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Optimization of Animal Nutrient Application for Reduced Environmental Loading Using GIS

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Abstract. Data collected to date illustrate opportunities to manage animal nutrients similar to the way inorganic sources of nutrients are managed using precision agriculture. Grid sampling has revealed opportunities for a return to the cropping enterprise based on the identification of those areas of a field best suited for animal waste application. The rules-based approach to identification of these areas and specification of the quantities of waste that the land will accept based on limiting factors including infiltration, slope, soil type, and productivity potential, are easily implemented in a GIS. Using GIS, application rate maps can be generated to guide producers in application using dead reckoning, or generation of application rate maps for automatic control of waste application. The remaining problem to overcome is the specification of nutrient content of animal waste to be applied.

Keywords. Animal manure, GPS, precision farming, precision agriculture, yield monitors.

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Optimization of Animal Nutrient Application for Reduced Environmental Loading Using GIS

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Introduction

Nutrient management in Kentucky continues to affect water quality in many areas of the Commonwealth (Taraba et. al., 1993). With the recent announcements by one swine integrator to expand their operations in Kentucky and the resulting moratorium on permitting new animal production facilities, nutrient management will remain a high priority for the next several years. Unlike producers in Iowa who view animal wastes as a source of nutrients for crop production, some Southern farmers see livestock waste as a by-product from animal production to be disposed of or discarded (Hoag and Roka, 1995). The intent of this project is to demonstrate how managing animal wastes on croplands with respect to soil variability can reduce nitrate-nitrogen, nitrite-nitrogen and phosphorus levels in ground and surface waters.

Traditional farming practices treat fields as independent units, and assume homogeneous agronomic factors. The reality, especially in upland regions, is that many of these fields exhibit a wide range of variability which may be a function of multiple soil series or mapping units and past non-uniform applications of animal wastes or inorganic fertilizers. Such variability may impact water quality if these fields are managed on a field-average basis, as current practices dictate.

"Site-specific" farming or precision agriculture is now possible with the development of technologies such as the Global Positioning System (GPS) and Geographic Information Systems (GIS). GPS enables equipment operators to quickly obtain positioning information while a GIS is essentially a database for managing these geographic data. For nutrient management fields are grid-sampled for soil fertility, usually on a one to three acre basis. Grain combines equipped with yield monitors and GPS receivers log instantaneous yield and position data. Fertility and yield maps are then generated using these data and a GIS package. Utilizing both historical yields and known fertility levels, and by estimating the nutrient content of the waste to be applied, crop consultants can then generate "site-specific" waste application recommendations in the form of rate maps. Utilizing the GIS generated maps and a GPS receiver, fields can be flagged for dead-reckoning waste application. Such a method would be necessary until this technology is demonstrated, and until GPS controlled variable-rate manure applicators are commercially available. Site-specific fertilizer application services are currently available from farm suppliers in some regions of Kentucky. It seems to be a natural extension to apply these practices to optimize application of animal wastes to meet crop nutrient requirements and minimize the impact on water quality. GIS and GPS technologies have been used to manage nutrients through the application of inorganic fertilizers (Robert et al., 1991; Mulla, 1991; Carr et al., 1991; Li et al., 1992; Neuhaus and Searcy, 1993; and Birrell et al., 1993).

Objective

To develop a prioritized set of rules for precision agriculture mapping packages to aid in selection of land areas within the farmstead that are best suited to handle the nutrient loading associated with animal waste application to minimize impacts on water quality.

Methods

The sight selected as the basis of for this investigation was Worth and Dee Ellis Farms in Shelby County, Kentucky. This site is comprised of approximately 4300 acres of grain crops, and swine and dairy enterprises. Approximately 1,000,000 pounds of milk is marketed each year through the dairy operation. The farrow to finish swine operation produces approximately 4,000 market weight hogs per year. Both animal operations utilize manure storage pits integral to the animal production facilities. A nearby earthen storage facility, design by NRCS, is also available to store animal wastes. Prior to field application, the pits are agitated to insure that the solids are suspended, and to provide a homogeneous slurry. All animal waste is injected to provide a source of nutrients to grain and silage crops, reduce run-off, and to minimize odor and volatilization of nutrients. Fields are selected for application in accordance with crop rotation and proximity to the animal enterprises. In cooperation with the farm operators the following fields were identified as potential sites to receive injected waste. Included as potential application sites are Fields 16, 21-42, 44 and 45. These 25 fields include a total of 1151.4 acres of cropped land.

