

MABOKO, MM; PLOOY, CP; CHILOANE, S. 2017. Yield of determinate tomato cultivars grown in a closed hydroponic system as affected by plant spacing. *Horticultura Brasileira* 35: 258-264. DOI - <http://dx.doi.org/10.1590/S0102-053620170217>

Yield of determinate tomato cultivars grown in a closed hydroponic system as affected by plant spacing

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ABSTRACT

In South Africa there are no established spacing recommendations for determinate tomato cultivar production under closed hydroponic systems. This study was conducted to determine yield and quality of hydroponically grown determinate tomato cultivars at different plant densities. Four determinate tomato cultivars (Dynimo, Mariana, Mion and Sama) were subjected to four plant densities (10, 16, 20 and 25 plants/m²) during the spring/summer and summer/fall seasons. Experimental layout was a randomized complete block design in a factorial scheme of four plant spacing x four cultivars with three replicates. There were no significant differences in marketable yield between the cultivars tested during the spring/summer and summer/fall seasons. Cultivar Mion showed higher incidence of blossom end rot, while Mariana showed the highest fruit rot during the spring/summer season as compared to the other cultivars. During the spring/summer season, marketable yield increased with increased plant density with the highest yield obtained at 25 plants/m² followed by 20 plants/m². During the summer/fall season, plant density did not show a significant effect on total and marketable yield although a tendency for declined yield with increased density was observed. Number of fruit per plant as well as fruit size decreased with increased plant density during both seasons which did not have an effect on overall yield per plot area. Increasing the plant density to 25 plants/m² can improve marketable yield of determinate tomato cultivars during spring/summer season while using a plant density of 10 plants/m² will be more cost effective during the summer/fall season. This information will enable farmers to optimise yield and quality of determinate tomato cultivars under closed hydroponic systems.

Keywords: *Solanum lycopersicum*, gravel-film technique, yield, soilless cultivation.

RESUMO

Rendimento de tomate cultivado em sistema hidropônico, afetado pelo espaçamento entre plantas

Na África do Sul não há recomendações de espaçamento estabelecidas para a produção de cultivares de tomate em sistemas hidropônicos fechados. Determinou-se o rendimento e a qualidade de cultivares de tomate de crescimento determinado (Dynimo, Mariana, Mion e Sama) em hidroponia e densidades de plantio (10, 16, 20 e 25 plantas/m²) durante primavera/verão e verão/outono. O delineamento experimental foi em blocos ao acaso, em esquema fatorial de quatro espaçamentos de plantas x quatro cultivares com três repetições. Não houve diferenças significativas no rendimento comercial entre as cultivares testadas nas duas épocas de plantio. A cultivar Mion apresentou maior incidência de podridão apical, enquanto 'Mariana' apresentou maior podridão de frutos durante a primavera/verão. Durante a primavera/verão, o rendimento comercializável aumentou com a maior densidade de plantas (25 pl/m²), seguido por 20 pl/m². Durante o verão/outono, a densidade de plantas não mostrou efeito significativo no rendimento total e comercializável, embora tenha sido observada tendência de declínio com maior densidade. O número de frutos por planta bem como o tamanho do fruto diminuíram com o aumento da densidade de plantas durante as duas estações, entretanto, sem efeito no rendimento global por área de parcela. O aumento da densidade de plantas para 25 pl/m² pode melhorar o rendimento comercializável de cultivares de tomate determinado durante a primavera/verão enquanto que a densidade de 10 pl/m² será mais rentável durante o verão/outono. Esta informação permitirá aos agricultores otimizar o rendimento e a qualidade de cultivares de tomate determinado em sistemas hidropônicos fechados.

Palavras-chave: *Solanum lycopersicum*, técnica de cascalho, produção comercializável, produção não comercializável, cultivo sem solo.

Received on January 15, 2016; accepted on November 22, 2016

Tomato production in South Africa is mainly under field conditions with diverse climatic conditions. Growing vegetables using soil has a range of challenges, such as variable temperatures, moisture holding capacity, available nutrient supply, proper root

aeration, as well as disease and pest infestation (Maboko & Du Plooy, 2014). Soilless production under protected conditions alleviates some of these problems, while giving the grower better control over plant growth and development (Du Plooy *et al.*, 2012).

