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ANALYSIS OF SPATIAL DISTRIBUTION OF CANADA THISTLE *(CIRSIUM ARVENSE)* IN NOTILL SOYBEAN *(GLYCINE MAX)*

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ABSTRACT

The nonuniform spatial distribution of weeds across a field landscape complicates sampling and modeling, but allows site specific rather than broadcast management of weed populations. Where weeds are aggregated, densities measured at random locations are not independent, but rather spatially related or autocorrelated. Geostatistical methods were used to describe and map nonrandom distribution and variation of shoot density across ten well established patches of Canada thistle, a perennial weed, in a 65 hectare notillage soybean field in Moody county, South Dakota in 1996. Canada thistle densities were determined by counting the number of shoots present in a 20 by 50 cm ($0.1m^2$) rectangle. Shoot densities were recorded at 3.04 m increments in 8 .directions from the center of each patch using adaptive sampling. The boundary of the thistle patch on each axis was arbitrarily defined as having 2 consecutive measurements of 0 shoots per 0.1 m^2.

Contour maps of weed densities were generated and overlaid on field topography maps. A contour map was generated to estimate the size and density of each thistle patch. Generally, the highest densities of Canada thistle appear in the center of the patches. Shoot density within the patches declined as the distance from the center of the patch increased. Near infrared images were generated with a digital camera and compared to weed maps produced with ground scouting.

INTRODUCTION

Environmental and social concerns about pesticide use has led to an interest in more sustainable farming systems with a reduced reliance on pesticides. Current research focusing on integrated pest management practices has demonstrated that a reduction in herbicide use must be accompanied by other control and management technologies to decrease weed infestation level and fitness (16). To date these approaches have been applied uniformly across fields. An alternative approach is to manage with rather than overcome spatial

heterogeneity (16). The importance of spatial distribution in sampling weed populations, modeling population dynamics, and for longterm weed management, has drawn attention to the need for reliable methods to describe and analyze spatial distribution of weeds in the field landscape.

Recent interest in spatial distribution of weeds represents a new direction for weed science with the potential to enhance the understanding of how weed populations develop, persist, and change across the landscape (3). Our ability to precisely determine the location and density of weed patches in the field will provide farmers with technologically superior methods to topographically map weed populations and the ability for more accurate herbicide decisions, which will have both economic and environmental benefits as the herbicides are only applied where required as opposed to blanketing the entire field. Many existing models and management strategies assume weed populations are not spatially structured, but randomly distributed, despite the fact that most fields are managed homogeneously. However, many perennial species such as Canada thistle grow in patches (7).

Canada thistle is a perennial weed with an extensive, spreading root system (4,7). Adventitious root buds arise from its roots to form new secondary shoots. This is the primary method of reproduction for Canada thistle after seedling establishment. The spread of horizontal creeping roots from one parent can result in dense round patches of shoots typically encountered in the field. Roots from one established plant can spread over a circular area of 1020 ft in diameter in one year (6). Many integrated control programs for Canada thistle have been proposed which likely would require 8 to 10 years of effort if implemented properly (8). Control measures need to be repeated in a timely manner to be effective. Increases in Canada thistle densities are greatest under minimum tillage cropping systems due to the fact that tillage disrupts root proliferation (17). There are few published studies of the effects of repeated annual herbicide treatment on Canada thistle patches in notill and how the perimeter and density of the patches change over time (12).

Weed species distribution and density maps may also be used for making decisions on herbicide applications in individual fields. Characterizing spatial distribution of weeds within fields could lead to better herbicide decisions and reduced herbicide use (19). Excess or inappropriate herbicide use reduces profit and may cause unnecessary environmental or health risks as well as unnecessary pressure for the development of herbicide resistant weeds (20). Economic threshold weed densities can be calculated as the lower limit at which herbicide control is cost effective.

