Acta Sci. Pol. Hortorum Cultus, 19(6) 2020, 125–138

https://czasopisma.up.lublin.pl/index.php/asphc ISSN 1644-0692 e-ISSN 2545-1405 DOI: 10.24326/asphc.2020.6.11

ORIGINAL PAPER

Accepted: 28.07.2020

INOCULATION WITH ARBUSCULAR MYCORRHIZAL FUNGI (AMF) AND PLANT IRRIGATION WITH YIELD – FORMING FACTORS IN ORGANIC SWEET PEPPER (*Capsicum annuum* L.) CULTIVATION

Halina Buczkowska, Andrzej Sałata✉

Department of Vegetable Crops and Medicinal Plants, Faculty of Horticulture and Landscape Architecture, University of Life Sciences, Akademicka 15, 20-950 Lublin, Poland

ABSTRACT

Sensitivity of plants of the genus *Capsicum* to water deficiency is a great problem in the cultivation of sweet and hot pepper. It is becoming necessary to use plant irrigation during the growing season and to apply alternative methods that increase plant tolerance to water deficit. A large role in this regard is given to arbuscular mycorrhizal fungi (AMF) which contribute to enhanced water supply to plants by increasing the absorptive area of the root system. The effects of AMF inoculation and irrigation of plants of a native sweet pepper cultivar, 'Roberta F_1', on fruit yield and yield structure as well as on fruiting dynamics were determined in a study conducted over the period 2016–2018 in an organic farm located in south-eastern Poland. The highest total and marketable yield as well as the largest number of pepper fruits produced were obtained for pepper cultivation with simultaneous AMF inoculation and irrigation throughout the entire growing season. Yield and number of pepper fruits were affected to a greater extent by AMF colonization than by plant irrigation. Inoculation of plants with AMF at the transplant stage also beneficially affected earliness of fruiting. Moreover, AMF inoculation and irrigation of plants significantly reduced the incidence of blossom-end rot (BER).

Key words: *Capsicum annuum,* yield, colonization (AMF), irrigation, ecological crop

INTRODUCTION

At each latitude, global warming is accompanied by weather anomalies, among which an insufficient amount of rainfall during the growing season is a great problem in plant production. Currently, a frequent phenomenon is rainfall deficiency or long-lasting lack of rainfall that causes drought. As a consequence, plant irrigation is an absolute need, in particular in warm regions of the world [Antony and Singandhupe 2004, Bolandnazar et al. 2007, Karam et al. 2009, Ismail 2010]. Climate change is also accompanied by progressive environmental degradation caused by excessive use of chemicals in crop production [Ronco et al. 2008]. For these reasons, seeking alternative methods enhancing plant tolerance to water deficit and less favorable environmental conditions should be considered as a priority in modern agriculture and horticulture. Nowadays, a large role in this regard is given to arbuscular mycorrhizal fungi (AMF) as well as other soil microorganisms: *Trichoderma* , *Pseudomonas fluorescens* which, by increasing the absorptive area of the root system, have an impact on improved supply of plants with water and nutrients, in effect contributing to enhanced plant growth and crop yield [Strack et al. 2003, Gosling et al. 2006, Pereira et al. 2016, Duc et al. 2017]. Mycorrhizal fungi increase plant adaptation to less favorable growing conditions caused by biotic and abiotic stresses, such as adverse thermal conditions, soil pH, water excess or deficit in soil, salinity and heavy metal

✉ andrzej.salata@up.lublin.pl

content, herbicide residues, deficiency of nutrients, in particular phosphorus, and also the presence of pathogenic fungi and nematodes [Ronco et al. 2008, Çekiç et al. 2012, Baum et al. 2015, Al-Karaki 2017, Kapoulas et al. 2019]. In nature, arbuscular mycorrhizal fungi (AMF) form a symbiosis with many crop plant species, in whose rhizosphere AMF fungi are found to exhibit high specific and generic diversity. In plants of the genus *Capsicum*, fungi of the genus *Glomus* are identified most frequently [Douds and Reider 2003, Boonlue et al. 2012, Nedorost et al. 2014]. It has been shown that the best effects in pepper cultivation can be achieved by inoculating plants at an early growth stage of seedlings or transplants [Regvar et al. 2003, Turkmen et al. 2008, Jamiołkowska and Michałek 2019, Kapoulas et al. 2019]. In such case, AMF-inoculated plants were characterized by more dynamic growth and accelerated flowering. They were also found to produce an earlier and higher fruit yield and, moreover, exhibited better health due to inhibition of pathogen development [Regvar et al. 2003, Demir 2004, Turkmen et al. 2008, Castillo 2009, Cimen et al. 2009, Boonlue et al. 2012, Zayed et al. 2013]. The main benefit arising from AMF application was a better use of nutrients from the rhizosphere of crop plants, primarily phosphorus but also potassium and nitrogen as well as micronutrients such as S, Fe, Zn, Cu, and Mn [Castillo et al. 2009, Boonlue et al. 2012, Salvioli et al. 2012, Thilagar and Bagyaraj 2015]. Under low soil phosphorus availability conditions, plant inoculation with AMF was found to beneficially affect fruiting. This was due to an increase in the phosphorus concentration in the soil solution and a faster uptake of this element through the increased root absorption area owing to mycorrhizal fungal hyphae [Sharif and Claassen 2011]. Protection of the roots against soil-borne pathogens is also a benefit for the pepper plant arising from mycorrhizal inoculation. Arbuscular mycorrhizal fungi (AMF) exhibit antagonistic activity towards the pathogens *Fusarium* spp., *Vertecillium* spp., *Pythium* spp., *Phytophtora* spp., and *Sclerotium* spp. In this respect, AMF effectiveness depends on pathogen aggressiveness and environmental conditions. Inoculation of plants with AMF has proven to be most effective during the period preceding the disease-causing infection [Salami 2002, Garmendia et al. 2005, Cimen et al. 2009, Demir et al. 2015, Jamiołkowska and Michałek 2019].

