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Combining effects of soil solarization and grafting on plant yield and soil-borne pathogens in cucumber

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Abstract

Combining effects of soil solarization and grafting on soilborne pathogens, plant height and yield in cucumber were compared in a greenhouse of Bati Akdeniz Agricultural Research Institute located in Antalya in 2008 fall season. The experiment was set in split plot design containing; 1, 2, 4 and 5 months soil solarization (MSS), and non-solarized control plots (NSC) on which grafted Maximus F_1+ Bergama F_1 and non-grafted Bergama F_1 were grown. Almost all of plants grown in non-solarized plots were infected with root-knot nematodes with severe root damages; however, only a few plants were affected by this nematode in 4 and 5 months solarized plots with very slight root galls. No resistance to root-knot nematodes was observed in both grafted and non-grafted plants. Almost half of the plants grown on non-solarized control plots were infected with *Fusarium oxysporum* f. sp. *cucumerinum* with relatively slight disease symptoms. In conclusion, combining solarization with grafting significantly promoted early flowering time, plant vigor, early and total yields and reduced nematode and fusarium wilt damages in this study.

Keywords: Fusarium wilt; Grafting; Root-knot nematodes; Soilborne pathogens; Solarization.

Introduction

Cucumber (*Cucumis sativus* L.) is a one of the important crop grown in open fields and protected areas in all over the world. According to 2007 statistics, 1.7 million tons of cucumber was produced in Turkey (FAO, 2009). Cucumber is affected by many different pests among which root-knot nematodes (Elekçioğlu and Uygun, 1994; Devran et al., 2008) and fusarium wilt (Punja and Parker, 2000; Moreno et al., 2001; Pavlou et al., 2002; Kirbag and Turan, 2005) are the most prevalent and damaging soilborne pathogens resulting in severe yield and quality loss in plants. Methyl bromide (MB), a strong fumigant diffusing easily and effectively, has been used to control these soilborne pathogens, for almost sixty years in many countries of the world (MBTOC, 2007). In Turkey, for over 30 years, MB has been efficiently applied in protected fields to control various fungi, bacteria, insects, mites, nematodes and rodents as well as many weeds (Yilmaz et al., 2008). MB, an ozone depleting substance, is expected to be phased out in 2015 in Turkey; however, it was banned at the beginning of 2008 due to its damaging effects on human beings and the environment, despite its major advantages as a fumigant. Therefore, some alternative measures for management of soilborne pathogens were urgently needed in Turkey. While MB had been gradually terminating from 2003 to 2008, some alternatives including; solarization, biofumigation, grafting, chemicals, steaming, compost application and soilless culture were introduced to the protected vegetables growers. Among these alternatives, researches were mostly focused on solarization and grafting, and their combined applications to have more yields and control soilborne pathogens (Yilmaz et al., 2007a).

Grafting has been used to control soilborne pathogens in vegetables since 1920 in Japan and Korea, where land use is very limited (Ashita, 1927; Lee, 1994). Grafting was first used in 1998 with only 70000 tomato seedling production in Turkey, from that time it has been rapidly and steadily growing and reached at 51.5 million in 2007. The highest number of grafted plants was in watermelon followed by tomato, eggplant, melon and cucumber (Yilmaz et al., 2007b).

Soil solarization, an effective and cheap soil disinfestations method, was first applied by Katan et al. (1976) in Israel and later it was speedily spread to the Mediterranean and South Europe Countries due to appropriate climatical conditions (Katan et al., 1987; Göçmen and Elekçioğlu, 1996). It was also combined with other alternatives such as; chemicals, grafting and biofumigation. Integration of soil solarization with grafting on resistant rootstocks considered an environmentally friendly and effective approach has recently expanding to manage soilborne pathogens (Ioannou, 2001; Besri, 2003; Morra et al., 2007). In Turkey, this combination was also applied to control soilborne pathogens and increase yield and quality in tomato, pepper, eggplant, melon and cucumber protected production by Yilmaz et al. (2007a).

The purposes of this study were to determine the combining effects of soil solarization applied in different time periods with grafting on plant early and total yields, first flowering date, plant height, fusarium wilt and nematode damages on roots.