For successful production of tomatoes, increasing the grower's profit and satisfying the local market, requires the application of different production methods to increase yield. These include plant spacing and cultivar choice. The number of plants per unit

area is one of the important agronomic practices to optimize yield (Rodriguez *et al.*, 2007; Kitila *et al.*, 2012; Maboko & Du Plooy, 2013). An ideal plant density can lead to optimum yields, whereas too high or too low plant densities can result in relatively lower yields of poor quality (Maboko & Du Plooy, 2013). In an optimal space, plants can efficiently utilize environmental factors, such as light, air, water and nutrients, and inter- or intra-specific competition should be at a minimum. It also ensures proper plant growth and development resulting in maximizing yield of crop and economic use of land. Manipulation of plant spacing is an important means to increase light interception and its efficient use in tomato production (Feng *et al.*, 2010). Tomato yield has been reported to be dependent on the number of plants accommodated per unit area (Mehla *et al.*, 2000; Belemi, 2008; Maboko *et al.*, 2011a). Castodi *et al.* (2012) reported that an increase in plant density resulted in a reduction in mean fresh weight of the plants and increased productivity to a certain extent. Yield of fresh market and processing tomatoes was reported to be greatly influenced by plant spacing (Belemi, 2008). Mehla *et*

al. (2000) also reported the importance of plant spacing on yield and quality parameters in tomato crop.

In South Africa, hydroponically grown tomatoes are generally produced in an open bag hydroponic system. However, research reports have indicated that hydroponic cultivation is inclined towards closed systems in order to reduce nutrient losses and control of the environment (Schwarz *et al.*, 2009). A closed hydroponic system provides efficient use of water and nutrients due to recirculating of the nutrient solution. In South Africa, the gravel-film technique has shown improved yield per unit area at high density planting of tomato with decapitated growing points (Maboko & Du Plooy, 2013). There are no established tomato spacing recommendations for determinate tomato cultivars production under a closed hydroponic system using the gravel-film technique. Cultivar selection is also a critical management decision that can impact yield and fruit quality (Maboko & Du Plooy, 2013). The study was aimed at determining yield of hydroponically grown determinate tomato cultivars at different plant spacings.

MATERIAL AND METHODS

The study was conducted during September to December 2013 (spring/summer season) and repeated in January to April 2014 (summer/fall season) in a 40% black and white shadenet structure at the Agricultural Research Council - Vegetable and Ornamental Plants (ARC-VOP), Roodeplaat, South Africa (25°59'S; 28°35'E, altitude 1.200 m).

Plantlets of four tomato cultivars were transplanted 35 days after seeding using a closed (gravel-film technique) hydroponic system. A randomized complete block design in a factorial scheme of 4x4 [four planting spacings (25x40, 25x25, 20x25 and 20x20 cm) x four determinate tomato cultivars (Dynimo, Mariana, Mion and Sama)], resulted in a total of 16 treatment combinations with three replicates. The planting spacings 25x40, 25x25, 20x25 and 20x20 cm comprised respectively the following planting densities: 10, 16, 20 and 25 plants/m². Area occupied by a single plot was 2x1 m. Tomato seedlings were transplanted 6 cm deep into gullies (17 m long x 1 m wide) filled to a depth of 6 cm with crushed granite rocks of irregular shape, with a diameter

Table 1. Effect of plant density on yield and fruit size of determinate tomato cultivars (spring/summer season). South Africa, Agricultural Research Council, 2014.

Treatment	Total yield (kg/m ²)	Total fruits (number/m ²)	Marketable yield (kg/m ²)	Marketable fruits (number/m ²)	Unmarketable yield (kg/m ²)	Extra-small fruits (number/m ²)	Extra-small fruits (kg/m ²)
Density (plants/m²)							
10	15.8c	231.7c	12.5c	140.7b	3.3b	78.7c	2.3c
16	24.6b	359.7b	19.6b	212.6a	5.0ab	128.3b	3.8b
20	25.2b	389.9ab	19.7ab	226.2a	5.5a	146.8ab	4.4ab
25	29.7a	431.5a	23.3a	252.4a	6.4a	151.2a	4.8a
LSD 0.05	3.8	51.17	3.4	40.08	0.7	22.07	0.63
Cultivars							
Dynimo	26.0a	379.5a	19.6	206.6ab	6.4a	154.5a	5.2a
Mariana	25.8ab	408.2a	19.6	231.6a	6.1a	149.2a	4.2b
Mion	22.2bc	398.2a	17.0	226.2a	5.2b	149.5a	4.0b
Sama	21.3c	226.9b	18.8	167.1b	2.5c	51.8b	1.9c
LSD 0.05	3.8	51.17	ns	40.08	0.7	22.07	0.63

Values in a column followed by the same letter are not significantly different ($p > 0.05$), using Fishers' protected t-test; LSD: least significant difference.

ranging from 16 to 19 mm. A gravel-film technique hydroponic system was used to perform the trial, as described by Maboko *et al.* (2011b). Plants were not trellised or pruned.

