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VERTICAL DISTRIBUTION OF NUTSEDGE (*CYPERUS* SPP. L.) AND BAHIAGRASS (*PASPALUM NOTATUM* L.) SEED BANK IN RICE GROWTH CYCLE

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Abstract

Weed management in rice continues to be a major challenge to the success of rice growers in northern Iran. Field experiments were conducted at Sari Agricultural Sciences and Natural Resources University to investigate the spatial distribution of weed seeds in the rice growth cycle in 2010 and 2011. Transplanting was done on June 6 in both years. Samples for seedbank analysis were collected 10 days before transplanting and emerged weed density was determined on three different dates during the growing season. Results indicated that nutsedge (*Cyperus* spp) and bahiagrass (*Paspalum notatum*) were the two most abundant weed species. The vertical distribution of weed seeds decreased by depth from 0.1 to 0.3 m, while weed pressure was the highest at the 0–0.1 m soil depth. There was no relationship between soil weed seedbanks (at different depths) and emerged weed populations, suggesting that weed seedbank data are not good predictors of weed seedling densities. Nevertheless, Kriging maps indicated that the spatial distribution of weed seeds was in accordance with seedling germination pattern. Also the regression coefficient for 0–0.1 m soil depth was $R^2 = 0.17$ and $R^2 = 0.34$ for relation between nutsedge and bahiagrass seedlings and their seedbank in 2010 and also, $R^2 = 0.18$ and $R^2 = 0.05$ in 2011, respectively. Therefore, results achieved from this depth can be used to predict the relationship between nutsedge and bahiagrass seedlings densities and weed seedbanks. The results of this study provide an option for the farmers growing rice to understand the dynamics of weed populations in a cost effective way.

Keywords: bahiagrass, kriging map, nutsedge, rice, spatial distribution, soil depth, weed

INTRODUCTION

Rice (*Oryza sativa* L.) is a main source of food for more than 50% of world population and 90% of the rice area worldwide is in Asia (Yaghoubi Khanghahi *et al.,* 2018a). In Iran rice is the main staple food of people, with approximately 600 000 hectares under rice cultivation and annual production of 1 683 000 tons (Shobha Rani, 2015). More than 80 percent of rice area is spread across the two northern provinces of Gilan and Mazandaran (Yaghoubi Khanghahi *et al.,* 2018b). Rice farmers face a number of challenges, such as weeds, disease and insect pests. Weeds compete with rice for light, water, and nutrients and cause more than 30% yield loss (Oerke and Dehne, 2004). Although chemical and mechanical methods for weed control are implemented, because rice is not cultivated in rotation with other crops in northern Iran, weed control continues to be a major challenge for rice growers in this region (Vakili-rad and Amiri, 2014).

All viable weed seeds and vegetative propagules parts, which can produce new plants, present on and in the soil which might be originated from the recent seed rain or previous years are included in the weed seedbank (Shrestha *et al.,* 2002). Seedbank management is an integral part of a long-term sustainable weed management system. The principal source of weed infestation in cropland is the soil weed seedbank. Therefore, the soil weed seedbank serves as a history of weed populations existed in the past (Hossain and Begum, 2015). Although seedbanks are made up of many weed species, but it has been reported that only a few dominant species will comprise 70 to 90% of the total seedbank (Koocheki *et al.,* 2009).

Changes in environmental factors (Albrecht and Auerswald, 2003) as well as shifts in soil and crop management practices (Moonen and Barberi 2004) can affect the species composition and their densities of aboveground and belowground ingredients of weed communities. Therefore, it is very difficult to estimate seedbank size of the arable weeds and predict the pattern of weed species emergence (Grundy, 2003). Reasons for estimating weed seedbanks include defining the flora of an area (Major and Pyott, 1966), predicting the dynamics of plant community and population (Allen and Nowak, 2008), and achieving relevant information about the soil weed seedbank (Forcella *et al.,* 2011).

Seedlings emergence are influenced by weed seeds distribution in the soil depths and depended on some factors such as soil type, weed species composition, type of tillage used, seeding and planting practice and applied herbicides have a intense bearing on the depth of seedling recruitment (du Croix Sissons *et al.,* 2000).

