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Sampling Weed Spatial Variability on a Fieldwide Scale

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Site-specific weed management recommendations require knowledge of weed species, density, and location in the field. This study compared several sampling techniques to estimate weed density and distribution in two 65-ha no-till *Zea mays–Glycine max* rotation fields in eastern South Dakota. The most common weeds (*Setaria viridis, Setaria glauca, Cirsium arvense, Ambrosia artemisiifolia,* and *Polygonum pensylvanicum*) were counted by species in 0.1-m² areas on a 15- by 30-m (1,352 points in each field) or 30- by 30-m (676 points in each field) grid pattern, and points were georeferenced and data spatially analyzed. Using different sampling approaches, weed populations were estimated by resampling the original data set. The average density for each technique was calculated and compared with the average field density calculated from the all-point data. All weeds had skewed population distributions with more than 60% of sampling points lacking the specific weed, but very high densities (i.e., > 100 plants m⁻²) were also observed. More than 300 random samples were required to estimate densities within 20% of the all-point means about 60% of the time. Sampling requirement increased as average density decreased. The W pattern produced average species densities that often were similar to the field averages, but information on patch location was absent. Weed counts taken on the 15- by 30-m grid were dependent spatially and weed contour maps were developed. Kriged maps presented both density and location of weed patches and could be used to establish management zones. However, grid-sampling production fields on a small enough scale to obtain spatially dependent data may have limited usefulness because of time, cost, and labor constraints.

Nomenclature: *Ambrosia artemisiifolia* L. AMBEL, common ragweed; *Cirsium arvense* (L.) Scop. CIRAR, Canada thistle; *Polygonum pensylvanicum* L. POLPY, Pennsylvania smartweed; *Setaria glauca* (L.) Beauv. SETLU, yellow foxtail; *S. viridis* (L.) Beauv. SETVI, green foxtail; *Glycine max* (L.) Merr., soybean; *Zea mays* L., corn.

Key words: Mapping, precision farming, site-specific weed management, AMBEL, CIRAR, POLPY, SETLU, SETVI.

Weeds occur in patches across field landscapes (Cardina et al. 1995; Clark et al. 1996; Johnson et al. 1995; Marshall 1988; Mortensen et al. 1995; Wiles et al. 1992; Wilson and Brain 1991). Weed patchiness presents the opportunity to reduce herbicide use while maintaining satisfactory weed control if areas with low or no weed infestations can be identified. For example, bioeconomic weed management recommendation models rely on accurate weed density estimates to predict optimal treatments (Wiles et al. 1992). Obtaining accurate population estimates is complicated because of field size, patch nonuniformity, and lack of standardized techniques for estimating weed populations.

If point data are spatially related, then spatial distribution maps can be generated using the geostatistical method of kriging that assigns an estimated value to unsampled or unknown areas based on a parameter calculated from known point information (Isaaks and Srivastava 1989; Trangmar et al. 1985). For research applications, weed contour maps have been developed from information obtained through grid sampling (Brown and Steckler 1995; Gerhards and Wyse-Pester 1997). To develop weed contour maps, selecting appropriate grid distances and sample sizes at each grid point are critical. For example, Conn et al. (1982) reported that increasing sampling area from 0.36 m² to 2.25 m² was necessary to measure populations of weed species that were rare in an area. Using a constant grid size of 0.25 m² but changing grid point spacing from 20 by 30 m to 10 by 10

m gave better precision and increased agreement with actual weed densities (Heisel et al. 1996).

Crop scouts usually assess weed populations subjectively rather than quantitatively. Densities typically are estimated as class variables (high, medium, or low) for each weed species. Rigorous scouting, such as grid sampling, is not done by field scouts because of time and labor constraints, complexity of information, and often a lack of equipment to manage weed variability information even when it is noted. Growers know where problem weed patches are through years of observations. Crop scouts gain this knowledge by working with the grower and have adapted sampling schemes to assess a field quickly. Some scouts drive 3 to 4 lines in the field, stopping to map weed patches. Another sampling method is to drive the field in a W- or Z-shaped pattern with weed problems measured at 10 to 15 points along each "leg." This method has been used to survey cereal and oil seed crops for weed density estimations in Canada (Thomas 1985).

To determine whether site-specific weed management is practical, the first criterion is to decide whether weeds (density, species) vary enough over a field to warrant different treatments. The second step is to obtain accurate and reliable information about weed location and density. The third step matches weed management solutions with problems. In this study, several sampling methods were used to estimate weed variability in two 65-ha fields with different weed spe-
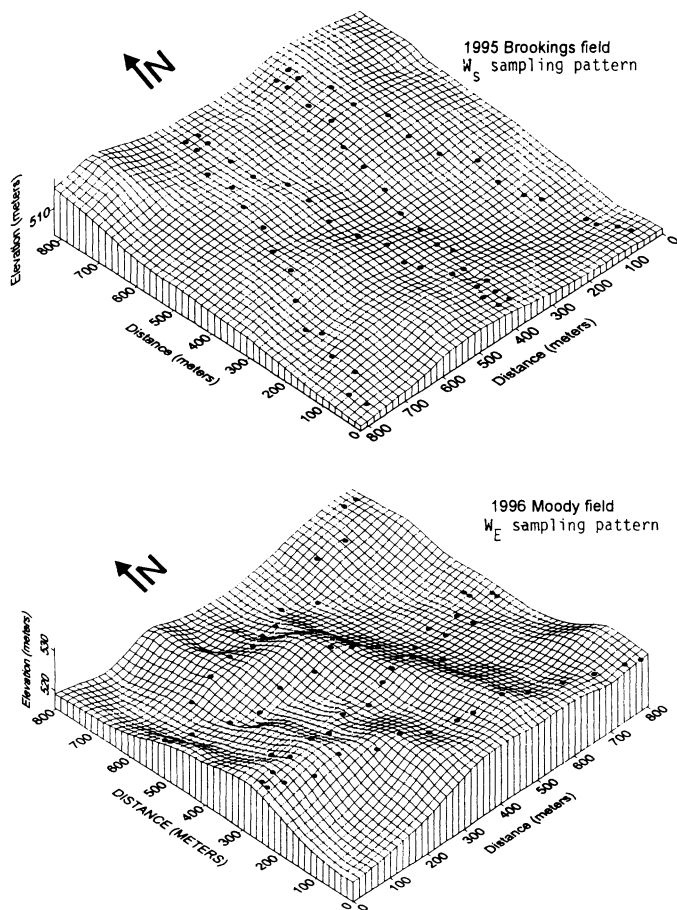
FIGURE 1. Examples of the 60-point W sampling schemes showing a W_S pattern for the Brookings field and a W_E pattern for the Moody field. These maps also illustrate the topography of both fields.

