Available online at www.scholarsresearchlibrary.com

Scholars Research Library

Annals of Biological Research, 2013, 4 (2):318-326
(http://scholarsresearchlibrary.com/archive.html)

Scholars Research Library
ISSN 0976-1233
CODEN (USA): ABRNBW

Suitable crop rotation results in effective weed control in potato field

Mostafa Serajchi[1], Hossein Reza Rouhi*[2], Reza Ghorbani[1], Mohammad Hasan Rashed Mohasel[1], MehdiNasiri[1], Korosh Shojaie[1]

[1]Department of Agronomy, Faculty of Agriculture, Ferdowsi University, Mashhad, Islamic Republic of Iran
[2]Department of Agronomy and Plant Breeding, Faculty of Agriculture, Bu-Ali Sina University, Hamedan, Islamic Republic of Iran

---

ABSTRACT

Crop rotation is one of the most traditional and sustainable techniques in weed management in a way that a proper rotation could diminishes a majority of problematic weeds. In order to assess the response of weeds to a number of different rotations, a study was carried out on a six-year experiment which was arranged based on a randomized complete block design with four replications at Agricultural Research Station of Khorasan Razavi, in Northeastern of Iran. In this study crop rotations included: vetch-potato, canola-potato, barley-potato and fallow-potato. Each rotation was repeated three times during the 6-year course of the experiment. The dominant weed species were spring annual plants including common lambsquarters (Chenopodium album L.) and redroot pigweed (Amaranthus retroflexus L.). Barley-potato rotation significantly reduced weeds populations. In fallow-potato rotation the highest density of perennial weeds was observed. Canola-potato rotation proved highly successful in controlling weeds during the growing season and potato yield in this rotation was the greatest compare to other rotations. Canola had a drastic potential of weed suppression, and it can reduce weed density and dry matters if located in the crop rotations.

Keywords: Barley, Canola, Fallow, potato yield, Sustainable weed management, Vetch.

INTRODUCTION

In the last decades weeds of row-crops have been managed using synthetic herbicides in combination with mechanical cultivation on millions of hectares across the world [21]. Despite dramatic advances in chemical control, weeds also have been remained as a problem in agricultural systems. One explanation why weeds have retained their rank as the most damaging crop pests is the fact that weed communities continue to change in response to new management measures. For example, reduced-tillage systems resulted in increased abundance of herbaceous and woody perennial weeds, and farmers responded by increasing the number of herbicide applications. Public concern over health and environmental hazards associated with intense herbicide use spurred the development of highly specific, low-rate, low-toxicity herbicides, which caused rapidly developing herbicide resistance [21]. On the other hand, with increasing the number of herbicide applications, other problems will be created like herbicide resistance. Crop and herbicide rotations are key points to prevent the problem of herbicide resistance [9,11].

Agroecosystems may be specific in weed species, although some species can be found in the majority of ecosystems due to their extended ecological adaptation. Compared to monocultures, different crop rotations can create inconsistent environmental conditions and limit weed species adaptation to continuous crop production [5] and so, weed management can be fulfilled more easily [8]. Booth and Swanton (2002) suggested that less weed population oscillation would occur with weed communities comprised of a diversity of species, in contrast, weed populations increased with shorter rotations. Weed density, diversity, and evenness are all critical factors that influence agronomic decisions. Diverse rotations, or those with longer intervals between similar crops, facilitate more varied management practices and could slow down the directional shift of pest populations [8].

Anderson et al. (2007) concluded that, an additional tactic that helps farmers in weed management is combining rotations [8]. For example, horseweed was predominant in winter wheat–safflower–proso millet rotation but not in winter wheat–corn–proso millet. Combining these rotations to form a 6-yr sequence rotation suppressed horseweed. Another study conducted by Anderson and Beck (2007), showed that crop rotation was favorable for low weed density when crops arranged in a cycle of four, like two cool-season crops (Pea-winter wheat) followed by two warm-season crops (corn-soybean) . On the other hand, Nielsen et al. (2011) concluded that in order to minimize negative effects of weed on crop yield, cropping systems should rotate broadleaf crops with grasses, and also rotate summer or spring crops with winter crops [19]. Compared with continuous monoculture, diverse rotation may differ in light transition through the crop canopy, the herbicide(s) used the timing of tillage operations and the natural enemies living in the crop; such conditions make it difficult for a weed to dominate the plant community [18].The objective of the present study was comparing various rotations for weeds density and dry matter.