The nutrient solution was renewed on a weekly basis. The composition and chemical concentration of fertilizers used in the nutrient solution were: Hygroponic® (Hygrotech (Pty). Ltd, South Africa) comprising of N (68 ppm), P (42 ppm), K (208 ppm), Mg (30 ppm), S (64 ppm), Fe (1.254 ppm), Cu (0.022 ppm), Zn (0.149 ppm), Mn (0.299 ppm), B (0.373 ppm), and Mo (0.037 ppm), as well as calcium nitrate [$\text{Ca}(\text{NO}_3)_2$] comprising of N (117 ppm) and Ca (166 ppm). The fertilizers applied from transplanting until the plants were three weeks old were 600 g Hygroponic and 600 g $\text{Ca}(\text{NO}_3)_2$ in 1000 L water. Thereafter, 900 g Hygroponic and 900 g calcium nitrate were applied per 1000 L water. The electrical conductivity (EC) and pH of the nutrient solution were maintained within a range of 1.9 to 2.3 mS/cm and 5.8 to 6.1, respectively.

Fruits were harvested on a weekly basis at breaker stage. The performance of the tomato cultivars was evaluated for total yield, marketable and unmarketable yield, as well as the occurrence of physiological disorders. Fruits were regarded as unmarketable when they exhibited cracking, zippering, rotting, blossom-end rot, rain-check, cat-face or fell into the extra small size category (less than 40 mm diameter). Marketable yield comprised of fruits that were larger than 40 mm diameter, whereas total yield was determined by adding marketable yield and unmarketable yield.

Data were subjected to analysis of variance (ANOVA) using the statistical program *GenStat*® version 11.1 (Payne *et al.*, 2008). Treatment means were separated using Fisher's protected T-test least significant difference (LSD) at the 5% level of significance (Snedecor & Cochran, 1980).

RESULTS AND DISCUSSION

High mass of extra-small sized

fruits were found at 20 and 25 plants/m², although plants/m² did not differ significantly with 16 plants/m² (Table 1). A close spacing (20 to 25 plants/m²) during the spring/summer season resulted in more small fruits of unmarketable size (Table 1) which could be explained most likely by a decrease in plant growth rate and inadequate supply of photosynthates due to shading and reduced light interception per plant (Heuvelink, 1995; Papadopoulos & Pararajasingham, 1997). The lower leaves were observed to be gradually shaded by the canopy especially at high plant density where

shading progressively decreases the light intensity (Van Henten *et al.*, 2002). Trouwborst *et al.* (2011) reported that shading of developed and matured leaves dramatically decreased leaf photosynthetic capacity and leaf chlorophyll content within a few days. Plants grown at closer spacing (20 to 25 plants/m²) grew taller with thinner stems than widely spaced plants (10 to 16 plants/m²) while lower leaves became yellowish as a result of shading. Tomato yield is determined primarily by the amount of intercepted light (Newton *et al.*, 1999) and assimilate partitioning (Ho, 1996).

Table 2. Effect of determinate tomato cultivars at different plant densities on tomato yield per plant during spring/summer season and summer/fall season. South Africa, Agricultural Research Council, 2014.

Treatment	Total fruits (number/plant)	Total yield (kg/plant)	Marketable yield (kg/plant)	Marketable fruits (num./plant)
Density (plants/m ²)				
10	23.2a	1.58a	1.25a	14.1a
16	22.5a	1.54a	1.23a	13.3a
20	19.5ab	1.26b	0.99b	11.3ab
25	17.3b	1.19b	0.93b	10.1b
LSD 0.05	3.79	0.25	0.23	2.85
Cultivar				
Dynimo	21.9a	1.49	1.14	12.2
Mariana	24.1a	1.54	1.16	13.5
Mion	23.0a	1.25	0.96	13.1
Sama	13.6b	1.28	1.14	10.0
LSD 0.05	3.79	ns	ns	ns
Density (plants/m ²)				
10	28.4a	2.20a	1.96a	23.3a
16	18.9b	1.40b	1.23b	15.1b
20	14.5c	1.03c	0.89c	11.3c
25	10.6d	0.76d	0.65c	8.3c
LSD 0.05	3.67	0.27	0.25	3.16
Cultivar				
Dynimo	17.2ab	1.26	1.078	13.5
Mariana	20.4a	1.38	1.181	15.5
Mion	20.1a	1.39	1.166	15.1
Sama	14.7b	1.34	1.296	13.9
LSD 0.05	3.67	ns	ns	ns

Values in a column followed by the same letter are not significantly different ($p > 0.05$), using Fishers' protected t-test: least significant difference.