cies. The sampling techniques tested included point sampling at two grid-point distances, random sampling, and a W sampling pattern. Weed locations and density were also defined by kriging when spatial dependency was present.

Materials and Methods

Site Characterization

Two no-till 65-ha fields in eastern South Dakota were grid sampled for weed seedlings in 1995 and 1996 (Lems 1998). One field was in Brookings County with an average elevation of 509 m above sea level and topographic relief of 14.4 m. The soils were formed by late Wisconsin glaciation. Soils at topographic summit and shoulder positions were

fine-loamy and coarse-loamy mixed Udic Haploborolls (Barnes, Egeland, and Vienna series). Soils at the back and footslope positions were fine-silty mixed, Pachic Udic Haploborolls (Brookings series) and fine-silty, frigid, Aeric Calciaquolls (McIntosh series), respectively.

The second field, in Moody County, was 523 m above sea level with 16.5 m of relief. Soils at this site were formed in glacial till with a loess cap. Soils at the summit and shoulder positions were fine-silty, mixed Udic Haploborolls (Kranzburg, Venagro, and Vienna series). Soils at the backslope positions were fine-silty, mixed Pachic Udic Haploborolls (Waubay series). At the foot and toeslope positions, several soil series were present including fine, montmorillonitic, frigid Typic Argiaquolls (Badger series); fine-silty, frigid Aeric Calciaquolls (Cubden and McIntosh series); and fine-silty, mixed (calcareous), frigid, Cumulic Enkoaquolls (Lamoure series).

At these sites the rotation was Z. mays followed by G. max and no tillage was used since 1992. The Moody field was planted to Z. mays in 1995 and G. max in 1996, whereas the Brookings field was planted to G. max in 1995 and Z. mays in 1996. Z. mays was planted in 57-cm rows and G. max in 19-cm rows. Preplant herbicide treatments of 2,4-D (isooctyl ester) plus glyphosate in Z. mays and glyphosate-only in G. max were applied in early May both years, and postemergence herbicides were applied in mid- to late June.

Weed Counts

Weeds were counted about 3 wk after preplant treatments, which was 3 to 7 d prior to postemergence herbicide application. The Brookings field was sampled on a 30- by 30-m fixed grid (total of 676 sampling points) on June 13, 1995, and June 10, 1996, starting 30 m from the field edge. The Moody field was sampled on May 31, 1995, and June 9, 1996, on a 15- by 30-m fixed grid (total of 1,352 sampling points) with rows 30 m apart and sample points every 15 m in the row. At each sample location, all weed seedlings in a 20- by 50-cm quadrat were identified and enumerated. Z. mays was in the 1- to 2-leaf growth stage, G. max was unifoliate to the first trifoliate growth stage, and weeds were 2 to 10 cm tall. All sample locations were georeferenced using a differential correction global positioning system (DGPS) with a spatial resolution of 2 cm. Coordinate points were overlaid on topography maps generated by rod and transect surveying.

Data Analysis

Data from the three weed species that occurred most often in the sampling areas were analyzed. A computer pro-

TABLE 1. Mean field weed density and confidence intervals for five sampling methods and three weed species in the Brookings field in 1995 and 1996.

Sampling scheme	Setaria spp.		Cirsium arvense		Polygonum pennsylvanicum	
	1995	1996	1995	1996	1995	1996
	plants m^{-2}					
All points	28.5 ± 8.0[a]	21.3 ± 4.4	2.7 ± 0.6	4.1 ± 0.8	2.3 ± 2.1	4.2 ± 3.9
W_S	31.2 ± 21.9	19.3 ± 9.8	3.0 ± 2.2	4.1 ± 3.2	10.6 ± 16	4.8 ± 9.0
W_N	48.7 ± 51.2	24.0 ± 16.6	4.2 ± 3.7	4.7 ± 2.6	0.7 ± 0.8	3.2 ± 4.9
W_E	8.3 ± 0.7	28.7 ± 28.2	3.4 ± 1.9	8.2 ± 5.4	8.5 ± 16	22.5 ± 40
W_W	18.0 ± 12.7	17.2 ± 13.9	5.5 ± 3.2	6.7 ± 3.8	0	1.3 ± 1.7

[a] n = 676 for all points data and n = 60 for each W sampling scheme.

