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Spatial relationships between weed seed bank and population and their distribution models in sugar beet crop (*Beta vulgaris*)

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ABSTRACT

A field experiment was conducted to study the spatial relationships between weed seed bank and population and their distribution models in sugar beet crop (Beta vulgaris) in 2009 at Motahari Agricultural Research Station of Karaj. Sampling from seed bank before sugar beet drilling and weed population in three stages during the growing season were done using square (50*50 cm) and rectangle (25*100 cm) frameworks. Seed and plant frequency of each weed species were recorded in the both frameworks. Geostatistics technique was used to investigate the local structure of the weeds and dynamic of the spots. Amaranth, lambsquarter and narrow-leaf weeds were the prevalent weed species in the field. Semi-variogram analysis showed a range of influence from 0.24 to 141.9 m depending on weed species and sampling stage. The highest range of influence belonged to amaranth, especially in the second stage of seedling sampling. Lambsquarter had a lowest range of influence between all weeds. The highest nugget effect (1.671 and 1.308) was observed for amaranth (at second sampling from seedlings) and narrow leaf-weeds (at the first sampling from seedlings), respectively. This led to weak local correlation for amaranth and narrow-leaf weeds. Strong local correlation was recorded for seed and seedling of lambsquarter at all sampling stages. Spot distribution of weeds was confirmed by local distribution maps. Spots structure changed during the growing season. Results suggested that weed local distribution could improve management decisions and comprehension of dynamic of weeds populations.

Keywords: Amaranth seed bank, Distribution pattern, Dynamics of weeds populations, Geostatistics, Lamb's quarter

INTRODUCTION

Soil resembles a bank with continual influx and outflow of the seeds of the weeds. Meantime, after the influx of the seeds, some of them outflow the soil environment by germination, death, decay and predation. Weeds have been always known as tough competitors of the crops owing to their specific characteristics such as the production of a great number of seeds, the high germination capability, quick establishment, high growth and development rate, long dormancy, conserving the viability, adaptation for the spread and distribution, and having vegetative and reproductive organs. Now, they are regarded as an inseparable constituent of the agronomical systems and despite the time and costs devoted to their management, they still impose a heavy damage to crops (Douglas 1995).

One of the reasons for inefficient weeds management is non-uniform distribution of the weeds which makes the sampling, modeling and management difficult (Cardina et al. 1995). Some factors playing a role in the deployment of the seeds in field include the diversity and interference of the crops and weeds, non-uniformity of the locations of maternal plants, seed shape and size, nonrandom dispersion of seeds, efficiency of distribution factors, wind direction and speed, germination and emergence, and seed mortality (Christensen et al. 1999). Knowledge of weeds

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spatial dynamics and their spatial control reduces the costs of the inputs (Dille et al. 2002). The importance of spatial distribution in sampling of weeds populations, modeling population dynamics and long-term management have drawn the attentions towards developing new methods for describing and analyzing spatial distribution of weeds (Swanton and Murphy 1996). Geostatistics can be used for describing the variations, mapping, developing sampling methods and studying ecological issues (Cardina et al. 1995). The data about the frequency and composition of seeds in seed bank of weeds are of crucial importance in the identification of the weeds. In addition, the use of the seed bank is very useful in the prediction of future weeds population (Ball and Miller 1989). Nowadays, in addition to the knowledge of the composition and density of weeds, the knowledge of spatial distribution and the dispersion pattern of weeds seems to be important in increasing the precision and efficiency of weeds management (Siyahmargoei et al. 2007).

The main goal of weeds management is to change the crop-weed relationship in favor of the crop. Preventing the weeds reproduction and inhibiting the re-growth of their vegetative parts are two examples of weeds management practices. The most important issue is the prediction of weeds germination time which specifies the time and location of weeds control. The best way to acquire this knowledge may be by studying the relationship between seed bank and weeds seedlings population. An examination of the density and the species combination at the beginning and at the end of the season makes it possible to estimate the population we will encounter in the growing season and the temporal range of weeds germination (Gholami Golafshan 2008) which is not, unfortunately, considered in Iran, whereas the knowledge of the density and distribution pattern of the weeds in the farm allows drawing farm map to be used in sound weeds management. Therefore, two types of quadrates with rectangular and square shapes with the same area were examined in the present study to investigate the feasibility of predicting weeds density in sugar beet farms by studying weeds seed bank before sugar beet sowing. The reason for the selection of these two types of quadrates was the row sowing of sugar beets. The present study hypothesized that sampling method (rectangular and square quadrate) influences final results and that one of these methods has a high correlation with weeds density and can predict it more precisely.

