Journal of Soil Science and Plant Nutrition (2021) 21:1856–1866
https://doi.org/10.1007/s42729-021-00485-1

ORIGINAL PAPER

Assessing the Effect of Biochar or Compost Application as a Spot Placement on Broomrape Control in Two Cultivars of Faba Bean

Hani Saber Saudy[1] · Mohamed Fawzy Hamed[1] · Ibrahim Mohamed El–Metwally[2] · Khaled Ameen Ramadan[3] · Karam Hafez Aisa[1]

Received: 7 February 2021 / Accepted: 11 April 2021 / Published online: 19 April 2021

Abstract

The presence of soil seed bank of broomrape weed (*Orobanche crenata* Forsk.) causes a severe biotic stress towards faba bean (*Vicia faba* L.) preventing its sustainable cultivation. Thus, the current work aimed to estimate the relative efficiency of biochar and compost as untraditional means of broomrape weed control at farm level. The current study aims to investigate the use of biochar or compost as a spot placement compared to glyphosate-isopropylammonium herbicide and unweeded treatment for combating broomrape weed in two faba bean cultivars (Misr–3 and Sakha–1). The experimental design was a strip-plot based on completely randomized block arrangement with six replications. Significant reduction in number and weight of broomrape shoots plot^{-1} and number of infected faba bean plants plot^{-1} was noticed with Misr–3 plants treated by glyphosate-isopropylammonium, compost, or biochar. Planting of Misr–3 cultivar with application of biochar or glyphosate-isopropylammonium as well as Sakha–1 with application of glyphosate-isopropylammonium were the remarkable combinations for increasing faba bean seed yield ha^{-1}. Regression relationships proved that broomrape shoots weight plot^{-1} was the most negatively correlated parameter with faba bean seed yield, since its R^2 (72.9%) value was higher than that of broomrape shoots number plot^{-1} (58.5%) and number of broomrape-infected plants plot^{-1} (44.7%). Planting Misr–3 cultivar plus treating soil by biochar or compost (spot placement) represents a promising practice for sustaining faba bean productivity in broomrape-infested lands.

Keywords Genotypic variation · Glyphosate · *Orobanche* · Root parasitic weeds · Soil rhizosphere

1 Introduction

Faba bean (*Vicia faba*, L.) is a multi-purpose crop, since it has a beneficial role in life of human, animals, and even for microorganisms. Faba bean is used as a source of protein in human diets, as fodder crop for animals, and for its excellent ability to fix atmospheric nitrogen. Faba bean seed has been regarded as a meat extender or substitute due to its high protein content ranging from 20 to 41% with valuable mineral micronutrients (Crepona et al. 2010). It is relatively high in lysine, which is an essential amino acid in human and monogastric diets (Khazaei et al. 2019). Owing to the ability of symbiotic N_2 fixation, faba bean cultivation increases the sustainability of cropping systems by adding nitrogen to the soil and therefore reducing the consumption of fossil fuel energy required for manufacturing nitrogen fertilizers (Jensen et al. 2010) with improving soil fertility. Also, faba bean plays a crucial role in crop rotation by breaking the disease cycles of various pathogens and pets (Nebiyu et al. 2016; Rose et al. 2016).

The elimination or reduction of weed seeds present as soil seed bank is an important weed control strategy in particularly for parasitic weeds. It is well known that broomrape (*Orobanche crenata* Forsk.) is a serious parasitic weed which causes distinctive losses in faba bean productivity all over the world (Ennami et al. 2020; Fernández–Aparicio et al. 2016). In several situations, no yield can be obtained because of high infestation of broomrape impeding faba bean cultivation. Thus, at farms highly infested with broomrape, farmers are

✉ Hani Saber Saudy
hani_saudy@agr.asu.edu.eg

[1] Agronomy Department, Faculty of Agriculture, Ain Shams University, P.O. Box 68, Hadayek Shoubra, Cairo 11241, Egypt

[2] Botany Department, National Research Centre, P.O. Box 12622, Dokki, El–Behos St. Dokki, Cairo, Egypt

[3] Biochemistry Department, Faculty of Agriculture, Ain Shams University, P.O. Box 68, Hadayek Shoubra, Cairo 11241, Egypt

obligated to forgo the cultivation of faba bean. Despite the significance of faba bean as a legume crop, its growth and development are restrained in several cultivated areas due to the existence of broomrape causing low yield and returns (Amri et al. 2019; Joel et al. 2007). The individual application of cultural or chemical practices for broomrape control have been exploited; however, the desired success was not enough (Rubiales 2014). Herein, the integration among these techniques should be exploited.

The first step for planning weed control program is choosing and cultivation the broomrape-tolerant cultivars. Resistant cultivars can grow satisfactorily and yield better in infested fields, thus alleviating the hazards of *Orobanche* attacks. Several cultivars of faba bean with varying degree of resistance to *Orobanche* species have been raised by plant breeders (Abbes et al. 2020; Amri et al. 2019). Resistant of faba bean cultivars to broomrape might be attributed to the callose sedimentation in the cortex cellular walls of the host and in contact with the scrounger tissues, as well as lignification of pericycle and endodermal tissues (Pérez–de–Luque et al. 2007).

The next step in effective programs to control broomrape weed is the application of treatments that reduce the soil seed bank by damaging broomrape seeds in the soil. In this regard, and along with cultivation the broomrape-tolerant cultivars, applicable field practices should be implemented. Herein, the properties of compost and biochar could be utilized and exploited; however, their importance in controlling broomrape is not well known. Commonly, application of compost to soils increased the microbial biomass activity, soil respiration, and the activity of various enzymes (Zhen et al. 2014). These changes in soil environment could affect nutrient availability to plants and nutrient movement in soils (Charles et al. 2017). Based on the type of compost, it can buffer soil pH (Butler et al. 2008). In this respect, an increase of soil pH following addition of compost from poultry litter is mainly due to addition of basic cations (K, Ca and Mg), ammonification, and production of NH_3 during decomposition of the added compost (Mandal et al. 2013). Unlike, soil pH can also decrease after application of compost from rice straw mixed with agroindustrial wastes due to the release of H^+ ions via nitrification and/or the production of organic acids during decomposition (Bolan and Hedley 2003; Rashad et al. 2011). Soil properties (water holding capacity, organic matter, aeration, pH value, cationic exchange capacity, and soil aggregation) have been improved by application of biochar into the soil (Manirakiza and Şeker 2020). Due to its large surface area, charged surface, and functional groups, biochar is of great potential to adsorb organic compounds reducing their bioavailability (Nartey and Zhao 2014).

It was discovered previously that parasitic plants, i.e., *Orobanche* spp., sense their host plant through the recognition of secondary metabolites released by its roots (Yoder 1999). Moreover, parasitic seeds germinate only when they receive chemical signals released from potential host roots (Joel et al. 2007). Germination of *Orobanche* spp. seeds are usually stimulated by strigolactone compounds (Bouwmeester et al. 2003).

Because of their physical and chemical properties, biochar or compost application to the soil as robust adsorbents may have remarkable impacts on the released root exudates of faba bean. As mentioned in literatures, due to certain phenotypic mechanisms (negative effect of natural stimulant broomrape seed germination and radical deformation), compost tea application showed adverse impact on broomrape seed germination, prevention of radical penetration inside the host roots, parasite yield reduction, and thus increasing the growth and vitality of faba bean (El–Halmouch et al. 2013).

Limited information is available on the effect of biochar, and compost in changing the stimulating effect of faba bean root exudates around the root zone to be unfavorable for growth and development of the broomrape. Our hypothesis of the current work is that broomrape infestation impacts could be reduced by application of biochar or compost in soil rhizosphere around root system. Hence, this preliminary study investigates the relative efficiency of biochar and compost as means of broomrape weed control at farm level for achieving sustainable productivity of faba bean.