MATERIALS AND METHODS

The present study was conducted in a field with various crop rotations for a period of 6 years at Agricultural Research Station of Khorasan Razavi (35o 50' N, 59^{o} E), 1600m a.s.l. North Eastern of Iran during 2002-2007. Maximum and minimum absolute temperatures were 36.5° C and -23.5° C during the last year of study, respectively. The soil texture was loamy clay with 24% sand, 48% silt and 28% clay, and pH = 8.3. The EC was 2-4 for soil and 1.7-2.1 mmho cm^{-1} for irrigated water. Average annual rainfall was 280 mm for the past 20 year and the maximum rain occurred during November to May.

Experimental design was randomized complete block with four replications. Plot size was 12 by 10 m. Crop rotations included vetch-potato, barley-potato, canola-potato and fallow-potato. Each rotation was repeated three times during the 6-year course of the experiment. For instance, Canola-Potato rotation was repeated as follow: canola (2002)- potato (2003)- canola (2004)- potato (2005)- canola (2006)- potato (2007).

During the course of study, canola (Okapi cultivar), barley (CB-74-20 line) were planted between November 1-5 and vetch (local variety) were planted between April 22-27. The row spacing of vetch and canola was 30cm and distances plants in the row was 3 cm. Barley was planted with the density of 350 seeds m^{-2} and row distance of 20 cm. The fields were fertilized according to soil test every year. In the second, fourth and sixth years of experiment potato (Agria cultivar) were planted in all treatments. The seeding rate for potato tuber was 2.5 t ha^{-1} with 75 cm between and 25 cm within the rows and plants were irrigated weekly. During this research, herbicides were not used and during the period of potato growth, weed management was conducted through hand-weeding only once. In the final year hand-weeding was carried out once after first sampling at July 21.

Weed sampling was carried out randomly from 6 points in each plot by using a quadrate of 0.5 × 0.5 m three times during summer 2007, in July 18, August 20 and September 26. The weeds were cut at ground level and identified then counted and after being dried in an oven at 80° C, dry mater weights were determined.

All data was log-transformed and subjected to analysis of variance (ANOVA). Data was analyzed, using SAS version 9.1 (SAS Inst 1988) and differences between treatments were compared, using Least Significant Difference (LSD) tests at the P = 0.05 level [12].

RESULTS

Weed species

From 11 identified weed species (Table 1), two of them including Russian knapweed (*Acroptilon repens*) and common purslane (*Portulaca oleracea*) were observed only in the first sampling and they were absent in the second and third sampling dates. Weeds were removed by hand weeding immediately after doing the first weed sampling. Table 1 show that the majority of observed weed species were annual broad leaves. Regardless of perennial or annual plants, all observed weeds were summer species. This could be due to planting potato in spring, and cultivating the soil before planting which eliminate winter weeds. Within these 11 species, redroot pigweed, common lambsquarters, barnyardgrass and black nightshade were some of the worst annual weeds of the world as well [14].

Weed density

First sampling date

Minimum and maximum numbers of weeds were observed in canola-potato and vetch-potato with 17 and 40.5 weeds m^{-2} respectively (Table 2). In the first sampling date, an outstanding part of the total density of weeds in different rotations was allocated only to 4 species; redroot pigweed, common lambsquarters, field bindweed and barnyard grass.

Higher weed density in rotation of vetch-potato could be due to the size of vetch seeds and it's weakness in establishment as well as decreasing the competitiveness and, therefore, inability in suppressing weeds. Moreover, 70.16% of weeds in vetch-potato rotation were annual broad leaves. In barley-potato rotation, low density of weeds was observed. Total weed density in barley-potato rotation was 24.4 plant m^{-2} from which 95.9% consisted annual weeds, and half of them was devoted to common lambersquarters.