Field boundaries were driven using an ATV equipped with Differential Global Positioning System (DGPS) receiver (Onmistar model 7000). The DGPS receiver used wide area differential correction. The system accuracy was reported to be 2 to 3 meters horizontal for 95% of position fixes. Once the boundary was established a 0.4 ha (1.0 ac) grid was positioned over the boundary. The technician then navigated to the grid intersections. Composited soil samples were collected at the grid points by pulling five soil cores at a 5 m (15 tf.) radius of the ATV to a depth 10 cm (4.0 in.). The sampling depth was selected for consistency with AGR-1 recommendations and no-till farming practices. The soil cores were placed in a sample box and labeled with the grid point identifier from the FieldLink software (Agris, Inc. Roswell, Georgia). The soil samples were submitted to the University of Kentucky Regulatory Services for Test 1 with optional organic matter analysis.

A GIS database was constructed utilizing soil grid sample analyses results for the cropland surrounding the animal enterprises. The GIS was constructed using SSToolbox (SST Development Group, Inc.) that is based on the ArcView GIS engine (ESRI, Inc.). In keeping with traditional agricultural mapping practices all data were entered on a field basis. The agronomic data entered in this database included soil tests for phosphorus, potassium, organic matter content, soil water pH, soil buffer pH, zinc, magnesium and calcium. Additional items of importance that were mapped included state highways, county roads, waterways, and city corporation limits. Features remaining to be mapped include sinkholes, water dens, springs, ponds and other environmentally sensitive areas.

A set of rules for applying animal wastes were developed based on environmental policies in the Commonwealth of Kentucky (Bowden, 1978; and Hoag and Roka, 1995) and the nutrient content of the waste (Collins et al., 1995; Sutton et al., 1979; Krider, 1995; and Wells, 1996). The rules were established based on historical cropping and manure application, and the need to reduce impacts on water quality. Application rules were constructed in variable and fixed rate formats. As application technology evolves, variable-rate waste application will become commonplace. For many Kentucky producers the rules will be used to select application areas within a field that lend themselves to dead reckoning for navigation. That is to either flag the field using GPS, or provide a map with landmarks that will guide the applicator.

The foundation of the rules coincides with Federal and State (including emergency swine) regulations for setbacks, AGR-1 (1999) for nutrient application levels, and, as a last resort, on a mass balance relationship to coincide with crop removal of P and K. The primary nutrient components considered in this rule-based approach were phosphorus and nitrogen.

Federal laws are applied by region with Kentucky being assigned to Region 4. Kentucky statutes tend to be more stringent, especially in the case of recently enacted swine regulations; Emergency 401 KAR 5:009E. These pertain to "swine-feeding operations" where the number of "animal units" exceeds the equivalence of 1,000 or more swine units. While the swine feeding operation at Worth and Dee Ellis Farms does not fall under these regulations, if the owners plan an expansion of 10% or more of the existing operation, they must abide by the emergency regulations. Unique to these regulations, and aside from the requirement that producers follow sound agronomic practices, are the setbacks for waste injections. The setbacks are as follows: 1,500 feet to any dwelling not owned by the applicant; 3,000 feet to incorporated city limits; 150 feet to lakes, rivers, or karstic feature; 150 feet to the property line; 1 mile to downstream water as listed in 401 KAR 5:030 as other than use protected; and 5 miles to downstream public water supply surface water intake. These setbacks apply to injection. For other surface application methodology, these values are increased by between 50 and 100 percent. Although these setbacks are not directly applicable, they will remain as part of the rule-based approach to site selection for waste application.

Baker (1996) estimated that 95% of the soluble form of nitrogen (urea) is available to the crop in the first year for injected manure. However, only one-third of the organic nitrogen is available in the first year. If the manure is stored in a lagoon, the available organic nitrogen is increased to 50%. Thereafter, the remaining organic matter is made available at the rate of 5% per year. Nearly all of the P and K in stored animal waste is available to the crop in the first year after application. Baker (1996) and Wells (1996) reduce these values to 80% of the total when liquid manure is stored in a lagoon and applied via injection.