Materials and Methods

Bergama F_1 and Maximus F_1 (AG 1355 F_1) (*Cucurbita maxima x C. moschata;* Shintoza) were used as variety and rootstock, respectively, in this study. Bergama F_1 grown in fall and full season is one of the commonly used cucumber variety known as tolerant to cold stress in Turkey. It is a beith alpha type cucumber which produces fruits that are 18-20 cm in length. Maximus F_1, one of the regular rootstock for watermelon and melon, is recently being used for cucumber as rootstock. Both rootstock and variety seedlings were kind gift of Antalya Tarim Inc, Antalya-Turkey.

The trail was set in regular glasshouse in Aksu Station of the Batı Akdeniz Agricultural Research Institute (BATEM), in Turkey. The experiment was set up completely randomized plots in split plot design with 3 replications and each plots contained 20 plants. The main plots were 1, 2, 4 and 5 months soil solarization (MSS), and non-solarized control plots (NSC). Each main plot contained grafted (G) and non-grafted control (NGC) subplots. Summer solarizations were started on July 20^{th} and August 20^{th} for 1 and 2 months, respectively and terminated on 25 September 2008. The whole season solarizations were commenced on the same dates for 4 and 5 months and terminated on January 5^{th}, 2009. The plots were covered with 35 µm VIF (virtually impermeable films) plastic. In summer solarized plots, regular solarization procedure was applied. However, in whole season plots, a slightly different solarization procedure was followed. In this technique, before solarization, the raised seedling beds were prepared, and the dripping hoses were placed. Later the beds were covered VIF plastic and solarized. At the time of planting, small holes were opened on the plastic and seedlings were planted. The plastic cover was kept up to the end of production season. The seedlings for all plots were planted on September 29th, 2008, with 0.85 x 0.40 m spacing.

The soil in greenhouse was a sandy clay loam (54% sand, 31% silt, 15% clay) with pH 8.0, EC 0.57 dS m^{-1} and organic matter 2.8%. Soil and air temperatures in the greenhouse in 10 cm depth and 2 m height, respectively, were measured by HOBO (temperature data logger, Henna H141JH) for solarized and non-solarized plots in every hour intervals from 8 August 2008 to 9 January 2009.

The experiment was set up in a greenhouse having nematode and fusaium wilt history. Nematode (*Meloidogyne incognita* (Kofoid & White) Chitwood) root-gall incidence (percentage of infected plants in plots) and severity was recorded at the end of season by pulling out cucumber plants according to 0-10 scale of Zeck (1971): 0= no galls, 1= very few small galls, 2= numerous small galls, 3= numerous small galls, some of which are grown together, 4= numerous small and some big galls, 5= severe galls on 25% of roots, 6 = severe galls on 50% of roots, 7= severe galls on 75% of roots, 8= no healthy roots but plant is still green, 9= roots rotting and plant dying, and 10= plant and roots dead. Hazards of *Fusarium oxysporum* (Schlecht.) emend. Snyd. et Hans. f. sp. *Cucu merinum* Owen, J.H. on plants were evaluated according to modified scale of Reis and Boiteux (2007) where: 1= plant free of symptoms, 2= plant without wilt symptoms but containing conspicuous vascular browning inside the roots, 3= plants showing vascular browning and wilt symptoms but without leaf yellowing, 4= severe wilting associated with the presence of foliar necrosis and chlorosis, 5= dead plant.

First flowering date was recorded when 50% of plants were flowered in plots. The plants heights were measured 70 days after planting. The first five cumulative yields for per plant were considered as early fruit yields. Total yield was compilation of 18 harvests from 30 October 2008 to 5 January 2009. Data for all measurements were subjected to analysis of variance in JMP 5.01 statistical program (SAS Institute Inc., Campus Drive, Cary, NC 27513). When the overall F test was significant ($P \leq 0.05$), means were compared by Turkey HSD test.

