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PRODUÇÃO DE MORANGO EM FUNÇÃO DO ARRANJO DE PLANTAS E DA DISTRIBUIÇÃO DA FERTIRRIGAÇÃO EM SUBSTRATOS

JANICE VALMORBIDA[1]; ANDERSON FERNANDO WAMSER[1] E JANAÍNA PEREIRA DOS SANTOS[1]

[1] *Estação Experimental de Caçador, Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina (Epagri), Rua Abílio Franco, 1.500, Bairro Bom Sucesso, 89.501-032, Caçador, SC, Brasil, E-mail: janicevalmorbida@epagri.sc.gov.br, afwamser@epagri.sc.gov.br e janapereira@epagri.sc.gov.br*

1 RESUMO

Expandir áreas de cultivo de morango em substrato demanda aperfeiçoar as técnicas de manejo da cultura. O objetivo deste trabalho foi avaliar arranjos de plantas e formas de distribuição da fertirrigação no cultivo do morango em substrato. O experimento foi conduzido em ambiente protegido, blocos casualizados, esquema fatorial com cinco arranjos de plantas, duas formas de distribuição da fertirrigação e três safras. A parcela foi composta por um saco de cultivo preenchido com substrato comercial, contendo oito plantas. Foram avaliadas, sobrevivência de plantas, produtividade, número e massa de fruto total, comercial e descarte. Não houve efeito do arranjo de plantas e da forma de distribuição da fertirrigação sobre o número e a produtividade de frutos comerciais nas classes 35 e 15. Os arranjos de plantas losangular e retangular proporcionaram menor sobrevivência de plantas a partir da terceira safra. A manutenção das plantas por três safras no mesmo substrato diminui a produtividade no terceiro ano. O uso de quatro estacas gotejadoras por saco de cultivo pode ser uma alternativa para diminuir os custos com a utilização do sistema de irrigação de maior precisão. Os arranjos de plantas avaliados não interferiram na produtividade de frutos de morango, em três safras sucessivas.

Palavras-chave: *Fragaria* x *ananassa* Duch., agricultura de precisão, cultivo sem solo.

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STRAWBERRY PRODUCTION AS A FUNCTION OF PLANT ARRANGEMENT AND FERTIRRIGATION DISTRIBUTION ON SUBSTRATES

2 ABSTRACT

Expanding strawberry growing areas in substrates requires improving crop management techniques. The objective of this work was to evaluate plant arrangements and distribution forms of fertigation in strawberry cultivation in substrate. The experiment was carried out in a protected environment, randomized blocks, and a factorial scheme with five plant arrangements, two forms of fertigation distribution and three harvests. The plot consisted of a cultivation bag filled with a commercial substrate, containing eight plants. Plant survival, productivity, number and mass of total, commercial and discarded fruits were evaluated. There was no effect of plant arrangement and fertigation distribution method on the number and yield of commercial fruits in classes 35 and 15. The lozenge and rectangular plant

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arrangements provided lower plant survival from the third harvest. Keeping the plants for three seasons in the same substrate decreases productivity in the third year. The use of four drip piles per cultivation bag can be an alternative to reduce costs with the use of a more accurate irrigation system. The plant arrangements evaluated did not affect the productivity of strawberry fruits in three successive harvests.

Keywords: *Fragaria* x *ananassa* Duch., precision agriculture, soilless cultivation

3 INTRODUCTION

The increase in strawberry production areas requires new cultivation technologies to be transferred to growers. Producers face solutions that end up burdening their work, and the answer is not always increased productivity. Many management practices currently used in strawberry cultivation require scientific testing and answers. Answering these questions will enable growers to adopt more rational and sustainable methods for growing strawberries in substrates.

The state of Minas Gerais is the largest national strawberry producer, but cultivation areas have expanded to other states. According to Freitas (2018), in Santa Catarina, cultivation encompasses the greater Florianópolis area, the southern coast, the Alto Vale do Rio do Peixe, the northern plateau, and the southern plateau. This expansion has been accompanied by the replacement of soil with substrate in suspended and protected cultivation. Substrate cultivation facilitates daily work but requires greater investment and management technologies.