2 Materials and Methods

2.1 Study Location

A 2-year field trial was undertaken in 2015/2016 and 2016/2017 winter seasons at El Nubaria experimental farm, National Research Centre, Egypt. The soil at the trial site was sandy and its physicochemical properties, estimated by the method of Page et al. (1982), are shown in Table 1. According to US Soil Taxonomy (Soil Survey Staff 1999), the soil is classified in the order Aridisol and suborder Durids. Maize was grown as the preceding crop in the first and second seasons.

2.2 Procedures and Treatments

The experiment consisted of four treatments for broomrape control (biochar, compost, glyphosate-isopropylammonium, and unweeded (control)) applied with two faba bean cultivars, i.e., Misr–3 (tolerant) and Sakha–1 (less tolerant). During soil preparation, single super phosphate was applied (15.5% P_2O_5), 360 kg ha^{-1}. Biochar and compost were added as a spot placement at a rate of 40 and 50 g hill^{-1}, respectively (these amounts calculated based on the size of hole occupied by biochar or compost instead of the removed soil before planting), after soil preparation (Fig. 1), and then soil was irrigated. Biochar and compost were prepared from dry plant

Table 1 Physicochemical properties of the experimental soil of the experimental station of agricultural production and research station, El Nubaria, El Beheira Governorate, Egypt

Property	Value
Physical	
Sand (%)	72.55±0.55
Silt (%)	10.00±1.30
Clay (%)	17.45±1.85
Bulk density (g m^{-3})	10.01±1.04
Water holding capacity %	22.91±2.12
Chemical	
pH	8.10±0.32
EC (dS m^{-1})	0.62±0.04
Ions (meq l^{-1})	
Ca^{++}	1.90±0.03
Mg^{++}	0.90±0.01
K^{+}	0.24±0.02
Na^{+}	3.36±0.11
Cl^{-}	1.80±0.03
$CO_3^{=}$	Not detected
HCO_3^{-}	3.60±0.21
$SO_4^{=}$	1.00±0.04

± standard error ($p \le 0.05$)

wastes of casuarina (*Casuarina equisetifolia*) and camphor (*Eucalyptus sideroxylon*) trees, respectively. According to Yu et al. (2013), the biochar was produced by heating air dried tree branch clippings using slow pyrolysis process for 2 h (about 350–420 °C). After cooling, the produced biochar was passed through a 2-mm sieve. The compost was prepared using the Indore method (Inckel et al. 2005). Briefly, the alternative layers of organic mixtures (90% camphor trees residues + 10% farmyard manure) were used to make the compost pile ($1.25 \times 2.5 \times 0.75$ m^3 in size). A plastic sheet was used to cover the ground before making the pile to keep up the leaching nutrients solution after watering. Also, the pile was covered by plastic sheet to keep up the moisture and to help in the decomposition process by increasing temperature. This process took approximately 4 months. According to Page et al. (1982), some chemical properties of used biochar and compost are estimated as shown in Table 2. Also, four faba bean plants from each experimental unit were thoroughly uprooted to obtain samples of the soil media substances around root zone. In these samples, some properties of biochar and compost were estimated comparing to untreated soil after harvest (Table 3).

On November 17, 2015/2016, and November 27, 2016/2017, seasons (10 days after soil irrigation), *Rhizobium*-inoculated faba bean seeds were sown (3–4 seeds per hill), with 0.25-m space on the two sides of the ridge, and then soil was irrigated. At 35 days after sowing (DAS), plants were hand hoed and thinned, leaving two plants per hill. Glyphosate-isopropylammonium, roundup 48% WSC (isopropylammonium *N*–(phosphonomethyl)glycinate) was applied thrice during faba bean flowering stages (60, 75, and 90 DAS, 0.18 L ha^{-1}). For all experimental treatments, ammonium nitrate (33.5% N) at a rate of 90 kg ha^{-1} was divided into two equal parts and applied 35 and 50 DAS. During growth stages, plants were watered through drip irrigation system using emitters of 1.5 L h^{-1} capacity.

2.3 Experimental Design

The trial design was a strip-plot in completely randomized block arrangement in six replications and applying the model presented in Formula 1 (Casella 2008). Cultivars occupied the vertical main plots as well as broomrape control treatments distributed in horizontal ones. The plot size was 11.40 m^2, comprising five furrows with a 3.5-m length and 0.65-m width.

$$Y_{ijk} = \mu + \tau_i + \beta_j + (\beta\tau)_{ij} + \gamma_k + (\beta\gamma)_{jk} + (\tau\gamma)_{ik} + (\beta\tau\gamma)_{ijk} + \varepsilon_{ijk} \quad (1)$$

where,

Y_{ijk} is response, μ is overall mean effect, τ is the treatment, β and γ are the blocks, and $\beta_j \sim N(0, \sigma^2_\beta)$, $\gamma_k \sim N(0, \sigma^2_\gamma)$, $\varepsilon_{ijk} \sim N(0, \sigma^2_\varepsilon)$, all independent {Assuming that the block factor to be random and the other factors to be fixed; independence between all errors}.

2.4 Assessments

2.4.1 Broomrape Traits

At 105 DAS, a number of broomrape shoots and infected faba bean plants $plot^{-1}$ were counted. Also, at harvest, broomrape shoots were uprooted, air dried for 10 days, and oven-dried for 24 h at 80 °C up to a constant weight for estimating the total biomass expressed in dry weight $plot^{-1}$.

2.4.2 Crop Traits

At harvest (on April 24 and April 27 in the first and second seasons, respectively), 10 faba bean plants were randomly chosen and uprooted from each plot to estimate plant dry weight and weight of 100 seeds. Moreover, whole plants of the plot were harvested to estimate seed yield ha^{-1}. According to AOAC (2012), total nitrogen was determined in seeds using the modified micro Kjeldahl method. Crude protein content was calculated by multiplying the total nitrogen by 6.25.

Table 2 Some chemical properties of applied biochar and compost

Material	pH	EC, dS m^{-1}	Macro nutrients, %		
			N	P	K
Biochar	9.05 ± 0.05	4.04 ± 0.65	1.31 ± 0.01	0.65 ± 0.04	1.04 ± 0.06
Compost	7.79 ± 0.01	4.21 ± 0.11	0.92 ± 0.02	0.41 ± 0.01	0.21 ± 0.01

Biochar and compost were prepared from dry plant wastes of casuarina (*Casuarina equisetifolia*) and camphor (*Eucalyptus sideroxylon*) trees, respectively; *pH* acidity; *EC* electric conductivity, *N* nitrogen, *P* phosphorus, *K* potassium, ± standard error ($p \leq 0.05$)

2.5 Regression Analysis

Regression analysis between faba bean seed yield ha^{-1} (dependent variable) and each of number and dry mass of broomrape shoots and number of infected faba bean plants $plot^{-1}$ (independent variables) was derived as explained by Draper and Smith (1998).

2.6 Statistical Analysis

The data obtained were subjected to homogeneity test prior to analysis of variance (ANOVA). The outputs proved that the homogeneity and normality of the data are satisfied for running further ANOVA. Thus, data of each season were undergone to ANOVA according to Casella (2008), using Costat software program, Version 6.303, 2004. At $p \leq 0.05$ level of probability, Duncan's multiple range test (alphabetical lowercase letters) was used for distinguishing among the treatment means.

