Iranian Journal of Weed Science,(2007)Vol 3, No. 1& 2, 1-21

Characterizing Distribution and Stability of Purple Nutsedge Population Using Geostatistics over two Growing Seasons

E. Mohammadvand, M.H. Rashed Mohassel, M. Nasiri mahallati and N. Pour tousi

Department of Agronomy, Faculty of Agriculture, Ferdowsi University, Mashhad, Iran

(Received 18 Agust 2008; returned 3 November2008; accepted 24 January 2009)

ABSTRACT

Distribution and stability of purple nutsedge (*Cyperus rotundus*) population within four fields under corn-fallow rotation were analyzed over two growing seasons in 2005 and 2006 at the Agricultural Research Station of Ferdowsi University, Mashhad, Iran. In 2005, N-fertilizer (urea) was applied at two different application methods (whole and split application). As a result of applying or not applying herbicide (a mixture of 2,4-D and MCPA) on the fields under the same N-fertilizer management, four treatments including N(whole)-herb, N(whole)- no herb, N(split)-herb and N(split)- no herb were assigned to four fields. In 2006, the field was kept under fallow. In both years, samplings were conducted at the same points (intersections of 2.5 m^{-2} grids) and dates (three times). Geostatistical techniques were used to examine the data. Purple nutsedge density was higher in corn fields than the fallow condition, with average densities of 51.73 and 19.61 plants m^{-2}, respectively. In

Correspondence to: E. Mohammadvand; E-mail: el_mo19@stu-mail.um.ac.ir

both years, the mean density of purple nutsedge was higher in fields with whole application of N-fertilizer compared with split application. Spherical and Exponentialmodels indicated strong or moderate spatial autocorrelation. Spatial distributions were found to be heterogeneous, with high-density patches and areas at lower density. The distribution pattern of purple nutsedge densities indicated that patch-level ‘spatial aggregation’ existed. Despite fluctuation in margins, spatial stability was observed for purple nutsedge patches. This suggests that purple nutsedge would be a good candidate for site-specific application; however more practical experiments are needed to confirm this issue.

Keywords: Purple nutsedge, Site-specific management, spatial dynamic, spatial distribution, kriging.

چکیده:

توزیع مکانی و ثبات جمعیت علف هرز اویارسلام‌ارغوانی(*Cyperus rotundus*) در چهار قطعه زمین تحت تناوب ذرت–آیش طی دو فصل رویش سالهای ۱۳۸۴ و ۱۳۸۵ در مزرعه تحقیقاتی دانشکده کشاورزی دانشگاه فردوسی مشهد مورد بررسی قرار گرفت. در سال ۱۳۸۴، کود نیتروژن (اوره) به دو روش مختلف (کاربرد یکباره و تقسیط شده) به کار رفت. در نتیجهٔ کاربرد یا عدم کاربرد علفکش (مخلوط توفوردی و ام‌سی‌پی‌آ) در قطعاتی که مدیریت نیتروژن در آنها یکسان بود، چهار تیمار در چهار قطعه زمین اعمال شد. در سال دوم قطعات تحت آیش بودند. در هر دو سال، نمونه برداری در نقاط (سیستم شبکه ای ۲/۵ متر* ۲/۵متر) و زمانهای (سه نوبت) مشابهی صورت گرفت. تکنیک های آمار مکانی برای ارزیابی داده ها مورد استفاده قرار گرفت. جمعیت اویارسلام‌ارغوانی در زراعت ذرت با میانگین تراکم ۵۱/۷۳ بوته در متر مربع بیشتر از سال آیش با میانگین تراکم ۱۹/۶۱ بوته درمترمربع بود. طی هر دو سال میانگین تراکم اویارسلام‌ارغوانی در قطعاتی که نیتروژن به صورت یکجا به کار رفته بود، بیشتر از قطعاتی بود که کود به صورت تقسیط شده به کار رفته بود. مدلهای کروی و نمایی سمی واریوگرام وجود همبستگی مکانی متوسط تا قوی درتمام فصل رشد را نشان دادند. توزیع مکانی در قطعات غیریکنواخت بود و لکه هایی با تراکم بالا و قسمتهایی با تراکم پایین مشاهده شد. الگوی توزیع مکانی اویارسلام‌ارغوانی نشان داد که تجمع مکانی در سطح لکه وجود دارد. علیرغم وجود نوساناتی در حاشیهٔ لکه ها، ثبات مکانی در لکه ها قابل مشاهده بود. نتایج این پژوهش نشان دادند که اویارسلام‌ارغوانی می تواند علف هرز مناسبی جهت کاربرد متناسب با مکان علفکش باشد.