In the fallow-potato rotation, weeds density reached 32.5 plant m^{-2} and field bindweed was most frequently observed (22% of all weeds). This could be due to the higher number of propaguls in fallow-potato rotation. Less soil manipulating during fallow year provided more stable conditions for perennial weeds. During fallow period, field bindweed had the opportunity to expand its roots and rhizomes and in the following year when potato was planted field bindweed caused more problem compare to other rotations.

Second sampling date

In the second sampling date, weed density was significantly decreased which was due to earlier hand weeding operation (Fig 1 and Table 1). In the second sampling date, Russian knapweed and common purslane, were not observed but it does not mean that they were eliminated completely. Number of weeds in different rotations was between 6-12 plant m^{-2}, however, this rise in weed density was accompanied by the increase in weed weight in each species. In other words, although many seedlings were deleted during the first hand-weeding, the remaining seedlings were capable to grow and occupy vacant places and compete with crops. In the second sampling date, the majority of weeds were negligible and only 5 weed species including common lambsquarters, redroot pigweed, field bindweed, barnyardgrass and spiny sowthistle were dominant species. Field bindweed was the only perennial weed with high density. Other perennial weeds such as camelthorn, hoary cress and Russian knapweed were observed at low densities in different rotations. Annual weeds contribute to a high percentage among which barnyardgrass was the densest species. Like the first sampling date, weed density was least in canola-potato rotation. In the fallow-potato rotation the densest weed species was field bindweed (42.9%).

Third sampling date

The third sampling stage was near the end of potato growth season and it is important stage for potato production. At this stage more than 60% of weeds were broad-leaves species. Similar to the first sampling dates, canola-potato rotation with 5.4 weed m^{-2} had the least number of weeds among other rotations (Fig 1). Field bindweed was one of the problematic weeds in the majority of rotations except canola-potato rotation (Table 2). In third sampling date, more than 90% of weeds were devoted to common lambsquarters, redroot pigweed, field bindweed, barnyardgrass and spiny sowthistle. It was also observed that common lambsquarters and barnyardgrass had the highest percentage of relative weed density. In fallow-potato rotation, field bindweed possessed the most percentage and barnyardgrass ranked second most important weed species.

Weeds dry matter

First sampling

In the first sampling date, the majority of plant species was small seed weeds and allocated mostly to common lambsquarters and redroot pigweed (Table 3). Since in the first sampling, common lambsquarters seedlings were very common weed, its higher dry weight was not surprising. Potato canopy was not closed and weeds were grown without any light restriction. In barley-potato rotation, more percentage of dry matter was devoted to redroot pigweed (53.7%), common lambsquarters (27.3%) and other weeds contribute a small part. In fallow-potato rotation, high percentage of weed dry matter (52.46%) was observed in perennial weeds, mainly field bindweed (47.4%) and this weed species had higher dry weight and population in fallow-potato compared to other rotations. Weed dry matter weights were considerable lower in canola-potato rotation than other rotations (Fig 2).

Second sampling

Weed density decreased severely in the second sampling due to hand weeding which was carried out after doing first sampling. However, the existing weeds could compensate their population and total dry weights. The highest weed dry weight was observed in vetch-potato rotation (48.8 g m^{-2}) and the least weed dry weight was in canola-potato rotation (13.4 g m^{-2}). More than 90% of the weed dry matters were belonged to 4 species including common lambesquarters, redroot pigweed, field bindweed and barnyardgrass. Barnyardgrasses which remained after the first hand-weeding was grew up rapidly and consisted about 33% of total weed dry weight in vetch-potato rotation. Weed dry matters in barley-potato rotation were allocated to common lambsquarters, redroot pigweed and barnyardgrass (about 93%). The lowest weeds dry weight (13.48 g m^{-2}) was observed in canola-potato rotation, in which 80% of them were allocated to annual broad-leaves species.

Third sampling date

Weed dry matter weights were considerably higher in majority of rotations during the third sampling stage. Vetch-potato rotation had higher rate of dry matter compared to other rotations (Fig 2). At this stage, the majority of redroot pigweeds were eliminated because of early season chilling and they were not involved in higher percentage of dry weights (Table 3). Generally, most part of dry weight was contributed to those weed species that tolerated early chilling conditions. It was observed that those weeds which escaped from hand-weeding such as common lambsquarters, being huge at this stage.