3 Results

3.1 Effect of Cultivar and Weed Control Treatment on Broomrape

Results in Table 4 showed the remarkable variation between the two tested cultivars of faba bean Misr–3 and Sakha–1 in their performance against broomrape weed in 2015/2016 and 2016/2017 seasons. Misr–3 showed a significant advantage over Sakha–1 in confronting the broomrape weed. In this respect, number of broomrape shoots $plot^{-1}$ reduced by 68.1% in 2015/16 season with Misr–3 compared to Sakha–1. Moreover, dry weight of broomrape shoots $plot^{-1}$ and number of infected plants $plot^{-1}$ in Misr–3 cultivar were lesser by 57.2 and 35.8% as well as 72.1 and 38.6% than Sakha–1 in 2015/2016 and 2016/2017 seasons, respectively.

ANOVA exhibited significant differences among various broomrape weed control treatments in number and dry weight of broomrape shoots as well as number of infected faba bean plants $plot^{-1}$ in 2015/2016 and 2016/2017 seasons (Table 4). Herein, the highly infestation of broomrape appeared in control treatment (unweeded). Contrarily, treated plots showed reduction in broomrape abundance than untreated one. Glyphosate effect statistically equaled biochar effect on number of emerged broomrape shoots in both seasons and infected faba bean plants $plot^{-1}$ in 2016/17 one. Also, compost effect was as similar as glyphosate for dry weight of broomrape shoots in 2016/2017 season and number of infected faba bean plants $plot^{-1}$ in 2015/2016 and 2016/2017. In both seasons, similar impacts of biochar and compost on all broomrape traits were obtained.

Considerable impact of the interaction between cultivars and broomrape control treatments was obtained (Table 4). It should be noted that the maximum values of broomrape shoots number and dry weight and number of infected faba bean plants were recorded in unweeded plots that involved Sakha–1 plants. Unlike, reductions in such studied traits were achieved due to treating both of Misr–3 and Sakha–1 plants with tested treatments, i.e., glyphosate, compost, or biochar. Glyphosate application as a common practice recorded the best controlling of broomrape in faba bean whether with Misr–3 or Sakha–1 cultivar. By and large, treating Misr–3 plants by glyphosate, compost, or biochar protected them

Table 3 Bulk density (BD), water holding capacity (WHC), cation exchange capacity (CEC), acidity (pH), and electric conductivity (EC) of applied biochar and compost as comparing to untreated soil

Variable	BD (g m^{-3})	WHC %	CEC (cmol kg^{-1})	pH	EC, dS m^{-1}
Biochar	0.52 ± 0.30	304.2 ± 4.21	54.9 ± 2.21	8.17 ± 0.03	3.85 ± 0.24
Compost	0.49 ± 0.60	386.5 ± 7.66	64.3 ± 3.91	7.07 ± 0.02	4.03 ± 0.20
Untreated soil	1.78 ± 0.52	23.2 ± 1.13	10.2 ± 1.24	8.41 ± 0.42	0.60 ± 0.02

Biochar and compost were prepared from dry plant wastes of casuarina (*Casuarina equisetifolia*) and camphor (*Eucalyptus sideroxylon*) trees, respectively; ± standard error ($p \leq 0.05$)

Fig. 1 Spot placement of biochar/compost before faba bean sowing

from broomrape attacking since low values of number and dry weight of broomrape shoots plot^{-1} as well as number of infected faba bean plants plot^{-1} were noticed (Table 4).

3.2 Effect of Cultivar and Weed Control Treatment on Faba Bean

Results in Table 5 clarify the remarkable disparities between Misr–3 and Sakha–1 in dry weight plant^{-1} and seed yield ha^{-1}, while weight of 100 seeds was not affected. Misr–3 surpassed Sakha–1 by 17.6 and 20.7% for dry weight plant^{-1} as well as 20.8 and 15.8% for seed yield ha^{-1} in 2015/2016 and 2016/2017.

All weed control treatments surpassed the control (unweeded) in dry weight plant^{-1} and seed yield ha^{-1} of faba bean in both growing seasons. Spot placement of biochar was the distinctive pattern for enhancing dry weight plant^{-1} and seed yield ha^{-1} (Table 5). Biochar treatment statistically leveled with glyphosate and compost (for dry weight plant^{-1}) and with glyphosate (for seed yield ha^{-1}) in both seasons.

Despite Misr–3 produced greater yield than Sakha–1 under broomrape infestation (unweeded), the disparity was not significant as presented in Table 5. On the contrary, controlling broomrape using compost, biochar, or glyphosate in Misr–3 plots along with using biochar in Sakha–1 plots recorded the maximum increases in dry weight plant^{-1}. Application of any weeded pattern, i.e., compost, biochar, or glyphosate, in each of Misr–3 or Sakha–1 plots gave similar seed yields ha^{-1} in the first season. However, planting Misr–3 either with biochar or glyphosate as well as Sakha–1 with glyphosate were the remarkable combinations for increasing seed yield ha^{-1} in the second season.

Regarding the seed quality, the illustrated result in Fig. 2 clarified that Misr–3 seeds had protein content as similar Sakha–1 seeds. Seed protein content significantly influenced by broomrape control treatments (Fig. 3) and their interaction with faba bean cultivars (Fig. 4). In this context, the maximum values of protein content were recorded with compost and biochar in both 2015/2016 and 2016/2017 seasons, in addition to glyphosate in 2016/2017 season. In 2015/2016 season, the interactions of Misr–3 x compost or biochar and Sakha–1 x compost showed the highest protein content. Moreover, Misr–3 x biochar or glyphosate and Sakha–1 x compost were the

Table 4 Number and weight of emerged broomrape shoots and number of broomrape-infected faba bean plants as influenced by cultivar and broomrape control treatment in 2015/2016 and 2016/2017 seasons

Variable		Emerged broomrape shoots plot^{-1}				Number of infected faba bean plants plot^{-1}	
		Number		Weight (g)			
		2015/2016	2016/2017	2015/2016	2016/2017	2015/2016	2016/2017
Cultivars, C							
Misr–3		14.58 ± 3.8^{b}	10.16 ± 1.3^{a}	39.91 ± 7.1^{b}	12.58 ± 1.5^{b}	8.16 ± 2.1^{b}	6.5 ± 1.0^{b}
Sakha–1		45.66 ± 9.6^{a}	15.08 ± 2.0^{a}	93.25 ± 19.4^{a}	19.58 ± 2.7^{a}	29.25 ± 6.1^{a}	10.58 ± 1.8^{a}
Treatment, T							
Compost		18.00 ± 3.5^{b}	11.83 ± 1.5^{b}	55.66 ± 4.4^{b}	12.5 ± 1.1^{bc}	12.5 ± 3.3^{bc}	8.83 ± 1.3^{b}
Biochar		24.83 ± 7.1^{b}	10.0 ± 1.6^{bc}	62.33 ± 13.8^{b}	16.0 ± 2.3^{b}	20.5 ± 6.6^{b}	6.66 ± 1.5^{b}
Glyphosate		12.83 ± 5.8^{b}	7.5 ± 0.4^{c}	17.16 ± 6.7^{c}	9.16 ± 1.5^{c}	4.3 ± 1.5^{c}	3.83 ± 0.4^{b}
Unweeded		64.83 ± 14.8^{a}	21.16 ± 2.0^{a}	131.16 ± 29.3^{a}	26.66 ± 3.0^{a}	$37. \pm 59.7^{a}$	14.83 ± 2.1^{a}
CxT							
Misr–3	Compost	11.0 ± 2.3^{def}	8.66 ± 0.3^{de}	49.00 ± 0.5^{cd}	10.00 ± 0.1^{cd}	6.66 ± 2.0^{c}	6.33 ± 0.8^{cd}
	Biochar	9.0 ± 0.5^{ef}	8.0 ± 1.0^{e}	34.33 ± 12.9^{de}	12.00 ± 1.5^{cd}	6.0 ± 0.5^{c}	5.0 ± 1.5^{cd}
	Glyphosate	5.33 ± 2.9^{f}	7.0 ± 0.5^{e}	9.66 ± 5.3^{e}	8.33 ± 3.3^{d}	1.66 ± 0.3^{d}	4.0 ± 1.0^{d}
	Unweeded	33.0 ± 2.0^{bc}	17.0 ± 2.0^{b}	66.66 ± 8.4^{bc}	20.0 ± 0.1^{b}	18.33 ± 3.7^{bc}	10.66 ± 2.3^{b}
Sakha–1	Compost	25.0 ± 2.8^{cd}	15.0 ± 1.5^{bc}	62.33 ± 7.2^{c}	15.0 ± 0.1^{bc}	18.3 ± 4.3^{bc}	11.33 ± 1.2^{b}
	Biochar	40.66 ± 2.6^{b}	12.0 ± 2.8^{cd}	90.33 ± 3.1^{b}	20.0 ± 2.8^{b}	35.0 ± 2.8^{b}	8.33 ± 2.7^{bc}
	Glyphosate	20.33 ± 10.1^{cde}	8.0 ± 0.5^{e}	24.66 ± 12.0^{de}	10.0 ± 0.1^{cd}	7.0 ± 2.0^{c}	3.66 ± 0.3^{d}
	Unweeded	96.66 ± 9.5^{a}	25.33 ± 0.6^{a}	195.66 ± 7.8^{a}	33.33 ± 1.6^{a}	56.66 ± 9.5^{a}	19.0 ± 0.5^{a}

