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Soilless greenhouse production of table grape under Mediterranean conditions

Donato Buttaro [1], Francesco Serio [2]* and Pietro Santamaria [1]

[1] *Dipartimento di Scienze Agro-Ambientali e Territoriali, University of Bari 'Aldo Moro', Via Amendola 165/A, 70126 Bari, Italy.*
[2] *Institute of Sciences of Food Production, CNR – National Research Council of Italy, Via Amendola 122/O, 70126 Bari, Italy.*
**e-mail: francesco.serio@ispa.cnr.it*

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Abstract

Soilless culture, widely used for vegetables, flowers and ornamental plants, can be an effective technique to grow table grape and to overcome several issues of the current vineyard production system (i.e. to facilitate variety change, no use of rootstock, extra-seasonal production and improved fruit quality). In this research two greenhouse experiments were carried out in Southern Italy, in a typical area for table grape cultivation, to determine the water consumption, vegetative growth, yield, and quality traits of table grapes grown in a soilless system. The first experiment was a simple comparison of two cultivars Cardinal and Victoria, whereas in the second experiment two cultivars ('Black Magic' and 'Victoria') were grown by using four nutrient solutions characterized by different macronutrient concentrations (100% Hoagland solution type *vs* 30%-reduced Hoagland: less N and P, or less N, P, Ca and Mg, or less N, P, K, Ca and Mg). In the first experiment, on average, at harvest the yield was 21.7 t ha^{-1}, with a cluster weight of 419 g and 14.9 °Brix. In the second experiment, yield and cluster weight were, on average, 29.4 t ha^{-1} and 686 g, respectively, and were not affected either by nutrient solution composition or by the cultivar. In both experiments the mean cluster weight and all the organoleptic characteristics were above the European Commission rule n. 2137/2002 limits. These results show that the soilless culture provides table grapes with quality traits completely suitable for international market quality standards, and it is possible to reduce the nutrient concentration of the nutrient solution without negative effects on yield and quality of soilless table grapes.

Key words: Table grape, soilless system, nutrient solution, water consumption, quality, variety turnover, *Phylloxera vastratix*, grafting, sustainable growing systems, cultivar.

Introduction

The world table grape production is about 20 Mt [1]. Italy is the leading producer (6.3%) in Europe, with the production concentrated in the South, mainly in Apulia region (about 65% of the total domestic production) (www.istat.it).

In Southern Italy, the overhead table grape vineyard system ('tendone' training system) is becoming more and more expensive, while its performance is decreasing. Before the establishment of table grape vineyards, farmers commonly adopt a deep tillage practice associated with rock fragmentation by hydraulic hammers and a grinding machinery, but this practice induces significant changes of the soil physical properties, with a great increase in the amount of skeleton and costs about 14,000 € ha^{-1} as found on the VITEN.NET web site (www.viten.net/pdf/236.pdf). The commercial life of a vineyard depends on continued market demand for a specific variety (or varieties), and is influenced by availability of new varieties [2].

In traditional viticultural areas, the presence of phylloxera (*Phylloxera vastratix*) requires the use of grafted vines [3, 4]. Several studies have shown that grafting delays the beginning of vineyard production by one year, and may affect yield and grape quality [5]. Moreover, rootstocks regulate water and mineral absorption, and grafting represents an element of perturbation of the upward and downward transport of the vine sap [6,7].

Soilless culture, widely used for vegetables, flowers, and ornamental plants, could be a good technique for growing table grapes and overcoming several issues of the current table grape production system. Soilless culture improves plant growth, increases crop productivity, and enhances product quality, while reduces human labor and excludes the presence of soil pathogens[8-11]. The application of soilless culture to table grape could: 1) allow the production when there is no soil available at all, or when soil salinity is high or there is an accumulation of soil pathogens; 2) exclude the grafting; 3) enable advanced production of marketable amounts of fruits; 4) facilitate rapid variety turnover and 5) produce high quality table grape [12].