Weed seedlings are not uniform, but spatially aggregated in the field (16). Aggregated populations are individual plants occurring in patches of varying density and size with few or no plants occurring between patches (16). Because of the aggregate nature of Canada thistle populations, herbicide cost and environmental degradation may be reduced if herbicide is applied only where weeds are present or exceed some predetermined threshold. Crop yield loss from competition can be predicted from weed density estimates. These data in turn could be used to determine if herbicides are economically practical and to select the best herbicide application strategy when control is required. Crop

loss from weed competition depends on the composition of the weed popula-tion and also its spatial distribution since weeds compete with each other as well as with the crop. Theoretical aspects have been discussed extensively, while little attention has been given to practical aspects, such as determining weed densities (1).

Weed scouting has relied on random sampling to calculate average popu-lation densities as the first step in determining control recommendations (3). Random sampling and estimating populations are appropriate if samples are in-dependent and the variance is uniform throughout the field (3). However, where weeds are aggregated, densities measured at several random locations are not independent, but rather spatially related or autocorrelated (3). Samples obtained close to one another are more similar than samples taken a greater distance apart, meaning the variance between pairs of samples is not uniform.

Methods of spatial statistics can be used to map weed distributions across landscapes and describe variables that are not uniformly dispersed across the landscape. Measured variables, including weed density, are assumed to have spatial relationship with one another. Geostatistics is one method of spatial statistics originally developed for spatial analysis of ore deposits in mining (5) and are now widely used in many earth sciences, including soil and weed sci-ence (7,16).

Geostatistics allows spatial relationships of sampled values for a variable to be used for estimating a value of a nearby unsampled location in preparing contour maps (16). Contour maps of estimated points between measured vari-ables are generated by a process called point kriging. Point kriging is a math-ematical interpolation process which estimates the values of unknown points from the values of known sample points and their distance from one another.

One method of geostatistics is remote sensing. Remote sensing has pro-vided agricultural crop and soil condition information for over 50 years (14). Recently, aerial photography and global positioning system (GPS) technology have been integrated and shown to be useful tools to map weed infestations in cropped areas. The latitude and longitude data provided by the GPS can be entered into a geographic information system (GIS) to georeference weed problems. Everitt et al. (10,11) used airborne videography and GPS technolo-gy to detect weed and brush infestations on rangelands and entered the geo-references data into a GIS to map noxious plant populations over an extensive area. The merging of remote sensing and GIS technologies can be useful to as-sess the extent of weed infestations, develop management strategies, and eval-uate control programs.

Conventional-color or colorinfrared aerial photography can be used for digital image analysis and spectral plant identification (2). The cameras typi-cally used produce high resolution digital images, 0.6 to 2 megapixels per im-age, using ChargeCoupled Device (CCD) photocells (2). These images are con-verted to video format and stored on a compact disk (cd) with up to 50 images per cd. These cameras can acquire up to 10 images per second, so the combi-nation of speed and data storage makes the system flexible for field use.

The objectives of this experiment were: (i) map Canada thistle shoot den-sities and locations of ten established Canada thistle patches; (ii) compare the

location and density of each Canada thistle patch with contour maps generated in the spring of 1996 using extensive coarse grid sampling data, and to maps generated from aerial photography; (iii) determine how accurately this particular sampling method estimates the size and density of the selected thistle patches.

OUTLINE OF RESEARCH METHODS

Ten Canada thistle patches were randomly selected in midSeptember, 1996, from a 65 hectare notill soybean field in Moody county, South Dakota. A center location for each patch was visually estimated and marked with a flag. Shoot density was determined in the center of each patch by counting the shoots present in a 20 by 50 cm (0.1 m²) rectangle. Shoot densities were recorded in 3.04 meter increments in 8 directions from the center of each patch. The outside boundary of the thistle patches on each axis was arbitrarily defined as having 2 consecutive axis measurements of 0 shoots per 0.1 m².

Latitude and longitude coordinates of the center location of each patch were determined using a differentially corrected GPS(Chervils MicroComputer Systems, Chervils, OR). GPS coordinates were converted into meters with the following equation: COS(minimum latitude°/(180)*3.14159))*minimum longitude°(96+37/60+((point longitude°960000)3700)/3600))*60* 1855 (15). The location of each patch in latitude and longitude degrees was converted to coordinate values in meters using the latitude and longitude of the southwest corner of the field as the origin.

