	----	----	----
1989.06.28	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00
1989.08.11	----	----	----	----	0.04	0.02	0.00	0.02	0.02	0.03	0.01	0.02	0.03	0.02	0.00	0.01	0.06	0.01	0.00	0.02
1989.09.03	----	----	----	----	0.00	0.01	0.00	0.01	----	----	----	----	----	----	----	----	----	----	----	----
Carroll clay loam:																				
1988.05.07	0.12	0.05	0.00	0.00	0.00	0.02	0.01	0.01	0.01	0.08	0.02	0.03	0.01	0.53	0.02	0.01	----	----	----	----
1988.06.14	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
1988.07.06[2]	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
1988.07.13	0.01	0.04	0.00	0.01	0.05	0.12	0.00	0.02	0.08	1.69	0.14	0.15	0.02	0.12	0.00	0.02	0.03	0.21	0.01	0.08
1988.08.18	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
1988.09.10	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
1988.09.18	----	----	----	----	0.00	0.02	0.00	0.00	----	----	----	----	----	----	----	----	----	----	----	----

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1. No sample due to a drainage problem.
2. System failed because of lightening strike prior to rainfall.
3. Fallow not sampled because of silting on the Coshocton sampler.

Ryerson SCL (1.25 to 1) and mid June on the Carroll CL (0.47 to 1).

Table 4.30 provides total nitrogen losses in g ha^{-1} in the dissolved phase. For all treatments, the dissolved fraction represented only 0.5% of the total nitrogen losses.

Table 4.30 Total dissolved nitrogen losses 1988 and 1989.

	Leary SL	Gretna C	Ryerson SCL	Carroll CL
	g N ha^{-1}			
Alfalfa	0.55	0.03	0.02	0.22
Corn	0.27	0.45	0.35	0.22
Fallow	0.19	0.89	0.13	2.02
CT wheat	0.95	0.16	0.21	0.70
MT wheat			0.01	0.25

4.6.1.1 Ammonium nitrogen in the dissolved fraction of surface runoff

The total losses of NH_4^+ in the dissolved fraction of runoff are given in Table 4.31. The greatest losses in the dissolved fraction were from the wheat treatment on the Leary SL (0.53 g ha^{-1}) and from the fallow treatment on the Gretna C (0.38 g ha^{-1}). These losses are 2 orders of magnitude lower than annual losses reported by Burwell et al (1975) and Timmons and Holt (1977). This may be related to the fact that 1988 and

Table 4.31 Dissolved ammonium nitrogen losses 1988 and 1989.

	Leary SL	Gretna C	Ryerson SCL	Carroll CL
	g N ha^{-1}			
Alfalfa	0.02	0.00	0.01	0.13
Corn	0.07	0.22	0.12	0.05
Fallow	0.08	0.38	0.04	0.09
CT wheat	0.53	0.04	0.10	0.03
MT wheat			0.13	0.03

1989 were dry years.

Concentrations of ammonium nitrogen were higher on fallow and corn treatments on the Gretna C (>2.0 $\mu g\ g^{-1}$) in September than at other times of the year. There were no September samplings from the wheat treatment. The highest concentration for all treatments was the Leary SL wheat on June 1, 1988 (3.7 $\mu g\ g^{-1}$). Concentrations decreased on the next 2 samplings.

On the Gretna C, concentrations of ammonium in 1988 were higher in May than in July on both the wheat (0.9 $\mu g\ g^{-1}$ to 0.1 $\mu g\ g^{-1}$) and fallow (1.6 $\mu g\ g^{-1}$ to 0.6 $\mu g\ g^{-1}$) treatments. The May sampling events occurred one day after fertilizer was applied. Higher ammonium concentrations were noted from the alfalfa treatment following fertilizer applications than later in July on both the Ryerson SCL (2.3 $\mu g\ g^{-1}$ to 0.3 $\mu g\ g^{-1}$) and the Carroll CL (1.6 $\mu g\ g^{-1}$ to 0.2 $\mu g\ g^{-1}$).

Total dissolved nitrogen losses in the form of ammonium on the minimum till wheat treatments were not different from the conventional till wheat treatments on either the Ryerson SCL or the Carroll CL. Concentrations of ammonium varied with each sampling event, but the variation appeared to be completely random.

4.6.1.2 Nitrate and nitrite nitrogen in the dissolved fraction of surface runoff

Table 4.32 contains dissolved nitrate and nitrite losses for 1988 and 1989. Total losses of nitrate ranged from 0.02 g ha^{-1} from the alfalfa treatment on the Ryerson SCL to 1.80 g ha^{-1} from the fallow treatment on the Carroll CL. Nitrite losses were smaller than nitrate in all

Table 4.32 Dissolved nitrate and nitrite nitrogen losses 1988 and 1989 .

	Leary SL		Gretna C		Ryerson SCL		Carroll CL	
	NO_3^-	NO_2^-	NO_3^-	NO_2^-	NO_3^-	NO_2^-	NO_3^-	NO_2^-
	$g\ N\ ha^{-1}$							
Alfalfa	0.41	0.12	0.03	0.00	0.02	0.00	0.09	0.00
Corn	0.14	0.06	0.20	0.03	0.18	0.05	0.16	0.01
Fallow	0.07	0.04	0.41	0.10	0.08	0.01	1.77	0.16
CT wheat	0.39	0.03	0.09	0.03	0.11	0.00	0.65	0.02
MT wheat					0.13	0.01	0.21	0.01

treatments and ranged from 0 g ha^{-1} to 0.16 g ha^{-1}. These losses were 2 to 3 orders of magnitude smaller than the annual losses reported from native prairie in Minnesota by Timmons and Holt (1977).

