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Impact of Nitrogen Fertigation on Watermelon Yield Grown on the Very Light Soil in Poland

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Abstract: The effect of nitrogen fertigation of two watermelon cultivars grown on the very light soil in the central part of Poland, during 2012–2014, was evaluated. The field experimental design was a split-plot with four replications. The main plot was the drip fertigation with nitrogen applied in two combinations: drip irrigation + broadcasted nitrogen fertilization (DI) used as a control, and drip irrigation + fertigation with nitrogen (DF); where, two cultivars: Bingo and Sugar Baby were used as a split-plot. The phosphorus and potassium fertilizers were applied pre plant in the spring, whereas, three rates of 40 kg ha^{-1} of nitrogen fertilizer were applied during the growing season. The fertigation was performed using a proportional mixing dispenser. The ripened fruits were harvested progressively as they mature. The marketable fruit yield, the single fruit weight and the number of fruits per plant, were evaluated. Tested factors presented a significant effect in the yield characteristics, further the interaction among the factors was important. DF, comparing to DI, notably improved fruit traits. Bingo cultivar had higher yield than Sugar Baby, but Sugar Baby cultivar produced more fruits than the Bingo under the DF treatment. This study provides the evidence that on a very light soil with low water and nutrients retention capacity the performance of watermelon can be optimized when nitrogen is applied directly through drip irrigation.

Keywords: *Citrullus lanatus*; cultivar; drip irrigation; fine sand; nitrogen fertigation

1. Introduction

Watermelon (*Citrullus lanatus* (Thunb.) Matsum. et Nakai) is a species cultivated in many parts of the world. The height of watermelon fruits production in 2012 amounted 105.3 million tons that is almost 10% of word total vegetable production [1]. The watermelon crop in Poland still takes place rather on the amateur scale, because the country is influenced by a temperate climate, which significantly reduces the cultivation of this vegetable. Nevertheless, the popularity of watermelon from year to year is growing, so in the Polish National List of Vegetable Plant Varieties already placed four cultivars that are well adapted to grow on Polish territory [2].

Among the factors that influenced the development of watermelon cultivation, water and nitrogen deserve special attention. Watermelon plants have a well-developed root system, so irrigation of this species in the Polish climate has a complementary function during periods of low precipitation,

notably in the stage of intensive vegetative growth and flowering, as well during the formation and growing of the fruits [3]. However, in view of the increasing popularity of watermelon in Poland, so there is a need to develop knowledge of its cultivation. Generally, researchers consider that the irrigation and fertilization of watermelon plants are important determinants of high fruit yield and quality. Morais et al. [4] using four irrigation levels and four levels of nitrogen fertigation reported increasing of watermelon fruit yield, but interaction between factors was invisible, nevertheless the sugar content was influenced by the depth of irrigation, depths of nitrogen and by its interaction. According to study published by Hendricks et al. [5] with increasing of fertilizer and soil moisture content rising total biomass, as well as yield and dry weight of watermelon fruits, but at the same time soluble solids content and hollowheart ratings were not affected by treatments. In the experiment carried out by Araújo et al. [6] increasing nitrogen doses resulted in better watermelon plant growth, higher fruit yield, as well as dry matter content, but not influenced the fruits pH, and reduced sugar content. Souza et al. [7] noticed that nitrogen and phosphorus fertigation has a positive effect on watermelon yield, because it allows avoiding deficiency of macronutrients such as N, P, K, Ca, Mg, Fe and Mn. Santos et al. [8] also noted better watermelon fruit yield and quality with nitrogen fertigation doses increasing, but at the same time it leads to the stronger infestation by diseases such as gummy stem blight and the downy mildew. On the other hand, rising potassium doses applied by Santos et al. [9] did not result in the development of these diseases, as well as did not increase the number, weight and quality of watermelon fruits, instead irrigation influenced the progress of downy mildew and significantly raised the total and marketable yield. While Oliveira et al. [10] reported a beneficial effect of potassium fertigation and irrigation on the yield of watermelon fruit. Silva et al. [11] testing the production of components and the soluble solids content of watermelon fruits in relation to the nitrogen and potassium fertigation, also stated that potassium did not cause the variables. In turn, Cecílio Filho et al. [12] did not record the effects of different doses of nitrogen and potassium fertigation on the yield of watermelon, but they found that reducing plant spacing decrease the fruit number and yield.