Results

Air and soil temperatures

Average monthly air and soil temperatures for solarized and non-solarized soils were given (Figure 1) and (Figure 2), respectively. Even though average temperatures for six months for air were very close (21.03 ºC and 20.36 ºC), the mean soil temperatures (24.87 ºC and 22.00 ºC) differed almost 3 ºC between solarized and non-solarized plots. Average soil temperature differences between solarized and non-solarized plots were 4.54 ºC, 5.44 ºC, 2.91 ºC, -0.27 ºC, 2.87 ºC and 1.69 ºC in August, September, October, November, December and January, respectively. The highest (47.5 ºC) and the lowest (2.5 ºC) air temperatures among all treatments were determined in non-solarized control plots in August and January, respectively. On the other hand, the highest (43.1 ºC) and the lowest (11.5 ºC) soil temperatures were observed in solarized plots in September and January.

Determining first flowering time

Effect of grafting and solarization on first flowering time was statistically significant (P≤0.0001). Among all treatments early flowering time was in NGC plants grown in 5 MSS with 9 days and late was in G plants grown in NSC plots with 13.3 days (Figure 3).

Plant height

Plant height was influenced by combining of solarization treatments and grafting. However, effect of solarization on plant growth was more prominent (P≤0.0001) than that of grafting. Even though the maximum plant height (306.5 cm) was obtained from G plants grown in 5 MSS plots (Figure 4), in our experiment, grafted cucumber plants grew slowly in first 45 days, later they promptly flourished and surpassed non-grafted ones. The minimum plant growth was in non-solarized plots containing both grafted and non-grafted plants.

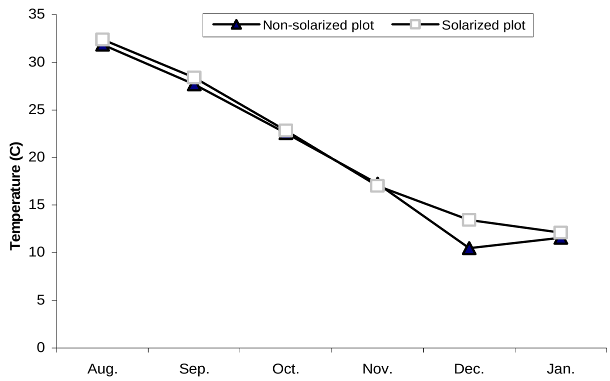

Figure 1. Average monthly air temperatures from 8 August 2008 to 9 January 2009.

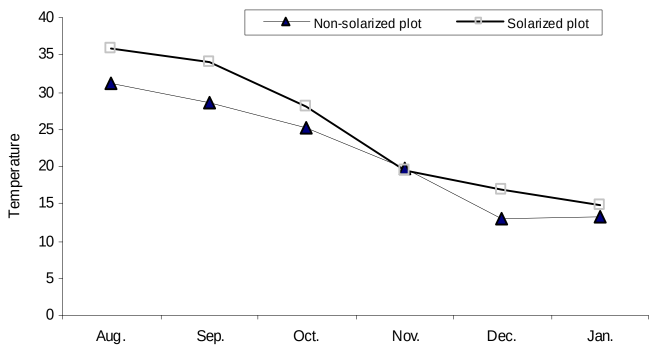

Figure 2. Average monthly soil temperatures from 8 August 2008 to 9 January 2009.

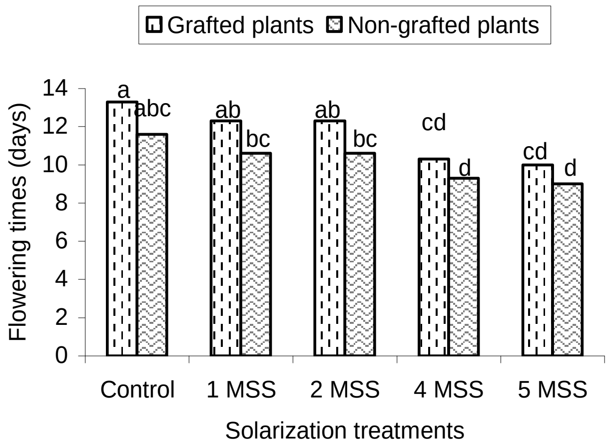

Figure 3. Determining the first flowering time in G and NGC plants.

