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Spatial Variability of Soil Properties and Weed Populations in the Mississippi Delta

L. A. Gaston,* M. A. Locke, R. M. Zablotowicz, and K. N. Reddy

ABSTRACT

Simulation models and precision agriculture practices may require more detail and certainty about soil spatial variability than provided by soil surveys. This study described soil and weed spatial variability in 50-ha subareas of two sites included in the Mississippi Delta Management Systems Evaluation Areas project. Objectives were (i) to describe the spatial variability of soil properties and (ii) to determine relationships between spatially variable weed populations and soil properties. Surface soil samples were collected at nodes of 60-m square grids prior to planting cotton (*Gossypium hirsutum* L.) in 1996. Field-moist soil was analyzed for microbial activity. Air-dried soil was used to determine soil organic C, pH, and texture. Fluometuron and either clomazone, metolachlor, or norflurazon were banded over the crop row at planting. Weed counts were taken 6 wk after herbicide application. The spatial variability of soil properties and weed populations was described using geostatistics. Soil microbiological activity exhibited limited spatial dependence, but pH, organic C, and texture semivariograms were well-described with spherical models. Although short-range (<60 m) variability was often high, the range of spatial dependence typically exceeded 120 m. Total weeds were spatially dependent both years; however, weeds susceptible to control by herbicide were not. Weed densities were significantly greater ($P < 0.05$) in areas that had higher organic C and finer texture. Areas of low organic C and coarse soil often had no weeds. Thus, more uniform weed control might be achieved by varying preemergence herbicide application rate. Acceptable weed control might be achieved with lower herbicide application rates in certain areas.

THE SPATIAL DISTRIBUTION of soils given in soil surveys is sufficiently detailed for many decisions regarding land use. However, finer detail and greater certainty may be needed for simulation modeling of chemical fate and transport or with precision farming programs. This must be provided by on-site, intensive sampling that quantifies soil properties in the transition from one mapping unit to another, accounts for variability within mapping units or otherwise generates data that is unavailable elsewhere.

Although the Delta (flood plain of the Mississippi from southeastern Missouri into Louisiana and Mississippi) is one of the most important agricultural regions of the country, data on the spatial variability of its soils is limited to studies on geomorphology (e.g., Shumacher et al., 1988) and information contained in soil surveys. This study was the first to examine the field-scale spatial variability of these alluvial soils using geostatistical methods and show that soil properties in the complex landscape of the Mississippi Delta may be described in sufficient detail for use with simulation modeling or precision farming without prohibitively intensive sampling protocols.

L.A. Gaston, Dep. of Agronomy, Louisiana State Univ. Agricultural Center, Baton Rouge, LA, and formerly, USDA-ARS, SWSRU; M.A. Locke, R.M. Zablotowicz, and K.N. Reddy, USDA-ARS, Southern Weed Science Research Unit, Stoneville, MS. Received 8 Oct. 1999. *Corresponding author (lgaston@agctr.lsu.edu).

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The spatial distribution of particle size, organic C (OC), pH, and fluorescein diacetate (FDA) hydrolytic activity in surface soil at two watersheds were determined in this study. Soil texture and OC content influence recommended rates of soil-applied herbicides. Sorption of most herbicides increases with higher clay and OC content of soil. Soil pH also affects the sorption of ionizable herbicides as well as several chemical degradation mechanisms. In turn, sorption affects herbicide efficacy and mobility in soil water. Hydrolysis of FDA is a measure of microbial activity in soil that has been correlated with soil microbial respiration (Schnürer and Rosswall, 1982). It was chosen as an indicator of the potential for herbicide biodegradation.

Earlier studies on the spatial variability of particle-size distribution in diverse soils include those by Campbell (1978), Gajem et al. (1981), Trangmar et al. (1986, 1987), Ovalles and Collins (1988), and Shouse et al. (1990). Spatial dependence occurred at scales ranging from a few meters (Gajem et al., 1981; Trangmar et al., 1987) to several (Trangmar et al., 1986) or many kilometers (Ovalles and Collins, 1988). The short-range spatial variability of soil OC extends to several meters (Trangmar et al., 1987); however, long-range spatial dependence of OC seems doubtful (Ovalles and Collins, 1988). Wood et al. (1987) and Novak et al. (1997) examined OC variability at the field scale in relation to the sorption of metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] and atrazine [6-chloro-*N*-ethyl-*N'*-(methylethyl)-1,3,5-triazine-2,4-diamine], respectively. Wood et al. (1987) encountered geometric anisotropy in the experimental semivariogram for organic matter in the Ap horizon, whereas Novak et al. (1997) found that the semivariogram for atrazine K_{oc} (sorption coefficient, K_d, normalized to OC content) was adequately described by an isotropic model. Trangmar et al. (1987) found short-range, whereas Yost et al. (1982) and Trangmar et al. (1986) observed long-range, spatial dependence of soil pH. However, Campbell (1978) found that the pH of samples separated by only 10 m were spatially independent.

There has been little work on possible relationships between weed populations and soil properties, yet it is known that the spatial distribution of weeds depends not only on seed dispersal mechanisms but also on spatially variable safe sites necessary for initiating germination and ensuring growth to maturity (van Groenendael, 1988; Zanin et al., 1998). Safe sites provide stimuli to break dormancy, conditions allowing germination to proceed, resources for growth, and absence of hazards (Zanin et al., 1998). Thus, the concept of spatially variable safe sites is related to heterogeneity in soil chemical and physical properties.

Abbreviations: FDA, fluorescein diacetate; MDMSEA, Mississippi Delta Management Systems Evaluation Areas; OC, organic C.

Chancellor and Goronea (1994), Zanin et al. (1998), and Dammer et al. (1999) have recently used geostatistical methods to describe weed distributions. Consistent with the typically patchy occurrence of weeds, Chancellor and Goronea (1994) found that the semivariogram of weed densities exhibited large zero-range semivariance (nugget) but spatial dependence for up to tens of meters. Dammer et al. (1999) obtained similar results for patchy weeds, but at high weed densities Zanin et al. (1998) obtained small or no nugget semivariances. The range across which densities were spatially dependent varied with weed species.

This study was undertaken as a component of the Mississippi Delta Management Systems Evaluation Areas (MDMSEA) project that is investigating the effects of conservation management on water quality in oxbow lake watersheds of the Mississippi Delta. The objectives of this study were (i) to characterize the spatial variability of soil properties that affect the fate of herbicides in the soil environment and (ii) to determine relationships between the spatial variability of weed populations and soil properties. Spatial delineation of soil properties in these watersheds was necessary not only to satisfy the second objective but also to support further work on herbicide sorption and field studies of herbicide dissipation.

MATERIALS AND METHODS

Soil Sampling

Two of three watershed sites included in the MDMSEA project were used in this study. These, identified by the name of the ox-bow lake into which the watersheds drain, are Beasley (former channel of the Sunflower River and located in Sunflower County, Mississippi) and Deep Hollow (former channel of the Yazoo River and located in Le Flöre County, Mississippi). Beasley includes >400 ha and Deep Hollow ≈240 ha. An ≈50-ha subarea planted to cotton from each watershed was used in this study. Soil survey data for Beasley (Soil Survey Staff, 1959a) indicated that Dundee (fine-silty, mixed, thermic Typic Endoaqualfs), Forestdale (fine, smectitic, thermic Typic Endoaqualfs), Dowling (very-fine, smectitic, thermic Vertic Epiaquepts), and Alligator (very-fine, smectitic, thermic Alic Dystraquerts) series are, in descending area of occurrence, the major soils in the study subarea. Similarly, at Deep Hollow, Dundee, Forestdale, and Dowling are the major series (Soil Survey Staff, 1959b).

