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TEMPORAL CHANGES IN THE SPATIAL VARIABILITY OF SOIL NUTRIENTS

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ABSTRACT

This paper reports the temporal changes in the spatial variability of soil nutrient concentrations across a field during the growing season, over a four-year period. This study is part of the *Site-Specific Technologies for Agriculture* (SST4Ag) precision farming research project at the INEEL. Uniform fertilization did not produce a uniform increase in fertility. During the growing season, several of the nutrients and micronutrients showed increases in concentration although no additional fertilization had occurred. Potato plant uptake did not explain all of these changes. Some soil micronutrient concentrations increased above levels considered detrimental to potatoes, but the plants did not show the effects in reduced yield. All the nutrients measured changed between the last sampling in the fall and the first sampling the next spring prior to fertilization. The soil microbial community may play a major role in the temporal changes in the spatial variability of soil nutrient concentrations. These temporal changes suggest potential impact when determining fertilizer recommendations, and when evaluating the results of spatially varying fertilizer application.

INTRODUCTION

Spatial variability of soil has been studied for many years. For the most part, this variability has been measured using samples collected in the field and analyzed in a laboratory. Understanding the spatial variability in the samples has increased with the availability of global positioning system (GPS) measurements of the sample locations, and geographic information systems (GIS) for the spatial mapping and analysis of these data. Burrough (1993) has reviewed many of these studies, and stated that if the spatial variation of soil fertility over a field can be mapped, one has enough information to adjust the amount of fertilizer spread at any spot to that which will be needed by the crop.

This concept has been widely adopted, and the capability to apply fertilizers at variable rates is almost commonplace. Luellan (1985) described a prototype system several years ago. Carr *et al.* (1991) measured the economic benefits of fertilizing wheat and barley using different application rates and different formulations of fertilizer in Montana. Hammond (1993) made a similar cost analysis of variable fertilizer management for potatoes in central Washington.

Our study integrates another form of soil variability, namely temporal variability, with the spatial variability. This temporal variability during the growing season seems to complicate the concept that variable rate application of fertilizer can be based only on the spatial variability of soil nutrients at a single point in time.

MATERIALS AND METHODS

Study field

Soil samples were collected repeatedly from a 72.4 ha field during the growing seasons in southeast Idaho from 1995 through 1998. Samples were collected from the same locations throughout the study, as determined by using differentially corrected global positioning system (DGPS) measurements.

The climate of the study area is very cold and moist from September through March. In spring it is wet and somewhat warmer. Summers are dry most years, and summer temperature ranges from below freezing to more than 32°C. The windiest periods of the year are spring and fall. Average annual precipitation is about 40 to 56 cm, and average annual temperature is about 5.5°C. Elevation is about 1615 m. Frost-free period is about 75 to 85 days, and cool temperatures restrict biological activity to only the summer months.

Almost the entire field (Figure 1) is categorized Kucera, bedrock substratum–Lostine, silt loams, 1 to 6 percent slopes, described as well-drained, coarse silty loams, on top of unweathered bedrock (Grow, 1993). The very small area along the north-center edge of the field (shown in black) is Kucera-Sarilda, silt loams, 2 to 6 percent slopes, also described as a well-drained, coarse silty-loam loams, on top of unweathered bedrock. The southeast corner of the field (shown in dark gray) is Robinlee-Marystown, silt loams, 1 to 4 percent slopes, described as a well-drained, fine silty loams to silty clay-loams, on top of unweathered bedrock.

The samples were collected based on about a 3.5 ha grid, from the point locations shown in Figure 1. Two center pivots (shown by circular wheel lines) irrigated the study field during the growing seasons in all years.

