# Variability of Soil Salinity and Nitrate within a Saline Area: Consequences for Soil Testing and Fertilizer Response

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Soil test field calibration trials are most often established within apparently uniform, usually small, areas within fields. Results from many such sites over several years are then used to develop criteria for providing fertilizer recommendations based on analysis of samples representing entire fields, typically 40 to 160 acres. Implicit in this approach is an assumption that optimum fertilization for the field (if fertilization is not to be varied within the field) will be similar to optimum fertilization for the average soil condition (as determined by the soil analysis) present in field. The validity of this assumption should always be a concern in soil test interpretation; it becomes a major concern where a field soil test shows a sufficient test level of a nutrient which is expected to be highly variable within the field. In those cases potentially large fertilizer response in deficient portions of the field may justify (economically) fertilization of the entire field. Soil salinity is known to be highly variable within fields, and to influence crop growth and soil residual nitrogen (N). This study examined the variation in levels of salinity and N present as nitrate ($NO_3$-N) within a 40 Ac saline stubble area, to assess the effectiveness of routine soil testing procedures for this situation.

It is recognized that truly economic optimum fertilization cannot be achieved for variable fields unless the fertilizer applications are correspondingly varied within the fields. However, the objective of this study was to evaluate conventional soil testing and fertilization practices, rather than to develope a variable rate fertilization system.

## Materials and Methods

The site selected for this study was a square 40 Ac area within a 160 Ac field on SE15-35-1-W3. A moderately poor wheat crop seeded into stubble was produced in 1987. A routine testing of the field in late September 1987 indicated that the surface (0-6" depth) soil was non-saline with a normal stubble N level (10 lb/Ac $NO_3$-N), but the subsoil was both moderately saline and high in $NO_3$. The soil is developed on a gently undulating shallow lacustrine plain with knoll and depression topography. It is a silt loam to silty clay loam soil of the Elstow Association (Dark Brown chernozem).

The study area was oriented obliquely within the field. One hundred sampling points were marked in a uniform (10 x 10) square grid pattern within the area; adjacent points were 132 ft apart. In mid-November 1987 a soil core was taken at each point and separated into the 0-6, 6-12, 12-24, 24-36, and 36-48" depths. A qualitative visual rating of the slope position of each sampling point was also made.

The samples were air-dried, ground to pass a 2mm sieve, and each was analyzed for several parameters; only conductivity and $NO_3$ results will be discussed in this report.

The electrical conductivity (EC, corrected to 25°C) was determined in the 1:1 (w/v) soil:water suspension of each sample. The suspension was stirred during the EC reading, and intermittently during the 30 min. equilibration time. Ten composite samples covering the range of EC values obtained were prepared; each contained only samples with similar EC. The composites were analyzed for EC by the 1:1 suspension procedure above as well as by the saturation extract procedure (Rhoades, 1982), to permit an estimation of extract EC values for the samples.

Nitrate (including nitrite) was determined in the 1:2 (w/v) soil:0.001M $CaCl_2$ extract (30 min. shaking time), by AutoAnalyzer® using a modification of Technicon Industrial Method No. 100-70W (Technicon Industrial Systems, Tarrytown, New York. Sept. 1973). Results are reported in units of "lb/Ac", assuming that each 6" thickness of soil weighs two million lb/Ac when air-dry.

A method was required to assign a salinity value to each sampling point which reflected the overall degree of salinity as it would affect crop growth. There is no standard method for arriving at such a salinity index using EC readings from several depths, so the following was used to produce a depth-weighted salinity index using EC readings from all depths for each sampling point:

$$EC_{0\text{-}48"} = (0.2125 \times EC_{0\text{-}6"}) + (0.1875 \times EC_{6\text{-}12"}) + (0.3 \times EC_{12\text{-}24"}) + (0.2 \times EC_{24\text{-}36"}) + (0.1 \times EC_{36\text{-}48"})$$

The constants are based on the general "rule of thumb" regarding the relative amounts of moisture taken up from successively deeper quarters of the root zone, i.e. 40-30-20-10% (Danielson, 1967). The same relative weightings among EC levels at the 0-6, 6-12, and 12-24" depths as used above were also used in calculating a 0-24" salinity index:

$$EC_{0\text{-}24"} = (0.304 \times EC_{0\text{-}6"}) + (0.268 \times EC_{6\text{-}12"}) + (0.429 \times EC_{12\text{-}24"})$$

In the case of each calculated index, the constants total 1.0, so that the calculated indices are in the same range as the EC readings themselves.