A 60 by 60 m square grid was laid out on each subarea, grid nodes flagged, column and row ends permanently marked, and global positioning system (Pathfinder ProXR, Timble Navigation, Ltd., Sunnyvale, CA) coordinates recorded so that this grid could be reestablished in subsequent years. Each grid node (124 at Beasley and 110 at Deep Hollow) was the center of a 2 by 2 m sampling plot from which four soil samples were taken from the upper 5 cm in April 1996. Two random samples were taken from within rows and two from between rows per plot. Subsamples were composited and mixed.

Soil Analyses

Subsamples of field-moist samples were stored at 4°C prior to assay for biological activity as characterized by FDA activity (Schnürer and Rosswall, 1982). The remainder of each sample was air-dried, ground, and sieved at 2 mm prior to chemical and physical analyses. Soil pH of triplicate samples was determined in 2:1 soil/0.005 *M* $CaCl_2$. Organic C was determined on triplicate samples using the modified Mebius method (Nelson and Sommers, 1982). Texture was determined by the hydrometer method (Gee and Bauder, 1986).

Agronomic Practices and Weed Counts

The Beasley study site was irrigated and in conventionally tilled, continuous cotton production. The Deep Hollow study site was also in continuous cotton and under conventional tillage through 1995, but at that time was converted to reduced tillage. It was unirrigated and had a wheat (*Triticum aestivum* L.) cover crop in 1995 and 1996.

Weed management at Beasley included initial dessication with glyphosate [*N*-(phosphonomethyl)glycine]. Following rebedding of rows, fluometuron [*N,N*-dimethyl-*N'*-[3-(trifluoromethyl)phenyl]urea] and metolachlor were applied preemergence at rates of 1.7 and 1.1 kg a.i. ha^{-1}, respectively, in a 43-cm band at planting. Weed counts were taken 6 wk following fluometuron and metolachlor application and prior to postemergence application of cyanazine [2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropanenitrile] and MSMA [monosodium methanearsonate].

Weed management at Deep Hollow was similar and included initial burndown of the wheat cover crop with glyphosate. Fluometuron and norflurazon [4-chloro-5-(methylamino)-2-(3-trifluoromethyl)phenyl)-3(2*H*)-pyridazinone] were applied at rates of 1.0 kg a.i. and 0.7 kg a.i. ha^{-1}, respectively, in a 51-cm band at planting in 1996. Fluometuron and clomazone [2-[(2-chlorophenyl)methyl]-4,4-dimethyl-3-isoxazolidinone] were applied at rates of 1.0 and 0.4 kg a.i. ha^{-1}, respectively, at planting in 1997. As at Beasley, weed counts were taken 6 wk following preemergence application of herbicide and prior to postemergence application of cyanazine and MSMA.

Weeds within a 1-m strip of the herbicide band at the center of soil sampling plots were counted, identified, and categorized as either controlled (good to excellent control; Mississippi Cooperative Extension Service, 1997) or not controlled (fair to no control) by fluometuron and either clomazone, metolachlor, or norflurazon. Weed counts were taken in 1996 and 1997.

Statistical Analyses

Experimental semivariograms for soil and weed data were calculated and checked for geometric anisotrophy (David, 1977). Linear or spherical models (David, 1977) were fitted to these data using average semivariances weighted by number of pairs per lag distance. The data were also checked for apparent stationarity using the approach of David (1977). Semivariogram models, together with the experimental data, were used to estimate average values (David, 1977) for soil properties and weed populations in square 0.36-ha areas centered about each sampling grid node. In addition, possible relationships between weed populations and soil properties were examined using regression analysis and cross-semivariograms (David, 1977; Yeats and Warrick, 1987).

RESULTS AND DISCUSSION

Spatial Variability of Soil Properties

Simple Statistics

Kolmogorov-Smirnov tests indicated that all soil properties were normally distributed. Sample means and variances for FDA activity, pH, organic C, and percentages clay and sand are given in Table 1. Average FDA activity at Deep Hollow was more than three times that at Beasley. Both locations were in continuous cotton; however, the Deep Hollow site was in the first year of reduced tillage management and samples were taken following burndown of the wheat cover crop. Beasley was conventionally tilled with no cover crop. Greater microbial (FDA hydrolysis) activity at Deep Hollow may have been related to greater plant residue at the soil surface.

Although surface soil textures varied from loamy to clayey at both locations, Deep Hollow generally had coarser texture soil than Beasley. Consistent with more sandy texture at Deep Hollow, the average pH and organic C content were lower than at Beasley. However, the only slightly lower OC content at Deep Hollow (1.50 vs. 1.65%) may reflect the presence of relatively persistent wheat residue left at the surface under reduced tillage. In contrast, winter annuals (more prominent at Beasley) generally produce less, but more labile, residue than wheat (Boquet et al., 1997). Also, tillage probably accelerated residue decomposition.

Table 1. Means and standard deviations of soil data.

	Beasley		Deep Hollow	
Soil property	Mean	SD	Mean	SD
FDA activity†	105	44	341	137
pH	5.10	1.67	4.71	1.23
Organic C, %	1.65	0.34	1.50	0.16
Clay, %	30.2	15.7	15.3	9.5
Sand, %	16.0	9.7	36.0	15.7

† Increase in optical density at 490 nm g^{-1} h^{-1}.

Spatial Statistics

Figures 1A to 1E show isotropic experimental semivariograms for FDA activity, pH, OC, percentage clay,

