JOURNAL OF NEMATOLOGY

VOLUME 34 SEPTEMBER 2002 NUMBER 3

Journal of Nematology 34(3):185–188. 2002.

Embracing the Emerging Precision Agriculture Technologies for Site-Specific Management of Yield-Limiting Factors[1]

H. Melakeberhan[2]

Abstract: Precision agriculture (PA) is providing an information revolution using Global Positioning (GPS) and Geographic Information (GIS) systems and Remote Sensing (RS). These technologies allow better decision making in the management of crop yield-limiting biotic and abiotic factors and their interactions on a site-specific (SSM) basis in a wide range of production systems. Characterizing the nature of the problem(s) and public education are among the challenges that scientists, producers, and industry face when adapting PA technologies. To apply SSM, spatio-temporal characteristics of the problem(s) need to be determined and variations within a field demonstrated. Spatio-temporal characteristics of a given pathogen or pest problem may be known but may not be the only or primary cause of the problem. Hence, exact cause-and-effect relationships need to be established by incorporating GIS, GPS, and RS-generated data as well as possible interactions. Exploiting the potential of PA technologies in sustainable ways depends on whether or not we first ask ''Are we doing the right thing?'' (strategic) as opposed to ''Are we doing it right?'' (tactical).

Key words: detection, distribution patterns, *Heterodera glycines*, sampling strategies, soybean cyst nematode, spatio-temporal structure, yield-limiting factor.

Precision agriculture (PA) technologies, encompassing geographic information (GIS), global positioning (GPS), and remote sensing (RS), arose from better awareness of soil and crop condition variabilities within fields in the mid-1970s and early 1980s (Robert, 1999). Remote sensing and GPS are key to detecting changes and locating ground positions, and GIS is key to quantifying the variabilities in soil texture and landscape information. Indeed, these technologies are being widely applied in various agricultural and non-agricultural systems, especially in managing soil-driven yield-limiting problems (Cassel et al., 2000; Pierce and Sadler, 1997). As the ecological and economic awareness of wise pesticide use and demands in conservation tillage increase, the potential of applying PA technologies to manage biotic crop yield-limiting factors on a site-specific basis also increases (Nelson et al., 1999; Strickland et al., 1998). Exploiting the potential and sustainability of site-specific management (SSM), however, depends on identifying the right spatio-temporal conditions for SSM that, in turn, are dependent on applying appropriate diagnostic sampling strategies (Pierce and Sadler, 1997), establishing cause-and-effect relationships of yield-limiting factor(s), and asking strategic questions before tactical questions.

Spatio-temporal structure requirements and sampling strategies for SSM: A yield-limiting factor in any given field could have small and large clusters that vary widely in density and spatial structure (Fig. 1). Because of current sampling strategies and cost-effectiveness limitations, however, it is not uncommon to see a management decision for biotic and abiotic yield-limiting factors based on the presence of the problem(s) from composite samples of large areas. By compositing samples, spatial structure variability (a key component of SSM) is eliminated (Oliver, 1999; Robertson et al., 1993). Let us assume that there are three 16-ha fields with three distribution patterns (DP) (DP1, DP2, and DP3) and two types of soil-borne yield-limiting problem(s) (Fig. 1). DP1 and DP2 have single yield-limiting factor 'A', which is well-clustered in DP1 but not in DP2. DP3 is similar to DP1 in spatial structure but has unidentified additional yield-limiting factor 'B'. If one is to apply SSM in any of these fields, it is necessary to apply the right sampling strategy that would map the yield-limiting factors. For example, many sampling schemes (SS) are applied to detect yield-limiting problems like plant-parasitic nematodes that may have similar spatial structures shown in DP1, DP2, or DP3 (Fig. 1). If one were to test three sampling schemes (SS1, SS2, and SS3) in these fields, the outcome would vary widely (Fig. 2). Most current management strategies call for an SS1-type of sampling plan, where samples are collected along a zigzag line across the whole field and the sample is composited and sub-samples analyzed to identify the problem (McSorley, 1998). In the short-term, this is the most economical way to find out whether or not a problem exists in the field. The limitation is that this sampling scheme does not identify the spatial structure of the yield-limiting factor(s). The only way this sampling scheme may give limited information

Received for publication 14 September 2001.

[1] Paper delivered in a symposium on Application of GIS and GPS Precision Agriculture Technologies in Nematology and Plant Pathology, Society of Nematologists Annual Meeting, 24–29 August 2001, Salt Lake City, UT.