Vertical weed seeds movement and their position in the soil is one of the major outcomes as various types of cultivation move seeds to different soil depths (Dessaint *et al.,* 1996). The importance of spatial distribution in mathematical modeling in population dynamics, sampling weed populations and long-term weed control strategies has attracted attention to the need for methods to characterize and analyze of weeds spatial distribution (Doyle, 1991). A major challenge for improving weed control is to estimate whether the weed seedbank data can used to predict the essence of future weed infestations and their effects on crop production (Cardina and Sparrow, 1996). Therefore, the knowledge of the weed seed bank becomes a crucial component of a successful weed management program (Roham *et al.,* 2014).

Seed densities in agricultural soils have been estimated up to 1 million seeds per square meter (Rao, 2000). Ranjit *et al.* (2007) reported that the vertical distribution of total weed seeds in the soil showed a declining trend in density as the depth increased from 0.05 to 0.2 m in all the soil samples regardless of season. Upadhyaya and Blackshaw (2007) noted that the majority of the weed seeds are concentrated within the upper 0.02 m of the soil profile and nearly the whole population can be found in the upper 0.15 m of the soil. Chauhan *et al.* (2006) reported that 60% of entire weed seeds can be found between 0 and 0.05 m of soil depth, and weed seed density decline logarithmically with soil depth.

The determination of the weed seedbank in topsoil is very time consuming work and rather difficult. Some questions concerning soil sampling, particularly the estimation of their numbers, size and sampling procedures, use of different types of soil samplers, and sampling depth have not been properly defined (Rahman *et al.,* 1995). Not only research on the spatial dynamics of seed banks has been limited the dynamics are poorly understood (Cousens and Mortimer, 1995).

Therefore the objectives of this study were to investigate the spatial distribution of the weed seed bank at different soil depths to determine the proper sampling depth and its relation to weed emergence pattern in rice growth cycle by regression and geostatistics.

MATERIAL AND METHODS

Field studies were conducted at the Sari Agricultural Sciences and Natural Resources University, Sari, Iran (36˚70′ N, 53˚21′ E, altitude of 11 m below the average of sea level, with long-term annual precipitation mean of 780.7 mm and long-term annual temperature mean of 18.1 °C) with Mediterranean climate conditions (according to Domarten classification), during the 2010 and 2011 growing seasons. The soil type was a clay loam with pH of 8.4 and organic matter content of 3.39%. To investigate the weed population and their soil seedbank, the farm was divided into 36 grids (2.5 × 2.5 m). Grid intersection points were determined and were marked. All sampling was performed at the marked points during the rice growing season. Seedbank samples were collected 10 day before transplanting on May 27, 2010 and May 26, 2011. Emerged weed density was determined by counting seedlings in square quadrat (0.5 × 0.5 m) 14 days after rice transplanting, at heading time, and one week before harvest, on June 13, July 6, and August 10, 2010 and on June 13, July 11, and August 13, 2011, respectively.

Each sample consisted of five soil cores from each intersection point, collected by a hand auger (50 mm diameter), set for 0–0.1, 0.1–0.2 and 0.2–0.3 m depths and were thoroughly mixed. In order to prevent seed germination, soil samples were placed into oven for 24 h. 100 g of each soil sample was placed into bags made of silk. Then, soil samples were washed through a fine mesh to remove soil particles. The remaining particles were passed through a descending size series of sieves after air drying. Whole seeds obtained from each sieving were identified and counted (Rahman *et al.,* 2004; Roham *et al.,* 2012a; 2012b).

Some descriptive statistics such as mean, standard deviation, variance, skewness and kurtosis were used to summarize a set of observations by Gs+ software (Version 7.0, Gamma Design Software, LLC Plainwell, Michigan). Forasmuch as, there were no seedlings in some quadrates, therefore weed seedling population data were positively skewed. For this reason, log (z + 1) transformation procedure was used in subsequent analysis (Colbach *et al.,* 2000).

