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Allelopathic interference of *Sonchus oleraceus* L. with wheat and the associated weeds: a field study

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Allelopathic interference of *Sonchus oleraceus* L. with wheat and the associated weeds: a field study

Abstract: A field study was conducted to examine the allelopathic potential of *Sonchus oleraceus* L. residue against the weeds associated with wheat crop. Residue application was carried out under field conditions in two doses: 150 and 300 g m^{-2}. Weed richness, density and above-ground biomass were assessed at 6 and 12 weeks after application to evaluate the potential effect of *S. oleaceus* manure on weed control. Some growth criteria and the total yield of the cultivated wheat crop were also measured. The residue-containing quadrates attained lower weed richness, density and biomass. Unlikely, residue application reduced the grain yield of wheat. The available nitrogen and phosphorus were increased in soil at the higher application dose. These results suggest that *S. oleraceus* could interfere most of winter weeds, but affect productivity of wheat. Weed suppression could be attributed to the allelopathic potential of *S. oleraceus* residue. These results suggest also that the manure of this weed could be used successfully in the integrated weed management programs to reduce weed infestation in winter crops. However, another crop species may be selected.

Key words: organic agriculture; ecological weed management; allelopathy; *Sonchus oleraceus*

Alelopatični učinek navadne škrbinke (*Sonchus oleraceus* L.) na pšenico in njene plevele: poljski poskus

Izvleček: Za preučitev alelopatičnega potenciala ostankov navadne škrbinke (*Sonchus oleraceus* L.) na plevele povezane s pridelovanjem pšenice je bil izveden poljski poskus. Ostanki škrbinke so bili uporabljeni v dveh odmerkih, 150 in 300 g m^{-2}. Pestrost plevelov, njihova gostota in nadzemna biomasa so bili ocenjeni 6 in 12 tednov po nanosu ostankov škrbinke za ocenitev njihovega potenciala za nadzor plevelov. Izmerjeni so bili tudi nekateri parametri rasti in pridelka pšenice. Kvadranti polja, ki so vsebovali ostanke škrbinke so imeli manjšo pestrost, gostoto in biomaso plevelov. Uporaba ostankov škrbinke je zmanjšala pridelek zrnja pšenice. Na območjih z večjim odmerkom ostankov škrbinke sta se povečali razpoložljivost dušika in fosforja v tleh. Rezultati kažejo, da ostanki škrbinke lahko vplivajo na večino ozimnih plevelov a hkrati vplivajo tudi na pridelek pšenice. Zaviranje rasti plevelov lahko torej pripišemo alelopatičnem učinku ostankov škrbinke. Ti rezultati tudi nakazujejo, da bi se ostanki škrbinke lahko uspešno uporabljali kot gnojilo pri integriranem upravljanju s pleveli pri ozimnih poljščinah, vendar bi v tem primeru namesto pšenice morali izbrati drugo vrsto poljščine.

Ključne besede: organsko kmetijstvo; ekološko upravljanje s pleveli; alelopatija; *Sonchus oleraceus*

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1 INTRODUCTION

As common practices in modern agriculture, large quantities of synthetic fertilizers and agrochemicals are used to enhance crop productivity (Rüegg et al., 2007). The continuous use of synthetic herbicides in agriculture produces the emergence of herbicide-resistant weeds and leads to environmental pollution with impacts on both human health and ecosystems (Qasem, 2013). Thus, there is an increasing demand for alternative and sustainable practices and, thereby, the research institutions are currently applying innovative approaches to improve agriculture without synthetic herbicides (Khanh et al., 2007; Chauhan and Gill, 2014). The increased incidence of herbicide-resistant weed species, and the related biological consequences, poses a major threat to the potential sustainability of crop production. Natural weed management practices are truly looking for solutions to minimize environmental impacts related to the input of synthetic herbicides into the agroecosystems. Now, organic farming is a substantial aspect that gives the environmentally safe practices with respect to weed control and crop productivity.

Organic agriculture provides several merits as an agriculture practice if compared with the conventional one. Briefly, organic agriculture represents an approach to land management that emphasizes preservation of the immediate environment, improves employment opportunities in the local communities as a social benefit, and finally has been positively correlated with economic growth (Luttikholt et al., 2007; Vaarst, 2010). Furthermore, it is considered as an environmentally safe tool for weed control (Lemessa & Wakjira, 2015). Within this context, there is an existing trend to incorporate ecological practices to the agroecosystems so as to design alternative and sustainable cropping systems (Hassan et al., 2018) either for weed management or crop safety.

Allelopathic interactions generally involve the release of chemical compounds (i.e. allelochemicals) from living or dead plant parts in sufficient quantities that may suppress germination and/or establishment of weed seedlings in the agroecosystem (Qasem & Foy, 2001; Hassan et al., 2014a). Used as cover crops, some plants produce relevant amounts of allelochemicals which are released from living or dead plant tissues that can exert a strong influence on the target weeds (Cheng & Cheng, 2015). In this regard, some ecologists pay attention to the use of allelochemicals as 'bioherbicides' in weed control, providing environmentally safe agriculture (Gomaa & Abd El-Gawad, 2012). Application of plant residues is a common practice that is frequently recurring in the agroecosystems, and it mostly offers a strategy for weed control (Campiglia et al., 2010). In this regard, the use of phytotoxic or allelopathic plants is gaining attention due to positive results in the potential weed management. Potential use of annual sowthistle residue as a weed species in this regard was still unknown. In this article, I used the residues of such common weed for this purpose.

