Phytotoxicity of black cumin (*Nigella sativa*), dragonhead (*Dracocephalum moldavica*), dill (*Anethum graveolens*), and soybean (*Glycin max*) residues on emergence and establishment of wheat

Sian Fallah[1]*, Zahra Alimohammadi[1], Zohrab Adavi[2] and Mojtaba Karimi[1]

1. Faculty of Agriculture, Shahrekord University, Shahrekord, Iran
2. College of Agriculture, Payame Noor University, Isfahan, Iran

Abstract

Allelopathic effects of plant residues is an important research avenue regarding optimization of rotation systems in agronomy. The aim of this study was to investigate the allelopathic effects of four plant residues, namely, black cumin, dragonhead, dill, and soybean on the germination and growth of wheat (*Triticum aestivum*) in different cropping systems. Results showed that application of organic manure for previous crops reduced the residue phytotoxicity and consequently alleviated the adverse effect of plant residues on the leaf area, length, and dry weight of the wheat root, affecting chlorophyll a, chlorophyll b, and carotenoids of wheat seedling leaves. In the presence of plant residue, the length and dry weight of the wheat roots were more negatively affected in comparison with shoots. The greatest allelopathic inhibition was observed for the wheat cultivated in the residue of black cumin, but soybean, dill, and dragonhead residues also potentially showed inhibition effects. It can be concluded that agroecosystems in which autumn wheat is in the rotation should be avoided where there are residues of soybean, black cumin, dragonhead, and dill. The tillage system in the same condition may not be agronomically suitable because of the allelopathic effects of previous crops.

Keywords: allelopathy; medicinal plant; photosynthetic pigment; phytotoxicity

Fallah, S., Z. Alimohammadi, Z. Adavi and **M. Karimi.** 2019. 'Phytotoxicity of black cumin (*Nigella sativa*), dragonhead (*Dracocephalum moldavica*), dill (*Anethum graveolens*), and soybean (*Glycin max*) residues on emergence and establishment of wheat'. *Iranian Journal of Plant Physiology,* 10 (1), 3059-3071.

Introduction

Common wheat (*Triticum aestivum* L.) supplies about 20% of the daily caloric intake and 21% of daily protein intake of humans (17) and it is a staple of the world's population diet, which includes poorest and low-income countries (Macias et al., 2007). Sustainability is a major aspect of production of food crops in agricultural ecosystems and also for protecting these ecosystems for current and future generations (Altieri and Nicholls, 2017). An increase in biodiversity through crop rotation can increase sustainability in agriculture. Rotation systems and allelopathic interactions between plants-plants would be important to exploit allelopathy in order to optimize the production of rotation systems (Li et al., 2010).

Allelopathic compounds such as phenolic acids, flavonoids, terpenoids, coumarins, tannins,

*Corresponding author
E-mail address: falah1357@yahoo.com
Received: May, 2019
Accepted: November, 2019

terpenes, steroids and quinones directly or indirectly affect the natural cycle of plant growth (Singh et al., 2006). The inhibitory or stimulatory effects of allelopathic compounds depend on the concentrations available to the succeeding plants and the sensitivity of the recipient plants (Mirtorabi et al., 2011). Additionally, the activity of allelochemicals in agroecosystems is highly dependent on their soil persistence (Fallah, et al., 2018). The mode of action of allelopathic materials may differ according to the plant species. The major effects of these materials on plants include the prevention of seed germination, damage to the root and other parts of the meristems, prevention of the growth of emerging buds, prevention of the ATP biosynthesis due to the lack of oxygen in the chloroplast, and severe prohibition of mitochondrial activity and cellular respiration (Rostaei et al., 2018a).

Abu-Romman (2011) reported that the essential oil of *A. biebersteinii*, which was found to be rich in ascaridol, p-cymene, carvenone oxide, and camphor, showed inhibitory effects on seed germination and seedling growth of several weed species. Similarly, α-pinene was found to have an inhibiting effect on the early root growth of soybean, causing an oxidative damage in the root tissue through the enhanced generation of reactive oxygen species as indicated by increased lipid peroxidation, and finally disrupting the membrane integrity and elevated antioxidant enzyme levels (Rostaei, et al., 2018b). Azirak and Karaman (2008) reported that thymol, carvacrol, and carvone showed a high inhibitory effect against weed seeds, even at low concentrations.

The essential oils of *Chenopodium ambrosioides* L., i.e. Alpha-terpinene, γ-terpinene, p-cymene, limonene, and ascaridole (1-methyl-4 (1-methylethyl) -2-3-dioxibicyclo (2.2.2) oct-5-ene), inhibited the germination of *Amaranthus hypochondriacus* by 50%, while the hypocotyl growth of the previously germinated seeds of the same species was inhibited by 50% (0.509 µl/petri dish) (Anaya, 1999).

The presence of β-phellandrene (51.2%), δ-2-carene (43.4%), dihydrotagetone (0.4%), and propyl butyrate (0.3%) in the aerial parts and phenylacetaldehyde (39.2%), δ-3-carene (31.7%), 6-methyl-5-hepten-2-one (16.4%), and α-phellandrene (12.6%) in the roots of Justicia *ancelliana* induced a remarkable reduction in the growth of the roots, the apparition of yellow leaves after two weeks of the treatment and the death of the *Vigna unguiculata* young plants (Qasem, 1992). Essential oil of *Thuja orientalis* has shown a high concentration of monoterpene hydrocarbons and the major constituents were *α*-pinene (64.2 and 49.3%, respectively in cones and needles), *β*-phellandrene (6.7-9.6%), and *α*-cedrol (3.9 and 8.2%). This essential oil had a strong

Table 1
Treatment descriptive of this experiment

Plant type (Previous crop) (4 levels)	Nutritional condition of previous crop (2 levels)	Plant residue applied before wheat sowing (2 levels)
Soybean	CF	+
Soybean	CF	-
Soybean	OM	+
Soybean	OM	-
Black cumin	CF	+
Black cumin	CF	-
Black cumin	OM	+
Black cumin	OM	-
Dill	CF	+
Dill	CF	-
Dill	OM	+
Dill	OM	-
dragonhead	CF	+
dragonhead	CF	-
dragonhead	OM	+
dragonhead	OM	-

CF and OM: represent chemical fertilizer and organic manure, respectively; + and - : with and without reside, respectively inhibitory effect on all tested weeds following a dose-dependent manner, an attribute that can be employed in biocontrol and management of weeds (Amri, I2015).

Although a soybean (*Glycine max* (L.) Merr)-wheat (*Triticum aestivum* L.) rotation appears to be a logical opportunity to use legume N as a sustainable grain production resource, the experimental results suggested that soybean root exudates were responsible for the decrease in wheat and triticale growth and yield (Mamolos, and Kalburtji, 2001). The drought-stressed soybean leaf extracts were found more effective in modulating the physiology of maize, indicating the higher allelopathic potential of soybean (Ahmad, et al., 2016).

In semi-arid regions, the cultivation of medicinal plants has increased due to value added of these plants and their increasing consumption. A large percentage of medicinal plant residues is released into a field after harvesting in both conventional and organic agricultural systems. These plant residues may have allelopathic effects on wheat seed germination and establishment. Because there is no information about the response of wheat to the residue of black cumin, soybeans, dragonhead, and dill, the present study was conducted to investigate the effects of these plant residues on the germination and establishment of common wheat.

