A Detailed Study of Spring Soil Test Nutrients along a Catena Sequence in a Thin Black Chernozem[1]

R.W. Popoff[2] and D.W. Anderson

Department of Soil Science
University of Saskatchewan

Introduction

Knowledge of the strengths and weaknesses of soil test results is important to determining the most reliable and economical fertilizer management practices. Soils are heterogeneous and the available nutrient status can be affected and vary in three directions: distance (spatial variability), vertical (profile variability) and time (temporal variability). Variation in any one of these can have great importance for fertilizer recommendations and crop implications.

Soil testing is usually done in the fall or the spring and is a one point in time chemical extraction to determine the amount of plant available nutrients. Soil testing does not consider the entire growing season, and the variability that can occur. On the other hand, soil tests give a general idea at that particular time point in time of the nutrient status, are affordable by the producer, and can have quick turn around times.

Most of the plant required nutrients are subject to dynamic transformations in the soil over time and their fate and crop use is determined by both physical and sometimes biological factors. Other variables such as: climate, crop rotations, soil properties, soil horizons, fertilizer use and application, macro- and micro- environments, tillage practices and management will affect the distributions and carryover amounts of nutrients.

Research has been conducted into the major plant nutrients in the soil, by research stations, universities and soil testing laboratories on the prairies. Findings such as the build-up of nitrate (NO_3-N) is known to increase during a summerfallow period. It is also shown that in general, soil properties and NO_3-N are not usually normally distributed spatially (Biggar, 1978; Tomasiewicz,

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[1] Paper presented at the 1991 Soils and Crops Workshop, Feb. 21st and 22nd, University of Saskatchewan, Saskatoon, SK.

[2] Presently working at the Saskatchewan Crop Insurance Corporation, Melville, SK.

1990). Research using landform elements has also shown that there is a relationship between landforms and soil properties (Pennock et al., 1987; Popoff and Anderson, 1990).

There also has been evidence that the mobile nutrient $N0_3$-N was being leached beyond the rooting zone for cereal crops in years of above average rainfall and in dry years with heavy rains (Campbell et al., 1983; Campbell et al., 1984). Leaching of NO_3-N can occur under continuous cropping but will be greatest under summerfallow (Campbell et al., 1983). Losses of this nitrate can be minimized by proper fertilizer management, by growing fall seeded crops, reducing fallowing and increasing the crop rotation length.

Biederbeck et al. (1984) found that crop rotations showing a gradual build up of organic N in the top 15 cm of soil were also the rotations that made the most efficient use of NO_3-N located in the lower root zone. In wheat- fallow systems the NO_3-N would have been lost by leaching.

Campbell et al., (1984) found that there is a correlation between a change in extractable-P, comparing summerfallowed and cropped treatments. The extractable-P fraction during the summerfallow period was also related to moisture and temperature conditions (Campbell et al., 1984; O'Halloran, 1986). They also found that extractable bicarbonate-P status increased between late fall and spring thaw.

Plant uptake of P and N is directly related to dry matter production. Nitrate levels have also been shown to be directly related to grain protein (Spratt et al., 1975). Ferguson and Gorby (1971) found that crop productivity was closest related to the amount of nitrate-N to depth of 122 cm, and was not related to total soil N. Grain protein will also be maximized when the available N pool meets or exceeds the requirement for crop growth (Ferguson and Gorby, 1971).

Crop production in the future probably will be restricted because of the depletion of plant nutrients from the soil without appropriate additions (Pittman, 1977). Nutrients have not yet reached critical levels in many soils, as well as, technology is still masking the long-term effects of the degradation of these resources (Pittman, 1977).

The objective of this paper was to help understand the available nutrient dynamics of the major plant required elements along a catena sequence, under different management practices. Consideration has also been given to other factors affecting the available nutrient status. Crop yields will also be compared to available spring nutrients.

Materials and Methods

Sites

The study sites were located at Blaine Lake, SK, on loam textured Blaine Lake - Hamlin soils, with gleyed soils found in the depressional areas (Acton and Ellis, 1978). The soils are of glacio- lacustrine origin underlain with till. The topography is gently undulating knoll and depressions.

Each site was a five by six grid of sample locations along a catena, that was surveyed, and landform elements determined at each sample location (Pennock et al., 1987). Landform elements were determined to be converging (C), diverging (D) and level (L). For analysis in some cases, sites were grouped into the three major landform categories: shoulders (SH), backslopes (BS) and footslopes (FS) (Figure 1). Data analysis was also done on the individual sampling sites. Least significant difference (LSD) at 90% is the statistical analysis used to compare the sites and landform elements.

Five catenas were studied under different crop rotations and cultural practices (Table 1). Sites #1-4 were broke around the turn of the century and site #5 was broke around 25 years ago. The same general fertilizer practices was used on each sites, including timing of application and amounts of actual nutrient put down.

Table 1. Crop Rotations

Site #	Crop Rotation
1	Canola(89) - Wheat(90) - Summerfallow
2	Wheat - Wheat(89) - Summerfallow(90)
3	Continuous Cereals (Barley 89, Canola 90)
4	Continuous Cereals with a Grain Legume (Peas 89, Wheat 90)
5	*Continuous Cereals with a Grain Legume (Wheat 89, Wheat 90)

* Site #5 broke 25 years ago.

Sampling

Soil samples were taken in the Spring of 1989 (fourth week in May and first week in June) and in 1990 (third and fourth week of May). Soils were sampled at four depth increments: 0-15, 15-30, 30-60 and 60-90 cm. Analysis was done at each of the grid locations in 1989, and in 1990 samples were analyzed according to landscape position. Available nitrate and sulfate were determined for all four depths, extractable phosphorus (P) and potassium (K) on the 0-15 cm depth only.