Annual sowthistle (*Sonchus oleraceus* L.) is an annual weed species native to Eurasia and North Africa. It has been introduced to a wide range of countries around the world and become a common weed causing a major problem in the agroecological systems (Peerzada et al., 2019; Widderick et al., 2010). It also dominates weed communities in winter crops and other urban areas where water is available (Gomaa et al., 2012; Hassan & Hassan, 2019). Therefore, this weed may give heavy biomass. Moreover, it may provide a cheapest, highly available and environmentally safe material to be used in the agroecology in terms of potential weed management due to its allelopathic capacity (Gomaa et al., 2014; Hassan et al., 2014b) and natural biofertilizer to enhance crop yield due to its fertilizing agency (Hassan et al., 2018).

During hoeing practices in cultivated fields, the farmers uproot this plant and mix it with the soil during ploughing, the phenomenon that may affect the incoming crops and its associated weed species due to the potential release of some phytotoxins from the plant residue. *S. oleraceus* was found to be allelopathic against some common weeds (Gomaa et al., 2014; Hassan et al., 2014a). Besides, the allelopathic compounds released from its residue were long persistent in soil (Hassan et al., 2014b). Nevertheless, the previous studies were performed under greenhouse conditions, and a field application to evaluate the allelopathic potential of this weed is still lacking. It was therefore necessary for wide-ranged researchers interested and specialized in this field to fill this gap. On the other hand, the amounts of residue application of such weed that were similar to those applied the current study stimulated growth and productivity of kidney bean crop (Hassan et al., 2018). In the view of these statements, I tested the hypotheses that (i) the strongly allelopathic *S. oleraceus* can display adverse effects on emergence and growth of the common weeds associated with wheat under field conditions and (ii) a potential stimulatory or, at least, no effect on the crop tested (i.e. wheat) could be obtained. The main objective of this field study was to assess the allelopathic potential of *S. oleraceus* residue against some common weeds associated with wheat (*Triticum aestivum* L.), i.e. its ability to suppress weeds, and the potent to use *S. oleraceus* as a bioherbicide.

2 MATERIALS AND METHODS

2.1 COLLECTION OF PLANT MATERIAL

Fresh shoots of *S. oleraceus* L. were collected during the growing season, from different locations in the agroecosystems of Beni-Suef governorate, Egypt, (from January to April 2015). Plant collection was carried out during flowering-early fruiting stage in order to facilitate the distinction of *S. oleraceous* from *S. asper* (L.) Hill. Furthermore, at this stage, plants mostly pose the maximum amounts of bioactive metabolites. Plant material was placed in polyethylene bags and immediately carried to the laboratory for further processing. In the lab, fruits and inflorescences were completely removed and the plant material was air dried and stored in refrigerator at 2 °C until use.

2.2 THE SELECTED CROP

Common wheat (*Triticum aestivum* L.) is one of the most important cereals in the world in terms of production and use for human and animal feeding under a wide range of climatic conditions and in many geographic regions (Feldman, 1995; Shewry and Hey, 2015). In addition, it was proved to be a major source of carbohydrates and energy, and it also provides substantial amounts of ingredients which are important or beneficial for health such as proteins, vitamins, dietary fibers, and other phytochemicals (Shewry and Hey, 2015). Due to considerable land extension dedicated to wheat production through the world, there were substantial amounts of economic funds invested in weed management. It was necessary to provide a potential safe weed management strategy in wheat fields as weeds threaten the production of wheat worldwide (Oerke, 2006). Consequently, increasing the wheat crop yield will be expected.

2.3 FIELD WORK

Field experiment was conducted at a crop farm land in Beni-Suef governorate; about 17 km north west of Beni-Suef University (lat. 29° 09.13 N, long. 031° 08.36 E, alt. 29 m a.s.l.), Egypt, in the period from the beginning of January to the mid of May 2016. This period was synchronized with the time of cultivation of this crop. Before cultivation soil surface was ploughed twice to homogenate the soil and simultaneously provide a high potential for the equal distribution for the weed seeds in the seed bank. The soil characteristics

Table 1: Soil physicochemical properties (mean ± S.D.) of study field prior to cultivation

	Soil type	Sandy clay loam
	Field capacity	39.08 ± 0.038
	pH	7.97 ± 0.04
	EC	0.42 ± 3.13
	OC	1.69 ± 0.052
	OM	2.975 ± 0.096
Available	N (mg kg^{-1} soil)	99.0 ± 9.31
	P (mg kg^{-1} soil)	2.83 ± 0.61
	K (mg kg^{-1} soil)	607.5 ± 92.78
	Zn (mg kg^{-1} soil)	5.9775 ±1.07