Materials and Methods

In this research, four crops (soybean (*Glycine max*), black cumin (*Nigella sativa*), dragonhead (*Dracocephalum ruyschiana*), and dill (*Anethum graveolens*)) were grown under two nutritional conditions (chemical and organic fertilizers) in the agricultural research farm of Shahrekord University (Latitude 32°21´ north and longitude 50° 49´ East, 2061 m above sea level) in 2016. The average annual rainfall of the region was 319 mm and annual average temperature was 11.5 °C. Soybean was cultivated as an important legume (control crop) and the other three plants were selected as important medicinal plants in the region and alternately with the wheat crop. Each crop was cultivated in two independent plots on 24 May 2016. One plot received the chemical fertilizer while the other plot was fertilized with organic manure. Organic manure (broiler litter manure) or chemical fertilizer (urea and superphosphate triplet) was mixed with the soil of the res plots before sowing.

Table 2
Effects of plant type, plant residue, and fertilization type on emergence rate, root and leaf length, and leaf area of common wheat (percentage compared to control)

Residue density	Plant type	Emergence rate (% control)	Root length (% control)	Leaf length (% control)	Leaf area (% control)
		Chemical fertilizer			
Without residue	Soybean	92.9^{bcd}	78.5^{bc}	78.9^{de}	83.7^{efg}
	Black cumin	84.6^{bcd}	50.1^{f}	76.5^{def}	87.0^{def}
	Dragonhead	92.0^{abcd}	74.3^{bcd}	108^{b}	98.4^{bcd}
	Dill	93.1^{abc}	67.0^{cd}	134^{a}	112^{b}
With residue	Soybean	63.0^{e}	16.2^{bc}	51.1^{gh}	76.4^{fg}
	Black cumin	42.8^{f}	7.8^{i}	29.6^{i}	17.8^{i}
	Dragonhead	85.5^{bcd}	53.2^{ef}	73.4^{def}	79.1^{fg}
	Dill	61.5^{e}	25.0^{gh}	59.1^{fg}	42.0^{h}
		Organic fertilizer			
Without residue	Soybean	81.1^{cd}	79.8^{b}	50.5^{cde}	95.7^{cde}
	Black cumin	94.0^{ab}	33.5^{g}	91.4^{bcd}	102^{bc}
	Dragonhead	98.1^{a}	64.4^{de}	138^{a}	163^{a}
	Dill	95.2^{ab}	139^{a}	98.0^{bc}	104^{bc}
With residue	Soybean	79.9^{d}	52.8^{ef}	71.6^{ef}	87.7^{def}
	Black cumin	46.7^{f}	11.2^{i}	35.6^{hi}	27.6^{ij}
	Dragonhead	60.1^{e}	17.4^{hi}	64.5^{efg}	70.8^{g}
	Dill	46.1^{f}	18.8^{hi}	63.6^{efg}	32.1^{hi}

In each column, means with different letters indicate significant differences at P < 0.05 by LSD test.

The dragonhead and dill were harvested at the complete flowering stage and the

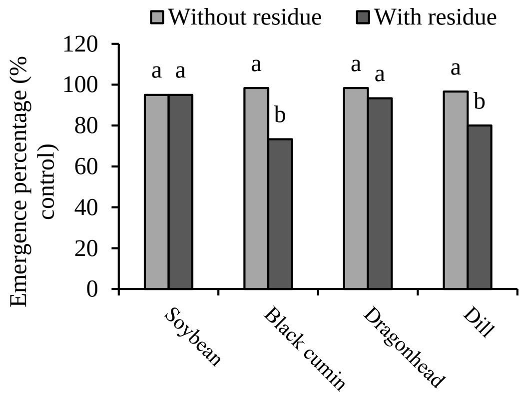

Fig. I. Wheat emergence percentage as affected by plant type × plant residue interaction; different letters indicate significant differences at P<0.05 by LSD test.

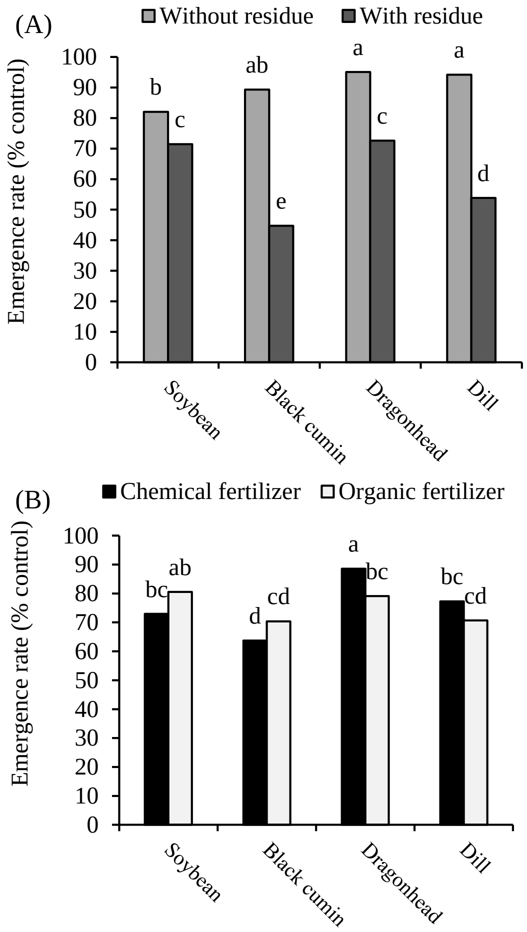

Fig. II. Wheat emergence rate as affected by plant type × plant residue (A) and plant type × fertilizer type interaction (B); Different letters indicate significant differences at P<0.05 by LSD test.

black cumin and soybean were harvested at maturity stage. Then, plant residues of each plot were separately collected from the soil surface on October 10, 2016. Plant residues were transferred to the laboratory and kept at 70° C to dry in an oven for 2 days. At the rhizosphere of each crop and each nutrition system, one kg soil was sampled and totally 8 soil treatments (previous crop × nutritional conditions, 4 × 2, respectively) of rhizosphere were prepared (Table 1).

Analysis of essential oils of dragonhead shoot, black cumin, and dill seeds by GC/MS were done and data presented in Fallah et al. (2018) and Rostaei et al. (2018a, 2018b).

The pots (14 cm in diameter and 9.5 cm in height) were filled with 500 g of respective rhizosphere soil treatments. Pots were divided into two groups (with and without plant residue, respectively). Then, plant residues were crushed into small pieces (1 to 2 cm) and 25 g of which was added to the pot and thoroughly mixed with the soil. The quantity of residues were 16250 kg/ha. The plowed soil under field cultivation was used for the control treatment. The study was conducted through a factorial (plant type, plant residue, and nutritional conditions with 4, 2, and 2 levels, respectively) experiment based on a completely randomized design with three replications.

Ten wheat seeds were sown at 3 cm depths on October 31, 2016. The wheat irrigation was done from the bottom of the pots based on the water requirements and the environmental conditions of the greenhouse. The emerging seedlings were counted from the onset of emergence to 10 days after planting (5 to 15 of November, 2016). After three weeks, the wheat seedlings were harvested from the pots and the following parameters were measured: root length, leaf length, root dry weight, leaf dry weight, and leaf area. In order to determine the dry weight, samples were dried in an oven at 72° C for 48 h.