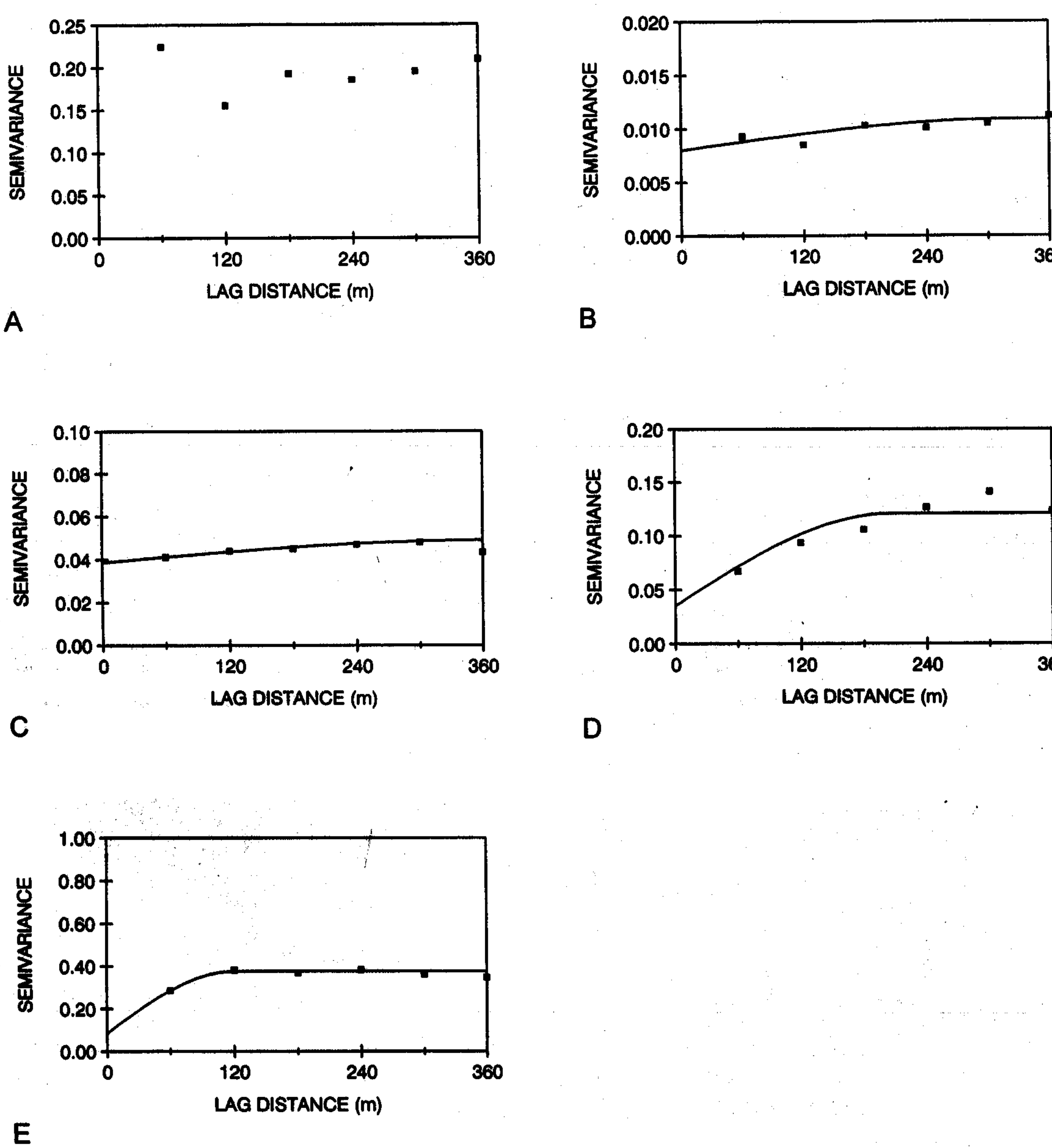

Fig. 1. Experimental semivariograms for (A) FDA activity, (B) pH, (C) organic C, (D) clay percentage, and (E) sand percentage in surface soil at Beasley. Spherical models are shown as smooth curves.

and percentage sand, respectively, at the Beasley location. Data normalized with respect to the mean were used in calculating semivariograms. Average semivariances are plotted at a separation interval of 60 m. Figures 2A to 2E show corresponding data for Deep Hollow. Both sites had undulating topography; thus, semivariograms were expected to show geometric anisotropies due to finer-textured soil in swales and coarser-textured soil on ridges. However, experimental semivarigrams calculated parallel to sample columns and rows as well as parallel to the diagonals showed only limited geometric anisotropy (data not shown) and attempts to model the semivariances of soil data using directionally dependent linear models (David, 1977) led to no better jack-knifing regeneration of the spatial data (Bras and Rodriguez-Iturbe, 1985) than when simpler isotropic models were used. These results probably reflect the fairly large width of ridges and swales compared with sample spacing. Also, maximum lag distances were restricted to less than one-half the study site width.

In general, the soil data showed spatial dependence. Exceptions were the FDA data from Beasley, which formed an apparent nugget semivariogram (Fig. 1A), and from Deep Hollow, which showed, at most, weak linear structure (Fig. 2A). No attempt was made to model the latter data. All other semivariograms exhibited spatial structure that could best be described using spherical models (see note, Table 2). Parameters for these models are given in Table 2. Goodness of fit was determined by jack-knifing. In all cases, reduced mean square error (mean of square error divided by kriging variance; Bras and Rodriguez-Iturbe, 1985) was close to one (Table 2).

Nugget semivariances for pH (Fig. 1B and 2B) and

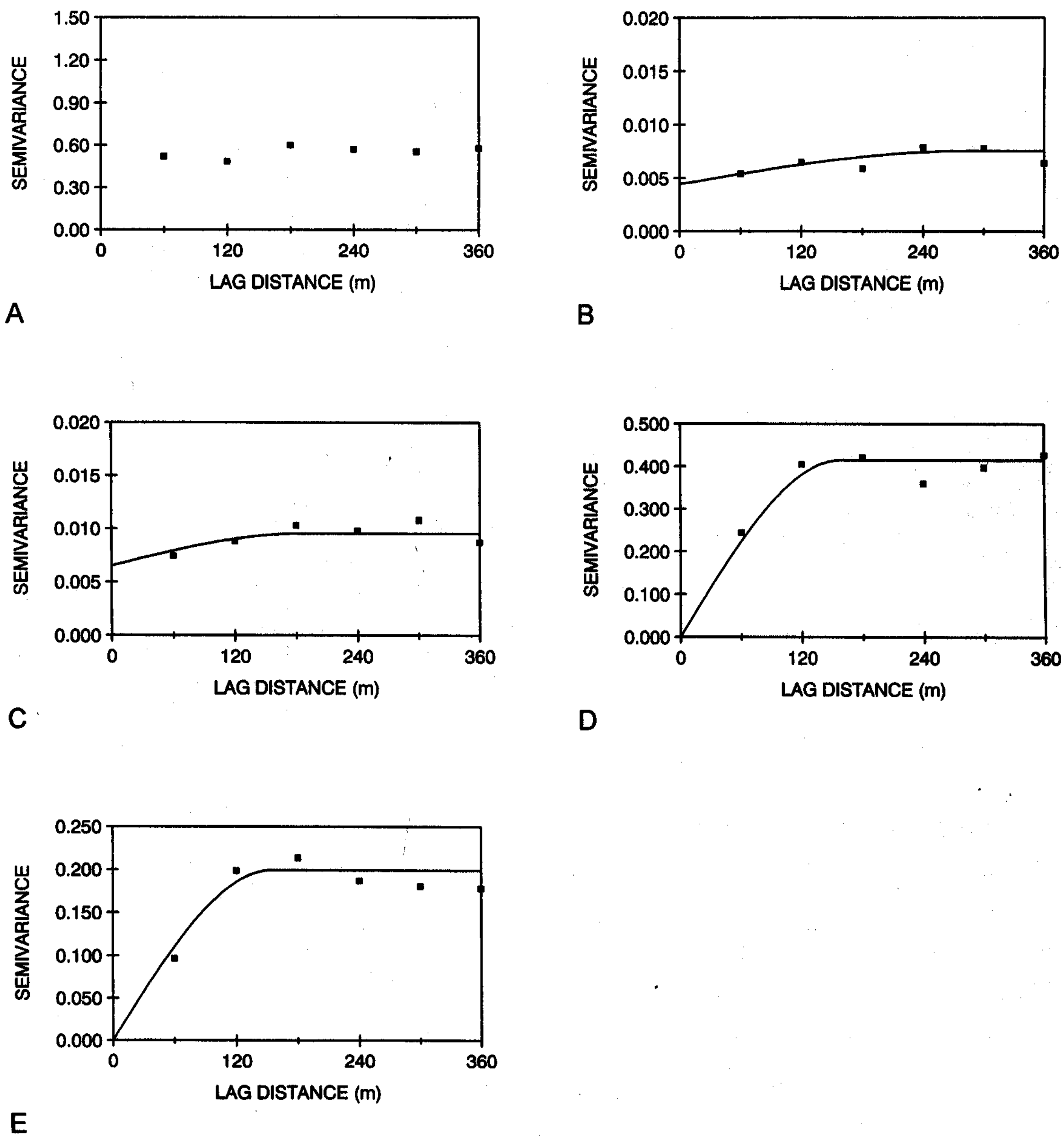

Fig. 2. Experimental semivariograms for (A) FDA activity, (B) pH, (C) organic C, (D) clay percentage, and (E) sand percentage in surface soil at Deep Hollow. Spherical models are shown as smooth curves.

Table 2. Spherical semivariogram model† parameters for normalized soil properties.

	Beasley				Deep Hollow			
Property	C_o	$C_o + C$	A (m)	RMSE‡	C_o	$C_o + C$	A (m)	RMSE
pH	0.080	0.109	320	0.96	0.0044	0.0076	280	0.96
Organic C, %	0.039	0.049	360	0.99	0.0065	0.0096	190	0.99
Clay, %	0.036	0.121	220	1.09	0.00	0.41	150	1.12
Sand, %	0.085	0.374	120	0.90	0.00	0.20	150	0.80

† $\gamma(h) = C_o + C[(1.5)(h/A) - (0.5)(h/A)^3]$, where $h < A$, and $\gamma(h) = C_o + C$, where $h \geq A$, where γ is semivariance, h lag distance, C_o nugget effect, $(C_o + C)$ sill and A range.
‡ Reduced mean square error.