Note: Different lowercase letters within the same column mean significant differences among different treatments at $p < 0.05$ level; ± standard error ($p \leq 0.05$)

Table 5 Dry weight plant^{-1}, weight of 100 seeds, and seed yield of faba bean as influenced by cultivar and broomrape control treatment in 2015/2016 and 2016/2017 seasons

Variable		Dry weight plant^{-1} (g)		Weight of 100 seeds (g)		Seed yield (ton ha^{-1})	
		2015/16	2016/17	2015/16	2016/17	2015/16	2016/17
Cultivars, C							
Misr–3		205.7 ± 23.3^{a}	128.1 ± 9.1^{a}	60.8 ± 1.48^{a}	62.5 ± 1.15^{a}	3.83 ± 0.23^{a}	5.86 ± 0.41^{a}
Sakha–1		174.9 ± 25.1^{b}	106.1 ± 8.7^{b}	60.8 ± 2.28^{a}	64.2 ± 1.72^{a}	3.17 ± 0.34^{b}	5.06 ± 0.40^{b}
Treatment, T							
Compost		194.9 ± 33.5^{a}	115.2 ± 7.1^{ab}	61.6 ± 1.05^{ab}	62.5 ± 3.09^{a}	3.45 ± 0.43^{b}	5.16 ± 0.29^{b}
Biochar		261.6 ± 27.5^{a}	146.0 ± 14.1^{a}	57.5 ± 2.50^{b}	61.6 ± 2.10^{a}	4.13 ± 0.34^{a}	6.65 ± 0.47^{a}
Glyphosate		203.8 ± 28.3^{a}	121.2 ± 12.5^{a}	66.6 ± 3.07^{a}	66.6 ± 1.05^{a}	4.09 ± 0.11^{ab}	6.39 ± 0.14^{a}
Unweeded		101.0 ± 5.1^{b}	86.1 ± 5.26^{b}	57.5 ± 2.14^{b}	62.5 ± 1.11^{a}	2.33 ± 0.34^{c}	3.65 ± 0.37^{c}
GxT							
Misr–3	Compost	214.1 ± 47.0^{ab}	123.6 ± 13.2^{ab}	61.6 ± 1.66^{a}	61.6 ± 1.66^{a}	3.61 ± 0.59^{ab}	5.19 ± 0.57^{bcd}
	Biochar	255.5 ± 33.2^{a}	158.8 ± 11.5^{a}	58.3 ± 4.40^{a}	58.3 ± 1.66^{a}	4.51 ± 0.34^{a}	7.46 ± 0.45^{a}
	Glyphosate	243.2 ± 45.2^{a}	132.8 ± 23.6^{ab}	65.0 ± 2.88^{a}	66.6 ± 1.66^{a}	4.18 ± 0.06^{ab}	6.56 ± 0.23^{ab}
	Unweeded	110.1 ± 6.7^{cd}	97.4 ± 1.1^{bc}	58.3 ± 1.66^{a}	63.3 ± 1.66^{a}	3.02 ± 0.30^{bc}	4.22 ± 0.36^{de}
Sakha–1	Compost	175.8 ± 55.3^{b}	106.8 ± 3.6^{bc}	61.6 ± 1.66^{a}	63.3 ± 6.66^{a}	3.28 ± 0.75^{ab}	5.12 ± 0.33^{cd}
	Biochar	267.6 ± 51.6^{a}	133.2 ± 26.4^{ab}	56.6 ± 3.33^{a}	65.0 ± 2.88^{a}	3.75 ± 0.58^{ab}	5.84 ± 0.53^{bc}
	Glyphosate	164.4 ± 20.9^{bc}	109.6 ± 10.0^{bc}	68.3 ± 6.00^{a}	66.6 ± 1.66^{a}	4.00 ± 0.22^{ab}	6.23 ± 0.17^{abc}
	Unweeded	92.0 ± 1.6^{d}	74.8 ± 3.1^{c}	56.6 ± 4.40^{a}	61.6 ± 1.66^{a}	1.64 ± 0.16^{c}	3.08 ± 0.49^{e}

Note: Different lowercase letters within the same column mean significant differences among different treatments at $p < 0.05$ level; ± standard error ($p \leq 0.05$)

effective combinations for increasing protein content in 2016/2017 season.

3.3 Regression Analysis

By studying the simple regression relationships and computing coefficient of determination (R^2) between faba bean seed yield, as a dependent variable, and each of number and dry weight of broomrape shoots as well as number of infected faba bean plants plot^{-1}, as independent variables, it is shown that the suitable mathematical uniform is the logarithmic relation (Figs. 5, 6, and 7). According to regression equations, there is a significant and negative relation between faba bean seed yield either with number and dry weight of broomrape shoots or number of infected faba bean plants plot^{-1}. From R^2 values, it is observed that dry weight of broomrape shoots plot^{-1} parameter is more effective in exhibiting changes in seed yield, since 72.9% of these changes were attributed to such parameter. Moreover, regression equations are forecasting that the higher the number and dry weight of broomrape shoots and number of infected faba bean plants plot^{-1} increase by 1.0%, the higher the seed yield decreases by 0.63, 0.54, and 0.48, respectively.