In order to measure the chlorophyll and carotenoid content, one gram of fresh leaf tissue was ground into small pieces in a Chinese mold containing 80% acetone. The mix was completely dissolved and the volume was adjusted to 20 ml with 80% acetone. The solution was passed through a filter paper and a sample volume was poured into the cuvette of the spectrophotometer. The adsorption was read at 663 nm for chlorophyll a, 647 nm for chlorophyll b, and 470 nm for carotenoids. Values were expressed as μg/g of fresh weight using the Lichten-Thalor method (Souto et al., 2015).

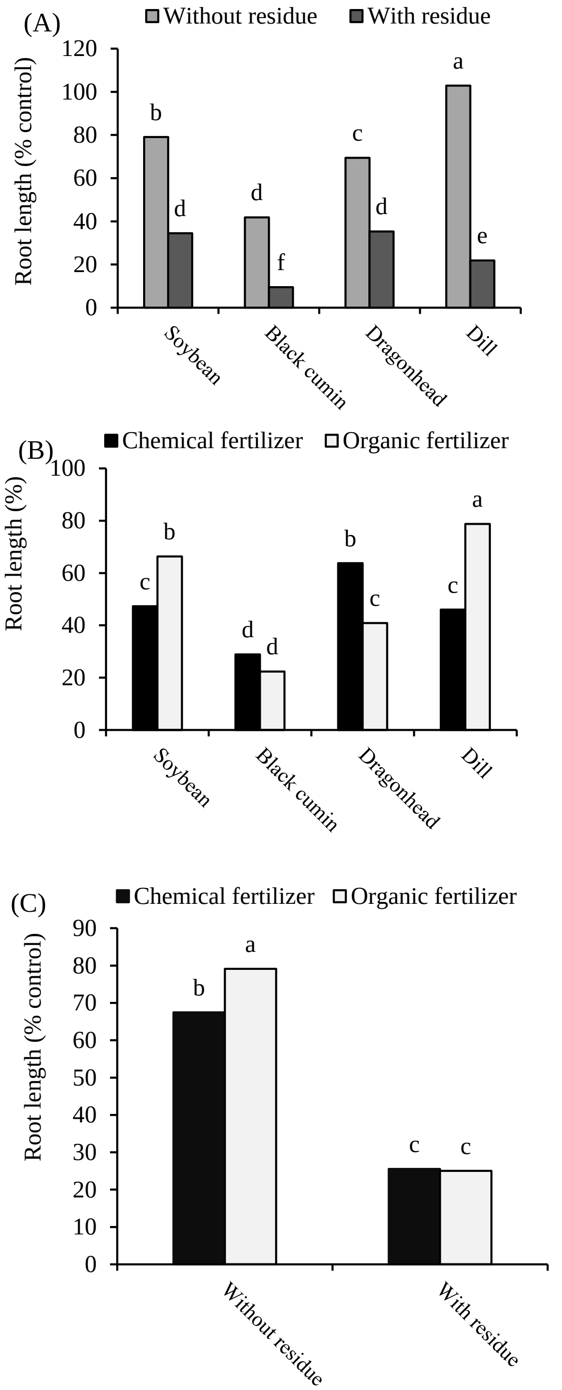

Fig. III. Wheat root length as affected by plant type × plant residue (A), plant type × fertilizer type (B), and plant residue × fertilizer type interaction (C); different letters indicate significant differences at P<0.05 by LSD test.

(1) Chlorophyll a = $(12.25 \times A_{663}) - (2.79 \times A_{647})$

(2) Chlorophyll b = $(21.50 \times A_{647}) - (5.10 \times A_{663})$

(3) Total carotenoids = $[(1000 \times A_{470}) - (1.82 \times Cl_a) - (85.02 \times Cl_b)] / 198$

The emergence percentage (EP) was calculated as (Nasr Isfahani and Shariati, 2007):

(4) $EP = (\frac{n}{N}) \times 100$

where n and N are the final number of germinating seeds and the total number of seeds, respectively.

To measure the emergence rate (ER), the Maguire formula was used as:

(5) $ER = \Sigma(\frac{Ni}{Ti})$

where Ni and Ti are the number of germinated seeds in the n count and the time from the beginning of the crop to the n count, respectively.

The average of each parameter was divided into the mean of the same parameter in the control treatment. Image software was used to calculate the leaf area. The percentage of change of each parameter compared to the control was analyzed using SAS 9.1 software. Comparisons of means were done using the LSD test at the 5% probability level.

Results

The lowest emergence percentage (73.33%) was observed for the control in wheat grown with black cumin residue. The maximum emergence percentage (control = 98.33%) was recorded in wheat grown in the rhizosphere soil of dragonhead and black cumin (Fig. I).

The wheat grown in soil containing black cumin residue and in dragonhead rhizosphere soil had the lowest and height germination rates, (44.75% and 95.06% of the control treatment, respectively) (Fig. II. A). Black cumin residue treated with chemical fertilizer and dill with organic fertilizer showed the greatest inhibitory effects on wheat seed germination rate (Table 2; Fig. II. B).

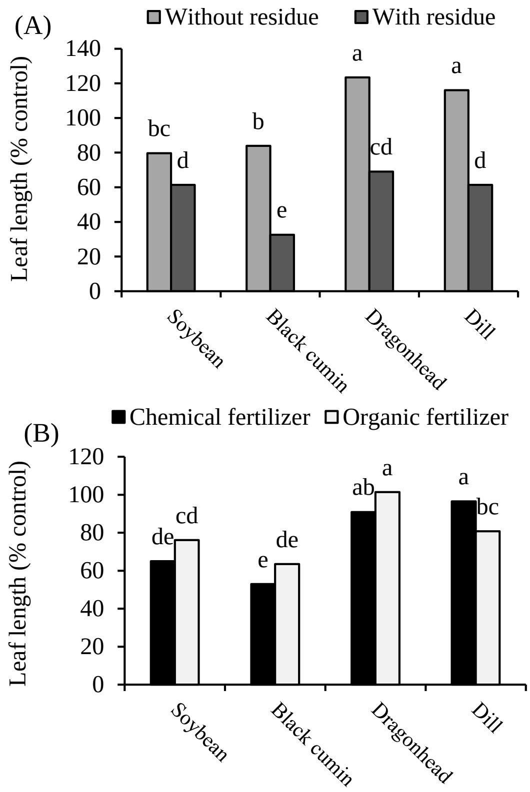

Fig. IV. Wheat leaf length as affected by plant type × plant residue (A), and plant type × fertilizer type interaction (B); different letters indicate significant differences at P<0.05 by LSD test.

The shortest wheat root length (9.5% of control) was found in the wheat cultivated in soil with black cumin residue while the longest (102.9% of control) was for wheat cultivated in dill rhizosphere soil (Fig. III. A). Black cumin residue treated with chemical and organic fertilizer treatments, soybean and dill residue treated with chemical fertilizer, and dill and dragonhead treated with organic fertilizer showed the greatest inhibitory effects on wheat root length (Table 2, Fig. III. B).

In the presence of plant residue conditions, wheat root length was not affected by the type of fertilizer while after removing the plant residue, organic fertilizers increased the growth of root in comparison with chemical fertilizer (Fig. III. C).