Analysis

Soil samples were air dried and sent to the Saskatchewan Soil Testing Laboratory. For nitrate and sulfate, 25 g of soil was shaken with 50 ml of 0.001M CaCl for 30 minutes. Nitrate was determined using cadmium reduction and S with the methyl thymol blue technique. For extractable P and K, 2.5 g of soil was shaken for 30 minutes with 0.005M of sodium bicarbonate and brought to a pH of 8.5. P was determined colorimetrically and K flame photometrically.

Organic carbon and total nitrogen were determined by using a C-H-N analyzer which combusts the samples at high temperatures. Soil samples analyzed, were air dried and finely ground using a ring grinder.

Electrical conductivity was determined using a 1:1 soil water suspension for all four depths.

Results and Discussion

Sites and Sampling

It is very important to understand the nature of the variability of mobile nutrients nitrate (NO_3-N) and sulfate (SO_4-S). Factors such as sampling dates, sampling times in the crop rotation, climate, macro- and micro- environments, tillage practices and management will affect the amounts of nutrients from year to year and making interpretation in some cases difficult. It should also be noted that 1988 was a very dry year and will have increased residual available nutrient carryover into 1989.

The water table will influence much of the soil properties and fertility along the catena. All of these sites were flooded at least once in the spring from the snow melt. The sites may flood a number of times during the summer, dependant on the amount of rain and intensity. The soils were gleyed in the footslope from continuous flooding, affecting the pedology, soil properties (Popoff and Anderson, 1990) and available nutrients for plant growth.

The nutrient status and available nutrients are also tied to the organic carbon content of the soil. The highest amount of organic carbon in the sites were found to be on the backslopes and shoulders, and not in the footslope areas. Figure 2 compares the amount of total N in the soil to the plant available NO_3-N, to a 15 cm depth. There is no correlation between these two factors, suggesting the different micro- environments at each site have a greater influence on the NO_3-N and mineralization rates than does the total N content.

Nitrate-N and Sulfate-S

Comparing the 30 sampling sites in each rotation to the other crop rotation sites, there is a quite a noticeable difference (Figure 3). Site #3 has the highest plant available, partly because some of the footslopes sites were broken a few years ago, and in some of these areas high fertility still exists. Generally in site #3, very good fertility status still persists on the midslopes and knolls. Site #5 is the site that was broken only about 25 years ago and been continuously cropped. Higher amounts of organic matter (reduced rate of breakdown from cropping practices) coupled with the rates of mineralization, still maintain high levels of available N. Site #1 has higher amounts of N because the previous year it was in summerfallow and had carryover of NO_3-N compared to site

#2 (the other site with summerfallow). Site #4 had the lowest nitrate N status across the entire catena.

If we compare the nitrate-N in the soil for each of the landforms for site #1 and site #5 (Figures 4 and 5) the nitrate-N and sulfate-S (Figures 7 and 8) content in the footslopes areas were low compared to the higher shoulder and backslope landform elements. This is due to the leaching of these mobile nutrients and salts from the lower slope positions deeper into the profile. Site #5 in this case actually has the highest plant available N on the backslope. Because of minimal erosion, and N lost in the footslope by leaching, the backslope has the highest nitrate N.

Comparing the average of the sites for sulfate, site #3 has the highest available amounts (Figure 6). This done not necessarily mean that all the sampling sites are high. In these cases, high amounts of sulfate S was found in the sub-soil in the shoulders. The high amounts of sulfate-S will be dependant on the salt content. Sulfate-S was found to be significantly correlated with samples with high soluble salt content (Figure 9). This correlation is to be expected since the majority of sulfate-S is in as salt form with mainly Mg^{2+} and Na^{+} ions. Sites #1 and #2 have lower amounts of sulfate, and less salinity persisting underneath the knolls. The error bars are large in all of the cases, reflecting the high amount of variability within and between sites.

Salinity persists sometimes under the knolls were the lack of sufficient percolation of soil water has not moved soluble salts downward. A concentration in this area can be from the movement of the salt from the parent material down into a concentrated area (shoulder in Figure 8). It is highly unlikely that the accumulation of salts was from upward movement from a high water table since this phenomenon occurs on the knolls. No detected salinity was found in other areas of the catena suggesting that there is no saline seep in these sites, confirming the idea that the net movement of soil water, mobile nutrients and salts is downward.

The sulphur content in these soils is naturally high and there is no need for additional applications of sulphur to these soils to meet the requirements of plants. It can also be noted that sulfur can be both maintained in the soil by sulfate salts and as a component of organic matter. The addition of N fertilizer to the soil is only recommended in areas where low nitrate status exists. Site #2 and #4 may need additional N fertilization to reach maximum crop potential (according to soil test recommendations). In Saskatchewan, the addition of small but still significant N and S in rainfall can be present.

Extractable Phosphorus (P)

The extractable inorganic P in 1989 was highest in sites #4 and #5 (Figure 10). Sites #1 and #2 probably are low in extractable P because of erosion from the sites. This extractable-P only represents the plant available amount and probably does not reflect the total P status.

Extractable-P in all cases was found to be highest in the footslope areas (Figures 11 and 12). This is partially due to a pH effect, where the pH in the footslopes can drop to 6.0 - 5.5 and have a different form and higher extractable amounts of P (Figure 13).

A small addition of P fertilizer would possibly be warranted in site #2, but would be site specific.

Extractable Potassium (K)

Potassium is inherently high in these soils studied (Figure 14). The highest plant available plant amounts found in the footslopes (Figure 15). Speculating that this noticeable difference is from the enhanced weathering of K bearing minerals under moister conditions found in the lower catena positions.

No additional K fertilizer would be required at any of the 30 sampling locations for any of the sites.