Nitrate concentrations ranged from 0.08 $\mu g\ g^{-1}$ from the alfalfa treatment on the Ryerson SCL to 5.69 $\mu g\ g^{-1}$ from the fallow treatment on the Carroll CL (Table 4.32). All events were lower than the 8 $\mu g\ g^{-1}$, which is generally regarded as a maximum concentration for drinking water. Nitrite concentrations ranged from 0 to 0.80 $\mu g\ g^{-1}$ from the alfalfa treatment on the Leary SL.

Concentrations of nitrate and nitrite were not higher following fertilizer application than at other times of the year.

Concentrations of nitrate decreased when the volume of runoff increased. The lowest concentration of nitrate in 1988 on the Gretna C occurred on July 6, the largest runoff event. Likewise, the lowest nitrate concentrations on the Leary SL were on August 3 1989 and on the Carroll CL on July 13 1988, the largest runoff event at these two sites.

Concentration of nitrates were higher from the minimum till wheat treatment than from the conventional till wheat treatment in 4 out of 5 sampling events on the Carroll CL and Ryerson SCL.

4.6.2 Total dissolved phosphorus in surface runoff

Accumulated losses of total dissolved phosphorus for 1988 and 1989 are reported in Table 4.33. Losses ranged from 0 g ha^{-1} to 0.23 g ha^{-1} from the alfalfa and corn treatments on the Leary SL. This was three orders of magnitude less than the losses reported from native prairie by Timmons and Holt (1977). The phosphorus losses in the dissolved fraction from the alfalfa treatment accounted for 0.1% of the total phosphorus lost by erosion.

Table 4.33 Total dissolved phosphorus losses 1988 and 1989.

	Leary SL	Gretna C	Ryerson SCL	Carroll CL
	g P ha^{-1}			
Alfalfa	0.23	0.00	0.01	0.01
Corn	0.23	0.02	0.16	0.03
Fallow	0.09	0.02	0.05	0.18
CT wheat	0.17	0.01	0.05	0.03
MT wheat			0.09	0.08

Concentrations of dissolved phosphorus were 0.06 $\mu g\ g^{-1}$ from the fallow and wheat treatments on the Gretna C, and the alfalfa treatment on the Carroll CL, to 2.15 $\mu g\ g^{-1}$ from the fallow treatment on the Leary SL. There were no observable seasonal differences in concentration of dissolved phosphorus.

Soil texture may have had an effect on dissolved phosphorus losses. Concentrations and total losses of dissolved phosphorus were lowest from the finer textured Gretna C and highest from the coarse textured Leary SL.

Concentrations of phosphorus were higher from the minimum till wheat treatment than the conventional till wheat treatment on the Carroll CL and Ryerson SCL in all runoff events. Total phosphorus losses were about double from the minimum till wheat treatment over the conventional till wheat treatment.

4.7 Implications for eutrophication

Even though 1988 and 1989 provided little water erosion, concentrations of ammonium, nitrate and phosphorus may be a cause for some concern.

Algal bloom can be accelerated by concentrations of 0.03 $\mu g\ g^{-1}$ of ammonium. Measured ammonium concentrations ranged from 0.03 to 3.69 $\mu g\ g^{-1}$.

Phosphorus concentrations in the runoff water from each runoff event exceeded 0.05 $\mu g\ P\ g^{-1}$, the level recommended for surface waters to maintain an ecological balance. An even lower level of 0.01 $P\ \mu g\ g^{-1}$ can accelerate algal growth in standing waters. Concentrations of up to 2.15 $\mu g\ P\ g^{-1}$ were observed in this experiment.

Although these observations point to increased algal growth, caution must be taken when considering the size of the receiving body of water and the total amount of runoff received by the water. In years such as 1990 and 1991 when larger runoff events were observed, eutrophication may have been a problem. In years such as 1988 and 1989 or on well managed land where runoff is minimized, loading of phosphorus and ammonium in larger bodies would have been minimal and not likely contributed to eutrophication.

5. SUMMARY and CONCLUSION

Soil loss was found to increase with maximum 30 minute intensity and the erosivity index, but was not greatly influenced by total rainfall or the duration of the rainfall. Higher antecedent moisture contents prior to rainfall initiated runoff at an earlier time and therefore increased total soil loss. Crop stage did not seem to influence soil loss, however, crop type did. Alfalfa was very effective in reducing soil loss. Wheat was more effective than corn or fallow. Soil loss was highest from the fine textured Gretna C followed by the coarse textured Leary SL. The medium textured Carroll CL and Ryerson SCL had much lower soil losses in this study.

The sediment fraction accounted for more than 99% of total nitrogen and total phosphorus losses in surface runoff.

Total nitrogen and phosphorus losses were variable from year to year. Total nitrogen losses on the Gretna C in 1990 were 455 kg ha^{-1}, 272 kg ha^{-1} and 418 kg ha^{-1} accounting for 95%, 90% and 86% of total nitrogen lost from the corn, wheat and fallow treatments, respectively, during the three year study. Similarly, total phosphorus losses in 1990 were 94% (193 kg ha^{-1}), 91% (112 kg ha^{-1}) and 89% (216 kg ha^{-1}) of the total losses on the Gretna C. The largest losses came from a small number of large, intense storms such as June 1, 1990 on the Gretna C which accounted for 48% of the total phosphorus and 59% total nitrogen loses during the study from corn (99 kg ha^{-1} total phosphorus and 283 kg ha^{-1} total nitrogen). Total nitrogen and total phosphorus losses were significantly lower from the alfalfa treatments. Losses from the wheat treatments were lower than from the corn and fallow treatments.

