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Full Length Research Paper

Effect of plant population, fruit and stem pruning on yield and quality of hydroponically grown tomato

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A study was conducted in 2009 to 2010 and 2010 to 2011 to investigate the effect of plant population, and fruit and stem pruning of hydroponically grown tomatoes in a 40% (black and white) shade-net structure at the ARC-Roodeplaat VOPI. An open bag hydroponic system containing sawdust as a growing medium was used in this experiment. Tomato plants were subjected to three plant populations (2, 2.5 or 3 plants/m^2), two stem pruning treatments (one stem and two stems) and three fruit pruning treatments (four fruits, six fruits per truss, and no fruit pruning). Experimental layout was a complete randomized block design with three replicates. Data on fruit number, fruit mass, unmarketable yield, marketable yield and total yield was collected from 10 plants for all treatments. Plants pruned to two stems with zero fruit pruning or pruned to six fruits produced significantly higher marketable and total yield, as compared to the other treatments. Plant population of 3 plants/m^2, resulted in significantly higher marketable yield of tomatoes, compared to 2.5 and 2 plants/m^2. Results showed that tomato yield and quality can be effectively manipulated by plant population and stem pruning, while fruit pruning had only a limited effect.

Key words: Fruit cracking, open-bag hydroponic system, plant population, pruning, shade-net structure, fruit yield.

INTRODUCTION

Tomatoes are amongst the most important and popular vegetables grown in South Africa. Its production in hydroponic systems is continuously increasing in South Africa, due to increase in market returns under conditions of limited agricultural resources, such as good soil and shortage of land. Tomatoes are an essential component of human diet for the supply of vitamins (A and C) and minerals (Jones, 2008). Growers in South Africa are faced with the challenge of producing high yield combined with good quality, in order to satisfy the local demand. Rarely this demand is met, mainly due to poor cultivation methods, inadequate plant nutrition, adverse climatic conditions, or pests and disease infestation. Unfavourable weather conditions, such as hail and high temperatures during summer season have resulted in farmers trying to optimise yield and quality of tomatoes by using soilless production systems under shadenet structures. Yield, quality and fruit size of tomatoes is influenced by many factors, including plant population (Ara et al., 2007; Davis and Estes, 1993), fruit pruning (Ghebremariam, 2005; Saglam and Yazgan, 1999), as well as stem pruning and cultivar selection (Maboko and Du Plooy, 2008). Fruit pruning is used to limit the number of fruit per truss/cluster and reduce the competition to increase fruit mass. Reducing fruit number from six to three fruits per truss increased the fruit weight by 42%, while the marketable yield reduced by 15 to 25% (Fanasca et al., 2007).

Similarly, increased total marketable yield, reduced cull yield and increased fruit weight was reported as a result of pruning trusses to three fruits (Hanna, 2009). Increased dry weight of tomato was due to fewer fruits retained per truss (Heuvelink, 1997, Gautier et al., 2005; Fanasca et al., 2007). The results contradict those

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reported by Saglam and Yazgan (1999) who found the optimum fruit number to be either four and/or six per cluster. An increase in total number of flowers and fruits has been shown to increase competition for photosynthates and, thus decreased fruit size (Veliath and Ferguson, 1972). According to Marcelis (1994) and Bertin (1995), plants that are subjected to high fruit load or sink:source ratio often result in flower or fruit abortion. Tomato fruits are prone to physiological disorders, such as fruit cracking when too many fruits are pruned from the plant (Ghebremariam, 2005). A large reduction in tomato yield was reported when side shoots were allowed to develop to 21 days, compared to 7 days (Navarrete and Jeannequin, 2000). In South Africa, pruning to a single stem and removing all side-shoots/ suckers is a common practice at a plant population of 2.5 plants/m^2. The number of stems per plant and planting density together affect the relationship between the number of fruits per surface unit area and the number of fruits per plant (Franco et al., 2009). Plant spacing and stem pruning are important factors in proper utilisation of production area, and to improve the yield and quality of tomatoes (Ara et al., 2007). Several studies have shown a linear increase in fruit yield when plant density was increased (Stoffella and Bryan, 1988; Ara et al., 2007). Yield per unit area tends to increase as plant density increases up to a point and then declines (Akintoye et al., 2009).

This study was conducted to find out the ideal combination of plant population, side stems and fruts per truss to get an optimum yield of tomato. This paper presents the results obtained in the evaluation of plant population, stem and fruit pruning treatments on marketable yield, total yield, unmarketable yield and fruit cracking (including physiological disorders) of hydroponically grown tomatoes.