The spacing and arrangement of strawberry plants are rarely studied factors in terms of substrate cultivation. Miranda et al. (2014) recommended a density of eight plants per grow bag (13.3 plants m $^{-2}$) in a triangular plant arrangement. Bortolozzo et al. (2007) recommended planting in a rectangular shape with a 20 cm spacing. On the other hand, linear planting is common in commercial strawberry cultivation in substrates. The different types of arrangements adopted, as well as other possible plant arrangements, can affect the ecophysiology of the crop and, consequently, fruit production.

The distribution of fertilizer commonly used by growers involves placing dripper tubes through the growing bags, with a 10-cm spacing between drippers (BORTOLOZZO et al., 2007). However, this technique is only recommended for soilless strawberry cultivation in gutters filled with substrate (MIRANDA et al., 2014). This system has the disadvantage of having many drippers located between the growing bags, and consequently, the nutrient solution from these drippers is lost to the environment. Another drawback is the impossibility of changing the position of the drippers throughout the crop cycle. Changing the dripper position is recommended to avoid the formation of preferential channels in the substrate, as well as regions with relatively high salt concentrations and relatively little root development (MORALES; URRESTARAZU, 2013).

For strawberry cultivation in grow bags, the use of drip stakes connected by microtubes to online drippers, also called drip buttons, is recommended (MIRANDA et al., 2014). However, this system is more costly than the drip tube system because of the need for one drip stake per plant. One possibility is to reduce the number of drip stakes, using one for every two plants. The distribution method can alter crop productivity (MORALES; URRESTARAZU, 2013); therefore, evaluating strawberry cultivation in substrates with different numbers of drip stakes per plant is important.

The objective of this work was to evaluate the plant arrangements and forms of fertigation distribution in strawberry cultivation substrate during three consecutive harvests.

4 MATERIALS AND METHODS

The experiment was conducted between June 2016 and March 2019, and three harvests were evaluated in a protected greenhouse with an arched roof that was four meters high, 16 m wide, and 48 m long. The greenhouse was covered with 150-micron plastic film and side-closed with a white screen with 20% shading. The greenhouse soil surface was covered with medium-grain gravel.

The experimental design was a randomized complete block design with a 5x2x3 factorial design and four replications. The treatments consisted of a combination of five plant arrangements: linear, rectangular, triangular, trapezoidal, and diamond-shaped (Figure 1); two fertigation distribution methods: 1) one dripper with four dripper stakes per grow bag and 2) two drippers with eight dripper stakes per grow bag (Figure 2); and three crop seasons: 2016/2017, 2017/2018, and 2018/2019. The plot consisted of a growth bag that was 120 cm long, 22 cm in diameter, and 45 L in volume and contained eight plants. The growth bags were filled with the commercial substrate Tecnomax® (Ferticel, Vargem Bonita, SC, Brazil).

The day-neutral cultivar San Andreas was used, with seedlings produced by a specialized nurseryman in Chile. Planting took place on June 28, 2016, and no further planting or replanting of seedlings was carried out in subsequent seasons. All the plants in the plot were considered useful.

The cultivation structure consisted of four six-meter-long benches, each containing two rows of growth bags spaced 30 cm apart. The spacing between benches was 90 cm.

The fertigation system consisted of a 1000 L nutrient solution tank, a 0.5 HP motor pump, a solenoid valve for each fertigation distribution factor level, a filter, and ¾" piping to transfer the nutrient mixture to the plots. Self-compensating, nondraining online drippers with a flow rate of 8 L h^{-1}, according to the treatment (Figure 2), were fixed to the ¾" piping. A fertigation distribution system was inserted into each online dripper, which consisted of a four-outlet *manifold*, four 70 cm long 4x6 mm microtubes, and four labyrinthine dripper stakes (Figure 2).