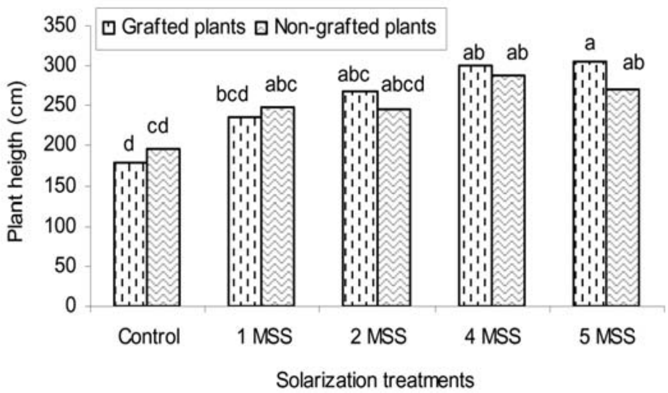

Figure 4. Plant height in G and NGC plants.

Early and total yields

Although early fruit yields were not statistically significant between the grafted and non-grafted sub-plots, the total fruit yields were statistically significant in the same sub-plots ($P \leq 0.0002$). Moreover the differences among all soil solarization treatments for early and total yields were statistically significant ($P \leq 0.0001$). Among all treatments, the highest early yields were obtained from 4 and 5 MSS treatments and the lowest from non-solarized control in both grafted and non-grafted plots (Table 1).

Statistical analysis showed that both solarization and grafting resulted in significant total yield increases ($P \leq 0.03$). In all treatments, grafted plants provided nearly 20% yield increase compared to non-grafted ones. On the other hand, more significant total yield increases were observed in 4 and 5 MSS (183%) and 1 and 2 MSS (127%) plots compared to NSC plots (Table 1).

Effect of soil solarization on nematode and Fusarium wilt in grafted and non-grafted plants

Meloidogyne incognita was detected in the experimental greenhouse before treatments applied. All of the cucumber plants grown in NSC plots were infected with *M. incognita* (Table 2).

Table 1. Effect of solarization treatments on early and total yields.

Solarization treatments	Early yield (g/plant)*		Total yield (g/plant)*	
	Grafted	Non-grafted	Grafted	Non-grafted
5 MSS	825^{ab}	848^{ab}	$3\,059^{ab}$	$2\,541^{bcd}$
4 MSS	849^{ab}	922^{a}	$3\,183^{a}$	$2\,611^{abcd}$
2 MSS	751^{ab}	695^{ab}	$2\,638^{abc}$	$2\,039^{cd}$
1 MSS	672^{ab}	615^{ab}	$2\,422^{cd}$	$2\,028^{d}$
NSC	445^{ab}	350^{b}	$1\,072^{e}$	936^{e}

*Numbers in the same column followed by the same letter are not significantly different (P<0.05) according to Tukey HSD.

Early Yield
HSD value for Solarization levels (P≤0.05) = 214.04
HSD value for Grafting Levels (P≤0.05) = 127.36
HSD value for S x G (P≤0.05) = 506.74
CV(%) =22.51

Total Yield
HSD value for Solarization levels (P≤0.05) = 357.9
HSD value for Grafting levels (P≤0.05) = 151.9
HSD value for S x G (P≤0.05) = 601.19
CV(%) =8.28

Table 2. Evaluation of nematode root-gall and fusarium wilt harm on plants.

Solarization treatments	Nematode Root-Gall Evaluation*				*Fusarium oxysporum* f. sp. *Cucu merinum* Evaluation*			
	Grafted		Non-grafted		Grafted		Non-grafted	
	Incidence (%)	Severity (1-10)	Incidence (%)	Severity (1-10)	Incidence (%)	Severity (1-5)	Incidence (%)	Severity (1-5)
5 MSS	12.5^{b}	0.75^{cd}	4.1^{b}	0.25^{cd}	4.2^{e}	1.04^{f}	4.2^{e}	1.04^{f}
4 MSS	16.6^{b}	1.00^{cd}	0^{b}	0.00^{d}	4.2^{e}	1.04^{f}	4.2^{e}	1.04^{f}
2 MSS	45.8^{ab}	2.83^{abcd}	37.5^{ab}	1.92^{bcd}	8.3^{d}	1.13^{e}	25^{b}	1.42^{b}
1 MSS	87.5^{a}	4.33^{abc}	0^{b}	0.00^{d}	8.3^{d}	1.13^{e}	25^{b}	1.33^{c}
NSC	100^{a}	6.04^{a}	100^{a}	5.63^{ab}	12.5^{c}	1.21^{d}	62.5^{a}	1.75^{a}

*Numbers in the same column followed by the same letter are not significantly different (P<0.05) according to Tukey HSD.