Total nitrogen concentrations were higher from post harvest residues than from cropped plots. The level of significance was greater on the coarser textured soils. Total nitrogen concentration in runoff sediment was highest from the alfalfa treatments and lowest from the corn and fallow treatments. Total nitrogen concentration was highest from the medium textured soils and lowest from the coarse textured soil.

There were no statistically significant seasonal variations in total phosphorus concentrations in runoff sediment in this study. Seasonal variations in total phosphorus concentrations were not consistent over soil textures or crop types. There were no consistent differences in mean total phosphorus concentration among crop type. Total phosphorus concentration was highest from the Gretna C and Ryerson SCL and lowest from the Leary SL.

Total nitrogen and total phosphorus losses were found to be very closely correlated with soil loss (r^2=0.954 to 0.999 for total nitrogen and 0.921 to 0.999 for total phosphorus), but the regression coefficients varied with soil texture and crop type. Total nitrogen concentration was not as easily predicted. Total rainfall, the duration of the rainfall and maximum 30 minute intensity vs. total nitrogen concentration was found to be a non-linear function, but r^2 values only ranged from 0.47 to 0.55. The addition of the variable soil loss improved these regression coefficients ranging from 0.57 to 0.71. More observations are needed to improve this correlation.

Ammonium concentration in the dissolved fraction ranged from 0.03 to 3.69 $\mu g\ g^{-1}$, which exceeds the 0.03 $\mu g\ g^{-1}$ needed for accelerated algal growth. Concentrations of total phosphorus were as high as 2.15 $\mu g\ g^{-1}$, much higher than the 0.01 $\mu g\ g^{-1}$ needed to accelerate algal growth in standing waters. For the most part concentrations of nitrates were far below 8 $\mu g\ g^{-1}$ which is generally regarded as the maximum concentration acceptable for drinking water. All concentrations were lower with larger storms. Thus, these studies indicated that there is very little danger of nutrient loading, especially where runoff is limited by good management practices.

These results were based on only three years data. Because of the temporal variability of rainfall and moisture conditions a much larger data base is needed to better quantify nitrogen and phosphorus losses.

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APPENDIX A: Summary of field operations.

Table A.1. Summary of field operations for Leary sandy loam in 1988.

Wheat	May 9	broadcast fertilizer	hand spread
		N (110 kg ha^{-1})	
		S (15 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		seeded (50 kg ha^{-1})	1.5m press drill
		P_2O_5 (35 kg ha^{-1})	
	May 26	Hoegrass II (3.5 L ha^{-1})	back pack sprayer
	Aug 15	harvest	Sickle mower
		removed residues	
	Sept 30	deep tillage	2.3m cultivator
Corn	May 9	broadcast fertilizer	hand spread
		N (110 kg ha^{-1})	
		S (15 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		P_2O_5 (35 kg ha^{-1})	1.5m press drill
		seeded (75000 plants ha^{-1})	jab planter
	June 7	Aatrex Plus (4.5 L ha^{-1})	back pack sprayer
	June 15	cultivated (2 passes)	2.3m cultivator
	Aug 23	harvest	hand sickle
		removed residues	
	Sept 30	deep tillage	2.3m cultivator
Alfalfa	May 9	broadcast fertilizer	hand spread
		P_2O_5 (35 kg ha^{-1})	
		S (15 kg ha^{-1})	
		N (20 kg ha^{-1})	
	June 7	Fusilade (2.0 L ha^{-1})	back pack sprayer
	June 22	harvest	sickle mower
		removed residues	
Fallow	May 9	cultivation (2 passes)	2.3m cultivator
	June 15	cultivation (2 passes)	2.3m cultivator
	July 20	cultivation (2 passes)	2.3m cultivator
	Aug 24	cultivation (2 passes)	2.3m cultivator
	Sept 30	deep tillage	2.3m cultivator

Table A.2. Summary of field operations for Gretna clay in 1988.

Wheat	May 6	broadcast fertilizer	hand spread
		N (50 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		seeded (50 kg ha^{-1})	1.5m press drill
		P_2O_5 (35 kg ha^{-1})	
	May 31	Hoegrass II (3.5 L ha^{-1})	back pack sprayer
	June 3	irrigation (750 L)	
	Aug 15	harvest	sickle mower
		removed residues	
	Sept 30	deep tillage	2.3m cultivator
Corn	May 6	broadcast fertilizer	hand spread
		N (100 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		seeded (75000 plants ha^{-1})	jab planter
		P_2O_5 (45 kg ha^{-1})	1.5m press drill
	June 3	irrigation (750 L)	
	June 7	Aatrex Plus (4.5 L ha^{-1})	back pack sprayer
	Aug 23	harvest	hand sickle
		removed residues	
	Sept 30	deep tillage	2.3m cultivator
Alfalfa	May 6	broadcast fertilizer	hand spread
		P_2O_5 (50 kg ha^{-1})	
		S (30 kg ha^{-1})	
		N (33 kg ha^{-1})	
	June 3	irrigation (900 L)	
	June 7	Fusilade (2 L ha^{-1})	back pack sprayer
	June 22	harvest	sickle mower
		removed residues	
	Aug 30	irrigation (900 L)	
Fallow	May 6	cultivation (2 passes)	2.3m cultivator
	June 3	irrigation (750 L)	
	June 15	cultivation (2 passes)	2.3m cultivator
	July 20	cultivation (2 passes)	2.3m cultivator
	Aug 24	cultivation (2 passes)	2.3m cultivator
	Sept 30	deep tillage	2.3m cultivator

Table A.3. Summary of field operations for Ryerson sandy clay loam in 1988.

