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Performance of Eggplant Grafted on Tomato and Eggplant Rootstocks

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Summary

Yield and fruit characteristics of eggplant, cv. 'Delica' (flask type fruit), were studied in relation to grafting and K rate. The vegetative growth and yield of plants grafted on to tomato rootstocks cv. '515' and '516' (Spyrou A.E.B.E., Athens) was superior to that of the non-grafted control, whereas plants grafted on to eggplant rootstocks cv. '494' and '543' (Spyrou A.E.B.E., Athens) showed similar development and yield to that of the control. The root systems of the tomato rootstocks were appreciably larger than those of the eggplant rootstocks, and this is likely to have encouraged the better vegetative growth of the former. Differences in yield were primarily due to larger sized fruit harvested from plants grafted on to tomato rootstocks, and fruit number was generally higher. Increasing the K content had a variable effect on mean fruit weight and yield of eggplant grafted on to tomato rootstocks, increasing both these parameters in experiment 1 (planting in early spring), but having virtually no effect in experiment 2 (summer planting). Rootstock or K rate did not affect the mineral composition of the fruit. It is concluded that for greenhouse eggplant cultivated under warm conditions, tomato may be the preferable rootstock for grafting. When planting occurs early in spring, a higher K rate may also be beneficial.

Zusammenfassung

Leistung von auf Tomaten- und Auberginenunterlagen veredelten Auberginenpflanzen. An Auberginen der Sorte 'Delica' (flaschenförmiger Typ) wurde der Einfluss von Veredlung und K-Düngung auf Erntemenge und Fruchteigenschaften untersucht. Das vegetative Wachstum und die Erntemenge war bei auf den Tomatenunterlagen '515' und '516' (Spyrou A.E.B.E., Athens) veredelten Pflanzen besser als bei der nicht veredelten Kontrolle, während Pflanzen, die auf den Auberginenunterlagen '494' und '543' (Spyrou A.E.B.E., Athens) veredelt waren, in Entwicklung und Ertrag der Kontrolle ähnelten. Die Wurzelsysteme der Tomatenunterlagen waren deutlich stärker ausgebildet als die der Auberginenunterlagen, was vermutlich das vegetative Wachstum ersterer förderte. Die größere Erntemenge bei auf Tomatenunterlagen veredelten Pflanzen war vor allem auf größere Früchte, aber auch auf die höheren Fruchtzahlen zurückzuführen. Die höhere K-Gabe hatte in den beiden Versuchsjahren unterschiedliche Auswirkungen auf Erntemenge und Fruchtqualität der auf Tomatenunterlagen veredelten Auberginen: In Versuch 1 (Pflanzen im zeitigen Frühjahr) stiegen beide Parameter an, in Versuch 2 (Pflanzen im Sommer) zeigte sich praktisch keine Wirkung. Unterlage und K-Düngung hatten keinen Einfluss auf die mineralischen Inhaltstoffe der Früchte. Zusammenfassend kann festgestellt werden, dass für in warmen Gebieten kultivierte Gewächshaus-Auberginen Tomaten wahrscheinlich die geeigneteren Unterlagen sind. Bei Pflanzungen im zeitigen Frühjahr kann eine höhere K-Gabe förderlich sein.

Key words. eggplant – aubergine – grafting – potassium – tomato – fertilizer – *Solanum melongena*

Introduction

The grafting of vegetable species onto compatible, disease-resistant rootstocks has been increasingly employed over recent years to reduce the incidence of wilt diseases caused by the soil-borne pathogens *Verticillium dahliae* Kleb. and *Fusarium oxysporum*. Moreover, in view of the restrictions and ultimate ban on the use of methyl bromide for soil fumigation, interest in grafting is likely to increase over the coming years. In Greece, virtually all watermelons are currently grafted onto disease resistant rootstocks of *Cucurbita* spp. or *Lagenaria* spp. Grafting is also common for melons (40–50 % of the total crop in southern Greece), but to a lesser extent for cucumbers (5–10 %), tomatoes and eggplants (2–3 %) (TRAKA-MAVRONA et al. 2000; PASSAM 2003). In Japan almost 60 % of greenhouse fruit-bearing vegetable crops are grafted (ODA 1999), whereas in Italy the annual rate of increase in grafting is stated to be as high as 100 % (MORRA et al. 1999).

Grafting has been reported to confer a number of additional advantages on crop performance. These include increased growth and development, increased nutrient uptake, increased tolerance to salinity and thermal stress, and a reduction in viral, fungal, and bacterial infections (RIVERO et al. 2003). Resistance to

stress is particularly important for greenhouse vegetables in the Mediterranean region because most greenhouses are located in coastal plains and crops are frequently subjected to stress due to poor water quality and high temperatures. Under such conditions, plants are also more susceptible to disease.