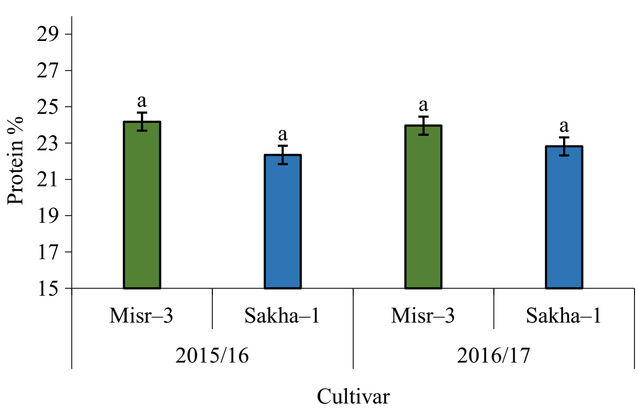

Fig. 2 Seed protein content of faba bean as influenced by cultivar in 2015/2016 and 2016/2017 seasons

4 Discussion

Regarding the importance of genetic variation of faba bean and occurrence of broomrape weed, the results showed less abundance of broomrape shoots associated Misr–3 cultivar compared to Sakha–1. The level of tolerance of Misr–3 cultivar to broomrape is expressed through low number and dry mass of broomrape shoots and number of infected faba bean plants (Table 4). Such finding refers to that Misr–3 is more tolerant to broomrape infection than Sakha–1. Several safeguard dynamics have been disclosed in plants resistant to broomrape aggression, fundamentally encompassing cellular

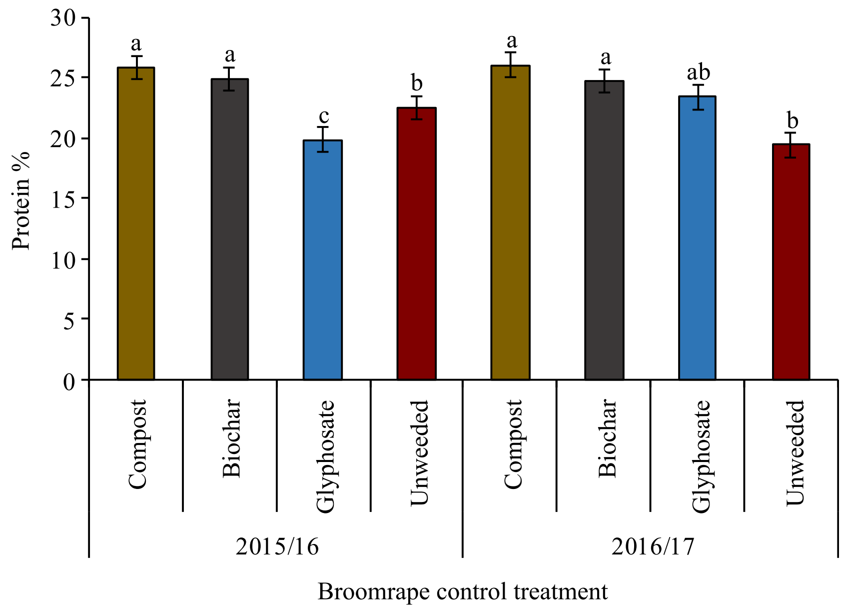

Fig. 3 Seed protein content of faba bean as influenced by broomrape control treatment in 2015/2016 and 2016/2017 seasons. Vertical bars represent means ± standard error ($p \leq 0.05$). Columns marked by various letters are significantly different

wall strengthening, production of toxic compounds (Pérez–De–Luque et al. 2006a, 2007), and sealing of vascular tissues (Pérez–de–Luque et al. 2006b). Recently, in some faba bean strains, it has been reported that the resistance is relying on low induction of O*robanche* seed germination due to low production of germination stimulants secreted by host root (Trabelsi et al. 2016, 2017). Genetic variation for the induction of broomrape germination has also been described in tomato that might be explained both by the presence of germination inhibitors (El–Halmouch et al. 2006) or by reduced exudation of strigolactones (Dor et al. 2010). Relative weakness in O*robanche* growth observed on the roots of tolerant cultivar associated low invertase activity in O*robanche*, low osmotic pressure of the infected root tissues, and reduction in nitrogen (Abbes et al. 2009). Furthermore, due to genetic variation and broomrape tolerance degree, distinctive differences between Misr–3 and Sakha–1 cultivars in dry matter production and seed yield, with superiority of Misr–3, were obtained (Table 5). Genotypic variations in broomrape tolerance and seed yield potentiality among faba bean cultivars were reported by Fernández–Aparicio et al. (2014) and Trabelsi et al. (2015).

As observed from the data, it was found that there were acceptable levels of broomrape control as a result of the applied different practices compared to the unweeded (Table 4). Because glyphosate herbicide can move through the host phloem to reach root-attached broomrape tubercles and kill them, the low occurrence of broomrape expressed in reduced

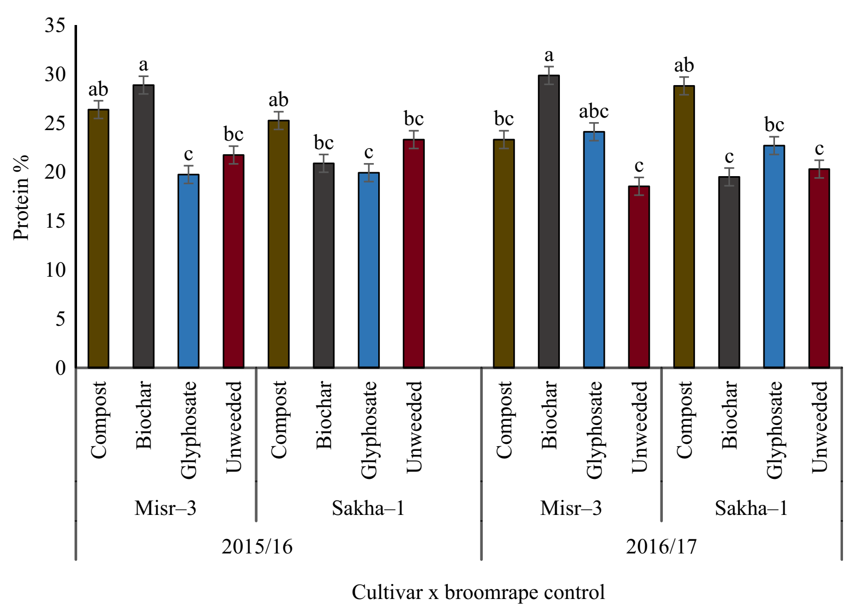

Fig. 4 Seed protein content of faba bean as influenced by cultivar x broomrape control treatment in 2015/2016 and 2016/2017 seasons. Vertical bars represent means ± standard error ($p \leq 0.05$). Columns marked by various letters are significantly different

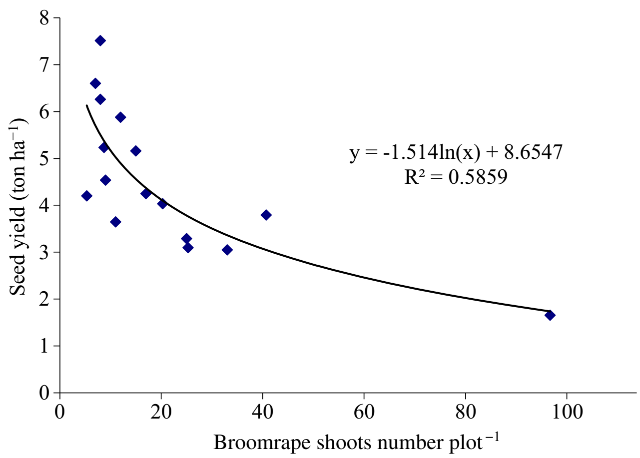

Fig. 5 Regression relationship between faba bean seed yield and broomrape shoots number plot^{-1}

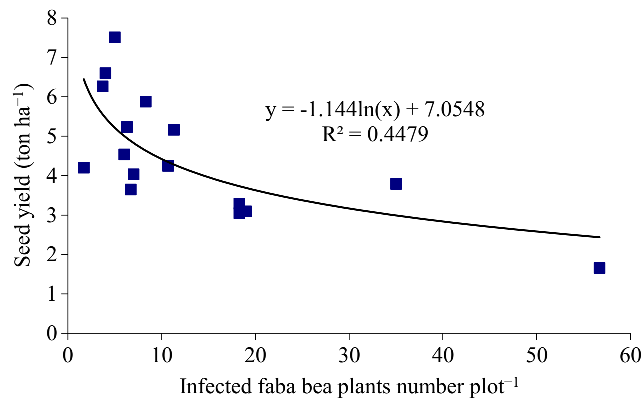

Fig. 7 Regression relationship between faba bean seed yield and number of broomrape-infected plants plot^{-1}

number and dry mass of broomrape shoots and number of infected faba bean plants plot^{-1} was obtained (Table 4). Since the activity of the 5-enolpyruvylshikimic acid-3-phosphate synthase enzyme, needed for the aromatic amino acids makeup, is inhibited by glyphosate herbicide (Gomes et al. 2014) impeding the biosynthesis of proteins, auxins, and other vital compounds (Moorman et al. 1992), a better control of broomrape has occurred (Table 4). Consequently, dry weight plant^{-1} and seed yield were improved (Table 5).