MATERIALS AND METHODS

The trial was conducted in a 40% shade-net structure (Black and white) at the ARC- Roodeplaat VOPI, South Africa (25° 59'S, 28° 35'E, at an altitude of 1200 m a.s.l.), from October 2009 to February 2010 and repeated in September 2010 to January 2011. Seed trays were filled with a commercial growth medium, Hygromix® (Hygrotech, South Africa), and covered with a thin layer of vermiculite after seeding. As soon as the first two true leaves were fully developed, foliar fertilizer (Multifeed® at 1 g/L water) was applied once daily, followed by irrigation to reduce the build-up of salts. Five week old tomato seedlings of cultivar 'FA593' (indeterminate growth) were transplanted into 10 L black plastic bags filled with sawdust as growing medium at three plant populations, that is 2, 2.5 and 3 plants/m^2. Plants were pruned to either one or two stems, with three fruit pruning treatments, namely, six fruits per truss, four fruits per truss and no fruit removal. Plot size for each treatment was 7 m^2. After selection of the main stems according to the method described by Maboko and Du Plooy (2008), all new side shoots were removed once a week. Plants were trained to double stem using the 'V' trellising system (Jovicich et al., 2004), and to a single stem by twisting trellis twine around the main stem and fixing it to a stay wire 2 m above ground surface to support the plant. Side branches were removed weekly to maintain a single and a double stem system. When plants had reached the horizontal wire at 2 m, the growing point was removed to restrict further plant growth.

Fruits were pruned when they were marble size. The experimental layout was a randomized complete block design with three replicates and ten data plants per treatment per replicate. The electrical conductivity (EC in mS/cm) and pH (Hanna Instruments, Mauritius) of the nutrient solution were measured and maintained at a range of 2.1 to 2.3 and 5.8 to 6.1, respectively. Plants were irrigated seven times a day for every 2 h, that is total daily irrigation from 735 to 2 205 ml per plant. The irrigation volume was gradually increased as plants developed to ensure that 10 to 15% of the applied water leached out to reduce salt build-up in the growth medium. The composition and chemical concentration of fertilizers used were: Hydroponic® (Hygrotech Pty. Ltd, South Africa) comprising of N (68 mg/kg), P (42 mg/kg), K (208 mg/kg), Mg (30 mg/kg), S (64 mg/kg), Fe (1.254 mg/kg), Cu (0.022 mg/kg), Zn (0.149 mg/kg), Mn (0.299 mg/kg), B (0.373 mg/kg) and Mo (0.037 mg/kg), calcium nitrate [$Ca(NO_3)_2$] comprising of N (117 mg/kg) and Ca (166 mg/kg), and potassium nitrate (KNO_3) comprising of K (38.6 mg/kg) and N (13.8 mg/kg). An amount of 800 g Hydroponic and 600 g $CaNO_3$ was applied in 1000 L water at transplanting until the first flower truss appeared. During development of the first to third flower truss, 900 g Hydroponic and 700 g calcium nitrate was applied per 1000 L water. Fertiliser applied from the third flower truss to the end of the experiment was 1000 g Hydroponic, 900 g [$Ca(NO_3)_2$] and 200 g KNO_3 per 1000 L of water.

Data collection included total, marketable and unmarketable yield, as well as pathological and physiological disorders. Fruits were regarded as unmarketable when they exhibited cracking, zippering, rotting, rain check, blossom end rot (BER), catface or fell into the extra small size category (< 40 mm fruit diameter). Data was subjected to analysis of variance (ANOVA) using *GenStat* (2003). Treatment means were separated using Fisher's protected t-test least significant difference (LSD) at the 5% level of significance (Snedecor and Cochran, 1980).

RESULTS AND DISCUSSION

Effect of plant population

Yield in both years was influenced by plant population (Table 1). Results obtained in 2009/2010 indicated that there was a significant increase in number of marketable fruits, marketable yield and total yield with an increase in plant population. These findings agreed with other research findings (Fandi et al., 2007; Ara et al., 2007; Charlo et al., 2007). Unmarketable yield was significantly higher at a plant population of 2.5 and 3 plants/m^2, compared to 2 plants/m^2, due to greater number of fruits exhibiting physiological disorders and fruits which fell into extra-small sized category. Higher incidences of fruit cracking were observed at plant population of 2 plants/m^2 than at 2.5 and 3 plants/m^2.

