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

by

Andrew Peter Hargrave

A thesis presented to the
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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:

$$\text{fallow} > \text{corn} > \text{oats} > \text{alfalfa}.$$

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)