VARIABLE-RATE FERTILIZER APPLICATION: UPDATE AND ECONOMICS

Nyle C. Wollenhaupt, Richard P. Wolkowski
and Harold F. Reetz, Jr.[1]

The potential for application of computer-controlled, satellite-guided, variable-rate application systems for fertilizer has opened an interesting new area of research and development. While variable-rate application is not new--and does not require the computer or satellite systems to be useful--the technology is definitely helping to convince dealers and farmers that this concept has broader potential. Economic pressures and environmental concerns are leading them to take a closer look at how the variable-rate concept might fit their management systems.

WISCONSIN VARIABLE-RATE FINDINGS

A research study is in progress to evaluate soil sampling strategies, methods for griding and contouring spatial data, yield response to variable-rate fertilizer applications, and the profitability of selected combinations of variable-rate practices for a variety of cropping practices and soil conditions in Wisconsin. Following is an abbreviated summary of findings for two farm sites located in central Wisconsin.

Methods and Procedures

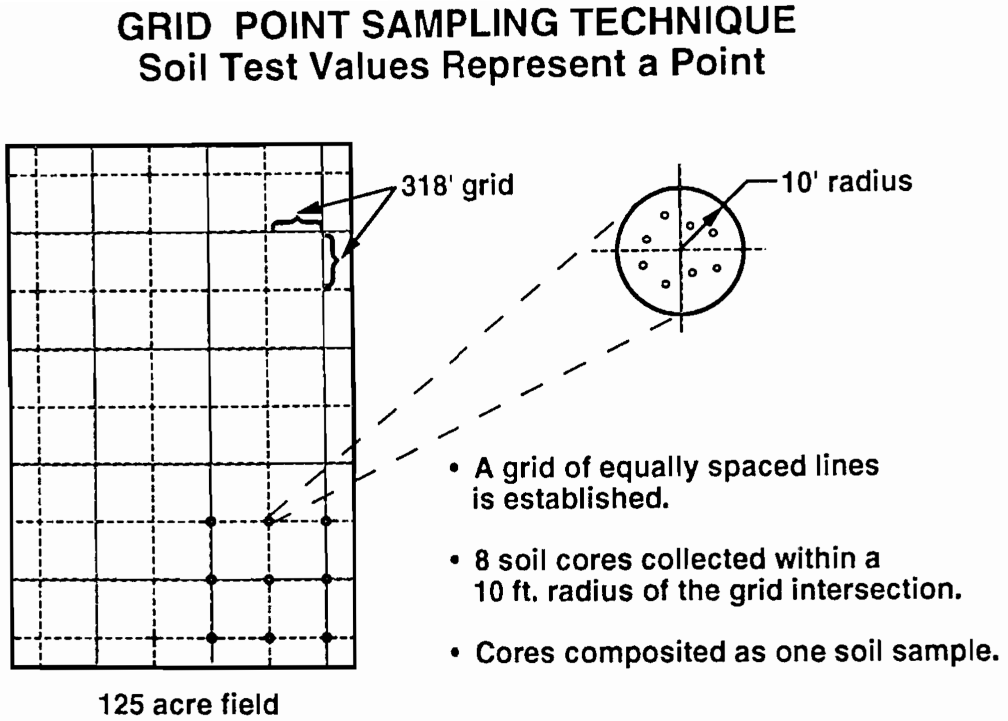
Two sites were selected in the spring of 1992 near the towns of Waupaca and Iola in central Wisconsin. The Waupaca field (56.2 acres) was mapped as Zurich silt loam soils and will be referred to as the Trinrud field. The field located near Iola (41.5 acres) consisted of Rosholt sandy loam and Plainfield loamy sand soils and will be referred to as the Kohel field. Both fields were in corn production in 1991 and 1992. ASCS photographs and soil survey maps show that historically the two fields were managed as a series of smaller fields by prior owner/operators. Nutrient management included manure applications at unknown rates and locations within the fields prior to this study.

Sampling

The fields were soil sampled using two strategies referred to as grid-point and grid-cell sampling. Both methods begin by laying out a grid of evenly spaced lines on the field. Eight, 8-inch deep soil cores were collected within a 10-ft radius of each line intersection point (Figure 1) for the grid-point method. The point spacing was 106-ft. Soil cores were composited to obtain a representative soil sample for each point (very small area). This procedure smooths the effect of soil test nutrient variability which occurs over very short distances.