Wheat	May 5	broadcast fertilizer	hand spread
		N (40 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		seeded (50 kg ha^{-1})	1.5m drill press
		P_2O_5 (45 kg ha^{-1})	
	June 1	Hoegrass II (3.5 L ha^{-1})	back pack sprayer
		MCPA Ester (8 L ha^{-1})	back pack sprayer
	Aug 17	harvest	sickle mower
		removed residues	
	Sept 13	Roundup	back pack sprayer
	Oct 1	deep tillage	2.3m cultivator
Corn	May 5	broadcast fertilizer	hand spread
		N (40 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		P_2O_5 (45 kg ha^{-1})	1.5m press drill
		seeded (75000 plants ha^{-1})	jab planter
	June 8	Aatrex Plus (7 L ha^{-1})	back pack sprayer
	June 15	cultivation (2 passes)	2.3m cultivator
	Aug 17	harvest	hand sickle
		removed residues	
	Oct 1	deep tillage	2.3m cultivator
Alfalfa	May 5	broadcast fertilizer	hand spread
		P_2O_5 (30 kg ha^{-1})	
		S (30 kg ha^{-1})	
		N (33 kg ha^{-1})	
	June 7	Fusilade (2 L ha^{-1})	back pack sprayer
	June 22	harvest	sickle mower
		removed residues	
	Aug 3	harvest	sickle mower
			remove residues
Fallow	May 5	cultivation (2 passes)	2.3m cultivator
	June 15	cultivation (2 passes)	2.3m cultivator
	July 20	cultivation (2 passes)	2.3m cultivator
	Aug 24	cultivation (2 passes)	2.3m cultivator
	Oct 1	deep tillage	2.3m cultivator
Min till	May 5	broadcast fertilizer	hand spread
		N (50 kg ha^{-1})	
		cultivation	2.3m cultivator
		harrow	diamond harrows
		seeded (50 kg ha^{-1})	1.5m drill press
		P_2O_5 (45 kg ha^{-1})	1.5m press drill
	June 1	Hoegrass II (3.5 L ha^{-1})	back pack sprayer
		MCPA Ester (8 L ha^{-1})	back pack sprayer
	Aug 17	harvest	sickle mower
		removed residues	
	Sept 13	Roundup	back pack sprayer

Table A.4. Summary of field operations for Carroll clay loam in 1988.

Wheat	May 6	broadcast fertilizer	hand spread
		N (90 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		seeded (50 kg ha^{-1})	1.5m drill press
		P_2O_5 (45 kg ha^{-1})	
	June 1	Hoegrass II (3.5 L ha^{-1})	back pack sprayer
	July 6	MCPA Amine (8 L ha^{-1})	back pack sprayer
	Aug 15	harvest	sickle mower
		removed residues	
	Sept 13	Roundup	back pack sprayer
	Oct 1	deep tillage	2.3m cultivator
Corn	May 5	broadcast fertilizer	hand spread
		N (40 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		P_2O_5 (45 kg ha^{-1})	1.5m drill press
		seeded (75000 plants ha^{-1})	jab planter
	June 8	Aatrex Plus (7 L ha^{-1})	back pack sprayer
	June 15	cultivation (2 passes)	2.3m cultivator
	Sept 13	harvest	hand sickle
		removed residues	
		Roundup	back pack sprayer
	Oct 1	deep tillage	2.3m cultivator
Alfalfa	May 5	broadcast fertilizer	hand spread
		P_2O_5 (50 kg ha^{-1})	
		N (11 kg ha^{-1})	
	June 22	harvest	sickle mower
		removed residues	
	Aug 3	harvest	sickle mower
			remove residues
Fallow	May 6	cultivation (2 passes)	2.3m cultivator
	June 15	cultivation (2 passes)	2.3m cultivator
	July 21	cultivation (2 passes)	2.3m cultivator
	Aug 25	cultivation (2 passes)	2.3m cultivator
	Oct 1	deep tillage	2.3m cultivator
Min till	May 6	broadcast fertilizer	hand spread
		N (100 kg ha^{-1})	
		cultivation	2.3m cultivator
		harrow	diamond harrows
		seeded (50 kg ha^{-1})	1.5m drill press
		P_2O_5 (45 kg ha^{-1})	
	June 1	Hoegrass II (3.5 L ha^{-1})	back pack sprayer
	July 6	MCPA Ester (8 L ha^{-1})	back pack sprayer
	July 27	MCPA Ester (8 L ha^{-1})	back pack sprayer
	Aug 15	harvest	sickle mower
		removed residues	
	Sept 13	Roundup	back pack sprayer

Table A.5. Summary of field operations for Leary sandy loam in 1989.