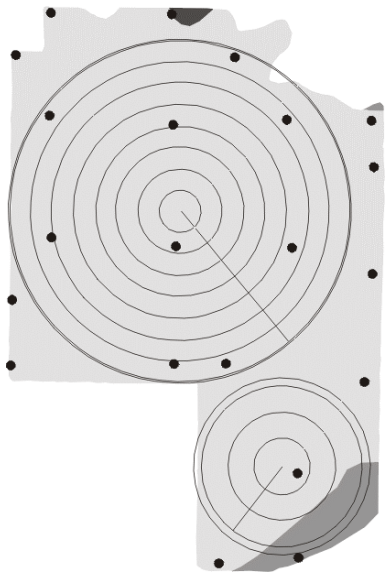

FIGURE 1. Study field, showing soil types, sampling locations, and irrigation pivots.

Soil sampling

Samples were collected with a soil probe from the top 30.5 cm of topsoil. At each location, approximately 10 cores were collected from within about one meter of the point, and were composited in a pail. From the composite, about 0.5 kg was placed in a sampling bag and submitted for analysis at a certified laboratory.

Samples were collected during the growing seasons from 1995 through 1998 (Table 1).

Table 1. Sampling dates during growing seasons 1995 through 1998.

1995 Potatoes	1996 Wheat	1997 Barley	1998 Potatoes
May 7[1]	April 23[1]	June 4	April 30[1]
July7	July 13	July 18	July 23
August 12	August 15	September 16	August 20
September 15	September 22		September 22

[1] samples collected prior to fertilization

Potato petiole sampling

Potato petiole samples were also collected from the same sampling locations in July and August of 1995 and 1998, when potatoes were grown in the field. At least 10 petioles, each from a separate plant, were collected from the top, mature leaves of the potato plants within approximately 3 m of the sample point. The samples were bagged and sent to the laboratory for analysis.

Laboratory Analytical Methods

All soil and plant tissue analyses were done under contract by a private, commercial analytical laboratory. All procedures followed by the laboratory were as specified by the North American Proficiency Testing Program for the western states laboratory proficiency testing program for soil and plant analytical methods (Miller *et al.*, 1998).

Graphical presentation

The following maps of the spatial variation in selected nutrients were created using Inverse Distance Weighted interpolation. The maps are presented to demonstrate the spatial and temporal changes discussed. Although the maps display interpolated values among the sampling points, and many others have discussed their opinions of different interpolation and kriging methods and sampling frequencies, we leave those debates for others and discuss the changes that occurred at the sample points.

RESULTS

Most of the soil nutrients' spatial variability in concentration changed over time during a growing season. Some areas of the field displayed increases in the concentration of

certain nutrients during summer, although no additional nutrients had been applied after initial fertilization.

Effect of fertilization

In 1995, 1996, and 1997, the field was uniformly fertilized. In 1995 the field was fertilized uniformly on May 12 with

449 kg ha^{-1} of 16-20-0
75 kg ha^{-1} of 0-0-60
39 kg ha^{-1} of 11-52-0

This fertilization could be expected to change the phosphorous concentration by just over 2 mg kg^{-1}. However, the changes in fertility were not a uniform step function increase as might have been expected, as demonstrated by the soil phosphorous in May and July (Figure 2). In fact, some areas of the field were lower in phosphorous after the fertilization than before. An area in the east central part of the field decreased in phosphorous concentration from 15 mg kg^{-1} in May to 13 mg kg^{-1} in July.

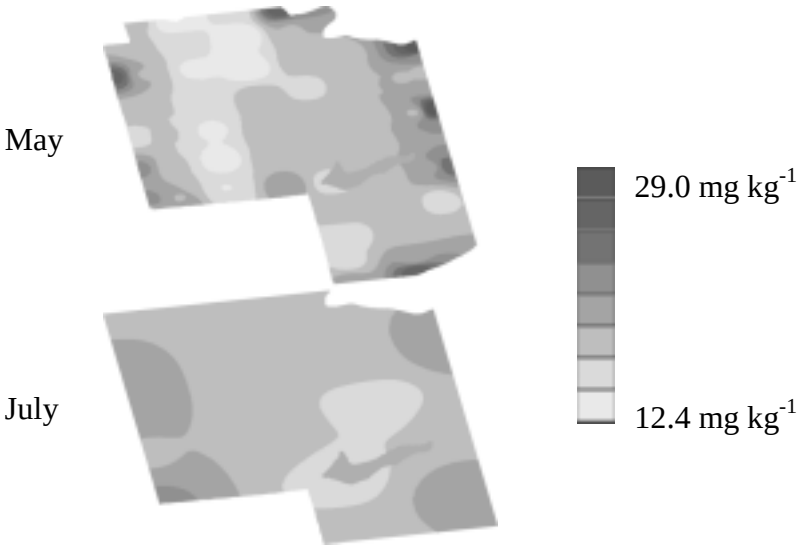

FIGURE 2. Soil phosphorous, May and July, 1995.