---

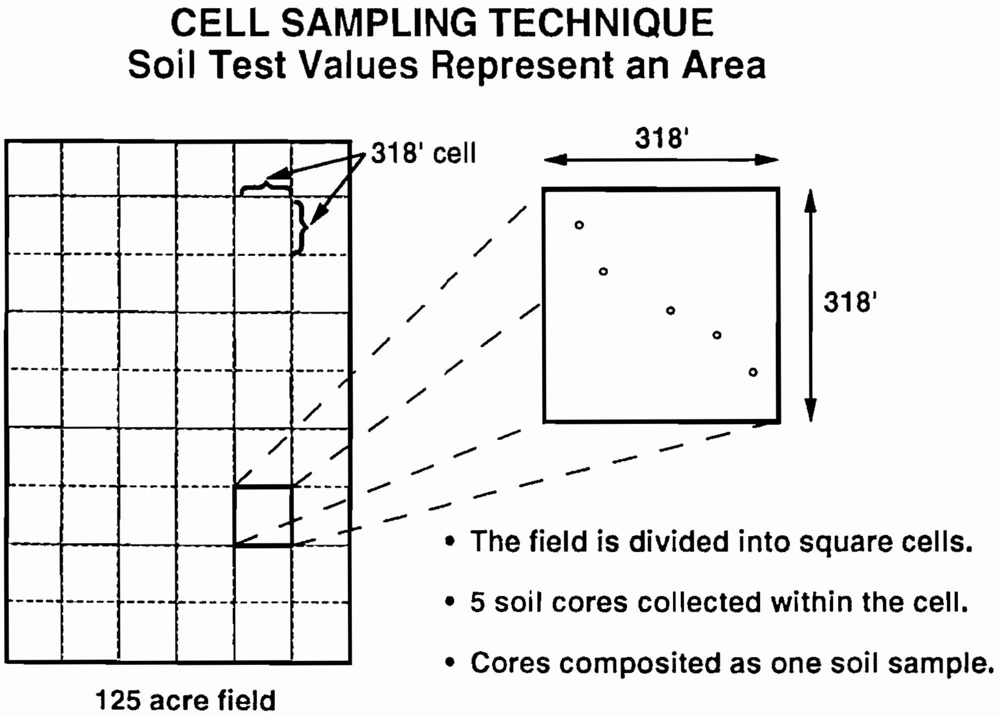
[1] Assistant Professor and Extension Soils Specialist, Department of Soil Science, University of Wisconsin-Madison, and Westcentral Director, Potash & Phosphate Institute, Monticello, Illinois.



GRID POINT SAMPLING TECHNIQUE
Soil Test Values Represent a Point

- A grid of equally spaced lines is established.
- 8 soil cores collected within a 10 ft. radius of the grid intersection.
- Cores composited as one soil sample.

Figure 1. Schematic showing the layout of a 318-ft grid and locations where soil cores are collected for a 125-acre field (total of 54 samples).



CELL SAMPLING TECHNIQUE
Soil Test Values Represent an Area

- The field is divided into square cells.
- 5 soil cores collected within the cell.
- Cores composited as one soil sample.

Figure 2. Schematic showing the layout of 318-ft cells and indicating where soil cores are collected for a 125-acre field (total of 54 samples).

Five soil cores, 8 inches deep, were collected along a diagonal line inside each cell for the grid-cell method (Figure 2). The cell dimensions were 318 by 318-ft. The cores were composited to obtain one soil sample per cell (CELL A). The goal of this method is to obtain a soil sample that represents the cell area. The diagonal soil sampling approach was chosen instead of a commonly recommended zig-zag pattern to increase the efficiency of soil sampling.

A second cell sampling approach (CELL B) was simulated by averaging the soil analysis data for the nine 106-ft grid sample points that occurred within each full-sized cell. With this approach, nine soil samples (nine sample points x eight cores) were averaged to create one soil test value for the area within a cell.

To simulate grid-point sampling on a 212-ft interval, every other row and column were deleted from the 106-ft data set. Likewise, a 318-ft sample interval data set was created by deleting two consecutive out of every three rows and columns from the 106-ft data set. The soil samples were analyzed for organic matter, pH, Bray-1 phosphorus (P), and exchangeable potassium (K). The analytical procedures are presented in Kelling et al. (1991).