In conclusion, canola-potato rotation showed the potential to decrease weed dry weight up the end of potato growth and had lowest weed dry weight compare to other rotations (17.5 g m^{-2}). The highest weed dry weight was recorded in vetch-potato rotation (68 g m^{-2}).

Potato yield

Results showed that potato yields were affected by different rotations in the last year of experiment (Fig 3). Potato yield in canola-potato rotation was greatest compared to other rotations (52.98 t ha^{-1}). On the other hand, the lowest potato yield was achieved by fallow-potato rotation (33.8 t ha^{-1}), however, no statistical difference was observed in either barely-potato or vetch-potato rotations.

DISCUSSION

Weed density

Legere and Sterenson (2002) noted that, different crops in various rotations can have outstanding effect on weed density. Based on the results in first sampling, it seems that the management of mentioned weed species in potato farms is crucial [15].

Dorado et al. (1999) found density of observed weeds in the farm under barley-mung bean rotation is more than continuous planting of barley [11]. They related it to the weakness competition of mung bean. It seems that the shortness of bush and open canopy of this plant let the light penetrate into the canopy, therefore, weeds could captured the light more efficiently. However, Anderson (1997) showed that the productivity of many weeds is higher in less-developed crop canopy [1].

Ability of a crop to cover and make a dense canopy in the ground in the first stage of growth period is the main factor for preventing weeds growth. It seems that due to having a dense plant canopy in barley and its allelopathic effects [16], it can have good potential to reduce weeds population.

In canola-potato rotation, canola decreased weed population to 17 plants m^{-2} by establishing dense canopy and possibly exudation of allelopatic products from its roots [13].

In third sampling date, more than 60% of weeds were broad-leaves species. It appears that morphological similarity of the crops and weeds influenced the type of weed species presence or appearance [10]. Based on results in third sampling, these dominant species (common lambsquarters, redroot pigweed, field bindweed, barnyardgrass and spiny sowthistle) were the most important weeds because they were resistant to control measures or adapted to the cropping systems [7]. In fallow-potato rotation, field bindweed possessed the most percentage and barnyardgrass ranked second most important weed species. It seems that frequent moving of perennial shoots could result in rhizome depletion [1]. Furthermore, Anderson and Beck (2007) observed that weed density varied 13-fold among different studied rotations [4]. Without application of herbicides the impact of crop rotation best demonstrated highly effective on *Bromus* spp. and its density varied 75-fold among different rotations. They also concluded that even with using herbicides, crop rotation still affected weed population.

Weeds dry matter

Mortensen et al. (2000) encouraged scientists and producers to broaden their perspective in considering weed-control tactics [17]. They suggested a better consideration in design of cropping systems for weed management. Our results also support this attitude, as weed density and dry matters were varied among rotations. Therefore, getting familiar with the suitable rotation for each region resulted in decreasing weed population and preventing weed species from outbreaking. Anderson (2005) reported that weed control in proper rotations costs 50% less [3]. In the present study, it was observed that canola could control weeds effectively. Canola can help farmers to control weeds with less relying on application herbicides in agroecosystems especially in organic and sustainable agricultural systems.

Potato yield

In our experiment, potato yield in canola-potato rotation was greatest in compared to other rotations, Verhulst et al. (2011) suggested that rotation can influence crop growth and development [22].

Table 1. Names and features of observed weeds in three sampling dates*

Scientific name	Common name	WSSA Code	Family	Life cycle
Acroptilon repens L.**	Russian knapweed	CENRE	Asteraceae	Perennial
Alhagi pseudalhagi (Bieb.) Desv. ex B. Kesler & Schapanenko.	Camelthorn	ALHPS	Fabaceae	Perennial
Amaranthus retroflexus L.	Redroot pigweed	AMARE	Amaranthaceae	Annual
Cardaria draba (L.) Desv.	Hoary cress	CADDR	Brassicaceae	Perennial
Chenopodium album L.	Common lambsquarters	CHEAL	Chenopodiaceae	Annual
Convolvulus arvensis L.	Field bindweed	CONAR	Convulvulaceae	Perennial
Echinochloa crus-galli (L.) Beauv.	Barnyardgrass	ECHCG	Poaceae	Annual
Hyoscyamus niger L.	Black henbane	HSYNI	Solanaceae	Annual
Portulaca oleracea L.**	Common purslane	POROL	Portulaceae	Annual
Solanum nigrum L.	Black nightshade	SOLNI	Solanaceae	Annual
Sonchus asper (L.) Hill	Spiny sowthistle	SONAS	Asteraceae	Annual