In Greece, over 200 ha of eggplant (*Solanum melongena* L.) are currently cultivated in greenhouses, mainly for domestic, out of season production, when market prices are high. BLETSOS (2003) has shown that eggplant, cv. 'Tsakoniki', grafted on to rootstocks of *Solanum torvum* Sw. and *S. sisymbriifolium* Lam., grew more vigorously than the non-grafted control, resulting in increased plant height, stem diameter and root weight. Moreover, grafted plants were less susceptible to wilt disease, resulting in significantly higher yields in comparison with the non-grafted control (BLETSOS et al. 2003). *S. torvum* was more resistant than *S. sisymbriifolium* to *V. dahliae*, when grown on both fumigated and *Verticillium*-infested soil, but germination and early growth of *S. torvum* prior to grafting was delayed due to the small seed size of this species (BLETSOS et al. 2003).

The success of grafting largely depends on the selection of the rootstock and the grafting technique employed (GINOUX and LATERROT 1991; VURUSKAN and YANMAZ 1991). It is an expensive, time-consuming process for which automation, e.g. a grafting robot (ODA et al. 1997), is required. Rootstock-scion combinations need to be tested in order to optimise crop performance and promote commercial acceptance of the technique. Also, since the rootstock may induce over-vigorous vegetative growth of the scion (ROMANO and PARATORE 2001; BLETSOS 2003), it may be necessary to adopt a different fertilizer programme so as to promote fruiting, for example by increasing the K:N ratio, as suggested by SMITH (1979). With these factors in mind, we examined the effect of grafting a popular eggplant, cv. 'Delica', on four rootstocks during cultivation under two rates of K fertilization.

Materials and Methods

Two experiments were carried out in an unheated, plastic-covered greenhouse at the Agricultural University of Athens over two growth periods: (1) from 14 March to 25 July 2001 (133 days), and (2) from 22 June to 16 October 2001 (116 days). Eggplant, cv. 'Delica', with flask shaped fruit, was grafted on to four different rootstocks at the plant propagation unit of S. Spyrou A.E.B.E. in Thivai, Attiki. The rootstocks consisted of eggplant *(Solanum melongena* L.), cv. '494' and '543', and tomato *(Lycopersicon esculentum* Mill.), cv. '515' and '516', all of which are numbered cultivars with resistance to *Verticillium* wilt, of the seed company S. Spyrou A.E.B.E., Athens. Grafting was carried out using the cleft method of ODA (1995) and plants were maintained at 15 °C (minimum) and 80–85 % r.h. for about one month until transfer to the University at the four-leaf stage.

The experimental design was completely randomised, with treatments comprising the 4 rootstocks plus a non-grafted control x 2 rates of K, replicated 5 times. In experiment 1, 50 plants were planted in non-fumigated soil of the greenhouse on 14 March. Solanaceous crops had not been cultivated in this soil for the previous 5 years. In experiment 2, 150 plants were transferred to an adjacent area of the same greenhouse on 22 June and grown in 11 l plastic pots containing a 1:1 mixture of riverbed sand and commercial peat. This permitted examination of the root system. Marble dust (600 g m^{-3}), to adjust the pH to 7.2, and 150 g m^{-3} of 0 N-46 P-0 K were added to the mixture. Plants were spaced at 30 cm in double rows 50 cm apart with paths of 1 m width, and a single shoot per plant was allowed to develop on vertical cordons. Side shoots were pinched out at an early stage and not included in the measurements. Liquid feeding (0.5 l $plant^{-1}$) was carried out by hand twice per week through harvest in accordance with the desired K rate. The fertilizers applied were NH_4NO_3 and KNO_3 in a ratio of 1:1 N:K (250 mg l^{-1}) and 1:2 N:K (175 mg l^{-1} N and 350 mg l^{-1} K), together with $MgSO_4$ (1:7 Mg:K). The electrical conductivity of the nutrient solutions was 1.75 and 1.69 mS cm^{-1} respectively and the pH 7.4 in both cases. Irrigation, via a drip system with one dripper per plant, was carried out as required and fruit were harvested at commercial maturity. Mean monthly air temperatures varied between 18 and 34 °C (experiment 1) and 28 and 34 °C (experiment 2).