Table 2: Mean average meteorological data of Beni-Suef governorate during the growing season

Parameter	Jan.	Feb.	Mar.	Apr.	May
Mean average high temperature (°C)	23	21.5	25.5	29.5	32.5
Mean average low temperature (°C)	10	11.5	14.5	16.5	19.5
Rainfall (mm)	7.5	355.5	14.5	1	0
Relative Humidity (%)	61.5	53.5	48.5	40.5	37.5

and the surrounding climatic conditions of the study site are well illustrated in Table 1 and 2, respectively. Thereafter, under field conditions, *S. oleaceus* residues were amended in the study area previously divided as quadrate (2 × 2 m^2 each) at the rates 150 and 300 g m^{-2}, whereas the residue-free quadrates were left as control. The experiments were conducted in a complete randomized design (CRD) involving four replicates for each treatment.

Weed control assessment was carried out twice: six and twenty weeks after residue application, during which I determined the emerging weed species, species richness, density and biomass of the total as well as individual weed species from each quadrat. Identification and nomenclature of the weed species detected were obtained using Boulos (1999, 2002 & 2005). The aboveground parts of the detected weeds were carefully cut and oven-dried at 70 °C till constant dry weight to obtain the biomass.

The grains of wheat were immediately seeded after residue incorporation via manual spraying, as usual in Egyptian wheat fields, obtaining quantities around 200 grains/m^2. After 3 weeks, the emerging individuals were thinned to the most similar 100 ones. No fertilization or herbicide regimes were applied, and irrigation process was carried out when need. At harvest, growth parameters of such crop were measured using ten randomly selected plants per quadrate. These parameters comprised shoot height, above-ground biomass, leaf area and grain yield (expressed as total dry weight m^{-2}). Besides, three soil samples were collected from each quadrate at 0–30 cm depth to form a single composite for each treatment. Soil properties comprising pH, soil electrical conductivity (EC), organic carbon, organic matter, available nitrogen, phosphorus, potassium, and zinc were determined using the standard methods (Allen, 1989).

2.4 STATISTICAL ANALYSIS

The obtained field data were first tested for their normality and homogeneity of variances using Kolmogorov-Smirnov and Levene's tests, respectively. If the data were normal and homogeneous, the data were analysed through one-way ANOVA followed by Tukey´s test ($p \leq 0.05$) for post hoc multiple comparison of means. When the data exhibited non-normal distribution and heteroscedasticity of variances, Kruskal-Wallis H test ($p \leq 0.05$) was performed. A correlation analysis was performed between the total weed richness, density and biomass vs. the dose of the residue applied. All statistical analyses were carried out using the IBM SPSS Statistics 20.0 software package (IBM SPSS Inc., Chicago, IL, USA).

3 RESULTS

3.1 WEED COMPOSITION

The weed species with their corresponding families detected in wheat field are listed in Table 3. A total of eight weed species belonging to five families were detected. Four of these species were monocots, whilst the remaining ones were dicot.

3.2 EFFECT OF *S. OLERACEUS* RESIDUE ON ON WEED DENSITY, RICHNESS AND BIOMASS

The effects of *S. oleraceus* residue depended mostly upon the amount of residue applied, weed species detected and time of harvest (Table 3). Amongst the weed species, the density of *Convolvulus arvensis* L. was not affected at all under the influence of *Sonchus* residue. However, the highest dose significantly reduced the biomass of such weed at both harvests. On converse, the highest dose significantly inhibited the emergence of *Coronopus niloticus* (Del.) Spreng. at both harvests. The biomass of this species was not affected in the treated quadrates. With respect to the first harvest, three weed species, namely: *Phalaris minor* Retz., *Polypogon monspeliensis* (L.) Desf. and *P. vridis* (Gouan) Breistr., were totally absent. Simultaneously, the density of *Matricaria chamomilla* L. was significantly reduced at the highest dose. Besides, its biomass was significantly supressed at both doses. The density of *Chenopodium murale* L. and *Poa annua* L. showed gradual decline with increasing the dose applied. At the end of the experiment (i.e. the second harvest), the density of *Phalaris minor* and *Poa annua* was substantially reduced. Additionally, *Polypogon monspeliensis* was completely absent at the higher application rate. On the contrary, the emergence and biomass of *Polypogon viridis* was significantly stimulated. Furthermore, the biomass of *Phalaris minor* was gradually increasing with the amount of residue applied.

As a whole, the total number of weeds (weed richness) was maintained in the treated plots at the first harvest only. However, density and biomass of the weeds observed were significantly decreased at both harvests in the residue-amended plots. Furthermore, the reduction in these criteria increased gradually with the increment in the dose applied (Table 4).

The correlation analysis between the measured criteria; weed richness, density and the above-ground biomass, with the amount of manure applied is shown in Table 5. Significant negative correlation was observed between the total weed density and biomass with the amount of residue applied at both harvest intervals. Besides, such correlation was also manifested between the weed richness and the dose applied at the second harvest.