Supplemental irrigation of watermelon plants clearly improves the root distribution and fruit yield [13]. According to Wakindiki and Kirambia [14] watermelon plants irrigation increases the number of fruits and yield, as well as the fruit weight, but it can also contribute to a reduction of soluble solids in fruits. Díaz-Pérez et al. [15] also noted decrease of watermelon fruit soluble solids concentration with increasing rate of irrigation, while fruits yield and weight were not visible affected by irrigation rates. Kuşçu et al. [16] testing different deficit irrigation strategies recorded maximum marketable watermelon fruit yield when the full irrigation level was used, which at the same time decreased the values of soluble solids, sugar, vitamin C and lycopene. Kirnak and Dogan [17] reported that watermelon canopy dry weights, leaf water and chlorophyll content, as well as fruit yield were considerably reduced by water stress. Melo et al. [18] analyzing different irrigation levels of watermelon plants observed positive effects of high doses of water on vegetative growth, stomatal resistance, photosynthetic efficiency and fruit yield.

The irrigation of the watermelon plants is especially important when the cultivation is carried out on a very light and sandy soil like a sand dune upland fields tested by Maruyama et al. [19]. Fernandes et al. [20] growing watermelon plants in semi-arid regions, in soil of sandy texture with low retention capacity of water and nutrients noticed a good influence of daily irrigation and nitrogen fertigation on the growth performance. Rolbiecki et al. [21,22] reported a notably beneficial effect of irrigation and fertigation on the yielding of watermelon cultivated on fine sand. Additionally, Rolbiecki et al. [22], Wakindiki and Kirambia [14], Costa et al. [23] and Souza et al. [7] comparing the effect of irrigation and fertilization on the yield characteristics of different watermelon cultivars have observed a significant influence of genetic factors on the studied traits.

The objective of this experiment was to evaluate the effect of nitrogen fertigation applied three times a growing season on the watermelon fruits yield characteristics. As the control drip irrigation and traditional fertilization were used. The marketable yield, the single fruit weight and the number

of fruits per plant of two watermelon cultivars: Bingo and Sugar Baby were evaluated. The field experience was conducted in the central region of Poland, which is characterized by high irrigation needs [24–26]. The use of nitrogen fertilization can be beneficial for crops and environment (decreased fertilizer and water use for irrigation) as well as for farmers (increased income).

2. Materials and Methods

The field experiment of nitrogen fertigation of two watermelon (*Citrullus lanatus* (Thunb.) Matsum. et Nakai) cultivars: Bingo and Sugar Baby was conducted in the central part of Poland in Kruszyn Krajeński near Bydgoszcz (53°04′53″ N, 17°51′52″ E) during the years 2012–2015. The experiment was conducted on a very light soil with the weak and very weak rye-soil-complex in a split-plot system with four replications. The soil was characterized by the low organic matter content (1.5%). The soil pH measured in KCl was 6.29. The elements content was as follows: P—62 mg 100 g^{-1}; K—87 mg 100 g^{-1} and Mg—70 mg 100 g^{-1}. The soil characteristic is presented in Table 1. Two factors were used in the study. The first factor was the nitrogen fertigation applied in two combinations: DI = drip irrigation + broadcasted nitrogen fertilization (control) and DF = drip irrigation + fertigation with nitrogen. The second factor was two watermelon cultivars: Bingo and Sugar Baby.

Table 1. Physical properties of the soil.

Genetic Horizon	Depth (cm)	Texture	Bulk Density				
			Specific (mg m^{-3})	Temporary (mg m^{-3})	Actual (mg m^{-3})	Porosity (% vol.)	Moisture (% vol.)
Ap	0–33	slightly loamy sand	2.290	1.426	1.324	42.2	10.02
AC	33–60	loose sand	2.680	1.620	1.591	40.6	2.90
C	60–150	loose sand	2.740	1.691	1.653	39.7	3.80

The soils of experimental area were ploughed using disc-plough before winter. In spring the field was harrowed to level the surface and was prepared for transplanting watermelon seedlings.