The reduced fruit cracking at higher plant populations might be due to fruit being covered by good foliage, thus protecting the fruit from direct sunlight and rainfall droplets. Peet (1992) reported that fruits with poor foliar coverage are prone to cracking. Fruit cracking might have

Table 1. Effect of plant population on tomato yield and fruit cracking.

Plant Population(m^2)	Marketable yield (g/m^2)	Number of marketable fruits/m^2	Unmarketable yield (g/m^2)	Total yield (g/m^2)	Fruit cracking	
					Number/m^2	Mass (g/m^2)
			2009/2010			
2.0	6075^a	71.8^c	2175^b	8251^c	10.5^a	1192^a
2.5	7728^b	90.9^b	2729^a	10511^b	15.1^b	1625^b
3.0	10062^c	112.9^a	3074^a	13136^a	15.9^b	1738^b
Lsd 0.05	795.8	7.59	358.8	990.5	2.7	315.2
			2010/2011			
2.0	9621^b	77.8^c	3619	13240^c	18.46	2344
2.5	11121^b	94.9^b	4003	15125^b	22.43	2726
3.0	13648^a	118.3^a	3843	17491^a	19.15	2335
Lsd 0.05	1516.4	11.50	ns	1470.7	ns	ns

Figures in a column followed by the same letter are not significantly different (P>0.05), using Fisher's protected t-test.

Table 2. Effect of stem pruning on tomato yield and fruit cracking.

No of side stems	Marketable yield (g/m^2)	Number of marketable fruits/m^2	Unmarketable yield (g/m^2)	Total yield (g/m^2)	Fruit cracking	
					Number/m^2	Mass g/m^2)
			2009/2010			
1 stem	7041^b	73.3^b	2995^a	10036^b	17.7^a	2055^a
2 stems	8906^a	110.4^a	2324^b	11230^a	10.0^b	982^b
Lsd 0.05	649.8	6.19	292.9	808.7	2.2	257.3
			2010/2011			
1 stem	9576^b	74.3^b	4634^a	14210^b	22.47^a	3042^a
2 stems	13351^a	119.7^a	3010^b	15768^a	17.56^b	1895^b
Lsd 0.05	1238.1	9.39	504	1200.8	3.619	393.4

Figures in a column followed by the same letter are not significantly different (P>0.05), using Fisher's protected t-test.

been worsened by rainfall (Maboko and Du Plooy, 2009; Peet, 2002), since the trial was conducted in a shade net structure which is not water proof. In 2010/2011, results showed that plants subjected to 3 plants/m^2 had the highest marketable yield compared to 2 or 2.5 plants/m^2. Number of marketable fruits and total yield increased significantly with an increase in plant population. Results are in agreement with the findings by Fandi et al. (2007) and Ara et al. (2007). Plant population did not show any significant effect on fruit cracking and unmarketable yield.

Effect of stem pruning

Results obtained in 2009/2010 showed a high number of marketable fruits, marketable yield and total yield, when plants were pruned to two stems (Table 2). Conversely, plants pruned to one stem had the highest unmarketable yield, mainly because of the higher number of fruits exhibiting cracking. A similar trend in the results was observed in 2010/2011. The results in both years are in agreement with the findings by Maboko and Du Plooy (2008, 2009), and Ara et al. (2007) that yield was found to increase with an increase in stem number. Reduced fruit cracking when plants are subjected to two stem was reported by Maboko and Du Plooy (2009). Fruits developing from a single stem tend to grow larger in size, as compared to fruits developing from two stems (Maboko and Du Plooy, 2008, 2009). The increased incidence of fruit cracking with the single stem pruning might be related to the larger fruit size obtained from this treatment (Maboko and Du Plooy, 2009).

Effect of fruit pruning

During 2009/2010, highest marketable yield and total yield were obtained from plants without fruit pruning or

Table 3. Effect of fruit pruning on tomato yield and fruit cracking.