## Results and Discussion

There are very wide variations among sampling points in both EC and $NO_3$-N levels (Table 1). It was not an objective of this work to "map" the field, but rather determine the proportions of the field in the various $NO_3$-N and EC test ranges; the distance between adjacent sampling points was larger than that which would be required for accurate mapping.

TABLE 1 Statistical Parameters for EC and $NO_3$-N levels at 100 sampling points within a 40 Ac field.

| Depth | Range | Mean | Std. Dev. | Median |
|---|---|---|---|---|
| | | Electrical Conductivity | | |
| 0-6" | 0.21-3.96 | 0.61 | 0.60 | 0.43 |
| 6-12" | 0.11-5.84 | 1.84 | 1.72 | 1.15 |
| 12-24" | 0.11-6.39 | 3.29 | 2.02 | 4.22 |
| 24-36" | 0.13-5.95 | 3.06 | 1.74 | 3.51 |
| 36-48" | 0.15-6.58 | 2.99 | 1.81 | 3.34 |
| 0-24" | 0.17-4.74 | 2.09 | 1.29 | 2.39 |
| 0-48" | 0.17-4.65 | 2.38 | 1.35 | 2.78 |
| | | Nitrate-Nitrogen lb/Ac | | |
| 0-6" | 1-103 | 23 | 23 | 14 |
| 6-12" | 1-118 | 25 | 26 | 16 |
| 12-24" | 2-370 | 56 | 61 | 40 |
| 24-36" | 2-178 | 31 | 35 | 20 |
| 36-48" | 2-160 | 26 | 28 | 17 |
| 0-24" | 5-482 | 104 | 92 | 91 |
| 0-48" | 9-820 | 161 | 141 | 142 |

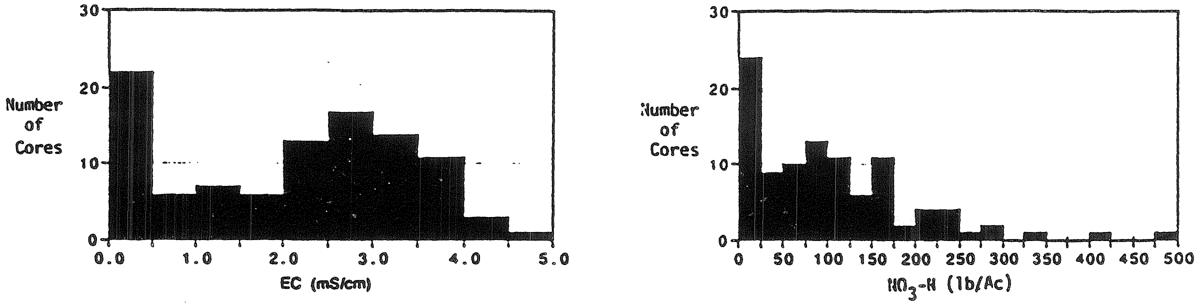
For the ten composite samples, there was a close linear relationship between the conductivity values as measured in the 1:1 suspension and those from the saturation extract:

$$EC_{SE} = EC_{1:1\ susp} \times 2.55 - 0.63 \qquad (r = 0.99)$$

For a wider range of soils, Hogg and Henry (1984) observed a similar relationship:

$$EC_{SE} = EC_{1:1\ susp} \times 2.75 - 0.69 \qquad (r = 0.98)$$

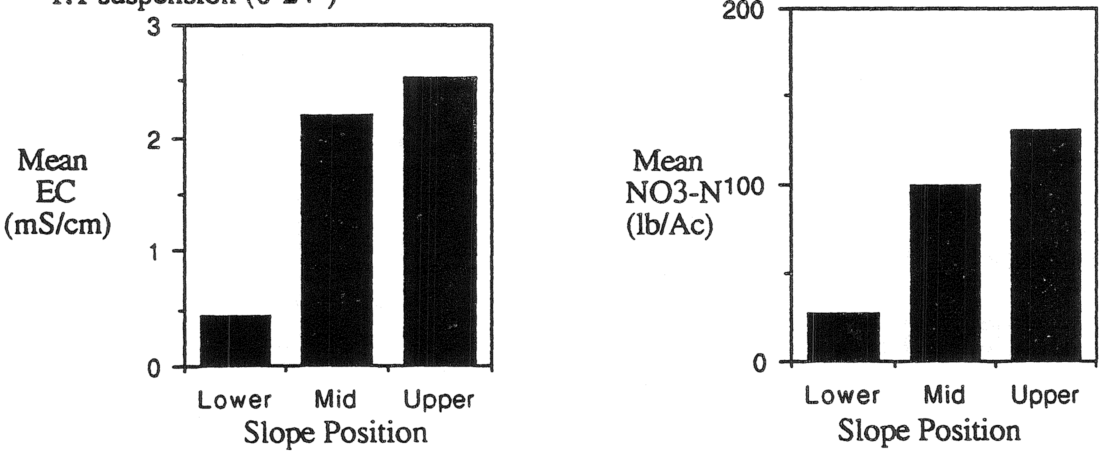
The EC and $NO_3$-N levels were not normally distributed within the range of values measured, as evidenced by comparisons among the ranges, means, and medians for these parameters (Table 1) and their frequency distributions (Fig. 1).


a) Electrical conductivity of 1:1 suspension (0-24" index)

b) Nitrate-N (0-24" total)

Fig. 1 Frequency distributions for a) EC (0-24") and b) $NO_3$-N (0-24") for 100 sampling points within a 40 Ac field.

Based on the visual ratings of slope position, the sampling points were separated into "Lower" (n = 16), "Mid" (n = 32), and "Upper" (n = 52) groups. The Lower slope positions were clearly lowest in both salinity and $NO_3$ (Fig. 2). Despite representing only 16 of the 100 sampling points, the Lower group included 15 of the 25 lowest 0-24" EC values ($\leq 0.55$ mS/cm), and 14 of the 25 lowest 0-24" $NO_3$-N values ($< 27$ lb/Ac). This could be explained by a net leaching of moisture (containing soluble salts including $NO_3$) through the root zone over the long term, which would occur only in the wetter (lower) positions in the landscape. Heavier crop growth, and hence $NO_3$ uptake, in the lower portions of the field would also contribute to the lower soil $NO_3$-N levels in those areas. The correlation of low soil nitrate levels with a readily visually identifiable parameter (i.e. slope position) would suggest that development of variable rate fertilization may be feasible in such cases.


a) Electrical conductivity of 1:1 suspension (0-24")

b) Nitrate-N (0-24" total)

Fig. 2 Means for a) EC (0-24") and b) $NO_3$-N (0-24") for Lower, Mid, and Upper slope positions.

The depth-distribution of soluble salts and $NO_3$ is noteworthy. Where accumulations of either were present, they tended to be most concentrated at the 12-24" depth. The 0-6" depth soils were generally non-saline, with only 10% having EC values in excess of 1.0 mS/cm, and only one sample having EC > 2.9 mS/cm. Approximately half of the 12-24" samples had EC > 4.0 mS/cm at 12-24"; in 62% of those cases EC values were at least 10% lower at 36-48" than at 12-24". The mean $NO_3$-N level at the 0-6" depth was only 22% of that present at 0-24". Routine sampling of the 0-6" depth only would usually fail to show both the salinity problem and the degree of $NO_3$-N accumulation in this situation.

Conductivity (0-24") and $NO_3$-N (0-24") levels were only weakly correlated ($r^2 = 0.22^{***}$, Fig. 3). Deletion of the data from the non-saline points ($EC_{0\text{-}24"} < 0.8$) results in no relationship ($r^2 = 0.02$ ns) between the two parameters, despite a wide range in each which remains. In effect, the existence of excess salts and high $NO_3$-N is related, though the degrees of each are not.