Results and Discussion

Grid soil sample results are reported in Table 1 for the study area identified at the Worth and Dee Ellis Farms. Of particular interest is the soil test P (phosphorus) levels in Fields 16, 23, 36, 37, 39, 40, 41 and 42. These fields consist of areas that are low in soil fertility when considering the P soil test levels, and therefore are excellent candidates for animal waste application. Furthermore, Fields 21, 32, 38, 44 and 45 have some potential as at least a portion

of these fields are below the threshold P level of 60 in accordance with AGR-1 (University of Kentucky, 1998). The correlation between the field averages of soil test P and K (potassium) values was found to be only 0.213. This indicates that it will be necessary to look at soil test K levels as another rule for the GIS classification scheme. Although, average soil test P level will give a good indication of which fields offer potential for accepting swine and or dairy waste. Obviously a combination of soil test P level and haul distance must be considered when identifying the best location.

Land application of waste via injection will be governed by phosphorus and nitrogen content of the waste, local soil test levels, AGR-1 recommendations, and setbacks as specified above. In the event soil P levels are considered "high," waste will be applied in accordance with crop removal rates. From Ohio State (1998), the nutrient levels associated with crop removal are summarized in Table 2. An indication of nutrient content of swine and dairy waste is given in Table 3 (Ohio State, 1998). Although the latter table lists nutrient contents, it must also be recognized that nitrogen and phosphorus may not be readily available for crop use.

Figure 1 depicts the relationship of the fields identified by the farm operators as being suitable for animal waste application. Boundaries of individual fields or production units are outlined in black and filled in dark gray. Field numbers are used to label each unit. Field 41, lower center of the farm map, was selected to illustrate the application of rules for P management.

Figure 2 shows a gray scale map depicting crop performance. The smaller grid cells have dimensions of 54 feet by 54 feet. Each cell represents 0.067 acres, or roughly one-sixteenth of an acre. The yield data file contained in excess of 28,000 data points that were reduced by averaging the yield data values over the 54 feet by 54 feet cells. This reduced the data set to approximately 1,400 data points, each associated with a single cell. This grid resolution was maintained for the remaining analysis.

Eighty-nine grid point locations were soil sampled within Field 41. Using a linear interpolation technique, each of the 54 feet by 54 feet cells were assigned a soil test P value. This rasterized version of a soil test P map was then used to estimate the quantity of swine waste to be applied. Data for the corn P_2O_5 recommendations in AGR-1 (1999) were regressed to determine a continuous relationship that could be used as a rule to guide phosphorus application. The relationship was as follows:

$$W_{P_2O_5} = 135.88 - 2.2321 P_{SoilTest}$$

where W_{P2O5} is the weight of P_2O_5 to be applied per acre and $P_{\text{Soil Test}}$ is the soil test value as determined using Mehlich III extraction. Using this relationship and 80% availability, and a P_2O_5 content of 27.0 lb/1000 gallons of swine waste as pumped from storage pits, the application map in Figure 3 was generated. Integrating the application rate over the surface area of the field results in a total applied waste volume of 134,471 gallons, or 39.6 slurry wagon loads of manure. This represents approximately one-half of the annual waste production from the finishing floors of the swine operation.

A second approach might be to limit waste application to crop removal rates. Assuming that the '98 corn crop in Field 41 extracts 0.37 lbs of P_2O_5 per bushel of grain harvested, Figure 2 can be changed to a swine manure application rate map as shown in Figure 4. Again, integrating the swine waste application rate over the field area results in a total applied waste volume of 136,064 gallons, or 40.0 slurry wagon loads of swine waste. This approach is less desirable than applying in accordance with AGR-1 as suggested in Figure 3. The reality is that "low" soil test P areas will remain low using this approach. However, application in accordance with crop removal should limit any build-up in soil test P levels.