Only few experiments have actually explored the possibility to use such techniques for fruit tree cultivation. In fact, preliminary researches on table grape soilless growing system have been conducted only in Sicily [13] and Apulia [14]. Similar studies have been conducted also on fig trees in Japan [15] and Spain [16].

Considering the need for competitive and more sustainable growing systems for dynamic table grape production, the aim of this study was to test the table grape soilless growing system, evaluating the effects of cultivars and nutrient solutions on water use, yield and quality.

Table 1. N, P, K, Ca, and Mg concentrations of the four nutrient solutions tested in Exp 2.

	N	P	K^+	Ca^{2+}	Mg^{2+}
Nutrient solution (NS)			mM		
NS1 (Hoagland-type)	16.0	2.0	6.0	4.0	1.0
NS2 (Hoagland - 30% N, P, K, Ca, and Mg)	11.2	1.4	4.2	2.8	0.7
NS3 (Hoagland - 30% N and P)	11.2	1.4	6.0	4.0	1.0
NS4 (Hoagland - 30% N, P, Ca, and Mg)	11.2	1.4	6.0	2.8	0.7

Materials and Methods

Experiments and location: Two experiments were carried out under greenhouse conditions on table grape (*Vitis vinifera* L.) soilless culture. The first was carried out at the "La Noria" experimental farm of the Institute of Science of Food Production of the Italian National Research Council (NCR), in Mola di Bari (Bari) to develop and test innovative technology (Exp 1). The second experiment was carried out, by program of agricultural extension, in a commercial table grape vineyard, located in Rutigliano (Bari), in a typical area for growing grapes characterized by serious problems of soil pathogens (Exp 2). A 600 m^2 greenhouse of polyvinylchloride and one of 1000 m^2 in ethylene vinyl-acetate copolymer, respectively, in Exp 1 and Exp 2, were used. Greenhouse ventilation was controlled by lateral and upper openings; the ventilation temperature was of 28°C. Exp 1 was conducted in 2009 on two cultivars ('Cardinal' and 'Victoria'). Exp 2 was conducted in 2010 by comparing two cultivars ('Black Magic' and 'Victoria') and four nutrient solutions characterized by different macronutrient concentrations (Table 1).

Plant material and propagation: On February 2009, virus free grapevine scion cuttings were taken from the germplasm repository of the Research and Experimentation in Agriculture Center 'Basile Caramia' (Palagiano, Taranto) and propagated in the greenhouse of the "La Noria" experimental farm (Fig. 1): two-bud cuttings were rooted in 0.4 L containers filled with peat moistened only with water throughout the whole rooting phase. One month later, the rooted cuttings were transplanted into pots (10 L), filled with 2:1 (v:v) perlite:peat, and placed outside the greenhouse for the entire training phase, which lasted eleven months (Fig. 1).

During such phase, by means of a drip irrigation system with one pressure auto-compensating emitter (10 L h^{-1}) per pot, vines were fertigated with a nutrient solution (NS) maintaining a drainage solution level of about 20% of the total NS volume applied. The NS contained (mM) 16 N, 2 P, 6 K^+, 4 Ca^{2+}, and 1 Mg^{2+} as macronutrients, whereas micronutrients were supplied according to Johnson *et al.* [17]. The NS pH was adjusted to 5.5–6.0 using 1 M H_2SO_4.

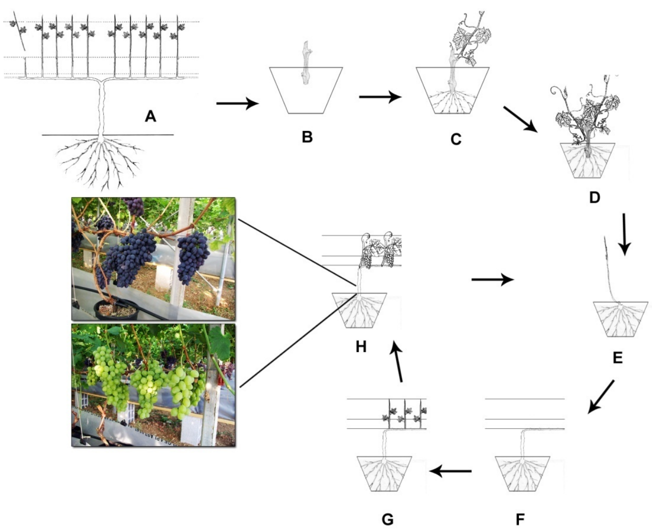

Figure 1. Diagram of the soilless table grape cultivation cycle from propagation by bi-nodal scion cuttings to the fruit production.