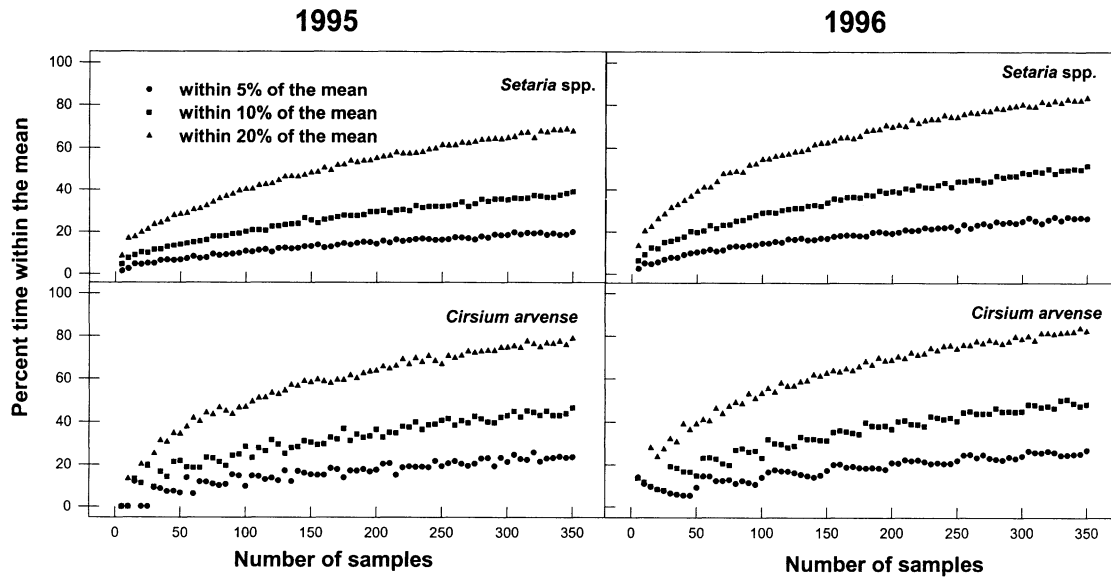Clay et al.: Sampling spatial variability • 675

FIGURE 2. Mean results of 5,000 random subsamplings in increments of 5 for all sampling point data for *Setaria* spp. and *Cirsium arvense* for 1995 and 1996 for the Brookings field.

gram was constructed that subsampled all-point data sets 5,000 times with replacement (Clay et al. 1995) from size classes from 5 to 350 (Brookings) and from 5 to 700 (Moody). For example, a size class of 100 would consist of 100 random values from the all-point data set. The mean of this subsample was calculated and the difference between the subsample and all-point data mean was determined. The percentage of the 5,000 samplings that had a mean within 5, 10, or 20% of the all-point mean was determined.

Four 60-point W-shaped patterns were generated from the original data set for each of three of the major weed species present. The W pattern consisted of four 15-sampling-point legs with the top 3 points of the W facing the four ordinate directions (N, S, E, W) (Figure 1). Mean and variance were calculated for each weed species both years for each of the five sampling schemes (all points, W_N, W_S, W_E, and W_W).

Skewness and kurtosis of the all-point data and each W pattern were calculated (Ott 1977). Skewness was calculated with the following equation:

$$\gamma_1 = \frac{m_3}{(m_2)^{3/2}}$$

where

$$m_3 = \frac{\sum (y - \bar{y})^3}{n} \quad \text{and} \quad m_2 = \frac{\sum (y - \bar{y})^2}{n}$$

where γ_1 is the coefficient of skewness, y is the sampled data, $\bar{y}$ is the mean, and n is the sample size. When γ_1 is equal to 0, then the population is said to be symmetrical, whereas a negative γ_1 value depicts a population shifted to the right (i.e., high values dominate the data set) and a positive γ_1 value indicates a population dominated by low values.

Kurtosis was calculated with the following equation:

$$\gamma_2 = \frac{m_4}{(m_2)^2} \quad \text{and} \quad m_4 = \frac{\sum (y - \bar{y})^4}{n}.$$

where γ_2 is the coefficient of kurtosis. The other variables have the same properties as stated above. A normal distribution has a kurtosis value of 3. A kurtosis greater than 3 indicates that data are distributed over a wider range of values than a normal distribution, and if less than 3, data are distributed over a narrower range than a normal distribution.

Semivariograms using all-point data were generated for each field. Semivariograms that were positive and definitive were fit to an exponential model. Those that were not definitive were fit to a second order polynomial. If the semivariogram indicated spatial dependence (i.e., equations were positive and definitive), data were kriged and results were overlaid on topographic field maps using Surfer 6.0 software.[1] Data were kriged using the following equation:

TABLE 2. Skewness and kurtosis values for the five sampling schemes at the Brookings field in 1995 and 1996.

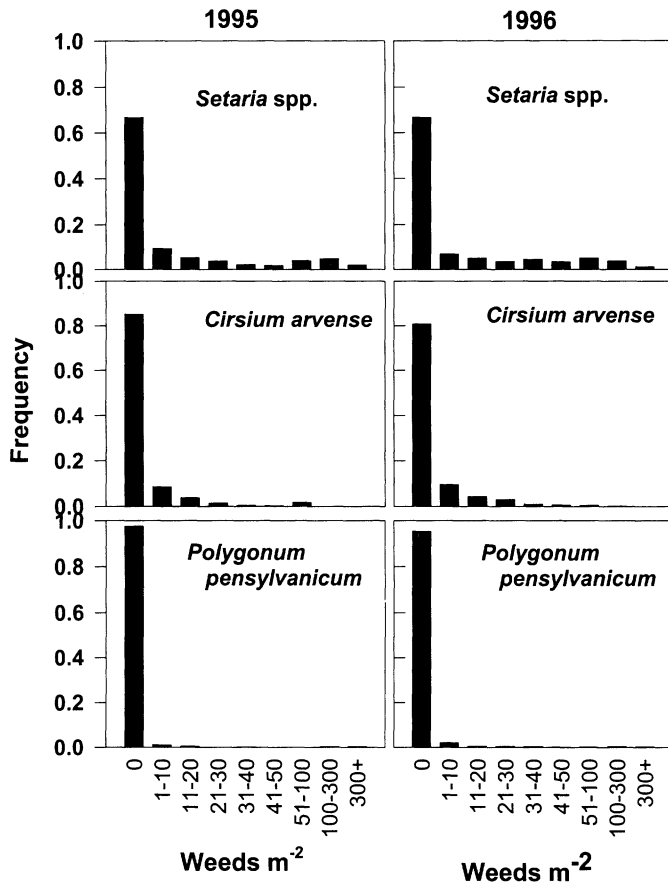| Sampling scheme	*Setaria* spp.				*Cirsium arvense*				*Polygonum pennsylvanicum*			
	1995		1996		1995		1996		1995		1996	
	Skewness	Kurtosis	Skewness	Kurtosis	Skewness	Kurtosis	Skewness	Kurtosis	Skewness	Kurtosis	Skewness	Kurtosis
All points	8	94	6	56	5	44	5	40	15	250	20	450
W_S	4	22	2	9	4	17	5	26	7	48	8	58
W_N	7	50	4	20	5	33	2	6	5	28	7	46
W_E	5	26	6	35	3	10	4	22	8	58	8	57
W_W	3	11	5	32	3	11	3	14	0	0	5	28