This example illustrates the potential of GIS to solve waste management problems associated with the swine and dairy enterprises at Worth and Dee Ellis Farms. The intent will be to place animal waste in locations in need of additional nutrients. This should also address the concerns relative to water quality as N application will be limited to crop needs while P application will be limited by crop removal for high fertility regions, or by AGR-1 when soil test P levels fall below the threshold value of 60.

Summary

Data collected to date illustrates the opportunities for Worth and Dee Ellis Farms to manage animal nutrients similar to the way inorganic sources of nutrients are managed using precision agriculture. Grid sampling has revealed opportunities for a return to the cropping enterprise based on the identification of those areas of a field best suited for animal waste application. The rules-based approach to identification of these areas and specification of the quantities of waste that the land will accept based on limiting factors including infiltration, slope, soil type, and productivity potential, are easily implemented in a GIS. From the GIS software package, application rate maps can be generated to guide producers in application using dead reckoning, or generation of application rate maps for automatic control of waste application. The remaining problem to overcome is the specification of nutrient content of animal waste to be applied. Investigation of nutrient content of animal wastes and ground water quality will provide the basis for subsequent work to be conducted in this project.

References

Bowden, J.P. 1978. *Livestock Waste Management – Questions and Answers Concerning Laws and Regulations*. Extension Publication AEN-44. College of Agriculture, University of Kentucky, Lexington.

Baker, J.C. 1996. *Livestock Waste Sampling, Analysis and Calculation of Land Application rates*. North Carolina Cooperative Extension service. Publication Number EBAE 111-84.

Collins, E.R., Jr., J.D. Jordan and T.A. Dillaha. 1995. Nutrient values of dairy manure and poultry litter as affected by storage and handling. *Animal Waste and the Land-Water Interface*. pp. 343-353.

Hoag, D.L. and F.M. Roka. 1995. Environmental policy and swine manure management: waste not or want not? *American Journal of Alternative Agriculture*. 10:163-166.

Krider, J.N. 1995. Innovative utilization of animal waste. *Proceedings of the National Livestock, Poultry and Aquacultural Waste Management Conference.* pp. 82-87. St. Joseph, Michigan: ASAE.

Ohio State University. 1998. *Ohio Livestock Manure and Waste Water Management Guide*. Bulletin 604. The Ohio State University, Extension Service.

Sutton, A.L., D.H. Vanderholm, and S.W. Melvin. 1979. Fertilizer value of swine manure. Pork Industry Handbook. Extension Publication No. ASC-80. College of Agriculture, University of Kentucky, Lexington.

University of Kentucky. 1998. *1998-1999 Lime and Fertilizer Recommendations*. University of Kentucky Cooperative Extension Service. Publication number AGR-1.

Wells, K.L. 1996. The agronomics of manure use for crop production. Extension Publication No. AGR-165. College of Agriculture, University of Kentucky.

Table 1: Soil fertility levels of land earmarked for animal waste application at Worth & Dee Ellis Farms, Shelby County, Kentucky.							
	Soil Test P		Soil Test K		Organic Matter		Area (ac)
Field No.	Mean	S.D.	Mean	S.D.	Mean	S.D.	
16	68.7	37.1	247.4	80.1	3.07	0.38	137.6
21	131.4	71.4	259.1	68.7	3.48	0.43	15.1
22	190.0	109.0	318.0	135.0	n/a	n/a	77.3
23	74.0	69.0	206.0	47.0	n/a	n/a	56.9
24	182.0	179.1	484.9	139.4	2.95	1.08	14.1
25	238.4	173.8	243.8	49.7	3.86	0.54	57.7
26	246.9	165.7	417.8	98.3	3.61	0.73	40.6
27	203.3	159.1	278.0	88.8	3.40	0.49	75.7
28	325.8	211.0	267.4	66.1	3.20	0.42	18.4
29	225.8	189.4	344.7	133.6	3.65	0.64	26.5
30	395.1	71.1	265.5	68.8	2.81	0.34	9.0
31	246.5	150.0	155.4	71.6	3.71	0.64	77.9
32	114.2	120.3	373.2	99.5	3.09	0.46	26.2
33	185.7	160.7	328.4	109.2	3.31	0.94	71.6
34	168.0	138.1	300.9	147.4	2.94	0.69	107.8
35	364.5	148.6	356.1	78.8	3.93	1.18	12.2
36	58.8	45.2	281.3	77.0	3.17	0.62	39.2
37	44.1	14.6	272.4	82.8	3.13	0.57	20.2
38	99.6	117.4	280.4	83.1	n/a	n/a	80.6
39	57.6	26.8	240.0	74.3	3.82	0.71	17.5
40	61.7	47.8	276.6	82.1	3.49	0.63	24.5
41	63.7	62.5	278.3	82.0	2.84	0.45	77.3
42	72.7	36.3	206.6	53.2	n/a	n/a	14.6
44	111.5	82.5	236.8	74.5	3.19	0.52	50.3
45	122.5	102.6	198.2	71.9	n/a	n/a	32.5