Mapping

Soil test category maps were created for the grid-point data with a variety of contouring and griding procedures. The grid-point data were first contoured using a Delaunay triangulation procedure, which creates a map similar to that achieved by hand contouring. This map was treated as the control map for map overlay comparisons.

Four other mapping procedures were evaluated: (1) inverse distance weighting, (2) fitting a third-order polynomial equation to the field data followed by inverse distance weighting the residuals and then adding the residuals to the equation created points, (3) point kriging, and 4) block kriging. Each began by creating a grid of finely spaced data points (53-ft grid) followed by contouring.

Soil test category maps were created for the cell maps by classifying each cell according to the soil test values.

Costs and Returns

Changes in corn yield and amount of fertilizer applied for the soil sampling and mapping methods were calculated using a procedure described by Buchholz (1991). The procedure is based on a theoretical technique proposed by Fisher (1974) to relate soil test measurements to crop yields. Corn was valued at \$2.50/bu, phosphate (P_2O_5) at \$0.25/lb and potash (K_2O) at \$0.12/lb.

Results

Soil Sampling and Mapping

Trinrud field. Soil test category maps were created for the various soil sampling densities and grid algorithms. The 106-ft Delaunay triangulation map was chosen as the control map since it classified all the sample points correctly and presented the most believable map. Although appearance of the contour map may not be a reliable guide to how well the model represents the original control points, the griding-type algorithms do not offer significant advantages when the original data is also on a grid.

Map area comparisons of soil test P and K category maps for the Trinrud field are summarized in Table 1. Fertilizer application based on a field average of all 199 soil samples would result in correct phosphate and potash application on only 37 and 24% of the field, respectively. A larger percentage of the field would receive the correct fertilizer application with the cell sampling method, especially CELL B.

We attribute the area comparison differences between the cell methods to soil sampling density. Only five soil cores were used to obtain the soil test P and K values for the CELL A method, whereas 72 cores were used in the CELL B method. Seventy-two cores are probably excessive but we cannot determine the optimum number from this study. The number of cores required to obtain a result, with some predetermined confidence, is dependent on the amount of variability in the area to be sampled. Splitting a field into small areas does not necessarily reduce variability within a defined area. Hence the question of how many soil cores and/or soil samples to collect does not diminish when sampling cells vs. fields.

Of greater interest is the fact that the same number of soil samples (24 for both cell and grid-point) collected using the grid-point sampling method, grided and contoured, resulted in soil test category maps that had a higher percentage area in common with the 106-ft Delaunay control map.

We also expected that by increasing the soil sampling density, soil test maps made by the five mapping procedures would more closely approximate the control map. This expectation holds for K but not P. The 318-ft sample spacing leads to a more correct map than the 212-ft spacing data for P. Soil test P maps not shown here reveal a narrow linear pattern for the soil test P category polygons. The effect would be similar to soil sampling an apple orchard with a systematic fixed grid. The grid may line up on a row or an alley with the resulting information not providing a complete picture of the row and alley effect. Soil sampling using a stratified systematic unaligned sampling procedure described by Webster and Oliver (1990) would avoid this problem. With the application of global positioning navigation, this type of sampling would involve about the same sampling effort as systematic grid sampling based on dead reckoning.

Table 1. Comparison of how soil sampling density and mapping procedures affect mapping soil test P and K in the Trinrud field.

Field sample spacing	Number of sample points	Grid/contour method	Map area comparisons	
			P	K
ft			------- %	-------
106	199	Delaunay	100	100
106	199	Point krig	89	96
106	199	Block krig	84	94
106	199	Inverse distance	96	96
106	199	Polynomial-inverse distance	96	96
212	51	Delaunay	64	77
212	51	Point krig	66	79
212	51	Block krig	66	79
212	51	Inverse distance	65	79
212	51	Polynomial-inverse distance	66	78
318	24	Delaunay	67	67
318	24	Point krig	69	70
318	24	Block krig	69	70
318	24	Inverse distance	69	70
318	24	Polynomial-inverse distance	59	71
1 sample/cell		CELL A (318-ft cell)	48	33
Avg. 9/cell		CELL B (318-ft cell)	60	67
Field average = 199			37	24

A comparison of the various grid and contouring methods clearly shows that the **number of soil samples used in mapping is of much greater importance than the various grid and contouring procedures.**

Kohel field. The Trinrud field observations and conclusions also apply for P in the Kohel field (Table 2). Potassium, however, is quite different. The soil test K levels were variable, but the variability was mostly within the very low soil test category. As a result, it makes little difference if several or 149 soil samples are collected. The K map is made up primarily of the very low soil test category. The same result would occur for variable soil test levels, but all occurring in the excessively high soil test category.

