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# Impact of Different Crop Rotations on Weed Infestations in Organic Pepper

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**Abstract:** We investigated how crop rotation in organic cultivation affects weed density and coverage for organic summer pepper (*Capsicum annuum* L.) grown in rotation with winter crops such as spinach (*Spinacia oleracea* L.), broccoli (*Brassica oleracea* L. var. *italica*), a common vetch (*Vicia sativa* L.) + barley (*Hordeum vulgare* L.) mixture, and faba bean (*Vicia faba* L.). The research was conducted in the organic cultivation area of the Aegean Agricultural Research Institute from 2012–2016. The coverage area and density (weeds $m^{-2}$) of various weed species were recorded in pepper crops grown in rotation with winter crops. The results indicated that pepper grown after barley + common vetch, broccoli and faba bean showed a considerable decrease in weed coverage area and density for all years. The highest average pepper yield per plant and per hectare was recorded from the pepper crop grown after faba bean. This was followed by the weed-free treatment, barley + common vetch and spinach planted before the cultivation of pepper. It can be concluded that the selection of crops in rotation plays a pivotal role in weed management of organic agriculture.

**Keywords:** Organic pepper; rotation; weed management; weed density; coverage; yield.

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## 1 Introduction

Sustainable food systems are source of healthy food to not only meet current food needs of today, but also help in ecosystem maintenance to ensure food supply for future generations without compromising environment (Crespo-Herrera and Ortiz, 2015; Kravchenko et al., 2017; Sihi et al., 2017). During the last two decades organic agriculture has gained popularity across the world (Meemken and Qaim, 2018; Meng et al., 2017; de Ponti et al., 2012).

Red pepper (*Capsicum annum* L.) is important cash crop among the condiments (Schreinemachers et al., 2015). Being good source of antioxidants, phenolics and vitamins it is important component of human diet (Alam et al., 2018; Zachariah and Leela. 2018). Moreover it provides protection against various diseases (Chopan and Littenberg 2017; Marin et al., 2004; Materska et al., 2015; Przygodzka et al., 2014; Seth et al., 2018). Capsaicin and dihydrocapsaicin present in red peppers are preservative and medicinally importance (Marrelli et al., 2016; Ranjita et al., 2018). Both are food flavoring ingredient for many food products (Momin et al., 2018; Ranjita et al., 2018). Pepper cultivation is an important source of income and employment for millions of small landholding farmers (Kuivanen et al., 2016; Parvathi and Waibel, 2016). However, weeds cause serious losses to crop growth and yield (Arora et al., 2015; Qureshi and Arshad, 2017).

In the crops rotation, broccoli is incorporated as winter crops. Due to abundant amount of vitamins, minerals, fibers and bioactive secondary metabolites broccoli possesses significant health-promoting potential (Vasanthi et al., 2009; Jahangir et al., 2009). Among these, glucosinolates, a class of secondary metabolites synthesized have ability to induce detoxification and beneficial in the prevention of cardiovascular diseases such as diabetes and cancer (Wagner at al., 2013; Houghton et al., 2013; Housley et al., 2018). So, broccoli is increasingly becoming popular as natural functional foods. Spinach is also a good source of vitamins and minerals (Kawazu et al., 2003). Faba beans are well known to be a traditional protein carbohydrate and fibre source, and are low in fat. Faba bean is one of the most important of the legumes, also incorporated in human diets for their additional nutritional benefits. Especially, their microconstituents including phenolic compounds, phytosterols and saponins are well known (Siah et al., 2012).

Pesticide residues damage important soil flora and fauna and pass from soil to crops and then to humans and animals (Hashmi, 2016; Iqbal et al., 2018; Kim et al., 2017; Lu et al., 2015). These pesticide residues cause harmful effects within the food chain. Pesticides leach down into underground waters subsequently harmful for the various trophic levels of different ecosystem and adverse impacts on fish, birds and many other living creatures (Chagnon et al., 2015). It is well known that only 0.015%–6% of the pesticides used in agriculture reach the target organism, while the remaining 94–99.9% become mixed into the ecosystem (Yildiz et al., 2005). Inorganic pesticides have high persistence properties in the environment.