OC (Fig. 1C and 2C) were large compared with sills. Thus, much of the variability in these spatial data was due to short-range variability that could not be described at the sample spacing used in this study. However, a small degree of spatial dependence (sill minus nugget) extended to ranges of ≈240 m (Fig. 1B, 1C, 2B, and 2C; Table 2). In contrast, spherical models for percentages clay (Fig. 1D and 2D) and sand (Fig. 1E and 2E) had small nuggets compared with sills.

Due to weak or nonexistent (at the sampling scale of this study) spatial structure, FDA semivariograms could not be used in further geostatistical calculations. However, models for pH, OC, clay, and sand semivariances were used to generate block-kriged maps of these properties at the two locations. Figures 3A to 3D show pH, OC content, and clay and sand percentages, respectively, at Beasley. Figures 4A to 4D are corresponding maps for Deep Hollow. Due to large nugget variances in the pH and OC data, estimation variances were high. Thus, estimates of clay and sand contents (Fig. 3C, 3D, 4C, and 4D) probably better reflect the spatial distribution of these properties.

Figure 3A shows a band of relatively high soil pH running diagonally across the Beasley location. This band roughly coincides with three long and broad depressional areas. Relatively high clay content in these depressional areas is shown in Fig. 3C. Conversely, low sand content (Fig. 3D) is associated with these areas. Highest content of sand was found closest to Lake Beasley, along an old natural levee (Fig. 3D, top).

The distribution of OC (Fig. 3B) does not follow topographical features as clearly as does pH (Fig. 3A); however, comparison of areas relatively high in OC to areas high in clay content (Fig. 3C) generally shows the expected relationship. Short-range variability in OC content (Fig. 1C) probably contributed to the somewhat weak spatial correspondence of OC to clay content shown by Fig. 3B and 3C; however, OC was positively correlated ($P < 0.01$) with clay content in the soil samples.

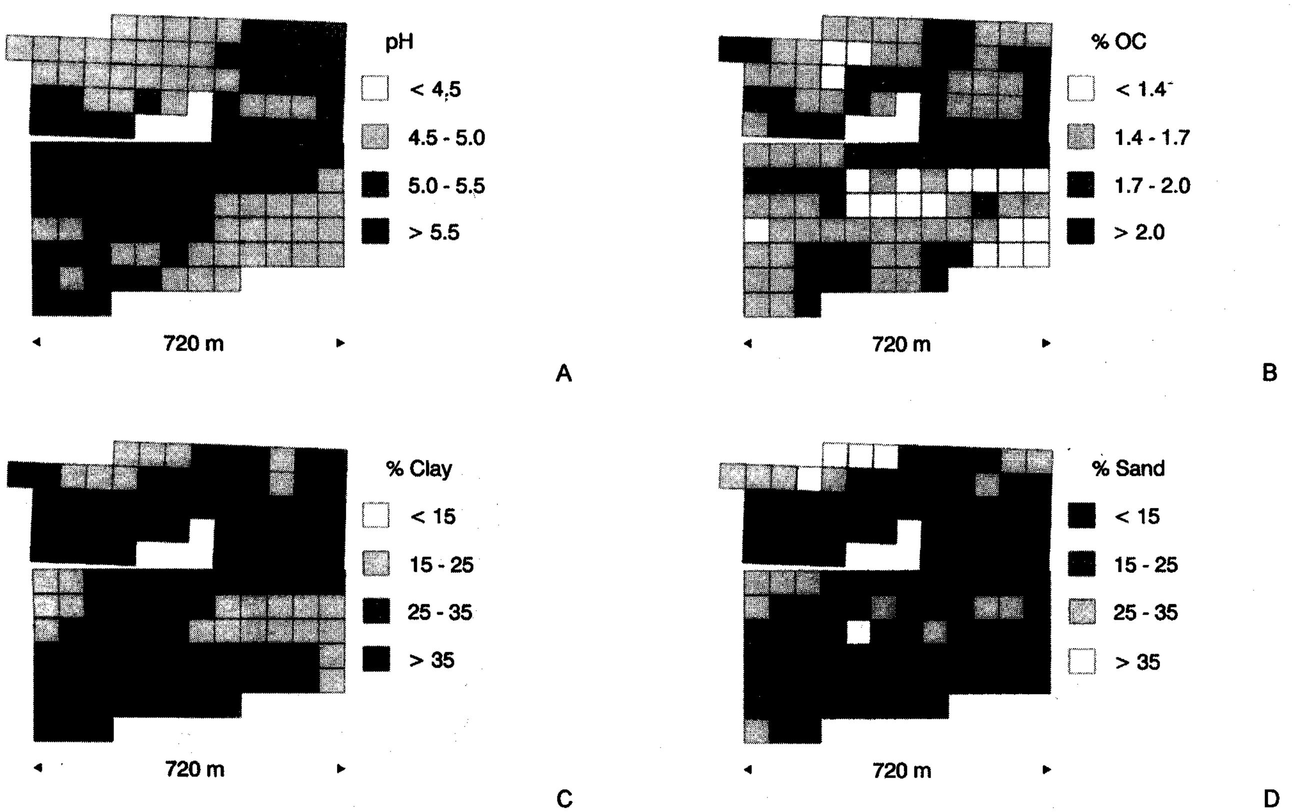

Fig. 3. Block-kriged estimates of (A) pH, (B) organic C, (C) clay percentage, and (D) sand percentage in surface soil at Beasley (legends C and D, reversed).

Soil pH was lower and spatially more uniform at Deep Hollow (Fig. 4A) than at Beasley (Fig. 3A). Also, there was no evident relationship between relatively high pH and depressional areas. This site has a broad natural levee that generally parallels its length. Highest clay contents (Fig. 4C) are found near the foot of this ridge, adjacent to Deep Hollow Lake. Since high positions on this levee dominate Deep Hollow, soils are more sandy (Fig. 4D) than at Beasley (Fig. 3D). There is even less apparent spatial correspondence between OC (Fig. 4B) and clay (Fig. 4C) or sand (Fig. 4D) than at Beasley; however, OC at Deep Hollow was positively correlated with clay ($P < 0.01$).

Spatial Variability of Weed Populations

Simple Statistics

Weed species and their average densities 6 wk after herbicide application are given in Table 3. Species were grouped into those controlled by herbicide programs at Beasley and Deep Hollow and those not controlled. Although norflurazon offers some degree of suppression of yellow nutsedge (Mississippi Cooperative Extension Service, 1997), this weed was not considered subject to preemergence herbicide control at Deep Hollow in 1996. Ten different weed species were identified and one-half of these were found in 1996 and again in 1997. Weed densities were greater at both locations in 1997 than in 1996 (Table 3).

Densities of weeds controlled by herbicide were also greater in 1997, especially at Beasley (Table 3). On the average there were about three plants per square meter in 1996, but in 1997, the density was almost five plants per square meter. At Deep Hollow the density of weeds controlled by preemergence herbicides was less than one plant per square meter in 1996, but in 1997 it was more than twice that great. Nevertheless, these are low densities and reflect good weed control. In fact, more than one-half of all sample plots at both locations contained no weeds in 1996 and 1997. Occurrence of weeds controlled by herbicide was even more spotty.