Table 2. Comparison of how soil sampling density and mapping procedures affect mapping soil test P and K in the Kohel field.

Field sample spacing	Number of sample points	Grid/contour method	Map area comparisons P	Map area comparisons K
ft			------- % -------	
106	149	Delaunay	100	100
106	149	Point krig	91	98
106	149	Block krig	80	98
106	149	Inverse distance	94	99
106	149	Polynomial-inverse distance	93	99
212	37	Delaunay	68	96
212	37	Point krig	64	98
212	37	Block krig	63	98
212	37	Inverse distance	66	96
212	37	Polynomial-inverse distance	68	97
318	19	Delaunay	69	96
318	19	Point krig	67	97
318	19	Block krig	67	97
318	19	Inverse distance	67	97
318	19	Polynomial-inverse distance	67	97
1 sample/cell		CELL A (318-ft cell)	47	93
Avg. 9/cell		CELL B (318-ft cell)	58	98
Field average = 149			27	97

Costs and Returns

Budgets were created for the following soil sampling and mapping methods: a) 106-ft grid point--Delaunay contours, b) 212-ft grid point--inverse distance grid, c) 318-ft grid point--inverse distance grid, d) 318-ft CELL A, and e) 318-ft CELL B. Returns are reported as the difference between a one composite soil sample and one fertilizer rate program, and the five alternative sampling and mapping methods.

The changes in income derived from yield gains and reduced or added fertilizer costs, compared to a single soil sample single fertilizer rate program, are presented in Table 3 in the column labeled additional gross returns. The various soil sampling and mapping methods all show income increases over the field average program. Previous studies subtracted the costs for variable-rate practices including soil sampling, soil analysis and fertilizer application from this practice return, to evaluate net profitability.

Table 3. Summary of variable-rate practice costs and returns for several soil sampling densities.†

Field site	Soil sampling method	Additional gross return‡	Additional corrected gross return	Variable§ rate costs	Net return to variable-rate practice¶
Trinrud	Grid point, 106 ft	$13.14	$13.14	$10.79	$2.35
	Grid point, 212 ft	$10.14	$3.76	$4.28	($0.52)
	Grid point, 318 ft	$10.29	$5.14	$3.07	$2.07
	318 ft CELL A	$ 5.72	($13.94)	$2.42	($16.37)
	318 ft CELL B	$ 7.53	$0.07	$2.42	($2.35)
Kohel	Grid point, 106 ft	$7.64	$7.64	$10.79	($3.15)
	Grid point, 212 ft	$7.46	$4.30	$4.28	$0.02
	Grid point, 318 ft	$10.29	$6.23	$3.07	$3.16
	318 ft CELL A	$5.09	($4.68)	$2.42	($7.10)
	318 ft CELL B	$4.53	($0.38)	$2.42	($2.80)

† Variable-rate costs include soil sampling, data management, and additional fertilizer application charge.

‡ Difference in returns compared to field average management program.

§ Table 3 costs plus three additional years spreading charge ($1.50/a) divided by 4 years.

¶ Additional corrected gross return minus variable-rate costs.

From the previous mapping discussion, we know that soil sampling and mapping methods b) through e) result in a more correct fertilizer application compared to a field average soil test-one fertilizer rate approach. However, these methods still over- or under-fertilize areas within the field. We know how much and to what extent by overlaying these maps with the 106-ft Delaunay control map. Therefore, it is necessary to create a second (correction) budget for yield and fertilizer adjustments.

The corrected or "true" additional gross returns are present in the second data column titled corrected additional gross return (Table 3). The "true" gross returns are substantially lower for all sampling and mapping methods other than the 106-ft grid-point control map, which does not change.