MATERIALS AND METHODS

The study was conducted at Motahari Research Station of Kamalshahr (Long. 5160 E., Lat. 3559 N., Alt. 1300 m., Annual precipitation 243 mm.) located in Karaj, Iran in 2009. To study the seed bank and the population of weeds, the farm preparation was finalized and then, it was divided into four 8-m^2 parts. Next, the crossing points of the parts were specified and labeled to take all samples from these points until the end of the season. In each point, two types of frameworks with equal areas were used: rectangular (100×25 cm) and square (50×50 cm).

The soil was sampled to check seed bank before sowing the sugar beets and the plant density of weeds was traced at three stages (May 26, July 5, and August 18) after the emergence of sugar beets. During sampling, 88 points were sampled. At the position of each pin, the frameworks were placed in the center of the sugar beet planting furrow. Then, five mixed soil samples from the depth of 0-10 cm were taken from each framework, they were then mixed and 150 g of this mixture was put in bags for washing (Beheshtian et al. 2007). Then, the samples were oven-dried at 65°C for 24 hours to hinder the germination of the weeds seeds. Then, the dried samples were bagged and soaked in water. After two days, the samples were cleansed and the seeds as well as very tiny stones were left (Rahman et al. 2004). Afterwards, the seeds were identified and counted by a binocular stereo microscope. Seeds that were not shrunk under the pressure of the clips and could stand it were regarded as healthy seeds. Then, the number of the counted seeds was calculated on the basis of the number per unit area with the depth of 10 cm considering the weight of the samples and Auger surface.

The populations, too, were sampled by frameworks at the same points where the seed banks had been sampled. All seedlings of the weeds emerged inside the frameworks were identified, counted and then, removed. Finally, the most appropriate relationship between seed bank and weeds density was fitted by computer software.

The spatial correlation between two samples was described as a mathematical model known as semi-variance with the following equation:

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

where, *N(h)* is the pairs of sample sites separated by distance *h*, *Z(xi)* is the density of weeds at point *i*, *Z(xi+h)* is the density of the weed at point *x* with the distance *h* from point *xi*, and *γ(h)* is the semivariance. Semivariogram describes spatial diversity as a function of the distance between geographical points (Mohammadi 2002).

Semivariogram includes threshold ($C_o + C_s$), influence range (A_o) and nugget effect (C_o). Threshold is the level at which variogram becomes constant. Influence range is the range beyond which samples do not influence each other. Nugget effect shows the spatial correlation, i.e. the lower the nugget effect is, the less probable the random distribution is and the highest the correlation between the samples is (Siyahmargoei et al. 2006). The parameters obtained from the fitting of these models are used for estimating the density of weeds on the basis of the data obtained from the present samples. Kriging is the most prevailing statistical method for estimating spatial variable and is known as a linear function of a set of distributed observations in the neighborhood of a point that is intended to be estimated (Ashrafi et al. 2003). The statistical analyzes were done by Gs+ software including mean, standard deviation, sample variance, minimum, maximum, skewness, kurtosis and the calculations related to variogram. To study the distribution pattern of the weeds in farm and to estimate weeds at different points of the farm, all data of networking method were transferred to Rockwork 99 software and the map of seed bank distribution pattern and the population of weed seedlings were drawn. The points between the points studied in networking method were estimated and calculated by Kriging method by which the distribution maps of the weeds were studied in farm.

RESULTS AND DISCUSSION

Spatial correlation among predominant weed species

The spatial correlations among predominant weed species sampled once from weed seed bank and sampled three times from weed seedlings (with rectangular framework) are presented in Table 1. The predominant species in field included amaranth, lamb's quarter and narrow-leaf weeds (*Echinochloa crus-galli*, quack grass and Anthurium). The variograms of these species conformed to spherical, linear and exponential models.

The influence range of these species and at different sampling stages varied in the range of 0.24-141.9 m (Table 1). The lowest influence range was found to be devoted to lamb's quarter in the sampling of seed bank whereas the highest influence range was devoted to narrow-leaf species and at the third sampling from weeds seedlings. Amaranth, too, had a wide influence range, particularly at the second sampling from seedlings which could be observed as long spots on the maps. Ashrafi et al. (2004) found similar results for amaranth. This influence range, in fact, shows the distribution pattern of weeds. Wide range implies that the seeds or reproductive vegetative parts are able to distribute in long distances which is made possible by plowing tools, harvest machineries, cultivators, etc. (Ashrafi et al. 2004).