INTRODUCTION

To evaluate the need for control measures and the response of weed populations to cultural practices and environmental variables, managers need realistic descriptions of weed populations (Cardina *et al*., 1997). Most weed population have been found to be distributed heterogeneously in time and space within agricultural fields (Wiles *et al*., 1992; Cardina *et al*., 1995; Johnson *et al*., 1996; Gerhardes *et al*., 1997; Dieleman & Mortensen, 1999; Gerhards & Oebel, 2006). They often occur in aggregated patches (Jurado-Exposito *et al*., 2004; Gerhards & Oebel, 2006; Clay *et al*., 2006; Makarian *et al*., 2007; Loghavi *et al*., 2008) of varying sizes or in stripes following the direction of cultivation (Gerhards & Oebel, 2006)., Due to persistent propagule banks and limitation of seed dispersal to short distances, they tend to cluster where conditions such as nutrient and soil moisture are favorable (Colbach *et al*., 2000). The majority of seeds are dispersed close to their source (< 2 m) (Rew & Cussans, 1995), enhancing patchiness. Patchiness is also enhanced with persistent seed or propagule banks (Dieleman & mortensen., 1999). Paice & Day (1997) described the impact of temporal variation in herbicide efficacy and reasoned that this may also increase patchiness.

Gerhards *et al*. (1997) defined a patch as ‘a continuous infestation in which neighboring cells (of a sampling grid) contained seedling densities greater than zero’. Spatial aggregation has been demonstrated for individual shoots in perennial weed patches (Donald, 1994, Webster & Cardina, 1998, Horowitz, 1973). Budhathoki (1997) concluded that perennials were more clustered than annuals.

A weed patch is considered stable if it is consistent in density and location over time (Rew & Cussans, 1995; Gerhards *et al*., 1997). To evaluate the dynamics of spatial distributions and to assess how stable these distributions are, the simplest and most common way is to compare successive maps visually (Rew & cousins, 2001). Chancellor (l985) showed that some species moved little, whereas others showed sudden range expansions which he interpreted as a result of sowing with contaminated crop seeds. Stability may be attributed to large seed size, local dispersal before crop harvest and long seed bank life (Lueschen *et al*., 1993; Burnside *et al*., 1996). Patches can be stable perpendicular to the direction of tillage (Johnson *et al*., 1996) and more stable under no-tillage system than plough or disk cultivation (Cardina *et al*, 1996). The relation between field infestation level and weed seedling density can contribute to a stable weed population. *Abutilon theophrasti* population was stable where less than 50% of the observations were free of weeds and the majority of the infested sample sites had an average of more than 2 seedlings in 0.38 m^{-2} (Wyse-pester & Mortensen, 1996). The relative importances of demographic processes that confer persistence probably differ among weed species and depend on the crop and weed management system in which they arise (Dieleman & mortensen., 1999). Clay *et al* (2006) found that grass patches were more stable in time, space, and density than common ragweed patches. Annual variability in total seed production is expected to cause patches to expand in years of high production and to contract in years of low production (Lutman *et al*., l998). Recent studies have shown that more seedlings survive after applications of pre- and post-emergence herbicides in high- rather than low-density populations (Dieleman *et al*., 1999), which may contribute to persistence (Dieleman & mortensen., 1999). Dieleman *et al*., l999 found that dense patches will be more stable over time than sparse ones, because by chance a small sub-population of plants will more often be completely eliminated by a herbicide than a large sub-population.

Stability is important from the patch management perspective, such that a patch map from one year can be used to direct weed control in subsequent years (Lutman *et al*., 1998; Mortensen *et al*., 1998). Currently, seedling maps are still the most practical approach to target management efforts (Cardina *et al*., 1996). To create a map of weed occurrence and density from the discrete data, geostatistics are currently used. Geostatistics are centered on modeling and interpreting the semivariogram, which is used to describe the relationship between variables at several discrete distance intervals. Semivariogram models provide the necessary information for interpolating the data at unsampled points (Rew *et al*., 2001). Krigings is an interpolation procedure which is used to describe the distribution of weeds (Donald, 1994; Cardina *et al*., 1996; Makarian *et al*., 2007), to create weed treatment maps for patch-spraying (Heisel *et al*., 1996; Makarian *et al*., 2007), and to study the stability of patches between years (Johnson *et al*., 1996). There are variable possible reasons for the existence of stable patches. Understanding the basic principles of patch dynamics is important and will help to predict future distribution patterns, as well as the implications of site-specific management in the long term (Rew & Cousins, 2001).

The objectives of this study were to survey patches of purple nutsedge, describe their spatial pattern, monitor the dynamics of patches over time, and create weed distribution maps in a field of corn-fallow rotation during two successive years.