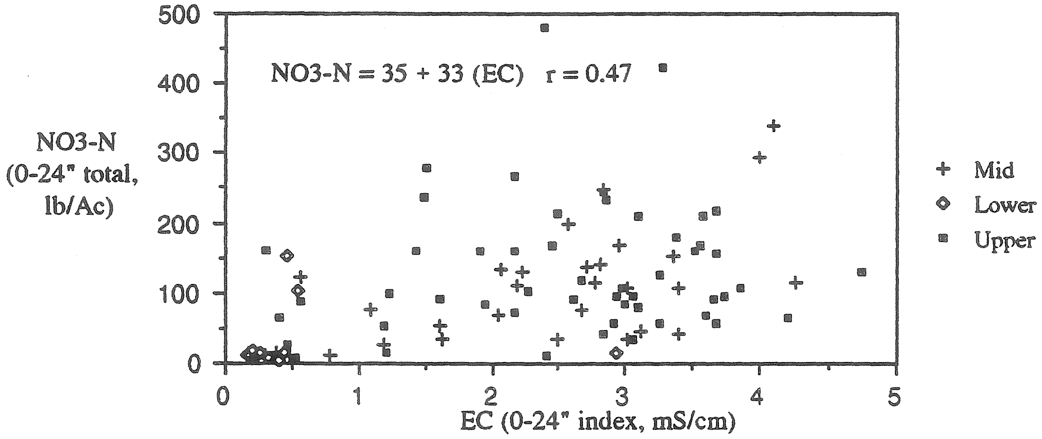


Fig. 3 Relationship between EC and $NO_3$-N for 100 sampling points within a 40 Ac field.

Nitrogen expected yield response and fertilizer recommendation criteria approved for use in Saskatchewan by the Fertility Committee of the Saskatchewan Advisory Council on Soils and Agronomy indicate that under "normal" moisture conditions in the Dark Brown Soil Zone, response to N fertilization would not be expected at soil $NO_3$-N levels (0-24") of 105 lb/Ac or higher. The maximum soil N test level at which an economic response would still be obtained is 86 lb/Ac, or 76 if a marginal return to marginal cost ratio (MR/MC) of 1.5 is required (as is used by the Saskatchewan Soil Testing Laboratory). These and following calculations assume wheat to be valued at $4.00 per bushel and fertilizer at $0.25 per pound of actual N. Clearly, the average soil test N level for this field, as would be determined by routine soil testing procedures, would suggest that the N level in the field is well above the range where economic responses to fertilizer would be obtained. In fact, "routine" sampling procedures might most often result in an even higher average soil test N level for such an area because the depressional areas, which were lowest in $NO_3$-N, would be avoided in sampling.

Response to fertilizer N would be expected in this situation, since one-quarter of the field has a $NO_3$-N test level of < 27 lb/Ac, and expected yield responses to 50 lb/Ac of fertilizer N exceed 9 bu/Ac at those low test levels. One approach to quantitatively predict the response to N is to assume that the proportion of the field at any $NO_3$-N test level is the same as the proportion of the cores taken at that test level. In effect, treat the 40 Ac field as one hundred 0.4 Ac "fields", each with a uniform $NO_3$-N level corresponding to that found in one of the cores. The same expected yield response criteria can then be applied to each small area, and the 100 individual responses averaged to arrive at a "field-specific" response curve for the area which takes the spatial $NO_3$-N distribution within the field into account.

The above procedure was carried out to generate field specific expected yield response curves (Fig. 4). When moisture conditions "normal" for the Dark Brown Soil Zone (moisture deficit index 13) were assumed for all parts of the field, a response of up to 4.6 bu/Ac was predicted at high fertilizer N rates. When moisture conditions associated with "dry" fertilizer N recommendations for the Dark Brown Soil Zone (mdi 17) were assumed for the upper slope positions, and those for "wet" recommendations (mdi) for the lower slope positions, a response of up to 5.0 bu/Ac was predicted. In both scenarios, economic optimum fertilizer N recommendations would be approximately 10 and 35 lb/Ac of N, and would result in predicted yield increases of about 1.1 and 3.0 bu/Ac, for MR/MC ratios of 1.5 and 1.0, respectively. The variable mdi assumption would usually be expected to result in much greater predicted responses where the low $NO_3$-N levels are associated with the lower slope position. However, in this case only 16% of the sampling points were rated as Lower, while 52% were rated as Upper, resulting in a much lower weighted average mdi for the field in the variable mdi scenario. Adjusting the indices so that their means are 13 in each scenario would provide a more realistic comparison.