The range of lamb's quarter was lower than other species during growing season, too, which can be related to its seeds distribution mechanism, i.e. its seeds are mostly casted down to the base of maternal plant. It seems that if the sampling intervals are shortened, the spatial dynamics of lamb's quarter population can be better understood (Siyahmargoei et al. 2006). Influence range

Table 1. Variogram components related to the prevalent species at different stages of sampling with rectangular framework

Sampling	Species	Model	Nugget effect (C_o)	Threshold (C_o+C)	Influence range (A_o)	Nugget effect percentage (C_o/C_o+C)×100	Spatial correlation
Seed bank	Amaranth	Exponential	0.99	2.48	11.55	39.9	Moderate
	Lambs' quarter	Exponential	0.076	0.725	0.24	10.4	Strong
	Narrow-leaf	Linear	0.666	1.045	40.21	63.7	Weak
First sampling of seedlings	Amaranth	Exponential	0.667	2.35	7.56	28.3	Moderate
	Lambs' quarter	Exponential	0.405	1.859	9.99	21.7	Strong
	Narrow-leaf	Linear	1.308	1.41	40.21	92.7	Very weak
Second sampling of seedlings	Amaranth	Linear	1.671	2.165	40.26	77.1	Very weak
	Lambs' quarter	Exponential	0.072	0.614	2.7	11.7	Strong
	Narrow-leaf	Linear	0.757	1.142	40.21	66.2	Weak
Third sampling of seedlings	Amaranth	Spherical	0.001	1.61	4.27	0.06	Strong
	Lambs' quarter	Spherical	0.003	0.04	3	7.5	Strong
	Narrow-leaf	Exponential	0.699	1.393	141.9	50.1	Weak

Table 2. Variogram components related to the prevalent species at different stages of sampling with square framework

Sampling	Species	Model	Nugget effect (C_o)	Threshold (C_o+C)	Influence range (A_o)	Nugget effect percentage (C_o/C_o+C)×100	Spatial correlation
Seed bank	Amaranth	Spherical	0.172	0.793	12.96	21.68	Strong
	Lambs' quarter	Exponential	0.077	0.726	0.24	10.6	Strong
	Narrow-leaf	Linear	0.674	0.967	33.24	92.83	Very weak
First sampling of seedlings	Amaranth	Spherical	0.112	3.033	3	3.69	Strong
	Lambs' quarter	Exponential	0.474	1.93	11.85	24.55	Strong
	Narrow-leaf	Linear	1.313	1.384	33.24	94.86	Very weak
Second sampling of seedlings	Amaranth	Spherical	0.001	2.032	4.13	0.049	Strong
	Lambs' quarter	Spherical	0.027	0.61	3.49	4.42	Strong
	Narrow-leaf	Linear	0.791	1.023	33.24	77.32	Very weak
Third sampling of seedlings	Amaranth	Spherical	0.001	1.478	8.41	0.067	Strong
	Lambs' quarter	Spherical	0.003	0.038	3	7.89	Strong
	Narrow-leaf	Linear	0.643	1.198	33.24	53.67	Weak

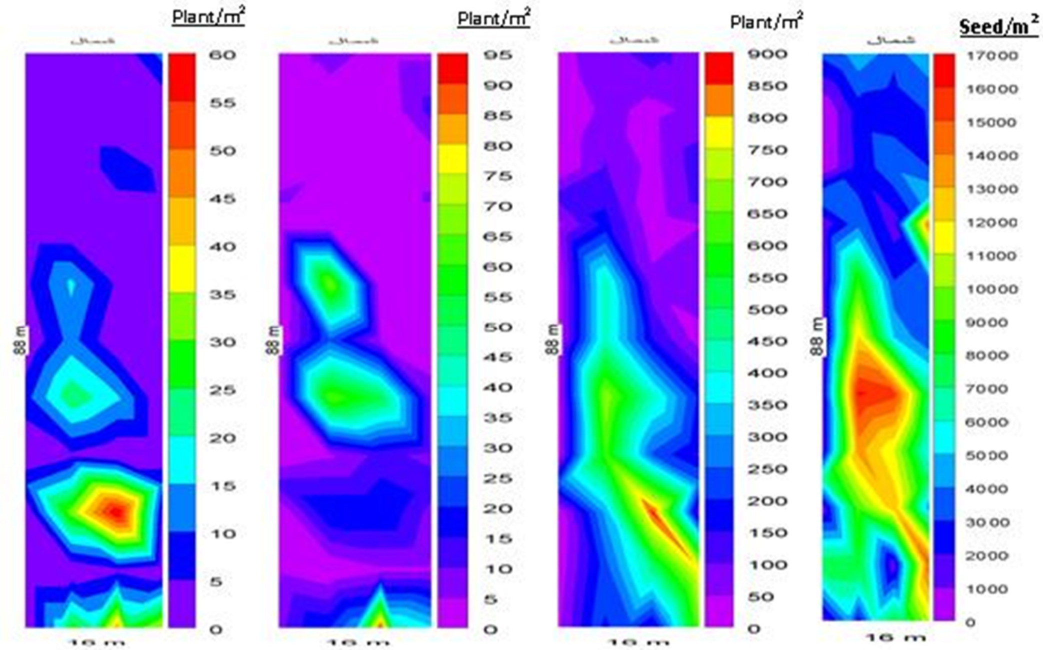
is important in selecting sampling strategy and the permitted sampling distance, too. For example, lamb's quarter with the influence range of 0.24, 2.7 and 3 meters needs sampling distances of lower than 4 meters used in the present study if sound distribution maps are required to be prepared for location-proportional management. For narrow-leaf species with wider influence range, sampling distances can be increased although with a weaker assumption, it is likely that some small spots disappear resulting in lower precision (Ashrafi et al. 2004). The widest influence range was devoted to narrow-leaf species. Seeds with higher adaptability for distribution would certainly have wider spots (Siyahmargoei et al. 2006).