MATERIALS AND METHODS

Site Description

An intensive field survey of weed populations was conducted in four fields of corn-fallow rotation in 2005 and 2006 at the Agricultural Research Station of Ferdowsi University, Mashhad, Iran (35˚15′N, 59˚28′E). The soil characteristics of the area were silty loam with a pH of 7.8. The mean annual rainfall was 286 mm, minimum and absolute maximum temperatures were -27.8˚C and 43˚C, respectively. Two years before the beginning of the study, the field was under winter wheat (2003) and fallow (2004).

Management Practices

A field, approximately 40 m wide (Northern East-Southern West) and 50 m long (Northern West-Southern East), was selected, moldboard plowed (20 cm deep), disked (10 cm deep) once, and was divided into four smaller fields of 10 m wide (Northern West-Southern East) and 30 m long (Northern East-Southern West). First year in mid-May, the field was planted manually with 'single cross 704' corn cultivar, at a density of 66000 plant ha^{-1} in rows 75-cm apart going Northern East and Southern West. Two seeds were sown (5-7 cm deep) into hills with 20 cm apart and thinned at the four-leaf stage of corn. In 2005, N-fertilizer (urea) was applied at two different application methods, consisting of 120 kg ha^{-1} N-fertilizer at the same time of corn planting and equal split application at the time of corn planting and at the six-leaf stage. As a result of applying or not applying herbicide on the fields under the same N-fertilizer management, four treatments including N(whole)-herb, N(whole)-no herb, N(split)-herb and N(split)-no herb) were assigned to four fields. In related plots, N-fertilizer was stripped immediately after sowing and post-emergence herbicide including a mixture of 2,4-D and MCPA was sprayed with 1 kg ai ha^{-1} (533 g ai ha^{-1} of 2,4-D plus 467 g ai ha^{-1} of MCPA) at the six-leaf stage of corn. After harvesting, the fields were moldboard plowed (20 cm deep), disked (10 cm deep) and kept in fallow without any further practices.

Weed Sampling Methods

All weed species were identified and counted within a $0.25m^2$ quadrate (0.5 x 0.5 m) at the intersections of 2.5 x 2.5-m grids, established over each field, providing 33 sample points. Directly after corn planting, sampling points within each field was flagged for locating throughout the growing season as permanent markers in first year. The points were relocated and reflagged in second year. So the sampling points in two years were the same and weed density by species was obtained at the same locations each year. Weeds were sampled three times (23 days interval) during growing season in 2005. The first samples were taken before fertilizer and herbicide application in related plots (June 23rd). Similarly, in 2006, the same dates of sampling were applied.

As purple nutsedge was the only dominant weed in the second year, this species was selected for characterizing spatial structure and stability of its patches in this study.

Data analysis

Summary Statistics.

At each sampling site data were converted to ground area unit. Then summary statistics were calculated for purple nutsedge (Table 1).

Data Transformation.

Since data of weed density were positively skewed, log(z+1) transformation was used in subsequent analysis (Colbach *et al*., 2000) and data were detrended by a median polishing procedure as described previously by Cardina *et al*. (1995).

Empirical Semivariograms.

Within each year, spatial autocorrelation between sample sites was analyzed using semivariance statistics (Cardina *et al*., 1995):

$$y(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(x_i) - Z(x_i + h) \right]^2 \qquad (1)$$

where, $y(h)$ is the empirical semivariance for sample sites separated by distance h, $Z(x)$ and $Z(xi+h)$ are purple nutsedge density at points x and $xi+h$, and $N(h)$ is the number of pairs of sample sites separated by distance h. Semivariograms are plots of semivariance against distance (h) between pairs of sample points (Cardina *et al*., 1995). All pairs of points separated by distance h in each plot were used to calculate the value of $y(h)$.

Fitting Models to Semivariograms.

A model was fitted to the semivariogram and the parameters from the model were used in the estimation of weed maps by kriging. In each case, the weed data was best fitted to either a spherical or an exponential model (Johnson *et al*., 1996; Goudy *et al*., 2001; Heisel *et al*., 1996).

Interpolation Using Block Kriging and Weed Mapping.

Kriging was used to provide estimates of purple nutsedge density by year at unsampled locations across the fields. Kriging is an interpolation technique that estimates the value of an attribute, z, at unsampled locations in the field based on available data at neighboring locations and semivariogram model parameters (Colbach *et al*.,2000). Kriging was performed; the resulting data was back-transformed into density (seedlings m^{-2}), and contour maps were constructed.

Computer Program.

The software package Gs+ was used to construct semivariograms, and also for kriging, and mapping procedures (Anonymous, 1994).

In this study, kriging method was used to investigate the spatial distribution and stability of purple nutsedge population over the course of two growing season and providing a visual representation of the spatial arrangement of this weed population. Only aboveground demographic parameters which are most likely to be influenced by management were estimated.

RESULTS AND DISCUSSTION

Spatial Description.