The macronutrient concentrations in the nutrient solution followed the recommendation of Castellane and Araújo (1994), with 125 of N-NO_3, 46 of P, 176 of K, 119 of Ca, 24 of Mg and 32 of S. Calcium nitrate (475 mg L^{-1}), potassium nitrate (255 mg L^{-1}), monopotassium phosphate (190 mg L^{-1}) and magnesium sulfate (205 mg L^{-1}) were used as sources of macronutrients. The macronutrient concentrations corresponded to the addition of 50 g 1000 L^{-1} commercial product (0.85% B, 0.5% Cu, 3.4% Fe, 3.2% Mn, 0.05% Mo, and 4.2% Zn), with values of 0.42 B, 0.24 Cu, 1.7 Fe, 1.6 Mn, 0.03 Mo and 2.1 Zn. Sixty-five milliliters of 1000 L^{-1} nitric acid (density = 1.39 g mL^{-1}; concentration = 65%) was also used to neutralize part of the bicarbonate in the irrigation water and maintain the pH of the nutrient solutions in the range of 5.8--6.2. The final electrical conductivity (EC) of the nutrient solutions was, on average, 1.2±0.2 dS cm^{-1}.

Figure 1. Strawberry plants (green clouds) were arranged in the growing bags according to the plant arrangement.

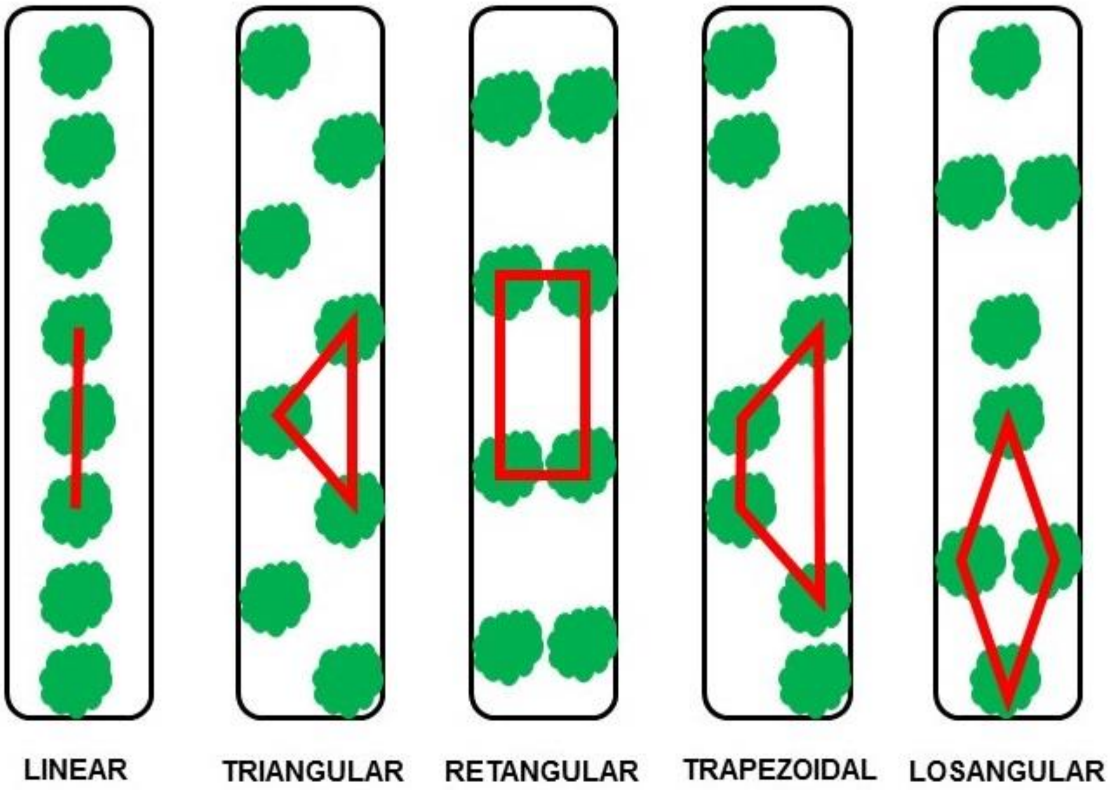
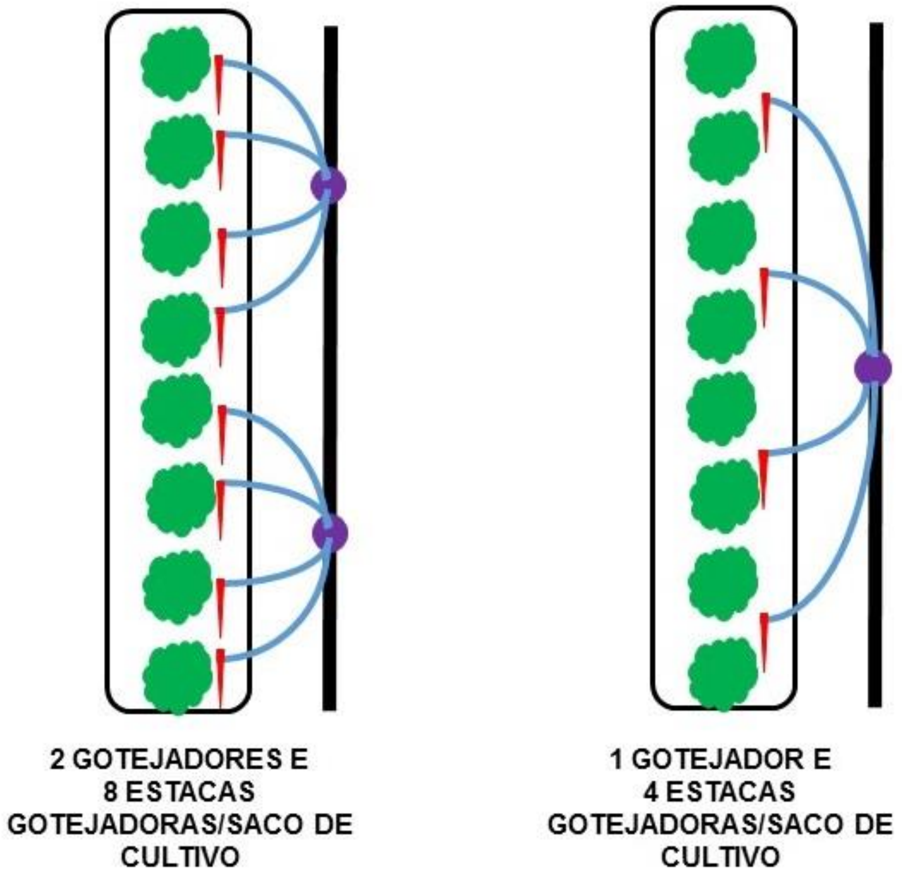