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FIGURE 3. Frequency distribution of *Setaria* spp., *Cirsium arvense,* and *Polygonum pensylvanicum* counts for all sampling point data in 1995 and 1996 in the Brookings field.

$$\hat{Y}(x_0) = \sum_{i=1}^{n} w_i Y(x_i)$$

where $\hat{Y}$ is the estimated value at the unsampled point x_0, n is the number of adjacent points, and $Y(x_i)$ and w_i are the assigned weighting factors to each sampling point.

Student's t tests and F tests were used to determine differences among population averages and variances at P = 0.10. All-point and W-pattern data were analyzed within a species and within and between years.

Results and Discussion

Brookings Field

In 1995 and 1996, the most prevalent weed at Brookings was *Setaria* spp. (a mixture of *S. viridis* and *S. glauca*) with

an average density (using all-point data) of about 25 plants m^{-2} (Table 1). *C. arvense* and *P. pensylvanicum* were the next most common weeds. The average densities for these species were about 2 plants m^{-2} in 1995 and 4 plants m^{-2} in 1996. Other weeds present included *Chenopodium album* L. (common lambsquarters), *Helianthus annuus* L. (common sunflower), *Asclepias syriaca* L. (common milkweed), *Taraxacum officinale* Weber in Wiggers (dandelion), *Solanum ptycanthum* Dun. (eastern black nightshade), *Elytrigia repens* (L.) Nevski (quackgrass), and *Panicum virgatum* L. (switchgrass).

Random resampling of *Setaria* spp. and *C. arvense* populations indicated that between 300 and 350 subsamples were needed for the field average to be within 20% of the field mean 65% of the time (Figure 2). Increasing precision to within 10% of the mean required at least 350 random samples, but the 10% criterion was only achieved 40% of the time. *P. pensylvanicum* infestations were very scattered and random resampling results were inconsistent (data not shown). Even when 300 random samples out of the 676 total samples were chosen 5,000 times, estimating the mean density to within 20% of the mean had less than 20% probability.

The direction of the W pattern influenced the population estimates (Table 1). For *Setaria* spp., the W$_E$ pattern in 1995 had a mean density of 8.3 plants m^{-2}, which was less than the field average and W$_S$ pattern. However, the majority of the means were similar when comparing the five sampling schemes, indicating that sampling direction had little influence on average *Setaria* density. Coefficients of variation for 1995 *Setaria* data ranged from about 7,600 to 81,000, which helps explain why large numerical differences were not statistically significant.

For all sampling schemes except the W$_W$ pattern for *P. pensylvanicum* in 1995, positive skewness values were observed, indicating that data sets were dominated by low values (Table 2). Because the data sets were skewed, the arithmetic mean may not be the most informative value to describe the central tendency in the data. The mode for each data set, the measure of central tendency described by the most frequent value in the data set, was 0, indicating that weeds were not present at most grid sampling points (Figure 3). About 70% of the grid points did not have *Setaria,* 80% did not have *C. arvense,* and about 95% did not have *P. pensylvanicum.* The density that had the next greatest frequency was 1 to 10 plants m^{-2}.

Kurtosis values were greater than 3, indicating that data sets had a wider than normal distribution. About 2% of sample points had *Setaria* or *P. pensylvanicum* densities > 300 plants m^{-2} with a few points exceeding 1,500 plants

TABLE 3. Mean field weed density and confidence intervals for five sampling methods and three weed species in the Moody field in 1995 and 1996.

Sampling scheme	*Setaria* spp.		*Cirsium arvense*		*Ambrosia artemisiifolia*	
	1995	1996	1995	1996	1995	1996
	plants m^{-2}					
All points	13.0 ± 3.9	67.7 ± 10.8	15.1 ± 1.9	2.3 ± 0.4	36.8 ± 6.3	8.4 ± 2.2
W$_S$	6.4 ± 0.5	41.5 ± 105	19.5 ± 14.2	1.1 ± 1.1	19.2 ± 22.6	5.8 ± 7.2
W$_N$	10.3 ± 7.6	114.3 ± 64.8	9.3 ± 5.3	2.1 ± 1.7	11.3 ± 10.7	12.5 ± 10.5
W$_E$	6.9 ± 6.2	65.7 ± 45.7	16.8 ± 8.1	1.3 ± 1.1	16.5 ± 14.0	19.3 ± 27.9
W$_W$	8.8 ± 9.2	59.9 ± 43.5	12.5 ± 5.8	4.2 ± 2.7	17.7 ± 25.5	7.7 ± 9.1