The highest nugget effects of 1.671 and 1.308 were devoted to amaranth (at the second sampling of the seedlings) and narrow-leaf species (at the first sampling of the seedlings), respectively, both of which resulted in very weak spatial correlation. Nugget effect means that the observations separated by infinitesimally small distances are dissimilar. The more the nugget effect approaches zero, the less randomized the weeds distribution is and the stronger the special correlation is. In fact, the distance between the threshold and nugget effect shows a part of the diversity which is explained by special correlation with the applied sampling method (Ashrafi et al. 2004). The difference between the nugget effect and the threshold during sampling stages might have been caused by the variations of population density rather than by the differences in the movement or spot behavior from one sampling stage to another (Ashrafi et al. 2004).

The spatial correlation between the seeds and seedlings of lambs' quarter was strong at all sampling stages, whereas it was weak for narrow-leaf species. The spatial correlation did not exhibit any clear behavior in the case of amaranth varying from very weak (the second stage of sampling from the seedlings) to strong spatial correlation (the third stage of sampling from the seedlings).

Spatial distribution of seed bank and the stages of sampling from amaranth seedlings

Amaranth had occupied an extensive part of the sugar beet fields and formed the highest density in samplings from seed bank and seedlings. The seed bank sampling of amaranth by rectangular framework showed that amaranths were established as a long spot in the central and southern part of the farm and that their highest seed density was 17000 seeds m^{-2} with depth of 10 cm. This density went below 1000 seeds.m^{-2} with the depth of 10 cm in some parts. Indeed, the direction of machinery traffic, irrigation rows and wind play a crucial role in increasing the range of extension along cultivated rows (Siyahmargoei et al. 2006). Considerable differences were observed between the population densities of seed bank inside a farm and between different parts of a farm. Since seed bank density may reach 1 000 000 seeds m^{-2} in a farm, unsuccessful management can pave the way for the growth of healthy, vigorous seeds into adult plants that can cause an extensive infection in a quite short time (Douglas et al. 1998). The estimation of the population of weeds seeds in soil can be used for estimating their germination time and seedling density (Forcella 1992). This spot did not change substantially at the first sampling from the seedlings either. Early-season spot structure was in conformity with germination pattern of the seedlings implying that seed bank map can be used as a source of information about germination pat-



(third stage) (second stage) (first stage) (soil seed bank)