Spatial Statistics

The typical distribution of weeds as localized clusters was expected to produce large short-range (nugget) semivariances for weed populations. As shown in Fig. 5A through 5D (semivariograms for normalized total weeds at Beasley in 1996 and 1997 and at Deep Hollow in 1996 and 1997, respectively), occurrence of weed-free plots, especially high fraction of weed-free plots, exacerbated the nugget effect. Semivariograms for total weed populations all exhibited weak spatial structure that was adequately described by isotropic, linear models (see note, Table 4). The large nugget effects and gradual slopes of the linear models for total weeds at Beasley and Deep Hollow are given in Table 4. Based on reduced mean square errors (Table 4), these models

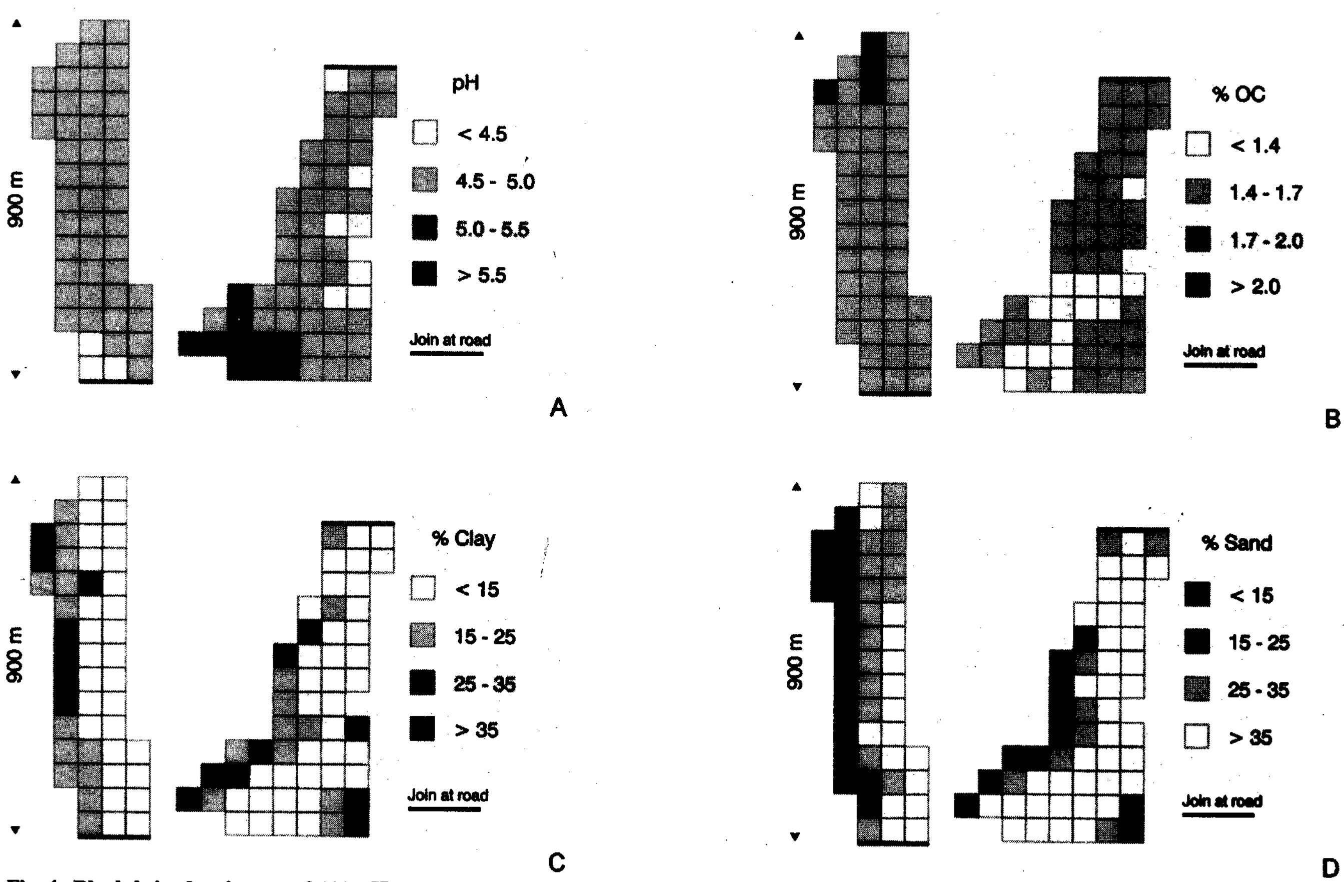

Fig. 4. Block-kriged estimates of (A) pH, (B) organic C, (C) clay percentage, and (D) sand percentage in surface soil at Deep Hollow (legends C and D, reversed).

Table 3. Weeds found at Beasley and Deep Hollow 6 wk after application of preemergence herbicides.

Weed	Controlled with herbicide program	Beasley 1996	Beasley 1997	Deep Hollow 1996	Deep Hollow 1997
		—— plants m^{-2} ——			
Cocklebur, common (*Xanthium strumarium* L.)	Yes	–	–	–	0.04
Milkweed, honeyvine [*Ampelamus albidus* (Nutt.) Britt.]	Yes	–	–	–	0.43
Morningglory (*Ipomoea spp.*)	Yes	–	1.42	–	0.28
Nutsedge, yellow (*Cyperus esculentus* L.)	Yes	3.22	3.34	–	–
Sida, prickly (*Sida spinosa* L.)	Yes	0.07	–	0.04	0.16
Spurge, prostrate and spotted (*Euphorbia spp.*)	Yes	0.07	0.15	0.60	0.43
Tansymustard, green [*Descurainia pinnata* spp. brachycarpa (Richards.)]	Yes	–	–	–	0.04
Mean susceptible weeds m^{-2}		3.36	4.91	0.63	1.38
Anoda, spurred [*Anoda cristata* (L.) Schlecht.]	No	–	0.41	–	–
Nutsedge, yellow (*Cyperus esculentus* L.)	No	–	–	0.88	1.35
Redvine [*Brunnichia ovata* (Walt.) Shinners]	No	0.15	1.80	0.80	1.63
Trumpetcreeper [*Campsis radicans* (L.) Seem. ex Bureau]	No	0.99	0.22	0.36	0.56
Mean total weeds m^{-2}		4.50	7.34	2.67	4.92

appeared adequate for describing the spatial variability of weed populations. Semivariograms for weeds at Beasley controlled by herbicide were similar (not shown), but the lower and more spotty distributions of weeds at Deep Hollow controlled by herbicide gave nugget semivariograms (not shown).

Figures 6A to 6D are estimates of total weed populations at Beasley in 1996 and 1997 and at Deep Hollow in 1996 and 1997, respectively. Comparison of Fig. 6A to 6B shows the increase in weeds from 1996 to 1997 but more strikingly reveals a shift in position of highest weed densities. The distribution of total weeds in 1996 (Fig. 6A) shows good spatial relationships to both areas of higher pH (Fig. 3A) and clay content (Fig. 3C). Due to the shift in weed populations, these relationships are less clear with the 1997 data (Fig. 6B).

Comparison of how total weeds were spatially distributed at Deep Hollow in 1996 and 1997 (Fig. 6C and 6D) shows a nearly uniform increase in numbers of weeds. Probably because of the generally coarser texture of soil at Deep Hollow, there appeared to be only a weak relationship between total weeds and clay content (compare Fig. 4C and Fig. 6C and 6D). On the other hand, lower weed densities spatially corresponded with higher sand content (Fig. 4D). As at Beasley, the relationship to soil texture was more clear for the 1996 than 1997 data.