** First, second and third stages of sampling were done in July 18, August 20 and September 26, 2007, respectively.*
*** A. repens and P. oleracea were observed only in the first sampling but not in the second and third sampling.*

Table 2. Relative weeds density in the last year of 6-year crop rotations at three sampling dates (July 18, August 20 and September 26) in potato field.

	Crop rotation with Potato											
	Fallow	Canola	Barley	Vetch	Fallow	Canola	Barley	Vetch	Fallow	Canola	Barley	Vetch
Scientific name	First sampling (%)				Second sampling (%)				Third sampling (%)			
Chenopodium album	30.8	46.07	45.72	42.21	20.12	57	38.24	18.82	14.82	39.46	38.46	21.99
Amaranthus retloflexus	18.49	13.72	17.45	15.19	8.38	5	13.11	16.13	4.23	9.4	10.82	11.39
Convolvulus arvensis	22.01	-	-	3.69	42.98	-	8.19	7.51	45.19	-	6.15	5.78
Echinocloa crus-galli	19.48	23.55	17.06	22.46	20.21	22.75	32.78	38.99	27.52	24.2	30.74	40.94
Alhagi pseudalhagi	1.02	2.94	2.04	2.46	6.7	5	5.06	12.1	3.05	9.1	4.68	13.99
Sonchus asper	4.12	2.94	4.08	8.44	-	2.5	2.64	1.29	2.09	-	3.07	1.97
Solanum nigrum	1.02	-	1.36	-	1.61	7.75	-	2.58	1.01	2.91	4.61	1.97
Hyoscyamus niger	2.04	6.86	8.87	2.31	-	-	-	1.29	-	2.91	-	1.97
Acroptilon repens	-	1.96	2.06	-	-	-	-	1.29	2.09	12.02	1.47	-
Cardaria draba	0.51	1.96	-	1.23	-	-	-	-	-	-	-	-
Portulaca oleracea	0.51	-	1.36	2.01	-	-	-	-	-	-	-	-
Total of relative weed density	100	100	100	100	100	100	100	100	100	100	100	100
Relative density of annual narrow leaf	19.48	23.55	17.06	22.46	20.21	22.75	32.76	38.99	27.52	24.2	30.74	40.94
Relative density of annual broad leaf	56.98	69.59	78.84	70.16	36.81	77.25	59.05	50.92	25.2	60.87	61.64	51.31
Relative density of perennial narrow leaf	-	-	-	-	-	-	-	-	-	-	-	-
Relative density of perennial broad leaf	23.54	6.86	4.1	7.38	42.98	-	8.19	10.09	47.28	14.93	7.62	7.75

Table 3. Relative weeds dry matter in the last year of 6-year crop rotations at three sampling dates (July 18, August 20 and September 26) in potato field.