As expected, mean and maximum density of purple nutsedge within a given field varied across sampling times (Table 1). Weed densities among sampling times may be influenced by herbicide application, type and timing of management inputs, environmental conditions, and the biology of each weed species (Cardina *et al*., 1997). In 2005 the highest mean density of purple nutsedge occurred in the second (N (split)-no herb) and third (N (whole)-no herb and N(split)-herb) sampling times. This may be occurred following the temperature increase as the growing season proceeded. However, with N(whole)-herb treatment, it seems that herbicide reduced mean density of purple nutsedge and therefore its highest mean density was observed in first sampling time. At the second sampling time, herbicide application slightly reduced purple nutsedge density in related fields

(N(whole)-herb and N(split)-herb); while, in the other fields (N(whole)-no herb and N(split)-no herb) its density increased (Table 1). Clearly, chemical control had no effect on the control of purple nutsedge. In 2005, the mean density of purple nutsedge for fields with whole and split application of N-fertilizer was recorded 68.10 and 35.35plm^{-2}, respectively. It seems that high level of soil fertility at the planting time causes high level of purple nutsedge emergence.

Table 1. Summary statistics for population data of purple nutsedge

Treatment[a]	Sam-pling time[b]	Mean density		Maximum density		Weed-free Sampling units	
		2005	2006	2005	2006	2005	2006
		plm^{-2}					
N(whole)-herb	1	69.33	33.58	248	88	9.09	18.18
	2	59.76	28.24	180	80	24.24	21.21
	3	56.36	24.61	160	80	15.15	12.12
N(whole)-no herb	1	62.18	24.73	464	132	21.21	15.15
	2	78.42	19.39	208	76	3.03	33.33
	3	82.55	17.82	220	72	12.12	27.27
N(split)-herb	1	30.79	13.09	124	80	24.24	24.24
	2	28.61	11.76	120	60	33.33	18.18
	3	42.30	12.24	180	88	24.24	18.18
N(split)-no herb	1	25.70	19.39	84	52	18.18	9.09
	2	43.52	14.67	176	60	18.18	21.21
	3	41.21	15.76	220	76	21.21	15.15

[a] **Treatment** application of 120 kg ha^{-1} N-fertilizer as whole at the time of corn planting with (N(whole)-herb) and without (N(whole)-no herb) application of herbicide*; equal split application at the time of corn planting and at the six-leaf stage with (N(split)-herb) and without (N(split)-no herb) application of herbicide.

[b] **Sampling time** 1st:before fertilizer and herbicide application in related plots(June 23rd); 2nd: after fertilizer and herbicide application in related plots (July 16th); 3rd: twenty three days after second sampling (August 8th).

* A mixture of 2.4.D and MCPA, sprayed with 1 kg ai ha^{-1} at the six-leaf stage of corn.

In 2006, the highest mean density of purple nutsedge was observed in the first sampling time in all fields. It seems that due to shortage of water and fertility arising from fallow condition, the mean density decreased moderately during the growing season. Also, the mean purple nutsedge density was higher in fields with whole application of N-fertilizer than those with split application. Regarding fallow condition in the second year of the experiment, it seems that higher population of purple nutsedge in previous year (2005) has resulted in higher reproduction of tubers leading to higher densities in the next year. The differences between population and variations within fields were presumably caused by differences between indigenous weed populations interacting with soil conditions and previous management system (Legendre & Fortin, 1989).

Comparing sampling times and fields indicate that purple nutsedge population was higher in 2005 when the fields were in corn, with average density of 51.73 plants.m^{-2}; however, in 2006, when the fields were under fallow, the average density was considerably lower (19.61 plm^{-2}). The highest mean density (82.55 plm^{-2}) occurred in with N(whole)-no herb (third sampling time, 2005), and the lowest mean density (11.76 plm^{-2}) was recorded for N(split)-herb (second sampling time, 2006) (table 1). In the first experimental year, higher levels of fertility (irrigation and fertilizer) resulted in higher emergence level of purple nutsedge. Over the three survey dates and fields, purple nutsedge occurred in 81.31% of the quadrates in 2005; however, in 2006, the average density was reduced, but the percentage of quadrates occupied by purple nutsedge remained almost unchanged and value of 80.56% was recorded (Table 1). Weed-free sampling units ranged from 3.03 to 33.33 % and 9.09 to 33.3% in 2005 and 2006, respectively (Table1).

Semivariogram Parameter Analysis.

