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Spring-summer tomato yield as a function of potassium fertilization in field and protected crops

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Off-season tomatoes produced in Southeast Brazil in Spring-Summer crops are highly valued, but crop yield is limited by high rainfall and temperatures. To overcome this situation and make off-season tomato crops more profitable, they can be grown under controlled conditions in protected cultivation systems. In addition, tomato yield and quality can be improved by adequate levels of potassium (K) fertilization. The present study evaluated the off-season (Spring-Summer) yield of tomato crops grown in the field or in protected systems (hydroponics and fertigation) using different levels of K application. Tomato plants (hybrid Saladinha) were simultaneously grown under the 3 systems from September 2005 to February 2006 (2005 off-season) and from July to November 2006 (2006 off-season) in Seropédica, RJ, Brazil. In 2005, four nitrogen:potassium (N:K) ratios were tested, and in 2006 two levels of K supply were evaluated. In 2005, marketable fruit yield was lower in the field and similar in the hydroponics and fertigation systems, without consistent effects of N:K ratios on tomato yield. In 2006, when a higher level of fruit yield was achieved, the hydroponic system yielded more marketable tomatoes than fertigation and field systems. In 2006, the higher K level stimulated the shoot growth in the three systems and increased by 11% the marketable fruit yield in the average of the three systems, indicating that increased K supplies are required to improve tomato growth and yield in protected crops.

Key words: *Solanum lycopersicum*, protected cultivation, fruit quality, fertilization.

INTRODUCTION

In the Southeast and South Regions of Brazil, market prices of tomatoes usually increase during summer owing to reduced cultivation in farming areas. Off-season Spring-Summer field tomato cropping in these regions is limited by high temperatures, sunlight exposure and rainfall rates, which promote physiological disturbances, pest attacks and diseases, thereby reducing fruit yield and quality (Peixoto et al., 1999). High temperatures in particular decrease respiration rates and net photosynthesis of tomato plants, reduce pollination rate and cause flower abortion (Antoniolli and Castro, 2008). They also compromise fruit growth rate and ripening

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homogeneity (Adams et al., 2001).

Tomato growth under protected cropping systems, in turn, allows the control of environmental factors (solar radiation, rainfall, wind and relative air humidity), pests and diseases (Caliman et al., 2005). Therefore, this technique improves tomato yield when local or seasonal conditions are unfavorable. Protected cropping may also increase tomato yield to two crops a year, yielding fruits with high market value in off-season periods (Valandro et al., 2007). Protected cropping systems such as hydroponics and fertigation can provide important benefits to crops. The efficient fertilizer application promoted by these systems minimizes crop losses and ensures adequate nutrient balance at each stage of plant development (Fernandes et al., 2002; Hebbar et al., 2004; Fontes et al., 2005; Soares et al., 2005).

Potassium (K) is the main nutrient absorbed by tomato plants, in both field and protected crops (Fayad et al., 2002), particularly during plant reproduction and fruit development (Fontes et al., 2000b; Kanai et al., 2007). Since K limits photosynthesis and the transport of photoassimilates to fruits, its deficiency reduces their number and size due to an imbalance in the source-sink relationship (Kanai et al., 2007).

An adequate K supply also attenuates the severity of plant diseases because it plays an important role in plant resistance (Walters and Bingham, 2007), metabolism regulation by enzyme activation and processes such as stoma regulation, carbohydrate transport and respiration (Shimazaki et al., 2007; Soetan et al., 2010; Montoya et al., 2012). Potassium can be provided as a function of N supply and plant stage (N:K ratio of 1:1 for plant growth, 1:2 in blooming and 1:3 in fruit development) to improve tomato quality (Fernandes et al., 2002; Alvarenga et al., 2004; Soares et al., 2005; Passam et al., 2007).

Given the role of K in plant development, an adequate supply of this nutrient can maintain adequate photosynthesis rates under high-temperature conditions, enhancing off-season production of high-quality fruits. Accordingly, the present study evaluated the growth and yield of tomato plants cropped under field, hydroponic and fertigation systems combined with crop fertilization at different N:K ratios during the Spring-Summer, in Rio de Janeiro state.