	Crop rotation with Potato											
	Fallow	Canola	Barley	Vetch	Fallow	Canola	Barley	Vetch	Fallow	Canola	Barley	Vetch
Scientific name	First sampling (%)				Second sampling (%)				Third sampling (%)			
Chenopodium album	19.24	51.42	27.31	38.05	26.24	62.36	43.2	33.88	54.14	37.71	35.09	47.11
Amaranthus retloflexus	23.65	25.14	53.79	20.04	8.66	16.28	35.37	17.32	7.32	23.87	45.45	19.14
Convolvulus arvensis	47.45	-	-	7.61	52.82	-	3.15	2.52	23.08	-	2.1	6.14
Echinocloa crus-galli	2.42	2.89	2.52	9.49	8.8	20.21	14.48	33.07	13.34	24.84	12.1	14.53
Alhagi pseudalhagi	4.92	14.51	3.97	18.01	2.8	0.05	3.3	8.5	2.05	8.53	2.09	9.58
Sonchus asper	0.72	0.1	0.78	1.93	-	0.1	0.5	2.1	0.01	-	2.02	2.4
Solanum nigrum	0.08	-	1.82	-	0.68	1	-	1.01	0.05	2.3	1.1	0.6
Hyoscyamus niger	1.4	1.11	2.65	0.94	-	-	-	0.5	-	1.35	-	0.5
Acroptilon repens	-	2.63	4.21	-	-	-	-	1.1	0.01	1.4	0.05	-
Cardaria draba	0.09	2.2	-	0.81	-	-	-	-	-	-	-	-
Portulaca oleracea	0.03	-	2.95	3.12	-	-	-	-	-	-	-	-
Total of relative weed dry mater	100	100	100	100	100	100	100	100	100	100	100	100
Relative dry mater of annual fine leaf	2.42	2.89	2.52	9.49	8.8	20.21	14.48	33.07	13.34	24.84	12.1	14.53
Relative dry mater of annual broad leaf	45.12	77.77	89.3	64.08	38.38	79.79	82.37	62.81	63.57	72.41	85.75	78.83
Relative dry mater of perennial fine leaf	-	-	-	-	-	-	-	-	-	-	-	-
Relative dry mater of perennial broad leaf	52.46	19.34	8.18	26.43	52.82	-	3.15	4.12	23.09	2.75	2.15	6.64