Relationships between Weed Populations and Soil Properties

In addition to the qualitative relationships between weed populations and soil properties inferred by comparing maps of total weeds and maps of different soil

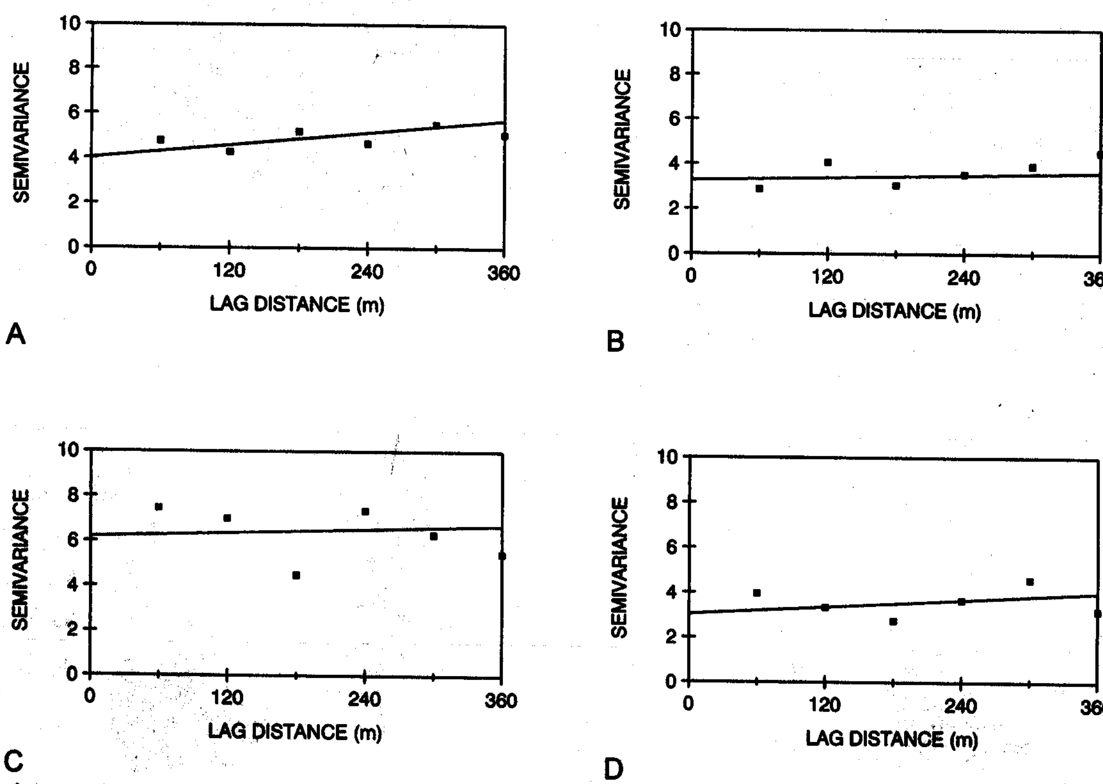

Fig. 5. Experimental semivariograms for total weeds at Beasley in (A) 1996 and (B) 1997 and at Deep Hollow in (C)1996 and (D) 1997. Linear models are shown as solid lines.

Table 4. Linear semivariogram model† parameters for normalized total weeds per square meter.

	Beasley			Deep Hollow		
Year	C_o	B	RMSE‡	C_o	B	RMSE
1996	4.59	0.00468	1.04	6.19	0.00142	1.15
1997	3.26	0.00092	1.07	3.03	0.00270	1.09

† $\gamma(h) = C_o + Bh$, where γ is semivariance, h is lag distance, C_o is nugget effect, and B is slope.
‡ Reduced mean square error.

properties, weed data were regressed on soil pH, OC, and clay content. Cross-semivariograms were also generated to examine spatial relationships between weed populations and soil properties. Changes in pH and OC from 1996 to 1997 were assumed small.

The R values for linear regressions are given in Table 5. Populations of total and controlled weeds at Beasley were positively related to clay and OC content in 1996. Controlled weeds were positively related to clay and OC in 1997. At Deep Hollow, total weeds in 1996 and 1997 were positively related only to clay. The variability of herbicide-controlled weeds in either year could not be described well by pH, OC, or clay.

A relationship between weeds susceptible to control by herbicide and relatively high levels of OC in the soil may be expected. Efficacy of a preemergence herbicide requires plant uptake and potential uptake is reduced by sorption of most herbicides (including fluometuron and norflurazon; Gaston and Locke, 1995; Gaston et al., 1996) by organic matter. Absence of this relationship at Deep Hollow probably reflects a lower and more uniform OC content than at Beasley. The basis for a positive relation between total weeds and clay content is indirect; that is, more available water content and higher fertility are associated with finer, rather than coarser, textured soil.

Table 5. Multiple correlation coefficient (R) values for linear regression of total and controlled weeds on soil properties.

		Beasley		Deep Hollow	
Weeds	Property	1996	1997	1996	1997
Total	pH	0.17	0.05	0.14	0.10
	Organic C	0.28*	0.18	0.06	0.16
	Clay	0.49**	0.14	0.52**	0.34*
Controlled	pH	0.25	0.06	0.00	0.04
	Organic C	0.27*	0.26*	0.20	0.16
	Clay	0.43**	0.29*	0.08	0.12

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.

Cross-semivariograms for total weeds and clay (1996), OC (1996), clay (1997), and OC (1997) at Beasley are shown in Fig. 7A through 7D, respectively. With the exception of total weeds and OC in 1997, all cross-semivariograms were adequately described by positive, linear models. Compared with the 1996 data (Fig. 7A), cross-semivariance for total weeds and clay in 1997 showed less spatial dependence. Weed populations in 1997, therefore, were less clearly related to clay or OC content than in 1996, consistent with regressions (Table

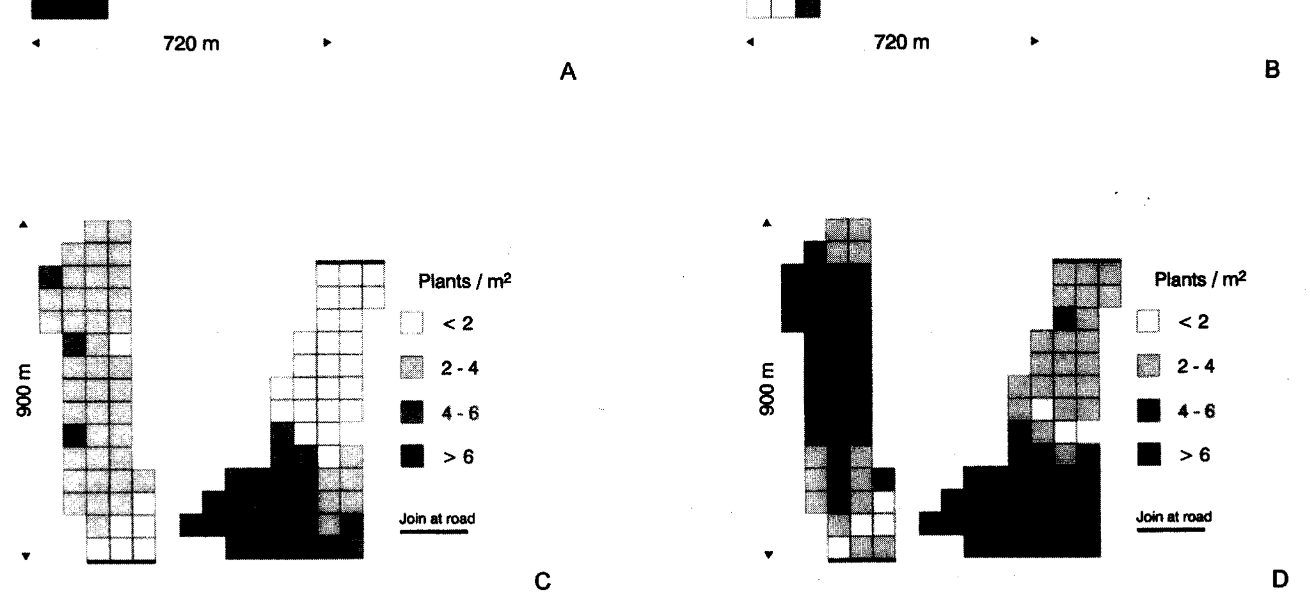

Fig. 6. Block-kriged estimates of total weeds at (A) Beasley in 1996, (B) Beasley in 1997, (C) Deep Hollow in 1996, and (D) Deep Hollow in 1997.