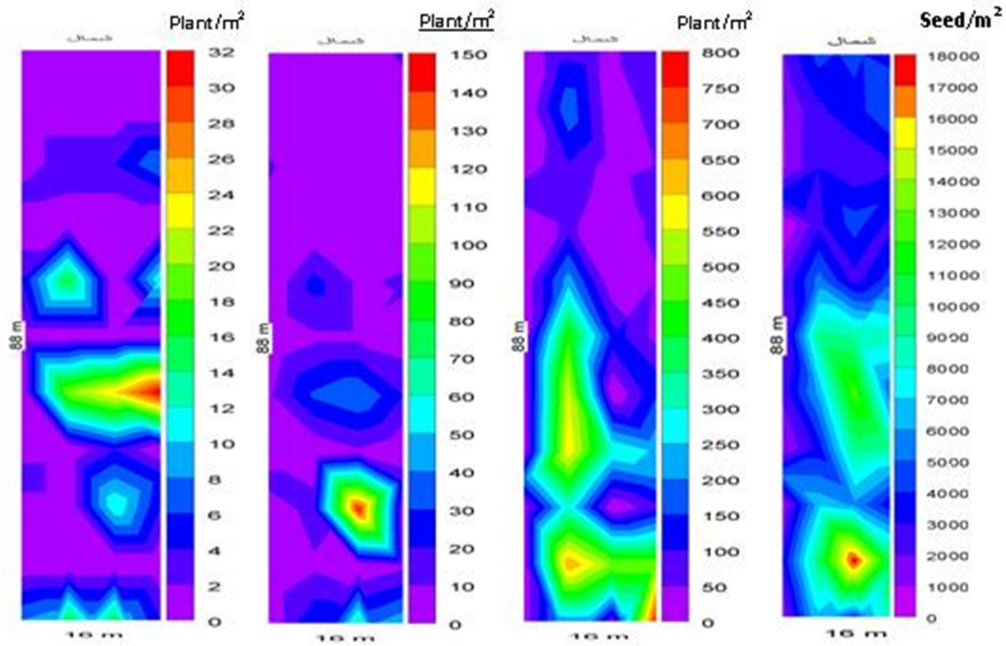
Fig. 1. Distribution and density of amaranth at different stages of sampling from its seedlings with rectangular framework

tern of seedlings. The density of a species in farm can be roughly predicted by considering its density in the previous year and the density of its seeds in seed bank (Forcella 1992).

Studies on spatial distribution show that the seedlings of the weeds are mostly observed as spots with varied sizes and densities (Schuster et al. 2007). Therefore, the spatial distribution of the seeds and seedlings of the weeds varies from regions with very high densities to regions free of weeds (Cardina et al. 1995), so that a part of the farm is always under and the other parts are over the economical threshold (Lutman et al. 2002). But, this fact is usually ignored in cultural practices and the decision about weeds management is usually based on mean pressure of the weeds and this management is practiced uniformly throughout the farm (Loghavi and Mackvandi 2008).

In the next samplings after the practice of the management during the growing season, the spot changed into three smaller spots with lower plant densities (Fig. 1). It is likely that some plants were removed as the plants grew up and the competition in the dense core of the spot intensified. The population of the weeds had decreased since the first sampling which can be related to the growth of the sugar beets and the weeds and the increased inter-specific and intra-specific competition. In fact, a farm having weeds in it is a dynamic system composed of crop-crop, weed-weed and crop-weed competition. The depletion of the resources intensifies the competition of the plants with each other and the increase in their volume increases the competition over space and radiation resulting in the loss of the weeds number (Mohammadvand et al. 2009). Hand weeding has been traditionally applied as an effective method for managing weeds in sugar beet farms and known as the most effective and harmless controlling method (Rashed Mohassel et al. 2001). Since the weeds were completely removed from the frameworks (after the first stage of sampling), at the second stage of sampling, even three weeks after the hand weeding, no weeds were observed in most parts of the farm. Cultivation one month before the third stage of seedlings sampling increased the weeds-free parts of the farm.

The dense core of the spots is the source of seeds production which results in the emergence of seedlings in the subsequent growing season. These cores, in fact, show a strong seed bank and favorable conditions for the germination and growth of the weeds (Mohammadvand et al. 2009). Ashrafi et al. (2004), also, reported the direction effect of the commuting path of the machineries and irrigation furrow on the formation of continuous long spots. Weeds are usually gathered in parts of the farm where the conditions are more suitable for their survival (Dutilleul 1993). The fact that the weeds are distributed in spot



(third stage) (second stage) (first stage) (soil seed bank)

Fig. 2. Distribution and density of amaranth at different stages of sampling from its seedlings with square framework

form in the farm is related to the interaction among weeds biology, environmental conditions and agronomic practices. The distribution of the weeds depends on various factors including the attributes of the reproductive organs (size, share, wing position, etc.) interacted with environmental conditions (wind, water, animals) and the processes driven by humans (crop planting pattern, plowing systems and crop harvest) (Gerhards et al. 1997).

The seed bank sample of amaranth taken from the square framework showed two distinct spots in the central and southern part of the farm. These spots did not change substantially at the first sampling but they change radically at the second sampling (Fig. 2). Studies show that the weed spots are formed at the initial stages, but their margins fluctuate after the practice of the management during growing season although the dense core of the spots does not change leading to the increased spatial correlation among the weeds (Rew and Cussans 1995; Johnson et al. 1996; Cardina et al. 1997).