Anisotropic calculations showed no improvements as compared with isotropic conditions, therefore isotropic conditions were chosen and the semivariogram models used were isotropic, which are independent of direction. Semivariograms were plotted and corresponding spherical or exponential model parameters were calculated for them (Table. 2). A representative spherical semivariogram related to N(whole)-herb (second sampling time) treatment in 2005 with a nugget of 0.25 is shown in figure 1. This parameter indicated sampling error and unresolved variation at a smaller scale than 2.5 m. As distance between pairs of samples increased, the variance between them increased up to 14.98 m (i.e. range). Thereafter, the semivariance leveled off, indicating that density data obtained from sites more than 14.98 m apart at field were essentially not related (Figure 1). Therefore, in sampling to estimate the average weed density in this field, the distance between sample sites should exceed 14.98 m to avoid spatial correlation among samples. Observations are correlated when the separation distance is less than the range of the semivariogram model. If the goal of sampling is to determine population density, samples should be taken at distances greater than the range, since this is the distance at which observations are uncorrelated. If kriging is the goal of sampling, then observations should be taken at a distance less than the range (Cardina *et al*., 1995). The sill minus the nugget effect was 1.078, representing the fraction of the variance that is spatially structured. Dividing this value by the value of the sill indicated that about 81.05% of the variations in the data were attributable to distance between samples sites.

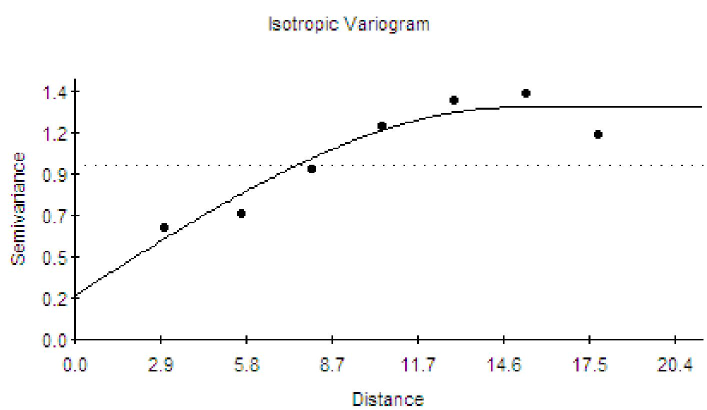

Figure 1. Spherical semivariogram related to first sampling time of T2 in 2005

Semivariogram parameters strongly varied among survey dates and fields, and also between years (Table 2). This variability might be in case of heterogeneity of propagule distribution in the soil, differences in topography, edaphic factors, soil treatments, etc.

The semivariogram in both years indicated spatial autocorrelation, with the nugget values ranging from 0.001 to 0.581 and 0.001 to 0.281 compared to sills varying from 1.03 to 3.03 and 0.98 to 2.15 in 2005 and 2006, respectively (Table 2). As shown in Table 2, the nugget effect was greater than zero in all cases, which means that observations separated by small distances were not similar (Isaaks & Srivastava, 1989; Johnson *et al*., 1996). This dissimilarity may result from seed dispersal, germination, and mortality events that occur at scales smaller than 2.5 m or may simply be the result of sampling error (Johnson *et al*., 1996). For all sampling times of all fields in both years, with an exception (second sampling time of N(split)-no herb, 2005), data indicated strong autocorrelation, with the ranges from 2.37 to 46.26 m and the percentage of autocorrelation was from 50% to 99.92% (Table 2). The percentage of autocorrelation is the percentage of variation over the range that is explained by distance and also is known as the structural variability of the weed density. Large range of spatial dependence may have been a result of spread of weed seeds by previous tillage or harvesting equipment (Cardina *et al*., 1995). Spatial dependence might be influenced by interactions of weed biology, local micro environmental conditions, and agricultural practices (Wyse pester *et al*., 2002).

Iranian Journal of Weed Science,(2007)Vol 3, No. 1& 2, 1-21

Table 2. Estimated parameters for the semivariogram models for purple nutsedge for both 2005 and 2006**.**

Treatment[a]	Sam-pling time[b]	Model[c]		Nugget effect		Sill		Range(m)		Spatial autocorrelation	
		2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
N(whole)-herb	1	Sph	Sph	0.060	0.028	2.23	2.07	31.52	27.87	97.31	98.65
	2	Sph	Sph	0.252	0.024	1.33	2.06	14.98	28.82	81.20	98.83
	3	Sph	Sph	0.225	0.072	1.77	2.15	24.27	30.77	87.01	96.65
N(whole)-no herb	1	Sph	Sph	0.072	0.158	1.11	1.36	5.10	14.49	93.69	88.38
	2	Sph	Sph	0.159	0.036	1.03	2.08	3.72	29.71	84.47	98.27
	3	Exp	Sph	0.512	0.281	3.03	1.14	46.26	11.59	83.17	75.35
N(split)-herb	1	Sph	Sph	0.001	0.001	1.29	1.03	10.36	2.95	99.92	99.90
	2	Sph	Sph	0.001	0.044	1.26	1.02	9.70	2.95	99.92	95.69
	3	Sph	Sph	0.138	0.001	1.21	1.03	10.31	3.05	88.43	99.90
N(split)-no herb	1	Exp	Sph	0.269	0.163	1.08	0.98	2.37	4.52	75.09	83.37
	2	Sph	Sph	0.581	0.128	1.16	1.00	15.38	4.71	50	87.20
	3	Sph	Sph	0.183	0.080	1.03	1.02	3.87	5.51	82.52	92.16

[a] **Treatment** application of 120 kg ha^{-1} N-fertilizer as whole at the time of corn planting with (N(whole)-herb) and without (N(whole)-no herb) application of herbicide*; equal split application at the time of corn planting and at the six-leaf stage with (N(split)-herb) and without (N(split)-no herb) application of herbicide.