Spatial dependence of weed populations was characterized by semivariograms (Fig. 1), calculated using Geoeas, a geostatistical software program. Spherical models were fitted to calculated semivariance values. Semivariograms plot lag (sampling) distances between sample pairs against semivariance statistic for samples at each lag distance. The computing formula for determining semivariance is:

$$Y(h) = \frac{1}{2N(h)} \sum_{i=1}^{N} [Z(x_i) - Z(x_i + h)]^2 \ (18)$$

$Y(h)$ is the semivariance of the variable $Z(x_i)$ with a lag distance of h. $N(h)$ is the number of pairs of points within the lag distance $[h + \Delta(h)]$. For ecological data, such as weed densities, the semivariance is expected to increase as the lag distance increases out to a distance where spatial dependence ceases to be detectable (9). Features of semivariograms that are important for interpretation of spatial data are shown in Figure 1. The nugget, (Co) is the distance on the y-axis from the origin to the y-intercept and is the variability due to experimental error and other random factors. The range is the lag distance at which samples are independent of one another. The value of the semivariance at this point is the sill and is equal to the combination of the nugget and random variability. The percentage of variability (C) explained by spatial dependence is estimated as % variability = C/(Co+C), where Co is the nugget erect and C is the variability due to spatial dependence as described by the distance from the nugget to the sill along the yaxis.

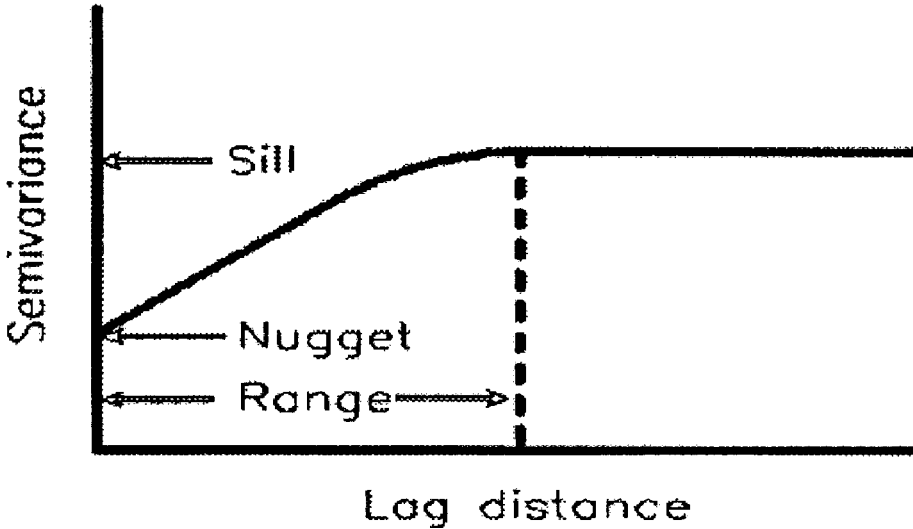Figure 1. Generalized semivariogam

Locations of the ten intensively sampled Canada thistle patches in relation to the entire field which was sampled in a 15 by 30 m grid in the spring of 1996 are shown in Figure 2. A 17 ha portion containing the intensively sampled Canada thistle patches lies inside the rectangle (Fig. 2). The 17 ha fraction of the field containing the 10 mapped thistle patches was enlarged and overlaid on previous coarse grid sampled data (Fig. 3). A contour map of the Canada thistle patches overlaid on a point map of individual sample points is shown in Figure 4. The area of each patch was also determined by estimating the perimeter. The patch sizes ranged from 90 to 1600 m². The total area of the ten patches was approximately 7035 m² (0.7 ha). Point maps were created from sampling point coordinates and transact sampling of the ten thistle patches. The point and contour maps were generated using Surfer₍₎ (13), a contouring and 3-dimensional graphics software program which analyzes geostatistical data. The maps were converted either to feet or meters in relation to the southwest corner of the field. The minimum latitude-longitude coordinate is in the southwest of the field and was converted to 0-latitude and 0-longitude.