3.3 EFFECT OF *S. OLERACEUS* MANURE ON YIELD COMPONENTS OF WHEAT

In general, the application of *S. oleraceus* manure had not affected shoot length and the above-ground biomass of wheat crop (Table 6). However, the leaf area showed significant reduction in wheat plants at the higher dose (10 %, $p \leq 0.05$). Furthermore, the grain output of wheat was significantly reduced at both treatments (Table 6).

3.4 SOIL ANALYSIS

The measured soil criteria after application of *S. oleraceus* residue are shown in Table 7. Clearly, most of the measured soil parameters were not affected on addition of the plant residue. However, the available soil nitrogen

Table 3: Effect of *Sonchus oleraceus* residue at the rates 150 and 300 g m^{-2} on density (no. quadrate^{-1}) and aboveground biomass (g quadrate^{-1}) (Mean ± SE) of the weed species detected in wheat crop at 6 and 12 weeks after application (WAA)

Weed species	Time after application	weed density at the dose applied			weed biomass at the dose applied		
		0	150	300	0	150	300
Chenopodium murale L. (Chenopodiaceae)	6 WAA	6.33^{a} ± 0.28	4.33^{b} ± 0.27	2.0^{c} ± 0.0	1.74^{a} ± 0.05	1.27^{b} ± 0.052	1.07^{c} ± 0.0
	12 WAA	-	-	-	-	-	-
Convulvulus arvensis L. (Convolvulaceae)	6 WAA	2.33^{a} ± 0.29	2.66^{a} ± 0.67	3.33^{a} ± 0.27	1.53^{a} ± 0.16	1.55^{a} ± 0.21	0.92^{b} ± 0.07
	12 WAA	2.33^{a} ± 0.28	2.33^{a} ± 0.27	3.66^{a} ± 0.29	3.42^{a} ± 0.18	2.93^{ab} ± 0.21	2.40^{b} ± 0.19
Coronopus niloticus (Delile) Spreng.(Brassicaceae)	6 WAA	4.33^{a} ± 0.29	4.33^{a} ± 0.29	2.0^{b} ± 0.0	1.01^{a} ± 0.04	0.96^{a} ± 0.1	0.84^{a} ± 0.03
	12 WAA	4.0^{a} ± 0.29	3.33^{ab} ± 0.52	2.33^{b} ± 0.29	1.12^{a} ± 0.10	1.01^{a} ± 0.2	0.95^{a} ± 0.03
Matricaria chamomilla L. (Astraceae)	6 WAA	4.33^{a} ± 0.27	3.33^{ab} ± 0.26	2.33^{b} ± 0.27	4.71^{a} ± 0.28	3.63^{b} ± 0.16	2.47^{b} ± 0.14
	12 WAA	3.66^{a} ± 0.0	3.33^{a} ± 0.77	2.0^{a} ± 0.27	1.83^{a} ± 0.01	5.1^{b} ± 0.061	3.33^{c} ± 0.006
Phalaris minor Retz. (Poaceae)	6 WAA	-	-	-	-	-	-
	12 WAA	9.0^{a} ± 0.56	4.33^{b} ± 0.28	1.67^{c} ± 0.26	1.67^{a} ± 0.01	2.67^{a} ± 0.007	6.70^{b} ± 0.006
Poa annua L. (Poaceae)	6 WAA	7.33^{a} ± 0.28	5.67^{b} ± 0.27	4.33^{c} ± 0.28	8.60^{a} ± 0.48	7.88^{a} ± 0.38	5.43^{b} ± 0.16
	12 WAA	6.33^{a} ± 0.30	4.33^{b} ± 0.29	2.33^{c} ± 0.28	6.70^{a} ± 0.36	2.67^{a} ± 0.46	1.67^{b} ± 0.27
Polypogon monspeliensis (L.) Desf. (Poaceae)	6 WAA	-	-	-	-	-	-
	12 WAA	10.33^{a} ± 0.77	3.33^{b} ± 0.27	0.0^{c} ± 0.0	10.37^{a} ± 0.78	4.50^{b} ± 0.28	0.0^{c} ± 0.0
Polypogon viridis (Gouan) Breistr.(Poaceae)	6 WAA	-	-	-	-	-	-
	12 WAA	2.33^{a} ± 0.29	8.0^{b} ± 0.51	8.0^{c} ± 0.51	8.4^{a} ± 0.42	13.67^{b} ± 0.44	19.34^{c} ± 0.38

Values in each row within the same parameter sharing the same letter are not significantly different at the 0.05 probability level according to Tukey's test. - = not detected.