MATERIALS AND METHODS

Growth conditions

Experiments on tomato growth under field, hydroponic and fertigation systems were carried out simultaneously from September 2005 to February 2006 (2005 off-season) and between July and November 2006 (2006 off-season), at the Federal Rural University of Rio de Janeiro, Seropédica, (22°45' S, 43°41' W), in the Lowland Metropolitan region of the Rio de Janeiro State, Brazil. Climate in the area corresponds to Köppen classification Aw, with hot and rainy summers and dry winters.

The tomato hybrid tested was Saladinha F_1, from the Sakata Seeds Company (Sakata Seeds, Brazil). It exhibits a determinate growth habit, 110-day cycle, and produces fruits with 200 g fresh matter. Seeds were germinated in a dark chamber and seedlings were grown in a foam tray under greenhouse conditions and supplied with Hoagland solution (Hoagland and Arnon, 1950) diluted to ¼ until 15 days after planting. At 35 days after sowing, the seedlings were transplanted to the respective crop systems. The greenhouse used for seedling production and protected cropping was arch-shaped, with 3.5 m headroom and 4.7 m span. Its ceiling and walls were covered with plastic film and anti-aphid screen.

Hydroponic system

In the hydroponic cropping system, 4 fertilization treatments were tested in the 2005 off-season, combining two levels of Hoagland's solution (50 and 75% ionic strength) and two N:K ratios (1:1.5 and 1:2) in a random block design with 3 replicates. In the 2006 off-season, treatments consisted of two N:K ratios (1:1.5 and 1:2) and Hoagland's solution at 50% ionic strength, with 4 replicates. The N:K ratios tested were achieved by adjusting calcium nitrate, potassium nitrate, calcium chloride and potassium chloride levels.

The nutrient film technique (NFT) hydroponic system was used. To that end, 12 propylene gullies (75 mm wide and 10 m long) were used, and double planting rows arranged 0.6 m apart, 0.5 m between plants, 1.0 m inter-double rows, 16 plants per line and 4% slope. The nutritive solutions were applied at 15 min intervals, at a 4 L/min flow in each gully. The nutritive solutions were monitored every 15 days by electrical conductivity and pH measurement and then renewed.

Fertigation system

In the fertigation system set up in the 2005 off-season, four N:K ratios were tested (200:300, 200:400, 300:450 and 300:600 kg/ha) in a randomized block design with 3 replicates. In the 2006 off-season, two N:K levels (200:300 and 200:400 kg/ha) were tested with 3 replicates. The fertigation technique was used to apply an amount equivalent to 100 kg P, 1,500 kg Ca and 175 kg Mg per hectare. The nutrient levels (in kg/ha) were calculated per plant, considering the plant density in the greenhouse. Micronutrient fertilization consisted of a stock solution containing 1.92 mg manganese sulfate, 0.23 zinc sulfate, 2.94 boric acid, 0.15 copper sulfate, 0.03 sodium molybdate and 10.50 FeEDDHA (6%) per liter (Alvarenga et al., 2004).

The plants were placed in 8 L polypropylene pots filled with coconut fiber and watered by drip irrigation according to Carrijo et al. (2002). Twelve crop lines were planted in double rows 0.6 m apart, 0.5 m between the pots and 1.0 m inter-double rows. The nutrients were distributed weekly by fertigation, and irrigation was controlled by tensiometers. The N:K fertilization applied (in percent value) was 20:25 at 10 DAT (days after transplanting), 25:25 at 40 DAT, 30:30 at 45 DAT and 25:20 at 70 DAT, according to Alvarenga et al. (2004).

In the 2006 off-season, a stock solution with twice the normal amount of boron, that is, 5.88 mg/L of boric acid, was applied. This was provided because of the high occurrence of open holes (locules) in the 2005 off-season in both hydroponic and fertigation systems.