[a] n = 1,352 for all points data and n = 60 for each W sampling scheme.
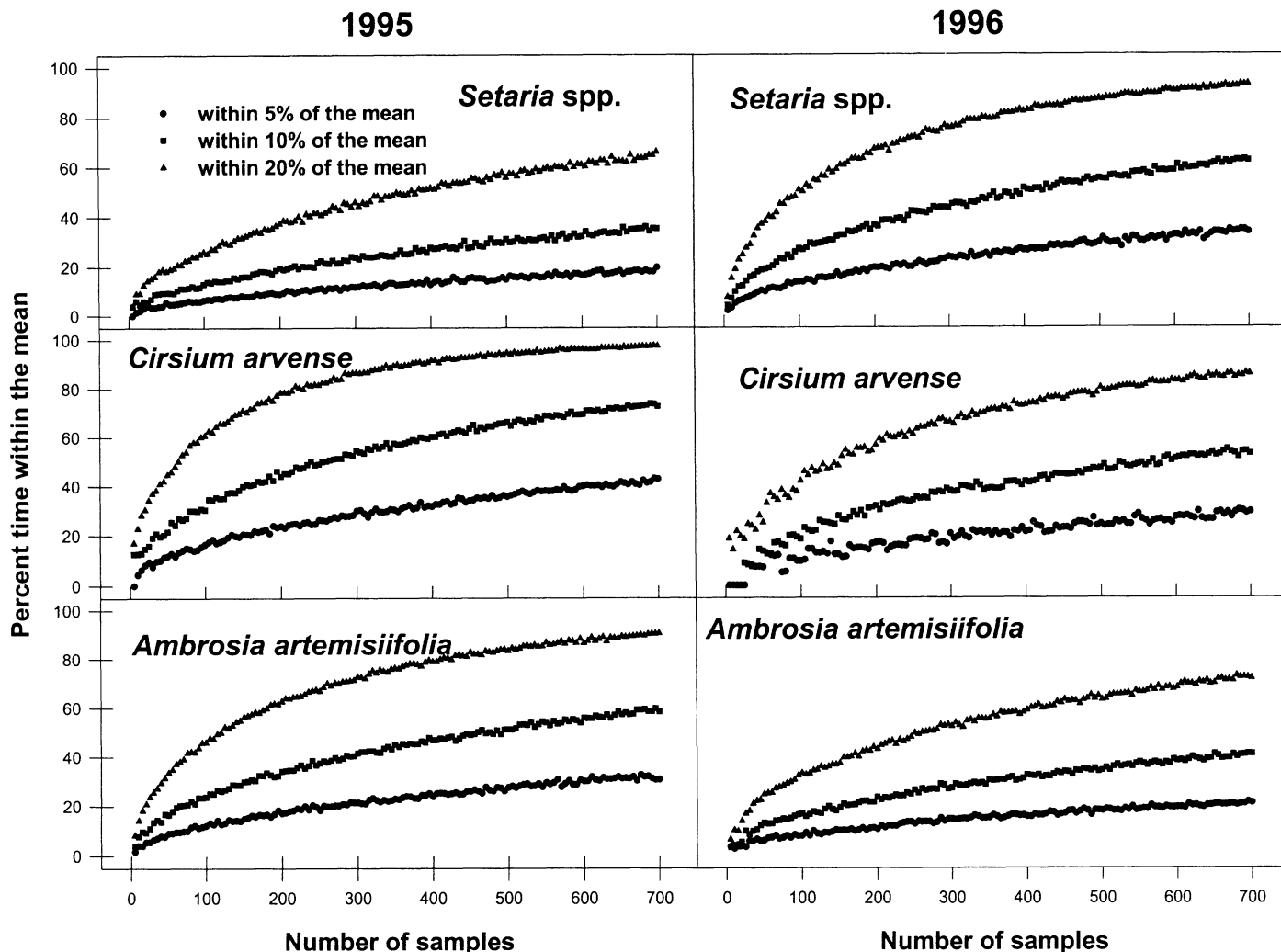
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FIGURE 4. Mean results of 5,000 random subsamplings in increments of 5 for all sampling point data for *Setaria* spp., *Cirsium arvense,* and *Ambrosia artemisiifolia* for 1995 and 1996 for the Moody field.

m^{-2}. Similar weed population distributions for *Ipomoea* (morningglory) species in a North Carolina *G. max* field (Wiles et al. 1992) and broadleaf species in a Nebraska *Z. mays* field (Mortensen et al. 1995) have been reported. The semivariograms for the all-point data set of each species were not positive and definitive, indicating no spatial correlation (data not shown). Therefore, kriging was not conducted.

Moody Field

The three most prevalent weed species in the Moody field were *Setaria* spp., *C. arvense*, and *A. artemisiifolia* with av-

erage plant densities of about 13, 15, and 37 plants m^{-2}, respectively, in 1995 (Table 3). In 1996, *Setaria* density increased to 67.7 plants m^{-2}, whereas densities of *C. arvense* and *A. artemisiifolia* decreased to 2.3 and 8.4 plants m^{-2}, respectively. Other weeds observed in < 10% of the sampling areas (in descending order of density) included *C. album, P. pensylvanicum, S. ptycanthum, Xanthium strumarium* L. (common cocklebur), *T. officinale, E. repens, Hippuris vulgaris* L. (marestail), *A. syriaca, Oxalis stricta* L. (yellow woodsorrel), *Calystegia sepium* (L.) R. Br. (hedge bindweed), *H. annuus*, and *Amaranthus retroflexus* L. (reedroot pigweed). Mean species density ranged from about 0.1 to 4 plants m^{-2}.

TABLE 4. Skewness and kurtosis values for the five sampling schemes at the Moody field in 1995 and 1996.