Foot note: (A) Cuttings of *Vitis vinifera* L. from field vines (February), (B) planting of cuttings (February), (C) beginning budding and rooting of cuttings (March-April), (D) growth of the rooted scions in pots (May-July), (E) pruning of the vines (November-February), (F) tying the canes to the wires (February-March), (G) bud break (March), (H) grape ripening (July). A, D, E in open air, B, C, F, G, H in greenhouse.

Crop cycle and experimental conditions: On 26th February of 2009 for Exp 1 and on 1st March of 2010 in Exp 2, vines were pruned, leaving only one cane (about 1.30 m from the collar), and then transferred into the greenhouse for the productive cycle. In both experiments, vines were grown using an 'tendone' training system (Fig. 1) and placed on a drain line with slope of 1%, covered by polyethylene film. Potted vines were placed on troughs spaced 1.20 m apart, with 0.75 m spacing between vines within the row in Exp 1. In Exp 2 vines were placed at a distance of 0.60 m within the row and 1.80 m between troughs. During the production cycle of Exp 1, vines were nourished with NS similar to that used during the training phase, previously described. Volumes of consumed NS, EC, and pH of the drained NS were checked and recorded three times per week. An integrated crop protection and management approach was used to control all major diseases and pests. However, in both experiments, diseases and pests control was limited to two applications of penconazole, for powdery mildew control (before and after grape flowering), and the sexual confusion technique, pheromones-based, to control *Lobesia botrana*. At the end of the cycle, in the second half of October, the potted vines were pruned at one cane and moved outside the greenhouse for the dormancy phase (Fig. 1).

Measurements: In both experiments, NS mean consumption was measured as difference between the volume of NS applied and the volume of NS drained (collected in a 90 L tank situated at the end of each drain line). Harvest was performed on 10th July 2009 for both cultivars in Exp 1 and on 21th and 26th July 2010, respectively, for 'Black Magic' and 'Victoria' in Exp 2, according to the marketing standard for table grapes set by the European Commission Regulation n. 2137/2002. Average fruit yield was obtained by measuring individual yield of all vines within each experimental unit, excluding the guard vines placed at the end of each trough. Water use efficiency (WUE) was calculated as the ratio of total fresh weight of fruits to the total volume of consumed NS by the vine. Fruit and berry mean weight, berry dry weight (DW), total soluble solids (TSS), titratable acidity (TA), and TSS TA^{-1} ratio were measured on five clusters randomly sampled within each experimental unit. TSS content was evaluated using a portable reflectometer (Brix-Stix BX 100 Hs, Techniquip Corporation, Livermore, CA). TA was determined by titrating 10 mL of juice with 0.1 M NaOH to pH 8.1 in the presence of phenolphthalein till the change in color using an automatic titrator machine (Technotrate, Kartell, Italy); results were expressed as g L^{-1} of tartaric acid in the juice [18]. Berries were dried until constant weight in a forced-draft oven at 65°C for the determination of the DW expressed in g kg^{-1} of fresh weight.

Experimental design and statistical analysis: A randomized block design with three replicates was used in both experiments. Two guard troughs were placed at both sides of the experimental area; each experimental unit consisted of eight vines. Analysis of variance was conducted using the GLM procedure of SAS (version 9.1; SAS Institute, Cary, NC) considering all experimental factors as fixed [19].

Results and Discussion

Daily mean temperature recorded inside the greenhouse increased progressively from the beginning to the end of the productive cycle in both experiments (Fig. 2) and varied within a range of values considered optimal for table grape cultivation [7].