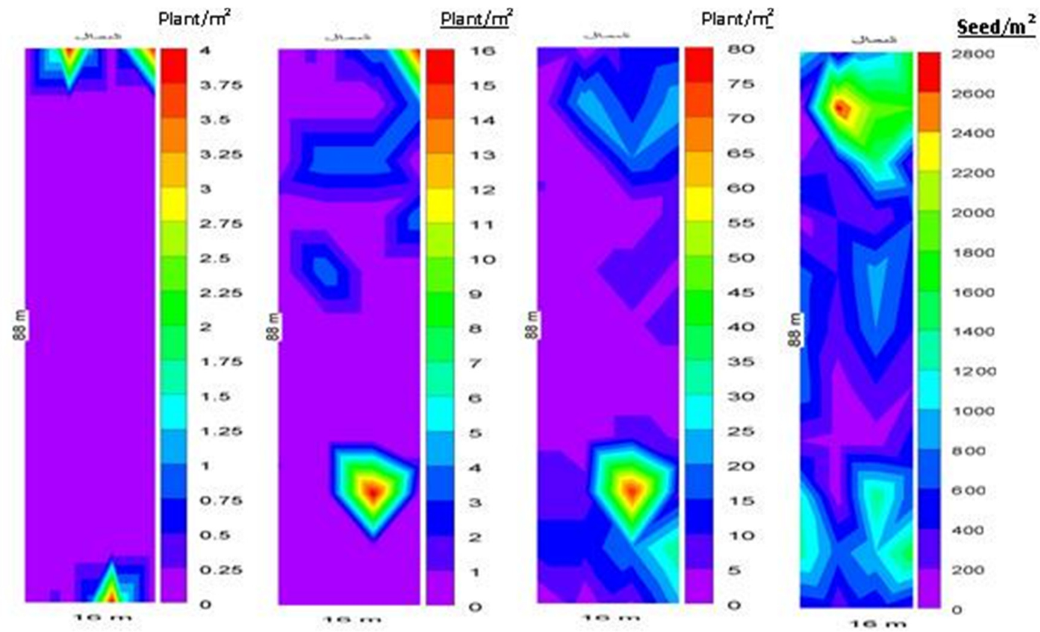
The density of the seeds of the weeds is a function of plant height, distance from seed production source, seed density in source, seed dispersal ability (the existence of extensions, seed weight, etc.), and the activity of factors effective on distribution such as wind, water, animals and humans which are usually the factors transferring the seeds (Harper 1977).

Distribution pattern

The map of each species was drawn by Rockwork 99 software and the distribution of the seeds and seedlings of the weeds were shown on both sampled and unsampled points. In Figs. 1 and 2, the figures on the right hand show the density of the seeds of each weed species in accordance with their color in the farm. Four points in the width and 100 points in the length of the farm were sampled by rectangular and square frameworks. The maps of the distribution and density of the weeds allows the visual comparison of the weeds arrangement in the farm. The maps consecutively drawn during growing season make it possible to evaluate the spatial dynamics and the floral variations of the weeds and their responses to the practiced management (Cardina et al. 1997).

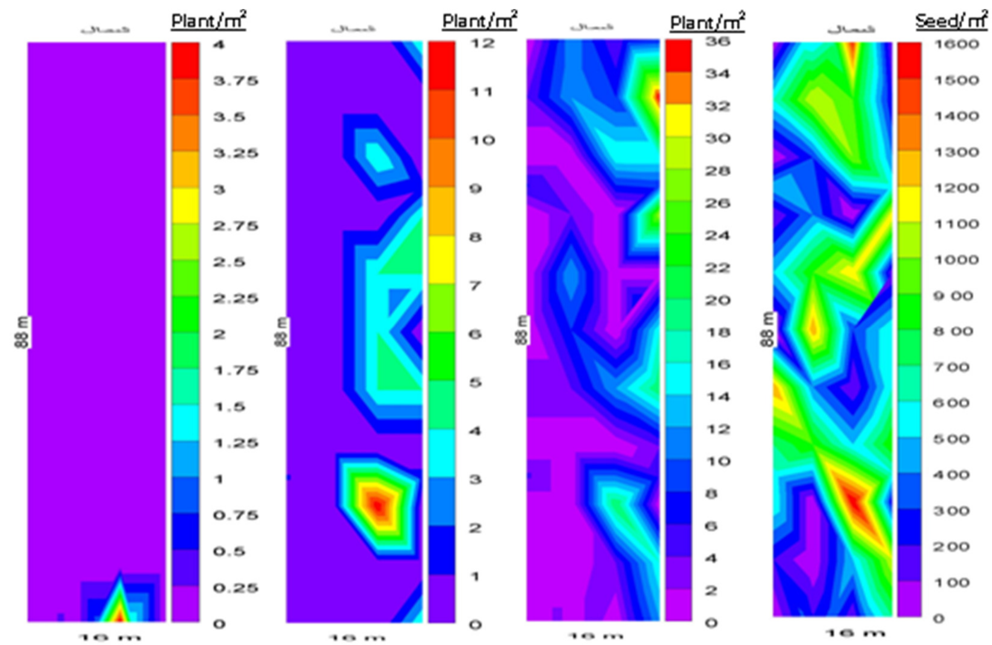
Spatial distribution of seed bank and the stages of sampling from the seedlings of lamb's quarter and narrow-leaf species