During the spring/summer season, cultivars planted at a density of 25 plants/m² produced significantly higher total yield while those planted at 10 plants/m² produced the lowest yield (Table 1). Marketable yield was higher at plant densities of 25 and 20 plants/m², although 20 plants/m² did not differ significantly from 16 plants/m². During the spring/summer season, number of marketable and unmarketable fruits/m² were significantly higher at 16, 20 and 25 plants/m² compared to 10 plants/m² (Table 1). Total number of fruits and number of marketable fruits per plant were high at 10 and 16 plants/m², although not significantly different from 20 plants/m² density (Table 2). A wider plant spacing of 10 and 16 plants/m² produced significantly higher total yield and marketable yield per plant than 20 and 25 plants/m² (Table 2). Tomato yield is directly related to the number of plants per unit area, number of harvested fruits per plant and average fruit mass (Streck *et al.*, 1998). During the summer/fall season, total number of fruits, total yield, marketable yield and number of marketable fruits per plant decreased with an increase in plant density (Table 2). In contrast, during the summer/fall season the yield and yield components

per unit area were not affected by plant density (Table 3). However, there was a decreased tendency in total and marketable yield with an increase in plant density (Table 3). Furthermore, effect of plant density was influenced by growing season/environmental conditions. An increase in plant density (Table 1) resulted in an increase in total yield during the spring/summer season while in summer/fall season plant density did not have a significant effect (Table 3). During the spring/

summer season, there was an increase in marketable yield with an increase in plant density (Table 1) whereas during the summer/fall season (Table 3) marketable yield increased with a decrease in plant density. Growers are only interested in high marketable yield to generate profit.

Generally, determinate tomato does not require sucker/stem pruning, and if pruned, the yield will be reduced. Each shoot of a determinate tomato results in a cluster/flower truss and consequently

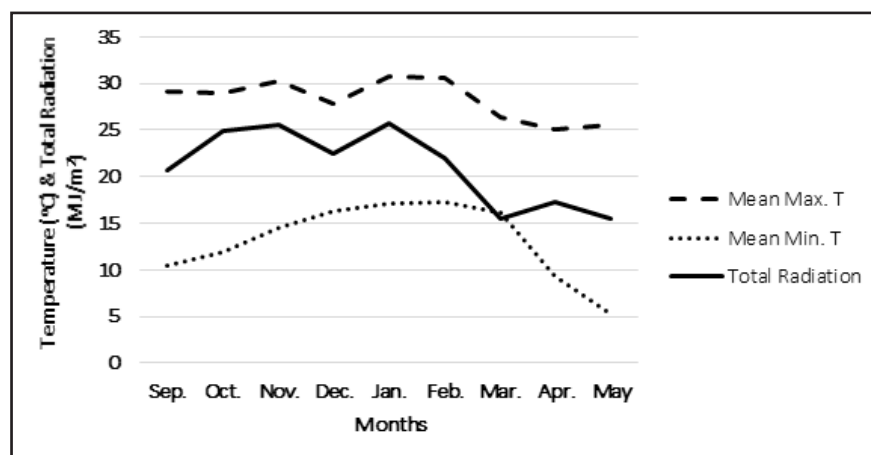


Figure 1. Temperature and total radiation conditions during the experimental period outside the shadenet structure (condições de temperatura e radiação total durante o experiment, fora da casa de vegetação). South Africa, Agricultural Research Council, 2014.

Table 3. Effect of plant density on yield and fruit size of determinate tomato cultivars (summer/fall season). South Africa, Agricultural Research Council, 2014.