Table 4: Effect of *Sonchus oleraceus* residue at the rates 150 and 300 g m^{-2} on the species richness, total weed density and above-ground biomass (Mean ± SE) of the weed species detected in the wheat field at 6 and 12 weeks after application (WAA)

Parameter	Time after application	Dose applied (g m^{-2}) 0	150	300
Species richness (No. m^{-2})	6 WAA	5.0^{a} ± 0.0	5.0^{a} ± 0.0	4.66^{a} ± 0.29
	12 WAA	6.67^{a} ± 0.28	6.0^{b} ± 0.0	5.67^{b} ± 0. 29
Total weed density (No. m^{-2})	6 WAA	24.67^{a} ± 0.76	21.0^{b} ± 0.88	13.0^{c} ± 0.29
	12 WAA	37.0^{a} ± 1.34	31.0^{b} ± 0.88	20.0^{c} ± 1.04
Total weed biomass (g m^{-2})	6 WAA	17.58^{a} ± 0.76	15.3^{b} ± 0.38	10.99^{c} ± 0.066
	12 WAA	40.6^{a} ± 1.04	37.69^{a} ± 1.30	30.02^{b} ± 0.43

Values in each row within the same crop sharing the same letter are not significantly different at the 0.05 probability level according to Tukey's test.

and phosphorus were significantly induced at the higher dose.

4 DISCUSSION

The results of this study indicated that *S. oleraceus* residue significantly reduced the richness, emergence and biomass of most of the detected weeds associated with the studied wheat field. This observation was consistent with that of Hassan et al. (2014b) who indicated that *Sonchus* residue reduced emergence and growth of some tested weeds under greenhouse conditions. This result was also consistent with field observations monitored by Hassan et al. (2018) who indicated that the same amounts of the residues applied suppressed weed density, richness and biomass in a kidney bean field (unpublished data). This result substantially obeys the first hypothesis of this study. This result suggests also that the residue added had a role in weed interference and declining species richness. In general, the decaying plant residues release phenolic compounds into the rhizosphere part of the soil (Djurdjević et al., 2011). Furthermore, these phenolic allelochemicals were found in the soils amended with *S. oleraceus* (Hassan et al., 2014b). Accumulation of phytotoxins in soil leads to inhibition of seed germination, seedling growth and uptake of mineral nutrients (Rice, 1984), the circumstances that decrease density of individual plant species from the plant communities as suggested by several authors (Barritt and Facelli, 2001; Djurdjević et al., 2011). Therefore, weed suppression could be related to the phenolic compounds released from the plant residues, i.e. allelopathic interaction. This notion may be consistent with that of Foy and Inderjit (2001) who reported that allelopathy had an important role in weed interference and declining weed diversity. Within this side, the dry matter of *S. oleraceus* shoots has been reported to be rich in saponins, alkaloids and total phenols (Gomaa et al., 2014). On the other hand, most of the measured soil criteria were not affected by the residue applied. However, the higher dose-amounts enhanced the available soil nitrogen and phosphorus. The increase in the available N and P could be attributed to the residue applied. May be, *Sonchus* residue is rich in nitrogenous and phosphorus compounds. This result obeys that obtained by Hassan et al. (2014b) and Hassan et al. (2018) who indicated that the residue of this species induced soil nutrients. Therefore, it was so difficult to claim that the reduction in weed diversity and growth was attributed to the change in soil criteria. This result confirms the phytotoxic effect of the residue applied.

Table 5: Correlation coefficients (r) between the measured weed criteria and the amount of *Sonchus oleraceus* residue applied in wheat field at both time intervals after residue application

Parameter	Time after application (weeks)	r value
Total weed richness	6	- 0.55
	12	- 0.71*
Total weed density	6	- 0.96**
	12	- 0.96**
Total weed biomass	6	- 0.96**
	12	- 0.91**

* Correlation is significant at $p \leq 0.05$.
**Correlation is significant at $p \leq 0.01$.

The field observations obtained by Hassan et al. (2018) showed that the same amounts of the incorporated residue had a stimulatory effect of on growth, productivity and several metabolites of the kidney beans. However, the effect of these amounts on wheat was contradictory. *S. oleraceus* produced a negative effect on the total seed yield of wheat. This result substantially does not obey the second hypothesis of this study. Such effect could be also attributed to the smaller seed size of wheat when compared with kidney bean. In this regard, larger seed-sized species were more resistant/tolerant for the released allelochemicals from plant litter (Hassan, 2018).

Table 6: Growth and yield parameters (mean ± SE) of wheat in response to *Sonchus oleraceus* residue at the rates 150 and 300 g m^{-2}

	Dose applied (g m^{-2})		
Parameter	Control	150	300
Shoot length (cm)	85.0^{a} ± 3.85	82.6^{a} ± 3.60	86.0^{a} ± 2.62
Shoot biomass (g individual^{-1})	14.4^{a} ± 0.70	13.44^{a} ± 0.59	13.28^{a} ± 0.64
Leaf area individual^{-1} (cm^{2})	162.92^{a} ± 5.50	153.15^{ab} ± 5.95	146.31^{b} ± 5.24
Number of spikes tiller^{-1}	4.27^{a} ± 0.32	4.43^{a} ± 0.27	4.20^{a} ± 0.20
Spike length (cm)	8.60^{a} ± 0.47	6.65^{a} ± 0.41	8.72^{a} ± 0.51
Seed/Grain yield (g m^{-2})	703.0^{a} ± 37.23	548.8^{b} ± 22.61	570.6^{b} ± 26.36

Values in each row within the same crop sharing the same letter are not significantly different at the 0.05 probability level according to Tukey's test.