The population of lamb's quarter distributes neither randomly nor normally but in spot form (Cardina et al. 1995). The sample of lamb's quarter seed bank taken with rectangular framework indicated that it was established as two distinct spots in the northern and southern part of the



(third stage) (second stage) (first stage) (soil seed bank)

Fig. 3. Distribution and density of lambs' quarter at different stages of sampling from its seedlings with rectangular framework

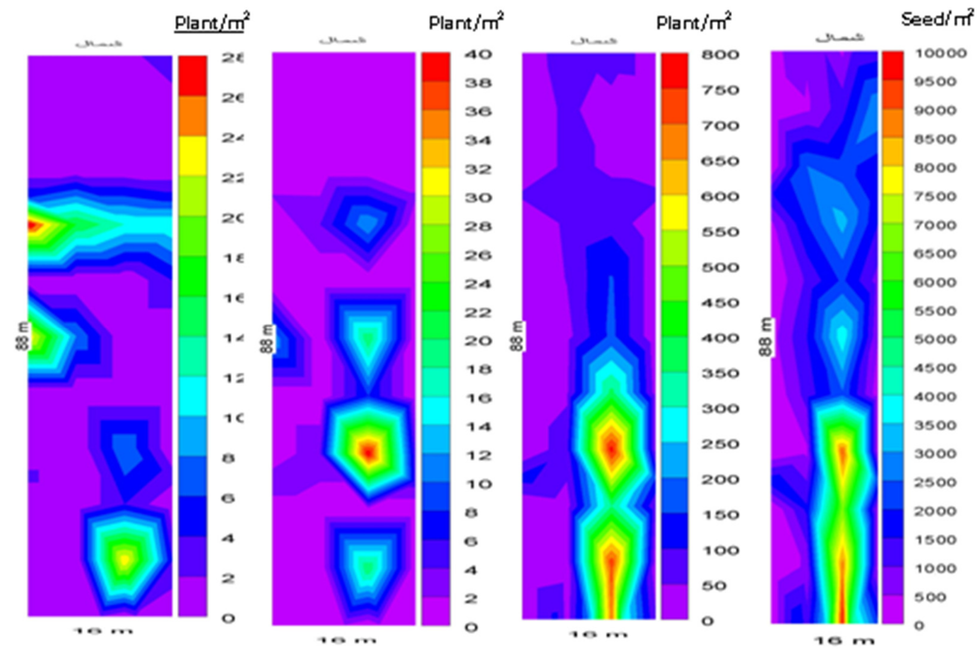


(third stage) (second stage) (first stage) (soil seed bank)

Fig. 4. Distribution and density of lambs' quarter at different stages of sampling from its seedlings with square framework

farm with the highest seed density of 27000 seeds m^{-2} at 10 cm depth. These spots did not change substantially at the first stage of sampling from the seedlings (Fig. 3). Like amaranth, the early-season structure of the spot of lamb's quarter was in conformity with its germination pattern implying that its seed bank map can be used as a source of information about its germination behavior. The relationship between the samples taken from the seed bank populations and seedlings revealed that sampling from seed bank was useful in generating a map of its populations to help estimating its population in the farm.