The shortest leaf length at 32.6% of the control was recorded in the wheat cultivated in black cumin residue while the highest length was observed (123.4% of the control) in the wheat cultivated in dragonhead rhizosphere soil (Fig. IV. A). Black cumin residue treated with chemical and

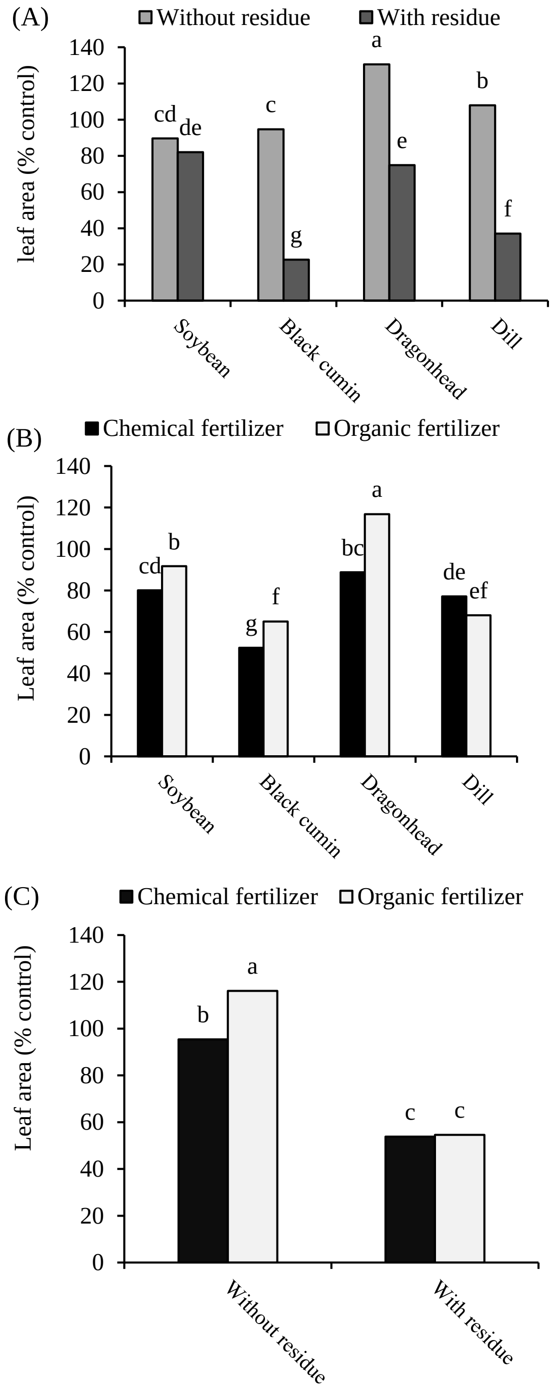

Fig. V. Wheat leaf area as affected by plant type × plant residue (A), plant type × fertilizer type (B), and plant residue × fertilizer type interaction (C); different letters indicate significant differences at P<0.05 by LSD test.

organic fertilizer and soybean residue treated with chemical fertilizer showed the greatest inhibitory effects on wheat leaf length (Table 2; Fig. IV. B).

The minimum wheat leaf area (22.7% of the control) was obtained from the wheat

Table 3
Effects of plant type, plant residue, and fertilization type on root weight, leaf weight, and photosynthesis pigments of common wheat (percentage compared to control)

Residue density	Plant type	Root weight (% control)	Leaf weight (% control)	Chlorophyll a (% control)	Chlorophyll b (% control)	Carotenoids (% control)
		Chemical fertilizer				
	Soybean	93.8^{b}	76.2^{ef}	102^{e}	230^{b}	108^{ef}
	Black cumin	54.4^{de}	98.1^{d}	133^{d}	133^{de}	126^{de}
Without residue	Dragonhead	75.3^{c}	119^{c}	213^{b}	238^{d}	248^{a}
	Dill	64.3^{cde}	155^{b}	234^{a}	314^{a}	213^{b}
	Soybean	14.8^{fg}	67.0^{fg}	49.9^{hi}	48.7^{h}	63.3^{g}
	Black cumin	7.4^{g}	14.7^{k}	11.3^{l}	10.9^{j}	11.9^{j}
With residue	Dragonhead	51.8^{e}	54.8^{gh}	35.5^{ijk}	32.2^{i}	41.8^{h}
	Dill	29.6^{f}	36.6^{hij}	41.6^{ij}	34.7^{hi}	39.7^{hi}
		Organic fertilizer				
	Soybean	77.9^{bc}	88.1^{de}	80.6^{fg}	100^{fg}	99.4^{f}
	Black cumin	78.3^{bc}	82.6^{def}	99.0^{ef}	86.8^{g}	98.6^{f}
Without residue	Dragonhead	68.1^{cd}	204^{a}	99.4^{ef}	116^{ef}	133^{d}
	Dill	133^{a}	121^{c}	169^{c}	184^{c}	177^{c}
	Soybean	51.9^{de}	75.9^{ef}	62.9^{gh}	51.2^{h}	78.8^{g}
	Black cumin	7.4^{g}	20.8^{jk}	21.6^{kl}	18.8^{ij}	20.8^{ij}
With residue	Dragonhead	16.1^{fg}	36.3^{ij}	19.0^{kl}	19.0^{ij}	24.5^{hij}
	Dill	22.1^{f}	39.4^{hi}	23.5^{jkl}	18.7^{ij}	25.8^{hij}

In each column, means with different letters indicate significant differences at P<0.05 by LSD test.

cultivated in soil with black cumin residue and the highest (130.6% of the control) was recorded in the wheat grown in dragonhead rhizosphere soil at (Fig. V. A). The black cumin and dill residues treated with chemical and organic fertilizers showed the greatest inhibitory effects on wheat leaf area (Table 2; Fig. V. B).

In the presence of plant residues, wheat leaf area was not affected by the type of fertilizer, but under removed plant residue conditions, organic fertilizers increased the leaf area in comparison with chemical fertilizer (Fig. V. C).

The lowest leaf dry weight was observed in the wheat grown in soil with black cumin residue (17.8% of the control) and the highest leaf dry weight was recorded in the wheat cultivated in dragonhead rhizosphere soil (161.5% of the control) (Fig. VI. A). Black cumin residue treated with chemical and organic fertilizers had the greatest inhibitory effects on leaf dry weight of the wheat (Table 3; Fig. VI. B).