Aerial imagery was acquired on October 1, 1996 using a Spectraview digital camera carried on a Piper PA34 equipped with a 15 cm belly hole. Imagery was acquired at a 486 m altitude. A near infrared (782-968 nm) spectral channel was used to determine the weeds present. The raw data for one of the photographs is shown in Figure 5. The image was acquired under sunny conditions around 2:30 p.m. solar time. The GPS latitude-longitude coordinates obtained from digital imagery were integrated with GIS technology to georeference weed populations on a fieldwide basis. The field lies in the center of the aerial image (Fig. 5). The road that borders the south and west edges of the field is light gray. The upper righthand corner of the field in this photo was used as the 0,0 coordinate as the photograph was superimposed on the topography map (Fig. 6.) The ten intensively sampled Canada thistle patches are displayed in the small squares.
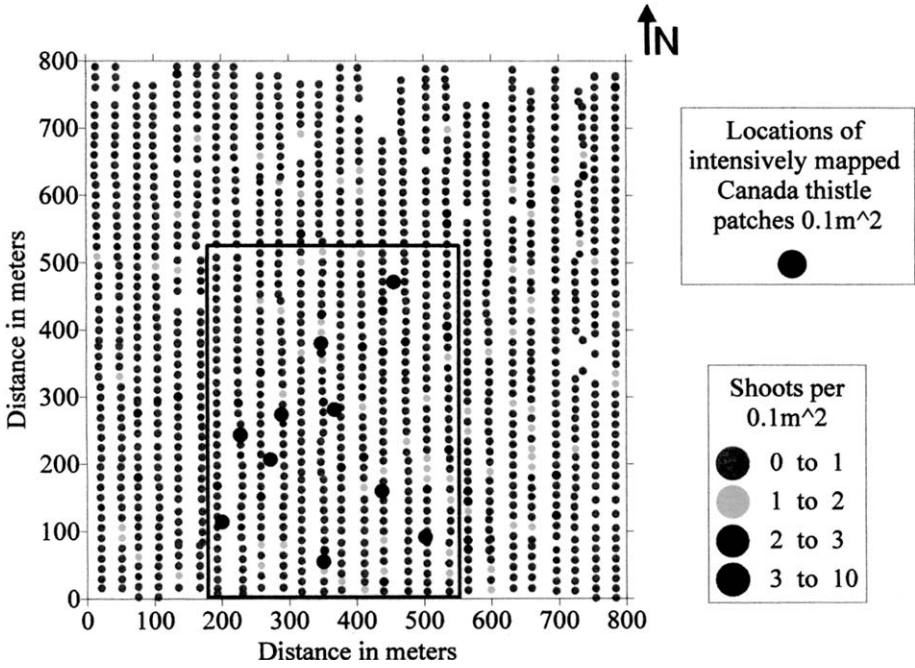
Figure 2. 1300 grid sampled points and 10 intensively mapped Canada thistle patches.
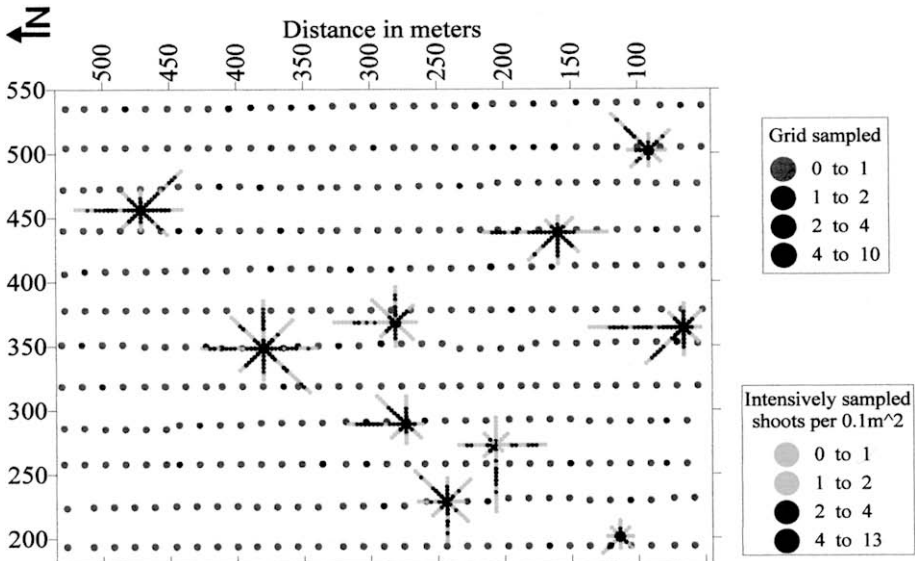