Figure 2. Number of drippers (purple circles) and distribution of drip stakes (red arrows) in the growth bag according to the fertigation distribution method.



Fertigation was performed at each irrigation site via complete nutrient mixture. The daily frequency and duration of each irrigation event were programmed on a digital timer so that the volume of nutrient solution applied was sufficient to promote 10 to 20% daily drainage. The volume of nutrient solution applied at each fertigation was the same for all the treatments. The volume and EC of the fertigated solutions were collected and measured daily via a dripper installed in each treatment. A container was established for each treatment to collect the drainage volume and EC.

When the EC of the drained solution was 0.5 dS m^{-1} higher than that of the applied nutrient solution, the drainage percentage was increased to prevent substrate salinization. Disease and pest control was monitored weekly, with chemical treatment applied when necessary. Weekly cleaning was carried out to remove diseased and/or damaged leaves and fruits. Renewal pruning was performed, leaving three crowns per plant (BACKES; COCCO; SCHILDT, 2020), on June 21, 2017, in the first year, and May 11, 2018, in the second year.

Strawberries were harvested at the ripe stage, with more than 70% of the surface red every three days. At each harvest, the number and mass (g) of commercial fruit were evaluated and classified as class 35 (largest equatorial diameter greater than 35 mm), class 15 (largest equatorial diameter between 15 and 35 mm) and discard (fruit with the largest equatorial diameter less than 15 mm, attacked by insect pests, with physiological disorders or diseased).

In the 2016/2017 and 2017/2018 harvests, 71 harvests were carried out over nine months, and in the 2018/2019 harvest, 50 harvests were carried out over eight months. At the end of each harvest, the number of surviving plants was evaluated.