Forty-day-old watermelon seedlings were transplanted at 0.6 m within the row and 1.6 m between rows. The area of each harvest plot was 12 m^2 (15 pcs × 1.6 m × 0.5 m) and included 15 plants. The fertilization consisted of 120:100:150 kg ha^{-1} NPK. The amount of nitrogen broadcasted in the soil was also 120 kg ha^{-1}. The phosphorus and potassium fertilization were performed preplant in the spring. Doses of potassium (potash salt) and phosphorus (superphosphate) fertilizations were dependent on the abundance of these nutrients in the soil. The nitrogen fertilization (ammonium nitrate—N-NH—17.2% and N-NO—17.2%) was supplied at three single rates of 40 kg ha^{-1} (the first at 7 day, the second at 28 day, the third at 42 day after planting) during the growing season for both variants of N-fertilization. The fertigation was carried out using a proportional fertilizer dispenser 'Dosatron'. The drip irrigation and drip fertigation were done using the 'T-Tape' drip line with 30 cm distance between the emitters. The efficiency of a single emitter was 1 l h^{-1}. Water from the subsurface well for irrigation was used. Deadlines of irrigations were established on the base of soil water potential measured by the tensiometers (Soil Moisture Equipment Corp, Santa Barbara, CA, USA). The tensiometers were located at the 25 cm depth in the soil and half distance between the emitters. The drip irrigation was started when the soil water pressure was near −0.04 MPa till 100% of FWC. Harvesting was done in the physiological maturity phase of the fruits.

In the experiment the marketable yield (t ha^{-1}), the weight of single fruit (kg) and the fruits number (pcs $plant^{-1}$), were rated.

The results of the study were statistically analyzed. The calculations were provided using computer package ANALWAR-5.FR, by the Fisher-Snedecor test to determine the significance of tested factors. The significant differences for examined traits were calculated using the Tukey test at the significance level of $p = 0.05$.

The mean air temperature in Kruszyn Krajeński during the growing of watermelon plants (IV-IX) in the years 2012–2015 was 14.8 °C that was 0.2 °C higher comparing to the mean for a long period (Table 2). The warmest month of the vegetation period was July, which was characterized by the mean of 19.4 °C (0.6 °C above the mean for long period). During the vegetation period in 2014, the mean air temperature was 21.5 °C in July that was 2.7 °C higher than the mean for the long period.

Table 2. Monthly mean air temperature (°C) data during the growing season of two watermelon cultivars: Bingo and Sugar Baby (2012–2015).

Years	Months of Growing Season						Mean
	April	May	June	July	August	September	
2012	8.4	14.5	15.2	18.8	17.6	13.3	14.6
2013	7.0	142	17.4	18.9	18.1	10.7	14.4
2014	9.9	13.3	16.0	21.5	17.2	14.4	15.4
2015	7.5	12.4	15.7	18.5	20.9	13.8	14.8
Mean for 2012–2015	8.2	13.6	16.1	19.4	18.4	13.0	14.8
Mean for long period 1986–2015	8.1	13.3	16.3	18.8	18.0	13.1	14.6

The precipitation in the period from 1 April until 30 September, as the mean for the years 2012–2015, was 303.9 mm that was 6.7 mm lower than the mean for long period (Table 3). The highest precipitation occurred during the vegetation period in 2012 and was 378.2 mm (67.6 mm above the mean for long period). The lowest total rainfall amounted 193.3 mm (117.3 mm below the mean for long period) was occurred during vegetation period in 2015. In May, June and July the mean rainfall for 2012–2015 was higher than the mean for long period. The highest monthly rainfall (133.8 mm in July and 115.6 mm in August) was noted during the growing season 2012.

Table 3. Monthly amounts of rainfall (mm) data during the growing season of two watermelon cultivars: Bingo and Sugar Baby (2012–2015).

Years	Months of Growing Season						Sum
	April	May	June	July	August	September	
2012	26.5	25.4	133.8	115.6	51.8	25.1	378.2
2013	13.6	91.7	49.3	79.0	56.6	64.1	354.3
2014	40.7	65.7	44.9	55.4	57.3	25.9	289.9
2015	15.6	21.6	33.0	50.4	20.3	52.4	193.3
Mean for 2012–2015	24.1	51.1	65.2	75.1	46.5	41.9	303.9
Mean for long period 1986–2015	26.9	50.2	54.9	71.4	59.7	47.5	310.6

The seasonal irrigation water rates applied during the experiment were closely related to the course of thermal and precipitation conditions for the object of research (Figure 1).