Spatial autocorrelation between sample sites was analyzed using semivariance statistics (Cardina *et al.*, 1995):

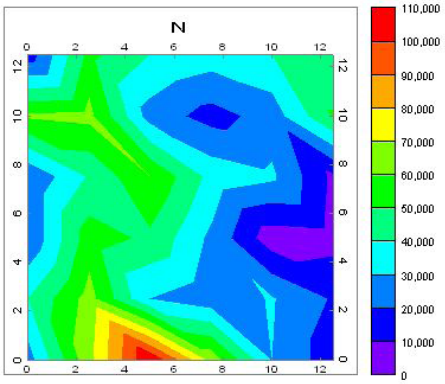
$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(Xi) - Z(Xi+h) \right]^2$$

where $\gamma(h)$ is the semivariance for interval distance class h, $z(x)$ and $z(x + h)$ are nutsedge and bahiagrass densities at points x and $x + h$, and $N(h)$ is the total number of pairs within the distance interval h (Cardina *et al.*, 1995). Kriging based on the semivariograms was used to predict weed seed and seedling population at unsampled places of the field by interpolation between the sampled points for each year (Nordmeyer, 2009). Relationships between emerged weed seedling and soil seedbank for each soil depth were calculated using SPSS software (version 16, IBM, New York, USA). Then, the best equation was fitted for weed data. Regression coefficients were determined to illustrate the relationship between the soil weed seedbank and the future weed communities (Roham *et al.,* 2012a). Finally, spatial distribution maps of weed seed and seedling were drawn by RockWork 99 software (RockWare Inc. Golden, Colorado, USA).

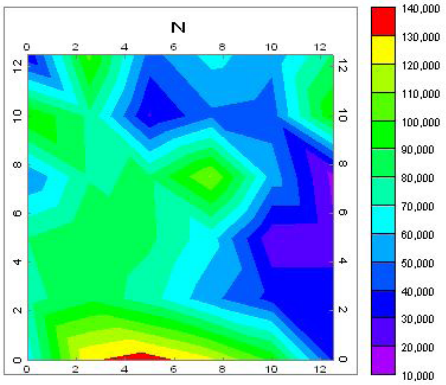
RESULTS AND DISCUSSION

Soil seed banks in the studied fields were limited in their species richness. There was a strong and moderate spatial correlation as spherical and exponential variogram models between nutsedge and bahiagrass seedbank and their seedlings at all stages of sampling. The results showed that nutsedge (*Cyperus* spp. L.) and bahiagrass (*Paspalum notatum* L.) had the highest density (data not shown). Nutsedge seeds were located in the central and western parts of the farm as long patches in 2010 (Fig. 1), but that changed in 2011 into several smaller patches with lower density (Fig. 2). Mapping results indicated that these patches were different in term of size and morphology within the field (Fig. 1–4). The highest nutsedge seed density in soil seedbanks were 189,000 and 150,000 seeds per square meter (in the 0–0.3 m soil depth) in 2010 and 2011, respectively, while it was less than 5,000 seeds per square meter in some parts of the field (Fig. 1 and 2). According to the results, vertical distribution of nutsedge seeds showed a descending order from 0.1 m to 0.3 m in the soil weed seedbank. The maximum density of weed seeds was at the 0–0.1 m soil depth (Fig. 1 and 2). The highest nutsedge seedling population was 175 and 134 seedling per m^2 in 2010 and 2011, respectively (Fig. 1 and 2).

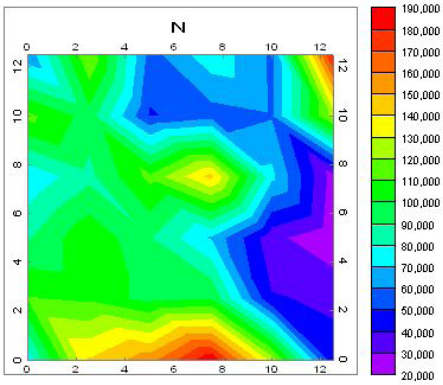
The soil seedbank maps showed that bahiagrass seed density within the upper 0.1 m of the soil profile was higher than 0.1–0.2 and 0.2–0.3 m of soil depth. The highest number of bahiagrass seeds was belong to 0.3 m of soil depth that was