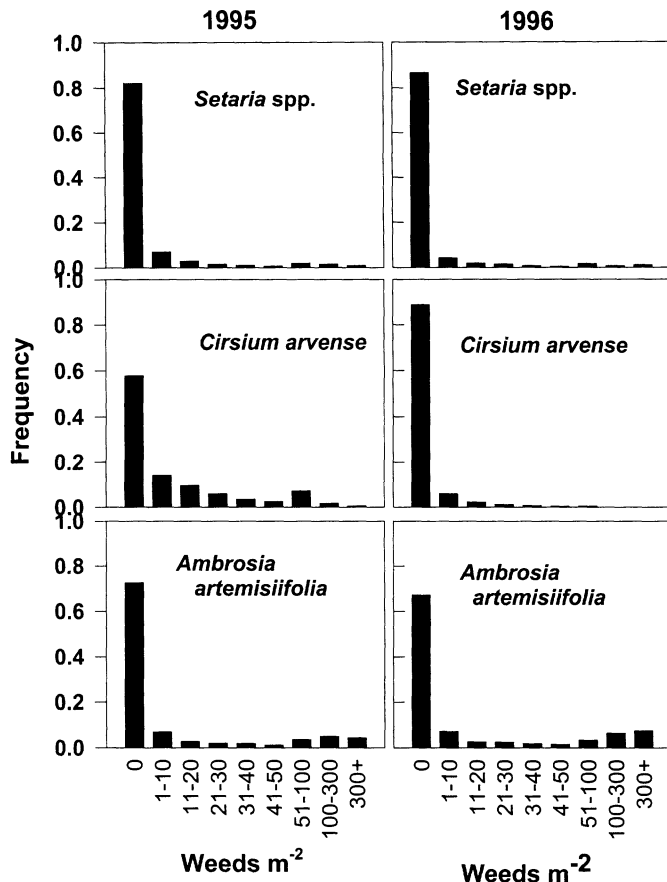| Sampling scheme	*Setaria* spp.				*Cirsium arvense*				*Ambrosia artemisiifolia*			
	1995		1996		1995		1996		1995		1996	
	Skewness	Kurtosis	Skewness	Kurtosis	Skewness	Kurtosis	Skewness	Kurtosis	Skewness	Kurtosis	Skewness	Kurtosis
All points	12	186	4	24	6	60	5	35	5	33	10	155
W_S	6	36	4	15	6	40	5	34	7	48	6	42
W_N	3	12	3	9	3	12	3	13	5	25	4	22
W_E	5	29	4	17	3	17	4	25	5	32	7	55
W_W	6	38	4	16	2	8	3	13	7	52	6	39

FIGURE 5. Frequency distribution of *Setaria* spp., *Cirsium arvense*, and *Ambrosia artemisiifolia* counts for all sampling point data in 1995 and 1996 in the Moody field.
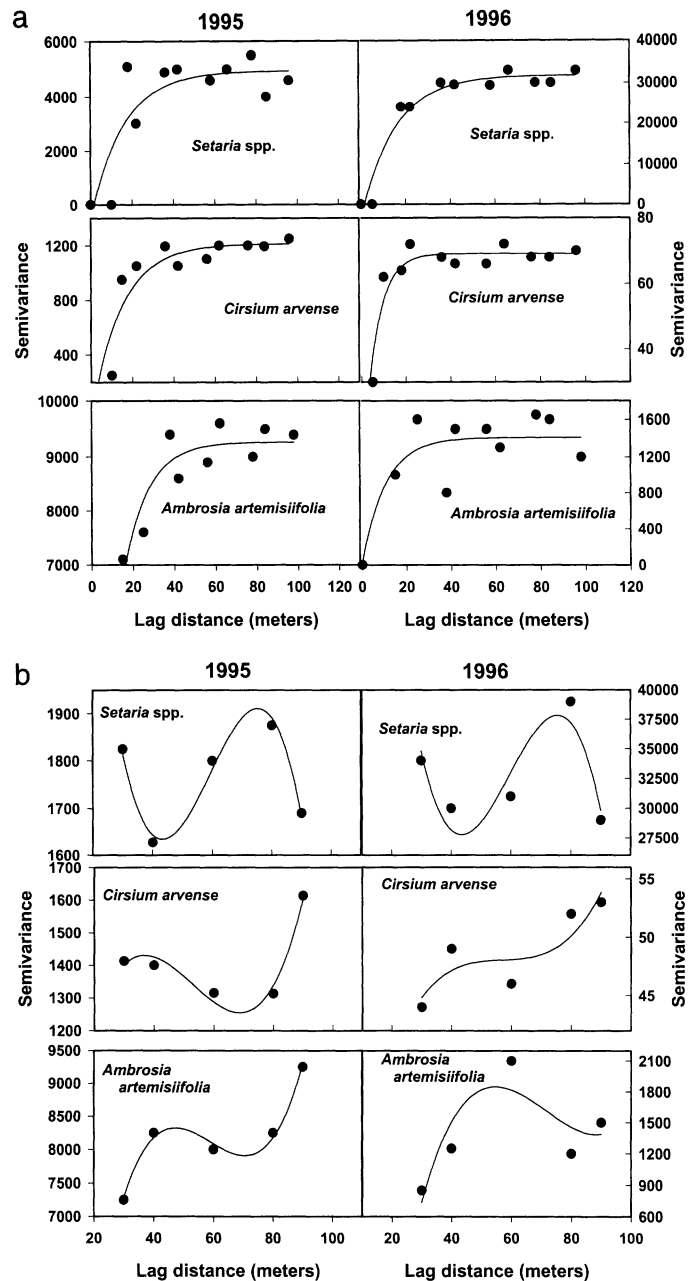

FIGURE 6. Semivariograms generated for *Setaria* spp., *Cirsium arvense*, and *Ambrosia artemisiifolia* in the Moody field in 1995 and 1996 using an exponential model with all sample point data (a) and second order polynomial with every other point of all the point data set (b).

Resampling the original data sets showed that as weed density decreased, the sampling requirement increased to achieve similar accuracy (Figure 4). For example, *C. arvense* density was 15 plants m^{-2} in 1995 and required about 250 samples to be within 20% of the mean 80% of the time. In 1996, when the density was 2.3 plants m^{-2}, 550 samples were needed to meet these criteria. Similar changes in the quantity and precision of sampling were observed for both *Setaria* spp. and *A. artemisiifolia* (Figure 4). The increased sampling requirement when density decreased may be caused by the decreased width of the confidence interval at lower densities (observed with *Setaria*) or increased frequency of low-density or weed-free areas, allowing these areas to be sampled more often (observed with *C. arvense*).