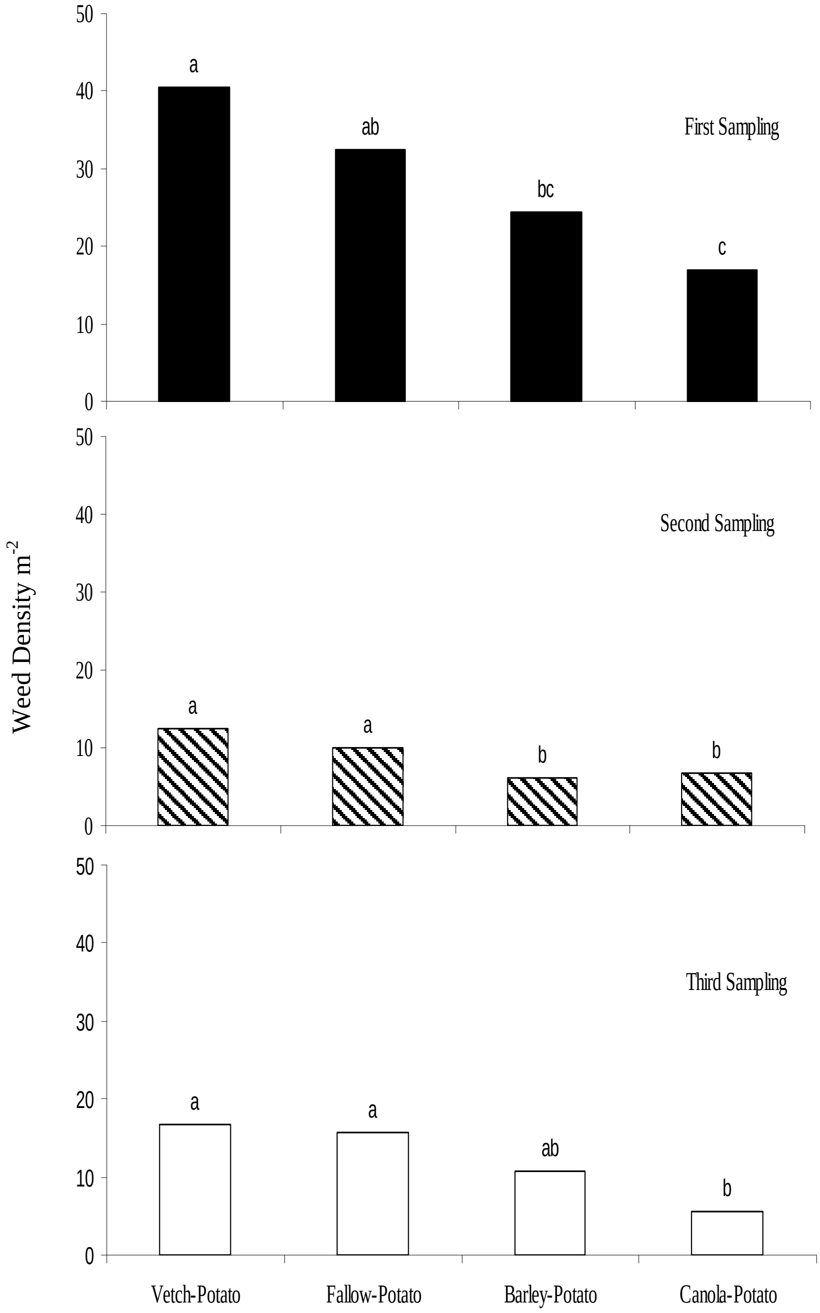

Fig 1. Total weed densities in the last year of 6-years crop rotations at three sampling dates of 2007, July 18, August 20 and September 26. Means with common letters in each sampling date are not significantly different at $p \leq 0.05$.

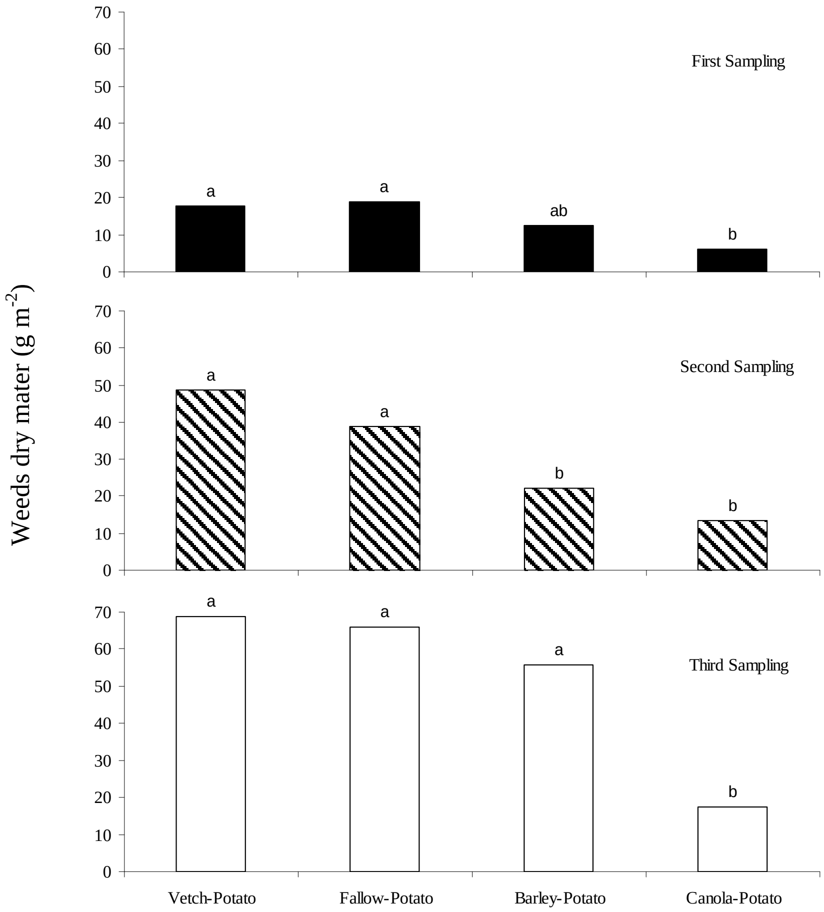

Fig 2. Total weed dry matter in the last year of 6-years crop rotations at three sampling dates of 2007, July 18, August 20 and September 26. Means with common letters in each sampling date are not significantly different at $p \leq 0.05$.