The minimum root dry weight of wheat (7.41% of the control) was obtained in wheat cultivated in soil with black cumin residue and the maximum root dry weight (98.82% of the control) was observed in the wheat grown in dill rhizosphere soil (Fig. VII. A). Black cumin and dill

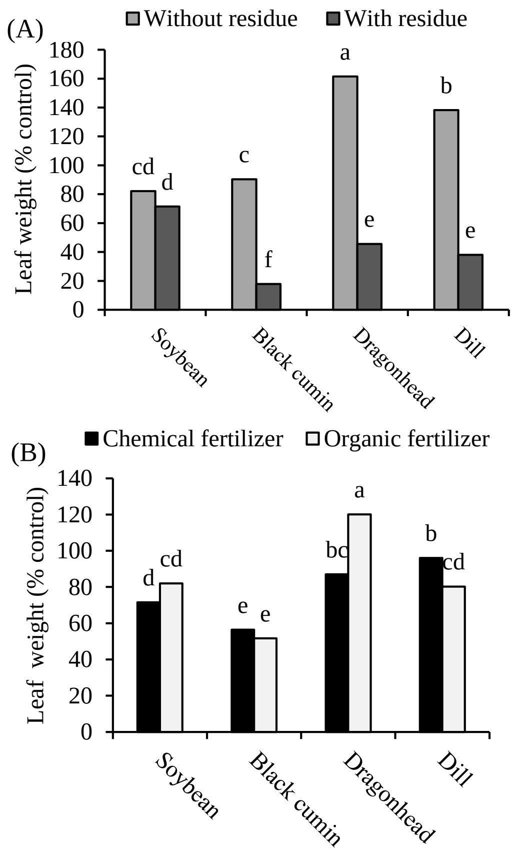

Fig. VI. Wheat leaf weight as affected by plant type × plant residue (A), and plant type × fertilizer type interaction (B); different letters indicate significant differences at P<0.05 by LSD test.

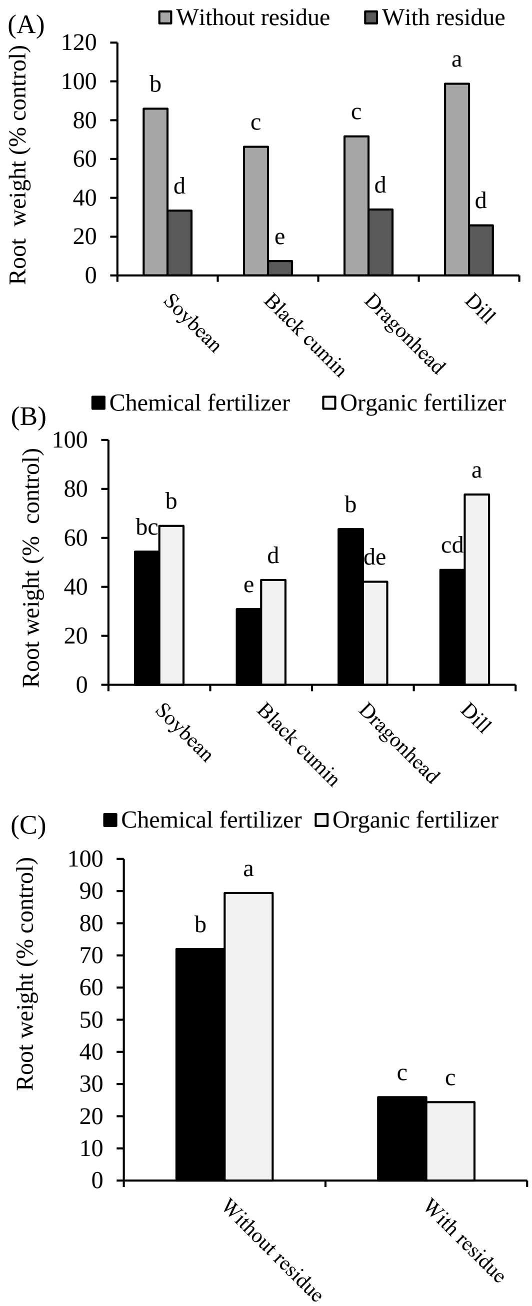

Fig. VII. Wheat root weight area as affected by plant type × plant residue (A), plant type × fertilizer type (B), and plant residue × fertilizer type interaction (C); different letters indicate significant differences at P<0.05 by LSD test

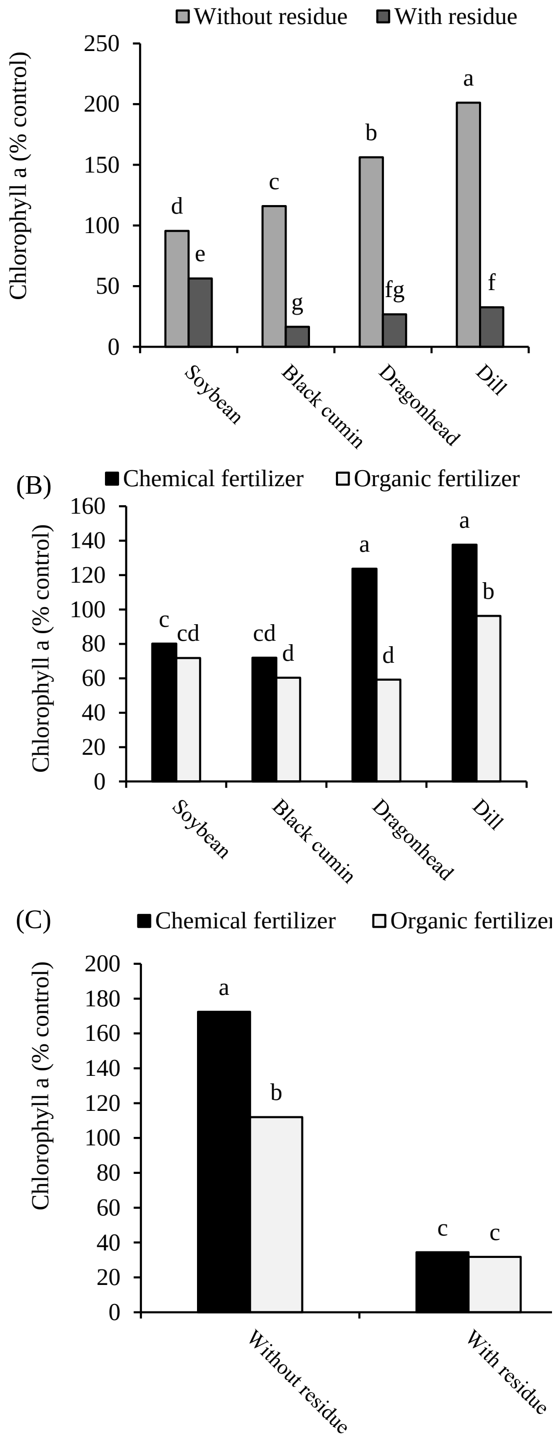

Fig. VIII. Wheat chlorophyll a as affected by plant type × plant residue (A), plant type × fertilizer type (B), and plant residue × fertilizer type interaction (C); different letters indicate significant differences at P<0.05 by LSD test.

residue treated with chemical fertilizer and black cumin and dragonhead residue treated with organic fertilizer showed the greatest inhibitory effects on the root dry weight of wheat (Table 3, Fig. VII. B).

In the presence of plant residues, wheat root weight was not affected by the type of fertilizer, but under removed plant residue conditions, organic fertilizers increased the root weight in comparison with the chemical fertilizer (Fig. VII. C).

The lowest and highest chlorophyll A contents were observed in the wheat grown in soil with black cumin residue and dill rhizosphere soil (16.5% and 201.2% of the control), respectively (Fig. VIII. A). Black cumin residue treated with chemical fertilizer and black cumin, dragonhead, and soybean residues treated with organic fertilizer showed the greatest inhibitory effects on the chlorophyll A content (Table 3, Fig. VIII. B).

Under plant residue conditions, wheat chlorophyll A was not affected by the type of fertilizer while under plant residues, chemical fertilizers increased the chlorophyll A as compared with organic fertilizer (Fig. IX. C).