Other Sampling Analysis

Besides spatial and temporal variability, profile variability is also present (Figure 16). (Sampling scheme for this analysis is denoted by square boxes in Figure 1). As expected NO_3-N (and the other extractable nutrients) decrease with depth in the majority of cases. The knoll and midslope site (Figure 16) could have the nitrate leached into the lower depths, increasing the amounts of nitrate N in the lower sampling layer. The variability of the nitrate N in the 0-15 cm layer can be quite large in some instances.

A comparison was made between four individual sampling sites (sampling scheme denoted by the four sampling sites circled in Figure 1) and bulking all four of the samples before analysis. Nutrients were analyzed to determine if landform analysis would give a good approximation of nutrient status.

e. g. Site #1 1989 Four sampling sites (footslope positions) for 0-15 cm,
$N0_3$-N (kg/ha)

#Footslope 38.11 kg/ha	#FS 67.25	
		Ave=48.73 kg/ha
#FS 49.32	#FS 40.35	

Bulking Footslope Landform = 43.71 kg/ha

Although bulking (43.71 kg/ha) is close to the average (48.73 kg/ha) of the four samples, it does not show the variability associated between sampling sites. Therefore, it is important to take into consideration the sampling scheme for nutrient determination and possible recommendations from the sampling scheme.

A comparison was made between 1989 and 1990 of spring nutrients along the catena. (Sampling denoted by square boxes in Figure 1.) 1988 was a dry year and much NO_3-N was carried over to 1989. The catena sequence had high available amounts of nitrate with the footslope the highest with decreasing amounts available in the knoll (Figure 17). 1989 was a wet year, a lot of nitrate would have been used the crop, with little carryover into 1990. The spring status in 1990 (Figure 17) was vastly different, where the footslope had the lowest plant available N. There were a number of fall and spring rains and would have easily leached the mobile nitrate deeper into the profile resulting in a low nitrate status along the catena in 1990.

Yields

The yield of the sites in all cases were not closely correlated with any of the four major nutrients studied. Figure 18 compares the spring nitrate status in 1989, with the grain yield (wheat) for site #5. There are a number of instances that there is 0 yield with fairly high levels of available N. These occurred in the footslopes where they were flooded out a number of times during the summer. With such a poor r^2, it can be deducted that the other factors affecting plant growth (e.g. soil moisture) had a greater influence on yield in this particular year than did the nitrate N (or any other tested spring soil nutrient).

Summary and Conclusions

Available spring nutrients are important to early crop growth, and may vary over short distances, but are related to landform position. Nutrients were found to vary with distance, profile and time. Other factors such as climate, present and past management practices will also affect the availability of plant nutrients. Soil moisture can greatly influence nutrient dynamics in the soil and crop yield. These factors must be understood and considered in soil test analysis.

There was found to be no correlation between total N and nitrate N. The total N at a sampling site did not represent the plant available N. There was also no correlation between spring available nutrients and crop yield in 1989.

It is also very important to understand the nature of sampling with proper techniques so as to not invalidate or jeopardize any results. Bulking of samples may give a idea of the average, but not of the magnitude of the variability involved. It is important to take into consideration the sampling scheme for nutrient determination and recommendations.

Nutrient extractions only represent the status of the soil at that particular point in time. A greater understanding and knowledge could be gained from integrating and using soil testing, management practices, and climatic factors to predict the available nutrient status. This information could then be utilized to help determine spatial, profile and temporal variability.

References

Acton, D.F. and Ellis, J.G. 1978. The soils of the Saskatoon map area 73-B, Saskatchewan. Saskatchewan Institute of Pedology Publication S4.

Biederbeck, V.O., Campbell, C.A. and Zentner, R.P. 1984. Effect of crop rotation and fertilization on some biological properties of a loam in southwestern Saskatchewan. Can. J. of Soil Sci. 64:355-367.

Biggar, J.W. 1978. Spatial variability of nitrogen in soils. p.201-211. *in* Nielsen, D.R. and MacDonald J.G. (ed.) Nitrogen in the environment. Vol. I. Academic Press, New York.

Campbell, C.A., Read, D.W.L., Biederbeck, V.O. and Winkleman, G.E. 1983. The first 12 years of a long-term crop rotation study in southwestern Saskatchewan - nitrate-N distribution in soil and N uptake by the plant. Can. J. Plant Sci. 63:563-578.

Campbell, C.A., Read, D.W.L., Winkleman, G.E. and McAndrew, D.W. 1984. First 12 years of a long-term crop rotation study in southwestern Saskatchewan - bicarbonate-P distribution in soil and P uptake by the plant. Can. J. Plant Sci. 64:125-137.

Ferguson, W.S. and Gorby, B.J. 1971. Effect of various periods of seed-down to alfalfa and bromegrass on soil nitrogen. Can. J. of Soil Sci. 51:65-73.

O'Halloran, I.P. 1986. Phosphorus transformations in soils as affected by management. Ph.D. Thesis, University of Saskatchewan, Saskatoon, SK.

Pennock, D.J., Zebarth, B.J. and de Jong, E. 1987. Landform classification and soil distribution in hummocky terrain, Saskatchewan, Canada. Geoderma 40:297-315.

Pittman, U.J. 1977. Crop yields and soil fertility as affected by dryland rotations in southern Alberta. Comm. Soil Sci. Plant Anal. 8:391-405.

Popoff, R.W. and Anderson D.W. 1990. Relationships among landform elements, soil properties, and crop yields on Blaine Lake - Hamlin soils. *in* Soils and Crops Workshop: New Frontiers in Prairie Agriculture. Saskatoon, SK. pp. 294-301.

Spratt, E.D., Strain, J.H. and Gorby, B.J. 1975. Summerfallow substitutes for western Manitoba. Can. J. Plant Sci. 59:685-689.