No of fruit pruned	Marketable yield (g/m^2)	Number of marketable fruits/m^2	Unmarketable yield (g/m^2)	Total yield (g/m^2)	Fruit cracking	
					Number/m^2	Mass (g/m^2)
			2009/2010			
0F	8686^a	106.6^a	2331^b	11017^a	10.6^b	1080^c
4F	6754^b	72.8^c	2929^a	9683^b	16.3^a	1913^a
6F	8480^a	96.2^b	2718^a	11198^a	14.7^a	1562^b
Lsd 0.05	795.8	7.59	358.8	990.5	2.7	315.2
			2010/2011			
0F	13032^a	115.2^a	3626	16658^a	20.43	2328
4F	9352^b	73.1^c	4078	13429^b	20.24	2700
6F	12007^a	102.8^b	3761	15768^a	19.37	2377
Lsd 0.05	1516.4	11.50	ns	1470.7	ns	ns

Figures in a column followed by the same letter are not significantly different (P>0.05), using Fisher's protected t-test.

Table 4. Interaction effect between stem and fruit pruning on marketable yield in 2009/10 (g/m^2 or fruit number/m^2).

Interaction stem x fruit	Marketable yield (g/m^2)	Number of marketable fruits/m^2
1S4F	6109^d	56.1^d
1S6F	6943^{cd}	71.8^c
1S0F	8071^b	91.94^b
2S4F	7399^{bc}	89.51^b
2S6F	10017^a	120.6^a
2S0F	9301^a	121.2^a
Lsd 0.05	1125.5	3.73

Figures in a column followed by the same letter are not significantly different (P>0.05), using Fisher's protected t-test.

plants pruned to six fruits per truss (Table 3). The number of marketable fruits was recorded highest at zero fruit pruning, followed by six fruits per truss, and the lowest was recorded at four fruits per truss. Fruit pruning at 4 or 6 fruits per truss tended to increase unmarketable yield. In 2010/2011, results showed a similar trend with the results obtained in 2009/2010 (Table 4).With regard to marketable yield, number of marketable fruits and total yield. Fruit pruning did not have a significant influence on unmarketable yield, number and mass of fruit exhibiting cracking. Similar results were reported by Maboko and Du Plooy (2009) that fruit pruning did not have a significant effect on tomato yield. Results are in disagreement with other publications stating that reduced fruit number increased the yield of tomatoes (Saglam and Yazgan, 1999; Hanna, 2009). Contradictions of the results reported in this study might be due to cultivar differences and production systems. However, the reason why fruit pruning (4 no) reduced the yield significantly was not clearly explained, although 0 and 6 did not have significant difference.

Interaction effect of stem and fruit pruning

There was an interaction effect between stem and fruit pruning on marketable yield and number of unmarketable fruits during 2009/2010 (Table 4). Plants without fruit pruning, pruned to two stems or pruning fruits to six per truss produced significantly higher marketable yield, as well as higher number of marketable fruits than the other treatments.

Interaction of plant population and stem pruning

An interaction between plant population and stem pruning was observed in terms of number of marketable fruits and unmarketable yield in year 2009/2010 (Table 5).

Plants pruned to two stems at a plant population of 3 plants/m^2 produced a significantly higher number of marketable fruits/m^2, followed by plants pruned to two stems at a population of 2.5 plants/m^2. Less marketable fruits were recorded with plants pruned to one stem at a

Table 5. Interaction effect between plant population and stem pruning on marketable yield and fruit cracking in 2009/2010.

Interaction(PxS)	Number of marketable fruits/m^2	Unmarketable yield (g/m^2)	Fruit cracking	
			Number/m^2	Mass (g/m^2)
P11S	58.8^e	2210^c	11.5^b	1431^b
P12S	84.9^c	2140^c	9.5^b	954^c
P21S	71.8^d	3348^a	21.0^a	2400^a
P22S	109.9^b	2110^c	9.2^b	850^c
P31S	89.3^c	3426^a	20.4^a	2333^a
P32S	136.5^a	2722^b	11.4^b	1142^{bc}
Lsd 0.05	10.73	507.4	3.76	445.7

Figures in a column followed by the same letter are not significantly different (P>0.05), using Fisher's protected t-test. P1=2 plants/m^2, P2=2.5 plants/m^2, P3=3 plants/m^2.

population of 2 plants/m^2. Jovicich et al. (1999) reported that sweet pepper plants pruned to four stems at a plant population of 4 plants/m^2 increased marketable and extra large fruit yield.

Conclusion

Results demonstrate that fruit pruning is not necessary for tomatoes grown hydroponically in a shade net structure; while allowing plants to have two stems at a plant population of 3 plants/m^2 resulted in increased yield and quality of tomatoes. Further studies need to be conducted to identify the optimal plant population and stem pruning, while looking at economic viability of the treatments.

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