Lamb's quarter is a plant that is propagated with seed. Since its seeds are mostly shed under the maternal plant, agricultural machineries are the main means for the distribution of its seeds. Therefore, lamb's quarters are observed as small



(third stage) (second stage) (first stage) (soil seed bank)

Fig. 5. Distribution and density of narrow-leaf weeds at different stages of sampling from its seedlings with rectangular framework

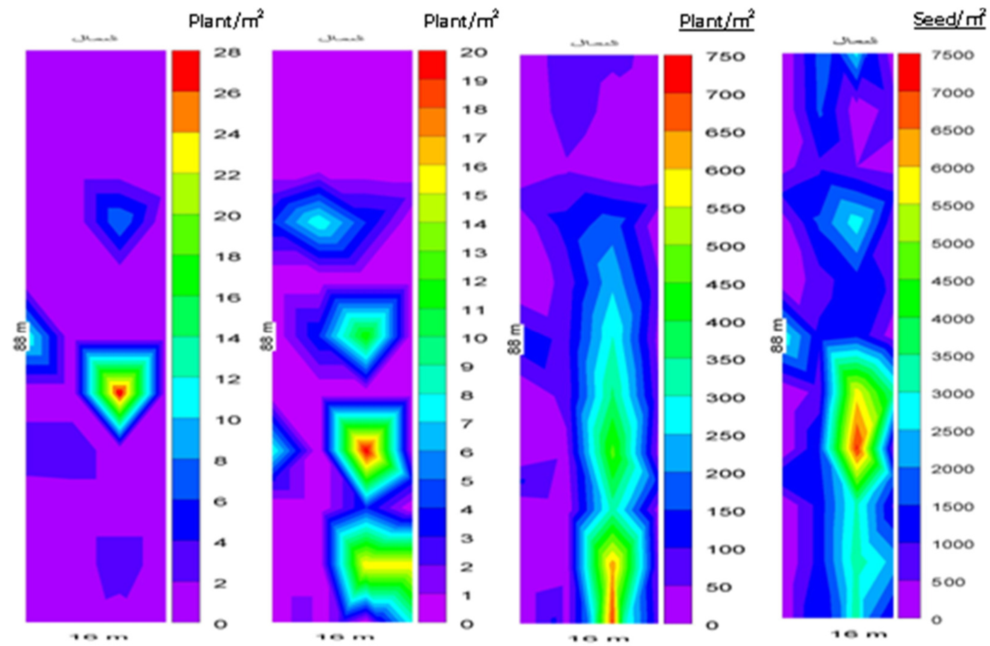
spots throughout the farm (Siyahmargoei et al. 2006). The seeds of the weeds enter seed bank through various ways, but they are mostly originated from the seed-shedding of the local plants (Douglas 1995). In total, seeds tend to shed around their maternal plants. As the distance from the maternal plant increases, the number of seeds is decreased. Seeds that are distributed around maternal plant in a distance of <2 m increase spot property (Howard et al. 1991).As can be seen in Fig. 3, the variation of the population of the seedlings is such that the number of the seedlings is maximal at the beginning of the season, but over the time some seeds germinate at mid-growing season and the seed bank is partially depleted. In the next samplings, the number of seedlings was decreased to even zero in some parts of the farm.

The sample of the seed bank of the narrow-leaf species collected with rectangular framework revealed that the narrow-leaf species were established as a long spot in central to southern parts of the farm. The highest seed density was 98000 seeds m^{-2} at the depth of 10 cm. It was decreased to less than 2000 seeds m^{-2} in some parts of the farm. The spot changed to smaller, less dense spots in the subsequent samplings after the practice of weeds management, so that a great part of the farm was weeds-free. But at the third sampling, the position of these smaller spots changed too (Fig. 5).

The consideration of ecological aspects of the weeds (seed bank, weeds distribution pattern, etc.) can be useful for their effective management and can give a new vision to researchers (Siyahmargoei et al. 2007). The knowledge of spatial distribution can improve managerial decision-making and can increase our understanding of the dynamics of weeds population (Ashrafi et al. 2004).

Conclusion

Amaranth had a long range of influence, particularly at the second sampling of the seedlings. The influence range of lamb's quarter was lower than that of other species during the growing season which may be associated with the mechanism of their seeds distribution because its seeds shed under maternal plants. The highest nugget effect was devoted to amaranth (at the second sampling of the seedlings) and narrow-leaf species (at the first sampling of the seedlings), respectively, in both of which it resulted in very weak spatial correlations. The strong spatial correlation was registered for the seeds and seedlings of lamb's quarter at all sampling stages. Spatial distribution maps confirmed the distribution of the weeds spots. The structure of the spots changed over growing season. It was found that the knowledge of spatial distribution of the weeds can improve managerial decision-making and can increase our



(third stage) (second stage) (first stage) (soil seed bank)

Fig. 6. Distribution and density of narrow-leaf weeds at different stages of sampling from its seedlings with square framework

understanding of the dynamics of weeds population. In total, in sampling with rectangular quadrate the correlation was higher between seed bank and the emerged seedlings (data are not presented) which is likely related to row-planting of the sugar beets.

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