Spot placement of biochar or compost as natural sources showed significant control of broomrape, since the broomrape number and dry weight and number of infected faba bean plants plot^{-1} diminished (Table 4). The properties of biochar or compost may play a dynamic role in this respect. As compared to the untreated soil cultivated by faba bean plants, biochar or compost exhibited significant differences in bulk density, water holding capacity, cation exchange capacity, and electric conductivity (Table 3). In this context, germination of root parasitic weed seeds promoted by stimulants emancipated into the soil medium by the host plant roots represents one model of underground plant–plant interference stimulated by decoding molecules (Yoneyama et al. 2010). Confusion of any action with parasite–host relation, such as adsorption of the exudates, or an alternation in exudates produced by the host, could affect parasitic weed seed germination and, hence, the ferocity of infection. Accordingly, adding biochar or compost as spot placement, to be surrounding crop root, may represent a barrier handicapping the accession of faba bean root stimulant to broomrape seeds preventing their germination. Since each of biochar or compost has high surface area and adsorption ability (Kasozi et al. 2010), they have the potentiality to control the released root exudates. Also, application of biochar or compost could change the rhizosphere environment to be unsuitable for broomrape seed germination or even causing damage to germinated seeds. Herein, since compost and biochar had lower bulk density and higher capacities of water holding and cation exchange than untreated soil (Table 3), they could alter the root milieu. Biochar prepared from various sources had pH of 8.2–13.0 (Jha et al. 2010) and phenols (DeLuca et al. 2006). Significant effects because of biochar applications were obtained on soil physicochemical properties such as increase in soil pH, soil aeration, and water retention capacity (Laird et al. 2010; Ouyang et al. 2014). Since toxicity of biological decomposition products is known to take place during compost genesis (Barker and Bryson 2002), broomrape seeds viability was reduced to 2% in soil amended with compost (Abu–Irmaileh and Abu–Rayyan 2006). Elevating heat and producing toxic compounds, associating the fermentation process of various organo-materials, can diminish seed viability of several species (Simpson 1986). Abu–Rayyan and Abu–Irmaileh (2004) found that compost can reduce the viability of broomrape seeds.

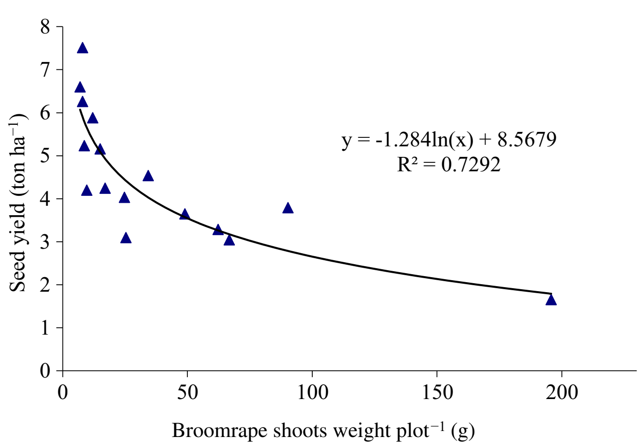

Fig. 6 Regression relationship between faba bean seed yield and broomrape shoots dry weight plot^{-1}

Our findings also revealed that improvements in faba bean biomass expressed in dry weight plant^{-1} and seed yield ha^{-1} as well as protein content were more evident with application of biochar emulating glyphosate. In this respect, biochar can hold nutrients and water due to its high surface area and porosity, in addition to providing a growth-stimulating medium for advantageous microorganisms (Glaser et al. 2002;

Lehmann and Rondon 2006; Warnock et al. 2007); thus, the enhancement in crop yield can be achieved. The beneficial role of biochar on plant growth with increasing yield has been reported (Lehmann and Joseph 2009). Both biological nitrogen fixation and beneficial mycorrhizal relationships in common beans (*Phaseolus vulgaris*) were enhanced by biochar applications (Rondon et al. 2007; Warnock et al. 2007). Because of higher cation exchange capacity of biochar or compost (438.2 and 530.4%) as well as water holding capacity (13.1 and 16.6 times) than the untreated soil (Table 3), greater nutrient retention capability could be occurred (Warnock et al. 2007). The conservation practices based on the use of compost had a beneficial effect on growth, diversity, and activity of diverse groups of rhizospheric microorganisms that promote plant growth (Gosling et al. 2006). Also, as organic amendment to soil, compost application caused improvement of soil organic matter content, soil water holding capacity, and nutrient availability to plant and increment in soil microbial population (Lim et al. 2018). Adekiya et al. (2019) found a significant effect on leaf N, P, K, Ca, and Mg uptake by crop plants after biochar and poultry manure additions. An improved crop yield following enhanced soil fertility was evidenced in the compost and biochar amended soils (Agegnehu et al. 2016; Doan et al. 2015).

Under broomrape infestation, Sakha–1 was less tolerant to broomrape than Misr–3. Self-defense mode of cultivar against broomrape may not be enough particularly with highly infested conditions. Therefore, the fierce attacks of broomrape should be faced by implementation of the effective methods of control along with the cultivar used. Herein, Misr–3 cultivar exhibited more stability against broomrape with relative biomass improvement under weeded practices, i.e., glyphosate, compost, or biochar.

Regression analysis proved that estimation of broomrape shoots dry weight is more indicative than broomrape shoots number and number of infected faba bean plants in broomrape–faba bean interaction. Thus, the practice that causes reduction in broomrape biomass is so significant for protecting faba bean plants from broomrape attacks. Herein, planting cultivar that may be infected by broomrape, but has defense mechanisms that suppress the development of attached broomrape shoots, is considered a distinct tool in broomrape management. Besides, lowering broomrape shoots' number and dry weight as well as number of infected faba bean plants using applicable pattern, i.e., biochar or compost, is significant too.

5 Conclusions

The current study is one of the first attempts to test, in field, the potentiality of biochar and compost in reducing broomrape attacks against faba bean plants. Not only depressive impact against broomrape was achieved, but also economic yield and protein content of faba bean was sustained, emphasizing the potent effect of spot placement of biochar or compost for faba bean sustainability in broomrape infested areas. With cultivating the most broomrape-tolerant cultivars, i.e., Misr–3, biochar or compost could present a modern environmentally safe manner to manage broomrape, and hence sustaining the productivity of faba bean. However, more investigations related to biochar and compost mechanisms against broomrape germination and its tubercles development are required. Moreover, plant breeders should focus on the genes which are related to defense mechanisms that suppress the development of attached broomrape shoots to improve faba bean cultivars in breeding programs.

Acknowledgements The authors would like to appreciate the technical support provided by the Faculty of Agriculture, Ain Shams University and National Research Centre, Egypt.

Declarations

Conflict of Interest The authors declare no competing interests.