The mean density for W patterns of all three species resulted in similar mean densities to the all-point mean in both years. Differences in mean *C. arvense* density was observed among W patterns in 1996; W_W and W_S had slightly lower estimated mean densities than the W_N pattern (Table 3).

Population frequency distributions were graphed for both years (Figure 5), and skewness and kurtosis values were generated from the all-point data set. Skewness values were positive and kurtosis values were all greater than 3 for each weed species in both years (Table 4). More than 80% of the sampling points had no *Setaria* spp. or *C. arvense* present in 1995, and about 60% of the sampling points had no *A. artemisiifolia* (Figure 5). However, densities of > 100 plants m^{-2} also were observed. These data are similar to the pop-

ulation frequency distributions reported for the Brookings field and by Wiles et al. (1992) and Mortensen et al. (1995).

Semivariograms showed strong to moderate spatial relationships existed for all weed species in both 1995 and 1996 (Figure 6). Semivariance sill values differed among species and year but had a direct relationship with mean density. For example, *A. artemisiifolia* density decreased from 37 to 8 plants m^{-2} between 1995 and 1996 and the semivariance sill value decreased from about 9,000 to about 1,400. These results were similar to those reported by Clark et al. (1996) with mean density and variance of weed populations. Although the semivariance sill value changed between years and among species, the range value (or lag distance) was about 40 m in both years for the three weed species.

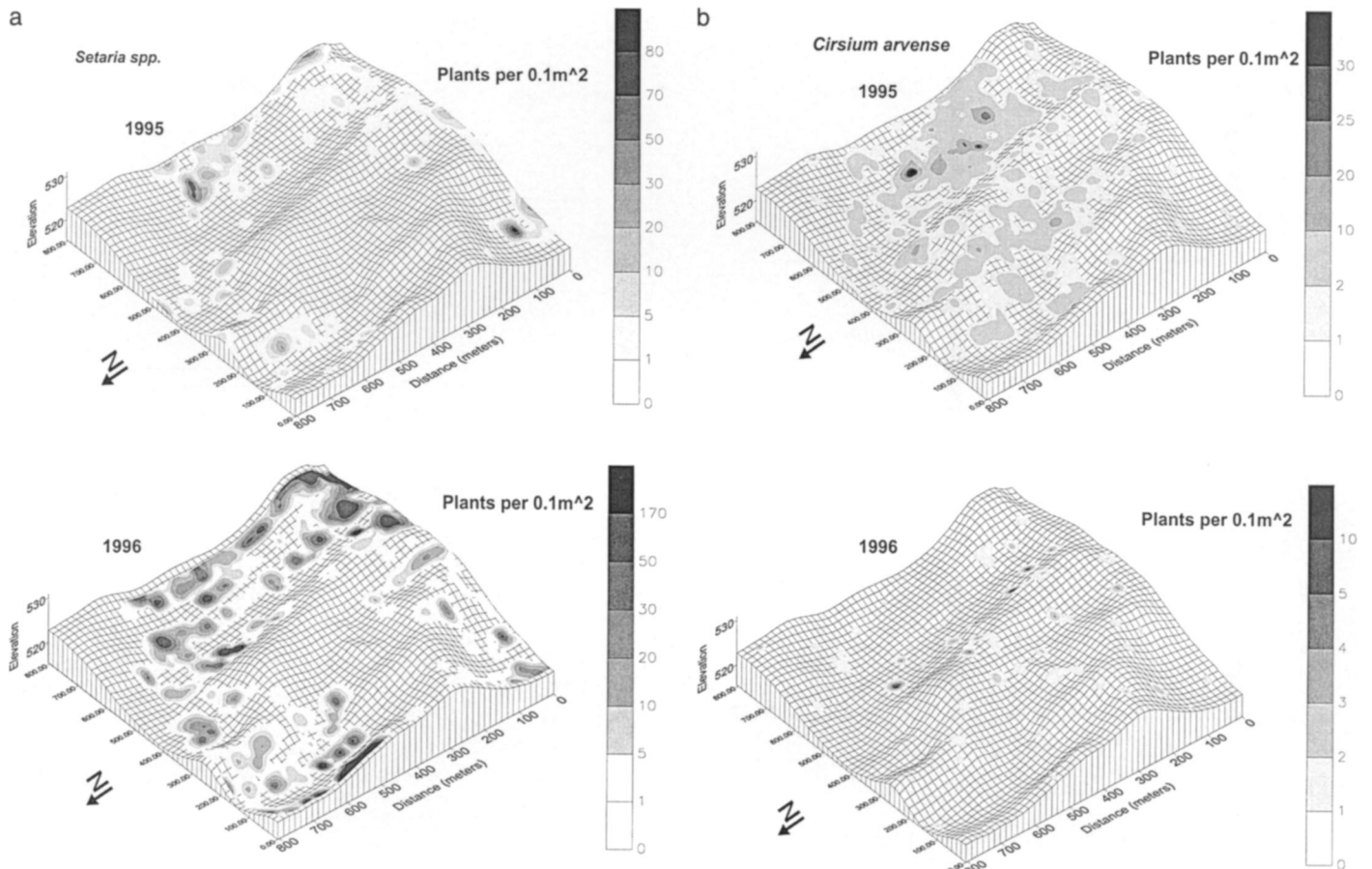Clay et al.: Sampling spatial variability • 679

FIGURE 7. Kriged maps of weed distribution and density for 1995 and 1996 in the Moody field for *Setaria* spp. (a), *Cirsium arvense* (b), and *Ambrosia artemisiifolia* (c).