Capsicum spp. plants belong to those that are very sensitive to water deficit. This is a big problem in the cultivation of sweet and hot pepper because currently a shortage or absence of rainfall is the most frequently occurring weather anomaly in both warm and temperate climate [Sezen et al. 2006, Ferrara et al. 2011]. Pepper is most sensitive to water deficit in the period of flowering and fruit set and growth. Insufficient soil moisture during this period is associated with the risk of incidence of blossom-end rot (BER), which is caused by calcium deficiency in setting and growing fruits [Taylor and Loscario 2004, Dorji et al. 2005, González-Dugo et al. 2007, Díaz-Perez and Hook 2017]. Under water deficit conditions, it is considered necessary to irrigate pepper crops throughout the entire growing season in order to obtain good quality fruit yield. Many papers have shown reduced pepper fruit yield due to drought stress [Delfine et al. 2001, Dorji et al. 2005, González-Dugo et al. 2007, Sezen et al. 2006, Gençoğlan et al. 2009, Kurunc et al. 2011, Ferrara et al. 2011]. It has been found that a symbiosis of crop plants with AMF contributes to increased uptake of water and nutrients under conditions of water stress, which frequently co-exists with soil salinity. By an appropriate selection of AMF species for inoculation of crop plants, including pepper, the effects of stress caused by drought and soil salinity can be largely mitigated [Mena-Violante et al. 2006, Subramanian et al. 2006, Kaya et al. 2009, Çekiç et al. 2012, Beltrano et al. 2013]. Irrigation during which water is applied directly to the soil, in particular drip irrigation, is the most appropriate method for pepper plants. In such case, aerial parts of plants remain dry, which is important for phytosanitary and water use efficiency reasons [Kirnak et al. 2003, Antony and Singandhupe 2004, Karam et al. 2009, Lodhi et al. 2014].

The aim of the study presented in this paper was to determine the effects of inoculation with arbuscular mycorrhizal fungi (AMF) and irrigation of plants on the quantity and structure of fruit yield as well as on fruiting earliness and dynamics of organic cultivation sweet pepper.

MATERIALS AND METHODS

Materials and growing conditions

A research experiment was conducted over the period 2016–2018 in a private, certified organic farm

(Agrobiotest 04557), located in south-eastern Poland (51.36°N, 22.83°E). 'Roberta F1' sweet pepper hybrid plants (breeder – the Department of Plant Genetics, Breeding and Biotechnology, SGGW Warsaw) were the subject of the study. This cultivar is very important for commercial production. The selection of this cultivar was guided by its adaptation to cultivation in less favorable weather conditions and fruiting earliness [Buczkowska et al. 2014].

A commercial mycorrhizal preparation inoculum (Mycoflor, Końskowola Poland) containing spores and dormant mycelium of enfomycorrhizal fungi: *Rhizophagus* aggregates (syn. *Glomus aggregatum*), *R. intraradices* (syn. *G. intraradices*), *Claroideoglomus etunicatum* (syn. *G. etunicatum*), *Endogone mosseae* (syn. *G. mosseae*), *Funneliformis caledonium* (syn. *G. caledonium*), *Gigaspora margarita* was used in ths experiment [Jamiołkowska and Michałek 2019]. Runner bean was the forecrop for pepper. In autumn, manure fertilization was applied at a rate of 30 t · ha^{-1}. The mineral content in the soil arable layer was determined in spring (Tab. 1). Fertilization of pepper plants was determined according to the fertilization standards defined for field cultivation of this vegetable [Sady 2014]. Two weeks before the planned date of planting transplants, an organic compound fertilizer, Fertikal (organic matter – 70%, N – 4,0%, P_2O_5 – 3,0%, K_2O – 3,0%, MgO – 1,0%, CaO – 9%, SO_4 – 1%), was applied at a rate of 10 kg · 100 m^{-2}. Pepper plants were foliar fertilized (2, 4, and 6 weeks after transplants were planted) by applying Bio-Algeen S90 three times at a concentration of 0.5%. Potted pepper transplants were grown in a greenhouse of the Experimental Station of the University of Life Sciences in Lublin, according to the commonly accepted principles for this plant. Seeds were sown during the third 10-day period of March.). Sweet pepper transplants were planted in the field at the turn of the second and third 10-day period of May at a row spacing of 0.67 × 0.35 m. The trial was conducted as a two-factor experiment in a randomized block design with 4 replicates, consisting of 20 plants per plot with an area of 4.7 m^2.

The experimental factors included the following: I. plant inoculation with arbuscular mycorrhizal fungi (AMF); II. plant irrigation. The following treatment combinations were used in this study: AMF & irrigation; AMF & non-irrigation; non-AMF & irrigation; and control (non-AMF & non-irrigation). When the transplants were planted in the field 3 ml of mycorrhizal inoculum (Mycoflor) was used for each plants at the combinations: AMF & irrigation; AMF & non-irrigation. The transplants at the combinations: non-AMF & irrigation; and control (non-AMF & non-irrigation) were planted without mycorrhizal inoculum (Mycoflor).