Tomasiewicz, D.J. 1990. Variability of soil salinity and nitrate within a saline area: Consequences for soil testing and fertilizer response. *in* Soils and Crops Workshop: New Frontiers in Prairie Agriculture. Saskatoon, SK. pp. 45-52.

Figure 1. Landform Elements for Site #3

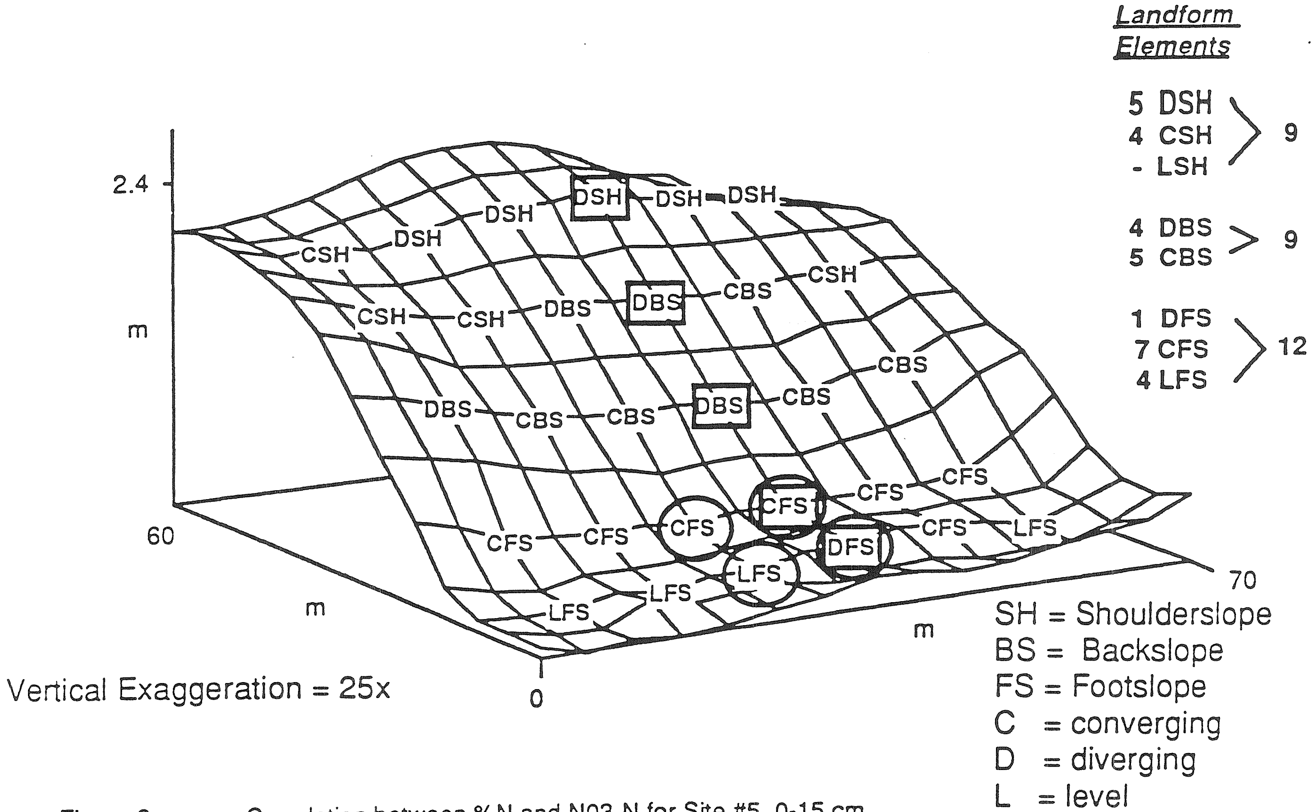


Figure 2. Correlation between %N and N03-N for Site #5 0-15 cm

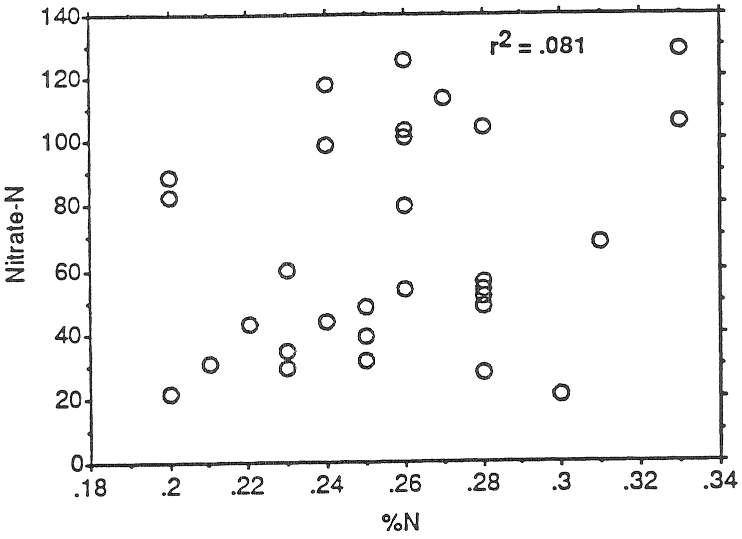


Figure 3.