Although the responses indicated above are not large, they serve to illustrate the point that the potential for economic yield increases due to fertilization is underestimated when field variability is disregarded under such conditions of extreme variation. A similarly variable field having a mean $NO_3$-N level of 80 lb/Ac would also normally receive a 0 lb/Ac fertilizer N recommendation, but similar calculations would predict much larger N responses and recommended fertilizer N rates than were found for the field in this study which had a mean $NO_3$-N level of 104 lb/Ac.

Where soil test levels vary greatly over the field, there is also concern over the ability of routine sampling procedures to yield a composite sample for the field which is a reliable indicator of the true average for the field. In this case, it is assumed that the means from all sampling points are a good estimate of the true field means, due to the large number of observations (100). In a variability study based on a grid sampling of two fields, Henry (1967) concluded that composite samples consisting of ten cores were adequately effective and reliable in characterizing the field fertility (for N and P). However, both fields had mean $NO_3$-N (0-24") levels of less than 35 lb/Ac, and ranges of less than 90 lb/Ac, compared to 104 and 477 lb/Ac, respectively, in the present study.

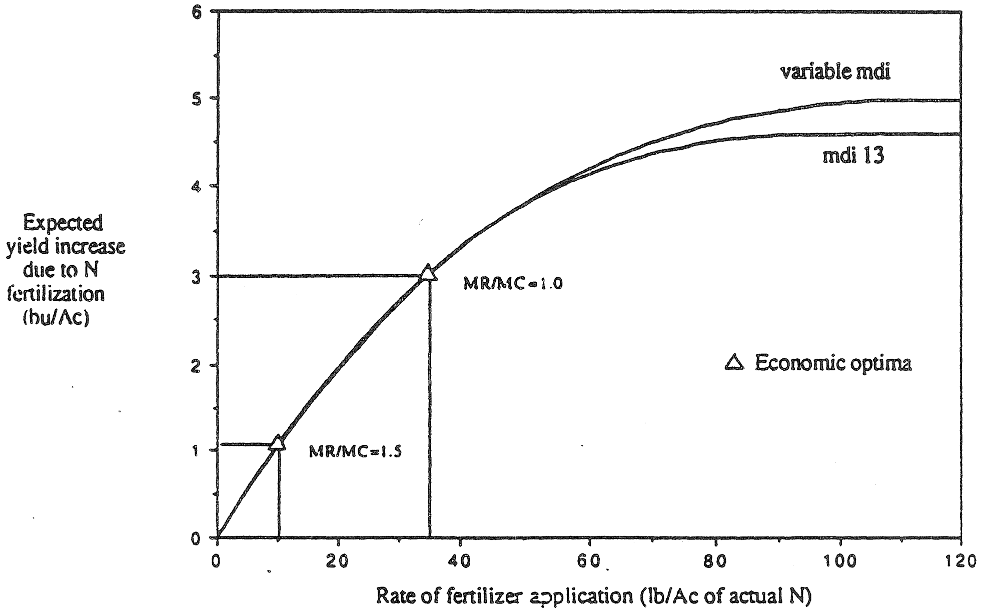


Fig. 4 "Field Specific" expected yield response curves for wheat.

The probability of a sample mean $NO_3$-N level falling within several selected intervals around the field mean, for several sample sizes is tabulated for the data from this study (Table 2). For this calculation, it was assumed that the $NO_3$-N levels were normally distributed, which was not the case. However, calculated means tend to be reasonably normally distributed around the population mean even if individual observations are not (central limit theorem). A simulation with a subset of the data from this study also showed similar distributions of actual and predicted sample means (for $n = 10$).