Table 2: Approximate quantity of nutrients removed in harvested crop.		
Crop	**Nutrient Removal**	
	P_2O_5	**K_2O**
Corn		
Grain	0.37 lb/bu	0.27 lb/bu
Silage	3.1 lb/T	9.0 lb/T
Soybeans		
Grain	0.80 lb/bu	1.4 lb/bu
Wheat		
Grain	0.64 lb/bu	0.36 lb/bu
Straw	0.09 lb/bu	0.91 lb/bu

Table 3: Approximate nutrient content of animal waste.							
Live-stock	**Storage Method**	**Dry Matter**	**Total N Lb/1000 gal**	**Organic N lb/1000 gal**	**NH_4 lb/1000 gal**	**P_2O_5 lb/1000 gal**	**K_2O lb/1000 gal**
Swine	**Liguid Pit**	4.0	36.0	10.0	26.0	27.0	22.0
	Lagoon	1.0	4.0	1.0	3.0	2.0	4.0
Dairy	**Liquid Pit**	8.0	24.0	12.0	12.0	18.0	29.0
	Lagoon	1.0	4.0	1.5	2.5	4.0	5.0

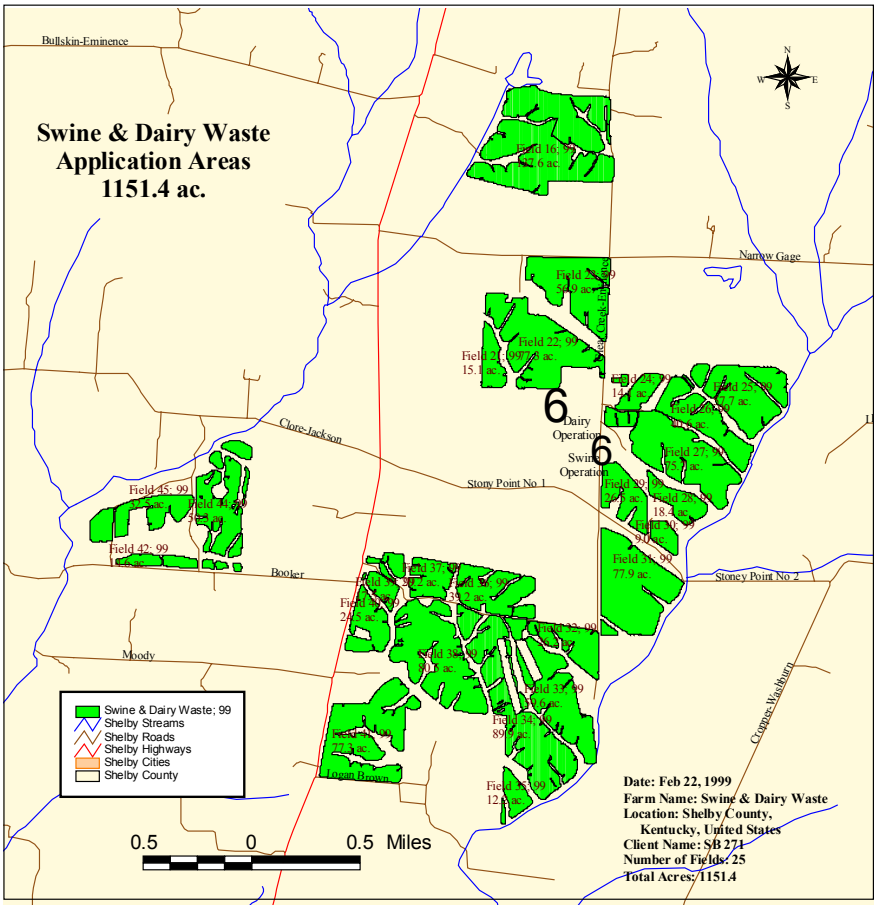

Figure 1: Animal waste application study area at Worth and Dee Ellis Farms in Shelby County, Kentucky.