Wheat	May 3	broadcast fertilizer	hand spread
		N (110 kg ha^{-1})	
		S (15 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		seeded (50 kg ha^{-1})	1.5m press drill
		P_2O_5 (35 kg ha^{-1})	
	May 26	Hoegrass II (3.5 L ha^{-1})	bicycle sprayer
	June 2	Hoegrass II (3.5 L ha^{-1})	bicycle sprayer
	Aug 9	harvest	Sickle mower
		removed residues	
	Sept 5	Roundup	back pack sprayer
	Sept 27	deep tillage	2.3m cultivator
Corn	May 3	broadcast fertilizer	hand spread
		N (110 kg ha^{-1})	
		S (15 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		P_2O_5 (35 kg ha^{-1})	1.5m drill press
		seeded (75000 plants ha^{-1})	jab planter
	June 14	cultivation (2 passes)	2.3m cultivator
	June 16	Aatrex (37 L ha^{-1})	bicycle sprayer
	Sept 20	harvest	hand sickle
		removed residues	
	Sept 27	deep tillage	2.3m cultivator
Alfalfa	May 3	broadcast fertilizer	hand spread
		N (26 kg ha^{-1})	
		P_2O_5 (35 kg ha^{-1})	
		S (30 kg ha^{-1})	
	June 28	harvest	sickle mower
		removed residues	
Fallow	May 3	cultivation (2 passes)	2.3m cultivator
	June 14	cultivation (2 passes)	2.3m cultivator
	July 11	cultivation (2 passes)	2.3m cultivator
	Aug 15	cultivation (2 passes)	2.3m cultivator
	Sept 27	deep tillage	2.3m cultivator

Table A.6. Summary of field operations for Gretna clay in 1989.

Wheat	May 3	broadcast fertilizer	hand spread
		N (50 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		seeded (50 kg ha^{-1})	1.5m press drill
		P_2O_5 (35 kg ha^{-1})	
	June 2	Hoegrass II (3.5 L ha^{-1})	bicycle sprayer
	Aug 9	harvest	sickle mower
		removed residues	
	Sept 4	Roundup	back pack sprayer
	Sept 27	deep tillage	2.3m cultivator
Corn	May 3	broadcast fertilizer	hand spread
		N (100 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		P_2O_5 (45 kg ha^{-1})	1.5m drill press
		seeded (75000 plants ha^{-1})	jab planter
	June 16	Aatrex (37 L ha^{-1})	bicycle sprayer
	June 20	cultivation (2 passes)	2.3m cultivator
	Sept 27	harvest	hand sickle
		removed residues	
	Sept 27	deep tillage	2.3m cultivator
Alfalfa	May 3	broadcast fertilizer	hand spread
		N (26 kg ha^{-1})	
		P_2O_5 (50 kg ha^{-1})	
		S (30 kg ha^{-1})	
	June 28	harvest	sickle mower
		removed residues	
	July 26	irrigation (900 L)	
Fallow	May 3	cultivation (2 passes)	2.3m cultivator
	June 20	cultivation (2 passes)	2.3m cultivator
	July 11	cultivation (2 passes)	2.3m cultivator
	Aug 15	cultivation (2 passes)	2.3m cultivator
	Sept 27	deep tillage	2.3m cultivator

Table A.7. Summary of field operations for Ryerson sandy clay loam in 1989.

Wheat	May 3	broadcast fertilizer	hand spread
		N (40 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		seeded (50 kg ha^{-1})	1.5m press drill
		P_2O_5 (45 kg ha^{-1})	
	May 26	Hoegrass II (3.5 L ha^{-1})	bicycle sprayer
	June 9	Hoegrass II (3.5 L ha^{-1})	bicycle sprayer
	June 16	Hoegrass II (7.0 L ha^{-1})	bicycle sprayer
	Aug 17	harvest	sickle mower
		removed residues	
	Sept 13	Roundup	back pack sprayer
	Sept 27	deep tillage	2.3m cultivator
Corn	May 3	broadcast fertilizer	hand spread
		N (40 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		P_2O_5 (45 kg ha^{-1})	1.5m drill press
		seeded (75000 plants ha^{-1})	jab planter
	June 16	Aatrex (37 L ha^{-1})	bicycle sprayer
	June 14	cultivation (2 passes)	2.3m cultivator
	Sept 27	harvest	hand sickle
		removed residues	
	Sept 27	deep tillage	2.3m cultivator
Alfalfa	May 3	broadcast fertilizer	hand spread
		N (26 kg ha^{-1})	
		P_2O_5 (50 kg ha^{-1})	
		S (30 kg ha^{-1})	
	June 22	harvest	sickle mower
		removed residues	
	Aug 3	harvest	sickle mower
		removed residues	
Fallow	May 3	cultivation (2 passes)	2.3m cultivator
	June 14	cultivation (2 passes)	2.3m cultivator
	July 12	cultivation (2 passes)	2.3m cultivator
	Aug 15	cultivation (2 passes)	2.3m cultivator
	Sept 27	deep tillage	2.3m cultivator
Min till	May 3	broadcast fertilizer	hand spread
		N (50 kg ha^{-1})	
		S (15 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		seeded (50 kg ha^{-1})	1.5m press drill
		P_2O_5 (45 kg ha^{-1})	
	May 26	Hoegrass II (3.5 L ha^{-1})	bicycle sprayer
	June 9	Hoegrass II (3.5 L ha^{-1})	bicycle sprayer
	Aug 17	harvest	sickle mower
		removed residues	

Table A.8. Summary of field operations for Carroll clay loam in 1989.