The pepper plants were irrigated using drip irrigation T-Tape with emitters spaced every 30 cm. Irrigation started when the value of the soil water potential at a depth of 25 cm was equal to or less than – 30 kPa, applying a single water dose of 15–20 mm. The soil water potential value was measured using a tensiometer (MMM Tensiometer, Standard, Agrosimex, Poland). The total water dose applied in irrigated plots was 140 mm, 120 mm, and 110 mm in 2016, 2017, and 2018, respectively.

The weather pattern for thermal and humidity conditions during the field cultivation period of sweet pepper is shown in Tab. 2 and Fig. 1. In the period

Table 1. The content of mineral components in the plough layer

Years	Mineral components (mg · dm^{-3})					pH	Salinity (mg KCl · dm^{-3})
	$N\text{-}NO_3$	P	K	Ca	Mg		
2016	40	90	160	1540	110	6.7	0.30
2017	25	68	140	1280	95	6.4	0.25
2018	37	75	128	1480	105	6.5	0.17

Table 2. Thermal conditions in the years 2016–2018 during the vegetation of sweet pepper compared with means from years 1951–2010

Month	Temperature (°C)			
	2016	2017	2018	1951–2010
May	+2.3	+2.1	+4.1	13.0
June	+2.3	+2.3	+2.5	16.3
July	+0.4	+1.0	+2.5	18.0
August	+0.8	+2.0	+2.8	18.0
September	+2.6	+1.4	+2.9	12.6
Mean	+1.7	+1.8	+3.1	15.4

2016–2018, there were favorable thermal conditions for the growth and development of pepper plants. The highest air temperature and the best thermal conditions occurred in 2018 when the daily average temperatures for the months June–September were higher by 2.5–2.9°C than their long-term mean values. The weather conditions in the period 2016–2018 are evidence that hot weather with very varied humidity conditions prevailed during the pepper growing season. The total rainfall in the first and second years of the experiment was lower by 39.8 mm and 42.8 mm, respectively, relative to its long-term mean value for the months May–September (333.0 mm), whereas in 2018 it exceeded this value by as much as 52.5 mm (Fig. 1). The humidity conditions during the pepper growing season were characterized by an uneven distribution of rainfall and high variations between the individual 10-day periods. In all years of the study, the highest rainfall deficit was recorded in May, whereas excessive rainfall was observed in July. The total rainfall in July during the study period significantly exceeded the long-term mean (82.0 mm), from 25.9 mm (2016) to 42.6 mm (2018). The weather pattern during the period 2016–2018 shows that very favorable thermal conditions for the cultivation of sweet pepper prevailed in south-eastern Poland, while the humidity conditions were driven by an uneven rainfall pattern, predominantly with violent torrential storm events.

Fruit measurements and harvest

Before the first harvest of fruits, measurements were made of plant height (cm) and number of main stems per plant (pcs · plant^{-1}) on 5 randomly selected plants in each replicate of the treatment combinations studied. Fruit harvest started in the second 10 days of August: August 12, 2016; August 19, 2017; and August 20, 2018. Fruits were harvested at full physiological maturity, successively every 7–10 days. The experiment was terminated in the first 10-day period of October. Fruits were picked separately from each replicate in the respective treatment and the total number of fruits as well as total and marketable yield were determined. The following parameters were distinguished: number of marketable fruits, number of fruits with visible blossom-end rot (BER) symptoms, and number of non-marketable fruits, which included fruits with other disease symptoms as well as underdeveloped and deformed fruits. Fruits with a weight of not less than 40 grams, fully ripe, with a shape typical for this cultivar, and without any visible disease symptoms were considered as marketable fruits of the cultivar 'Roberta F_1'. After the termination of the experiment, total fruit yield (kg) and marketable fruit yield (kg) per 1 m^2 were calculated for each treatment combination. The fruiting dynamics was also presented in relation to the total yield (kg · m^{-2}) obtained at each fruit harvest date. The linear function was used to express the relationship between the increase in to-