Table 6. Linear model† parameters for cross-semivariograms of normalized total weeds and soil properties at Beasley and Deep Hollow in 1996 and 1997.

	Beasley				Deep Hollow			
	1996		1997		1996		1997	
Weeds and	C_o	B	C_o	B	C_o	B	C_o	B
Organic C	0.079	0.00026	—	—	0.000	0.00083	0.000	0.00090
Clay	0.187	0.00066	0.077	0.00028	0.592	0.00061	0.184	0.00060

† $\gamma(h) = C_o + Bh$.

5). Parameters for cross-semivariogram models shown in Fig. 7A through 7C, as well as for corresponding models of the Deep Hollow data, are given in Table 6.

Figure 8A suggests that weed population densities at Beasley increased with increasing clay. The density of total weeds where clay was >30% was significantly greater than where clay was <30% (7.9 and 2.9 plants m^{-2}, $P < 0.05$). Similarly, the average density of controlled weeds was greater where clay content was >30% (5.7 and 1.6 plants m^{-2}, $P < 0.05$). Figure 8B shows a similar trend for increasing OC content. Densities of total and controlled weeds were significantly higher where soil OC content was >1.6% than where OC was lower (7.7 and 2.0 total weeds m^{-2}; 5.9 and 0.2 controlled weeds m^{-2}, $P < 0.05$). At Deep Hollow there were nearly eight times as many total weeds (15.8 and 2.0 plants m^{-2}, $P < 0.01$) on soil with >20% clay compared with soil with <20% clay. However, the effect of clay content on the density of weeds susceptible to herbicide (Fig. 9A) and effect of OC on either total or controlled weeds (Fig. 9B) were minor.

The weed data may also be examined from the perspective of potential for increased uniformity of weed control and/or reduced herbicide application if ~~the~~ herbicide application rate were varied according to soil properties. Higher weed densities where clay and OC are relatively high suggests that greater uniformity of weed control and better yields might be achieved by a higher rate of herbicide application in those areas. The average clay content of plots where weeds occurred in 1996 and again 1997 at Beasley was significantly greater than the average clay content of plots where weeds did not occur both years (39 and 29%, $P < 0.01$). Clay content associated with reoccurrence of weeds at Deep Hollow was greater than clay where weeds did not occur both years (20 and 13%, $P < 0.05$). Also, OC was higher in plots where weeds reoccurred at Beasley (1.96 vs. 1.63%, $P < 0.01$) and Deep Hollow (1.61 vs. 1.49%, $P < 0.05$). Figures 10A and 10B illustrate this apparent tendency for weeds to reoccur at Beasley and Deep Hollow where clay or OC, respectively, is relatively high, indicating localized problems of weed persistence and the need for more aggressive control in these areas.

Increased uniformity of weed control by using locally

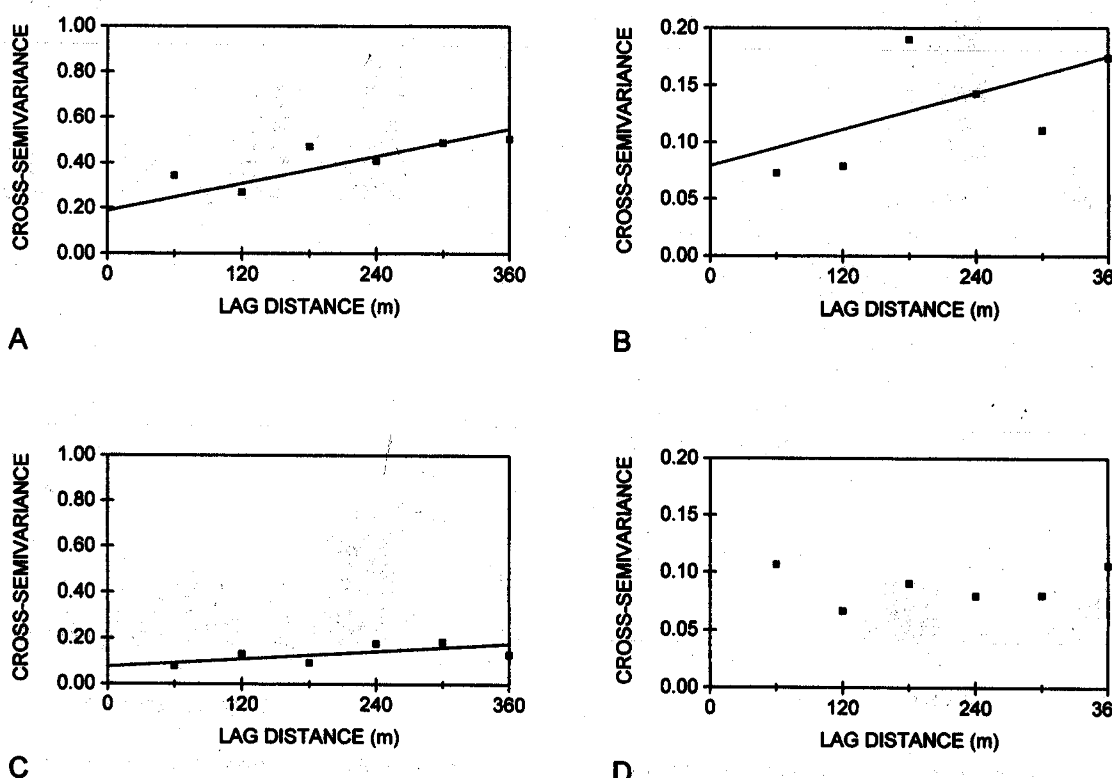

Fig. 7. Cross-semivariograms for normalized (A) total weeds and clay in 1996, (B) organic C in 1996, (C) clay in 1997, and (D) organic C in 1997 at Beasley. Linear models are shown as solid lines.

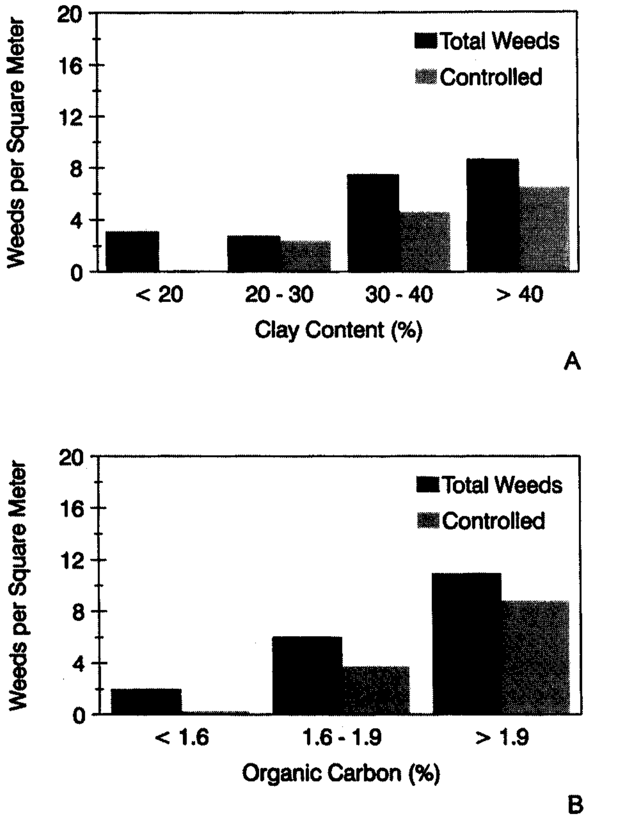

Fig. 8. Density of total weeds and weeds controlled by herbicide at Beasley as affected by (A) clay and (B) organic C of soil. Weed data for 1996 and 1997 combined.