Application of pesticides has significantly increased, which has inevitably resulted in increased environmental and human health problems, leading to acute and chronic toxicity together with soil and water pollution (Mahmood et al., 2015; Jaishankar et al., 2014). All of these adverse effects have accelerated the search for alternative pest management (Kausar et al., 2017). Agronomic weed management in organic farming may be crucial to maintain profitability leading to sustainable agriculture (Bilalis et al., 2010; Nhemachena et al., 2018; Wezel et al., 2014). Crop rotation is an important agronomic tool for weed management through allelochemicals and modification in the timing of crop and demand of resources (Farooq et al., 2011; Latif et al., 2017; Nicholas et al., 2015; Reddy, 2016).

Organic agriculture is one of these alternative production systems, and it includes human- and environmentally-friendly production systems aimed at restoring the natural balance that is lost after the misapplication of pesticides in the ecological system. It has been reported that organic products contain higher net protein, vitamin C, antioxidant and nitrogen than traditionally produced products (Petr et al., 2004; Kapoulas et al., 2011; Langenkämper et al., 2006). Similar to conventional production systems, weed management accounts for the highest cost in organic production. The most important damage caused by weeds is reduced yields in agricultural areas. Weeds are considered to be the biggest problem in organic vegetable farming systems (Reddiex et al., 2001; Peruzzi et al., 2004; Uygur and Lanini, 2006; Peruzzi et al., 2007).

There is an average loss of 10% of agricultural production worldwide due to weeds (Oerke et al., 1994; Oerke, 2006). In Turkey, the average yield losses vary between 10% and 50% depending on weed species and density (Tepe, 1998), and this loss is even higher for vegetable cultivation. This study was carried out to investigate the effects of rotating winter crops such as spinach, broccoli, faba bean and barley + common vetch to suppress weeds in organic pepper grown in summer. The results of the study will determine the most suitable vegetable rotation in terms of sustainable agriculture.

## 2. Materials and Methods

### 2.1. Experimental Material

This study was carried out at the organic experiment area of the Aegean Agricultural Research Institute (38°36'36.98" North, 27°6'10.09" East) from 2012–2016 (Fig. 1). The crops grown in winter rotation were broccoli (*Brassica oleracea* L. var. italica) AG 3317 variety, faba bean (*Vivia faba* L.) Sevilla variety, spinach (*Spinacia oleracea* L.) Matador variety, and common vetch (*Vicia sativa* L.) Kubilay-82 variety + barley (*Hordeum vulgare* L.) Akhisar-98 variety.

### 2.2. Climate and Soil

The average annual rainfall of the experimental site is 616 mm, while the average annual temperature is 16.6°C. The average temperature during the coldest month is 5.6°C, whereas the average temperature during the warmest month is 28°C. The physico-chemical characteristics of the soil samples are shown in Table 1.

**Table 1. Chemicalandphysicalcharacteristics of thesoil in experiment field**

| Evaluated Characters | Values | Evaluated Characters | Values |
|---|---|---|---|
| pH | 7.42 | K (ppm) | 493.3 |
| Salt | 0.12 | Ca (ppm) | 6400 |
| Lime (%) | 8.21 | Mg (ppm) | 483.3 |
| Organic matter | 1.20 | Fe (ppm) | 5.68 |
| N (%) | 0.10 | Cu (ppm) | 2.92 |
| P (ppm) | 2.31 | Zn (ppm) | 0.68 |
| Structure | Clay-loamy | Mn (ppm) | 6.36 |


38°36'36.98" N, 27°6'10.09" E

**Fig. 1. GPS coordinates of theorganicexperimentalfields**

**Fig. 2. The views of the experiment field**

### 2.3. Experimental Details and Treatments

The experiments were carried out using randomize block design with 4 repetitions. The net plot size was 4 m × 5 m = 20 $m^{-2}$ (Fig. 2). The weed coverage data were estimated by visual observation using the percentage of surface infested by weeds. The data on total weed count and coverage were recorded at 40 days after sowing during the experimental years.