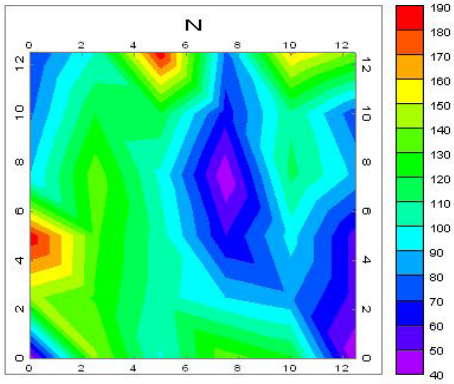
A – 0–0.1 m soil depth



B – 0–0.2 m soil depth

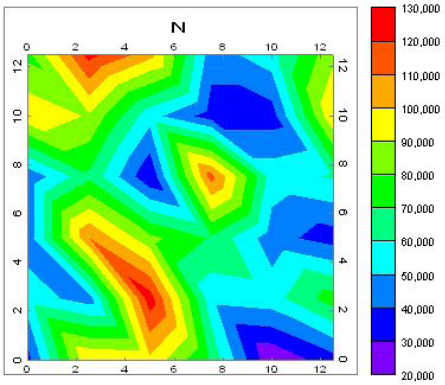


C – 0–0.3 m soil depth

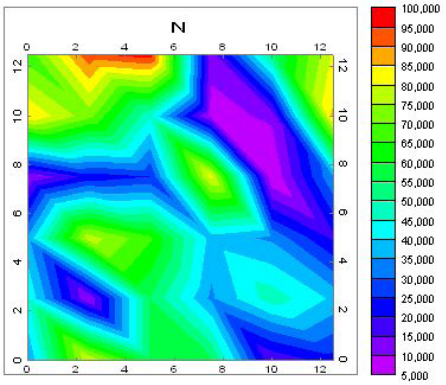


D – weed seedling

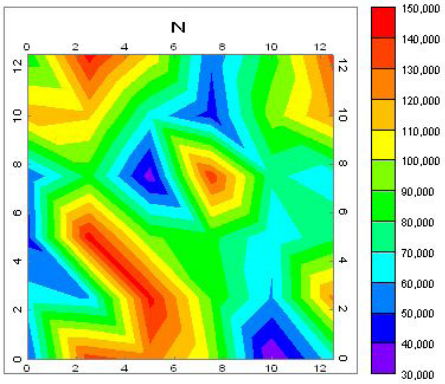
1: *Nutsedge (Cyperus spp. L.) seed and seedling distribution at different soil depths at Sari, Iran in 2010.*