Field system

In the field system, four N:K ratios (100:150, 100:200, 150:200 and

150:250 kg/ha) were tested in the 2005 off-season in a randomized block design with three replicates. In the 2006 off-season, two N:K levels (150: 225 and 150: 300 kg/ha) were tested in experimental plots in a randomized block design with four replicates. The crop field area was covered by *Argissolo Vermelho Amarelo* (Typic Ultisol). The chemical characteristics of soil were determined in samples collected in the 0-20 cm layer, according to Embrapa (1997). Before the experimental treatments, the soil exhibited water pH 5.3 and contained 2.4 $cmol_c/dm^3$ of Ca, 1.5 $cmol_c/dm^3$ of Mg, 0.2 $cmol_c/dm^3$ of Al, 2.3 mg/kg of available P and 92 mg/kg of available K. In the 2005 off-season, soil received 2.2 tons/ha of dolomite lime to increase Ca+Mg levels to 6.0 $cmol_c/dm^3$. This was performed to homogenize the study area, which contained 5.6 $cmol_c/dm^3$ of Ca+Mg. In the 2005 and 2006 off-seasons, 15 tons/ha of aged cattle manure (0.9% of N, 0.3% of P and 0.8% of K) were applied in the total area along with 50 kg/ha of P as simple superphosphate, 5 kg/ha of zinc sulfate, 10 kg/ha of borax, 10 kg/ha of copper sulfate and 0.25 kg/ha of sodium molybdate, as recommended by Almeida et al. (1988). The N and K levels, in the form of urea and potassium chloride, were equally divided into three applications, the first at planting and then at 35 and 70 DAT.

The experimental plots measured 3 × 1.2 m in 2005 and 6 × 1.2 m in 2006, with 0.6 m between plots, 0.5 m between rows and 0.5 m between plants. In the 2005 off-season, each plot contained 8 plants and in 2006 each plot held 36 plants. Plant density was increased in 2006 in order to evaluate dry matter accumulation throughout the crop cycle. Irrigation was performed by dripping, with water potential kept near -0.03 MPa.

Tomato plant growth

In all cultivation systems, tomato plants were staked to maintain upright growth and axillary buds were trimmed weekly. No more than 7 bunches were maintained in each plant. When necessary, the pests *Frankliniella schulzei, Liriomyza huidobrensis*, *Bemisia* spp., *Aculops lycopersici*, *Myzus persicae*, *Neoleucinodes elegantalis* and *Hecoverpa zea*, and of the pathogens *Alternaria solani, Septoria lycopersici, Cladosporium fulvum, Phytopthora infestans* and *Pectobacterium* spp. were chemically controlled, as recommended by Feitosa and Cruz (2003). Temperature and relative air humidity in protected and field systems were recorded daily at 9:00 and 15:00 h, using a maximum/minimum analog thermometer and thermo-hygrometer. In the 2005 off-season, the average maximum temperatures were 33.3°C in the greenhouse and 34.7°C in the field. However, during the hottest experimental period between 84 and 113 DAT, the difference between the environments were wider, with maximum temperatures 3.0°C higher in the field. Average minimum temperatures reached 22.4°C in the protected environment and 21.8°C in the field. Average relative air humidity was 74% in the greenhouse and 67% in the field. In the 2006 off-season, average maximum temperature was 35.1°C in the greenhouse and 32.2°C in the field, but these higher maximum temperatures in protected system occurred mainly during the initial growth season in cooler months. The average minimum temperature was 19.5 in the greenhouse and 19.3°C in the field. Average air humidity in 2006 was 66% in the greenhouse and 72% in the field.

Tomato sampling and analysis

In the 2005 and 2006 off-seasons, fruits that were physiologically mature (Cá et al., 2006) were harvested weekly from the 8 plants located in the middle of each plot. They were used for fresh matter determination and measurement of the transversal diameter. They were also used to detect the occurrence of lesions caused by biotic and abiotic agents, which were indicators of non-commercial fruits (cull). Six fruits from the second and third bunches were sampled for determination of total soluble solids (°Brix) and titratable acidity of the pulp (Fontes et al., 2000a).

Only in the 2006 off-season 2 tomato plants were collected in each plot at different ages to evaluate dry matter accumulation throughout crop development. As such, plants were sampled 15, 30, 45, 60, 75 and 90 days after transplant (DAT) in all the systems. Because biotic and abiotic factors in hydroponics and fertigation allowed longer plant development, plants in these systems were also collected at 105 DAT. The plants collected were cut close to the ground and their shoots separated into leaves (petiole + leaf blade), stem, inflorescence and fruits. Each plant part was dried in an air circulation oven at 70°C for 72 h to determine dry matter mass.