Total plant height, leaf number (experiment 2), the onset of flowering, the height of the first-formed flower on the stem, the number of flowers formed and the percent flower abortion, fruit number and yield were recorded. All fruits were harvested at market maturity. Any immature fruits of unmarketable size remaining on the plants at the end of the experiments were not included in the measurements. In experiment 2, one plant per replicate was removed 10 weeks after planting for the measurement of root mass, while the pots containing the remaining plants were moved as necessary so as to retain the original crop density. Roots were carefully washed free of the substrate, dried superficially at room temperature for 1 day and then weighed.

Random samples of fruit (1 fruit per replicate) from experiment 2 were surface-washed, diced into cubes (1–2 cm), and dried at room temperature, followed by milling and homogenisation. Samples were enclosed in airtight plastic bags and stored at 4 °C for approximately 3 months. The concentrations of K, Ca, Mg, Fe, and Mn were determined by atomic absorption spectrophotometry (Model 932AA, GBC Scientific Equipment, Gilberts, I11.) in an air-acetylene flame following dry ashing of the tissue at 550 °C and extraction with HCl (HANLON 1992). For the Ca and Mg assays, La_2O_3 was added to both the standard and the diluted samples to achieve a concentration of 4500 mg l^{-1} La. Total N was determined by the Kjeldahl method using a DK6 heating digester (Velp Scientifica, Milan, Italy) and a UDK 126 D steam distillation unit (Velp Scientifica, Milan, Italy) (JONES 1991).

Data were evaluated by analysis of variance, and means were compared by the method of Duncan, using a significance level of 5 % (GOMEZ and GOMEZ 1984).

Results

The plants that were grafted on to tomato rootstocks '515' and '516' showed significantly greater vegetative

growth at both levels of fertilizer application, leading to taller, more robust plants than those grafted on to eggplant rootstocks '494' and '543', as well as in relation to the non-grafted control (Table 1). Plants grafted on to tomato rootstock '515' produced a significantly higher number of leaves per plant than in the control or other grafting treatments (experiment 2). Fertilizer level did not significantly affect leaf number, with the exception of plants grafted on to eggplant rootstock '543', where the leaf number was reduced at the higher K level. Root mass, measured 10 weeks after planting in peat and sand, was significantly higher in the tomato rootstocks than in the eggplant rootstocks and non-grafted control, with the exception of '516' at the 1:2 N:K ratio (Table 1). The effect of K rate on both root and vegetative growth was generally not significant, with the exception of '515' and '516' in experiment 2, where the higher K rate caused a reduction in plant height and root growth, respectively.

The length of time from planting until the onset of flowering was less in the second experiment due to the warmer growth conditions during the early stages of plant development. During experiment 1, there was no effect of rootstock on the time to flowering of plants fertilized with N:K at a rate of 1:1, while at the higher K rate (1:2) flowering occurred earlier in the control and '515' than in the other grafted plants. The higher K rate (1:2) significantly decreased the time until flowering of '515' (experiment 1), but increased the time to flowering of '543'. Although the height at which the first flower formed was lower in the control than in the grafted plants, no differences between rootstocks were observed in experiment 1. In experiment 2, the onset of flowering in plants grafted on to rootstocks '494', '543' and '515' occurred earlier than in the control at the 1:1 N:K rate, whereas at the 1:2 rate only '543' differed significantly from the control. In experiment 2, the first flower of eggplant grafted on to tomato rootstocks formed at a significantly greater height than in the non-grafted control, whereas the height of flower formation in the eggplant rootstocks was intermediate between that of the tomato rootstocks and the control. In experiment 2, there was no effect of K rate on the onset of flowering or the height of formation of the first flower (Table 2).

The number of flowers formed per plant varied between 30.6 and 41.2 in experiment 1 (133 days) and between 15.0 and 23.6 in experiment 2 (116 days). Flower

Table 1. Mean total plant height, leaf number, and root weight 10 weeks after planting of grafted and non-grafted eggplant plants.

Grafting treatment	Mean plant height (cm)				Mean leaf number plant^{-1}		Mean root weight (g)	
	Experiment 1		Experiment 2		Experiment 2		Experiment 2	
	N:K level							
	1:1	1:2	1:1	1:2	1:1	1:2	1:1	1:2
Control [z]	106.0 b[x]	106.0 c	171.4 b	145.2 b	33.6 b	28.2 b	86.1 c	97.2 bc
'494' (E)	97.3 b	103.4 c	147.8 bc	144.8 b	43.8 b	32.0 b	84.1 c	84.3 bc
'543' (E)	86.2 b	79.8 d	137.8 c	122.6 b	39.2 b(a)	27.8 b(b)	72.7 c	66.3 c
'515' (T)	134.4 a	132.6 b	229.6 a(a)[y]	192.4 a(b)	65.4 a	48.8 a	222.2 a	226.4 a
'516' (T)	148.2 a	163.0 a	243.8 a	205.8 a	48.6 b	32.6 b	130.2 b(a)	103.4 b(b)

[z]Control = not grafted; E = eggplant, T = tomato.
[x]Means in the same column followed by a different letter differ significantly at P=0.05 by Duncan's test.
[y]Means between two levels of N:K within the same trial followed by a different letter in parenthesis differ significantly at P=0.05.