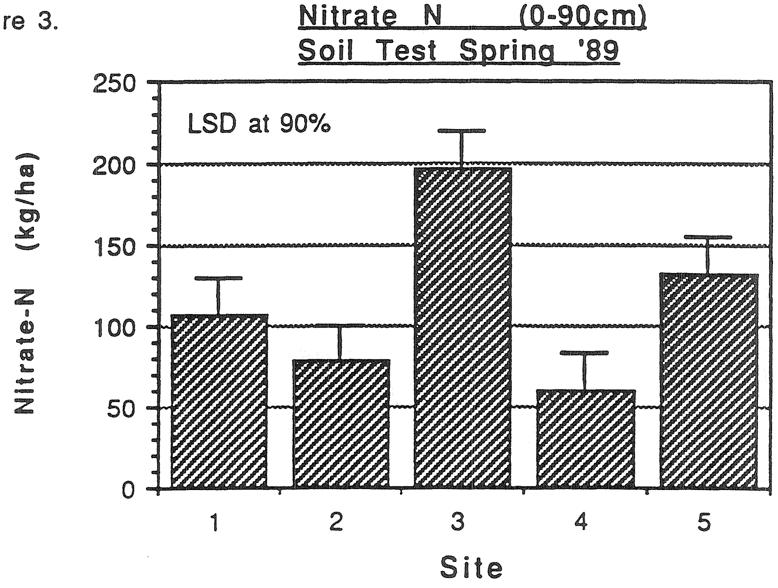


Figure 4.

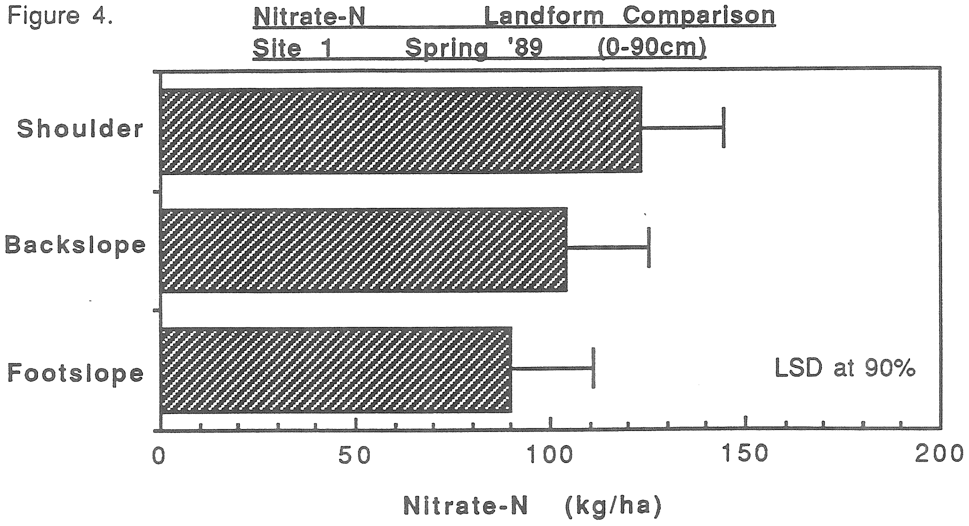


Figure 5.

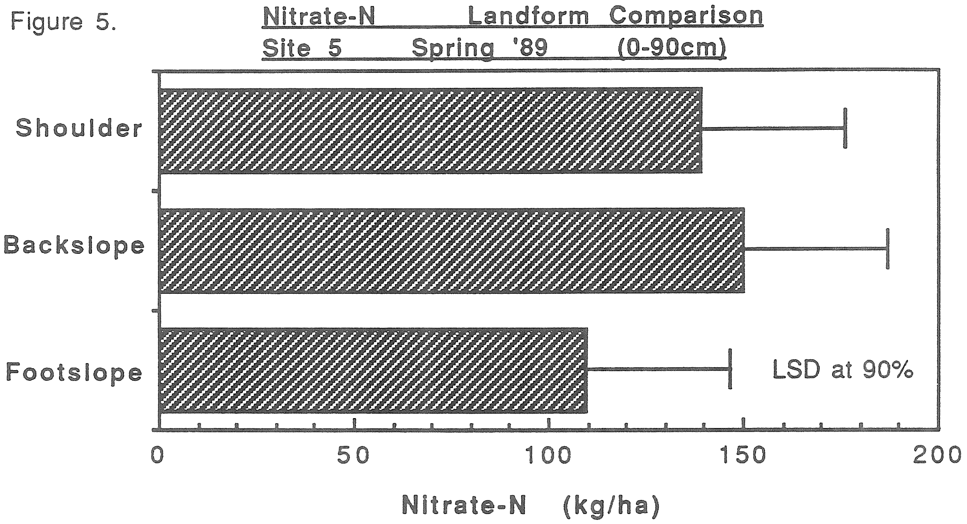


Figure 6.

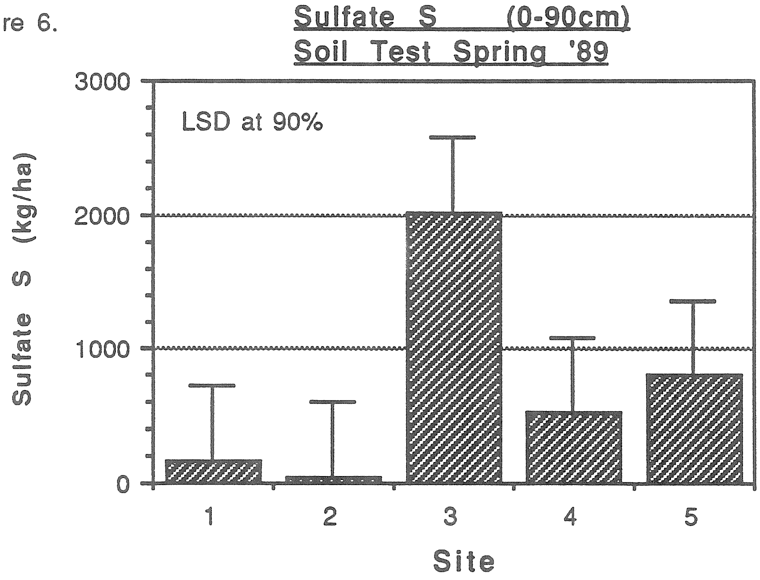


Figure 7. Sulfate-S Landform Comparison
Site 1 Spring '89 (0-90cm)