Table 6: Influence of *Sonchus oleraceus* residue at the rates 150 and 300 g m^{-2} on the measured soil properties (Mean ± SE) at harvest of wheat

		Dose applied (g m^{-2})		
	Soil Properties	control	150	300
	pH	7.95^{a} ± 0.015	7.95^{a} ± 0.017	7.88^{a} ± 0.035
	EC (mS cm^{-1})	0.38^{a} ± 0.025	0.39^{a} ± 0.004	0.46^{a} ± 0.027
	OC (%)	1.54^{a} ± 0.028	1.77^{a} ± 0.095	1.48^{a} ± 0.16
	OM (%)	2.7^{a} ± 0.048	3.08^{a} ± 0.16	2.60^{a} ± 0.28
	N (mg kg^{-1} soil)	91.0^{a} ± 7.50	113.0^{a} ± 6.80	139.0^{b} ± 2.20
Available	P (mg kg^{-1} soil)	1.77^{a} ± 0.11	2.25^{ab} ± 0.13	3.09^{b} ± 0.07
	K (mg kg^{-1} soil)	590.0^{a} ± 50.68	647.0^{a} ± 45.53	562.0^{a} ± 82.53
	Zn (mg kg^{-1} soil)	4.75^{a} ± 0.46	4.71^{a} ± 0.43	4.38^{a} ± 0.76

Values in each row within the same crop sharing the same letter are not significantly different at the 0.05 probability level according to Tukey's test.

Besides, wheat germination and early growth displayed a degree of sensitivity to phytotoxic species (Tamak et al., 1994; Al-Sherif et al., 2013). Therefore, the dose of the applied residue should be further explored and adjusted to add benefits in weed control and, at the same time, avoid undesirable phytotoxicity on the selected crop.

As proved by Hassan et al. (2014b), the phenolic compounds released from *S. oleraceus* residues have been detected during 60 days after residue incorporation into the soil, the result that may explain the extending effect of the residue. In this study, the bioactivity of *S. oleraceus* manure seems to be extended in time since herbicidal effects were still evident 12 weeks after manure application. Progressive and long-term effects collected suggest that *S. oleraceus* manure gradually releases phytotoxic compounds, showing a strong suppressive effect on weed emergence. The extending bioactivity of the phytotoxic residue applied is highly needed because weeds in the soil seed bank are not synchronized, but germinate gradually all along the establishment of the crop (Mohler et al., 2001; Puig et al., 2013).

In this study, as expected, the weed suppression seemed to be related to the dose of *S. oleraceus* manure applied. In general, the magnitude of weed suppression is quantitatively proportional to the applied dose in the studies related to phytotoxicity (Hassan et al., 2014b; Hassan, 2018).

While the emergence and biomass of *Phalaris minor*, *Poa annua*, *Polypogon monspeliensis* was significantly reduced through the phytotoxicity of *S. oleraceus* manure, *Polypogon viridis* was notably increasing with respect to its density and biomass in the long term. Different responses to chemical compounds can be associated to the amplitude of weed sensitivity to phytotoxicity (Latif et al., 2017), even those weed species are closely related. Moreover, selective inhibition of weed growth may be related to concentration and distribution of allelochemicals in the rhizosphere soil (Blum et al., 1999; Aslam et al., 2017). However, rather than indicating phytotoxic resistance, the emergence of *P. viridis* could be also associated with seed germination dynamics or better competitive abilities that allows this weed to rapidly occupy its own niche after the decline of other monocot species.

The results also indicate a punctual weed increase in the case of *Matricaria chamomilla* at the second harvest and mainly *Polypogon viridis* at both. None of them was considered as a highly problematic weed. In this sense, weed stimulation can be related with differential responses as plant residues are able to exhibit positive or negative effects on target species based on chemical concentration or environmental conditions (Cheng and Cheng, 2015). Also, punctual weed stimulation could be related to the nutritional benefits provided by the residue incorporated (Hassan et al., 2014b).

5 CONCLUSION

The present study represents evidence that *S. oleraceus* residue showed remarkable weed suppression. This investigation had the merit of field application. Apparently, reduction of richness, density and biomass of the weeds associated with wheat crop was manifested. The inhibitory effect of the residue was not attributed to soil properties, but it could be related to some phytotoxins released from the residue that reduce or, perhaps, completely inhibit the emergence and growth of the detected weeds. The undesirable result obtained in this study was the reduction of grain yield of wheat. Therefore, application of such residue in another crop species, probably with larger seeds, may be recommended. Moreover, the dose of the manure applied should be adjusted in order to attain the desired weed management with a potential stimulatory or, at least, no effect on the cultivated crop. The experimental approach described was adequate to demonstrate the efficacy of *S. oleraceus* residues as a bioactive green manure for future weed management practices.

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7 REFERENCES

Allen, S. E. (1989). *Chemical Analysis of Ecological Materials*. Blackwell Scientific Publishers, London.