Absolute growth rate was estimated in the 2006 off-season, using the functional approach for plant growth analysis (Hunt, 1982). The Gompertz model was fitted to raw shoot dry matter data by the Marquadt algorithm, which is an iterative technique (SAEG package, Artur Bernardes Foundation, Federal University of Viçosa). This asymptoptic model (Hunt, 1982) describes the development of tomato plants that do not exhibit significant senescence throughout the crop cycle. Absolute growth rate was obtained from the first derivative of the Gompertz function, according to the following equations (Hunt, 1982): $W = ae^{-be^{-cT}}$; and $\mathrm{AGR} = \mathrm{abce}^{-\mathrm{cT}}\mathrm{e}^{-\mathrm{be}^{-\mathrm{cT}}}$. The first equation represents the Gompertz model and the second equation the absolute growth rate; a, b and c are coefficients adjusted for regression, and T is time in DAT.

Data analysis

Data on tomato yield and quality obtained in 2005 and 2006 were evaluated by a single factor analysis of variance (ANOVA), which was applied to each crop system and season in order to evaluate the effects of different fertilization levels. The three crop systems were also compared in each off-season, consisting of a bifactorial ANOVA combination between the systems and fertilization levels (considered as subplots). Means of the treatments and systems were compared using the Duncan test at a significance level of 0.05. Since the variance of shoot dry data matter obtained in 2006 was very heterogeneous between the plant ages, data were ln-transformed before being subjected to ANOVA. Thus, the ANOVA was conducted in each crop system, considering a factorial scheme between K levels and plant age, to detect the effect of K levels on plant growth (Araújo, 2003).

RESULTS

In the 2005 off-season, total yield of the tomato hybrid Saladinha was higher in protected crops (hydroponics and fertigation) than in the field (Table 1), with the highest yield of marketable fruits obtained with fertigation. In the field, fewer fruits (marketable fruits + cull) were produced, but the marketable fruits showed a higher fresh matter content per unit.

In the 2006 off-season, total and marketable fruit yield and total number of fruits were higher in the hydroponic

Table 1. Mean production and quality of tomatoes under hydroponic, fertigation and field systems in 2005 and 2006 off-seasons.

Parameter	2005 off-season			2006 off-season		
	Hydroponics	Fertigation	Field	Hydroponics	Fertigation	Field
Marketable yield (g plant^{-1})	607 ^{b}	923 ^{a}	744 ^{ab}	3038 ^{a}	978 ^{c}	1657 ^{b}
Cull yield (g plant^{-1})	1417 ^{a}	1104 ^{a}	657 ^{b}	628 ^{b}	347 ^{c}	1065 ^{a}
Total yield (g plant^{-1})	2024 ^{a}	2026 ^{a}	1344 ^{b}	3665 ^{a}	1325 ^{c}	2723 ^{b}
Marketable number (fruit plant^{-1})	12.3 ^{a}	15.2 ^{a}	7.6 ^{b}	23.8 ^{a}	11.2 ^{b}	10.1 ^{b}
Cull number (fruit plant^{-1})	22.3 ^{a}	20.5 ^{a}	5.4 ^{b}	5.3 ^{ab}	5.1 ^{b}	7.8 ^{a}
Total number (fruit plant^{-1})	34.5 ^{a}	35.6 ^{a}	12.4 ^{b}	29.1 ^{a}	16.2 ^{b}	17.9 ^{b}
Marketable diameter (mm)	47 ^{a}	50 ^{a}	51 ^{a}	60 ^{b}	52 ^{c}	67 ^{a}
Marketable fresh matter (g fruit^{-1})	50 ^{c}	61 ^{b}	101 ^{a}	130 ^{b}	87 ^{c}	160 ^{a}
Total soluble solids (^{o}Brix)	5.9 ^{a}	5.1 ^{b}	5.2 ^{b}	4.7 ^{ab}	4.9 ^{a}	4.5 ^{b}
Titratable acidity (%)	0.21 ^{b}	0.26 ^{a}	0.21 ^{b}	0.30 ^{b}	0.37 ^{a}	0.37 ^{a}