References

Abbes Z, Kharrat M, Delavault P, Chaïbi W, Simier P (2009) Osmoregulation and nutritional relationships between *Orobanche foetida* and faba bean. Plant Signal Behav 4:336–338 10.4161%2Fpsb.4.4.8192

Abbes Z, Bouallegue A, Trabelsi I, Trabelsi N, Taamalli A, Amri M, Mhadhbi H, Kharrat M (2020) Investigation of some biochemical mechanisms involved in the resistance of faba bean (*Vicia faba* L.) varieties to *Orobanche* spp. Plant Prot Sci 56:317-328 https://doi.org/10.17221/103/2019-PPS

Abu–Irmaileh BE, Abu–Rayyan AM (2006) Pre–plant black plastic mulching and manure composting for controlling hemp broomrape (*Orobanche ramosa*) in tomato. Jord J Agric Sci 2:54–63

Abu–Rayyan AM, Abu–Irmaileh BE (2004) Efficiency of fermenting poultry manure for weed control in organically grown eggplants (*Solanum melongena* L.). Arab J Plant Prot 22:35–40

Adekiya AO, Agbede TM, Aboyeji CM, Dunsin O, Simeon VT (2019) Biochar and poultry manure effects on soil properties and radish (*Raphanus sativus* L.) yield. Biol Agric Hortic 35:33–45. https://doi.org/10.1080/01448765.2018.1500306

Agegnehu G, Bass AM, Nelson PN, Bird MI (2016) Benefits of biochar, compost and biochar–compost for soil quality, maize yield and greenhouse gas emissions in a tropical agricultural soil. Sci Total Environ 543:295–306. https://doi.org/10.1016/j.scitotenv.2015.11.054

Amri M, Trabelsi I, Abbes Z, Kharrat M (2019) Release of a new faba bean variety "Chourouk" resistant to the parasitic plants *Orobanche foetida* Poir, and *Orobanche crenata* Forsk, in Tunisia. Int J Agric Biol 23:499–505 https://doi.org/10.17957/IJAB/15.0921

AOAC (2012) In: Hormitz W (ed) Association of Official Agriculture Chemists, Official methods of analysis 19th edn, Washington, DC, USA

Barker AV, Bryson GM (2002) Bioremediation of heavy metals and organic toxicants by composting. Sci World J 2:407–420. https://doi.org/10.1100/tsw.2002.91

Bolan NS, Hedley MJ (2003) Role of carbon, nitrogen and sulfur cycles in soil acidification, Rengel, 2., (Ed.) edn. Handbook of Soil Acidity. Marcel Dekker AG, New York, pp 29–56

Bouwmeester HJ, Matusova R, Zhongkui S, Beale MH (2003) Secondary metabolite signaling in host–parasitic plant interactions. Curr Opin Plant Biol 6:358–364. https://doi.org/10.1016/s1369-5266(03)00065-7

Butler TJ, Han KJ, Muir JP, Weindorf DC, Lastly L (2008) Dairy manure compost effects on corn silage production and soil properties. Agron J 100:1541-1545. https://doi.org/10.2134/agronj2008.0033

Casella G (2008) Statistical Design, 1st edn. Springer, Gainesville, FL 32611–545, USA

Charles A, Rochette P, Whalen JK, Angers DA, Chantigny MH, Bertrand N (2017) Global nitrous oxide emission factors from agricultural soils after addition of organic amendments: a meta–analysis. Agric Ecosyst Environ 236:88–98. https://doi.org/10.1016/j.agee.2016.11.021

Crepona K, Marget P, Peyronnet C, Carrouea B, Arese P, Duc G (2010) Nutritional value of faba bean (*Vicia faba* L.) seeds for feed and food. Field Crop Res 115:329–339. https://doi.org/10.1016/j.fcr.2009.09.016

DeLuca TH, MacKenzie MD, Gundale MJ, Holben WE (2006) Wildfire–produced charcoal directly influences nitrogen cycling in ponderosa pine forests. Soil Sci Soc Amer J 70:448–453. https://doi.org/10.2136/sssaj2005.0096

Doan TT, Henry–Des–Tureaux T, Rumpel C, Janeau JL, Jouquet P (2015) Impact of compost, vermicompost and biochar on soil fertility, maize yield and soil erosion in northern Vietnam: a three year mesocosm experiment. Sci Total Environ 514:147–154. https://doi.org/10.1016/j.scitotenv.2015.02.005

Dor E, Alperin B, Wininger S, Ben–Dor B, Somvanshi VS, Koltai H, Kapulnik Y, Hershenhorn J (2010) Characterization of a novel tomato mutant resistant to *Orobanche* and *Phelipanche* spp. weedy parasites. Euphytica 171:371–380. https://doi.org/10.1007/s10681-009-0041-2

Draper NR, Smith H (1998) Applied regression analysis, 3rd edn. John Wiley & Sons, New York

El–Halmouch Y, Benharrat H, Thalouarn P (2006) Effect of root exudates from different tomato genotypes on broomrape (*O. aegyptiaca*) seed germination and tubercle development. Crop Prot 25:501-507. https://doi.org/10.1016/j.cropro.2005.08.005

El–Halmouch Y, Mehesen A, El–Shanshoury AR (2013) The potential of cell–free cultures of *Rhizobium leguminosarum, Azotobacter chroococcum* and compost tea as biocontrol agents for faba bean broomrape (*Orobanche crenata,* Forsk.). J Plant Pathol Microb 4: 205. https://doi.org/10.4172/2157-7471.1000205

Ennami M, Mbasani–mansi J, Briache FZ, Oussible N, Gaboun F, Ghaouti L, Belqadi L, Ghanem ME, Aberkani K, Westwood J, Mentag R (2020) Growth–defense tradeoffs and source–sink relationship during both faba bean and lentil interactions with *Orobanche crenata* Forsk. Crop Prot 127:104924. https://doi.org/10.1016/j.cropro.2019.104924

Fernández–Aparicio M, Kisugi T, Xie X, Rubiales D, Yoneyama K (2014) Low strigolactone root exudation: a novel mechanism of broomrape (*Orobanche* and *Phelipanche* spp.) resistance available for faba bean breeding. J Agric Food Chem 62:7063–7071. https://doi.org/10.1021/jf5027235

Fernández–Aparicio M, Flores F, Rubiales D (2016) The effect of *Orobanche crenata* infection severity in faba bean, field pea and grass pea productivity. Front Plant Sci 7:1049. https://doi.org/10.3389/fpls.2016.01409

Glaser B, Lehmann J, Zech W (2002) Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal–a review. Biol Fertil Soils 35:219–230. https://doi.org/10.1007/s00374-002-0466-4

Gomes MP, Smedbol E, Chalifour A, Hénault-Ethier L, Labrecque M, Lepage L, Lucotte M, Juneau P (2014) Alteration of plant physiology by glyphosate and its by–product aminomethylphosphonic acid: an overview. J Exp Bot 65:4691–4703. https://doi.org/10.1093/jxb/eru269

Gosling P, Hodge A, Goodlass G, Bending GD (2006) Arbuscular mycorrhizal fungi and organic farming. Agric Ecosyst Environ 113:17–35. https://doi.org/10.1016/j.agee.2005.09.009

Inckel M, Smet PD, Tersmette T, Veldkamp T (2005) The preparation and use of compost. Agromisa Foundation, Wageningen. Digigrafi, Wageningen, the Netherland.P:22–24

Jensen ES, Peoples MB, HauggaardNielsen H (2010) Faba bean in cropping systems. Field Crop Res 115:203–216. https://doi.org/10.1016/j.fcr.2009.10.008

Jha P, Biswas AK, Lakaria BL, Subba Rao A (2010) Biochar in agriculture–prospects and related implications. Curr Sci 99:1218–1225 http://www.ias.ac.in/currsci