Even before the costs of variable-rate programs are added in, the cell sampling methods are showing less income than the single rate program. The area comparisons in Tables 1 and 2 show a better correlation between the cell maps and control map than the field average-control map comparison. How then can the cell methods return less income, even before the costs of cell sampling and variable-rate application are included? The area comparisons give equal weight to all areas correctly or incorrectly classified. Misclassification of the excessively high, non-responsive areas has little effect on returns. Misclassification of very low soil test soils leading to under-fertilization (lower yields) will quickly show up as less income in the returns column. Although the overall spatial classification was better with the cell techniques, the responsive soil test areas received less fertilizer by the cell treatment than with one rate for the whole field.

To complete the profit analysis, based on P and K management only, it is necessary to subtract the variable-rate costs. Table 4 presents the costs of soil sampling, data management and fertilizer application associated for several soil sampling densities.

Table 4. Variable-rate soil sampling, fertilizer application, and data management costs.†

	450 ft grid (≈ 5 acres)	300 ft grid (≈ 2 acres)	200 ft grid (≈ 1 acre)	100 ft grid (≈ 0.25 acre)
	----------------	---------------- $/acre	----------------	----------------
Sampling‡				
2 hr (20 samples)	$1.70			
5.7 hr (48 samples)		$4.29		
10.9 hr (109 samples)			9.09	
36 hr (436 samples)				$35.16
Fertilizer application (additional variable-rate charge)	$1.50	$1.50	$1.50	$1.50
Data management	$1.50	$1.50	$1.50	$1.50
Computer chip	$0.50	$0.50	$0.50	$0.50
TOTAL COST	$5.20	$7.79	$12.59	$38.66

† 100-acre field with labor @ $25.00/hr and soil testing @ $6.00/soil sample.
‡ 1 hr (1 sample) = $0.31.

Variable-rate practice costs are averaged over 4 years (Table 3). This analysis does not include the cost of borrowing money to pay for the practice. The one soil sample-single fertilizer rate program cost of $0.31/a was subtracted from the grid methods. Then three additional years of variable-rate fertilizer application charges ($1.50/yr) are added with the total being divided by 4 years. Note: The 450-ft grid costs are used to represent the cell costs, although CELL B required considerably more time to complete field soil sampling.

The net return per year for the various variable-rate programs is also shown in Table 3. The cell sampling methods result in less income compared to applying one fertilizer rate across the entire field. The 318-ft grid-point sampling method shows an income increase for both Trinrud and Kohel fields. Sampling on a 106-ft grid was profitable in the highly variable (responsive soil test categories) Trinrud field. In the Kohel field where only soil test P varied across soil test categories, the 106-ft grid sampling decreased income.

Conclusions

Cell sampling does a better job of accounting for spatially variable soil test levels than representing the field with one soil test report. However, contoured grid-point data using the same number of soil samples as the cell method resulted in a substantially better soil test category map. Also, grid-point soil sampling can be conducted more efficiently than cell sampling.

The number of soil samples collected within a field is clearly more important than the methods that may be used to analyze and contour the field data. Data manipulation is not an alternative to collecting more soil samples.

Cell soil sampling and variable-rate fertilizer application lowered income substantially over a single-rate application program. Grid-point sampling and variable-rate fertilizer application net returns, managing only P and K, clustered around break even when costs were distributed over a 4-year time period.

Does the fact that cell sampling leads to less profit suggest that large fields should not be divided into smaller areas? We believe not necessarily so if soil test variability is anticipated based on prior knowledge. For example, recognition of areas in the field receiving extra manure, differences in crops or cropping practices within a field, approximate location of old fence boundaries delineating smaller fields now managed as larger fields, eroded hillslopes vs. ridgetops and bottoms, or soils with contrasting soil texture; are all situations where we expect soil test variability and which can be defined on a map prior to soil sampling and fertilizer application. In contrast, arbitrarily dividing a field into small, geometric cells will likely result in as much variability occurring within some cells as across the field as a whole.

When prior field histories are not known, then unaligned, systematic grid-point sampling would be recommended. If we know the extent of soil test level variability within a field prior to grid sampling, then we could establish the correct grid sampling intensity. A single soil sampling density will not be correct for sampling all fields. It may be necessary to travel to a field twice, once to conduct some type of reconnaissance sampling followed by a second sampling in areas of the field requiring more data for accurate soil test category boundary determination.

Finally, this analysis only looks at P and K management. Variable-rate liming could be profitable for certain crops. Nitrogen and herbicides, which are rate dependent on organic matter, could be varied based on soil test organic matter data. Also the potential environmental benefits, even if only perceived by the public have a value which some producers would accept as enough reason to adopt a variable rate practice that only broke even.