TABLE 2 Probabilities of $NO_3$-N (0-24") sample means falling within five selected ranges about the field mean, for six selected samples sizes.

| Sample Size | ------------Range about the field mean ($NO_3$-N, 0-24")------------ | | | | |
|---|---|---|---|---|---|
| | ± 10 lb/Ac | ± 20 lb/Ac | ± 30 lb/Ac | ± 40 lb/Ac | ± 50 lb/Ac |
| (no. of cores) | --------------Probability of sample mean within the range (percent)---------- | | | | |
| 5 | 19 | 37 | 53 | 67 | 78 |
| 10 | 27 | 50 | 70 | 83 | 91 |
| 15 | 33 | 60 | 79 | 91 | 96 |
| 20 | 37 | 67 | 85 | 95 | 98 |
| 25 | 41 | 72 | 90 | 97 | 99 |
| 100 | 72 | 97 | 100 | 100 | 100 |

It is obvious that routine field sampling procedures could not reliably determine the two field mean $NO_3$-N level within even 20-30 lb/Ac in a field with this level of $NO_3$-N and variability. For example, $NO_3$-N levels in composites of ten randomly-located cores would differ from the true field mean $NO_3$-N level by more than 30 lb/Ac in three out of ten cases. The improvements in reliability resulting from taking more cores per field are modest within the limits which might be considered. Even sampling of 25 cores each would yield composite means not within 30 lb/Ac of the true field mean one time in ten. Selecting sampling points in a zigzag pattern over the entire field, rather than entirely randomly, and a stratified approach, would somewhat improve the predicted performance.

There are no objectively established "required" degrees of accuracy and precision in soil sampling. These could be calculated for individual cases by considering the cost of sampling additional cores and the probabilities and economic consequences of varying degrees of error. Results would not be applicable to the general case where the mean $NO_3$-N level and spatial variation in $NO_3$-N is not known *a priori*. No sampling approach which includes compositing of all cores from a sampled area into one sample (or sample set) could reveal the nature of the variation in test levels within the field. In this study, it is the variability, rather than the mean test level, for the field which accounts for the predicted fertilizer response.

Three points should be made which can reduce the seriousness of the field variability problem with respect to soil testing. Firstly, the problem does not exist for low-testing fields (e.g. < 25 lb/Ac of $NO_3$-N, 0-24"), since the variance in test levels would undoubtedly be much lower for low-testing fields than for high-testing fields. Even a small proportion of very high $NO_3$-N cores in a composite sample will result in the composite having a relatively high test level, so a composite which tests low in $NO_3$-N is almost certainly from a field with very little if any of its area high in $NO_3$-N.

Secondly, the economic loss from applying more or less fertilizer than the economic optimum for the field may be less for a highly variable field, since the yield response curve will be "flatter" with less curvature around the optimum rate (Fig. 5). High field variability would result in the straighter response curve because the very high $NO_3$-N portions of the field would not respond well to even the first increments of fertilizer, whereas the low $NO_3$-N areas would continue to respond up to very high fertilizer N levels. It is obvious from the two curve types in Fig. 5 that even through the economic optimum fertilizer N rate is the same for both, the yield loss due to moderate under-fertilization, and excess of additional costs over added returns due to moderate over-fertilization, are less for the flatter response curve typical of highly variable soils.

Thirdly, soil test correlation experiments are carried out under field conditions where some spatial variability is always present. Variability in long "strip" trials could approach that for entire fields, though extreme variability situations such as in this study would normally be avoided. To the extent that soil test correlation experiments have been conducted over areas with variability, test interpretive criteria resulting from those trials should be applicable to areas with similar variability. However, existing recommendation criteria does not appear to take into account the greater spatial variability of high test levels as compared to low, or specific conditions which likely influence variability, such as salinity or landform.