Post-fertilization changes

During every growing season, there were changes in the spatial variation in many of the soil parameters. The 1996 maps (Figure 3) represent seasonal change in soil pH, both increases and decreases. As an example, the soil pH along the south end of the field was 6.0 and 6.3 at two sampling points in April, was 7.4 and 7.8 at the same points in July, and was 5.7 and 6.1 at the two points in October.

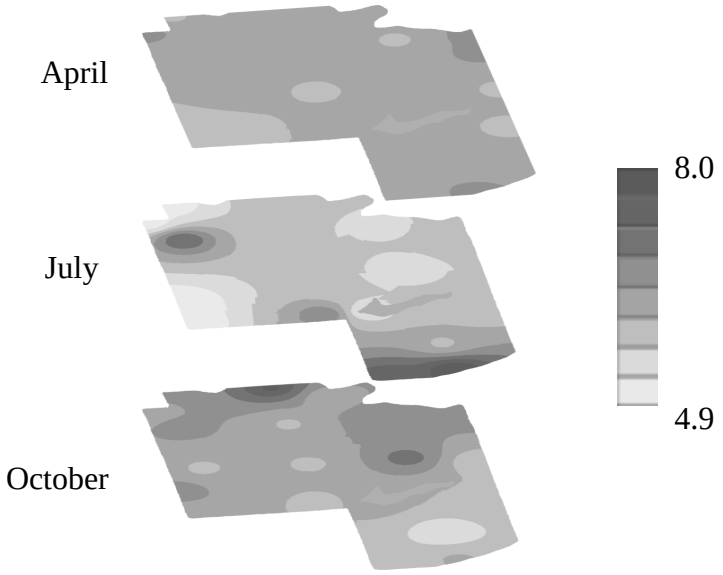

FIGURE 3. Changes in 1996 soil pH during the growing season.

One example of dramatic increases in the concentration of soil nutrients during the growing season in areas of the field, without any fertilizer inputs, is shown by the changes in the 1997 potassium (Figure 4), where in the southwest corner of the field, the potassium was 136 mg kg^{-1} in June, 188 mg kg^{-1} in July, and 290 mg kg^{-1} in September. Several other increases were also observed, such as in the 1996 organic nitrogen which was 40 mg kg^{-1} in the center of the field in July, but had increased to 50 mg kg^{-1} at the same location in October.