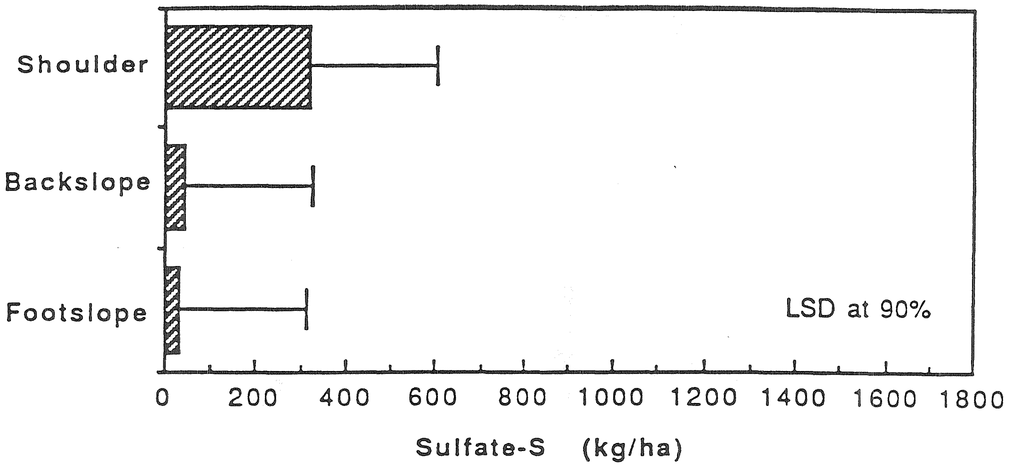


Figure 8. Sulfate-S Landform Comparison
Site 4 Spring '89 (0-90cm)

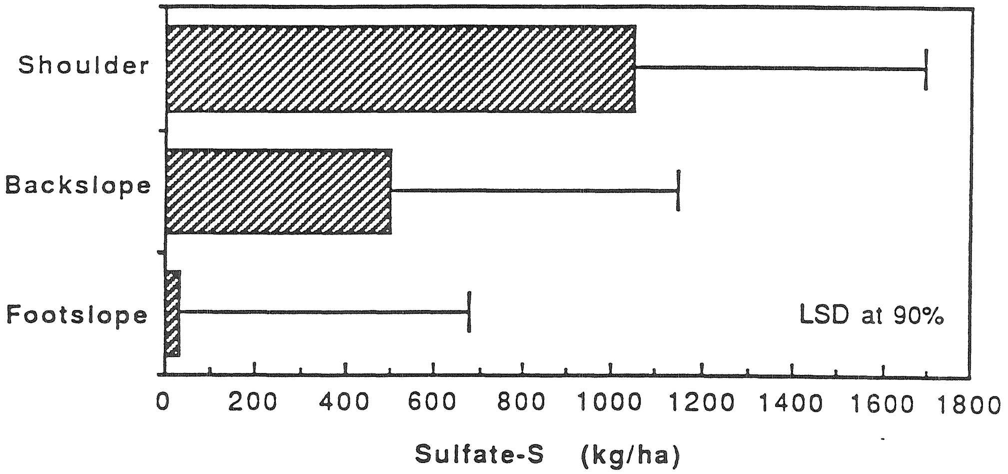
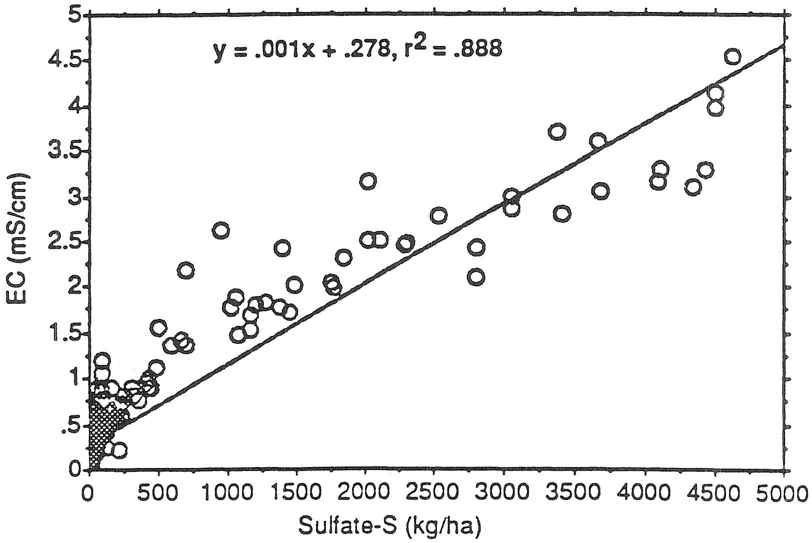


Figure 9. Regression analysis between Electrical Conductivity and Sulfate -S



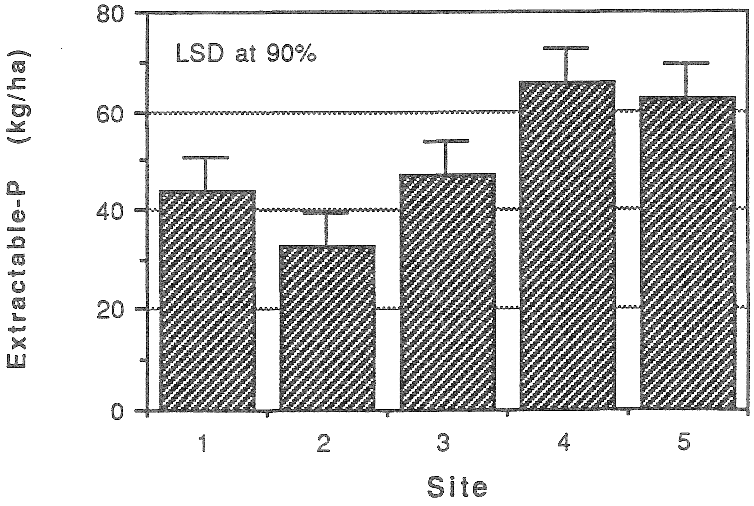


Figure 10. Extractable Inorganic P
Soil Test Spring '89 (0-15cm)