Treatment	Total yield (kg/m ²)	Total fruits (number/m ²)	Marketable yield (kg/m ²)	Marketable yield (number/m ²)	Unmarketable yield (kg/m ²)	Extra-small fruits (number/m ²)	Extra-small fruits (kg/m ²)
Density (plants/m²)							
10	22.0	284	19.6	233.0	2.4	47.0	2.1
16	22.4	303	19.7	242.2	2.7	54.6	2.3
20	20.5	289	17.7	226.8	2.8	56.9	2.4
25	18.9	264	16.1	206.3	2.7	53.0	2.3
LSD 0.05	ns	ns	ns	ns	ns	ns	ns
Cultivar							
Dynimo	20.1	276	17.0	214.6	3.1a	55.3b	2.6b
Mariana	21.5	320	18.2	241.8	3.3a	72.5a	2.9ab
Mion	20.8	305	17.3	225.4	3.6a	73.5a	3.2a
Sama	21.4	239	20.7	226.5	0.7b	10.2c	0.5c
LSD 0.05	ns	ns	ns	ns	0.57	11.89	0.49

Values in a column followed by the same letter are not significantly different ($p > 0.05$), using Fishers' protected t-test; ns= not significant LSD: least significant difference.

Table 4. Effect of plant density on fruit physiological disorders of determinate tomato cultivars (spring/summer season). South Africa, Agricultural Research Council, 2014.

Treatment	Fruit cracking		Blossom-end rot		Cat-face		
	(number/m ²)	Mass (g/m ²)	(number/m ²)	Mass (g/m ²)	(number/m ²)	Mass (g/m ²)	
Density (plants/m²)							
10	0.0	0.9	0.3c	10.7b	0.0	0.3	
16	0.1	12.5	1.6a	61.5a	0.0	6.3	
20	0.0	0.0	0.3c	13.6b	0.1	14.5	
25	0.2	12.6	0.9b	56.7a	0.1	17.7	
LSD 0.05	ns	ns	0.57	27.58	ns	ns	
Cultivar							
Dynimo	0.2	16.1	0.5b	22.1bc	0.2	27.6	
Mariana	0.0	1.7	0.2b	11.6c	0.0	0.5	
Mion	0.1	8.2	1.8a	59.7a	0.0	0.0	
Sama	0.0	0.0	0.7b	49.0ab	0.1	10.5	
LSD 0.05	ns	ns	0.57	27.58	ns	ns	
		Fruit rot		Zippering			
		(number/m ²)	Mass (g/m ²)	(number/m ²)	Mass (g/m ²)		
Density (plants/m²)							
10	4.8b	626	6.2b	351b			
16	11.5a	713	5.8b	421b			
20	11.3a	673	5.4b	404b			
25	15.2a	838	11.5a	651a			
LSD 0.05	4.75	ns	4.1	202.7			
Cultivar							
Dynimo	9.5b	616b	7.0ab	471b			
Mariana	16.1a	1204a	10.9a	690a			
Mion	13.4ab	721b	7.3ab	352b			
Sama	3.9c	310b	3.7b	314b			
LSD 0.05	4.75	441.1	4.1	202.7			

Values in a column followed by the same letter are not significantly different ($p > 0.05$), using Fishers' protected t-test; ns= not significant
LSD: least significant difference.

fruit cluster/fruit truss. It was observed that plants grown at the wider spacing (10 and 16 plants/m²) exhibited more side shoots and continuous vegetative growth due to less population pressure per unit area which resulted in similar marketable yield to plants grown at a higher population density (20 and 25 plants/m²). Wide spacing might have an advantage of optimum conditions for vegetative growth and better plant canopy due to maximum light interception, photosynthesis, assimilation and accumulation of more photosynthates into the plant system (Mazumdar *et al.*, 2007). This was

evident from the increase in number of fruits, total yield and marketable yield per plant at a wider spacing of 10 and 16 plants/m² (Table 2). Increased total yield at high density planting can be attributed to the high number of plants/m² (Table 1). During the summer/fall season, plants were exposed to shorter days, lower temperature and radiation, which might have not fully benefited densely planted plants as a result of competition for light (Figure 1). Increase in total number of fruits, total yield and marketable yield per plant as well as increased tendency of tomato yield/m² with a decrease in plant density

during summer/fall season (Tables 2 and 3) as opposed to spring/summer season (Tables 1 and 2) could also be due to shorter day length and lower radiation (Figure 1). We observed that plants tended to produce fewer flowers at closer spacing which contributed to lower yield compared to wider spacing during summer/fall season. Temperature and radiation during spring/summer season might have been sufficient to benefit closer spaced plants to produce high yield (Figure 1).

Plants grown at 16 or 25 plants/m² produced more fruits exhibiting blossom-end rot (Table 4). Number

Table 5. Effect of plant density on fruit physiological disorders of determinate tomato cultivars (summer/fall season). South Africa, Agricultural Research Council, 2014.