Al-Sherif E., Hegazy, A. K., Gomaa, N. H., Hassan, M. O. (2013). Allelopathic effect of black mustard tissues and root exudates on some crops and weeds. *Planta Daninha*, *31*, 11-19. https://doi.org/10.1590/S0100-83582013000100002

Aslam, F., Khaliq, A., Matloob, A., Tanveer, A., Hussain, S., Zahir Z. A. (2017). Allelopathy in agro-ecosystems: a critical review of wheat allelopathy-concepts and implications. *Chemoecology*, *27*, 1–24. https://doi.org/10.1007/s00049-016-0225-x

Barritt, A. R. & Facelli, J. M. (2001). Effects of *Casuarina pauper* litter and grove soil on emergence and growth of understorey species in arid lands of South Australia. *Journal of Arid Environments*, *49*, 569-579. https://doi.org/10.1006/jare.2001.0808

Batish, D. R., Setia, N., Singh, H. B. Kohli, R. K. (2004). Phytotoxicity of lemon-scented eucalypt oil and its potential use as a bioherbicide. *Crop Protection*, *23*, 1209–1214. https://doi.org/10.1016/j.cropro.2004.05.009

Blum, U., Shafer, S. R., Lehman, M. E. (1999). Evidence for inhibitory allelopathic interactions involving phenolic acids in field soils: Concepts vs. an experimental model. *Critical Reviews in Plant Science*, *18*, 673–693. https://doi.org/10.1080/07352689991309441

Boulos, L. (1999). *Flora of Egypt.* vol. 1. (Azollaceae–Oxalidace). Al Hadara Publishing, Cairo.

Boulos, L. (2002). *Flora of Egypt.* vol. 3. (Verbenaceae–Compositae). Al Hadara Publishing, Cairo

Boulos, L. (2005). *Flora of Egypt.* vol. 4. *(*Monocotyledons: Alismataceae–Orchidaceae). Al Hadara Publishing, Cairo.

Campiglia, E., Mancinelli, R., Radicetti, E., Caporali, F. (2010). Effect of cover crops and mulches on weed control and nitrogen fertilization in tomato (*Lycopersicon esculentum* Mill.). *Crop Protection*, *29*, 354-363. https://doi.org/10.1016/j.cropro.2009.12.001

Chauhan, B. S. & Gill, G. S. (2014). Ecologically based weed management strategies. In: B.S. Chauhan, G. Mahajan (Eds.) *Recent Advances in Weed Management* (pp. 1-11). Springer, New York, NY. https://doi.org/10.1007/978-1-4939-1019-9_1

Cheng, F., & Cheng, Z. (2015). Research progress on the use of plant allelopathy in agriculture and the physiological and ecological mechanisms of allelopathy. *Frontiers in Plant Science*, *6*, 1020. https://doi.org/10.3389/fpls.2015.01020

Djurdjević, L., Mitrović, M., Gajić, G., Jarić, S., Kostić, O., Oberan, L., Pavlović, P. (2011). An allelopathic investigation of the domination of the introduced invasive *Conyza canadensis* L. *Flora*, *206*, 921-927. https://doi.org/10.1016/j.flora.2011.06.001

Feldman, M. (1995). Wheats. In: J. Smartt & N. W. Simmonds (Eds.), *Evolution of crop plants* (pp. 185–192). Harlow, UK: Longman Scientific & Technical.

Foy, C.L., & Inderjit. (2001). Understanding the role of allelopathy in weed interference and declining plant diversity. *Weed Technology*, *15*, 873–878. https://doi.org/10.1614/0890-037X(2001)015[0873:UTROAI]2.0.CO;2

Gomaa, N. H. & AbdElgawad, H. R. (2012). Phytotoxic effects of Echinochloa colona (L.) Link. (Poaceae) extracts on the germination and seedling growth of weeds. Spanish Journal of Agricultural Research, 10, 492-501. http://doi.org./10.5424/sjar/2012102-194-11

Gomaa, N.H., E.A. Al-Sherif, A.K. Hegazy, M.O. Hassan. (2012). Floristic diversity and vegetation analysis of *Brassica nigra* (L.) Koch communities. *Egyptian Journal of Biology*, *14*, 63–72. https://doi.org/10.4314/ejb.v14i1.8

Gomaa, N. H., Hassan, M. O., Fahmy, G. M., González, L., Hammouda, O., Atteya, A. M. (2014). Allelopathic effects of *Sonchus oleraceus* L. on the germination and seedling growth of crop and weed species. *Acta Botanica Brasilica*, *28*, 408–416. https://doi.org/10.1590/0102-33062014abb3433

Hassan, M. O., Gomaa, N. H., Fahmy, G. M., González, L., Hammouda, O., Atteya, A. M. (2014a). Interactions between *Sonchus oleraceus* L. and some weeds in agroecosystems in Egypt. *Annals of Agricultural Sciences*, *59*, 221–228. https://doi.org/10.1016/j.aoas.2014.11.009

Hassan, M. O., Gomaa, N. H., Fahmy, G. M., González, L., Hammouda, O., Atteya, A. M. (2014b). Influence of *Sonchus oleraceus* L. residue on soil properties and growth of some plants. *Philippine Agricultural Scientists*, *97*, 368–376.