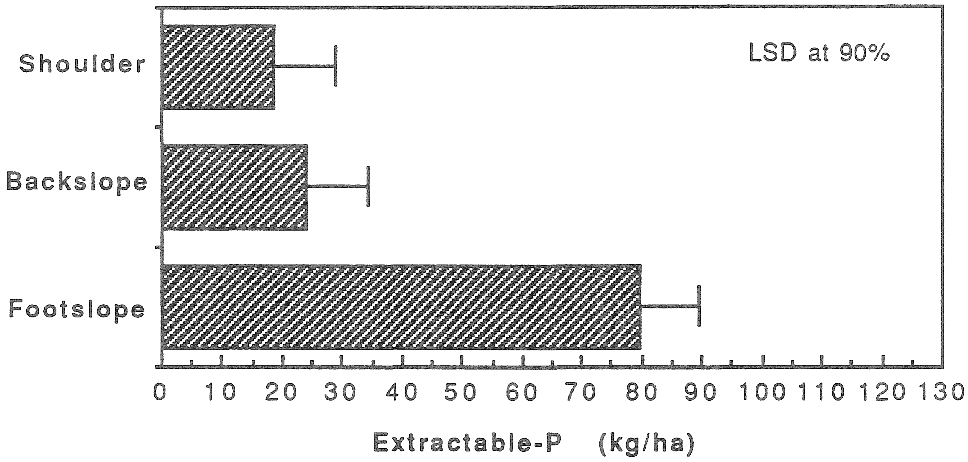


Figure 11. Extractable-P Landform Comparison
Site 1 Spring '89 (0-15cm)

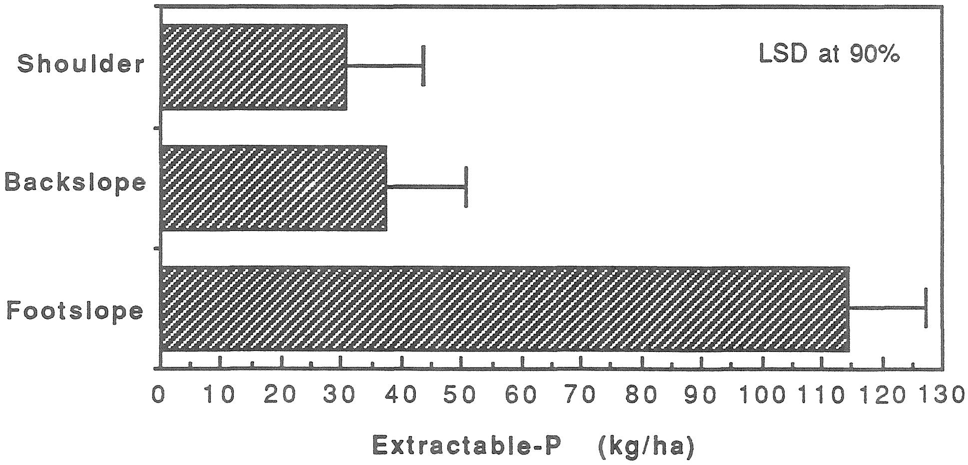


Figure 12. Extractable-P Landform Comparison
Site 4 Spring '89 (0-15cm)

Figure 13. Correlation between pH and Extractable-P

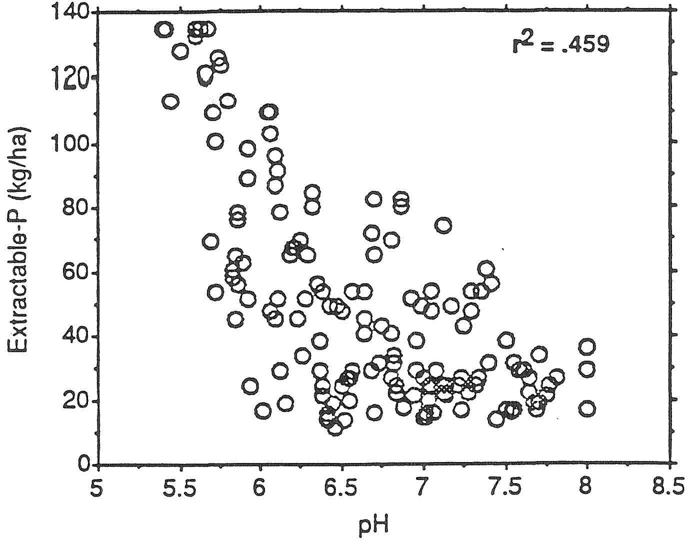


Figure 14. Extractable K (0-15cm) Soil Test Spring '89

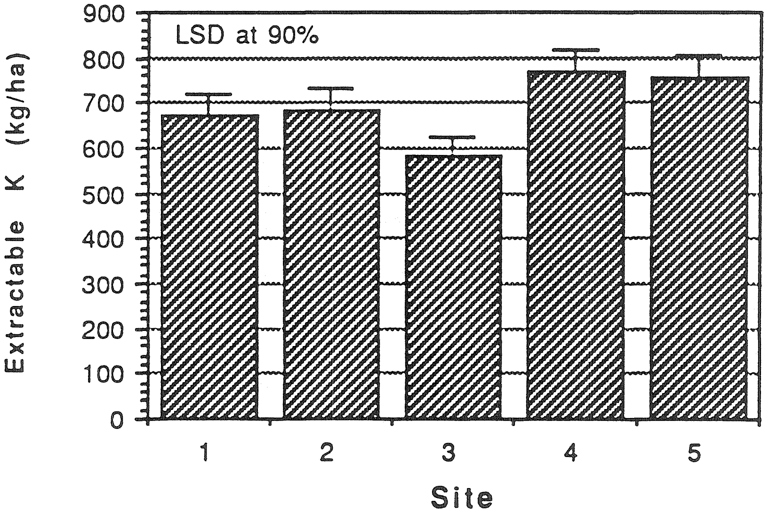


Figure 15. Extractable-K Landform Comparison Site 4 Spring '89 (0-15cm)