[b] **Sampling time** 1st:before fertilizer and herbicide application in related plots(June 23rd); 2nd:after fertilizer and herbicide application in related plots (July 16th); 3rd:twenty three days after second sampling (August 8th).

[c] **model** Sph: Spherical; Exp: Exponential.

* A mixture of 2.4.D and MCPA, sprayed with 1 kg ai ha^{-1} at six-leaf stage of corn.

Semivariogram model parameters were then used in kriging to provide estimates of purple nutsedge density at unsampled locations. Maps of kriged estimates provide a visual representation of the arrangement of the population.

Weed Mapping.

The results of kriging were transformed to the original scale and presented as grey-scale maps in Figures 2-5. Contour maps were used to visually compare the spatial and temporal distribution and stability of purple nutsedge population. Weeds interact with the environment that is variable in both space and time. They "sample" space through dispersal, and time through dormancy (Levin, 1992). Therefore, the interaction of weed population processes over space and time helps to determine how weed populations change in response to management (Cardina *et al*., 1997).

A visual assessment reveals strong spatial dependence, which is supported by the semivariogram analyses (with an exception of moderate spatial dependence in second sampling time of N(split)-no herb in 2005). Spatial distributions were found to be heterogeneous, with high-density patches and also areas with lower density. Single or multiple focal points of high density were observed within each field. Weed density was high in the center, decreasing gradually (sometimes abruptly) toward the edges. The distribution pattern of purple nutsedge densities indicated that patch-level 'spatial aggregation' existed and all the maps generally indicated patchy distributions. Shoot densities of perennial species tended to be high in the patch center and decreased towards the edges (Donald, 1994). Explanations for the patchiness of weeds include intrinsic demographic factors (seed or vegetative reproduction, in- or out-breeding), edaphic factors (influence of soil type, drainage), management factors (cultivation, harvesting) and interactions between organisms (plant:animal, plant:plant and plant:pathogen) (Cousens & Croft, 2000). It is likely that localized dispersal coupled with the creation of a persistent spatially patterned propagule bank are demographic processes contributing to the observed spatial pattern.

Spatial distribution varied considerably among fields. At the first year of study, patches with higher central density were observed with whole application of N-fertilizer (N(whole)-herb and N(whole)-no herb) comparing with split application. Nevertheless, patchy distribution was obvious in all treatments. Higher effects of the N(whole)-herb herbicide application treatment on the central part of the patch and besides decreasing the mean density results in a new patch center. With N(split)-herb application treatment, the patch center did not involve in much movement, but expansion of the patch was limited. In the fields without application of herbicide, expansion of the patches was observed and mean density increased. Variability in distribution of purple nutsedge over fields mainly reflected the dispersal process and the distribution of 'safe sites'. Dispersibility is in turn a property of the propagule itself (size, shape, possession of wings and plumes) in combination with ecosystem vectors (wind, water currents, animals) and with human-mediated dispersal processes (crop sowing pattern, tillage system, harvesting) (Ghersa & Roush, 1993). The safe-site distribution is influenced by the microtopography of the soil surface, depending on the tillage system adopted and the various seed adaptations that may improve their chances for acquiring resources or being buried in the soil. The distribution of safe sites can cause spatial variability even when seeds are homogeneously distributed (Van Groenendael, 1988). In general, chemical weed control does not have much effect on spatial structure of purple nutsedge. Patch survivorship was ensured in the face of applied weed control because of persistent high-density patch centers. In 2006, as a result of low level of fertility due to fallow conditions, patchy structures that were made in the early growing season were contracted during the growing season, but patch centers were kept. In some years, it is expected that reduced intensity and efficacy of weed control practices in combination with high weed densities could result in more survivors in patch centers that would contribute to increasing seeds into the seedbank (Dieleman *et al*., 1999) or propagules to propagule bank. Despite differences in spatial dependence of purple nutsedge over fields, there was a large area of no or low seedling density in all of them, indicating inefficiency of herbicide application for weed control. Improvements in weed control could be achieved by adjusting intensity and placement of tactics with respect to seedling density distribution and orientation of weed patches.