Nematode severity
HSD value for Solarization levels (P≤0.05) = 2.42
HSD value for Grafting Levels (P≤0.05) = 1.02
HSD value for S x G (P≤0.05) = 4.08
CV(%) = 55.62

Fusarium severity
HSD value for Solarization levels (P≤0.05) = 0.344
HSD value for Grafting levels (P≤0.05) = 0.160
HSD value for S x G (P≤0.05) = 0.637
CV(%) = 14.33

Nematode incidence (%)
HSD value for S levels (P≤0.05) = 28.75
HSD value for G Levels (P≤0.05) = 17.35
HSD value for S x G (P≤0.05) = 69.04
CV(%) = 52.97

Fusarium incidence (%)
HSD value for S levels (P≤0.05) = 15.01
HSD value for G Levels(P≤0.05) = 10.46
HSD value for S x G (P≤0.05) = 41.62
CV(%) = 45.56

Although nematode damages were severe in plants grown in NSC compared to plants in solarized plots, the highest disease severity was observed in grafted plants grown in NSC plots. Moreover, in all other treatments, both disease incidence and severity were higher in grafted plants than non-grafted ones. Neither rootstock (Shintoza) nor cucumber variety (Bergama F_1) was resistant to nematode in this experiment.

In grafted plots, only a few plants infected with *F. oxy.* f. sp. *Cucu merinum* without any symptoms on the upper parts of plants, but having vascular browning on roots (Table 2). The vascular browning symptoms on roots were mostly present in the plants infected with both nematode and fusarium. However, disease incidence and severity of non-grafted plants were higher than that of grafted ones. Among the non-grafted control plants, the highest disease incidence and severity were observed in plants grown in non-solarized plots. In general, diseases severity was also low in non-grafted plants. Even though fusarium wilt was detected in both grafted and non-grafted plants, none of the plants were dead due to this disease. However, only a few plant showed mild wilting symptoms on non-grafted plants but not in grafted ones. Soil solarization was also effective to control fusarium, especially in 4 and 5 MSS in this trail (Table 2).

Discussion

Combining solarization with grafting significantly affected early flowering time, plant vigor, early and total yields and reduced nematode and fusarium wilt damages. The main effect on early flowering time resulted from soil solarization ($P \leq 0.0001$). In this experiment, approximately 4 days earliness on flowering time may stem from the soil temperature increase due to solarization. In a parallel study, Streck et al. (1995) reported that regular tomato plants flowered 6 days earlier in solarized plots than non-solarized ones. Significant differences were also detected for early flowering time between grafted and non-grafted plants grown in solarized and non-solarized plots ($P \leq 0.004$). In contrast to solarization treatments, grafting delayed flowering times approximately 2 days in all treatments. Similarly, Yilmaz et al. (2007a) reported that the flowering time were delayed 3-5 days in grafted tomato, pepper and watermelon plants compared to NGC plants. Flowering time and fruit maturity were ten days later in grafted plants than non-grafted ones in tomato (Rashid et al., 2002). On the other hand, grafted watermelon plants on *Lagenaria siceraria* flowered 6 days earlier than non-grafted ones (Chouka and Jebari, 1999).

According to our results, 4 and 5 MSS and grafting induced plant growth. Krug and Theiel (1985) reported that increase in soil temperature significantly promoted the growth of cucumber. In another study, El-Nemr (2006) stated that mulching contributed to higher soil temperature two months after transplanting and consequently improved plant growth and yield of cucumber.