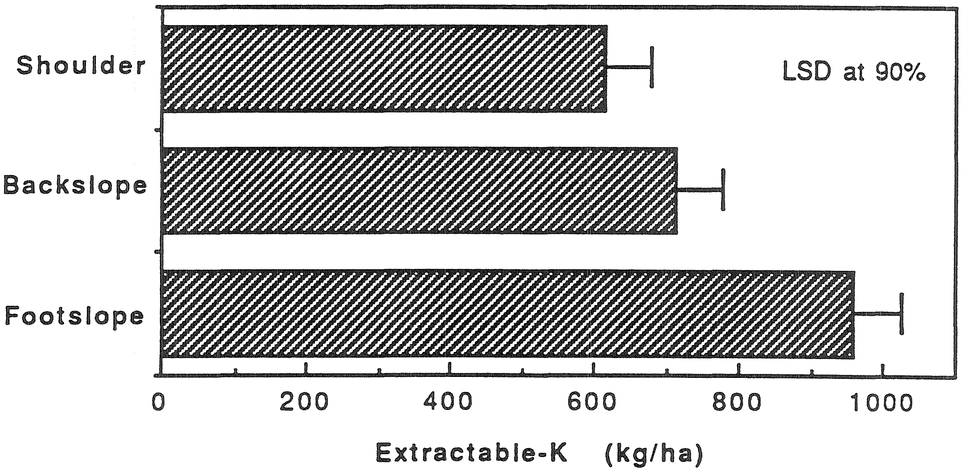


Figure 16. NO3-N to Depth (90cm) Site #1 1989

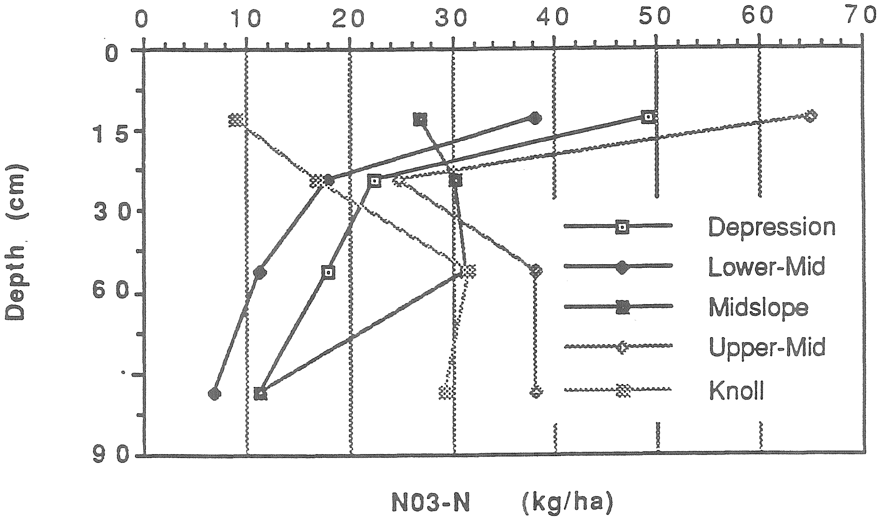


Figure 17. Catena Sequence of NO3-N for 1989 and 1990 Site 1 (0-30 cm depth)

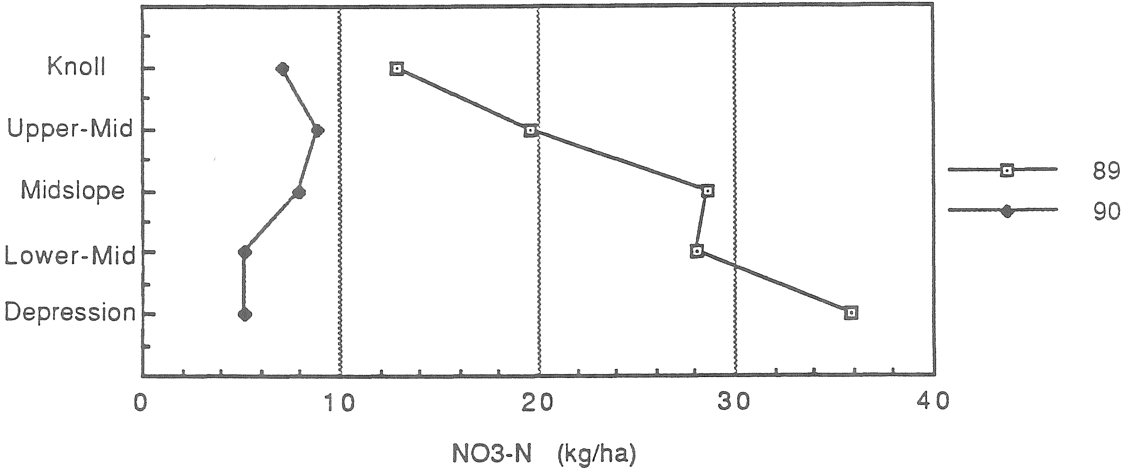


Figure 18. Correlation between spring Nitrate N (0-90cm) and Wheat Yield. Site 5 1989