The experiment area was prepared using a passing chopper and disc harrow in autumn. The treatments (crops in rotation) included in the experiment were spinach, broccoli, barley + common vetch and faba bean as winter crops and pepper as the summer crop. In addition to winter applications, weed-free and continuously weedy plots were also included in the study. Every year in the autumn, common vetch (30 kg $ha^{-1}$) + barley (40 kg $ha^{-1}$) and faba bean (200 kg $ha^{-1}$) were sown. Broccoli was sown at distance of 60 × 70 cm, whereas spinach was planted at 10 × 30 cm. Pepper seeds were planted in February, while broccoli seeds were planted in August. Pepper seedlings were transferred to the fields in April and broccoli in September. Composting applications were made before and after sowing, so as not to exceed 170 kg N $ha^{-1}$ per year. The weed density and coverage area were determined randomly using a 0.5 x 0.5 = 0.25 $m^{-2}$ quadrate twice in each experimental unit. Irrigation was carried out when the amount of water in the root zone of the plant fell below half of the field capacity according to a soil tensiometer.

### 2.4. Statistical Analysis

The data collected during the 5-year experiment were analyzed statistically using Fisher's analysis of variance technique (Steel et al., 1997). The least significant difference (LSD) test was used to compare the differences between treatment means at 5% probability. The years' effect and the interactive effects of crop rotations were significant; therefore, data for 5 years are presented separately, and interaction among the crop rotations is used for the interpretation of the results.

**Table 2. Effects of winter crops on weed density and weed coverage (2012–2016).**

| Treatment | 5-year Mea | |
|---|---|---|
| | Weed Density | Weed Coverage |
| barley + | 44.97 d | 21.25 c |
| Faba bean | 84.92 cd | 32.50 b |
| Broccoli | 76.33 cd | 21.75 c |
| Weed-free | 148.58 b | 38.58 b |
| Spinach | 120.75 bc | 35.25 b |
| Control | 276.25 a | 92.50 a |
| LSD (p 0.05) | 0.001 | 0.000 |

**Table 3. Effects of winter crops on weed density and weed among the years (2012–2016)**

| Years | Annual Mean | |
|---|---|---|
| | Weed Density (weeds m$^{-2}$) | Weed Coverage (%) |
| 2013 | 137.06 b | 35.56 b |
| 2014 | 181.83 a | 64.89 a |
| 2015 | 52.56 c | 33.50 b |
| 2016 | 129.76 b | 27.28 c |
| LSD (p 0.05) | 0.0001 | 0.0001 |

## 3. Results

Crop rotation had a significant effect in terms of weed density and coverage area as a result of the 4-year experiment (Table 2). Barley + common vetch in rotation with the pepper crop resulted in the lowest weed density and coverage area compared to the other crops sown in rotation with pepper. In contrast, the highest weed coverage and density were found in spinach rotation compared to the other winter crops. The differences in crop rotations were statistically significant when the average weed coverage areas of all experimental years were compared. Likewise, differences between years were also significant. The differences between pepper applications and year × pepper interactions were non-significant for weed coverage area.

As a result of the statistical analysis, winter applications of barley + common vetch and broccoli were the most effective in terms of reducing weed coverage area for organic pepper in summer. Their weed coverage areas were found to be 78% lower than the control application. The average weed coverage rates from lowest to highest for all years were barley + common vetch (21.25%), broccoli (21.75%), faba bean (32.50%), spinach (35.25%) and weed-free (38.58%).