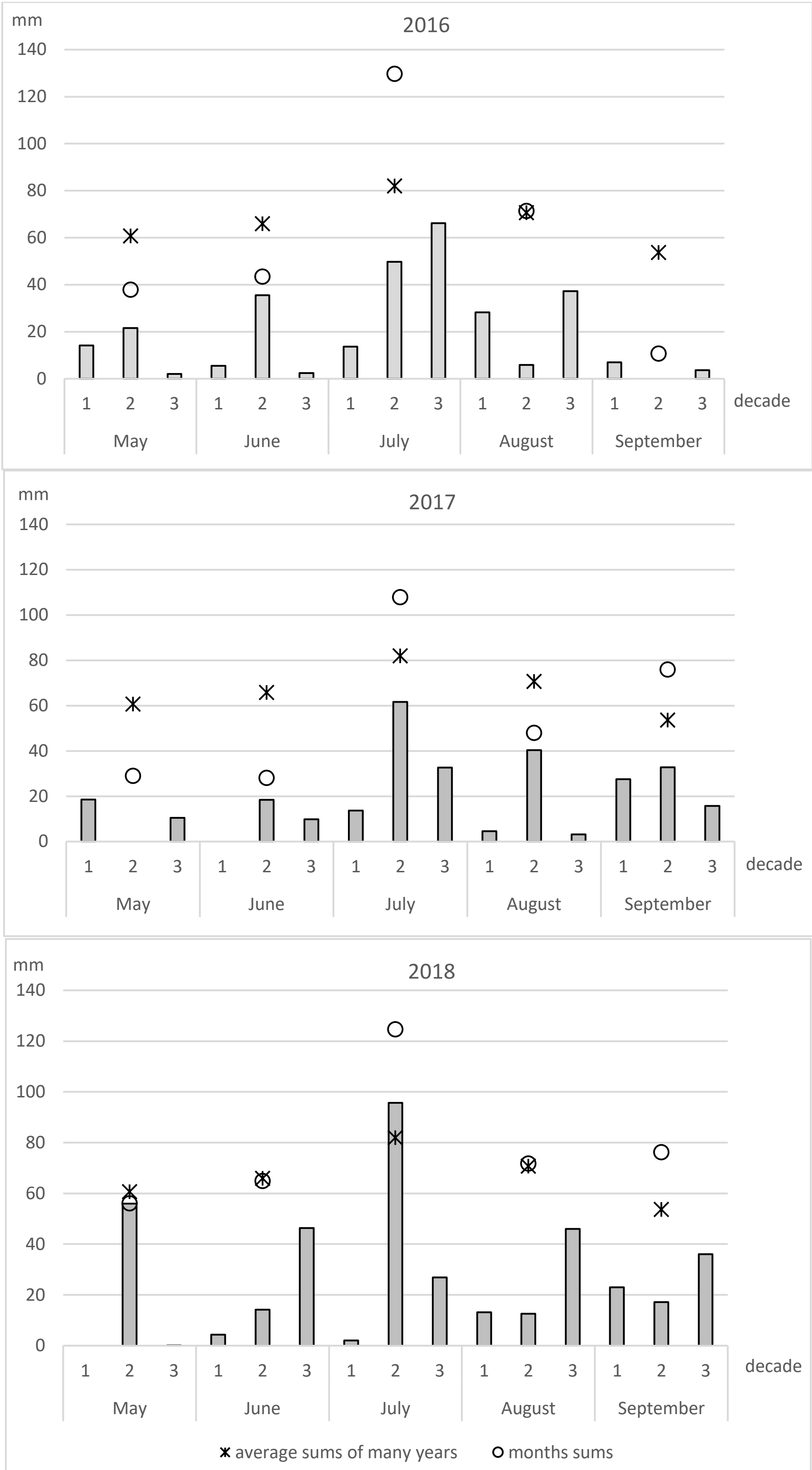

Fig. 1. Rainfalls sums during the vegetation of sweet pepper in the years 2016–2018 compared with sum from years 1951–2010

tal fruit yield and the number of days from planting transplants. Based on the derived number of marketable fruits, fruits with blossom-end rot symptoms and other disease symptoms as well as of underdeveloped and deformed fruits, the structure of total fruits was characterized (pcs · m^{-2}).

The results were analyzed statistically using Statistica 13.2 software. The significance of differences was evaluated on the basis of Tukey's multiple test at a significance level of $\alpha = 0.05$.

RESULTS

During the ripening period of first fruits, the effect of inoculation of sweet pepper transplants with arbuscular mycorrhizal fungi (AMF) and irrigation on plant height and number of main stems per plant was determined (Tab. 3). Inoculation of plants with AMF and irrigation were shown to have a significant impact on plant height in cv. 'Roberta F_1'. Plants grown in the treatment with AMF inoculation and irrigation were characterized by a significantly higher average height compared to plants in the control treatment. No significant differences in the value of this parameter were found for the other treatments. Regardless of irrigation, inoculated pepper plants had a significantly higher height compared to non-inoculated ones. Irrespective of the inoculation treatment, on average irrigated plants were also higher than non-irrigated ones. Cv. 'Roberta F_1' sweet pepper plants differed significantly in height between years. Pepper plants exhibited a higher value of the above parameter at the beginning of fruiting in the years 2017 and 2018 in comparison with 2016. Treatment of plants with AMF was demonstrated to significantly affect the number of main stems produced per plant. On average, AMF-treated and irrigated plants were characterized by significantly the highest number of stems relative to plants in the control treatment, where plants produced on average 1.0 stems less. AMF-inoculated plants developed a higher number of stems, on average by 0.8, compared to plants without inoculation. Irrigation was not proven to affect the number of main stems per plant. Regardless of the factors studied, pepper plants differed significantly between years in terms of the number of main stems. In 2016 plants were characterized by a statistically lower number in comparison with the years 2017 and 2018.

