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Evaluation of competition, essential oil quality and quantity of peppermint intercropped with soybean

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ABSTRACT

Intercropping is a sustainable practice to achieve higher production per unit land area and time by maximizing the utilization of available resources. This work was aimed to study the effectiveness of peppermint/soybean intercropping patterns on the yield, quality of peppermint essential oil, competition and monetary indices in two years (2015–2016) and two harvests. The experiment was conducted in randomized complete block design keeping ratio of peppermint and soybean in 1:1, 1;2, 2:1, 2:3, 3:2, 1:3 and 3:1, respectively, along with sole plot of both crops. The results demonstrated that the highest biomass yield of peppermint in the first harvest was achieved in sole cropping pattern (317.2 $g\ m^{-2}$) followed by 3:2, 3:1, 2:3 and 2:1 intercropping ratios. In the second harvest, the highest biomass yield of peppermint was recorded in peppermint monoculture (289.1 $g\ m^{-2}$) and intercropping ratios of 3:2 and 3:1. In both harvests, the highest essential oil content and yield was obtained in the intercropping ratio of 3:2. Notably, the intercropping patterns gave 24.8% (first harvest) and 16.9% (second harvest) more essential oil than peppermint monoculture. Furthermore, the essential oil quality, in terms of high levels of menthol, 1,8-cineole, *neo-iso*-menthol, *p*-menth-1-en-9-ol, (*E*)-caryophyllene, (*E*)-*β*-farnesene and germacrene D and low content of menthofuran, improved significantly in intercropping treatments. The highest values of land equivalent ratio (LER), area time equivalent ratio (ATER), area harvest equivalent ratio (AHER), land use efficiency (LUE), monetary intercropping advantage (MAI) and system productivity index (SPI) were obtained in intercropping ratios of 2:3 and 3:2. Additionally, in all planting patterns the partial aggressivity (A) and crowding ratio (CR) values of peppermint were higher than soybean, indicating that the former was more competitive than the latter. According to our results, intercropping peppermint with soybean can improve the quality of peppermint essential oil and maintaining the crop productivity with limited external inputs; thus, this technique can be considered to be a sustainable practice for field management.

1. Introduction

World population is estimated to reach over nine billion by the year 2050, and increasing in food production for an additional two billion people with deteriorating environmental resources represents a major agricultural challenge (Bedoussac et al., 2015). Intensive agricultural systems, which produce higher yield with generous using of non-renewable energy and chemical inputs, is currently being called into question (Duchene et al., 2017). Most of these systems are vulnerable due to using similar genetically plants and reducing biodiversity (De La Fuente et al., 2014). The nature of these challenges suggests that more effort is needed to develop sustainable practices in agricultural systems to achieve high production that is scalable to large farms.

In the fields, temporal arrangement can be enhanced by growing several plants consecutively, while spatial arrangement could be increased by intercropping species that differ in the patterns of resource use and their associated flora and fauna (Duchene et al., 2017). Intercropping may be defined as a sustainable agricultural practice in which two or more species are grown contemporaneously in the same area during a growing season (Amani Machiani et al., 2018). The main aim of intercropping is to limit external inputs and apply standardized chemical management in order to achieve higher crop production

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without risks compared with monoculture systems (Carrubba et al., 2008; Adesogan et al., 2002). Most of the intercropping systems produce higher yields compared with equivalent areas of monoculture due to the higher efficiency in using available environmental resources such as water, nutrients and solar radiation, accompanied by a reduced growth of weeds and pests (Nassiri Mahallati et al., 2015; Barker and Dennett, 2013; Amossé et al., 2013). Among the different intercropping systems that are associated with higher production, intercropping legumes, as nitrogen fixation crops, with other species are common (Ashworth et al., 2015; Stoltz and Nadeau, 2014). Intercropping legumes with other species, which can provide nitrogen benefits to companion crops, is a strategy to improve nitrogen supply through belowground nitrogen transfer (Thilakarathna et al., 2016). Previous studies have demonstrated that legumes are the key species in promoting resource efficiency (Duchene et al., 2017; Monti et al., 2016; Chapagain and Riseman, 2014; Stoltz and Nadeau, 2014; Hauggaard-Nielsen et al., 2008). In general, using legumes in intercropping systems have a wide range of additional services such as improving grain protein content (Pelzer et al., 2012), improving essential oil quality and quantity in medicinal and aromatic plants (Maffei and Mucciarelli, 2003), better use of symbiotic nitrogen fixation and soil nitrogen enrichment (Latati et al., 2016) and increasing soil organism's biomass, activity and diversity (Ratnadass et al., 2012).

Soybean, being a leguminous crop, is an important component in cropping systems (temporal and spatial arrangements). Soybean (*Glycine max* (L.) Merr.) is an annual legume crop belonging to Leguminosae family and Papilionaceae subfamily. Soybean, as a legume crop, is capable to provide atmospheric nitrogen to the system with nitrogen biological fixation and is therefore less dependent on synthetic nitrogen fertilizers consumption. Overall, the amount of nitrogen fixation by soybean is estimated as 65–115 kg ha^{-1} during the growing season (Herridge et al., 1990).