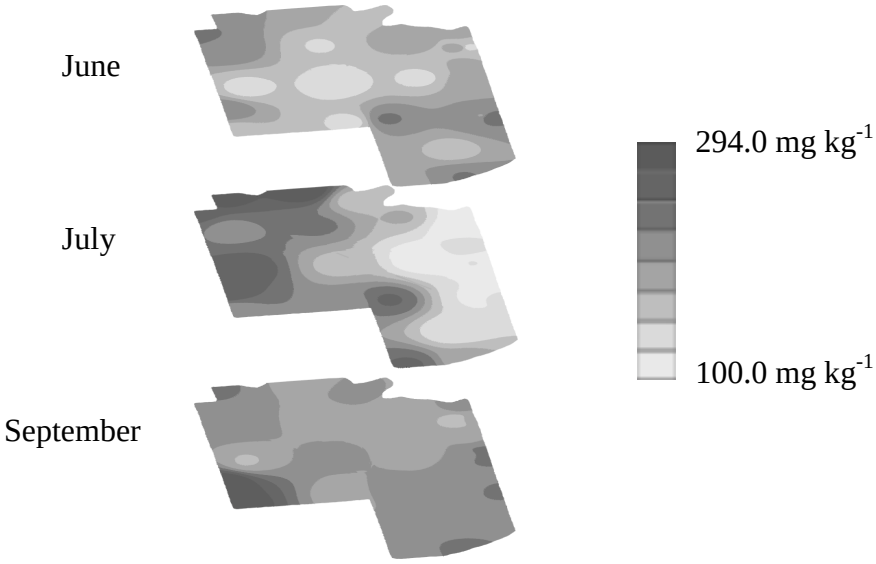

FIGURE 4. Changes in 1997 potassium during the growing season.

Soil/potato plant interchanges

In 1995 and 1998 potato petioles were also sampled during the growing season at the same locations. Temporal changes in the spatial variation of a nutrient in both the soil and the petiole often showed no relation between the soil changes and the petiole

changes. The temporal changes in spatial variation in 1995 sulfur concentrations in July and August for both the soil (Figure 5) and the petioles (Figure 6) showed little relation between them in much of the field.

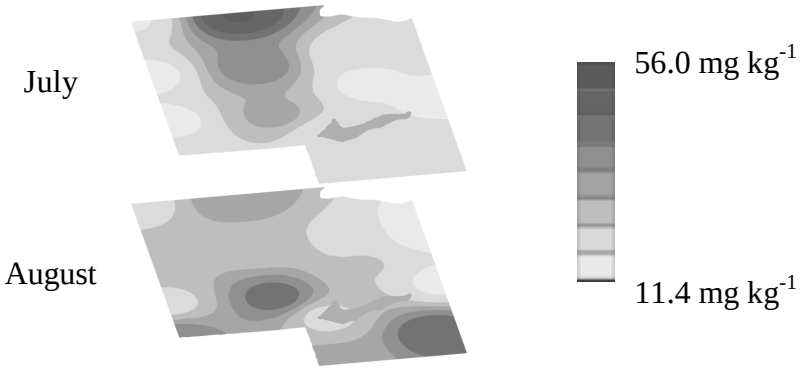

FIGURE 5. Changes in 1995 soil sulfur between July and August.

Between July and August, the sulfur concentrations in both the soil and the petioles increased in the south-central area of the field. The soil concentration increased from 26 mg kg^{-1} to 40 mg kg^{-1} and the petiole concentration increased from 0.23% to 0.28%. However, during the same time period the soil sulfur concentration also increased in the southeast corner of the field from 16 mg kg^{-1} to 42 mg kg^{-1} but the petiole sulfur concentration decreased in that corner of the field from 0.25% to 0.22%.

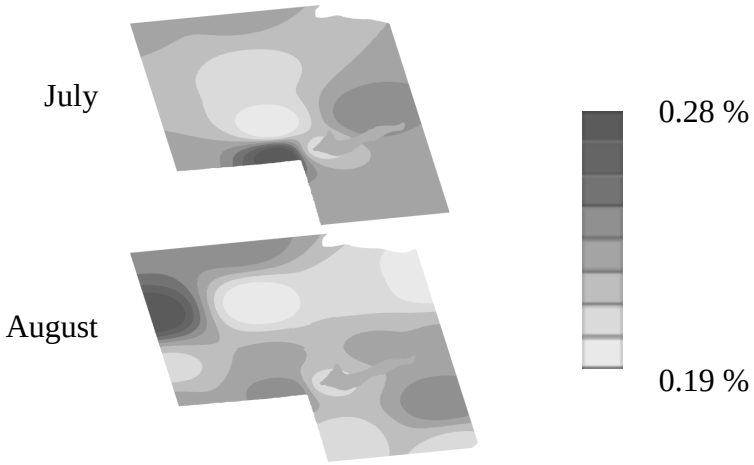

FIGURE 6. Changes in 1995 potato petiole sulfur between July and August.