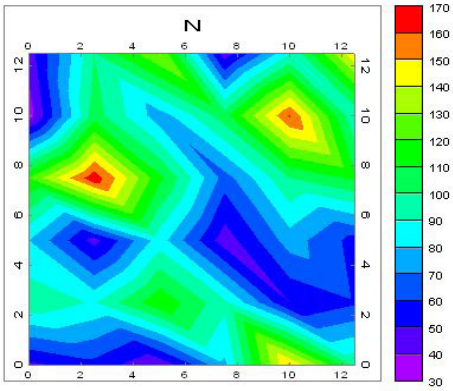
A – 0–0.1 m soil depth



B – 0–0.2 m soil depth

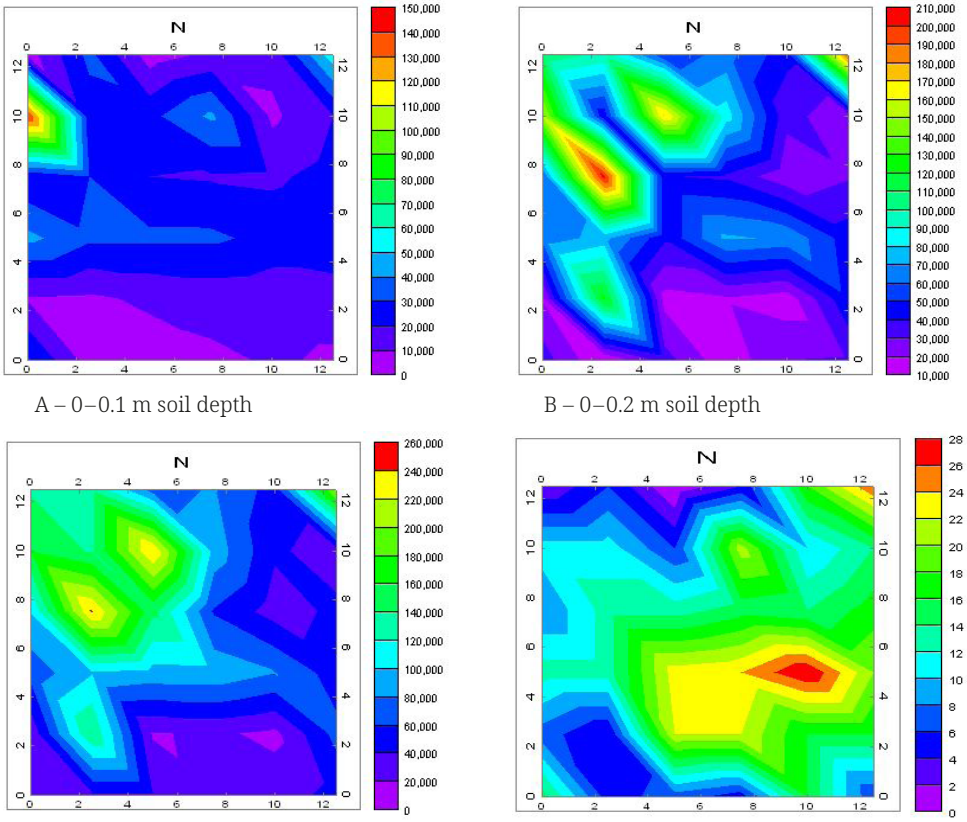


C – 0–0.3 m soil depth



D – weed seedling

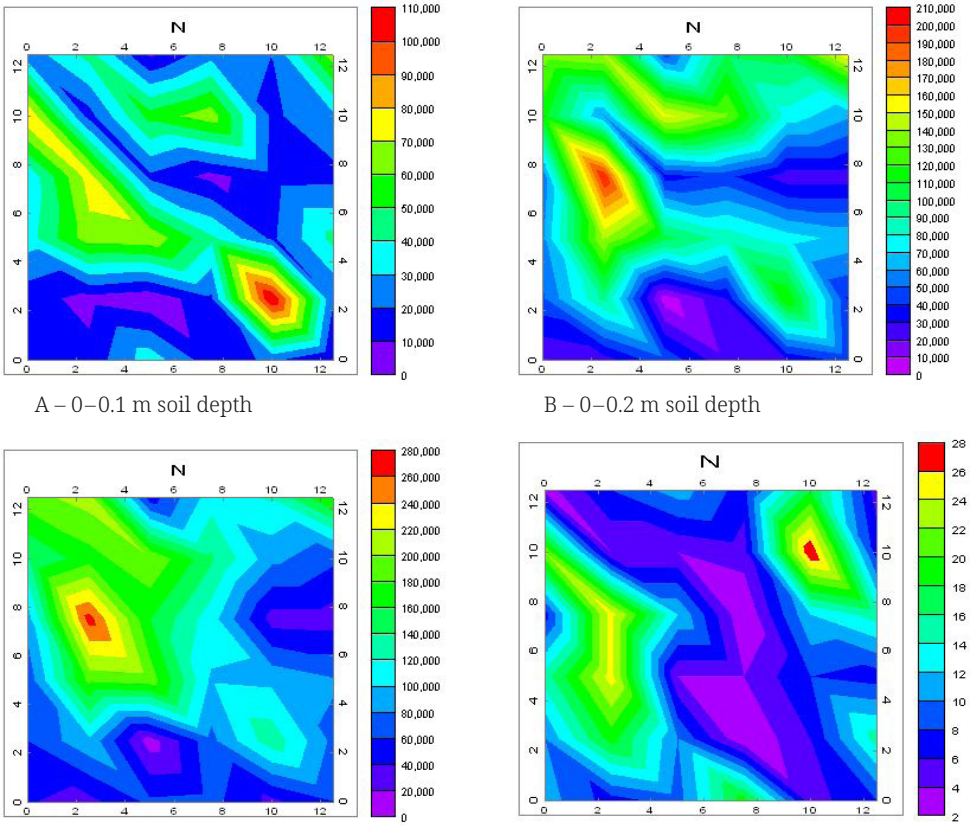
2: *Nutsedge (Cyperus spp. L.) seed and seedling distribution at different soil depths at Sari, Iran in 2011.*