It was found that the weed coverage area for spinach rotations was approximately 65% higher than for barley + common vetch and broccoli rotations, while the weed-free application was 81% higher than barley + common vetch. Barley + common vetch the most effective application to reduce weed density. Therefore, the density for barley + common vetch was less than $^{1}/_{6}$ of the density for the control plots. Faba bean and broccoli applications also had lower densities than the control plots, at about $^{1}/_{3}$, and were thus grouped with barley + common vetch (Table 2).

When examining differences between the years, the highest weed coverage area occurred in 2014 (64.89%), followed by 2013 (35.56%), 2015 (33.50%) and 2016 (27.28%; Table 3). In terms of weed density, the highest density occurred in 2014 (181.83 weeds m$^{-2}$). This was followed by 2013 (137.06 weeds m$^{-2}$), 2016 (129.76 weeds m$^{-2}$) and 2015 (52.56 weeds m$^{-2}$). The relationship was not completely parallel, however. 2015 had a higher coverage but a lower density than 2016 (Tables 3 and Table 4).

**Table 4. Effect of different crop rotations on total weeds density and coverage in Crops.**

| Treatment | 2012–2013 | | 2013–2014 | | 2014–2015 | | 2015–2016 | |
|---|---|---|---|---|---|---|---|---|
| | WD (m$^{-2}$) | WC (%) | WD (m$^{-2}$) | WC (%) | WD (m$^{-2}$) | WC (%) | WD (m$^{-2}$) | WC (%) |
| Barley + common vetch | 53.0 c | 13.33 c | 92.7 c | 50.0 cd | 16.00 b | 12.67b | 35.56b | 11.0b |
| Broccoli | 45.6 c | 21.67 c | 90.0 c | 38.3 d | 17.33 b | 13.33b | 32.33b | 11.7b |
| Faba bean | 52.6 c | 13.33 c | 261.3 ab | 76.7 ab | 23.67 b | 21.67b | 152.33ab | 18.3b |
| Spanich | 146.4 b | 26.67 c | 185.3 b | 65.0 bc | 30.67 b | 23.33b | 108.33b | 12.7c |
| Weed-free | 232.1 a | 51.67 b | 190.0 b | 69.3 b | 68.33b | 36.67ab | 163.33ab | 20.0b |
| Control | 250.2 a | 97.67 a | 271.7 a | 90.0 a | 129.33a | 93.33a | 267.56a | 90.0a |
| LSD (p 0.05) | 0.000 | 0.000 | 0.001 | 0.002 | 0.002 | 0.000 | 0.022 | 0.000 |

**WD, weed density (m$^{-2}$); WC, weed coverage (%)**

**Table 5. Effects of winter crops on yield of organic pepper among the years (2012-2016)**.

| Years | 2012–2013 | | 2013–2014 | | 2014–2015 | | 2015–2016 | |
|---|---|---|---|---|---|---|---|---|
| Treatment | YP (g plant- | Y (kg ha-1) | YP (g plant-1) | Y (kg ha-1) | YP (g plant-1) | Y (kg ha-1) | YP (g plant-1) | Y (kg ha-1) |
| Barley + | 880.2 a | 35206a | 828.0 a | 33117 ab | 799.4a | 31978 a | 949.6a | 37985a |
| Broccoli | 624.7b | 24987b | 487.1cd | 19484 cd | 654.0 a | 26159 a | 1017.9a | 40719 a |
| Faba bean | 978.6 a | 39142a | 998.8a | 39954 a | 842.6 a | 33702a | 1206.2a | 48249 a |
| Spinach | 672.4b | 26895b | 593.8bc | 23713 bc | 707.3 a | 28293a | 1000.7a | 40030a |
| Weed-free | 831.6 a | 33262a | 806.6 ab | 32263 ab | 769.4 a | 30776 a | 1056.6a | 42264a |
| Control | 350.9 c | 18778 c | 285.6 d | 11514 d | 283.7 b | 11496b | 339.1b | 8504 b |
| LSD (p 0.05) | 0.000 | 0.000 | 0.001 | 0.001 | 0.001 | 0.000 | 0.001 | 0.000 |