Medicinal and aromatic plants have a wide ecological adaptation and have been used by humans since ancient times for the treatment of several diseases such as skin infections, indigestion, coughs, flu and other ailments (Gupta et al., 2017; Shiwakoti et al., 2016). Mints (*Mentha* sp.), belonging to the 'Lamiaceae' family, are commercially important herbs, due to the presence of high value monoterpenes in their essential oils (Barros et al., 2015). After Citrus species, *Mentha* (peppermint and other *Mentha* species) essential oils are the second commercially most important essential oil in the world, with an annual production of 14000 tons' (Gupta et al., 2017; Lubbe and Verpoorte, 2011). *Mentha* spp. essential oils contain a large number of aroma chemical constituents such as menthol, menthone, isomenthone and menthyl acetate that are exploited in a variety of applications including pharmaceuticals, foodstuffs, cosmetics and perfumery (Shiwakoti et al., 2016; Kumar et al., 2011). The most important *Mentha* species cultivated in Iran include horse mint (*Mentha longifolia* L.), peppermint (*Mentha* x *piperita* L.) and spearmint (*Mentha spicata* L.) (Heydarizadeh et al., 2013). *Mentha piperita* has a wide adaptation ability in different climate and soil conditions allowing to achieve a higher quality of essential oil compared with other mint species (Telci et al., 2011). Also, peppermint essential oil has antibacterial, antifungal, antimutagenic, antidiabetic and other biological activities. The main chemical constituents of peppermint essential oil are menthol and menthone, followed by menthyl acetate, 1,8-cineole, linalool, piperitone and limonene (Tiwari, 2016; Kamatou et al., 2013). The quality of the essential oil depends on the correct combination of chemical constituents, especially menthol and menthone, and on the low content of menthofuran (Tiwari, 2016; Shiwakoti et al., 2016). Kumar et al. (2011) reported that the peppermint essential oil contains 30–55% of menthol and 14–32% of menthone. The peppermint essential oil composition not only is controlled by many genes but also is highly affected by environmental conditions such as nutrient availability, temperature, rainfall, day length and radiation characteristics (Evans, 2002).

Competition between plants in intercropping systems is one of the most important factors that significantly affects the plant growth and yield (Lithourgidis et al., 2011). Intercropping systems could be advantageous when inter-specific competition is lower than intra-specific competition and also when there is a mutualistic relationship between intercropping components (Carrubba et al., 2008; Banik et al., 2006). There are several indices used to evaluate the potential advantages of intercropping systems and species interactions including land equivalent ratio (LER), area time equivalent ratio (ATER), land use efficiency (LUE), relative crowding coefficient (RCC or K), competitive ratio (CR), aggressivity (A), actual yield loss (AYL), monetary advantage (MAI), system productivity index (SPI) and intercropping advantage (IA). The mentioned indices have been developed to describe competition and economic advantage in different soybean-peppermint intercropping systems (Yilmaz et al., 2014; Lithourgidis et al., 2011; Dhima et al., 2007; Ghosh, 2004; Midya et al., 2005; Willey, 1979).

Despite of the suitable environmental factors for peppermint growth in Iran, peppermint essential oil has not yet been commercially produced in this country. Thus, an experiment was conducted to evaluate the effects of intercropping systems of peppermint with soybean on: (i) the peppermint and soybean yield in different cropping patterns, (ii) the peppermint essential oil content, (iii) the peppermint essential oil quality, (iv) the competition and monetary indices in different intercropping patterns and (v) to assess which system is better for resource management with respect to productivity.

2. Materials and methods

2.1. Site description

The experiment was conducted in two years (2015 and 2016) by performing two harvests at the agricultural research station of Maragheh University, Maragheh, Iran, which is located at 46°16′E and 37°23′N, at an altitude of 1485 m. The region has a cold and semi-arid climate. Meteorological data including monthly average temperature and monthly total rainfall of the experimental area during the two growing seasons and long term averages are presented in Table 1. In order to analyze the physical and chemical characteristics of the soil, four random samples from the whole of experimental site and depth of 0–30 cm was collected (Table 2).

2.2. Treatments details

The experiment was conducted based on a randomized complete block design (RCBD) with nine treatments and three replications. Treatments included peppermint (*Mentha* × *piperita* L. CV. Mitcham) monoculture (P_m), soybean (*Glycine max* L. CV. Williams) monoculture

Table 1
Monthly average temperature and monthly total rainfall in 2015 and 2016 growing seasons and long term averages in the experimental area.

Year	April	May	June	July	August	September	October
Monthly average temperature (°C)							
2015	14.4	21.8	29	31.2	31.8	25.5	18.9
2016	15.1	21.6	26.1	30.4	31.5	23.8	17.3
2-year mean	14.7	21.7	27.5	30.8	31.7	24.7	18.1
10-year mean	12.7	17.8	23.7	27.1	26.9	22.1	15.2
Monthly average rainfall (mm)							
2015	76.7	37.9	1.3	1.6	4.3	26.1	64.6
2016	34.5	23.9	25.5	2.2	0.4	1.7	19.3
2-year mean	55.6	30.9	13.4	1.9	2.4	13.9	42
10-year mean	51.6	21.8	4.1	0.8	0.6	7.9	36.1
Total monthly sunshine (hours)							
2-year mean	208.9	308	377.3	369.6	358.3	309.5	240.5
The period of lighting during the day (hours)							
2-year mean	12.6	13.8	14.5	14.5	13.7	12.5	11.3