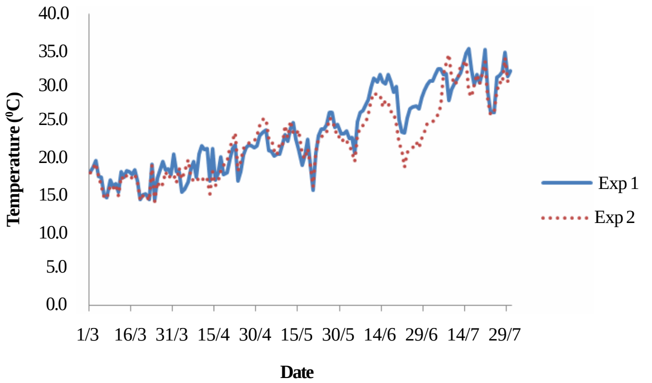

Figure 2. Daily mean temperatures recorded inside the greenhouses during Exp 1 (experimental farm, 2009) and Exp 2 (commercial farm, 2010).

In Exp 1, on average, yield was 1.95 kg $vine^{-1}$, with a cluster weight of 419 g (Table 2), and a berry weight of 10.6 g. On average, TSS was 14.9 °Brix, TA was 3.9 g L^{-1} and DW was 160 g kg^{-1} (Table 2).

In Exp 2, mean yield and cluster weight 3.18 kg $vine^{-1}$ and 686 g, respectively, were not affected either by NS or by the cultivars; mean berry weight of 'Victoria' was double that of the cultivar 'Black Magic' (11.0 g *vs.* 5.5 g, respectively). 'Black Magic' showed values of TSS, TA, and DW higher than 'Victoria', 1.6 °Brix, 25%, and 30%, respectively (Table 3). The mean commercial yield obtained in Exp 1 (21.7 t ha^{-1}) or in Exp 2 (29.4 t ha^{-1}) was completely comparable to that achievable using the same cultivars and the traditional cultivation system [20].

Table grape organoleptic quality is defined by several parameters, among which the most important are considered by the European Commission rule n. 2137/2002 as minimum standards for table grape marketability: 1) TSS $\geq$ 12 °Brix for early cultivars; 2) cluster weight of 300, 250, and 150 g for grapes of the classes extra, I, and II, respectively. In both experiments the mean cluster weight and the organoleptic characteristics were above the mentioned limits.

Consumer acceptability of fruits is highly dependent on TSS and TA concentration [21, 22]. Crisosto and Crisosto [23] found a high correlation between consumer acceptance and TSS TA^{-1} ratio on 'Red globe' table grapes, but within a certain range of acidity or sugar contents. Jayasena and Cameron [18] found the best time to harvest 'Crimson Seedless' table grape is when berries attain a TSS TA^{-1} ratio of 3.5-4.0. In our study the TSS TA^{-1} ratio was, on average, 3.9 in Exp 1 and 3.6 in Exp 2. However, this value can be considered good for consumer acceptability only in Exp 1, whereas in Exp 2 the TSS TA^{-1} ratio of 'Victoria' was distorted by the low

Table 2. Yield, cluster weight, water use efficiency (WUE), total soluble solids (TSS), titratable acidity (TA),and berry dry weight (DW) of table grape grown in soilless culture (Exp 1).

Cultivar	Total fruit yield (kg $vine^{-1}$)	Mean cluster weight (g)	WUE (g L^{-1})	TSS (°Brix)	TA (g L^{-1} tartaric acid)	DW (g kg^{-1})
Cardinal	1.77	381	15.5	15.9	4.1	170
Victoria	2.13	456	20.7	14.0	3.7	150
Significance[1]	ns	ns	*	ns	ns	ns

[1]: ns and * = not significant or significant at P≤0.05, respectively.

Table 3. Yield, cluster weight, water use efficiency (WUE), total soluble solids (TSS), titratable acidity (TA), and berry dry weight (DW) of table grape grown in soilless culture (Exp 2).