The lowest content of chlorophyll b (14.9% of the control) was observed in the wheat cultivated in soil with black cumin residue and the highest content (250% of the control) was recorded in the wheat cultivated in dill rhizosphere soil (Fig. IX. A). Black cumin residue treated with chemical fertilizer and black cumin, dragonhead, and soybean residues treated with organic fertilizer had the greatest inhibitory effects on the chlorophyll b content (Table 3, Fig. IX. B).

In the presence of plant residue, wheat chlorophyll b was not affected by the type of fertilizer while under removed plant residue conditions, chemical fertilizers increased the chlorophyll b in comparison with organic fertilizer (Fig. IX. C).

The minimum and maximum carotenoid contents were recorded in the wheat cultivated in soil with black cumin residue and dill rhizosphere soil (16.3%, and 194.7% of the control, respectively) (Fig. X. A). Black cumin residue treated with chemical fertilizer and black cumin and dragonhead residue treated with organic fertilizer had the greatest inhibitory effects on the carotenoid content (Table 3, Fig. X. B).

Under plant residue treatments, wheat carotenoids were not affected by the type of fertilizer, but by removing plant residues, chemical fertilizers increased carotenoids in comparison with the organic fertilizer (Fig. X. C).

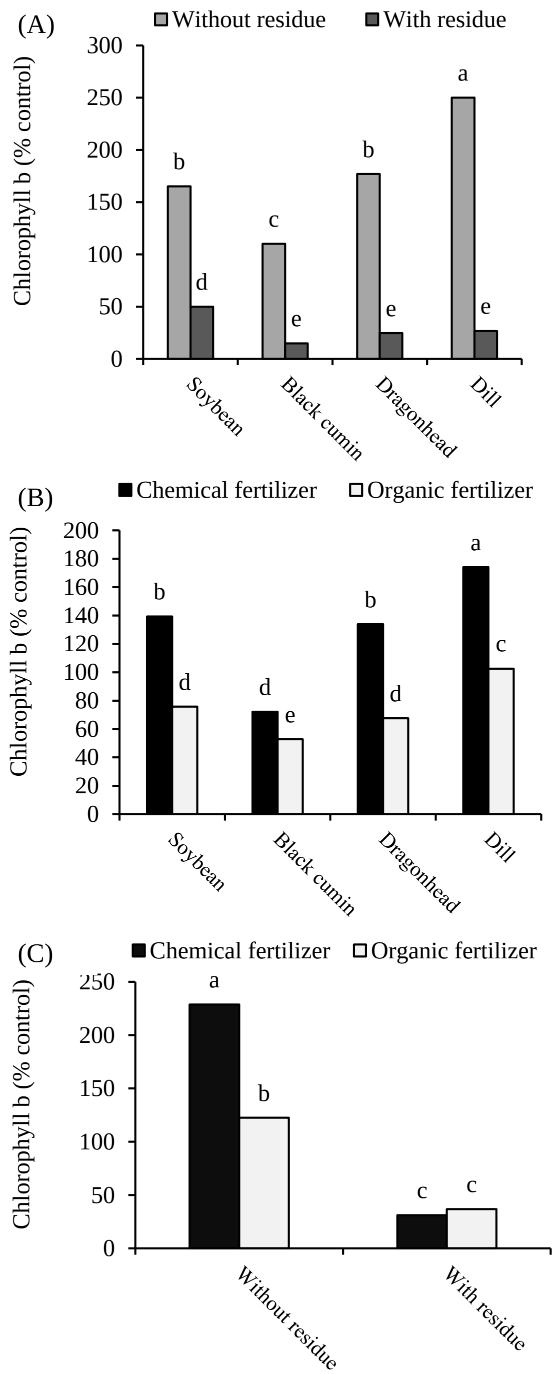

Fig. IX. Wheat chlorophyll b as affected by plant type × plant residue (A), plant type × fertilizer type (B), and plant residue × fertilizer type interaction (C); different letters indicate significant differences at P < 0.05 by LSD test.

Discussion

The results of this research showed that soybeans, black cumin, dill, and dragonhead residues had allelopathic effects on wheat seedling growth and decreased the percentage and rate of wheat germination. Some of the allelopathic compounds such as 1,8 cineol, which have been recorded in dill (Rostaei et al., 2018a) may cause the root tip swelling, mitochondrial respiration, stop mitosis, and DNA synthesis (Macias et al., 2007). Furthermore, Abu-Romman (2011) reported that the essential oil of *A. biebersteinii* was found to be rich in ascaridol, p-cymene, carvenone oxide, and camphor, having inhibitory effects on seed germination and seedling growth in several weed species. There is a probability that the presence of cymene in black cumin and dill (Rostaei et al., 2018a) has led to the reduced seed germination and growth of wheat seedlings.

Anaya (1999) reported that the compounds of alpha-terpinene, γ-terpinene, p-cymene, limonene, and ascaridole in the essential oil of *Chenopodium ambrosioides* inhibited the germination of *Amaranthus hypochondriacus* by 50%. Black cumin and dill also contain these compounds (Rostaei et al., 2018b). The main effect of these compounds could be due to the reduction in the seed germination. Allelopathic materials released by various plant organs can affect the seed germination of plants by preventing or blocking hormone activity, preventing the formation of protein structures, reducing the membrane permeability of the cells, inhibiting enzyme activity, and also reducing or blocking seed germination (Jefferson and Pennacchio, 2003).

The sensitivity of wheat to different plant residues was not similar. The maximum inhibition in the wheat growth parameters was recorded by black cumin and the chemical fertilizer treatment intensified the inhibitory effects of plant residues (Tables 2 and 4). The variability in plant sensitivity to plant residues could be relating to their different physiological and biochemical properties (Kobayashi, 2004). Dill and black cumin contain thymol, carvacrol, and carvone compounds (Rostaei et al., 2018a). Azirak and Karaman (2008) have reported that thymol, carvacrol, and carvone showed a high inhibition effect on weed seedling, even at low concentrations. The presence of these compounds can reduce seed germination and growth of the wheat treated with black cumin and dill residues.

Fine roots and small leaves were observed in the rhizosphere soil with black cumin residue.