**YP,** Yield per plant (g plant$^{-1}$); **Y**, Yield (kg ha$^{-1}$).

The average yield of pepper per plant and per hectare was determined. In all winter applications, approximately 2 to 2.8 times more pepper yield was obtained compared to the control plots. The differences in yield results were statistically significant for the 2013, 2014 and 2015 growing seasons, and the highest yield was obtained from the winter sowing of faba bean (37464.3 kg ha$^{-1}$), weed-free (36137.7 kg ha$^{-1}$) and barley + common vetch (34571.8 kg ha$^{-1}$). In contrast, the lowest yield was obtained from the broccoli (27837.3 kg ha$^{-1}$). The faba bean application yielded 52.25% more pepper than rotated with broccoli, 31.59% in weed-free rotation, 30.03% in barley + common vetch rotation and 8.95% in rotation with spinach. The highest yielding faba bean application yielded 78.3% more crops than the lowest yielding broccoli application in the 2014–2015 growing season (Table 5).

When the annual average per plant yield results were examined, it was determined that there was a statistically significant the differences between the applications and years at the rate of 5%, while the efficiency differences between the repetitions were not significant. Among the applications, the highest yield per plant was obtained from the faba bean application (975.09 plant$^{-1}$). The second highest yield was obtained from the weed-free plots (948.01 plant$^{-1}$) that did not have any winter planting. This was followed by the application of barley + common vetch (904.11 g plant$^{-1}$) and spinach (802.04 plant$^{-1}$). The lowest pepper yield was obtained from the broccoli application (756.26 plant$^{-1}$). Faba bean application yielded 28.9% more pepper was obtained compared to the broccoli application. The spinach application yielded 6.05% more pepper than the broccoli application (Table 6). Examining the yield per plant by year, 2012 had the highest yield followed by 2015, 2014 and 2016, although the differences between these years were not significant (Table 5).

Examining the average yield per hectare by application type revealed that the differences in yields between years and applications were statistically significant, and that these were more or less the same as the yield per plant. However, the highest average yield per hectare was obtained from the faba bean application. This was followed by the weed-free plot, barley + common vetch and then spinach (Table 6).

## 4. Discussion

The first principle for weed management is to keep the weed population below the economic loss threshold during the production season. Estimation of weed population dynamics should be used as a guide for selecting control methods. Indeed, crops with different life cycles can change the interactions between weeds and crops when sown in rotation (Karlen et al., 1994; Derksen et al., 2002). Density of weeds in 19 of the 25 crops sown in rotation reported to lower than the crops sown in the same area continuously (Liebman and Ohno, 1998). Different planting and harvesting times in the rotation provide opportunities for agricultural applications to prevent the production and maturation of weed seeds.

**Table 6. Yield of organic pepper when rotated with different winter crops**

| Treatment | **Yield (g plant$^{-1}$)** | **Yield (kg ha$^{-1}$)** |
|---|---|---|
| Barley + common vetch | 904.1 ab | 34572 a |
| Broccoli | 756.3 c | 27837 b |
| Faba bean | 975.1 a | 37464 a |
| Spinach | 802.0 bc | 29733 b |
| Weed-free | 948.0 a | 36138 a |
| Control | 330.9 d | 13323 c |
| LSD (p 0.05) | 0.000 | 0.000 |

Different planting and harvesting dates of alternative crops ensure to opportunities for preventing to weed seed reserves in soil and seed production. For example, cheat grass (*Bromus tectorum* L.) usually develops before the sowing of crops such as corn or sunflower in early spring or autumn. In this study, it has found that a 80% decrease in the cheat grass seed in the first year (Roberts, 1981). During a 6-year study in Canada, the density of cheat grass was reduced by 93% in canola and wheat (50 weeds $m^{-2}$) crops planted in rotation compared with 740 weeds $m^{-2}$ continuously sown wheat fields (Blackshaw, 1994). In a similar study in the United States, the density of cheat grass (*B. tectorum*) and goat grass (*Aegilops cylindrical* Host.) decreased significantly in sunflower and corn crops sown in rotation with winter wheat (Daugovish et al., 1999).