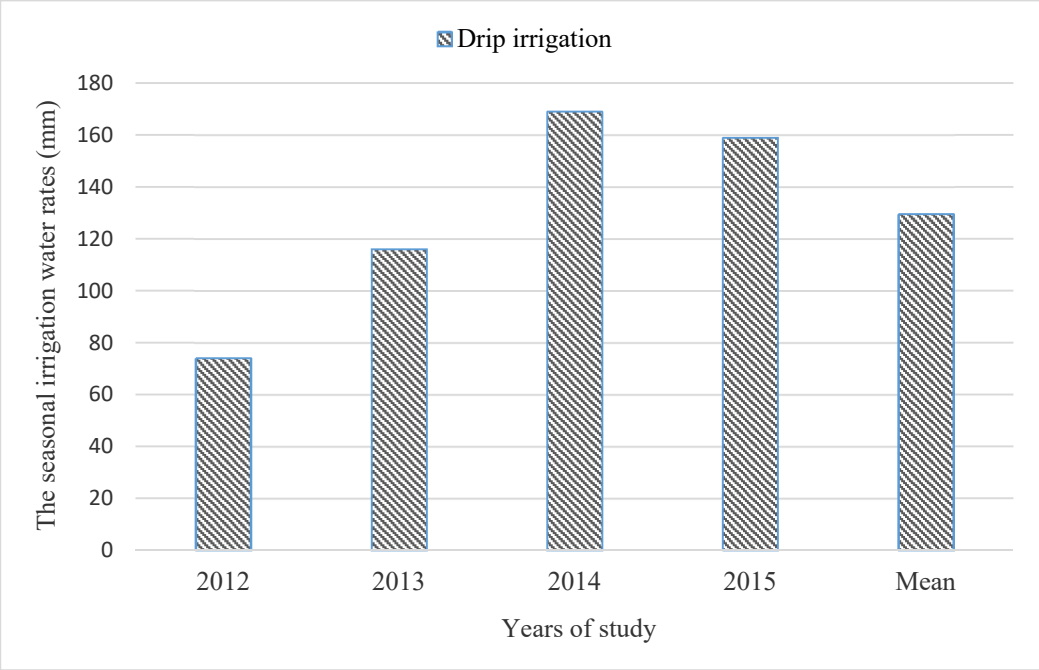

Figure 1. The seasonal water rates (mm) used for irrigation of two watermelon cultivars: Bingo and Sugar Baby during the years 2012–2015.

3. Results and Discussion

In the control field (drip irrigation combined with standard nitrogen fertilization) the mean marketable yield of two watermelon cultivars: Bingo and Sugar Baby in the years 2012–2015 was 44.31 t ha^{-1} and 40.56 t ha^{-1}, respectively (Table 4). The drip irrigation combined with nitrogen fertigation significantly influenced the increase in yields on average from 42.44 to 51.36 t ha^{-1} (by 8.92 t ha^{-1}, i.e., by 21%). As compared to the control, the liquid fertilization, supplying nitrogen to the plants, used during the cultivation of two watermelon cultivars: Bingo and Sugar Baby on a very light soil, significantly increased the fruit yield of both cultivars by 20% and 22%, respectively. The second factor of the study—watermelon cultivars—also significantly influenced the yield. The marketable yield of 'Bingo' fruits was higher by 9%, compared with the 'Sugar Baby'. According to study published by Maruyama et al. [19] and Rolbiecki et al. [21,22,27] the irrigation of the watermelon plants is especially important when the cultivation is carried out on a very light and sandy soil. Drip irrigation on a very light soil also has a positive effect on marketable yields of other vegetable species, such as zucchini, lettuce, radish and asparagus [28–30]. The yield of watermelon fruits measured in the present experiment during the years 2012–2015 was similar to those in other studies. In research by Wang et al. [31] in China watermelon yields ranged under irrigation from 44.6 to 58.5 t ha^{-1}, depending on the irrigation quantity and the year. In the study conducted in Turkey, Kuşçu et al. [16] testing different deficit irrigation strategies recorded maximum marketable watermelon fruit yield (up to 86.2 t ha^{-1}) when the full irrigation level was used. Rolbiecki et al. [21,22,27] also noted a particularly beneficial effect of irrigation and fertigation on the yielding of watermelon cultivated in Poland on very light soil with low water retention capacity. The irrigation of the cultivar Bingo grown on the same soil during the years 2005–2006 significantly increased the yield of fruits from 17.66 to 45.16 t ha^{-1} (by 156%) and from 40.1 to 51.0 t ha^{-1} (by 27%) [21]. Rolbiecki et al. [22] reporting the study on comparison of watermelon fruit yields for plants grown under conditions of drip irrigation connected with nitrogen fertigation, recorded fruit yields ranged from 32.62 to 37.87 t ha^{-1}, and from 29.09 to 30.35 t ha^{-1}, in the experiments conducted in Poland and in Turkey, respectively. Fernandes et al. [20] growing watermelon plants in semi-arid regions of Brazil, in soil of sandy texture with low retention capacity of water and nutrients, noticed a good influence of irrigation and nitrogen fertigation on the growth performance;