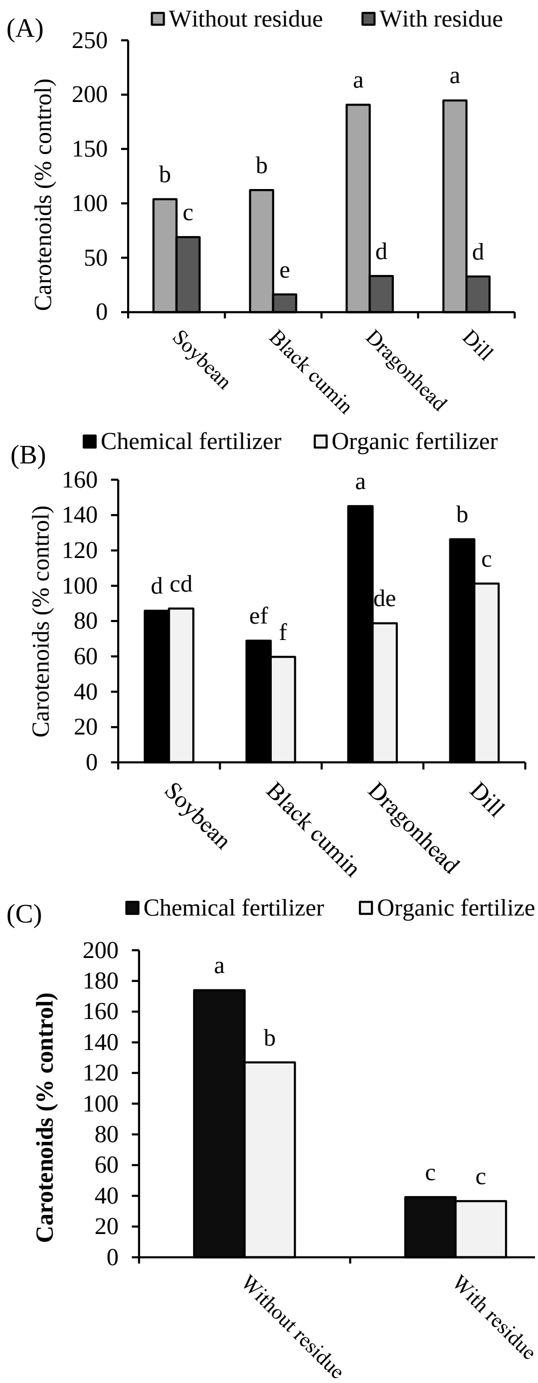

Fig. X. Wheat carotenoids a as affected by plant type × plant residue (A), plant type × fertilizer type (B), and plant residue × fertilizer type interaction (C); different letters indicate significant differences at P<0.05 by LSD test.

The wheat roots were more significantly affected by soybean, black cumin, dragonhead, and dill in comparison with wheat shoots (Figs. II and III). The more inhibitory effects of plant residues on the wheat root can be attributed to the fact that roots are the first organ of the plant that contact with the extracts of residues (Turk and Tawaha, 2002). *Salvia leucophylla* produces several volatile monoterpenoids (camphor, 1,8-cineole, beta-pinene, alpha-pinene, and camphene) that potentially act as allelochemicals. These monoterpenoids produced by *S. leucophylla* could interfere with the growth of other plants in its vicinity through inhibition of cell proliferation in the root apical meristem (Nishida et al., 2005).

It has been reported that allelopathic materials influence the action of gibberellin and indoleacetic acid, thereby preventing prolongation of cells (Qasem, 1992). Dill and black cumin can contain the α-pinene (Rostaei et al., 2018a; 2018b) which is able to inhibit the early root growth and cause oxidative damage in root tissue (Singh et al., 2006). The application of organic fertilizer for the crops under study ameliorated the negative effect of black cumin and soybean residue on the wheat root and leaf length (Figs. II. B and III. B).

Nitrogen is one of the essential nutrients for growing plants and developing leaf area. Allelopathic compositions can reduce the nitrogen content of the plant by affecting all phases of the nitrogen cycle and consequently, the development of leaves. Additionally, allelopathic compositions limit the development of various parts including leaves by reducing cell division and cell growth (El-Khatib et al., 2004).

In the presence of plant residue, the root and leaf weights of wheat were significantly decreased, with the greatest decrease being related to black cumin residues (Fig. VI. A). Application of organic fertilizer in soybean cropping neutralized the negative effects of previous crop residues. It appears that soil with organic fertilizer provides better conditions for rhizobium activity, thereby reducing the inhibitory effects of the allelopathic materials on the soil. Destruction of cell membranes by allelopathic compounds is a major reason for the decline in the growth of the target plants (Yu et al., 2003). Ahmad et al. (2016) in their study found that drought-stressed soybean leaf extracts were more effective in modulating the physiology of maize, indicating the higher allelopathic potential of soybean.

Although a soybean (*Glycine max* (L.) Merr)-wheat (*Triticum aestivum* L.) rotation appears to be a logical opportunity to use legume N as a sustainable grain production resource, the experimental results suggest that soybean root exudates were responsible for the decrease in wheat and triticale growth and yield (Mays et al., (1998).

In the present study, black cumin residues showed more severe inhibitory effects on wheat photosynthesis pigment than those of other species. The inhibitory effect of dragonhead and dill residues on photosynthetic pigmentation contents of wheat was intensified by the use of organic fertilizer (Figs. VII, VIII, and IX). In general, there are many known materials that may reduce the chlorophyll content in target species. For example, according to Yang et al. (2002), there was a significant decrease in chlorophyll content in rice seedlings (*Oryza sativa*) treated with vanillic, ferulic, and para-comaric acids. Studies confirm that phenolic compounds reduce the amount of chlorophyll a and b and thereby, reduce the plants' photosynthetic potential. Caffeine acid, comic acid, ferulic acid, cinnamon acid, and vanillic acid, significantly inhibited the growth of soybeans (*Glycine max*) and reduced photosynthetic and chlorophyll contents of this plant (Patterson, 1981).

Kobayashi (2004) reported that phenolic alkaloids decreased the chlorophyll content and rate of photosynthesis. Apparently, alkaloids have shown allelopathic effects on the germination and emergence of wheat seedlings when released by irrigation (Dastres et al., 2014). Additionally, photosynthetic pigments could be decreased by disturbances in the absorption of nutrients such as nitrogen as well as cellular degradation.

Conclusions

The results of this research showed that soybeans, black cumin, dill and dragonhead residues had allelopathic effects on wheat seedling growth. Based on the findings it is suggested that in agricultural ecosystems where wheat is grown in rotation with soybeans, black cumin, dill, and dragonhead, it is necessary to avoid wheat cultivation particularly in the presence of plant residue and it would be difficult to implement a minimum tillage system in such areas. Although the organic nutrition of medicinal plants under study decreased the inhibitory effects of the plant residues on some growth factors of common wheat, the extent of the effect of these plant residues on wheat growth factors was so great that it cannot be ignored. If plant residue conservation is practiced in an area, the cultivation of soybeans, black cumin, dill, and dragonhead are not suitable as rotation crops for wheat. In such cases, the plant residues of dill and dragonhead should be removed from the field in order to improve wheat cropping.

Acknowledgement

The authors thank Shahrekord University for funding this study.

References

Abu-Romman, S. 2011. 'Allelopathic potential of *Achillea biebersteinii* Afan. (Asteraceae)'. *World Applied Sciences Journal* و**15**: 947-952.

Ahmad, N., F. Ullah, I. Hussain, K. Ahmad, G. Raza, Y. Sajjadc, M. Iqbal, M. Adil and **M. Ali. M.** 2016. 'Soybean (*Glycine max*) extracts impact on plant and soil biology'. *Communications in Soil Science and Plant Analysis* **47**: 1751-1763.

Altieri, M. and **C. Nicholls**. 2017. 'Agroecology: a brief account of its origins and currents of thought in latin america'. *Agroecology and Sustainable Food System* 41: 231-237.

Amri, I., M. Hanana, B. Jamoussi and **L. Hamrouni.** 2015. 'Chemical composition of *Thuja orientalis* L. essential oils and study of their allelopathic potential on germination and seedling growth of weeds'. *Archives of Phytopathology and Plant Protection* 48: 18-27.

Anaya, A.L. 1999. 'Allelopathy as a tool in the management of biotic resources in agroecosystems'. *Critical Reviews in Plant Sciences*, 18: 697-739.