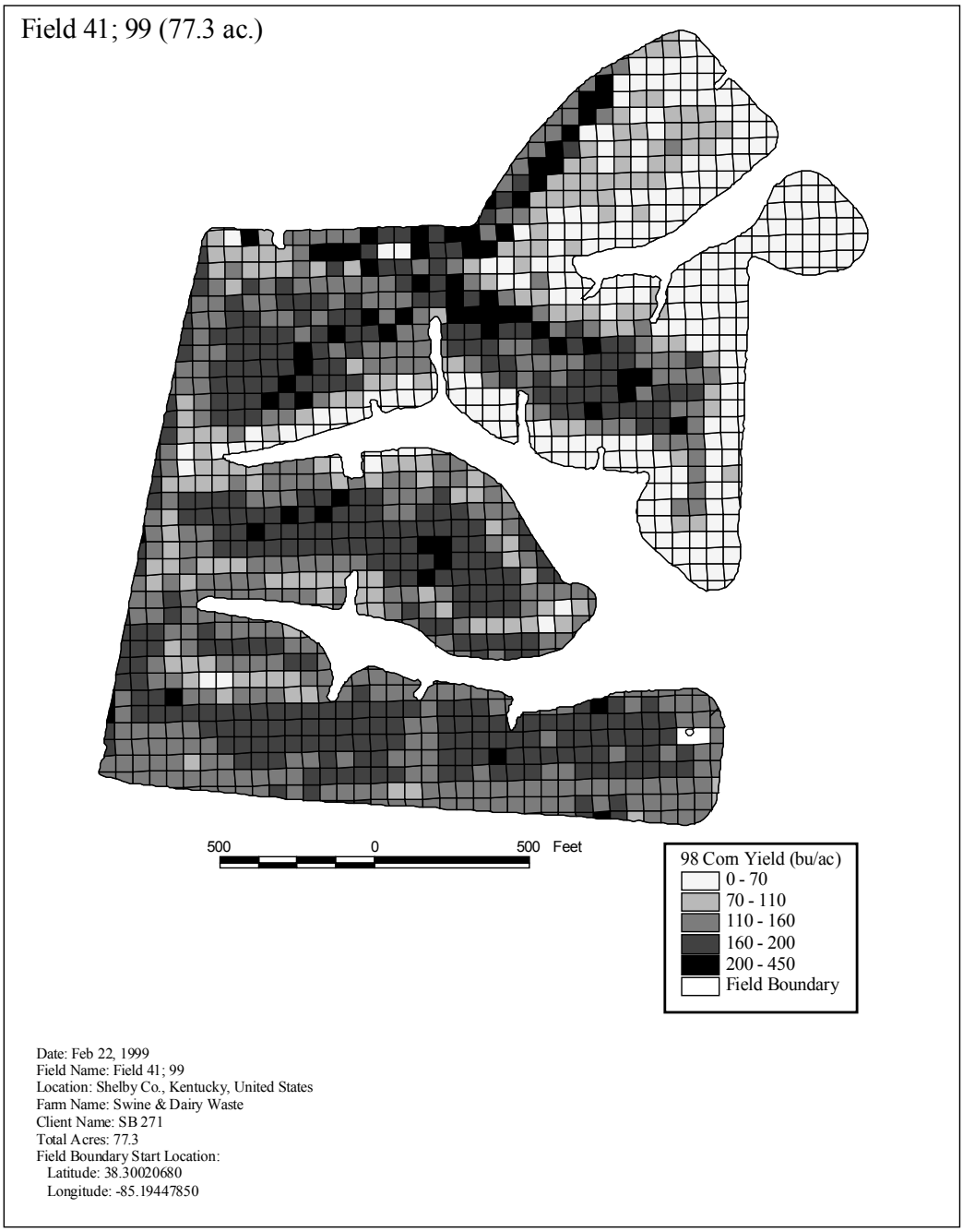

Figure 2: '98 corn yield map for Field 41 at Worth and Dee Ellis Farms in Shelby County, Kentucky.