Figure 3. Intensively sampled Canada thistle patches overlaid on 17 ha grid sampling.
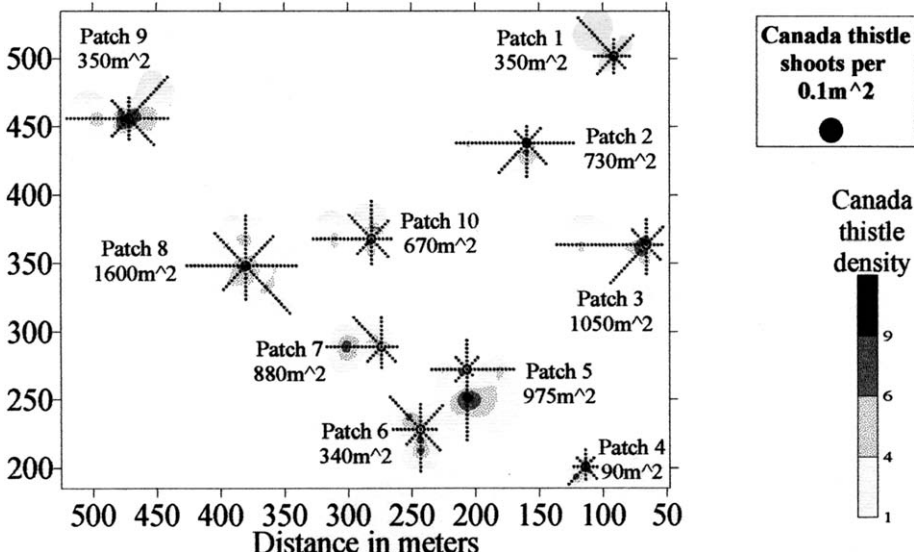
Figure 4. Contour map of 10 sampled Canada thistle patches overlaid on individual sampling points.

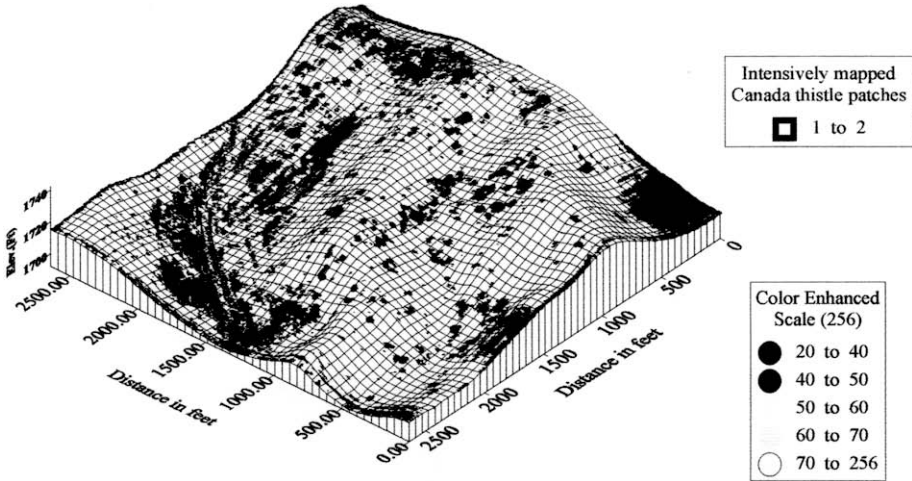Figure 5. Near infrared photograph superimposed on a topography map.