Wheat	May 4	broadcast fertilizer	hand spread
		N (40 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		seeded (50 kg ha^{-1})	1.5m press drill
		P_2O_5 (45 kg ha^{-1})	
	Aug 17	harvest	sickle mower
		removed residues	
	Sept 13	Roundup	back pack sprayer
	Sept 27	deep tillage	2.3m cultivator
Corn	May 4	broadcast fertilizer	hand spread
		N (100 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		P_2O_5 (45 kg ha^{-1})	1.5m drill press
		seeded (75000 plants ha^{-1})	jab planter
	June 15	cultivation (2 passes)	2.3m cultivator
	Sept 27	harvest	hand sickle
		removed residue	
	Sept 27	Roundup	back pack sprayer
	Oct 1	deep tillage	2.3m cultivator
Alfalfa	May 4	broadcast fertilizer	hand spread
		P_2O_5 (50 kg ha^{-1})	
		N (11 kg ha^{-1})	
	July 12	harvest	sickle mower
		removed residues	
Fallow	May 4	cultivation (2 passes)	2.3m cultivator
	June 15	cultivation (2 passes)	2.3m cultivator
	July 12	cultivation (2 passes)	2.3m cultivator
	Aug 16	cultivation (2 passes)	2.3m cultivator
	Oct 1	deep tillage	2.3m cultivator
Min till	May 4	fertilizer	hand spread
		N (90 kg ha^{-1})	
		cultivation	2.3m cultivator
		harrow	diamond harrows
		seeded (50 kg ha^{-1})	1.5m press drill
		P_2O_5 (45 kg ha^{-1})	
	Aug 17	harvest	sickle mower
		removed residues	
	Sept 13	Roundup	back pack sprayer

Table A.9. Summary of field operations for Leary sandy loam in 1990.

Wheat	May 22	broadcast fertilizer	hand spread
		N (15 kg ha^{-1})	
		S (15 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		seeded (50 kg ha^{-1})	1.5m press drill
		P_2O_5 (10 kg ha^{-1})	
	June 21	Hoegrass II (3.5 L ha^{-1})	bicycle sprayer
	Aug 28	harvest	Sickle mower
		removed residues	
	Sept 27	deep tillage	2.3m cultivator
Corn	May 22	broadcast fertilizer	hand spread
		N (15 kg ha^{-1})	
		S (15 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		P_2O_5 (10 kg ha^{-1})	1.5m press drill
		seeded (75000 plants ha^{-1})	jab planter
	July 5	cultivated (2 passes)	2.3m cultivator
	Sept 17	harvest	hand sickle
		removed residues	
	Sept 27	deep tillage	2.3m cultivator
Alfalfa	May 22	broadcast fertilizer	hand spread
		P_2O_5 (10 kg ha^{-1})	
		S (30 kg ha^{-1})	
		N (27 kg ha^{-1})	
	June 27	harvest	sickle mower
		removed residues	
Fallow	May 22	cultivation (2 passes)	2.3m cultivator
	July 5	cultivation (2 passes)	2.3m cultivator
	Aug 15	cultivation (2 passes)	2.3m cultivator
	Sept 27	deep tillage	2.3m cultivator

Table A.10. Summary of field operations for Gretna clay in 1990.

Wheat	May 25	broadcast fertilizer	hand spread
		N (18 kg ha^{-1})	
		S (15 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		seeded (50 kg ha^{-1})	1.5m press drill
		P_2O_5 (20 kg ha^{-1})	
	Aug 28	harvest	sickle mower
		removed residues	
	Sept 27	deep tillage	2.3m cultivator
Corn	May 25	cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		seeded (75000 plants ha^{-1})	jab planter
		P_2O_5 (45 kg ha^{-1})	1.5m press drill
		N (5 kg ha^{-1})	
	July 5	cultivation (2 passes)	2.3m cultivator
	Sept 19	harvest	hand sickle
		removed residues	
	Sept 27	deep tillage	2.3m cultivator
Alfalfa	May 25	broadcast fertilizer	hand spread
		P_2O_5 (20 kg ha^{-1})	
		N (5 kg ha^{-1})	
	June 21	harvest	sickle mower
		removed residues	
Fallow	May 25	cultivation (2 passes)	2.3m cultivator
	July 5	cultivation (2 passes)	2.3m cultivator
	Aug 15	cultivation (2 passes)	2.3m cultivator
	Sept 27	deep tillage	2.3m cultivator

Table A.11. Summary of field operations for Ryerson sandy clay loam in 1990.

Wheat	May 22	broadcast fertilizer	hand spread
		N (60 kg ha^{-1})	
		S (15 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		seeded (50 kg ha^{-1})	1.5m drill press
		P_2O_5 (45 kg ha^{-1})	
	June 26	Hoegrass II (3.5 L ha^{-1})	back pack sprayer
	Sept 6	harvest	sickle mower
			removed residues
	Sept 12	Roundup	back pack sprayer
	Sept 27	deep tillage	2.3m cultivator
Corn	May 22	broadcast fertilizer	hand spread
		N (40 kg ha^{-1})	
		S (15 kg ha^{-1})	
		K (60 kg ha^{-1})	
		cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		P_2O_5 (40 kg ha^{-1})	1.5m press drill
	Sept 28	seeded (75000 plants ha^{-1})	jab planter
	July 5	cultivation (2 passes)	2.3m cultivator
	Sept 19	harvest	hand sickle
		removed residues	
	Sept 27	deep tillage	2.3m cultivator
Alfalfa	May 22	broadcast fertilizer	hand spread
		P_2O_5 (55 kg ha^{-1})	
		S (30 kg ha^{-1})	
		N (38 kg ha^{-1})	
	July 5	harvest	sickle mower
		removed residues	
Fallow	May 22	cultivation (2 passes)	2.3m cultivator
	July 5	cultivation (2 passes)	2.3m cultivator
	Aug 15	cultivation (2 passes)	2.3m cultivator
	Sept 27	deep tillage	2.3m cultivator
Min till	May 22	broadcast fertilizer	hand spread
		N (50 kg ha^{-1})	
		S (15 kg ha^{-1})	
		cultivation	2.3m cultivator
		harrow	diamond harrows
		seeded (50 kg ha^{-1})	1.5m press drill
		P_2O_5 (20 kg ha^{-1})	
	June 26	Hoegrass II (3.5 L ha^{-1})	bicycle sprayer
	Sept 6	harvest	sickle mower
		removed residues	
	Sept 12	Roundup	back pack sprayer