<u>High concentration</u>

In the 1995 potato field, soil manganese concentration increased to over 40 mg kg^{-1} in the north-central section of the field and in the southwest corner of the field in August during the growing season. Even in September just prior to harvest, the soil manganese concentration in the south-central section of the field remained over 39 mg kg^{-1} (Figure 7). Although these soil values are very high, the plant tissue concentration never exceeded 200 mg kg^{-1}, well within the limits for potatoes (Ulrich, 1993).

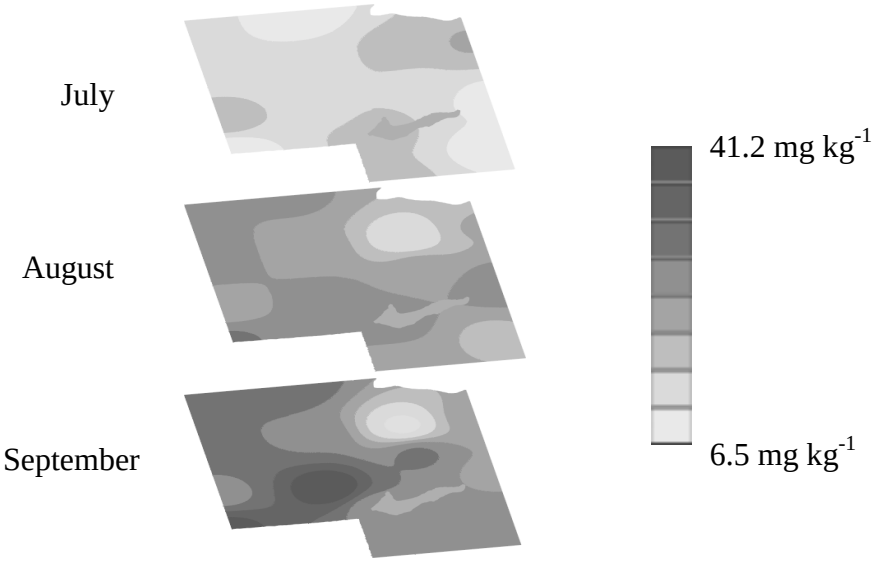

FIGURE 7. Changes in 1995 soil manganese.

Fertility changes during winter 1997-1998

Many fertilization management plans assume no change, or at least a spatially uniform change, in soil fertility between late fall sampling and the next spring's fertilization and planting. However, all the soil fertility parameters measured in this study not only changed between the last measurement in the fall and the first one the next spring, but also changed in a spatially non-uniform manner. This is shown in the spatial differences in the soil nitrates in September 1997, after harvest, when compared to the soil nitrates in April 1998, prior to fertilization (Figure 8). Much of the south-central area of the field that was the most fertile in September 1997, was the least fertile area of the field by April 1998.

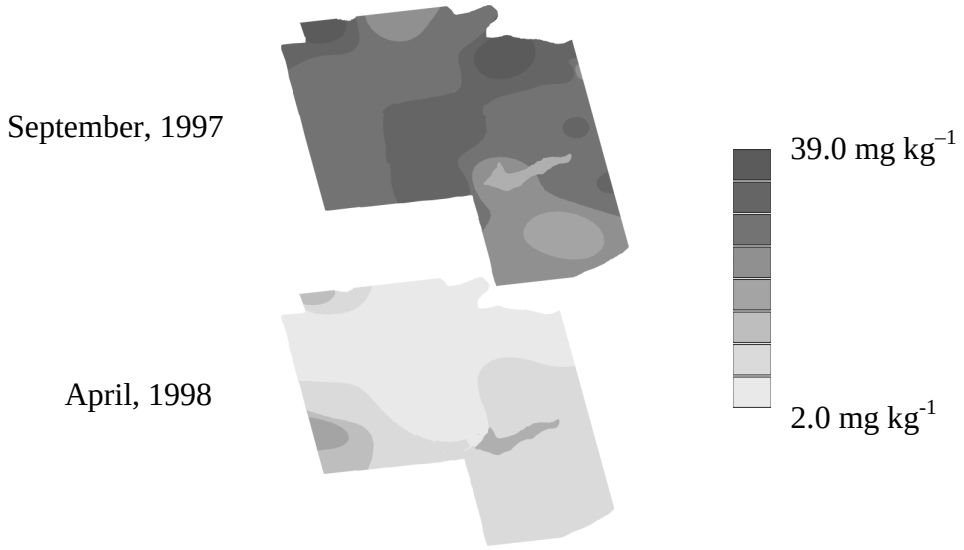

FIGURE 8. Soil nitrate change during winter 1997-1998.