For the 2005 season, means corresponded to 4 treatments combining different N:K ratios (N=3); for the 2006 season, they corresponded to 2 N:K ratios (N=4). Values followed by a same superscript in a row and relative to a same year are not statistically different (Duncan test, P<0.05).

system, whereas plants under fertigation produced a lower number of total and marketable fruits. Marketable fruits from the field system exhibited the highest diameter and fresh matter content per unit (Table 1)

In the 2005 off-season, the content of total soluble solids (^{o}Brix) in the fruits was higher in the hydroponic system, and titratable acidity was higher in plants under fertigation (Table 1). In 2006, the lowest levels of total soluble solids were detected in fruits grown in the field, and the lowest titratable acidity was found in fruits from the hydroponic system (Table 1). Shoot dry matter of tomato plants, evaluated only in the 2006 off-season, was affected by the interaction between K levels and transplant age in hydroponic and field systems and by K levels in the fertigation system (as indicated by ANOVA of ln-transformed data, P<0.05). In the hydroponic system, plants receiving a N:K ratio of 1:2 exhibited higher dry matter production and absolute growth rate in the last development stages (Figure 1). In the fertigation system, higher shoot dry matter production and absolute growth rate throughout the cycle was obtained using a K level of 400 kg/ha (Figure 1). In the field, shoot dry matter at 60 and 90 DAT was higher in treatments receiving 300 kg/ha of K than in those receiving 225 kg/ha, resulting in a higher growth rate of the former in the last development stages (Figure 1). Therefore, tomato plant growth was higher in treatments using the highest K levels, irrespective of the crop system (Figure 1). In addition, shoot growth was higher in the hydroponic system, intermediary in the field and lower in the fertigation system (Figure 1).

In the 2005 off-season, marketable fruit yield was lower in the hydroponic system using a 1:2 N:K ratio, with both 50% and 75% ionic strength, but the levels of fertilization did not affect the average diameter of marketable fruits (Table 2). In fertigation, the highest yield of marketable fruits was obtained using N:K levels of 200:300 and 200:400 kg/ha. In the field crop, the highest diameter of marketable fruit was obtained using 100 kg/ha of N and 200 kg/ha of K, with no significant effect of fertilization treatments on the production of marketable fruits (Table 2). In the 2006 off-season, marketable fruit yield was not affected by K levels in each of the three cultivation system (Table 2). However, considering the average of the three cropping system, the production of marketable fruits treated with the higher K level was 11% greater than those treated with the lower K level (Table 2). The occurrence of “open holes” was very high in 2005 (Figure 2), and culled fruits accounted for 64% of total fruits in hydroponics, 56% in fertigation and 42% in the field system (Figure 2). In the fertigation system, 22% of fruits exhibited blossom-end rot in both off-seasons (Figure 2 and Table 1). In both off-season crops, culled fruits were produced primarily by fruit borer (*Neoleucinodes elegantalis*) attack (Figure 2). In 2006, other defects such as cracks and sunscald occurred in 9% of the fruits cropped in the field (Figure 2). In the protected cropping systems, maximum temperatures were kept at adequate levels and fruit borer control was higher than in the field system (Figure 2).

DISCUSSION

Maximum temperatures in the 2005 and 2006 off-seasons were quite elevated, an usual pattern during Spring-Summer in Southeast region of Brazil. High temperatures may compromise tomato production, especially in the last maturation stages (Adams et al., 2001), as observed in the 2005 off-season particularly in