The average prices of irrigation system components were obtained from two regional companies, with the aim of analyzing the cost of fertigation distribution methods in growing bags.

The data were subjected to analysis of variance via the F test, and when statistical significance was reached ($p<0.05$), the means were compared via the Tukey test at 5% probability.

5 RESULTS AND DISCUSSION

There was a significant interaction only for plant survival as a function of plant arrangement and harvest ($p<0.05$). Regardless of the arrangement, plant survival decreased significantly only at the third harvest evaluated. Plant survival was not influenced by the way in which fertigation was distributed in the growth bag (Table 1).

Among the plant arrangements, at the third harvest, the rectangular arrangement led to greater plant mortality, similar to the diamond arrangement (Table 1). These two arrangements have two plants in the same transverse line across the grow bag. In this system, vegetative growth mutually forces the plants in the same transverse line, loosening their anchorage in the substrate. Because these plants are located on the sides of the growth bag, their support base decreases, placing greater stress on the root system under the weight of the plants during the fruiting phase. This study provides the first report demonstrating that plant mortality increases from the third harvest onward and is more significant in arrangements with plants located on the sides of the growing bags, such as rectangular and diamond arrangements.

Table 1. Survival of strawberry plants of the San Andreas cultivar according to the harvest, plant arrangement and fertigation distribution methods in the growing bags.

Factor level	**Harvests [1]**		
	2016/17	**2017/18**	**2018/19**
	----------------------------	%	----------------------------
Plant arrangement			
Linear	100 aA	96.8 aA	76.5 aB
Diamond-shaped	100 aA	92.1 aA	60.9 abB
Rectangular	100 aA	92.1 aA	45.3 bB
Trapezoidal	100 aA	93.7 aA	67.1 aB
Triangular	100 aA	95.3 aA	65.6 aB
Distribution of fertigation per grow bag			
1 dripper and 4 stakes		52.9 ^{ns}	
2 drippers and 8 stakes		51.8	

[1] Plant survival determined at the end of each season. ^{ns} Not significant according to the F test at a 5% probability of error. Means followed by the same lowercase letters in the columns and uppercase letters in the rows are not different from each other according to Tukey's multiple comparisons of means test at a 5% probability of error.

Plant arrangement did not affect the number of commercial fruits or the number of fruits in classes 35 and 15 (Table 2). However, there was a greater production of fruits classified as discarded in the linear plant arrangement, which did not differ from the diamond and triangular arrangements. With respect to the cultivation seasons, in 2017/18, there was a greater number of commercial fruits, although the proportion of Class 35 fruits in the composition of commercial fruits decreased considerably compared with that in the first season. The lowest number of commercial fruits was found in the previous season.

Table 2. Number of strawberry fruits, cultivar San Andreas, according to the harvest, the form of fertigation distribution and the arrangement of plants in the growing bags.

Factor level	Class 35	Class 15	Commercial [1]	Disposal	Total
	------------------ Number of fruits (x 1000)/hectare -----------------				
Harvest					
2016/17	1,474 a	5,784 b	7,258 b	1.150 c	8,408 b
2017/18	74 c	9.108 a	9.182 a	3,081 a	12,263 a
2018/19	145 b	6.204b	6,349 c	2,317 b	8,666 b
Distribution of fertigation per grow bag					
1 dripper and 4 stakes	548 ^{ns}	6,876 ^{ns}	7,424 ^{ns}	2,128 ^{ns}	9,552 b
2 drippers and 8 stakes	580	7.188	7,768	2,238	10,006 a
Plant arrangement					
Linear	528 ^{ns}	7,313 ^{ns}	7,841 ^{ns}	2,462 a	10.303 a
Diamond-shaped	569	7.193	7,762	2,150 ab	9,912 ab
Rectangular	551	6,738	7,289	2.019 b	9,308 b
Trapezoidal	568	6,799	7,367	2,038 b	9.405ab
Triangular	605	7.121	7,726	2,243 ab	9,969 ab