Joel DM, Hershenhorn J, Eizenberg H, Aly R, Ejeta G, Rich PJ, Ransom JK, Sauerborn J, Rubiales D (2007) Biology and management of weedy root parasites. Hortic Rev 33:267–349. https://doi.org/10.1002/9780470168011.ch4

Kasozi GN, Zimmerman AR, Nkedi–Kizza P, Gao B (2010) Catechol and humic acid sorption onto a range of laboratory–produced black carbons (biochars). Environ Sci Technol 44:6189–6195. https://doi.org/10.1021/es1014423

Khazaei H, Subedi M, Nickerson M, Martínez–Villaluenga C, Frias J, Vandenberg A (2019) Seed protein of lentils: current status, progress, and food applications. Foods 8:391. https://doi.org/10.3390/foods8090391

Laird DA, Fleming P, Davis DD, Horton R, Wang B, Karlen DL (2010) Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. Geoderma 158:443–449 10.1016

Lehmann J, Joseph S (2009) Biochar for environmental management. Science and technology, Earthscan, London, EC1N 8XA, UK, pp 67–102

Lehmann J, Rondon M (2006) Bio char soil management on highly weathered soils in the humid tropics. In: Uphoff N et al (eds) biological approaches to sustainable soil systems. CRC press, Taylor and Francis Group, Florida, pp 517–530

Lim LY, Lee CT, Bong CPC, Lim JS, Sarmidi MR, Klemeš JJ (2018) A review on the impacts of compost on soil nitrogen dynamics. Chem Eng Trans 63:349–354. https://doi.org/10.3303/CET1863059

Mandal M, Chandran RS, Sencindiver JC (2013) Amending subsoil with composted poultry litter–I: effects on soil physical and chemical properties. Agron 3:657–669. https://doi.org/10.3390/agronomy3040657

Manirakiza N, Şeker C (2020) Effects of compost and biochar amendments on soil fertility and crop growth in a calcareous soil. J Plant Nutr 43:3002–3019. https://doi.org/10.1080/01904167.2020.1806307

Moorman TB, Becerril JM, Lyndon J, Duke SO (1992) Production of hydroxybenzoic acids by *Bradyrhizobium japonicum* strains after treatment with glyphosate. J Agric Food Chem 40:289–293. https://doi.org/10.1021/jf00014a025

Nartey OD, Zhao B (2014) Biochar preparation, characterization, and adsorptive capacity and its effect on bioavailability of contaminants: an overview. Adv Mater Sci Eng 2014:1–12. https://doi.org/10.1155/2014/715398

Nebiyu A, Diels J, Boeckx P (2016) Phosphorus use efficiency of improved faba bean (*Vicia faba*) varieties in low–input agro–ecosystems. J Plant Nutr Soil Sci 179:347–354. https://doi.org/10.1002/jpln.201500488

Ouyang L, Yu L, Zhang R (2014) Effects of amendment of different biochars on soil carbon mineralisation and sequestration. Soil Res 52:46–54. https://doi.org/10.1071/SR13186
Page AL, Miller RH, Keeney DR (1982) Methods of soil analysis: part 2, chemical and microbiological properties. Agronomy series no 9, American Society of Agronomy, Madison, WI
Pérez–De–Luque A, Gonzalez–Verdejo CI, Lozano MD, Dita MA, Cubero JI, Gonzalez–Melendi P, Risueno MC, Rubiales D (2006a) Protein cross–linking, peroxidase and ß–1.3–endoglucanase involved in resistance of pea against *Orobanche crenata*. J Exp Bot 57:1461–1469. https://doi.org/10.1093/jxb/erj127
Pérez–De–Luque A, Lozano MD, Cubero JI, Gonzalez–Melendi P, Risueño MC, Rubiales D (2006b) Mucilage production during the incompatible interaction between *Orobanche crenata* and *Vicia sativa*. J Exp Bot 57:931–942. https://doi.org/10.1093/jxb/erj078
Pérez–De–Luque A, Lozano MD, Moreno MT, Testillano PS, Rubiales D (2007) Resistance to broomrape (*Orobanche crenata*) in faba bean (*Vicia faba*): cell wall changes associated with pre–haustorial defensive mechanisms. Ann Appl Biol 151:89–98. https://doi.org/10.1111/j.1744-7348.2007.00164.x
Rashad FM, Kesba HH, Saleh WD, Moselhy MA (2011) Impact of rice straw composts on microbial population, plant growth, nutrient uptake and root–knot nematode under greenhouse conditions. Afr J Agric Res 6:188–1203. https://doi.org/10.5897/AJAR10.986
Rondon MA, Lehmann J, Ramirez J, Hurtado M (2007) Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with biochar additions. Biol Fertil Soils 43:699–708. https://doi.org/10.1007/s00374-006-0152-z
Rose TJ, Julia CC, Shepherd M, Rose MT, Van Zwieten L (2016) Faba bean is less susceptible to fertiliser N impacts on biological N_2 fixation than chickpea in monoculture and intercropping systems. Biol Fertil Soils 52:271–276. https://doi.org/10.1007/s00374-015-1062-8
Rubiales D (2014) Legume breeding for broomrape resistance. Czech J Genet Plant Breed 50:144-150. https://doi.org/10.17221/106/2013-CJGPB
Simpson K (1986) Fertilizers and manures. Longman, London Chapter 8, pp.: 83–108
Soil Survey Staff (1999) Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys. In: Natural Resources Conservation Service, 2nd edn. U.S. Department of Agriculture Handbook 436. https://doi.org/10.1016/S0016-7061(00)00097-5
Trabelsi I, Abbes Z, Amri M, Kharrat M (2015) Performance of faba bean genotypes with *Orobanche foetida* Poir. And *Orobanche crenata* Forsk. Infestation in Tunisia. Chil J Agric Res 75:27–34. https://doi.org/10.4067/S0718-58392015000100004
Trabelsi I, Abbes Z, Amri M, Kharrat M (2016) Study of some resistance mechanisms to *Orobanche* spp. infestation in faba bean (*Vicia faba* L.) breeding lines in Tunisia. Plant Prod Sci 19:562–573. https://doi.org/10.1080/1343943X.2016.1221734
Trabelsi I, Yoneyama K, Abbes Z, Xie X, Amri M, Kharrat M, Yoneyama K (2017) Characterization of strigolactones produced by *Orobanche foetida* and *Orobanche crenata* resistant and susceptible faba bean genotypes and effect of phosphorous, nitrogen, and potassium deficiencies on strigolactone production. South Afr J Bot 108:15–22. https://doi.org/10.1016/j.sajb.2016.09.009
Warnock DD, Lehmann J, Kuper TW, Rillig MC (2007) Mycorrhizal responses to biochar in soil–concepts and mechanisms. Plant Soil 300:9–20. https://doi.org/10.1007/s11104-007-9391-5
Yoder JI (1999) Parasitic plant response to host plant signals: a model for subterranean plant–plant interactions. Curr Opin Plant Biol 2:65–70. https://doi.org/10.1016/s1369-5266(99)80013-2
Yoneyama K, Awad AA, Xie X, Yoneyama K, Takeuchi Y (2010) Strigolactones as germination stimulants for root parasitic plants. Plant Cell Physiol 51:1095–1103. https://doi.org/10.1093/pcp/pcq055
Yu L, Tang J, Zhang R, Wu Q, Gong M (2013) Effects of biochar application on soil methane emission at different soil moisture levels. Biol Fertil Soils 49:119–128. https://doi.org/10.1007/s00374-012-0703-4
Zhen Z, Liu H, Wang N, Guo L, Meng J, Ding N, Wu G, Jiang G (2014) Effects of manure compost application on soil microbial community diversity and soil microenvironments in a temperate cropland in China. PLoS One 9:e108555. https://doi.org/10.1371/journal.pone.0108555