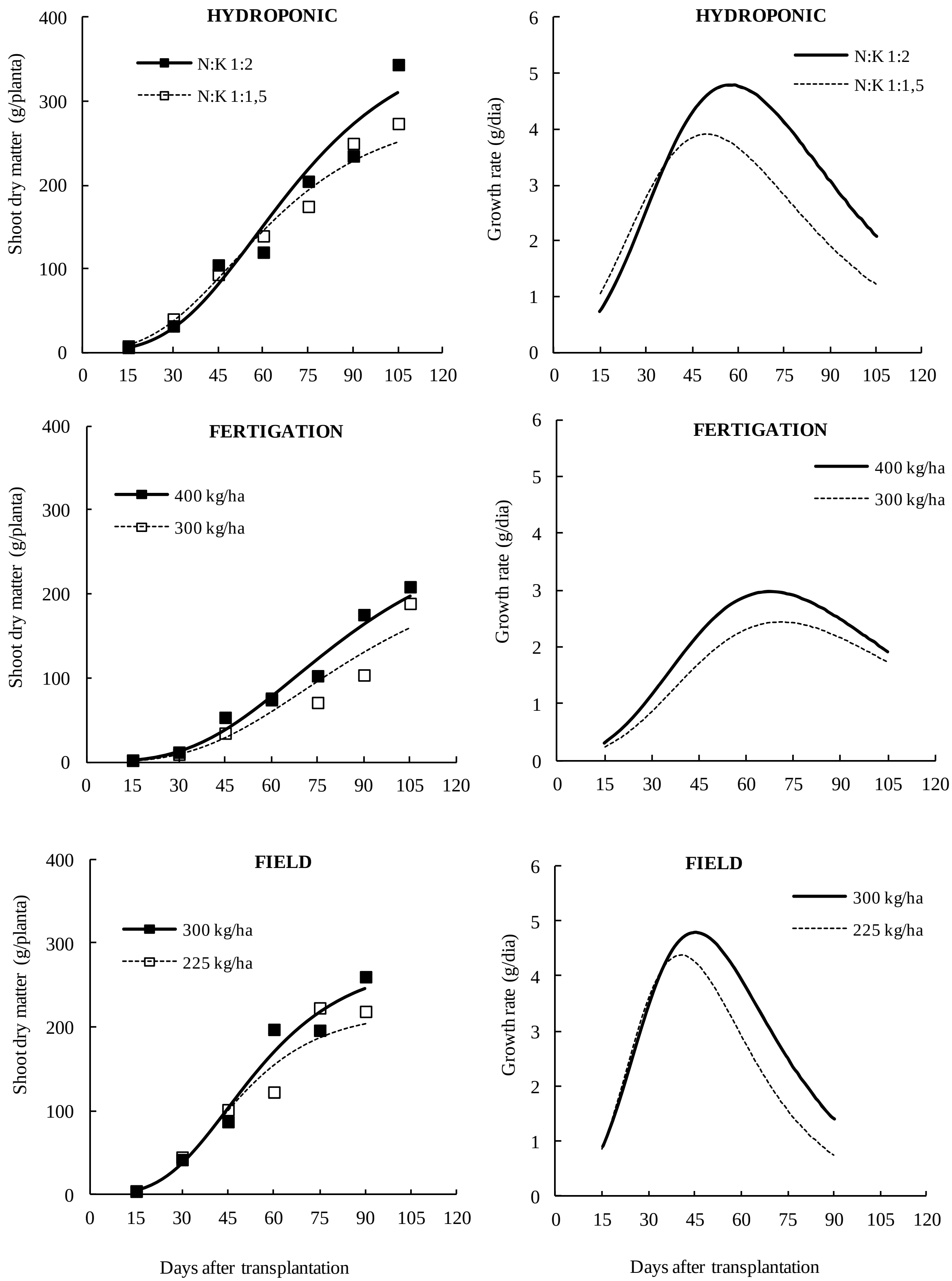

Figure 1. Shoot dry matter and absolute growth rate of tomato plants in the 2006 off-season, under hydroponic, fertigation and field systems. Two N:K ratios were evaluated in the hydroponic system and two K levels in fertigation and field systems. Squares represent experimental means, and lines correspond to the Gompertz model fitted to raw data.

Table 2. Marketable tomato yield and diameter under hydroponic, fertigation and field cultivation systems in 2005 and 2006 off-seasons, at different levels of N and K supplies.