Table 2. Days from planting until the onset of flowering and the height of formation of the first flower in relation to grafting and N:K rate.

Grafting treatment	Days from planting to flowering				Height of first flower (cm)			
	Experiment 1		Experiment 2		Experiment 1		Experiment 2	
	N:K level							
	1:1	1:2	1:1	1:2	1:1	1:2	1:1	1:2
Control[z]	50.0 a[x]	45.5 b	25.4 a	22.4 a	16.8 b	15.0 b	26.6 c	21.0 d
'494' (E)	53.3 a	54.8 a	20.3 b	23.3 a	27.5 a	28.0 a	31.8 bc	28.8 c
'543' (E)	40.8a(b)[y]	58.0 a(a)	21.0 b	19.0 b	25.6 ab	27.4 a	34.2 b	33.2 bc
'515' (T)	56.8a (a)	46.8 b(b)	20.2 b	21.4 ab	33.6 a(a)	27.6 a(b)	42.8 a	41.8 a
'516' (T)	52.2 a	55.0 a	22.8 ab	20.6 ab	35.4 a(a)	29.6 a(b)	42.8 a	39.4 ab

[z]Control = not grafted; E = eggplant, T = tomato.
[x]Means in the same column followed by a different letter differ significantly at P=0.05 by Duncan's test.
[y]Means between two levels of N:K within the same trial followed by a different letter in parenthesis differ significantly at P=0.05.

number was not significantly affected by rootstock or K level in either experiment. The majority of flowers aborted: 83–92 % in experiment 1, and 77–86 % in experiment 2, irrespective of rootstock and K level. There was no effect of rootstock or fertilizer level on fruit growth period, the average time from flowering until maturity being 25–31 days.

Eggplant grafted on to tomato rootstocks gave a higher total yield than the non-grafted control, to a statistically significant level in the case of '516', whereas the yield of plants grafted on to eggplant rootstocks did not differ from the control (Table 3). The increased yield resulted mainly from an increase in fruit size (mean fruit weight), but in experiment 1 the number of fruit was also significantly higher in plants grafted on to tomato '516'. In experiment 2, the number of fruit produced by '515' and '516' at a N:K rate of 1:1 was significantly higher than that of '494' and '543', but not the control, and at a N:K rate of 1:2 more fruit were produced by '516' than in all the other treatments. K rate did not affect the number of fruit formed, except '515' (experiment 2) where fruit number was reduced at the higher K level. The mean fruit weight of fruits formed on plants grafted on to tomato rootstocks '515' and '516', as well as in the control, was significantly higher at the 1:2 K rate in experiment 1, but K had no effect in experiment 2. Overall, K rate had little effect on total yield, in experiment 1 yield being increased at the higher K rate only in the case of '515', whereas in experiment 2 a decrease was observed in '494' and '515'.

The mineral composition of fruit was not significantly affected by grafting or by K rate. Expressed on a dry weight basis, the mean N, K, Ca and Mg contents averaged over all treatments were 3.60, 2.63, 0.31 and 0.27 % respectively, while Fe and Mn were 22.6 and 15.1 mg kg^{-1} respectively. Apart from variations in size (Table 3), no other macroscopic differences were observed in the morphological characteristics of the fruit in relation to grafting or K rate. There was no incidence of blossom-end rot and all fruit were dark mauve and glossy at the time of harvest.

Table 3. Number and yield of fruit per plant and mean fruit weight in relation to grafting treatment and N:K rate.