authors noted an increase in the yield from 50.00 to 82.95 t ha^{-1} after application of daily irrigation and nitrogen fertigation. Morais et al. [4] using the irrigation and nitrogen fertigation treatments, reported increasing of the watermelon fruit yield from 38.13 to 77.80 t ha^{-1}. Santos et al. [8] also noted in the Netherlands better watermelon fruit yield and quality with the nitrogen fertigation doses increasing. According to the authors, the dose of 40 kg ha^{-1} N has already increased the watermelon marketable fruit yield by 14 t ha^{-1}, when compared to the control without the nitrogen fertilization.

Table 4. Influence of nitrogen fertigation on the marketable yield of fruits (t ha^{-1}) of two watermelon cultivars: Bingo and Sugar Baby (2012–2015).

Treatment	Cultivar	Years of Study				Mean 2012–2015
		2012	2013	2014	2015	
DI [a]	Bingo	33.99	33.45	51.57	58.25	44.31
	Sugar Baby	38.14	28.72	45.26	50.11	40.56
	Mean	36.06	31.09	48.41	54.18	42.44
DF	Bingo	38.07	34.70	72.83	66.82	53.10
	Sugar Baby	37.60	33.95	65.61	61.29	49.61
	Mean	37.83	34.32	69.22	64.06	51.36
$LSD_{0.05}$ [b]						
Irrigation (I)		2.725	3.112	8.567	7.268	6.324
Cultivars (II)		3.664	3.082	3.660	4.680	3.071
Interaction		n.s. [c]	n.s.	n.s.	n.s.	n.s.

[a] DI = drip irrigation + broadcasted nitrogen fertilization (control); DF = drip irrigation + fertigation with nitrogen. [b] LSD—the lowest significant difference (Tukey's confidence half-interval) at $p < 0.05$. [c] n.s.—not significant at $p < 0.05$.

The increase in the marketable yield of fruits results primarily from a significant increase in the single fruit weight and the number of fruits from one plant. The plants of 'Bingo' produced fruits with significantly higher weight than the plants of 'Sugar Baby'. The drip fertigation with nitrogen considerably increased the average weight of the single fruit of both watermelon cultivars: Bingo and Sugar Baby by 0.85 kg (fruit weight 3.69 kg) and by 0.59 kg (fruit weight 3.00 kg), respectively (Table 5). In the study conducted during 2005–2006 with 'Bingo', the weight of single fruits (3.25 kg) collected from irrigated plots was similar to the weight obtained in the present experiment [27], but in 2008 the weight of fruits (5.47 kg) was much higher [21]. According to the study published by Wang et al. [31] the watermelon fruit weight ranged—depending on the irrigation treatment—from 2.62 to 3.79 kg. In the experiment carried out by Fernandes et al. [20], the fruit weight was higher and ranged—under conditions of drip irrigation and fertigation—from 8.00 to 11.62 kg. According to Wakindiki and Kirambia [14] irrigation of watermelon plants increases the fruit weight, as well as the number of fruits and the yield. In the experiment carried out in semi-dry climates of Kenya the fruit weight ranged from 4.00 kg in the control to 7.42 kg in the irrigated treatments, whereas the number of fruits per plant ranged from 0.0 to 6.6 pcs plant^{-1}.

In the present research the nitrogen fertigation significantly influenced the increase of the number of fruits per plant (Table 6). The mean number of fruits per plant in the case of drip fertigated ones was 1.80 pcs plant^{-1}. Comparing to the control (drip irrigation combined with standard nitrogen fertilization), the rise of the number of watermelon fruits per plant was 20% when the drip fertigation was applied. A similar increase, of 20%, in the number of 'Bingo' fruits harvested from the plants that were drip fertigated with nitrogen, was reported by Rolbiecki et al. [21].