ON-THE-GO YIELD MONITORS

A missing link in fully utilizing grid-sampling and variable-rate fertilizer application in a complete site-specific management system has been the inability to conveniently track yield levels for different parts of a field. On-the-go yield monitors now available may provide the solution. Major progress has been made in the past year in improving the technology of yield monitors. Several different systems are on the market. Field tests this fall have shown these systems to be even more accurate than expected, with differences between monitor totals and actual scale measurements on the order of ±1%. Early tests in Indiana showed yields ranging from 130 to 205 bu/acre in one field, and differences from actual truckload weight tickets ranging from -1.2 to +0.4%. Similar results were obtained on field tests in wheat fields in the Red River Valley.

These yield-monitor systems measure yield using a pressure plate in the clean grain auger. In-flow sensors measure moisture so that yield appropriate moisture corrections can be made. Global positioning satellite (GPS) tracking systems identify the location of each yield check (with a 15 second delay to account for flow through the machine). Yield checks are made about 20 times per minute and can be plotted directly to provide a yield response map of the field. The data can then be integrated into a GIS-based record system to be correlated with soil tests, fertilizer applications, soil survey, and other data bases used in management decisions.

While these yield monitors should be regarded as experimental, they offer the first practical means of relating yield variability to physical characteristics and management factors that vary within a field. Utilizing these data in management decisions may require expanded research into the direct relationships between these factors and yield. But the yield monitors may also open new possibilities for conducting field-scale and on-farm research to help provide the data needed to determine these relationships.

OVERVIEW SUMMARY

Agronomically

Variable-rate systems provide a means of targeted application of fertilizer based on detailed soil tests and other data bases. Collecting one soil sample for a field and/or using the same rate of fertilizer across the whole field generally leads to excess applications in parts of the field that have reduced yield potential and inadequate applications for the more productive parts of the field. Detailed sampling and variable-rate application can help optimize the yield potential of the entire field.

Economically

Variable-rate systems allow fertilizer dollars to be spent on areas within a field where they will most likely provide a response, and to be saved where response is unlikely. Fertilizing for the field average will nearly always result in declining soil test levels in the more productive areas of the field and increasing soil test levels in the less productive parts of the field--and a net decline in overall productivity of the field. Fertilizing for the needs of the most productive part of the field will generally result in unnecessary fertilizer expense--and a decrease in profitability. Variable-rate systems lead to increased efficiency of fertilizer dollars and increased overall profitability.

Environmentally

Variable-rate systems help prevent over-application of fertilizer where it could result in environmental problems. Equally important, adequate amounts can be applied to parts of the field where additional fertilizer would produce more crop residue to increase yield potential and enhance erosion control.

Socially

Variable-rate application systems provide an acceptable means of assuring fertilizer applications are made only in the amounts and locations where they are needed--the kind of responsible use of fertilizer materials that the general public is asking for.

Is It For Everyone?

Probably not--but nearly every field that has been sampled intensively has been found to have more variability in nutrient levels than might be expected from soil survey maps or other information available. Many of these cases would show an economic advantage to variable-rate application.

REFERENCES

Buchholz, D.D. 1991. Missouri grid soil sampling project. In Proc. 21st North Central Extension-Industry Soil Fertility Conference. Potash & Phosphate Institute, Manhattan, KS.

Fisher, T.R. 1974. Some considerations for interpretation of soil tests for phosphorus and potassium. Missouri Agric. Exp. Stn. Bull. 1007, Columbia, MO.

Kelling, K.A., E.E. Schulte, L.G. Bundy, S.M. Combs, and J.B. Peters. 1991. Soil test recommendations for field, vegetable and fruit crops. Univ. of Wisconsin-Extension Bull. A2809, Madison, WI.

Webster, R., and M.A. Oliver. 1990. Statistical methods in soil and land resource survey. Oxford University Press, New York.

PROCEEDINGS OF THE TWENTY-THIRD
NORTH CENTRAL EXTENSION - INDUSTRY
SOIL FERTILITY CONFERENCE

October 27-28, 1993, Holiday Inn St. Louis Airport

Bridgeton, Missouri

Volume 9

Program Chairman and Editor:

Dr. Lloyd Murdock
University of Kentucky
Research and Education Center
P.O. Box 469
Princeton, KY 42445