Parameter and grafting treatment	Experiment 1		Experiment 2	
	N:K level			
	1:1	1:2	1:1	1:2
Fruit number				
Control[z]	3.3 b[x]	3.0 b	4.0 ab	3.2 bc
'494' (E)	3.0 b	3.2 b	3.0 b	2.3 c
'543' (E)	3.8 ab	2.6 b	3.0 b	3.0 bc
'515' (T)	3.2 b	3.8 ab	4.8 a(a)[y]	3.2 bc(b)
'516' (T)	4.0 a	5.0 a	5.4 a	4.8 a
Yield (g $plant^{-1}$)				
Control	539.8 b	702.4 bc	964.8 bc	674.6 c
'494' (E)	631.8 b	583.0 bc	754.3 c(a)	538.6 c(b)
'543' (E)	525.4 b	405.2 c	485.2 c	433.0 c
'515' (T)	697.2 b(b)	1001.2 ab(a)	1452.4 ab(a)	1029.6 b(b)
'516' (T)	1037.6 a	1396.2 a	1842.3 a	1740.3 a
Mean fruit weight (g)				
Control	166.0 b(b)	226.5 b(a)	242.6 b	212.0 b
'494' (E)	210.6 ab	185.9 bc	256.8 b	191.5 b
'543' (E)	140.3 b	148.2 c	168.3 c	149.6 c
'515' (T)	216.6 ab(b)	261.7 ab(a)	307.7 a	291.5 a
'516' (T)	267.6 a(b)	301.2 a(a)	331.3 a	366.5 a

[z]Control = not grafted; E = eggplant, T = tomato.
[x]Means in the same column followed by a different letter differ significantly at P=0.05 by Duncan's test.
[y]Means between two levels of N:K within the same trial followed by a different letter in parenthesis differ significantly at P=0.05.

Discussion

From the results it is clear that the grafting of eggplant cv. 'Delica' on to tomato rootstocks improved the vegetative growth of the plants in comparison with the non-grafted control, as reflected by the greater plant height and, '515', by a higher leaf number. This resulted in larger fruits and higher yields. By contrast, grafting on to eggplant rootstocks resulted in plants which had growth and yield similar to the control. Although fumigation was not carried out, in both experiments there was no incidence of wilt disease in either the control or the grafted plants. Yield increase of eggplants grafted on to rootstocks of other Solanaceous species (*S. torvum* and *S. sisymbriifolium)* has previously been reported to result from an increase in the number of fruit set per plant (Bletsos 1998), as well as a lower incidence of disease in grafted plants compared with the control (Bletsos 2003; Bletsos et al. 2003). Romano and Paratore (2001) reported no differences in yield between winter-grown eggplants that were not grafted (control), or plants that were self-grafted, or grafted on to interspecific or tomato rootstocks. The differences in yield response observed in this experiment, and those of Romano and Paratore (2001), Bletsos (2003) and Bletsos et al. (2003) may relate to several factors, including the method of grafting, the growth period, and the compatibility of the rootstocks and scions. The high rate of flower abortion of cv. 'Delica' is a common feature of profusely flowering eggplants and is increased during the stages of active growth of previously set fruit (Kader Mohideen et al. 1977; Passam et al. 2001). However, the results of the present experiments indicate that rootstock and K level do not significantly influence either flower formation or flower drop.

Recommended K application rates for field-grown eggplants are 14.6 g m^{-2} K_2O, and increasing K rates above 18 g m^{-2} does not lead to higher yields or better fruit quality (Hochmuth and Cordasco 2004). On the other hand, increasing the ratio of K:N from 1:1 to 2:1 is recommended as a means of reducing excessive vegetative growth in the greenhouse crop (Smith 1979). In the present experiments, although vegetative growth was significantly higher in the plants grafted on to tomato rootstocks, this did not occur at the expense of fruit formation. The positive effect of increased K rate on flowering, yield and mean fruit weight of the spring

crop (experiment 1) is of interest to greenhouse growers who aim mainly at early, more lucrative production, rather than increased overall yield. Harvest in the present trials was restricted to the first 4–5 fruits since it is during early plant development that over-vegetative growth, with concomitant lack of fruit set, can be of particular concern for producers of the out of season crop. The lack of effect of K rate above that required by the plants in the summer crop (trial 2) is in agreement with the findings summarized for field crops by HOCHMUTH and CORDASCO (2004).

The greater vegetative growth of the plants grafted on to tomato rootstocks reflected the larger root system of the tomato rootstock which, with the exception of '516' at a N:K rate of 1:2, was significantly higher than that of the control 10 weeks after planting (Table 1). Although fruit of plants grafted on to tomato rootstocks were larger in size than those of the control or of plants grafted on to eggplant rootstocks, no differences in appearance or mineral composition were observed, indicating that quality was unaffected by the treatments.

We conclude that for the grafting of eggplant for cultivation in a warm climate, such as that prevailing in the Mediterranean basin during spring and summer, a tomato rootstock may be preferable to an eggplant rootstock. In addition, a higher K rate may be beneficial for crops planted early in spring (e.g. as in experiment 1), where growth conditions are cooler. However, for other climatic conditions or grafting techniques, it may be necessary to examine different rootstock-scion combinations and fertilizer rates.

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