Inoculation of pepper plants with arbuscular mycorrhizal fungi at the transplant stage was found to have a statistically significant effect on the average total and marketable fruit yield (Tab. 4). The high-

Table 3. The height of plants and number of the main shoots at the beginning of fruiting of sweet pepper (mean for 2016–2018)

Treatment	Height of plant (cm · m^{-2})	Number of main shoots (pcs · $plant^{-1}$)
AMF* &irrigation	59.9 ±2.8 a	5.9 ±1.0 a
AMF & non-irrigation	59.3 ±2.5 ab	5.6 ±0.6 ab
non-AMF & irrigation	58.5 ±2.1 ab	5.2 ±0.9 bc
non-AMF & non-irrigation	57.7 ±2.4 b	4.9 ±0.6 c
Mean for AMF	59.6 ±2.6 A	5.8 ±0.8 A
Mean for non-AMF	58.1 ±2.2 B	5.0 ±0.8 B
Mean for irrigation	59.2 ±2.5 A	5.6 ±1.0 A
Mean for non-irrigation	58.5 ± 2.6 B	5.3 ±0.7 A
Mean for years		
2016	55.9 ±2.5 A	5.2 ±0.9 A
2017	60.8 ±2.4 B	5.4 ±0.7 B
2018	59.7 ±3.1 B	5.6 ±0.8 B

Means followed by the same letters do not significantly at $\alpha = 0.05$. AMF – arbuscular mycorrhizal fungi est and statistically significant fruit marketable yield (5.22 kg · m^{-2}) of the sweet pepper cultivar 'Roberta F^1' was obtained from the cultivation with simultaneous AMF colonization and irrigation of plants. The average marketable fruit yield from this treatment was higher by 11.3–33.7% than the yield obtained in the other experimental treatments. Fruiting of AMF-inoculated and irrigated sweet pepper plants exhibited the highest percentage of marketable yield in the total yield (on average 88.2%) compared to the yields in the other treatments (on average 71.5–76.4%). AMF colonization of field-grown sweet pepper plants had a more beneficial impact than irrigation alone during the growing season. Regardless of irrigation, the marketable fruit yield from AMF-colonized plants was on average higher by 26.2% compared to the yield from plants grown without AMF colonization. It also had a higher percentage in the total yield (on average 83.0%) in comparison with the percentage of marketable yield from plants grown without inoculation (on average 72.7%). Irrespective of the plant inoculation treatment, irrigation was also found to have a positive, though smaller, effect on sweet pepper fruiting. The average marketable fruit yield from irrigated cultivation was greater by 12.9% than the yield from plants grown without irrigation; its average percentage in the total yield was 82.1% and it was higher than the percentage of marketable yield from plants grown without irrigation (on average 74.3%). Regardless of the investigated factors, statistically significant variations were found in pepper yield between years. Significantly the lowest average marketable fruit yield was harvested in 2017 compared to the years 2016 and 2018, respectively by more than 17% and 26%. By far the highest average total fruit yield was obtained in 2018, but the percentage of marketable yield in it was only 68.9%. In the years 2016 and 2017, on the other hand, a significantly lower total fruit yield was obtained, but with a distinctly higher percentage of marketable yield, which was 92.0% and 84.8%, respectively. This was due to the fact that in 2018 significantly more underdeveloped and deformed fruits were picked during the last liquidation harvest. Based on the increase rate of total yield and the linear function describing the relationship between this parameter and the number of days from planting transplants, it was determined that inoculation of pepper plants and irrigation beneficially influenced earliness of sweet pepper fruiting (Fig. 2). In each year of the study, an earlier and larger pepper fruit yield was obtained in two experimental treatments – from AMF-inoculated and irrigated plants as well as from AMF-inoculated plants grown without irrigation. The maximum yield in these treatments was harvested in the period between the second 10 days of August and the second 10 days of September. In the treatment with non-colonized but irrigated plants as well as in the control treatment, fruiting occurred later because the highest fruit yield was harvested in the period between the second 10 days of September and the first 10 days of October.

Inoculation of pepper plants with AMF at the transplant stage and irrigation during the growing period had a beneficial effect on the number of fruits produced (Tab. 5). Statistically, on average a higher number of total fruits and marketable fruits was obtained in two treatments – with AMF inoculation and irrigation of plants as well as in the treatment with AMF inoculation of plants alone – relative to the number of fruits from plants only irrigated and from control plants. Regardless of irrigation, on average more total and marketable fruits were harvested from AMF-colonized plants, respectively by 16.8% and 20.8%, in comparison to the number of fruits obtained from non-inoculated plants. Irrespective of AMF treatment of plants, irrigation during the soil water deficit period did not cause significant differences in the total number of fruits. It only slightly influenced the number of marketable fruits. On average, a 10.8% higher number of marketable fruits was harvested from irrigated plants compared to that obtained from non-irrigated ones. Plant inoculation with AMF and irrigation were found to reduce significantly the incidence of blossom-end rot (BER) since the lowest number of fruits with its symptoms was harvested from AMF-inoculated and irrigated plants in comparison with the number of such fruits harvested in the other treatments. Regardless of the factors analyzed, the structure of total fruits varied between years and this was due to the number of fruits with blossom-end rot symptoms and underdeveloped fruits. Significantly the highest total number of fruits was obtained in 2018, but non-marketable fruits accounted for as much as 30.6% of their total number. These were fruits with blossom-end rot (BER) symptoms that were picked successively and underdevel-

Table 4. The total and marketable yield of sweet pepper depending on AMF and irrigation (mean for 2016–2018)

Treatment	Total yield (kg · m^{-2})	Marketable yield (kg · m^{-2})	Share of marketable yield in the total yield (%)
AMF & irrigation	5.92 ±0.86 a	5.22 ±0.67 a	88.2
AMF & non-irrigation	6.06 ±1.39 a	4.63 ±0.91 b	76.4
non-AMF & irrigation	5.27 ±1.68 b	3.87 ±0.80 c	73.4
non-AMF & non-irrigation	4.84 ±1.33 c	3.46 ±0.78 c	71.5
Mean for AMF	5.99 ±1.35 A	4.9 7 ±0.86 A	83.0
Mean for non-AMF	5.05 ±1.60 B	3.67 ±0.80 B	72.7
Mean for irrigation	5.59 ±1.35 A	4.59 ±0.93 A	82.1
Mean for non-irrigation	5.45 ±1.60 A	4.05 ±0.85 B	74.3
Mean for years			
2016	4.79 ±0.70 A	4.44 ±0.66 A	92.0
2017	4.45 ±1.29 A	3.77 ±1.25 B	84.8
2018	6.94 ±0.89 B	4.78 ±0.96 A	68.9