Treatment	Total fruit yield (kg $vine^{-1}$)	Mean cluster weight (g)	WUE (g L^{-1})	TSS (°Brix)	TA (g L^{-1} tartaric acid)	DW (g kg^{-1})
Nutrient solution						
NS1	3.34	645	19.8	12.7	3.7	127
NS2	3.06	841	18.1	12.9	3.3	132
NS3	3.27	658	19.3	13.4	3.8	132
NS4	3.04	601	18.0	12.3	3.6	119
Cultivar						
Black magic	3.15	634	18.6	13.6	4.0	144
Victoria	3.20	738	18.9	12.0	3.2	111
Significance [1]						
Nutrient solution (NS)	ns	ns	ns	ns	ns	ns
Cultivar (cv)	ns	ns	ns	*	*	**
NS x cv	ns	ns	ns	ns	ns	ns

[1] ns, *, and ** not significant or significant at P≤0.05 or ≤0.01, respectively.

values of TA and TSS contents (Table 3).

The results obtained in Exp 2 suggest the need for further investigations either on the effects of a greater reduction of nutritive elements in the NS and water and/or osmotic stress on the vegetative/reproductive growth equilibrium. According to Rolle *et al.* [24], TSS, TA and sugar-acid balance in the table grape are important quality criteria for consumer acceptability, but non-suitable to define an universally valid table-grape quality standard. In Exp 1, the water consumption during the production cycle was 114 L vine^{-1} for 'Cardinal' and 103 L vine^{-1} for 'Victoria' (corresponding to 1,267 and 1,144 m^3 ha^{-1}), respectively; while in Exp 2, water consumption was 169 L vine^{-1} and not affected either by nutrient solution composition or the cultivar and corresponding, on average, to 1,565 m^3 ha^{-1} of water consumption. WUE during the first production cycle was lower for 'Cardinal' than for 'Victoria' (Table 2), while in Exp 2 WUE was not affected either by nutrient solution composition or the cultivar (Table 3). These results show that the soilless culture may allow water savings compared to the field based cultivation system, in which water consumption ranges from about 1,600-1,800 m^3 ha^{-1}, in medium-early maturation cultivars, to 2,000-2,300 m^3 ha^{-1}, in late cultivars [25]. Such results represent an important advantage of table grape soilless culture, considering that water is becoming an economic scarce resource in many areas of the world, especially in arid and semi-arid regions, such as the Mediterranean area [26], and considering that the WUE of table grape soilless culture could be further improved by using a closed soilless growing system [11].

Another aspect, particularly important for the fruit quality and environmental sustainability of the crop, is represented by the very low need for agri-chemicals application recorded in the table grape soilless growing system as compared to the table grape traditional production system. In fact, according to the local cultivation practices, the production of table grape following the regional pest integrated management rules, usually requires from at least one insecticide application and the use of the sexual confusion method, or at worst, four-five insecticide treatments for the control of *Lobesia botrana*, and two or three applications for the control of thrips. It also requires five or six applications for powdery mildew control and at least two applications for the control of downy mildew. In both our experimental and commercial table grape soilless growing systems, *Lobesia botrana* was controlled organically using the sexual confusion method, whereas only two fungicide applications (before and after flowering) were needed for powdery mildew control.

Conclusions

The results obtained from soilless table grape cultivation experiments allow us to draw the following considerations: i) using pathogen free propagated material in soilless culture, self-rooted vines provide good yields, without the need to use rootstocks resistant to phylloxera, one year after the propagation; ii) soilless culture provides table grape with quality traits suitable for the European and international market quality standards; iii) vines may be repeatedly used in soilless growing systems, occupying the greenhouse less than five months per year; iv) the water consumption in table grape soilless culture is lower than in the traditional table grape soil production system; v) it is possible to reduce by 30% the nutrient concentration of the base (i.e. Hoagland) NS without negative effects on yield or quality of table grapes. However, further investigation are needed to verify the true economic potential of this technique.

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