Table 5. Influence of nitrogen fertigation on the single fruit weight (kg) of two watermelon cultivars: Bingo and Sugar Baby (2012–2015).

Treatment	Cultivar	Years of Study				Mean 2012–2015
		2012	2013	2014	2015	
DI	Bingo	3.22	2.23	3.80	2.13	2.84
	Sugar Baby	3.44	2.12	2.64	1.45	2.41
	Mean	3.33	2.18	3.22	1.79	2.63
DF	Bingo	5.53	2.73	4.02	2.48	3.69
	Sugar Baby	4.90	2.37	2.97	1.78	3.00
	Mean	5.21	2.55	3.50	2.13	3.35
$LSD_{0.05}$						
Irrigation (I)		0.748	0.207	0.131	0.240	0.461
Cultivars (II)		0.696	0.214	0.209	0.221	0.412
Interaction		n.s.	n.s.	n.s.	n.s.	n.s.

Explanations: see Table 4.

Table 6. Influence of nitrogen fertigation on the number of fruits of two watermelon cultivars: Bingo and Sugar Baby (pcs plant^{-1}).

Treatment	Cultivar	Years of Study				Mean 2012–2015
		2012	2013	2014	2015	
DI	Bingo	0.95	1.10	1.23	1.24	1.13
	Sugar Baby	1.05	1.25	1.59	1.55	1.36
	Mean	1.00	1.17	1.41	1.39	1.25
DF	Bingo	1.15	1.70	1.72	1.66	1.56
	Sugar B	1.75	2.20	2.04	2.18	2.04
	Mean	1.45	1.95	1.88	1.92	1.80
$LSD_{0.05}$						
Irrigation (I)		0.265	0.481	0.188	0.222	0.239
Cultivars (II)		0.224	0.347	0.097	0.145	0.105
Interaction (II × I)		0.317	n.s.	n.s.	n.s.	0.149
Interaction (I × II)		0.333	n.s.	n.s.	n.s.	0.259

Explanations: see Table 4.

Studying the effect of drip fertigation with nitrogen on the amount of fruits harvested from one plant in the case of two watermelon cultivars: Bingo and Sugar Baby, the significant interaction between tested factors was obtained in 2012 and in the period 2012–2015 (Table 6). 'Sugar Baby' produced 31% more fruits than 'Bingo' when the liquid fertilization was applied. During the period 2012–2015 'Sugar Baby' plants cultivated under drip fertigation produced significantly higher number of fruits per plant than 'Bingo' plants. Wakindiki and Kirambia [14], Costa et al. [23] and Souza et al. [7], comparing the effect of irrigation and fertilization on the yield characteristics of different watermelon cultivars, also observed a significant influence of genetic factors on the studied traits.

The novelty of the above field studies is that they first of all filled the existing cognitive gap in the literature and proved that nitrogen fertigation in watermelon cultivation is also effective in the soil and climate conditions of Central Europe (central Poland), giving valuable results comparable to those obtained in different soil and climate conditions of other regions of the world [32–35].

4. Conclusions

Through the results found in this study, it could be stated that on a very light soil with low retention capacity of water and nutrients, watermelon plants should be drip fertigated with nitrogen (liquid fertilization), in order to obtain the best performance of the cultivation. As compared to the control (drip irrigation combined with standard nitrogen fertilization), the liquid fertilization, supplying nitrogen to the plants, used during the cultivation of two watermelon cultivars: Bingo and Sugar Baby on a very light soil, significantly increased the fruit yield from 44.31 to 53.10 t ha^{-1} (by 20%) for 'Bingo' and from 40.56 to 49.61 t ha^{-1} (by 22%) for 'Sugar Baby'. Fertilization applied in liquid form (drip fertigation) increased also the weight of single fruits and the number of fruits per plant of both tested cultivars, in relation to the control. 'Sugar Baby' produced 31% more fruits than 'Bingo' when the liquid fertilization was applied. During the period 2012–2015 the plants of 'Sugar Baby' produced under drip fertigation significantly higher number of fruits per plant than 'Bingo' plants.

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Abbreviations

DI (drip irrigation + broadcasted nitrogen fertilization)
DF (drip irrigation + fertigation with nitrogen)

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