Field Scale Fertilizer Recommendations and Spatial Variability of Soil Test Values

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Often farmers and crop advisers indicate that economical response to fertilizer application occurs at soil test levels higher than what is indicated by soil test calibration research. In this article, Ontario researchers explain why this might happen.

IT IS WELL KNOWN that many fields have significant spatial variability of soil fertility. This is the basis behind the development of technology to spatially vary the application rate of fertilizer within a field. However, a majority of fields still have a single rate of fertilizer applied evenly across the field. Soil test calibration relationships (i.e., recommended fertilizer rate versus soil test values) are used to obtain the recommended fertilizer rate from a soil test on a composite soil sample from the field.

Research has shown that the relationship among yield response, applied fertilizer, and soil test levels is highly non-linear. In other words, yields increase with increased fertility up to some level, after which they remain constant. Unfortunately, there are significant problems with estimating spatial averages of non-linear relationships.

Spatial Variability and Response

Suppose you have two fields (Fields 1 and 2) as given in **Table 1**. Both fields have the same **average** soil test value of 23, but three areas within each field have different soil test values. Note that the only difference between the two fields is the relative proportion of each of the three areas. The average soil test is obtained from the sum of the value of the soil test in each of the different areas multiplied by the proportion of the field occupied by each area. This average soil test would be equal to the average soil test from a composite soil sample taken from the field.

It is assumed that a relationship between maximum yield gain from applied fertilizer and soil test exists and is known. It is also assumed that no additional response occurs above a soil test of 30. The values of the yield increases from soil test values of 20 and 10 are assumed to be 16 bu/A and 48 bu/A, respectively. The average maximum yield gain for each field is calculated from the maximum yield gain in each of the three areas with different soil test values multiplied by the proportion of the field occupied by each area. This average yield gain would be the

Table 1. An example of the spatial scaling problem.

	Field 1			Field 2		
Field area	% of field	Soil test, ppm	Crop response, bu/A	% of field	Soil test, ppm	Crop response, bu/A
1	50	30	0	20	60	0
2	30	20	16	30	20	16
3	20	10	48	50	10	48
Average		23[1]	14[2]		23[3]	28[4]

[1](0.5 x 30) + (0.3 x 20) + (0.2 x 10) = 23.
[2](0.5 x 0) + (0.3 x 16) + (0.2 x 48) = 14.
[3](0.2 x 60) + (0.3 x 20) + (0.5 x 10) = 23.
[4](0.2 x 0) + (0.3 x 16) + (0.5 x 48) = 28.

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yield increase obtained from the entire field (machine harvested yield).

The average maximum yield increase possible from applied fertilizer is 14 bu/A in Field 1 compared to 28 bu/A in Field 2, even though both fields have the same average soil test value and the same yield response for a given soil test level within the fields. The different average yield responses of the two fields is caused by the non-linear relationship between soil test and crop yield response. If yield response decreased linearly with increasing soil test values then both fields would have the same average yield increase. The sharp non-linear change in yield response near the critical value is the main cause of the spatial averaging problem. Since many . . . perhaps all . . . nutrient calibrations have similar yield response relationships, the problem is widespread.

Examples from Ontario

In this study, equations were developed to describe the average field yield increase from fertilizer applied evenly to the whole field in a field with variable soil fertility. Mathematical and verbal descriptions of the process used are given in *Nutrient Management on Highly Productive Soils*, PPI/FAR Special Publication 1994-1.

Although generalized equations were developed, the illustrations used here are for nitrogen (N) and potassium (K) for corn in Ontario.

The relationship between optimum fertilizer N rate and soil nitrate levels at planting time is given in **Table 2** for different levels of variability. The column labeled "Low" is the calibration curve for fields with zero variability. This column is similar to calibration data reported by researchers in the humid north-central areas of the U.S. As variability of a field increases, the optimum rate of N fertilizer also increases. The largest increase in fertilizer rate occurs at the soil test level where the optimum rate drops to zero when no variability exists, 100 in this example.

Table 2. Influence of soil nitrate variability on optimum N fertilizer rate.