[2] Associate Professor of Nematology, Department of Entomology, Michigan State University, East Lansing, MI 48824.
E-mail: melakebe@msu.edu

This paper was edited by B. C. Hyman.

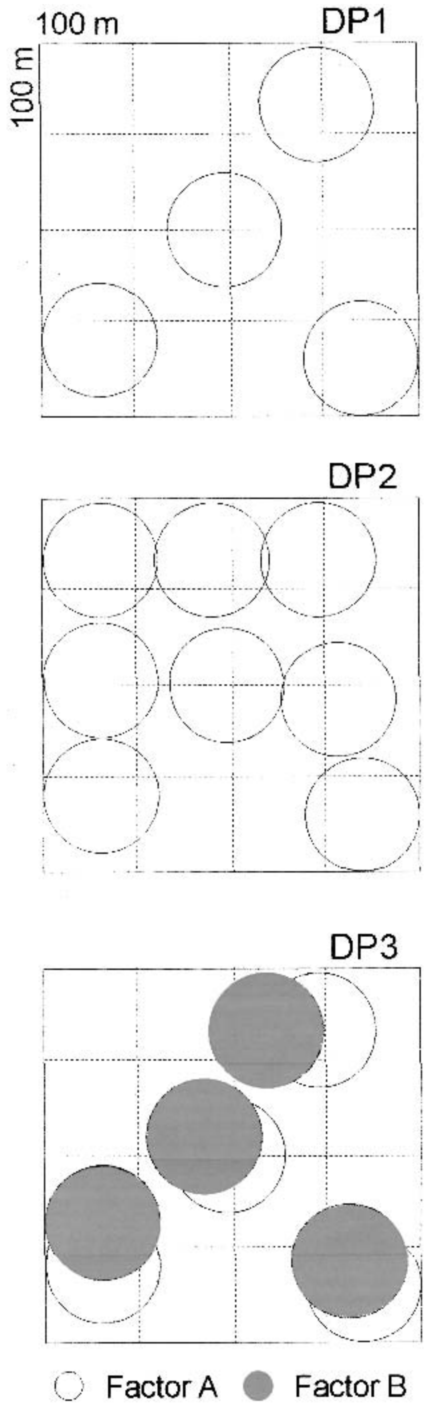

FIG. 1. Three hypothetical distribution patterns (DP) of yield-limiting factor(s) in a 16-ha field. DP1 and DP2 show distribution of single factor (A), whereas, DP3 exhibits similar distribution patterns to DP1, but with two yield-limiting factors. Recognize that yield-limiting factors can have a range of shapes and densities.

of the location of the yield-limiting problem is if GPS is applied. Hence, it will not yield accurate information for SSM purposes.

Depending on the nature of the distribution of the yield-limiting factor(s) and the accuracy of detection, determining its spatial distribution increases with increasing number of samples. Here, quadratic types (SS2

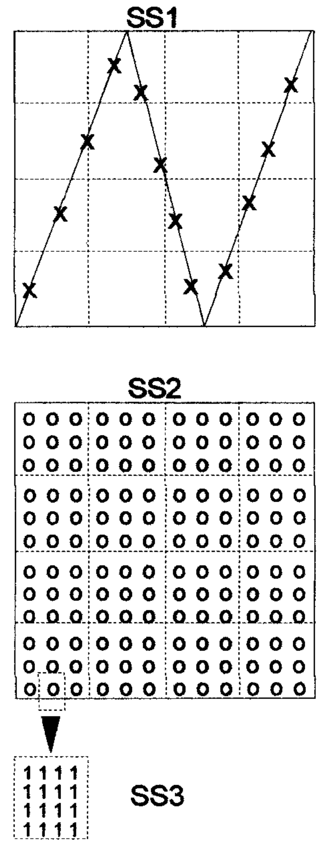

FIG. 2. Three hypothetical sampling schemes (SS) that may be applied to detect yield-limiting factors. Samples are collected at the 'x' points along the zigzag line (SS1), from the points of individual circles in a 16ha field (SS2), and from 16 points within a 30-m × 30-m area (SS3).

and SS3) of sampling plans along with GPS and appropriate geostatistical tools (Oliver, 1999) will have to be considered for better decision-making purposes (Fig. 2). The degree of accurately identifying the spatial structure of a yield-limiting factor described in Figure 1 increases with the number of samples and how systematically the samples are collected (Fig. 2). For example, SS3 represents the most intensive, and likely the most accurate, sampling plan for identifying the spatial structure of the yield-limiting factor(s). However, it is the most expensive one. The type of sampling plan, which depends on the value of the crop, influences the accuracy of spatial structure of the yield-limiting factor.