Figure 6. Near infrared photograph superimposed on a topography map.

The latitude-longitude coordinates of the four corners of the field were previously determined with a GPS receiver. The data in the aerial image was reduced by sorting the latitude-longitude points from the aerial image and eliminating the points outside the field perimeter. Each of over 60,000 points in the digital image was designated a number from 0 to 256 based on reflectance. Colors (red, yellow, etc.) were assigned to these points in Surfer®.

RESULTS AND DISCUSSION

Semivariogram functions relate the variance of each variable to the sampling distance intervals between the pairs of values at increasing distances from one another at sampling points (7). Graphs of semivariance verses lag distance are usually used to establish whether known variables have spatial dependence and at what lag distance the values become independent of one another (7). Variogram functions indicated that four of the ten patches exhibited strong spatial dependence at lag distances less than 20 meters. These lag distances are the "sills" of the variograms. The sill is the plateau value of the variogram function and is the lag distance between measurements at which one value is not spatially related to neighboring values (7). Lag distances beyond the sill value are not spatially related. Variogram functions showed that 6 of the 10 patches did not display spatial dependence at the lag distances modeled. This suggests that the samples were collected too far apart or that a different sampling method should be used to determine if spatial dependence is present.

In the spring of 1996 the entire field was intensively sampled on a 15 by 30 m grid. A point map of Canada thistle density across the entire field according to coarse grid sampling is shown in figure 2. The large black dots point out where the ten random patches were sampled in the fall of 1996. It appears that only 6 of the 10 patches mapped in the fall overlay on a patch mapped

the previous spring because many of the patches fall between the 1336 grid sampled points. This indicated that to accurately map weed species present across an entire field, an adaptive sampling method should be implemented to avoid weed patches present between grid sample points. This adaptive process should sample only areas of the field where weeds exist to maximize sampling efficiency.

Generally, the highest densities of Canada thistle shoots were in the centers of the patches (Figs. 3 & 4). Shoot density within the patches declined as the distance from the center of the patch increased. Many of the patches appeared to be larger in the north-south direction than in the east-west direction possibly due to the notill cropping practices. The field is combined in a north-south direction which distributed weed seeds in a similar pattern.

Figures 5 and 6 show aerial digital images of weed infestations in the 65 ha field in the raw and topographically superimposed forms, respectively. The aerial image was acquired on October 1, 1996, which was about 1 week prior to the first killing frost. Most of the leaves on the soybean plants were brown and thus not transpiring or photosynthesizing. The near infrared wavelengths in the digital camera detect transpiration or water loss by plants. Since the soybeans had reached physiological maturity they were not carrying on transpiration and appeared a lighter color in the image. The weeds were still green and transpiring, showing up as a darker color on the images. The weeds have a conspicuous brown-red color that can easily be distinguished from soybean plants and bare soil. Integration of the latitudelongitude coordinates with the digital image was useful to georeference weed populations over the entire field.

Geostatistics can be used to map spatial distribution of weeds in a field. Variograms provide the ability to test whether or not the variables exhibit spatial dependence. In this type of research, sample spacing is important and may not have been optimum for sampling the Canada thistle shoots in this experiment. Better kriged maps may have been developed if the patches had been intensively grid sampled instead of sampled in transects. By sampling in transects, the center of the patches are mapped very accurately because the transects come together at the centers of the patches. However, as the sampling points moved away from the center, the sampling points on the axis become farther away from each other which leaves more unsampled area between the transects. By grid sampling the entire patch there is less unsampled area between each sampling point. In this particular field, geostatistics can be used to analyze how weed control treatments change weed distribution and densities across landscapes over time.

Site-specific weed management can improve our knowledge of the factors influencing the location and densities of weed patches across a field. An understanding of these factors will aid in selecting appropriate weed management strategies that decrease the presence of weeds. These management strategies may lead to reductions in herbicide use and increased profitability as well as reduce negative environmental impacts.

ACKNOWLEDGMENTS

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