The stability of purple nutsedge patches could be visually followed through maps. Despite fluctuations in margins, spatial stability of high-density focal points was observed for purple nutsedge patches across the three survey dates in each year (Figure 2-5). Patches of purple nutsedge with N(whole)-herb and N(whole)-no herb make a move to upper parts of the field. Continuity among patches was decreased with N(split)-herb and N(split)-no herb, and several separate patches were seen in the fields. Harvesting practices followed by cultivation possibly resulted in the movement of patches. Nevertheless, patches of purple nutsedge were found to be almost stable over 2 years. Location stability of purple nutsedge patches was probably the result of a spatially patterned and persistent propagule bank. The issue of patch stability is very important to the success of site-specific applications (Goudy *et al*, 2001), because the usefulness of the infestation maps obtained with kriging for improving the decision-making process is strictly dependent on weed patch dynamics (Zanin *et al*. 1998). If patches expand or the location shift from year to year, the cost of creating expensive weed maps every year may outweigh the economic benefit of site-specific applications (Goudy *et al*, 2001). It is assumed that developing accurate weed maps will be a costly aspect of site-specific herbicide applications; therefore, if patches remain relatively stable in a field over years, farmers could then use the same weed maps for several years without having their fields remapped annually. Taking advantage of these weed population characteristics is critical to the success of future weed management strategies which aims to reduce herbicide amount and cost. Therefore, processes (both abiotic and biotic) that give rise to patterned distributions must be evaluated in order to adjust management practices to address this variability (Cardina *et al.,* 1995; Johnson *et al*., 1996).

The results of this study demonstrate that purple nutsedge populations were not random; they were spatially structured in a way that can be described mathematically. Also the results confirmed stability of purple nutsedge patches. Therefore, we expect that this weed would be a good candidate for site-specific management issues; however more practical experiments are needed to confirm this issue.

REFERENCES

Anonymous,1994. GS+: Geostatistics for the Environmental Sciences. Version 2.3. Plainwell, MI: Gamma Design Software. 44p.

Budhathoki, C.B. 1997. *A spatial study of seven weed species in arable crops*. MSc. Thesis. University of Reading, Uk.

Burnside, O.C., Wilson, R.G., Weisenberg, S. & Mubbard, K.G. 1996. Seed longevity of 41 weed species buried 17 years in eastern and western Nebraska. *Weed Science* **44**:74-86.

Cardina, J., Sparrow, D.H. & McCoy, E.L. 1995. Analysis of spatial distribution of common lambsquarters (Chenopodium album) in notill soybean (Glycine max). *Weed Science* **43**:258–268.

Cardina, J., Sparrow, D.H. & Mccoy, E.L. 1996. Spatial relationships between seedbank and seedling populations of common lambsquarters (*Chenopodium album*) and annual grasses. *Weed Science* **44**:298–308.

Cardina, J., Johnson, G.A. & Sparrow, D.H. 1997. The nature and consequence of weed spatial distribution. *Weed Science* **45**:364-373.

Chancellor, R.J. 1985. Changes in the weed flora of an arable field cultivated for 20 years. *Journal of Applied Ecology* **22:**491-501.

Clay, S.A., Kreutner, B., Clay, D.E., Reese, C., Kleinjan, J. & Forcella, F. 2006. Spatial distribution, temporal stability, and yield loss estimates for annual grasses and common ragweed (Ambrosia artimisiifolia) in a corn/soybean production field over nine years. *Weed Science* **54**:380–390.

Colbach, N., Forcella, F. & Johnson, G.A. 2000. Spatial and temporal stability of weed populations over five years. *Weed science* **48**:366-377.

Cousens, R. & Croft, A.M. 2000. Weed populations and pathogens. Weed Research. 40:63-82.

Dielman, J.A. & Mortensen, D.A. 1999. Characterizing the spatial pattern of Abutilon theophrasti seedling patches. *Weed Research* **39**:455-467.

Dielman, J.A., Mortensen, D.A., Martin, A.R. & Wyse-pester, D.Y. 1999. Influence of velvetleaf (Abutilon thephrasti) and common sunflower (Helianthus annuus) density variation on weed management outcomes. *Weed Science* **47**:81-89.

Donald, W.W. 1994. Geostatistics for mapping weeds, with a Canada thistle (Cirsium arvense) patch as a case study. *Weed Science* **42**: 648-657.

Gerhards, R., Wyse-Pester, D.Y., Mortensen, D. & Johnson, G.A. 1997. Characterizing spatial stability of weed populations using interpolated maps. *Weed Science.* **45**:108–119.

Gerhards, R. & Oebel, H. 2006. Practical experiences with a system for site-specific weed control in arable crops using real-time image analysis and GPS-controlled patch spraying. *Weed Research*. **46**:185-193.