Soil microbial community

In 1995, soil samples for microbial analysis were collected in July at the same time and at the same locations as the July soil and petiole samples. A microbiologist, using standard procedures for collecting soil microbial samples, collected the samples. The samples were refrigerated until early 1996, at which time they were analyzed for microbial population. Figure 9 shows the spatial variation in the number of colony forming units per gram (cfu/g) for both total fungi and heterotrophic bacteria.

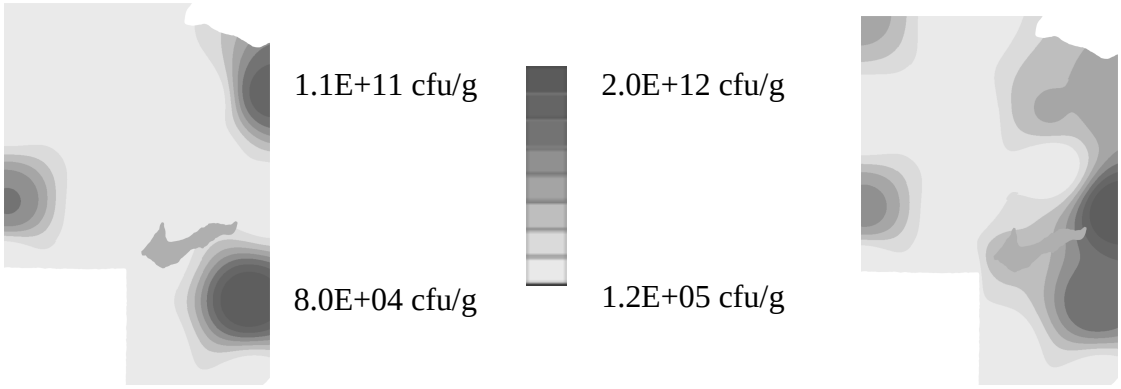

FIGURE 9. Soil microbe maps.

DISCUSSION

Several changes in the spatial variability of soil nutrient concentrations during four growing seasons have been shown. Very little is understood about many of the phenomena that caused these changes. Under controlled laboratory conditions, crop growth and development can be described in detail (Gardner *et al*., 1985), but in cropping systems such descriptions are compounded by changing environmental factors and the genetic and physiological abilities of plants to adapt to these complex cropping environments.

Many theories about the availability of plant growth factors (*e.g.*, nutrients, water, light, temperature, *etc*.) and their potential limiting effects on plant growth have been put forward. In most general terms, some of these theories have been referred to as laws, such as Liebig's "Law" of the minimum, based on his statement that "growth of a plant is dependent on the amount of foodstuff which is presented to it in minimum quantity" (Odum, 1971). The complexity of plant growth and development, compounded by the non-steady-state of the production agriculture environment, the interaction of growth factors, and the ability of crop plants to adjust or omit physiological pathways in response to environmental conditions results in a myriad of possible interactions that are too extensive to be predicted by such simplistic models (Gardner *et al.*, 1985). As mineral nutrition management becomes spatially and temporally more refined, the interacting affect of many factors will have significant implications in site-specific crop nutrient management. The unpredictable spatial by temporal variations in pH (Figure 3) and those variations' lack of correlation to plant nutrient status, is an example of this point. This suggests that site-specific management may necessarily include the

characterization and management of unique rhizosphere ecology that effects nutrient availability.