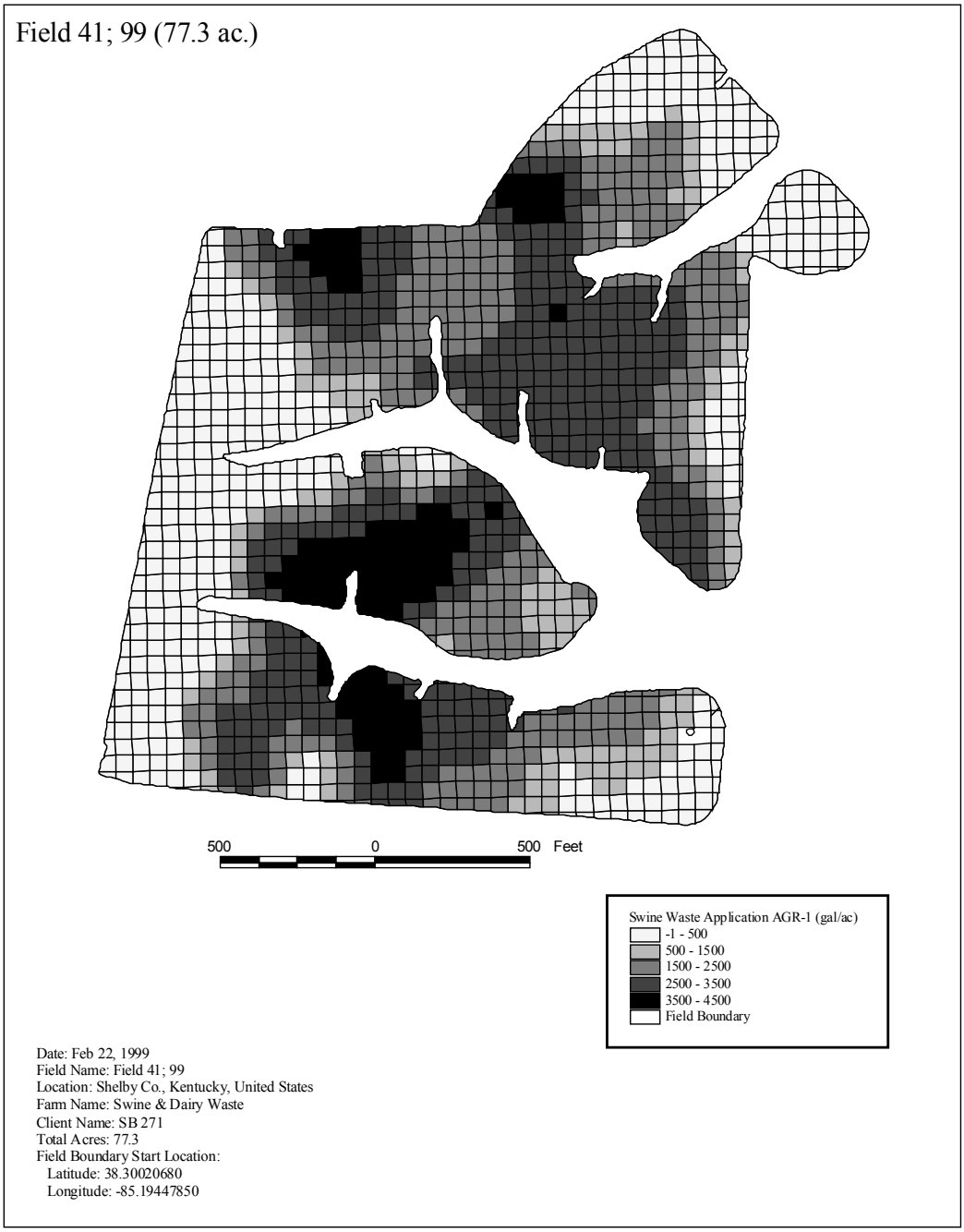

Figure 3: Swine waste application rate map based on phosphorus needs in accordance with AGR-1.