Means followed by the same letters do not significantly at α = 0.05. AMF – arbuscular mycorrhizal fungi

Table 5. The total and marketable fruits number of sweet pepper depending on AMF and irrigation (mean for 2016–2018)

Treatment	Total fruits number (pcs · m^{-2})	Marketable fruits number (pcs · m^{-2})	BER fruits number (pcs · m^{-2})	Fruits number with other disease symptoms and unformed (pcs · m^{-2})
AMF & irrigation	49.9 ±10.9 ab	39.1 ±6.6 a	3.7 ±0.3 a	7.1 ±0.8 a
AMF & non-irrigation	50.5 ±12.9 a	36.8 ±10.6 a	4.9 ±0.5 b	8.8 ±2.1 a
non-AMF & irrigation	43.4 ±8.0 b	32.8 ±8.4 b	5.0 ±0.5 b	5.6 ±1.1 b
non-AMF & non-irrigation	37.6 ±6.9 c	27.5 ±8.0 c	5.4 ±0.5 b	4.7 ±1.6 b
Mean for AMF	48.7 ±6.0 A	38.0 ±8.7 A	4.3 ±0.4 A	6.4 ±1.4 A
Mean for non-AMF	40.5 ±6.0 B	30.1 ±8.4 B	5.2 ±6.5 B	5.2 ±1.3 B
Mean for irrigation	45.1 ±3.6 A	36.0 ±8.0 A	4.3 ±0.4 A	4.8 ±1.3 A
Mean for non-irrigation	44.1 ±9.1 A	32.1 ±10.3 B	5.2 ±0.4 B	6.8 ±1.6 B
Mean for years				
2016	31.4 ±6.2 A	28.0 ±5.3 A	0.7 ±0.09 A	2.7 ±0.7 A
2017	40.0 ±8.8 B	30.9 ±7.3 A	2.9 ±0.6 B	6.2 ±1.3 B
2018	62.4 ±6.4 C	43.3 ±6.8 B	10.6 ±2.7 C	8.5 ±2.1 B

Means followed by the same letters do not significantly at α = 0.05. AMF – arbuscular mycorrhizal fungi. BER – blossom-end rot