Cropping systems and fertilization	Yield (g/plant)	Diameter (mm)
2005 off-season		
Hydroponics		
50% ionic strength, 1:1.5 N:K ratio	701 [a]	50 [a]
50% ionic strength, 1:2 N:K	525 [ab]	46 [a]
75% ionic strength, 1:1.5 N:K ratio	754 [a]	46 [a]
75% ionic strength, 1:2 N:K ratio	448 [b]	46 [a]
Fertigation		
200:300 N:K (in kg/ha)	1132 [a]	51 [a]
200:400 N:K (in kg/ha)	1110 [a]	51 [a]
300:450 N:K (in kg/ha)	873 [ab]	49 [a]
300:600 N:K (in kg/ha)	575 [b]	50 [a]
Field		
100:150 N:K (in kg/ha)	955 [a]	40 [b]
100:200 N:K (in kg/ha)	683 [a]	59 [a]
150:200 N:K (in kg/ha)	658 [a]	49 [ab]
150:250 N:K (in kg/ha)	681 [a]	55 [ab]
2006 off-season		
Hydroponics		
50% ionic strength, 1:1.5 N:K ratio	2912 [a]	61 [a]
50% ionic strength, 1:2 N:K ratio	3164 [a]	59 [a]
Fertigation		
200:300 N:K (in kg/ha)	898 [a]	51 [a]
200:400 N:K (in kg/ha)	1059 [a]	53 [a]
Field		
150:225 N:K (in kg/ha)	1569 [a]	66 [a]
150:300 N:K (in kg/ha)	1746 [a]	68 [a]
Mean of the three systems		
Lowest K level	1793 [b]	59 [a]
Highest K level	1990 [a]	60 [a]

Values followed by a same superscript in a column and within a cropping system are not statistically different (Duncan test, $P<0.05$).

the field. However, in 2006 the high temperatures recorded in the protected crop during cooler months at the beginning of the experiment are likely to contribute for increasing yields in hydroponic and fertigation systems as compared to the field (Table 1). These results indicate that tomato off-season crops in protected environments in Southeast Brazil must be planted by the end of winter, with an early summer harvest to avoid fruit maturation during the hottest period.

We did not find a specific N:K ratio that could improve consistently marketable tomato yield under field, hydroponic or fertigation systems in 2005 or 2006 off-seasons (Table 2). However, in 2006 off-season the higher K level increased the shoot growth of tomato plants in the three cropping systems (Figure 1) and the yield of marketable fruits by 11% in the average of the three cropping systems (Table 2), denoting that increased K supplies are required to improve tomato

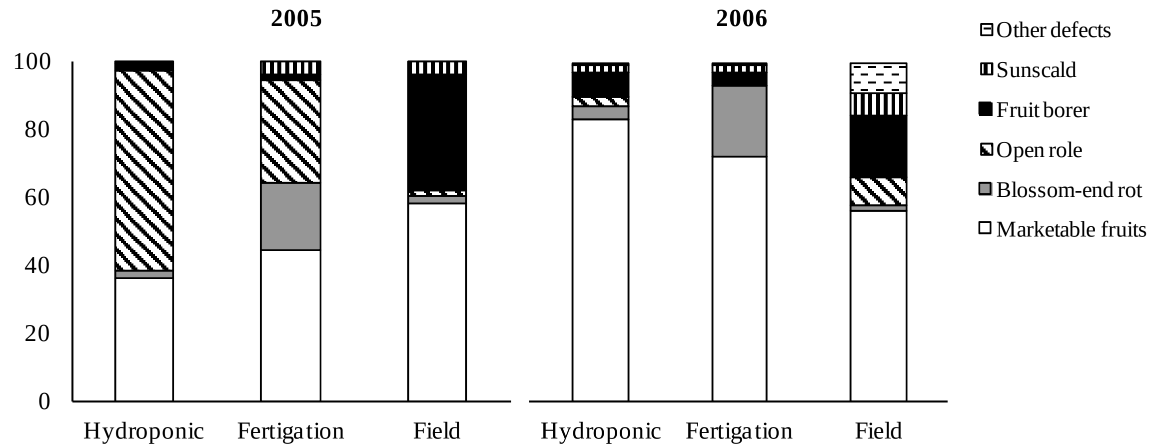

Figure 2. Proportion of marketable fruits and culls with biotic and abiotic defects produced in hydroponic, fertigation and field systems in the 2005 and 2006 off-seasons.

growth and yield in protected crops particularly at a higher level of productivity such as in 2006.