Average soil nitrate-N	Soil nitrate variability[1] Low[2] (0)	Med. (30%)	High (53%)
lb/A to 2 ft.		N, lb/A	
35	131	142	146
50	97	128	137
100	0	23	75

[1]Value in parentheses is the coefficient of variability.
[2]Standard recommendation of Univ. of Guelph.

The impact of spatial variability on optimum phosphorus (P) and K fertilizer rates was similar to the previous results for N. Optimum K fertilizer rates at various average soil test levels and variability levels are given in **Table 3**. Again, the most dramatic increase occurred at the soil test level where the optimum rate dropped to zero.

Table 3. Influence of soil test K variability on optimum K fertilizer rate.

Average soil test K, ppm	Soil test variability,[1] lb K_2O/A Low[2] (0)	Med. (53%)	High (131%)
45	100	101	106
90	50	58	77
135	0	30	58

[1]Value in parentheses is the coefficient of variability.
[2]Standard recommendation by Univ. of Guelph.

The major implications of spatial variability in extending soil test calibration data to farm fields follows:

> Since the relationships among yield response, soil test, and applied fertilizer are non-linear, a single calibration (recommended fertilizer versus soil test) cannot exist for fields with different spatial variability. Calibrations obtained from sites with low variability of soil test values (small plots) will not hold for sites with higher variability (farm fields). Calibrations obtained from sites with low variability of soil test values will underpredict the optimum fertilizer rate for maximum economic yield for sites with high variability of soil test.

(continued on page 23)

Table 2. Examples of application error due to use of conventional fertilizer application.

Field	Acres	Under-application	Over-application
1	135	60 lb/A P_2O_5 on 34.9A 100 lb/A K_2O on 18.3A	70 lb/A P_2O_5 on 29.2A 45 lb/A P_2O_5 on 26.7A
2	150	105 lb/A P_2O_5 on 14.8A 80 lb/A K_2O on 84A	
3	153	75 lb/A P_2O_5 on 47.4A 85 lb/A P_2O_5 on 33.8A 45 lb/A K_2O on 87.9A	155 lb/A K_2O on 20.1A
4	142	55 lb/A P_2O_5 on 37.7A 85 lb/A P_2O_5 on 18.8A	175 lb/A K_2O on 13.3A 75 lb/A K_2O on 25.5A
5	130		120 lb/A P_2O_5 on 12.1A 95 lb/A P_2O_5 on 23.3A
6	140	70 lb/A P_2O_5 on 39.1A 40 lb/A K_2O on 83.1A	

had an increase in K application. When the changes were calculated on a per acre basis, the changes were minor and support the findings of the previous study.

Of more significance is the reduction in application rate error. A comparison of efficiency between conventional and variable application was made across all five management levels.

The results of this comparison revealed the most serious errors using conventional application were under-application of P and K in the low and very low testing zones. Under-application errors in these zones will contribute to yield loss and, more importantly, quality reductions in potatoes. Over-application is neither economically nor environmentally acceptable. While there were over-application errors in some fields in the high and very high testing zones, in most cases the acreage involved was small. Examples of application rate errors are provided in **Table 2**.

The utilization of five levels of nutrient management gave more versatility to accommodating field variation.

While the average across the six fields showed little change in fertilizer usage, some fields did show appreciable changes in application rates of P and/or K. Thus, there are fields which will require more . . . or . . . less P and K due to variable fertility management.

Comparison of total P and K utilized may be of interest in nutrient management budgeting. However, it is more important to demonstrate the reduction in application error that occurs through the use of variable rate fertility management. ■

Field Scale . . . from page 21

Summary

The previous statements, if accurate, are rather disturbing. A majority of fertilizer recommendations from soil tests are made from a composite soil sample from a field and a calibration relationship obtained from research plots selected for uniformity (i.e., low spatial variability of soil test). The results may also help explain why many farmers and fertilizer dealers insist they get an economical increase in yield with fertilizer application rates higher than those predicted by such calibration relationships. If they have a variable field, the theory presented here suggests they will get economic yield increases with higher rates. This does not invalidate the calibration relationship. It just suggests that we have to utilize the calibration relationship in a different manner. In fact, because of the spatial variability problem, it is more important than ever to have accurate calibration relationships among soil test, yield response, and applied fertilizer. The challenge is to combine these calibrations with additional knowledge about the spatial distribution and field scale variability of soil test values. ■