A – 0–0.1 m soil depth B – 0–0.2 m soil depth

C – 0–0.3 m soil depth D – weed seedling

3: *Bahiagrass (Paspalum notatum L.) seed and seedling distribution at different soil depths at Sari, Iran in 2010.*



A – 0–0.1 m soil depth B – 0–0.2 m soil depth

C – 0–0.3 m soil depth D – weed seedling

4: *Bahiagrass (Paspalum notatum L.) seed and seedling distribution at different soil depths at Sari, Iran in 2011.*

equal to 260,000 and 280,000 seeds per m^2 in 2010 and 2011, respectively (Fig. 3 and 4). Bahiagrass weeds appear in the farm as patchy with different size and density similar to nutsedge (Fig. 3 and 4). Therefore bahiagrass and nutsedge were not uniformly distributed. Our data are similar to those reported by Roham *et al.* (2014) where they found that visual assessments of the weed emergence in the field that they studied was an indication of the existence of weeds in patches.

Kriging maps expressed that the spatial distribution of the weed seed bank was roughly in accordance with seedling germination pattern (Fig. 1–4). Mapping results showed some unusual features of the spatial distribution of weed seedbank and seedling communicates. For example, there were some parts of the field without seed or with very low seeds density in the soil seedbank, while weed seedling were more than several seedlings per square meter such as bahiagrass seed bank and seedling maps in 2010. There were also some areas within fields with high seedbank density but low seedling populations.

There were no significant relationships between soil seed banks (at different depths) and weed seedlings. Relation between nutsedge and bahiagrass seedlings and their seed bank at 0–0.1 m soil depth in 2010 were equivalent to $R^2 = 0.17$ and $R^2 = 0.34$ (as cubic equation), respectively (Tab. 1). While these coefficients at 0–0.2 and 0–0.3 m soil depth were less than 0–0.1 m soil depth. Regression coefficients for 0–0.2 m of soil depth were $R^2 = 0.08$ and $R^2 = 0.10$ (as cubic equation), and for 0–0.3 m of soil depth were $R^2 = 0.01$ and $R^2 = 0.13$ (as cubic equation), respectively (Tab. 1).

Our results demonstrated that there was a considerable variation among species and years. These coefficients for correlation between nutsedge seed bank and seedling in 2011 were $R^2 = 0.18$ (at 0–0.1 m soil depth), $R^2 = 0.08$ (at 0–0.2 m of soil depth) and $R^2 = 0.06$ (at 0-0.3 m of soil depth), respectively (Tab. 1). Regression analysis for bahiagrass indicated that the correlations were $R^2 = 0.05$ (at 0–0.1 m soil depth), $R^2 = 0.07$ (at 0–0.2 m soil depth) and $R^2 = 0.12$ (at 0–0.3 m soil depth), respectively (Tab. 1).

Visual evaluation of the weed seedling emergence in the field proved that the weeds often appear to occur in patches. Kriging maps indicated that the spatial distribution of weed seedlings is patchy across the field. Actually, these patches with high population are representative of a viable seedbank and proper conditions for weed seed germination (Mohammadvand *et al.,* 2007). These results comply with those of other research teams who have reported that nutsedge and bahiagrass are not uniformly distributed (Schuster *et al.* 2007; Loghavi and Mackvandi, 2008). By monitoring seedling emergence, Hughes (1996) also reported that most seedlings were germinated in patches with various densities, different sizes and shapes while a few individual plants appeared between patches. The patchy distribution of weed seeds and seedlings in a field depends on many factors such

I: *Regression coefficient for determining the relationship between weed seedbank and seedling of nutsedge (Cyperus spp. L.) and bahiagrass (Paspalum notatum L.) at Sari, Iran in 2010 and 2011.*