^{ns} Nonsignificant according to the F test at a 5% probability of error. Means followed by the same letters in the same column do not differ from each other according to Tukey's multiple comparisons of means test at a 5% probability of error.
[1] Commercial = sum of class 35 + class 15

With a greater number of commercial fruits (Table 2), the second harvest presented a lower average commercial fruit weight (10.9 grams) (Table 3). Thus, the increase in the number of fruits produced by the strawberry plant reduced the individual fruit weight due to the decrease in the source–demand relationship. These results are in agreement with the work of Menezes Júnior and Vieira Neto (2019), who demonstrated that an increase in the number of fruits contributes to a reduction in the average weight of the fruits of the San Andreas cultivar. According to Lima et al. (2021), higher yields result in smaller fruits.

Table 3. Average mass of commercial strawberry fruit, cultivar San Andreas, according to the harvest, the form of fertigation distribution and the arrangement of plants in the growing bags.

Factor level	**Class 35**	**Class 15**	**Commercial**
	-------------------------	grams/fruit	-------------------------
Harvest			
2016/17	22.2 c	11.2 a	13.4 a
2017/18	26.6 a	10.8 b	10.9 c
2018/19	25.0 b	11.1 a	11.5 b
Distribution of fertigation per grow bag			
1 dripper and 4 stakes	24.6 ^{ns}	11.1 ^{ns}	12.0 ^{ns}
2 drippers and 8 stakes	24.7	11.0	11.9
Plant arrangement			
Linear	24.5 ^{ns}	10.8 b	11.6 b
Diamond-shaped	24.6	11.0 ab	11.9 ab
Rectangular	24.4	11.2 a	12.1 a
Trapezoidal	24.6	11.0 ab	12.0 ab
Triangular	24.9	11.1 a	12.1 a

^{ns} Nonsignificant according to the F test at a 5% probability of error. Means followed by the same letters in the same column do not differ from each other according to Tukey's multiple comparisons of means test at a 5% probability of error.

The yields of commercial fruits and classes 35 and 15 were not influenced by the fertigation distribution method or plant arrangement (Table 4). The production of discarded fruit was greater in the linear and triangular plant arrangements. Commercial fruit yield decreased only from the third harvest analyzed, although fruit yield in class 35 declined from the second harvest onward. The decrease in commercial productivity at the third harvest was 27.3% compared with that at the previous harvest, indicating that, from the third year of cultivation onward, a decrease in productivity may indicate the need to renew the growing substrate and seedlings. According to Adams (2004), the substrate should be replaced when the loss in yield revenue covers the cost of acquiring new substrates and seedlings. Commercial productivity, among the three harvests evaluated, was greater than the average recorded in the state of Santa Catarina for a similar strawberry training system (FREITAS, 2018).

The number of drip stakes did not influence the number, average mass, or yield of commercial fruits or classes 35 and 15 (Tables 2, 3, and 4). These results contrast with those of Morales and Urrestarazu (2013), who reported that, in tomato, an increase in drip stakes per plant increased the number of large fruits, although there was no increase in commercial production. According to the authors, increasing the number of drip stakes allows for better distribution of the nutrient solution throughout the growing bag, thus avoiding areas of salt accumulation in the substrate and promoting greater root development of the plants.

Table 4. Productivity of strawberry fruits, cultivar San Andreas, according to the harvest, the form of fertigation distribution and the arrangement of plants in the growing bags.

Factor levels	Class 35	Class 15	Commercial [1]	Disposal	Total
	--------------------------- tons/hectare				---------------------------
Harvest					
2016/17	32.8 a	64.8 b	97.6 a	6.7 c	104.3 b
2017/18	1.9 c	98.5 to	100.4 a	15.7 to	116.1 a
2018/19	3.6 b	69.4 b	73.0 b	12.0 b	85.0 c
Distribution of fertigation per grow bag					
1 dripper and 4 stakes	12.5 ^{ns}	76.1 ^{ns}	88.6 ^{ns}	11.1 ^{ns}	99.7 b
2 drippers and 8 stakes	13.1	79.0	92.1	11.7	103.8 a
Plant arrangement					
Linear	12.0 ^{ns}	79.0 ^{ns}	91.0 ^{ns}	13.0 a	104.0 ^{ns}
Diamond-shaped	12.9	79.2	92.1	10.9 b	103.0
Rectangular	12.3	75.1	87.4	10.8 b	98.2
Trapezoidal	13.0	75.1	88.1	10.8 b	98.9
Triangular	13.8	79.3	93.1	11.7 ab	104.8

^{ns} Nonsignificant according to the F test at a 5% probability of error. Means followed by the same letters in the same column do not differ from each other according to Tukey's multiple comparisons of means test at a 5% probability of error.