Table A.12. Summary of field operations for Carroll clay loam in 1990.

Wheat	May 23	cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		seeded (50 kg ha^{-1})	1.5m drill press
		P_2O_5 (35 kg ha^{-1})	
		N (9 kg ha^{-1})	
	June 26	Hoegrass II (3.5 L ha^{-1})	bicycle sprayer
	Sept 6	harvest	sickle mower
		removed residues	
	Sept 13	Roundup	back pack sprayer
	Sept 28	deep tillage	2.3m cultivator
Corn	May 23	cultivation (2 passes)	2.3m cultivator
		harrow	diamond harrows
		P_2O_5 (35 kg ha^{-1})	1.5m drill press
		N (9 kg ha^{-1})	
		seeded (75000 plants ha^{-1})	jab planter
	July 6	cultivation (2 passes)	2.3m cultivator
	Sept 20	harvest	hand sickle
		removed residues	
	Sept 28	deep tillage	2.3m cultivator
Alfalfa	May 23	broadcast fertilizer	hand spread
		P_2O_5 (55 kg ha^{-1})	
		S (30 kg ha^{-1})	
		N (28 kg ha^{-1})	
	July 6	harvest	sickle mower
		removed residues	
Fallow	May 23	cultivation (2 passes)	2.3m cultivator
	July 6	cultivation (2 passes)	2.3m cultivator
	Aug 16	cultivation (2 passes)	2.3m cultivator
	Sept 28	deep tillage	2.3m cultivator
Min till	May 23	cultivation	2.3m cultivator
		harrow	diamond harrows
		seeded (50 kg ha^{-1})	1.5m drill press
		P_2O_5 (45 kg ha^{-1})	
		N (10 kg ha^{-1})	
	June 26	Hoegrass II (3.5 L ha^{-1})	bicycle sprayer
	Sept 6	harvest	sickle mower
		removed residues	
	Sept 13	Roundup	back pack sprayer

Appendix B Biomass and grain yields 1988 - 1990.

Crop Yields 1988

	Leary SL	Gretna C	Ryerson SCL	Carroll CL
	-------------------kg ha^{-1}----------------			
	Biomass			
Alfalfa	1810	2200	5340	4010
Corn	1930	2910	4040	3490
CT Wheat	4080	3080	3440	2560
MT Wheat			6800	2600
	Grain Yield			
CT Wheat	1900	2920	2940	2360
MT Wheat			3120	2290

Crop Yields 1989

	Leary SL	Gretna C	Ryerson SCL
	Biomass		
Alfalfa	2230	1950	4620
Corn	4480	1740	4140
CT Wheat	4560	4850	4650
MT Wheat			3710
	Grain Yield		
CT Wheat	1030	2060	2010
MT Wheat			1680

Crop Yields 1990

	Leary SL	Gretna C	Ryerson SCL	Carroll CL
	-------------------kg ha^{-1}----------------			
	Biomass			
Alfalfa	4030	1910	4210	4810
Corn	3350	3660	3290	3090
CT Wheat	5080	4880	7120	3720
MT Wheat			7160	2960
	Grain Yield			
CT Wheat	2280	2000	3120	2880
MT Wheat			3360	2530

Appendix C Antecedent concentration of total nitrogen and total phosphorus October 1987.

	Leary SL	Gretna C	Ryerson SCL	Carroll CL
	Total Nitrogen			
	$\mu g\ g^{-1}$			
Alfalfa	832	2286	3308	2658
Corn	568	2546	2420	2319
CT Wheat	525	2418	2146	2911
MT Wheat	---	----	2508	2545
Fallow	408	1630	2216	2374
	Total Phosphorus			
	$\mu g\ g^{-1}$			
Alfalfa	468	1004	737	783
Corn	519	1042	716	793
CT Wheat	494	917	714	823
MT Wheat	---	---	741	767
Fallow	514	788	677	757

Appendix D Additional soil physical properties.