Hassan, M.O., Saleh, A.M., AbdElgawad, H. (2018). *Sonchus oleraceus* residue improves nutritive and health-promoting value of common bean (*Phaseolus vulgaris* L.): A metabolic study. *Journal of Agricultural and Food Chemistry*, *66*, 2092–2100. https://doi.org/10.1021/acs.jafc.7b05821

Hassan, M. O. (2018). Leaf litter of *Bombax ceiba* L. threatens plant cover and floristic diversity in a new urban ecosystem. *Flora*, *242*, 22-30. https://doi.org/10.1016/j.flora.2018.03.004

Hassan, M. O. & Hassan, Y. M. (2019). Effect of human activities on floristic composition and diversity of desert and urban vegetation in a new urbanized desert ecosystem. *Heliyon*, *5*, e02283. https://doi.org/10.1016/j.heliyon.2019.e02283

Khanh, T. D., Chung, M. I., Tawata, S., Xuan, T. D. (2007). Allelopathy for weed management in sustainable agriculture. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, *2*, 034. https://doi.org/10.1079/PAVSNNR20072034

Latif, S., G. Chiapusio and L.A. Weston. (2017). Allelopathy and the role of allelochemicals in plant defence. *Advances in Botanical Research*, *82*, 19-53. https://doi.org/10.1016/bs.abr.2016.12.001

Lemessa, F., & Wakjira, M. (2015). Cover crops as a means of ecological weed management in agroecosystems. *Journal of Crop Science and Biotechnology*, *18*, 133 – 145. https://doi.org/10.1007/s12892-014-0085-2

Luttikholt, L.W. (2007). Principles of organic agriculture as formulated by the International Federation of Organic Agriculture Movements (IFOAM). *NJAS-Wageningen Journal of Life Sciences*, *54*, 347–360. https://doi.org/10.1016/S1573-5214(07)80008-X

Mohler, C.L. (2001). Weed life history: identifying vulnerabilities. Ecological management of agricultural weeds. In: M. Liebman, C.L. Mohler, C.P. Staver (Eds.), *Ecological management of agricultural weeds* (pp. 40–98). Cambridge University Press. https://doi.org/10.1017/CBO9780511541810.003

Oerke, E.C. (2006). Crop losses to pests. *Journal of Agricultural Science*, *144*, 31–43. https://doi.org/10.1017/S0021859605005708

Peerzada, A. M., O'Donnell, C., Adkins, S. (2019). Biology, impact, and management of common sowthistle (*Sonchus oleraceus* L.). *Acta Physiologiae Plantarum*, *41*, 136. https://doi.org/10.1007/s11738-019-2920-z

Puig, C. G., Álvarez-Iglesias, L., Reigosa, M. J., Pedrol, N. (2013). *Eucalyptus globulus* leaves incorporated as green manure for weed control in maize. *Weed Science*, *61*, 154–161. https://doi.org/10.1614/WS-D-12-00056.1

Qasem, J.R., & Foy, C.L. (2001). Weed Allelopathy, its ecological impact and future prospects. *Journal of Crop Production*, *4*, 43-119. https://doi.org/10.1300/J144v04n02_02

Qasem, J. R. (2013). Applied Allelopathy in weed management, an update. In: Z. A. Cheema, M. Farooq and Abdul Wahid (Eds.), *Allelopathy: Current Trends and Future Applications* (pp. 251-297). Springer, Netherlands. https://doi.org/10.1007/978-3-642-30595-5_11

Rice, E.L. (1984). *Allelopathy*, second ed. Academic Press Orlando, Florida, USA.

Rüegg, W. T., Quadranti, M., Zoschke, A. (2007). Herbicide research and development: challenges and opportunities. *Weed Research*, *47*, 271–275. https://doi.org/10.1111/j.1365-3180.2007.00572.x

Shewry, P. R., & Hey, S. J. (2015). The contribution of wheat to human diet and health. *Food Energy and Security*, *4*, 178–202. https://doi.org/10.1002/fes3.64

Singh, H. P., Batish, D. R., Kohli, R. K. (2008). Allelopathy in agroecosystems: An overview. *Journal of Crop Production*, *4*, 1-41. https://doi.org/10.1300/J144v04n02_01

Tamak, J. C., Narwal, S. S., Singh, L., Singh, I. (1994). Effect of aqueous extract of rice stubble and straw + stubble on the germination and seedling growth of wheat, oat, berseem and lentil. *Crop Research*, *8*, 180-185.

Vaarst, M. (2010). Organic farming as a development strategy: Who are interested and who are not? *Journal of Sustainability and Development*, *3*, 38-50. https://doi.org/10.5539/jsd.v3n1p38

Widderick, M. J., Walker, S. R., Sindel, B. M., Bell, K. L. (2010). Germination, emergence, and persistence of *Sonchus oleraceus*, a major crop weed in subtropical Australia. *Weed Biology and Management*, *10*, 102–112. https://doi.org/10.1111/j.1445-6664.2010.00370.x