Weed	Year	Soil Depth (m)	Equation	Mean Square	R Square	Constant	b1	b2	b3
Nutsedge	2010	0–0.1	Cubic	2942.45	NS	57.195	0.002	1.58×10^{-8}	1.25×10^{-14}
		0–0.2	Cubic	1424.21	NS	44.687	0.002	1.59×10^{-8}	4.51×10^{-14}
		0–0.3	Cubic	2265.32	NS	3.841	0.003	2.97×10^{-8}	8.94×10^{-14}
	2011	0–0.1	Cubic	2738.17	NS	111.758	1.57×10^{-7}	3.24×10^{-8}	3.37×10^{-13}
		0–0.2	Cubic	1341.16	NS	179.631	–0.002	3.11×10^{-8}	8.87×10^{-14}
		0–0.3	Cubic	976.608	NS	242.473	–0.006	6.46×10^{-8}	2.30×10^{-13}
Bahiagrass	2010	0–0.1	Cubic	625.403	0.346**	3.002	0.001	9.98×10^{-9}	3.62×10^{-14}
		0–0.2	Cubic	61.644	NS	8.118	0	4.61×10^{-9}	1.63×10^{-14}
		0–0.3	Cubic	6.633	NS	13.784	7.93×10^{-6}	2.79×10^{-10}	9.16×10^{-14}
	2011	0–0.1	Cubic	31.25	NS	15.126	0	1.11×10^{-8}	6.55×10^{-14}
		0–0.2	Cubic	44.463	NS	8.106	0	1.88×10^{-9}	7.93×10^{-15}
		0–0.3	Cubic	72.628	NS	5.594	0	2.15×10^{-9}	6.04×10^{-15}

as interaction effects of weed biology, agricultural practices and local environmental conditions (Neve *et al.,* 2009; Nichols *et al.,* 2015)

The soil seedbanks density is generally higher in the upper soil layer. This pattern is supposed to illustrate the entry of seeds regularly at the surface and a more or less gradual decline in viability as seeds move vertically down the soil profile (Erfanzadeh *et al.,* 2010). Konstantinovic *et al.* (2011) reported that agronomic practices related to field preparation and tillage move most seeds into the lower depths of the soil. Moreover, weed seedbank composition and density are different according to the cultivated land history, differences in the amount of seeds produced, seed viability, germination and dormancy characteristics and genetic characteristics of native plants (Fleix and Owen, 2001).

Since the regression coefficients were not significant for any relationship between weed seed bank and seedling (except for relationship between bahiagrass seed bank and seedling at the 0–0.1 m soil depth in 2010), these finding cannot properly help to predict weed seedling emergence by determination of weed seeds population during the growing season. This section of our results is not consistent with other researches (Manley *et al.,* 2002; Barralis *et al.,* 1986) who reported that the information concerning the abundance and the composition of the weed seeds in seedbank is very momentous in recognizing the dynamics of the weed populations; and the use of the information on the seedbank is very useful in predicting future weed populations. Also, other researchers have indicated that the correlations between seed bank and field populations in the range of 0.30 to 0.50 (Wilson *et al.,* 1985). However in the case of nutsedge, Nishimoto *et al.* (1998) reported that the seeds are not often the source of new nutsedge (purple nutsedge) plants. Results of other investigators showed that soil seed banks are sometimes highly correlated (Looney and Gibson, 1995) and sometimes poorly correlated (Leck *et al.,* 1989) to the species composition of the vegetative community from which they are extracted. One of the reasons could be a seed source outside the measured area and the dispersal of seeds from outside the study site into this area.

Because the regression coefficient for the 0–0.1 m soil depth was more than other soil depths (Tab. 1), knowledge of the abundance and composition of seeds in the weed seedbank at this depth is important for better understanding the dynamics of weed populations. This may be caused because weed seedling emergence and seed bank depletion are greater from seeds near the soil surface, which also has a more favorable condition for seed germination, than from those more deeply buried (Zhang *et al.,* 1998). Also, Caetano *et al.* (2001) reported that weed seeds are a viable reservoir in the upper part of the soil profile, which determines the composition of weed flora in the region.

CONCLUSION

Determination of weed seeds in the soil is a tedious, time consuming and costly exercise. Thus, it will be very useful to determine the proper sampling depth that can be trusted in terms of prediction and accuracy of results and also acceptable, with respect to the time and the cost. Although study of weed seed bank, because of the inherent inconsistency of data from seed bank samples, has some difficulties, results of the current experiment demonstrate that geostatistics could improve the understanding of vertical distribution of two important weeds in rice. Based on these findings it can be concluded that the relationship between weed seed bank and weed emergence can be an efficient method to predict weed behavior throughout rice growth cycle. In the regions where rice fields infested with nutsedge and bahiagrass, soil samples obtained from 0–0.1 m of soil depth are the most appropriate in terms of accuracy and cost.

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