In the field in 2005, fruits with higher diameter were obtained using 100:200 N:K (in kg/ha), similar to that reported by Fontes et al. (2000b) for Santa Clara tomato variety. These authors tested K levels from 0 to 400 kg/ha and identified cumulative responses of the variables studied, with maximum commercial production of 73 tons/ha obtained with a K level of 194 kg/ha, applied by fertigation to a field crop. However, Papadopoulos and Khosla (1993) found no effects of different N:K ratios applied by fertigation on the yield and quality of tomatoes grown in the field. In the present study we found that the highest yield of marketable fruits in the fertigation system was obtained up to 400 kg/ha of K (Table 2), indicating that very high levels of fertilization, nearly 300 kg/ha of N and above 400 kg/ha of K, can damage tomato plants in this system.

Physiological disturbances related to blossom-end rot and open holes in tomatoes are related to calcium (Ca) and boron (B) deficiency, respectively (Antoniolli and Castro, 2008). The mobilization of Ca and B in crops may be impeded by high temperatures (Antoniolli and Castro, 2008). This could explain the high incidence of these defects in the 2005 off-season, under high temperatures during late growth stages. In 2005, open holes were found in 59% of hydroponically-grown fruits and 30% of those grown under fertigation (Figure 2), indicating that B content in Hoagland's solution should be modified. As such, B levels were doubled in the nutritive stock solution applied in 2006, which likely contributed to reducing open holes prevalence and increasing hydroponic tomato production (Table 1).

With respect to Ca deficiency, fruits produced using fertigation exhibited high occurrence of blossom-end rot. Loos et al. (2008) reported that this defect accounted for the highest losses in marketable tomato yield in a protected cropping system. In fertigation, nutrient availability and balance can be modified by the cation exchange capacity of coconut fiber, which likely reduced Ca availability. Furthermore, lower water content is available to plants grown in artificial substrate (in pots) than to those grown in soil (Valandro et al., 2007), and with reduced transpiration rate, the former can exhibit low Ca flow in xylem. Therefore, fertilization recommendations for tomatoes grown in coconut fiber substrate and under a fertigation system should be adapted, especially in relation to Ca levels. Another aspect to be further studied concerns the portion of fertilizer to apply to the substrate via fertigation in each growth stage, since inadequate levels can compromise commercial fruit production (Alvarenga et al., 2004).

Fruit borer occurrence in the field crop was lower in 2006 (Figure 2), probably because of chemical control during the blooming period. In the protected crops, the incidence of this pest was prevented by the anti-aphid screen covering the greenhouse. Fruit borers must be intensively controlled in tomato crops since they are known to attack different varieties, such as Débora Plus and Santa Clara (Loos et al., 2008), in both protected and field crops (Caliman et al., 2005). The effects of applying different K levels on total soluble solids and titatrable acidity were not consistent (data not shown). Fontes et al. (2000a) found no effects of K levels ranging from 0 to 400 kg/ha on vitamin C, soluble solids or lycopene levels in tomatoes, although pH decreased in fruits grown under the highest K levels. The levels of total soluble solid and titratrable acidity measured in the two off-seasons (Table 1) are slightly below the values reported for tomatoes cropped in the field and in different substrate types in protected cropping (Fontes et al., 2004) and for different tomato hybrids cropped in the field (Carvalho et al., 2005), respectively.

Conclusions

The results obtained indicate that protected tomato crops grown under hydroponics produce higher marketable fruit yield during the off-season (Spring-Summer) than crops grown under fertigation and field conditions. Protected tomato crops in Southeast Brazil must be planted by the end of winter, with an early summer harvest to avoid fruit maturation during the hottest period. With respect to fertilizer management, higher K levels applied stimulate shoot growth and increased the yield of marketable fruits in the three cultivation systems, particularly at a higher level of fruit productivity, indicating that increased K supplies are required to improve tomato growth and yield in protected crops.

Conflict of Interest

The authors have not declared any conflict of interest.

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