Ghersa, C.M. & Roush, M.L. 1993. Searching for solutions to weed problems. Do we study competition or dispersion? *Bio Science*. **43**:104-109.

Goudy, H.J., Bennett, K.A., Brown, R.B. & Tardif, F.J. 2001. Evaluation of site-specific weed management using a direct-injection sprayer. *Weed Science*. **49**: 359-366.

Heisel, T., Andreasen, C. & Ersbqll, A.K. 1996. Annual weed distribution can be mapped with kriging. *Weed Research*. **36**: 325-337.

Horowitz, M. 1973. Spatial growth of *Sorghum halepense* (L.) Pers. *Weed Research*. **13**: 200-208.

Isaaks, E.H. & Srivastava, R.M. 1989. *An Introduction to Aapplied Geostatistics*. Oxford University Press. New York.

Johnson, G.A., Mortensen, D.A. & Gotway, C.A. 1996. Spatial and temporal analysis of weed seedling populations using geostatistics. *Weed Science*. **44**:704–710.

Jurado-Exposito, M., Lopez-Granados, F., Gonzalez-Andujar, J.L. & Garcia-Torres, L. 2004. Spatial and temporal analysis of *Convolvulus arvensis* L. populations over four growing seasons. *Europeah. Journal of Agronomy*. **21**:287–296.

Legendre, P. & Fortin, M.J. 1989. Spatial pattern and ecological analysis. *Vegetatio*. **80**:107–138.

Levin, S.A. 1992. The problem of pattern and scale in ecology. *Ecology*. **73**: 1943-1967.

Loghavi, M. & Mackvandi, B.B. 2008. Development of a target oriented weed control system. *Computers and Electronics in Agriculture*. **63**:112–118

Lueschen, W.E., Andersen, R.N., Hoverstad, T.R. & Kanne, B.K. 1993. Seventeen years of cropping systems and tillage affect velvetleaf (*Abutilon theophrasti*) seed longevity. *Weed Science*. **41**: 82-86.

Lutman, P.J.W., Rew, L.J., Cussans, G.W., Miller, P.C.H., Paice, M.E.R. & Stafford, J.E. 1998. Development of a patch spraying system to control weeds in winter wheat. Home-Grown Cereals Authority Project Report No. 158. HGCA, London.

Makarian, H., Rashed-Mohassel, M.H., Bannayan, M. & Nassiri, M. 2007. Soil seed bank and seedling populations of *Hordeum murinum* and *Cardaria draba* in saffron fields. *Agriculture, Ecosystems and Environment*. **120**:307–312.

Mortensen, D.A., Dieleman, J.A. & Johnson. G,A. 1998. *Weed spatial variation and weed management*. In: Integrated weed and soil management (eds. J.L. Hatfild, D.D. Buhler, & B.A. Stewart), 293-309. Ann. Arbor Press, Chelsea, MI.

Paice, M.E.R. & Day, W. 1997. Using computer simulation to compare patch spraying strategies. In: *Proceedings Precision Agriculture 1997 Conference* (ed. J.V. Stafford), Warwick, UK, 414-428.

Rew, L.J. & Cussans, G.W. 1995. Patch ecology and dynamics-how much do we know? In: *Proceedings 1995 Brighton Crop Protection Conference-Weeds*, Brighton, UK, pp. 1059-1068.

Rew, L.J. & Cousens, R.D. 2001. Spatial distribution of weeds in arable crops: are current sampling and analytical methods appropriate? *Weed Research*. **41**: 1-18.

Rew, L.J., Whelan, B. & McBratney, A.B. 2001. Does kriging predict weed distribution accurately enough for site-specific weed control? *Weed Research*. **41**: 245-263.

Van Groenendael, J.M. 1988. Patchy distribution of weeds and some implications for modeling population dynamics: a short literature review. *Weed Research*. **28**: 437-441.

Webster, T.M. & Cardina, J. 1998. Spatial and temporal emergence patterns of hemp dogbane (*Apocynum cannabinum*). In: *Proceedings Weed Science Society of America*, Chicago, IL. **38**:9-12.

Wiles, L.J., Oliver, G.W., York, A.C., Gold, H.J. & Wilkerson, G.G. 1992. Spatial distribution of broadleaf weeds in North Carolina soybean (*Glycine max*) fields. *Weed Science*. **40**:554–557.

Wyse-Pester D.Y. & Mortensen D.A. 1996. The stability in spatial patterns and density of weed populations. *Weed Science Society of America Abstract*. **36**: 44.

Wyse-pester, D.Y., Wiles, L.J. & Westra, P. 2002. Infestation and spatial dependence of weed seedling and mature weed populations in corn. *Weed Science*. **50:** 54-63.

Zanin, G., Berti, A. & Riello, L. 1998. Incorporation of weed spatial variability into the weed control decision –making process. *Weed Research*. **38**: 107-118.