Weed population density and biomass in the rotation crops, which are an important element in the control of weeds in the organic production system examined in our study, were reduced with the introduction of feed crops (Anderson, 2010), lentil (Gruber, 2012), corn-soybean-wheat rotation (Gonzalez et al., 2011; Simic et al., 2016) and legume (alfalfa, pea) crops (Schweizer and Zimdahl, 1984; Dotzenko et al., 1969). The rotation of cereal crops led to reduced herbicide use in conventional cultivation (Schoofs et al., 2005), weed inhibition and higher crop yield (Lapinsh et al., 2008). Furthermore, the rotation system has been determined to be sustainable for weed control in areas where herbicide tolerance was observed (Reddy et al., 2006).

As a result of the experiment, it was determined that different crop rotations had a significant effect on weed suppression and product yield. In this study, the known allelopathic effect of barley (Lovett and Hoult, 1995; Liu and Lovett, 1993; Zoheir and Sadeghi, 2007), which occurs during the winter mixed sowing of barley + common vetch, was confirmed to be the most effective application to decrease weed coverage and density. The allelopathic effect of broccoli (Zeng et al., 2008; Osornio et al., 1987) also controlled the weed populations in a similar manner, as shown in previous studies (Bajgai et al., 2013; Finney et al., 2009). Although the application of spinach sown in winter appears to have suppressed the weed population in subsequent crops rather than controlled it, this occurred at a much lower level than the other applications.

Barley + common vetch sown in rotation with pepper yielded the next best results after the application of faba bean and the weed-free plot. Winter broccoli sowing had a significant effect on weed density and coverage, but this effect was not reflected in the pepper yield. Spinach planted in plots appeared to be the least efficient application in subsequent crops.

In terms of weed control In the third place after the application of common vetch + barley and broccoli, third place faba bean were found to be one of the most effective legume products to increase yield by reducing weed density and coverage as a result of soil nitrogen fixation (Jensen et al., 2010; Dubova et al., 2017; Ilyas et al., 2018). In addition, after the application of winter faba bean, the second highest pepper yield was determined in weed-free application which the weeds was controlled by hand hoe. It has been shown that significant increases in yields can be achieved by weed-freeing the extremely tired soils and agricultural areas subjected to intensive farming.

## 5. Conclusion

The effects of winter crop rotation on weed density and coverage area as well as pepper crop yield were investigated in this study. As a result of this comparison, it was determined that barley + common vetch, broccoli and faba bean applications from winter crops decreased weed coverage and density and increased organic pepper yield for all years. The highest average yield was obtained from the crop rotation with faba bean. Pepper yields after faba bean applications were found to be three times higher than the control. This was followed by weed-free plots, barley + common vetch, spinach and broccoli, in that order. Winter barley + common vetch, broccoli and faba bean rotations controlled the weed populations, while faba bean and barley + common vetch increased the organic pepper yield compared to the other applications. Thus, it was determined that barley + vetch, broccoli and faba bean applications should be recommended in organic crop rotations.

**List of Abbreviations:** LSD; least significant difference; WD: weed density; WC: weed coverage; YP: Yield per plant (g $plant^{-1}$); Y: Yield (kg $ha^{-1}$).

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**Conflict of Interest:** The authors declare that they have no conflict of interest.

**Authors Contribution:** A.K, and Y.N developed the idea, prepared initial research plan, A.K, A.K and Y.N. helped during the experimentation.

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