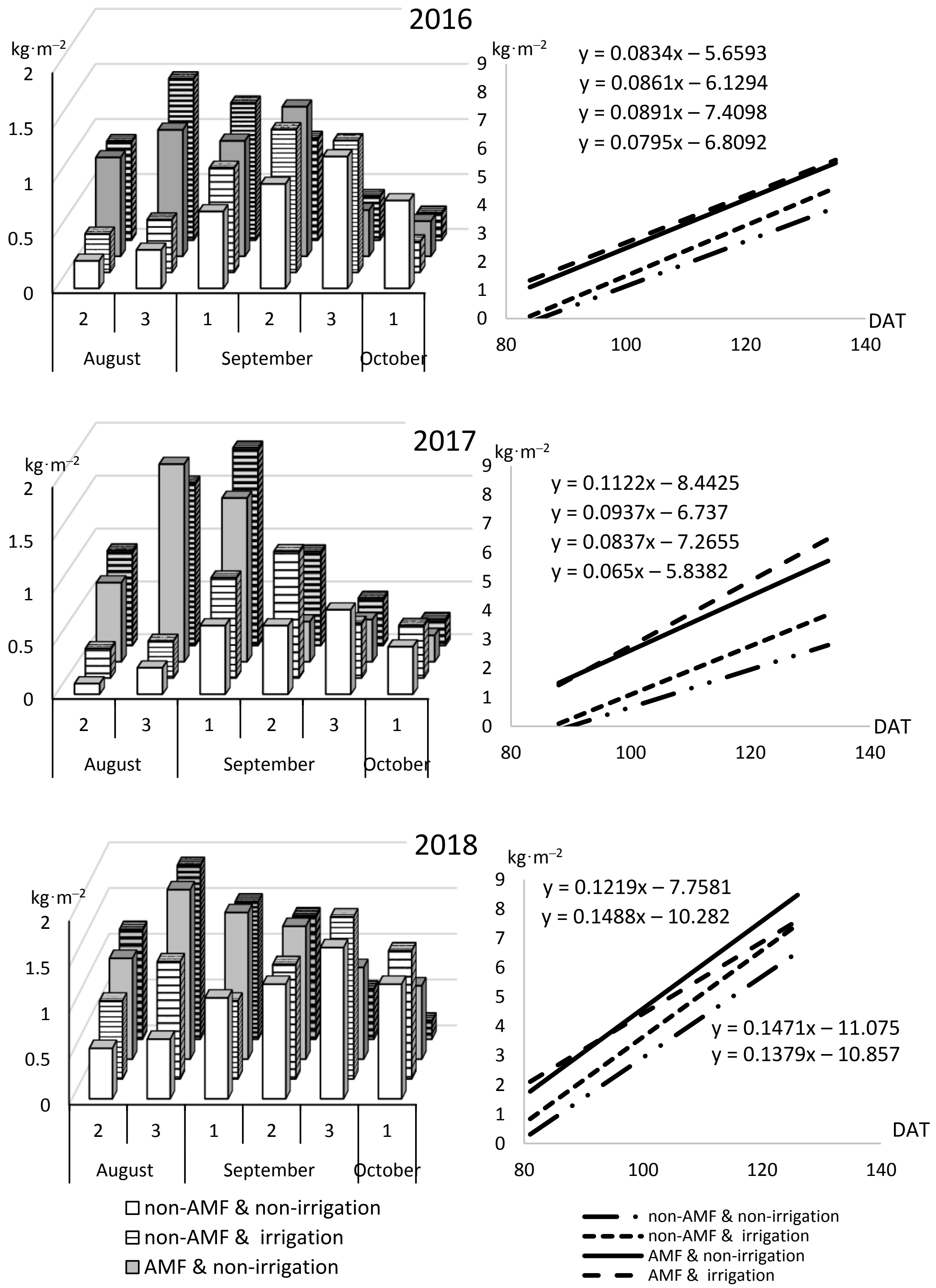

Fig. 2. The influence of AMF and plant irrigation on dynamic total yield of sweet pepper; DAT – days after transplanting

oped fruits obtained from the liquidation harvest. Significant differences were also revealed in the number of marketable fruits harvested per 1m^2 between years. Most fruits were harvested in 2018 (43.3 pcs) compared to the years 2016 and 2017, in which respectively 28.0% and 30.9% fewer fruits were obtained. The differences found in the number of total fruits and marketable fruits between years were attributable to varying thermal and humidity conditions during the plant growth period. The weather in 2018 proved to be the most favorable for pepper growth and yield.

DISCUSSION

The beneficial effect of the interaction of plant inoculation with arbuscular mycorrhizal fungi (AMF) and irrigation on plant vegetative growth has been confirmed by many authors. In his study on common onion, Bolandnazar et al. [2007] demonstrated that the interaction of plant colonization with 3 fungal species of the genus *Glomus* and irrigation at different frequencies had a positive effect on a significant increase in the unit weight and diameter, leaf area, and marketable yield of onion. Treating field-grown tomato plants with *G. intraradices* at different water deficit levels, Subramanian et al. [2006] showed that optimally irrigated plants produced significantly more stems (14.7 pcs) compared to those without mycorrhiza and grown under drought conditions (9.0 pcs). Demir et al. [2015] found that inoculation of tomato, pepper and eggplant seedlings with arbuscular mycorrhizal fungi produced plants with higher growth parameters, a better nutritional status, and lower intensity of *Verticillium dahlia* symptoms. The positive impact of AMF inoculation of pepper plants on growth parameters already at the seedling and transplant stage has been shown in papers of authors such as Regvar et al. [2003], Turkmen et al. [2008] as well as Jamiołkowska and Michałek [2019]. Castillo et al. [2009] found the treatment of hot pepper with natural *G. claroideum* and a commercial fungal product containing G. *intraradices* to have a beneficial influence on the plant growth rate under the conditions of Chile. Boonlue et al. [2012], on the other hand, studied the effect of inoculation of hot pepper plants with multiple AMF species, including 7 species of the genus *Glomus*, and showed that *G. clarum*-colonized plants were characterized by the highest plant height and the largest number of flowers and fruits per plant. Ronco et al. [2008] proved that *G. mosseae*-inoculated pepper plants grown under abiotic stress conditions caused by glyphosate residues in the soil exhibited the largest biomass, plant height, number of leaves, and leaf area. According to a study by Salami [2002], colonization of pepper plants with *G. etunicatum* effectively reduced infection with *Phytophtora infestans*, while AMF-treated plants had a higher height and number of leaves. Many authors have found that irrigation provides favorable soil moisture conditions for plants and contributes to an improvement in growth parameters, regardless of various agronomic practices. Antony and Singandhupe [2004] demonstrated that irrigated plants of the sweet pepper cultivar ‘California Wonder’ were characterized by a higher height and a distinctly larger number of main stems per plant (9.0 pcs) than those grown under water deficiency conditions (5.0 pcs). According to a study by Kirnak et al. [2003], pepper plants grown under favorable moisture conditions also exhibited better growth parameters at different levels of nitrogen fertilization. In a greenhouse study, Ferrara et al. [2011] showed that water deficit during the vegetative growth period of pepper plants significantly determined the number of flowers. Under water deficiency conditions, the number of flowers per plant was lower by 65% compared to optimum moisture conditions (30.9 pcs).

Many papers have proven the beneficial effect of treatment of pepper plants with various mycorrhizal fungal species on fruiting of pepper cultivation both under optimum environmental conditions and under water deficit. The suitability of both single fungal species and mixtures of fungi of the genus *Glomus* have been evaluated. Kapoulas et al. [2019] revealed that inoculation of bell pepper plants cv. Raiko F_1 with *Glomus intradies* cultivated in high P saline soil generally enhanced growth and increased fruit yield and number of fruits per plant when applied at planting time in the greenhouse.