Contour maps of *Setaria* spp. showed that low densities were observed throughout most of the field, but large dense patches occurred close to field edges (Figure 7a). *C. arvense* contour maps showed that in 1995 high populations were observed in higher-elevation areas (Figure 7b), whereas in 1996, patches became more defined and smaller in size. Two low-elevation areas had the greatest densities of *A. artemisiifolia* in 1995 (Figure 7c). In 1996, both the area and density of *A. artemisiifolia* patches were reduced significantly. Changes in patch size and density from 1995 to 1996 are similar to results reported for other species. Wilson and Brain (1991) reported that patch location of *Alopecurus myosuroides* Huds. was stable over a 10-yr period although changes in density were noted. Also, evidence of *Abutilon theophrasti* Medicus patch stability was reported in a *Z. mays* and *G. max* rotation in Nebraska (Johnson et al. 1995).

In examining the spatial distribution of the kriged data, it is important to note that while a W pattern often resulted in a mean density similar to the field average, weed patches could be missed. For example, a W_W pattern would not have predicted the *A. artemisiifolia* population in the northeast portion of the field, and any of the W patterns probably would not have accurately depicted the small patch distribution of *C. arvense* in 1996.

Comparison of Spatial Dependency of Weed Infestations in Brookings and Moody Fields

Spatial dependency of weed data varied between the Brookings and Moody fields. Differences could be explained by the smaller sampling grid used at the Moody field. To test this hypothesis, every other sampling point in each sampling row was removed from the Moody data set to achieve the same sampling grid as the Brookings field. Semivariograms constructed from half the points of the original data set were not positive definitive and had results similar to the Brookings field. There was little or no spatial dependency among these points on the 30- by 30-m grid for any of the three weed species in either year (Figure 6b). When using all points in the 15- by 30-m grid, the first lag distance of 15 m explained the majority of the variance associated with distance. By removing half the points and increasing the sampling distance to 30 m, about half the variation related to distance was removed and populations appeared to lack spatial dependence (Figure 6b).

These data had high variability in species density and indicate an opportunity for site-specific recommendations. Weed densities have been used in decision aid models to determine whether control measures are needed. Indeed, crop loss caused by different weed densities is reported frequently in the literature. The scale of information used for model input must be evaluated carefully. Clearly, data were skewed in these two fields. For example, field means of about 2 *C. arvense* plants m^{-2} were reported for Brookings in 1995 and Moody in 1996 and may result in a "no treatment" recommendation. However, treatment would be desired in patches that had greater than 10 plants m^{-2} that occurred in more than 10% of the sampling areas.
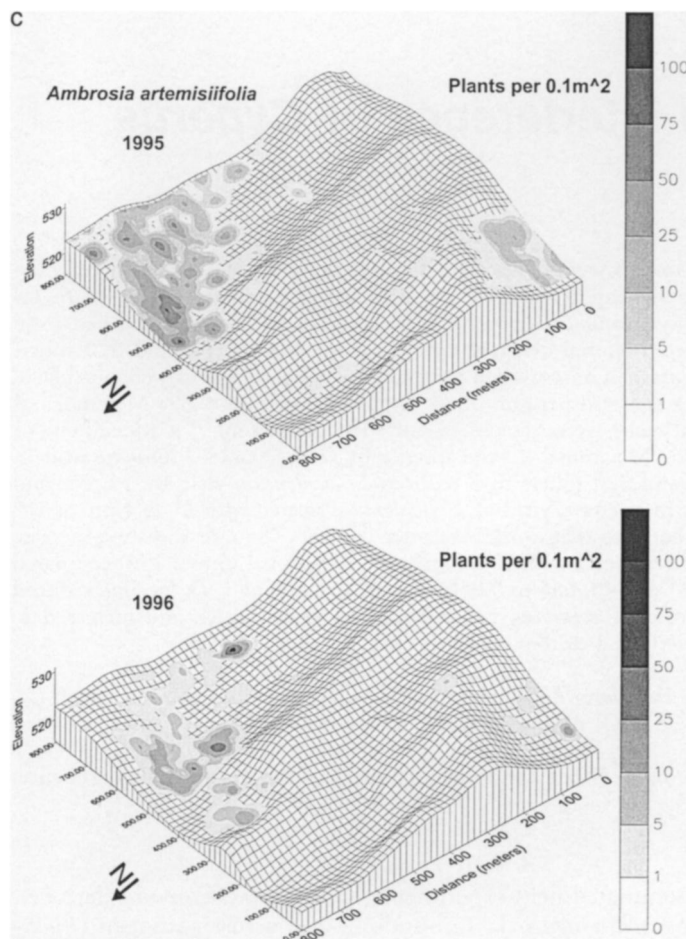
FIGURE 7. Continued.

Accurately locating dense weed populations is problematic because of the high variability and nonuniform weed distributions in production-sized fields. Random sampling results indicated that more than 300 samples were needed to estimate the field average with various levels of accuracy. Using a W pattern with 60 points resulted in mean densities similar to those determined through grid sampling; however, patch locations were missed.

Grid sampling provided information about weed location and densities that could be used as an application guide. Scouting production fields using grid sampling techniques requires a large number of sampling points with closer grid points providing more accurate information (Heisel et al. 1996). However, grid sampling may be impractical in production fields because of the time, cost, and labor required. The information from 0.1 m² areas on a 15- by 30-m grid pattern required 24 hr of labor to collect. Scouting on a 2-ha grid (resulting in < 35 sampling points in a 65-ha field), a grid that is often used for soil sampling, most likely would not result in a map that would have the precision or accuracy needed to confidently recommend site-specific weed management treatments.

Proposed techniques for reducing sampling time requirements for grid sampling include using a presence/absence approach or censored sampling (Johnson et al. 1996). Presence/absence sampling strategy would record the presence of the weed but would give no indication about density. Censored sampling would record the species and density either subjectively (low, medium, or high) or quantitatively using arbitrary cutoff numbers (when to stop counting) designated as the economic threshold value for a given species in the crop.

Source of Materials

Acknowledgments

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