In addition to spatial structure, SSM requires a determination of the temporal changes of yield-limiting factors. If the problem moves from one place to another within a given management application time, SSM would not work (Pierce and Sadler, 1997). While temporal movements are important when considering insects and airborne pathogens, they are less likely to affect organisms such as plant-parasitic nematodes, whose mobility on their own is limited. However, determining the temporal aspect of when nematode population dynamics peak is important because it affects when remedial management may be applied. For example, the most common way of analyzing nematode reproduction has been sampling at planting (P_i) and at harvest (P_f) (McSorley, 1998). A P_f/P_i ratio of more than 1.0 indicates reproduction and is often used as an indicator of impact on yield loss. Increase in nematode population density at harvest, however, is a function of host type, the amount of root damage over the growing season, and prevailing soil conditions (McSorley, 1998). Making remedial management recommendations based on P_f/P_i ratio may not be as useful as determining the nematode population dynamics and the plant host phenology over the growing season.

Determining the spatial-temporal structure of problems is as important as knowing that there is a yield-limiting issue when considering SSM (Oliver, 1999). Assuming that an accurate sampling strategy has been applied to demonstrate the distribution pattern of the yield-limiting factors shown in DP1, DP2, and DP3 (Fig. 1), one can then make decisions about SSM. A yield-limiting factor with DP2-type spatial structure will not be suitable for SSM because the problem consumes the entire field. Assuming that variable application technologies are available and that the economic value of the crop justifies it, DP1 and DP3 types of yield-limiting problems will be suitable for SSM.

Establishing cause-and-effect relationships: Under natural conditions, it is rare that crop yield is limited by a single factor. Yet most diagnostic methods may identify one factor and miss one or more additional factors. Even if the spatio-temporal dynamics of a given problem are determined and SSM recommendations effected, the identified problem may not be the only cause of the yield limitation. Consider the yield-limiting spatial structure of DP3, which seems suitable for SSM of both factors, but only factor 'A' is recognized (Fig. 1). Yield loss may continue after SSM has been applied to manage factor 'A' and may lead to negative views about accepting the PA technologies in general. This kind of inaccuracy could be minimized by looking beyond the obvious and exploring broadly. As the following scenario shows, misdiagnosis could happen at small scales more often than is generally recognized. For example, an approximately 4-m × 4-m area in a soybean field revealed patches of chlorotic plants. Four soil samples from the chlorotic area and four samples from an adjacent area were collected and analyzed for soybean cyst nematode (*Heterodera glycines*), the prime suspect. Both categories had high numbers of cysts per 100 cc of soil that would warrant management recommendations in any soybean production system (Table 1). However, there were significantly more *H. glycines* cysts in soil from the healthy-looking plants compared with the soil on which the chlorotic-looking plants were growing. On the surface, this may look as if there were more roots in the healthy plants and, hence, can support the nematodes without showing visible symptoms. From the management point of view, the *H. glycines* levels were high and the 16 m^2 would be ideal for SSM because that is the area where the problem is visible. Looking at the difference in the levels of macronutrients between the two categories of samples, however, the problem does not seem to be only *H. glycines* and the explanation may not be simple (Table 1). Soil pH was 7.8 and 8.0 in the yellow and green areas, respectively, probably driven high by the high levels of calcium and magnesium. The soil concentrations of nitrogen, phosphorus, and potassium and the cation exchange capacity (CEC) were significantly lower in the soil where the chlorotic plants were growing compared with the soil on which the healthy plants were propagated (Table 1). The soil nutrient problem could be due to lack of availability of nutrients or limited by factors such as soil pH not being in the right ranges for certain nutrients (Marschner, 1995). Nonetheless, it is known that the impact of nematodes on plant growth is worse when soil nutrients are less favorable to plant growth than when conditions are favorable (Kaitany et al., 2000). Furthermore, the level of nutrient differences between favorable and less favorable conditions need not have large differences to show a significant impact of host response to the problem (Melakeberhan, 1999). Although not determined in this study, soil texture is one of the primary factors that influence soil nutrient balance (Marschner, 1995, Robertson et al., 1993) and *H. glycines* pathogenesis (Workneh et al., 1999). This, in turn, raises the need for incorporating GIS data in identifying the cause-and-effect relationships.