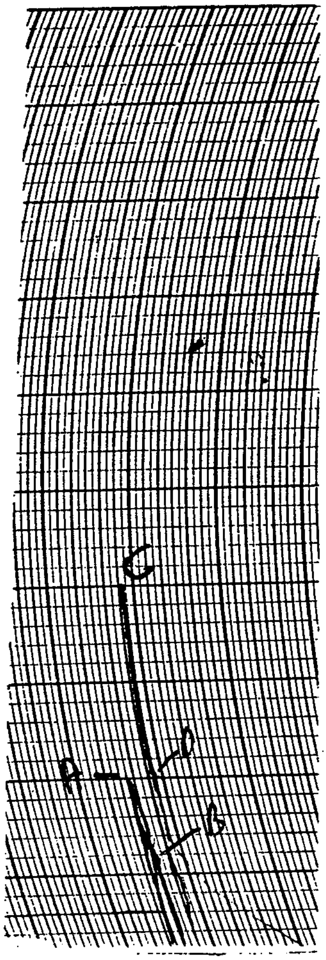
Soil Type	OM	Montmorillonite	Suspension	Dispersion	Aggregate Index	PWP
	%					%
Leary SL	0.9	3.0	3.2	13.0	0.1	7.3
Gretna C	4.3	11.0	15.0	19.1	0.9	18.0
Ryerson SCL	5.8	6.7	9.4	22.2	0.2	13.5
Carroll CL	4.9	7.8	11.2	19.3	0.4	14.5

Appendix E Evaluation of water level recorder chart.

Table E. Runoff example from Gretna C fallow May 20, 1990.

Level	Time (min)
10.1	10
0.0	5
5.9	5
0.0	5
20.1	10
0.0	5
10.5	5
0.0	10

Total rainfall 16.2 mm
Duration 481 min
Runoff 492 L



A problem was encountered reading a chart because it reflected sediment build up in the trough. Therefore it seemed to take longer to descend on the chart than was actually occurring. It was necessary to study the rainfall pattern to for the duration of rainfall with special attention to intense periods. Then the rainfall pattern was matched to the runoff pattern. The duration of the increasing flow was directly read from the chart. The decreasing flow was assumed to fall linearly to zero within 5 to 15 minutes to match the duration of intense rainfall. It was important to look for peaks on the chart. In the example given major peaks were found at A and C and minor peaks at B and D. This method was compared to actual runoff volumes collected and seemed to be a reasonable estimate for total runoff.

Appendix F Soil physical values for the experimental soils.

Grid No.	Si+VFS	Si+S	OM	Structure Code	Permeability Class	Aggregate Index	Bulk Density	Suspension Percentage	Dispersion Ratio
		-------------%----------					-%-		
Gretna C									
1	30.1	63.2	4.0	4	6	0.18	1.37	15.5	24.0
2	31.2	61.4	5.5	4	6	0.17	1.43	15.8	23.1
3	31.6	55.2	4.7	4	6	0.15	1.50	8.8	11.8
4	27.4	44.5	4.3	4	6	0.31	1.46	17.3	21.4
5	25.5	44.2	4.3	4	6	0.18	1.42	16.8	21.1
6	28.9	43.5	4.3	4	6	0.17	1.46	15.0	17.8
7	30.9	40.2	3.0	4	6	0.25	1.50	18.6	20.6
8	34.5	48.8	3.1	4	6	0.16	1.43	13.3	15.8
9	30.8	45.3	5.2	4	6	0.16	1.44	13.9	16.5
Leary SL									
1	23.2	89.4	0.5	4	2	0.19	1.52	3.7	15.7
2	23.0	88.4	1.0	4	2	0.11	1.54	3.3	13.5
3	22.2	87.6	0.8	4	2	0.09	1.55	3.9	15.7
4	24.7	91.4	0.8	4	2	0.04	1.58	2.9	13.0
5	21.5	91.0	1.1	4	2	0.04	1.62	3.7	19.0
6	22.9	90.0	1.0	4	2	0.08	1.56	2.8	11.9
7	25.9	87.8	0.8	4	2	0.23	1.50	2.5	8.6
8	25.1	87.0	0.6	4	2	0.19	1.51	3.3	10.9
9	28.8	88.0	1.2	4	2	0.07	1.55	2.7	8.6

Source, after Pauls (1987)

Appendix F continued. Soil physical values for the experimental soils.

Grid No.	Si+vfS	Si+S	OM	Structure Code	Permeability Class	Aggregate Index	Bulk Density	Suspension Percentage	Dispersion Ratio
	--------------	%	----------				-%-		
Ryerson SCL									
1	46.5	70.9	3.6	4	4	0.42	1.32	12.2	22.5
2	42.7	70.1	3.4	4	4	0.49	1.50	11.9	25.1
3	45.9	69.9	6.7	4	4	0.25	1.33	5.8	13.9
4	47.9	74.3	5.1	4	4	0.37	1.14	11.7	28.6
5	74.6	97.2	8.4	4	4	0.09	1.21	7.6	18.2
6	53.6	78.5	7.4	4	4	0.08	1.20	7.2	18.5
7	41.8	72.8	6.8	4	4	0.14	1.15	8.7	28.0
8	42.8	75.4	5.0	4	4	0.16	1.26	8.3	19.8
9	54.1	80.3	5.7	4	4	0.12	0.96	10.8	25.4
Carroll CL									
1	69.8	74.7	5.0	4	4	0.16	1.33	11.5	25.7
2	59.5	62.6	4.1	4	4	0.24	1.36	10.7	18.5
3	56.2	61.5	4.0	4	4	0.43	1.27	12.8	21.6
4	63.8	70.6	4.9	4	4	0.48	1.10	12.0	24.2
5	60.4	66.2	5.4	4	4	0.52	1.33	12.8	21.4
6	59.4	64.0	5.6	4	4	0.48	1.14	9.0	12.8
7	57.0	61.5	5.1	4	4	0.30	1.13	13.1	18.0
8	61.6	66.3	5.7	4	4	0.22	1.30	7.9	13.6
9	57.9	63.8	4.3	4	4	0.33	1.37	10.9	17.6

Source, after Wahome (1989)