In cropping systems, nutrient availability generally has a greater impact on determining plant nutrient status than absolute nutrient concentrations. The availability or unavailability of nutrients can be dramatically effected by a combination of factors including soil pH, CEC, microbial activity and other factors (Marscher, 1995). Variations in pH and soil organic matter change throughout the growing season and such changes affect the availability of mineral nutrients (Gardner *et al.,* 1985; Marscher, 1995). In temperate climates, a drop in pH will increase the availability of micronutrients such as manganese, iron, zinc and copper, and decrease the availability of nitrogen and phosphorus (Marscher, 1995).

In the current study, observed changes in levels of iron correlated well with changes in pH, but such a simple relationships can be misleading, as in the case of nitrogen, which lacked any apparent correlation to changes in soil pH (Figure 3). Nitrogen level and availability is not only determined by soil nitrogen concentration, moisture, pH and other factors, but is also altered by biological processes, which processes are also affected by pH, moisture and even temperature and soil organic matter (Marscher, 1995). Microbes not only convert essential nutrients like nitrogen to a usable form, but also can benefit or inhibit plant growth by immobilizing nutrients. Dramatic changes in soil organic nitrogen both spatially and throughout the season were attributed in part to microbial activity. Decay of crop residue by microbes can immobilize large amounts of nitrogen, while soil sterilization, which kills microorganisms, can result in the release of toxic levels of manganese (Gardner *et al.*, 1985). The introduction of microbial communities into the crop growth and development equation substantially increases the complexity of defining spatial factors affecting crop nutrition. However, the importance of these factors cannot be ignored if we expect to develop reliable and accurate site-specific crop nutrient recommendations.

CONCLUSION

Advances in plant nutrition and commercial fertilizers are dominant factors attributing to the present day yields and crop quality of many cereal grains and other crops. Crop nutrition still remains one of the best hopes for the next generation of significant gains in crop production. However, simply using spatially variable fertility management without developing and employing tools that consider the interacting complexities of spatial and temporal crop nutrient requirements/utilization will not yield the next generation of gains in crop productivity, quality or environmental surety.

ACKNOWLEDGEMENTS

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REFERENCES

Burrough, P.A. (1993) Soil Variability: a late 20th century view. *Soils and Fertilizers* **56**(5) 529-562.

Carr, P.M., Carlson, G.R., Jacobsen, J.S., Nielsen, G.A., Skogley, E.O. (1991) Farming Soils, Not Fields: A strategy for increasing fertilizer profitability. *Journal of Production Agriculture* **4**(1) 57-61.

Gardner, F.P., Pearce, R.B., Mitchell, R.L. (1985) *Physiology of crop plants*. 2nd Edn, Iowa State University Press: Ames, 327 pp.

Grow, R. (1993) Soil Survey of Fremont County, Idaho, Western Part. U.S. Department of Agriculture, Soil Conservation Service, Map 55.

Hammond, M.W. (1993) Cost analysis of variable fertility management of phosphorous and potassium for potato production in central Washington. In: *Soil Specific Crop Management*, P.C. Robert, R.H. Rust, and W.E. Larson (Eds), Madison, WI, ASA/CSSA/SSSA, pp. 213-228.

Luellen, W.R. (1985) Fine-Tuned Fertility, Tomorrow's technology here today. *Crops and Soils*, November, pp. 18-22.

Marschner, H. (1995) *Mineral nutrition of higher plants*. 2nd Edn, Academic Press, Inc.: San Diego, 889 pp.

Miller, R.O., Kotuby-Amacher, J., Rodriguez, J.B. (1998) Western States Laboratory Proficiency Testing Program Soil and Plant Analytical Methods. Ver 4.10. From: *Plant, Soil and Water Reference Methods for the Western Region.* (1994) R.G. Gavlak, D.A. Horneck, R.O. Miller. WREP 125.

Odum, E.P. (1971) *Fundamentals of Ecology*. 3rd Edn, W.B. Saunders Co.: Philadelphia, 574 pp.

Ulrich, A. (1993) Potato. In: *Nutrient Deficiencies & Toxicities in Crop Plants*, W. F. Bennett (Ed), St. Paul, MN, American Phytopath Society. pp. 149-156.