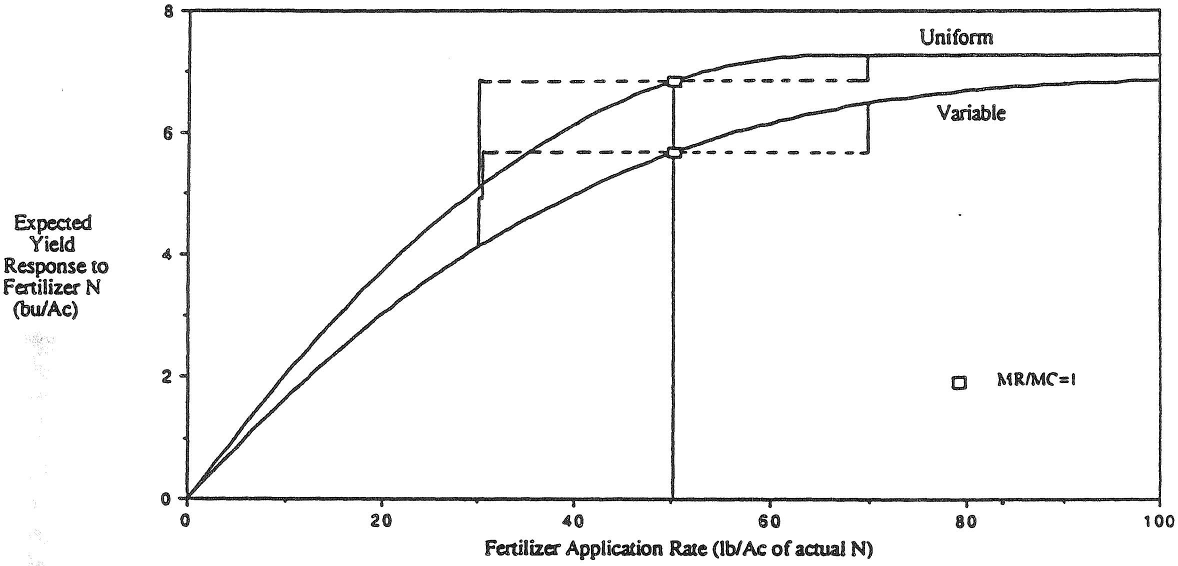


Fig 5. Generalized expected yield increase curves for relatively uniform and variable fields with the same optimum fertilization rate.

The effect of soil salinity on the availability of soil $NO_3$-N to plants is a concern. Is $NO_3$-N in saline soil less available to the crop, so that N fertilizer responses might be expected on saline soils containing $NO_3$-N levels which would be regarded as sufficient on normal soils? Salinity can reduce N uptake under some conditions such as in nutrient culture. However, under Saskatchewan dryland field conditions, the growth restrictions due to other salinity effects (on moisture availability, for example) may be much more important and reduce the need for N by the crop, resulting in poorer N response under saline conditions. Peters (1983) reported poorer yields and little response of barley to N fertilization in saline, high $NO_3$-N portions of sites studied.

## Conclusions

The site studied showed extreme variability in subsurface salinity and $NO_3$-N levels. The Lower slope position samples were generally non-saline and low in nitrate. However, for the saline majority of the cores, there was no relationship between EC and $NO_3$-N levels despite wide ranges in observed values for each.

Approximately one-quarter of the area studied would be expected to normally respond strongly to fertilizer N, based on $NO_3$-N level and slope position, yet the overall $NO_3$-N level for the field as would be determined by routine soil testing would suggest that the N level is above the range where yield responses would occur. Routine methods of interpreting soil test N results for highly variable fields (and perhaps most stubble fields high in $NO_3$-N) do not take into account the strong response that might occur on considerable portions of the field, so may be inappropriate. Responses to fertilizer N at moderately high mean $NO_3$-N test levels would be much more likely in highly variable fields than under relatively uniform conditions, such as in a level fallowed field. Such responses could often be economically justifiable even if fertilizer N is applied uniformly to the whole field to achieve them. However, this practice would imply over-fertilization of much of the field, with environmental implications which should not be ignored.

For fields with such extreme variation in $NO_3$-N levels as the one studied, routine sampling procedures would be unreliable in determining the true field mean $NO_3$-N levels. Improvement in reliability from increasing the number of cores taken, to 20, for example, would be insufficient to solve the problem.

Improvement in soil test interpretive criteria for highly variable (e.g. saline, hilly) fields would be possible by taking the expected degree of variability in $NO_3$-N levels and growing conditions into account. Existing information on spatial variability may be useful for this purpose.

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