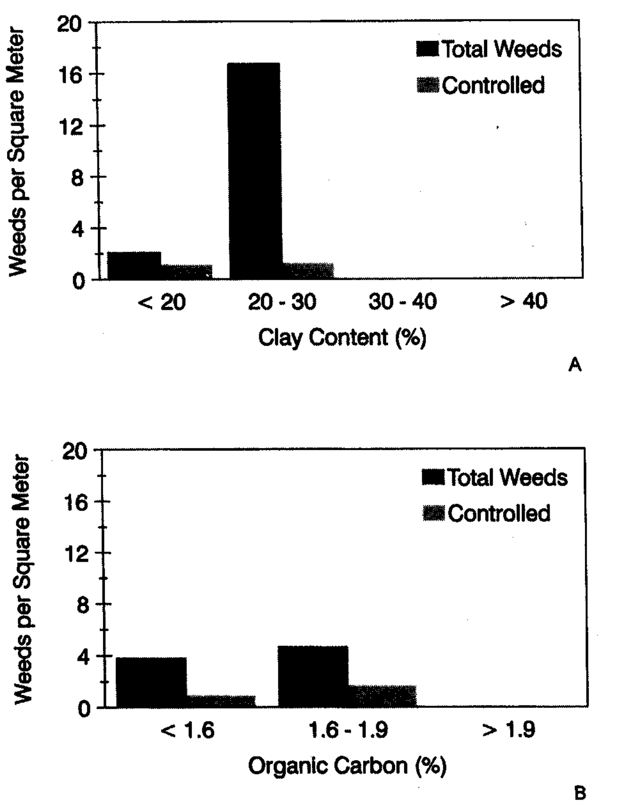

Fig. 9. Density of total weeds and weeds controlled by herbicide at Deep Hollow as affected by (A) clay and (B) OC of soil. Weed data for 1996 and 1997 combined.

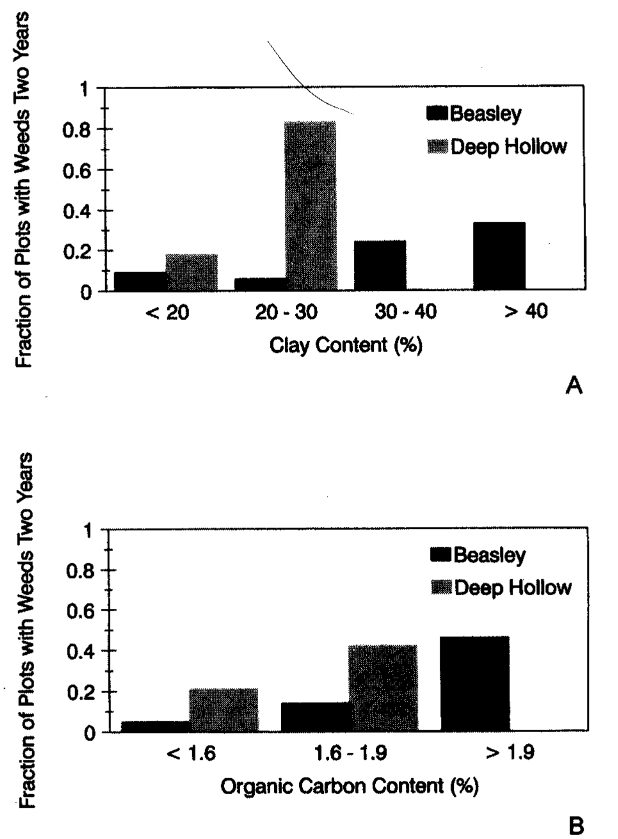

Fig. 10. Reoccurrence of weeds at Beasley and Deep Hollow as affected by (A) clay and (B) OC content of soil. Weed data for 1996 and 1997 combined.

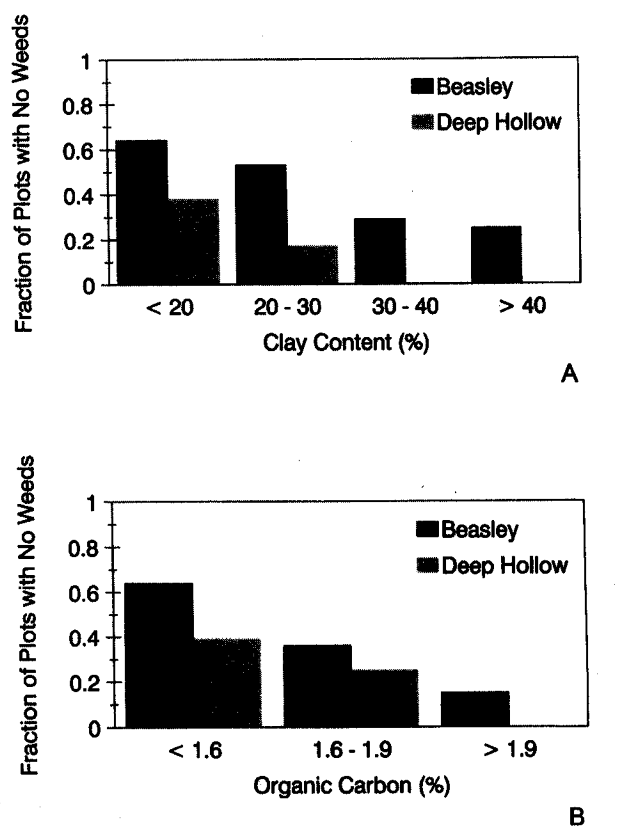

Fig. 11. Relationship between weed-free plots and (A) clay and (B) OC content of soil at Beasley and Deep Hollow. Weed data for 1996 and 1997 combined.

higher rates of herbicide increases production costs and the potential for adverse, off-site environmental impact. Weed control at these study sites was good. Even in those areas where soil properties apparently limited herbicide efficacy, on the average no more than one to two (Deep Hollow, Fig. 9A and 9B) or six to eight (Beasley, Fig. 8A and 9B) susceptible weeds per square meter emerged and survived. Therefore, if this level of control was achieved at less than locally optimal application rates, then where soil properties are less prone to limit herbicide efficacy, lower rates of application might achieve adequate weed control. More than 50% of the sample plots at Deep Hollow had no weeds and more than 60% of those at Beasley were weed-free. Nearly 80% contained no weeds susceptible to herbicide control. Such a high level of complete weed control may not be economically justified. Figures 11A and 11B suggest a nearly linear relationship between increasing frequency of weed-free plots and decreasing soil OC and clay. At Beasley, the average clay content of plots with no weeds in 1996 and 1997 was significantly less than that of plots with weeds at least one year (27 and 34%, $P < 0.01$). Organic C in the weed-free plots was also lower (1.57 vs. 1.77%, $P < 0.05$). At Deep Hollow, although the average clay (13 compared with 15%) and OC (1.47 and 1.56%) contents of weed-free plots were lower than in those of plots with weeds at least one year, these differences were not significant.

CONCLUSIONS

The variability of pH, OC, clay, and sand at two locations in the Mississippi Delta exhibited spatial dependence that could be well-described using semivariogram models. Similarly, the variability of weed densities at these locations could be described by semivariogram models. In general, OC and clay content were positively related to densities of total weeds. These relationships were less clear for weed species subject to herbicide control, particularly at Deep Hollow where the variability in clay and OC content was less than at Beasley. However, weeds tended to reoccur at both locations on plots where clay and OC were relatively high, indicating persistence related to soil properties. On the other hand, relatively coarse-textured plots at both locations were commonly weed-free for 2 yr. These observations suggest that greater uniformity of weed control might be achieved by a variable rate of herbicide application. Also, adequate weed control might be achieved at a reduced rate of application in sandy, low OC areas. Not only is herbicide efficacy enhanced by low organic matter and coarse texture, so too is its potential for movement with soil water.

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