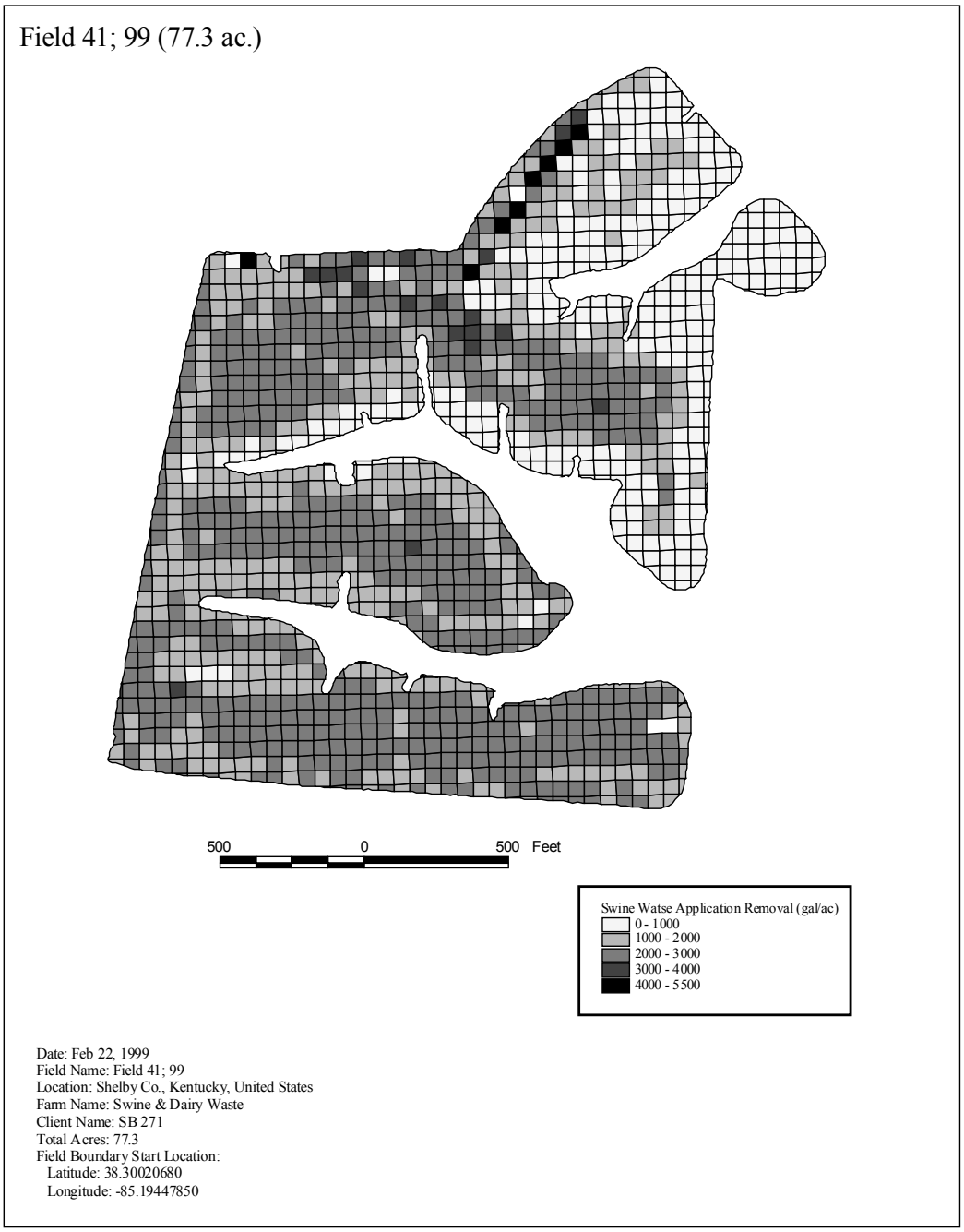

Figure 4: Swine waste application rate map based on phosphorus removal rates of '98 corn crop (0.37 lb P_2O_5 per bushel of corn).