[1] Commercial = sum of class 35 + class 15

Compared with the use of two drippers and eight drip stakes per grow bag, the use of one dripper and four drip stakes per grow bag reduced the cost of the localized drip irrigation system by 44% (Table 5). However, the cost is 8.3 times greater than that of using a drip tape system threaded through grow bags. These results support the recommendation of using fewer drippers and drip stakes per plant, reducing the cost of implementing a fertigation system using self-compensating, nondraining *online drippers* and drip stakes to distribute the nutrient solution in the growing bags.

Table 5. Reference prices of individual components of the drip irrigation system and cost per plant.

Treatment	Component	Items	Number/Grow Bag [6]	R$/unit [7]	R$/plant [10]
2 drippers and 8 dripper stakes/grow bag	Dripper [1]	Items	2	1.09	0.27
	Tube [2]	m	1,2	1.35	0.20
	Manifold [3]	Items	2	0.67	0.17
	Microtube [4]	m	5.6	0.85	0.60
	Stake [5]	Items	8	0.55	0.55
					Total = 1.79
1 dripper and 4 dripper stakes/grow bag	Dripper [1]	Items	1	1.09	0.14
	Tube [2]	m	1,2	1.35	0.20
	Manifold [3]	Items	1	0.67	0.08
	Microtube [4]	m	2.8	0.85	0.30
	Stake [5]	Items	4	0.55	0.28
					Total = 1.00
Drip tape (producer's standard) [8]	Drip tape [9]	m	1,2	0.80	0.12
					Total = 0.12

[1] Online dripper with a flow rate of 8 h $^{-1}$, self-compensating and nondraining. [2] Flexible irrigation tubing with a 16 mm diameter (3/4). [3] Manifold with four outlets. [4] Microtubing with a 6x4 mm diameter. [5] Labyrinthine dripper stake. [6] Grow bags containing eight strawberry plants. [7] Lowest price obtained in three regional stores (Santa Catarina) in July 2021. [8] Treatment not evaluated in this study. Prices were obtained only for comparison without considering possible differences in plant production. [9] Nonself-compensating drip tape with 10 cm spacing between drippers. [10] Average price considering the assembly of a structure with 4,000 plants.

Currently, strawberry growers use drip tapes threaded through the inside of growing bags. One of the disadvantages of this system is that it does not allow the dripper position to be changed throughout the crop cycle, preventing the formation of preferential channels. Furthermore, the drippers remain in contact with the substrate and can become clogged by root growth (root intrusion).

The lack of differences between the plant arrangements tested for productivity and fruit quality allows growers to choose the plant arrangement that best suits them. The linear plant arrangement makes it easier to open the holes in the growth bags. for seedling placement, potentially reducing the time required for this operation. However, characteristics such as the severity of foliar and fruit diseases, as well as attack by insect pests and mites, have not been evaluated. These factors can be influenced by the plant arrangement, which creates favorable conditions for disease development or hinders fungicide or insecticide coverage. In longer growing cycles, which exceed two harvests, the use of a linear arrangement is preferable because it promotes lower plant mortality, contradicting the recommendations of Bortolozzo et al. (2007) and Miranda et al. (2014), who recommended rectangular and triangular arrangements, respectively.

6 CONCLUSIONS

In the production systems tested, the strawberry yield potential increased over two harvests. One dripper and four drip stakes should be used per grow bag. Linear, diamond-shaped, rectangular, trapezoidal, and triangular plant arrangements can be used in strawberry cultivation without compromising productivity.

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