Early fruit yield was very similar in most of the grafted and non-grafted plots in this study. This may results from identical plant growth between grafted and non-grafted plants at the beginning of the growing season; however, grafted cucumber plants promptly flourished and surpassed non-grafted ones at the middle of the growing season. The highest yield was obtained from non-grafted plants grown in 4 MSS plots. These results were in agreement with findings of Echebarria (2001) and in contrast with the results of Yarsi et al. (2008). However, early fruit yield was significantly improved by solarization treatments.

The early fruit yield was almost doubling in 4 and 5 MSS plots compared to NSC. El-Nemr (2006) stated that mulching remarkably increased early fruit yield in cucumber due to in increase soil temperature.

Total yield was significantly improved in the plots combining solarization with grafting. It was reported that grafting alone promoted plants growth and yield (Echebarria et al., 2002; El-Nemr, 2006), boosted the resistance to soilborne pathogens (Chellemi and Olson, 1994; Ioannou, 2001), augmented tolerance to adverse soil conditions (Oda, 1995) and increased water and nutrient uptake (Kato and Lou, 1989) based on rootstocks which mostly had very strong root system (Huh et al., 2007). Nevertheless, the augmented yield in this study mostly resulted from whole growing season solarization rather than grafting (Table 1). Solarizing soil during fall and winter months brought about increase in soil temperature around roots and controlled the soilborne pathogens. Consequently, 3-5 ºC of average soil temperature increase (Figure 2) in cucumbers grown in 4 and 5 MSS plots may lead to vigorous plant growth and better nutrient absorption and uptake. These results were in agreement with findings of Chellemi and Olson (1994); Ioannou (2001); Echebarria et al. (2002) and El-Nemr (2006).

Nematode incidence and severity were higher in grafted plants than non-grafted ones in this study. These results were in line with finding of Huh et al. (2007) and Huitron et al. (2007). On the other hand, solarization significantly reduced both incidence and severity of *M. incognita.* However, both incidence and severity of *M. incognita* was lower in 4 and 5 MSS plots than in 1-2 MSS plots. Solarization, particularly 4 or 5 months, was very effective against nematode, also noted by Katan et al. (1987), Gocmen and Elekcioglu (1996), Ioannou (2001).

Results of the present study indicate that grafted plants were resistant to fusarium wilt and could be used to control this disease. It was reported that *C. maxima x C. moschata* rootstock was highly resistant to *Fusarium oxysporum* f. sp. *niveum, Fusarium oxysporum* f. sp. *cucumerinum*, *Fusarium oxysporum* f. sp. *melonis* and *Fusarium oxysporum* f. sp. *lagenariae* (Huh et al., 2007; Huitron et al., 2007). To control root and stem rot of cucumber caused by *Fusarium oxysporum* f. sp. radicis-*cucu merinum* in Greece, Pavlou et al. (2002) suggested that grafting commercial Dutch type cucumber hybrids onto different resistant *Cucurbita* roostocks such as *C. maxima*, *C. ficifolia* and *C. maxima x C. moschata* could be used as an alternative control method to MB. Studies in Israel, the USA and Cyprus showed that soil solarization significantly reduced the fusarium wilt in various plants reported by Katan et al. (1976), Chellemi and Olson (1994), Iannou (2001), respectively.

In this study, the soil temperature increased 3-5 ºC in solarized plots compared to non-solarized control plots due to covering soil with VIF plastic during whole growing season.

In conclusion; solarization alone may be effective to control soil-borne pathogens and increases yield. Even tough the cost of solarization was slightly more expensive (US$100/da) than non-solarized control, the yield provided by solarization treatments compensated this cost and supplied at least twofold more profit. On the other hand, using grafting was not economical in NSC and short term solarization plots due to high cost of grafted seedlings (US$950/da) in this study. However, long term solarization (4 or 5 months) in combination with resistant rootstock was also effective, providing not only broad protection of cucumber from soilborne pathogens but also significantly increasing plant yield and supplied the highest net profit (approximately US$2000/da). To our knowledge, this was the first report in world showing that summer solarization was extended to whole growing season in this study. Moreover, this new solarization technique which was unique due to using raised plant beds before solarization was also integrated with grafting. Therefore, this technique may be suggested as a sustainable IPM alternative to MB fumigation in Turkey and Mediterranean region and possibly world's other areas with a similar climate.

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