In a greenhouse study, Kaya et al. [2009] demonstrated that *Glomus clarum* colonization of pepper plants grown under high substrate salinity conditions resulted in a 53.4% higher fruit yield and an increase in dry plant weight by 36.7%. Salami [2002] observed that pepper plants inoculated with *Glomus etunicatum* were characterized by more intense flowering and fruiting as well as lower infection caused by *Phytophtora infestans* compared to control plants. Douds and Reider [2003] obtained a higher pepper fruit yield by 14–23% by applying a mixture of *Glomus* spp. fungi in comparison to the yield from control plants. Both under optimum moisture conditions and water deficiency, Mena-Violante et al. [2006] revealed that inoculation of hot pepper plants with *Glomus fasciculatum* and two commercial products containing fungi of the genus *Glomus* had a beneficial effect on increasing the fresh fruit weight, even by 25%. In a plastic greenhouse study, Al-Karaki [2017] showed that a 38% higher fruit yield and a 30% higher number of fruits were obtained from the green pepper cv. 'Zingaro' plants inoculated with *Glomus mossae* in comparison to the yield (8.2 kg $\cdot$ m^{-2}) and number of fruits (60 pcs $\cdot$ m^{-2}) from the control plants. Nedorost et al. [2014], in turn, obtained a 21% higher fruit yield from pepper plants grown in a foil tunnel and inoculated with six *Glomus* spp. species in comparison to control plants (3.67 kg □ m^{2}) and a 28% higher yield under optimum moisture conditions, regardless of inoculation. When testing as many as eleven AMF species, Thilagar and Bagyaraj [2015] found their effect on hot pepper growth and yield to vary. In terms of fruit yield and stem and root phosphorus content, they obtained the best results by colonizing pepper plants with *G. mosseae.* Many papers have shown that optimum irrigation of plants throughout the entire growing season is an essential factor that guarantees obtaining good fruit pepper yield. It has been found that the fruit yield from pepper cultivation under continuous water deficit is lower by even 40–44% in comparison to that harvested under optimum moisture conditions [González-Dugo et al. 2007, Karam et al. 2009, Ismail 2010, Kurunc et al. 2011].

This paper has shown AMF inoculation and, to a smaller degree, irrigation to have beneficial effects on accelerated yield of sweet pepper. In a study conducted in the climate of Nigeria, Salami [2002] found this treatment to have a positive impact on more dynamic flowering and earlier fruiting of pepper compared to control plants. Castillo et al. [2009] also demonstrated that in Chile fruit harvesting from plants inoculated with *Glomus* spp fungi started distinctly earlier. Cimen et al. [2009] also observed accelerated flowering and fruit setting in pepper plants inoculated with *G. intraradices* and grown under soil solarization conditions. Lodhi et al. [2014] showed that in field-grown pepper crops irrigation method also has an impact on the acceleration of plant growth stages and fruiting. They obtained earlier flowering as well as fruit setting and ripening in plants that were drip irrigated compared to those that were furrow irrigated.

The results obtained in the present study for the total number of fruits harvested per 1 m^2 and their structure indicate that the applied treatments involving AMF inoculation and irrigation of sweet pepper plants effectively reduced the incidence of blossom-end rot (BER) on fruits. Reports of other authors also show a positive effect of arbuscular mycorrhizal fungi and irrigation on decreasing the number of pepper fruits with such symptoms. Díaz-Perez and Hook [2017] showed that the quantity and quality of marketable pepper yield was dependent on irrigation intensity and calcium fertilization applied. These treatments reduced the occurrence of fruits with blossom-end rot (BER) symptoms. In research studying the effect of deficit irrigation and partial rootzone drying in hot pepper, Dorji et al. [2005] obtained yield of fruits with intense symptoms of blossom-end rot. Under water deficit, the percentage of such fruits in the total number of fruits was 20.4%, under drought conditions it was 29.5%, whereas in the control 9.3%. Plants of the cultivar 'Roberta F$_1$', which belongs to sweet pepper cultivars suitable for cultivation in a less favorable climate, were the object of this study. Results of previous studies that evaluated the quantity and quality of fruit yield of this cultivar and of other cultivars recommended for field cultivation indicate that fruiting of these sweet pepper cultivars is dependent to some extent on weather conditions in a given year [Gajc-Wolska and Skąpski 2002, Szafirowska and Elkner 2008, Rożek et al. 2012, Buczkowska et al. 2014].

CONCLUSIONS

Based on the study results obtained over the period 2016–2018, it was shown that the cultivation with simultaneous plant inoculation with arbuscular mycorrhizal fungi (AMF) and irrigation throughout the entire growing season gave the highest total and marketable yield as well as the highest number of fruits of the sweet pepper cultivar 'Roberta F$_1$'. AMF colonization had a greater effect on yield and number of sweet pepper fruits than irrigation of plants. Inoculation of pepper plants with AMF before planting transplants in the field also affected beneficially earliness of fruiting. An earlier and higher fruit yield was obtained from AMF-inoculated plants, grown both with and without irrigation. AMF colonization and irrigation of plants significantly reduced the incidence of blossom-end rot (BER). The lowest number of fruits with such symptoms was harvested from AMF-inoculated and irrigated plants compared to the number of such fruits obtained from control plants. At the beginning of fruiting, AMF-inoculated and irrigated plants were also characterized by a higher height and a larger number of main stems. Regardless of the factors studied, significant differences were found in yield and number of 'Roberta F_1' fruits between years. This was due to the impact of different weather conditions during the growing season of field-grown pepper.

ACKNOWLEDGEMENTS

This research was funded by the University of Life Sciences, Department of Vegetable Crops and Medicinal Plants.

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