Treatment	Cat-face		Fruit rot		Zippering	
	(number/m ²)	Mass (g/m ²)	(number/m ²)	Mass (g/m ²)	(number/m ²)	Mass (g/m ²)
Density (plants/m²)						
10	0.00	0.0	3.54	254	0.83	76
16	0.00	0.0	5.58	357	0.58	55
20	0.04	5.6	4.42	316	0.96	76
25	0.00	0.0	3.50	286	1.46	115
LSD 0.05	ns	ns	ns	ns	ns	ns
Cultivar						
Dynimo	0.00	0.0	5.04a	404a	1.21	105
Mariana	0.00	0.0	5.00a	272ab	1.12	77
Mion	0.00	0.0	5.17a	355a	0.88	64
Sama	0.04	5.6	1.83b	181b	0.62	77
LSD 0.05	ns	ns	2.12	142	ns	ns

Values in a column followed by the same letter are not significantly different ($p > 0.05$), using Fishers' protected t-test; ns= not significant LSD: least significant difference.

of fruit rot was significantly higher at plant density of 16, 20 or 25 plants/m². A closer spacing of 25 plants/m² produced significantly higher incidence of fruit zippering (Table 4). High density planting (16, 20 and 25 plants/m²) created problems of phyto-sanitation due to moisture accumulation and poor ventilation at the bottom of the plants, which facilitated fruit rot (Table 4). High incidence of zippering was found at high plant density which could be due to poor ventilation or pollination. This is in agreement with the study conducted by Maboko & Du Plooy (2013). Zippering is a physiological disorder whereby an anther becomes attached to the ovary wall of the newly forming fruit causing zipper to form. Plant density did not have a significant effect on fruit physiological disorders during summer/fall season (Table 5).

During the spring/summer season, the highest total yield was obtained by Dynimo and Mariana, although Mariana did not differ significantly from Mion (Table 1). Total number of fruits was significantly higher for Dynimo, Mariana (control) and Mion compared to Sama. Marketable yield was not affected by cultivar choice, however, number of marketable fruits was higher for Dynimo, Mariana and Mion (Table

1). Dynimo and Mariana produced significantly higher unmarketable yield followed by Mion and the least was Sama. Dynimo and Mariana were the cultivars with the highest total yield. However, marketable yield of all cultivars was similar, due to more unmarketable fruits in Dynimo and Mariana (Table 1). Mion had the highest incidence of blossom-end rot, although did not differ significantly from Sama (Table 4). Mariana was more susceptible to incidence of fruit rot and zippering compared to Dynimo, Mion and Sama (Table 4).

During spring/summer season, there were no significant differences in total yield, marketable yield and number of marketable fruits per plant in all cultivars with the exception of lower total number of fruits for Sama (Table 2). Furthermore, there were no differences in total yield, total number of fruits, marketable yield and number of marketable fruits/m² amongst the four cultivars (Table 3). However, Sama produced the smallest unmarketable yield and mass of extra-small sized fruits compared to Dynimo, Mariana and Mion. Similar to results obtained in spring/summer season, extra-small sized fruits contributed to high unmarketable yield for cultivars Dynimo, Mariana

and Mion (Table 3). Generally, Dynimo produced a small number of fruits (Tables 1 and 2), but larger sized fruits. Results showed that spring/summer season cultivars produced higher unmarketable yield and total yield than summer/fall growing season. Incidence of cat-face and zippering were not affected by cultivar, however, fruit rots were high for cultivars Dynimo, Mariana and Mion during summer/fall season (Table 5). When selecting tomato cultivars, growers should consider the market demand, fruit characteristics as well as the yielding potential and resistance to diseases. Mariana was more susceptible to incidence of fruit rot and zippering compared to Dynimo, Mion and Sama which contributed to high unmarketable yield. Although, Sama produced fruits with the least unmarketable yield and number of marketable fruits, it performed similarly to other cultivars in terms of marketable yield. The reason is due to the larger sized fruits produced by this cultivar, Sama. High incidence of extra-small sized fruits (Table 1) contributed to high unmarketable yield among the cultivars.

Results indicate that a plant density of 20 plants/m² can improve marketable yield of determinate tomato cultivars during spring/summer season in closed

hydroponic system using gravel-film technique. However, during summer/fall season a plant density of 10 plants/m² was most cost effective, with no significant increase in yield at higher densities. Prior to this study there was no standard plant density recommendation available for determinate tomato cultivars in a closed (gravel) hydroponic system. This information will enable farmers to optimise yield and quality of determinate tomato cultivars under closed hydroponic systems.

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