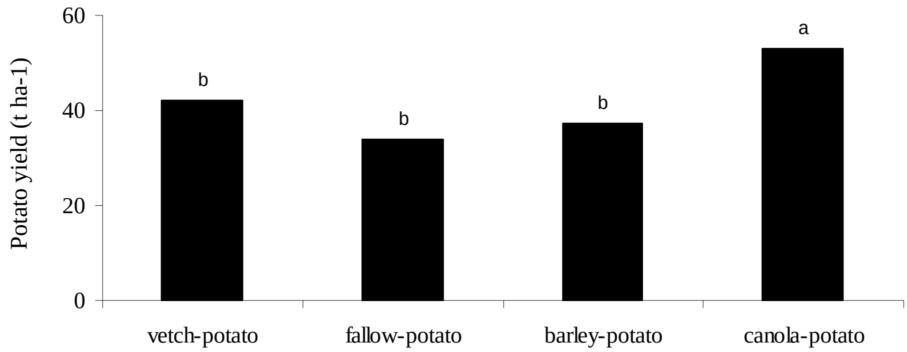

Fig 3. Potato yield in final year of different rotations.
Means with common letters are not significantly difference at $p \leq 0.05$.

Acknowledgements
Special thanks to Agriculture Research and Natural Resources Center of Khorasan Razavi province for their kind cooperation and assistance. We would like to thank Mrs. Asieh Siahmarguee and Mr. Farzin Pour-Amir for their assistance. This project was partially sponsored by Faculty of Agriculture, Ferdowsi University.

REFERENCES

[1] RJ. Aldrich, and RJ. Kremer, *John Wiley and Sons, New York.***1999.**
[2] RL. Anderson, *Weed Technology.* **1997.** 11: 608-613.
[3] RL. Anderson, *Agron Journal.* **2005.** 97:1579-1583.
[4] RL. Anderson, and Dl. Beck, *Weed Technology.* **2007.**21: 76-79.
[5] RL. Anderson, CE. Stymiest, BA. Swan, and JR. Rickertsen, *Weed Technology.* **2007.** 21:131-135.
[6] BD. Booth, and CJ. Swanton, *Weed Science.* **2002.** 50: 2-13.
[7] DD. Buhler, KA. Kohler, and RL. Thompson, *Weed Technology.***2001.** 15:170-176.
[8] RJ. Cathcart, AK. Topinka, P. Kharbanda, R. Yang, and LM. Hall, *Weed Science.* **2006.** 54:726-734.
[9] R. Cousens, and AM. Croft, *Weed Research.* **2000.** 40: 63-82.
[10] DA. Derksen, GP. Lafond, AG. Thomas, HA. Loeppky, and CJ. Swanton, *Weed Science.* **1993.** 41: 409-417.
[11] J. Dorado, JP. Delmonte, and C. Lopex–Fando, *Weed Science.* **1999.** 47: 67-73.
[12] K. Gomez, and A.Gomez, John Wiley and Sons, New York.**1984.**
[13] ER. Haramoto, and ER. Gallandt, *Weed Science.* **2005.** 53:695-701.
[14] LG. Holm, DL. Plucknett, JV. Pancho, and JP. Herberger, *University press of Hawaii, Honolulu.***1977.**
[15] A. Legere, and FC. Sterenson, *Weed Science.* **2002.** 50:101-111.
[16] DL. Liu, and JV. Loverr, *Journal of Chemial Ecology.* **1993.** 19: 31-44.
[17] DA. Mortensen, L. Bastiaans, and M. Sattin, *Weed Research.* **2000.** 40: 49-62.
[18] SD. Murphy, DR. Clements, S. Belaoussoff, PG. Kevan, and CJ. Swanton, *Weed Science.* **2006.** 54: 69-77.
[19] DC. Nielsen, MF. Vigil, JG. Benjamin, *Field Crops Research.* **2011.** 120:254-261.
[20] A. Shrestha, SZ. Knezevice, RC. Roy, Ball-Coelho and CJ. Swanton, *Weed Research.* **2002.** 42:76-87.
[21] LM. Sosnoskie and J. Cardina, Weed Science. **2006.** 54:263-273.
[22] N.Verhulst, B.Govaerts, V. Nelissen, KD. Sayre, J. Crossa, D. Raes, J. Deckers, *Field Crops Research.* **2011.** 120: 58–67.