Azirak, S. and **S. Karaman**. 2008. 'Allelopathic effect of some essential oils and components on germination of weed species. *Acta Agriculturae Scandinavica, Section B - Soil & Plant Science,* 58: 88-92.

Dastres, A., M. Safari and **A. A. Maghsoudi-mood** .2014. 'Identification and study of allelopathic datura (*Datura Stramonium*) alkaloids on germination characteristics of maize cultivars'. *Journal of Seed Science and Research* 1: 17-28.

El-Khatib, A.A., A. K. Hegazy and **H. K. Galal**. 2004. 'Does allelopathy have a role in the ecology of *Chenopodium murale'. Annual Botan Fennici* 41: 37-45.

Fallah, S., M. Rostaei, Z. Lorigooini and **A. Abbasi Surkia**. 2018. 'Chemical compositions of essential oil and antioxidant activity of dragonhead (*Dracocephalum moldavica*) in sole crop and dragonhead/soybean (*Glycine max*) intercropping system under organic manure and chemical fertilizers'. *Industrial Crops and Products,* 115:158-165.

Gámiz, B., G. Facenda and **R. Celis**. 2018. 'Modulating the persistence and bioactivity of allelochemicals in the rhizosphere: salicylic acid, a case of study'. *Archives of Agronomy and Soil Science* https://doi.org/10.1080/03650340.2018.1512102

Hartman, H., D. Kester and **F. Davis**. 1990. '*Plant propagation, principle and practices'*. Prentice Hall International, Inc., United States of America. 647pp.

Jefferson, L.V. and **M. Pennacchio**. 2003. 'Allelopathic effect of ginger on seed germination and seedling growth of soybean and chive'. *Science Horticulture,* 116: 330-336.

Kalita, D., H. Choudhury and **S. C. Dey**. 1999. 'Assessment of allelopathic potential of same common upland rice. Weed speeches on morpo-physiological properties of rice plant'. *Crop Research,* 17: 41-45.

Kobayashi, K. 2004. 'Factors affecting phytotoxic activity of allelochemicals in soi'l. *Weed Biology and Management,* 4: 1-7.

Li, Z.H., Q. Wang, X. Ruan, C. D. Pan and **D. A. Jiang**. 2010.' Phenolics and plant allelopathy'. *Molecules,* 15: 8933-8952.

Mamolos, A.P. and **K. L. Kalburtji**. 2001. 'Significance of allelopathy in crop rotation'. *Journal of Crop Production* **4**: 197-218.

Mays, D.A., K. R. Sistani and **U. R. Bishnoi**. 1998. 'Adverse effects of soybeans on subsequent wheat and triticale crops'. *Journal of Sustainable Agriculture,* 12: 79-87.

Meulan, A. and B. **S. Chaulan.** 2016. 'A review of weed management in wheat using crop competition'. *Crop Protection,* 3: 1-7.

Macias, F.A., J. Molinillo, R. M. Varela and **J.C.G. Galindo**. 2007. 'Allelopathy a natural alternative for weed control'. *Pest Manag Science,* 63: 327-348.

Mirtorabi, M., M. Hosseini and **N. Alizadeh** .2011. 'Effective factors on wheat farmers' attitudes on wheat waste management (Case study: Hashtgerd wheat farmers)'. *Journal of Agricultural Extension and Education Research* 4: 1-13.

Mondal, M.D.F., M. D. Asaduzzaman and **T. Asao**. 2015. 'Adverse effects of allelopathy from legume crops and its possible avoidance'. *American Journal of Plant Sciences,* 6: 804-810.

Nasr Isfahani, M. and **M. Shariati**. 2007. 'The effect of some allelochemicals on seed germination of *Coronill avaria* L'. *American-Eurasian Journal of Agricultural and Environmental Sciences,* 33: 531-540.

Nishida N, S. Tamotsu. N. Nagata ,C. Saito and **A. Sakai.**2005.' Allelopathic effects of volatile monoterpenoids produced by *Salvia leucophylla*: Inhibition of cell proliferation and DNA synthesis in the root apical meristem of *Brassica campestris* seedlings'. *Journal of Chemical Ecology,* 31:1187-203.

Patterson, D.T. 1981. 'Effects of allelopathic chemicals on growth and physiological response of soybean (*Glycine max*)'. *Weed Science,* 29: 53-58.

Qasem, J.R. .1992. 'Pigweed (*Amaranthus spp.*) interference in transplanted tomato (*Lycopersicom esculentum*)'. *Horticultural Science,* 67: 421-427.

Rostaei, M., S. Fallah, Z. Lorigooini and **A. Abbasi Surki**. 2018a. 'The effect of organic manure and chemical fertilizer on essential oil, chemical compositions and antioxidant activity of dill (*Anethum graveolens*) in sole and intercropped with soybean (*Glycine max*)'. *Journal of Cleaner Production,* 199: 18-26.

Rostaei, M., S. Fallah, Z. Lorigooini and **A. Abbasi Surki**. 2018b. 'Crop productivity and chemical compositions of black cumin essential oil in sole crop and intercropped with soybean under contrasting fertilization'. *Industrial Crops and Products,* 125:612-629.

Salomé Kpoviessi, D. S., J. D. Gbenou, F. A. Gbaguidi, L. Ahoussi, G. C. Accrombessi, M. Moudachirou and **J. Quetin-Leclercq**. 2009. '*Justicia anselliana* (Nees) T. anders essential oils compounds and allelopathic effects on cowpea (*Vigna unguiculata* L.) Walp plant'. *Journal of Essential Oil Research,* 21: 83-88.

Shao-Lin, P., W. Jun and **G. Qin-Feng**. 2004. 'Mechanism and active variety of allelochemicals'. *Acta Botanica Sinica,* 46: 757-766.

Singh, H.P., D. R. Batish, SH. Kaur, K. Arora and **R. K. Kohli**. 2006. ' α-Pinene inhibits growth and induces oxidative stress in roots'. *Annals of Botany,* 98: 1261-1269.

Souto, A.G., L. F. Cavalcante, H. R. Gheyi, J. C. Nunes, F. Oliveira and **D. Oresca**. 2015. 'Photosynthetic pigments and biomass in non-irrigated with saline waters with and without leaching'. *Revista Brasileira de Engenharia Agricola e Ambiental,* 19: 1035-1041.

Turk, M.A. and **A. M. Tawaha**. 2002. 'Inhibitory effects of aqueous extracts of black mustard on germination and growth of lentil'. *Pakistan Journal of Agronomy,* 1: 28-30.

Xuan, T.D., S. Tawata, T. D. Khanh and **I. M. Chung**. 2005.' Biological control of weeds and plants pathogens in paddy rice by exploiting plant allelopathy: an overview'. *Crop Protection,* 24: 197-206.

Yang, C.M., C. N. Lee and **C. H. Chou**. 2002.' Effects of three allelopathic phenolic on chlorophyll accumulation of rice (*Oryza sativa*) seedlings: II. Inhibition of supply-orientation'. *Botanical Bulletin of Academia Sinica*, 43: 229-304.

Yu, J.Q., S. F. Ye, M. F. Zhang and **W. H. Hu**. 2003. 'Effects of root exudates and aqueous root extract of cucumber and allelochemicals on photosynthesis and antioxidant enzymes in cucumber'. *Biological Systems and Ecology,* 31: 129-139.