TABLE 1. The mean number of SCN cysts per 100 cc soil, soil NO^3-N, $H_2PO_4^-$, K^+, Mg^{2+}, Ca^{2+} (kg/ha) and cation exchange capacity (CEC, meq/100 g dry soil) from approximately 4-m × 4-m area with chlorotic and green-looking soybean plants in a grower field[1] in Michigan in 1998.

		Soil nutrients					
Location	Cysts	NO^3-N	$H_2PO_4^-$	K^+	Mg^{2+}	Ca^{2+}	CEC
Chlorotic	296 a[2]	1.98 a	158 a	280 a	359 a	1962 a	6.0 a
Green	857 b	4.78 b	180 b	440 b	359 a	3830 b	8.5 b
Average[3]	577	3.38	169	360	359	2896	7.3

[1] The field received recommended rates of lime and fertilizer (without N).
[2] Data means are of four samples per category, and means followed by different letters are statistically significant according to *t*-test.
[3] Average of the chlorotic and green-looking areas are shown to demonstrate the traditional way of analyzing the data.

Conclusion: Sustained application of SSM will very much depend on how holistic our approaches are toward solving agricultural problems. In doing so, we need to ask if we are doing it right (tactical) or if we are doing the right thing (strategic) (Holt, 1991). Weighing the strategic question over the tactical question is likely to result in a long-term solution. For example, how many samples to collect per unit area is dependent on crop value and sampling purpose. To identify the appropriate conditions for SSM, however, some sort of grid-sampling must be considered so that the spatial structure of the problem can be identified. It is only when the spatio-temporal structures and cause-and-effect relationships of a yield-limiting factor(s) are known that SSM should be considered (Avendano et al., 2000; Cassel et al., 2000; Robertson et al., 1993). One needs to recognize that the interactions between and among biotic and abiotic yield-limiting factors and their environment are vitally intertwined.

Literature Cited

Avendano, F., F. Pierce, O. Schabenberger, and H. Melakeberhan. 2000. Assessing spatial variability in *Heterodera glycines* as a prerequisite for its site-specific management. Journal of Nematology 32:416–417.

Cassel, D. K., O. Wendroth, and D. R. Nielson. 2000. Assessing spatial variability in an agricultural experiment station field: Opportunities arising from spatial dependence. Agronomy Journal 92:706–714.

Holt, D. 1991. Organizational paradigms of agricultural research and development. Agricultural Research Institute Proceedings and Minutes. No. 39:8–20.

Kaitany, R., H. Melakeberhan, G. W. Bird, and G. Safir. 2000. Association of *Phytophthora sojae* with *Heterodera glycines* and nutrient stress. Nematropica 30:193–199.

Marschner, H. 1995. Mineral nutrition of higher plants. 2nd ed. New York: Academic Press.

McSorley, R. 1998. Population dynamics. Pp. 109–134 *in* K. R. Barker, G. A. Pederson, and G. L. Windham, eds. Plant and nematode interactions. Agronomy Monograph No. 36. Madison, WI: American Society of Agronomy Miscellaneous Publication. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America Publishers.

Melakeberhan, H. 1999. Effects of nutrient source on the physiological mechanisms of *Heterodera glycines* and soybean genotypes interactions. Nematology 1:113–120.

Nelson, M. R., T. V. Orum, and R. Jaime-Garcia. 1999. Applications of geographic information systems and geostatictics in plant disease epidemiology and management. Plant Disease 83:308–319.

Oliver, M. A. 1999. Exploring soil spatial variation geostatiscally. Pp. 3–17 *in* J. V. Stafford, ed. Precision agriculture '99 Part 1. Sheffield, UK: Academic Press.

Pierce, F. J., and E. J. Sadler, 1997. The state of site-specific management for agriculture. Madison, WI: American Society of Agronomy Miscellaneous Publication. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America Publishers.

Robert, P. C. 1999. Precision agriculture: Research needs and status in the USA. Pp. 19–33 *in* J. V. Stafford, ed. Precision agriculture '99 Part 1. Sheffield, UK: Academic Press.

Robertson, G. P., J. R., Crum, and B. G. Ellis. 1993. The spatial variability of soil resources following long-term disturbance. Oecologia 96:451–456.

Strickland, R. M., D. R. Ess, and S. D. Parsons. 1998. Precision farming and precision pest management: The power of new crop production technologies. Journal of Nematology 30:431–435.

Workneh, F., X. B. Yang, and G. L. Tylka. 1999. Soybean brown stem rot, *Phytophthora sojae,* and *Heterodera glycines* affected by soil texture and tillage relations. Phytopathology 89:844–850.