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Watermelon cultivation in regeneration areas of a sugarcane field under different soil managements

Abstract – The objective of this work was to evaluate watermelon (*Citrullus lanatus*) cultivation in regeneration areas of a sugarcane field, under different soil management systems and N fertilization regimes. Two experiments were carried out in the 2014/2015 and 2015/2016 harvest seasons, in areas of sugarcane plantation in Andradina, in the state of São Paulo, Brazil. Cultivations were performed in a randomized complete block design, with plots and subplots, and four replicates. The plots represented the tillage systems (conventional, minimum tillage, and no-tillage), and the subplots, the different N fertilization rates (0, 100, 200, and 300 kg ha⁻¹) applied as topdressing. In 2014/2015, the minimum tillage system resulted in the highest commercial yield of 70.2 Mg ha⁻¹. In 2015/2016, there were no differences for yield among tillage systems; however, yield differed among N treatments. The highest commercial yields of 64.1 and 31.1 Mg ha⁻¹ were achieved with the N doses of 253 and 209 kg ha⁻¹ as topdressing, respectively, in 2014/2015 and 2015/2016. Watermelon can be cultivated in regeneration areas of sugarcane field, and the demand of N by the plant does not depend on the soil tillage system.

Index terms: *Citrullus lanatus*, conservational system, crop rotation, nitrogen fertilization.

Cultivo de melancia em áreas de renovação de canal sob diferentes manejos do solo

Resumo – O objetivo deste trabalho foi avaliar o cultivo de melancia (*Citrullus lanatus*) em áreas de renovação de canal, em diferentes sistemas de preparo do solo e adubação nitrogenada. Foram realizados dois experimentos nas safras de 2014/2015 e 2015/2016, em áreas de plantio de cana-de-açúcar, em Andradina, no Estado de São Paulo, Brasil. Os cultivos foram feitos em delineamento experimental de blocos ao acaso, com parcelas, subparcelas e quatro repetições. As parcelas representaram os sistemas de preparo do solo (plantio convencional, cultivo mínimo e plantio direto), e as subparcelas, as diferentes doses de N aplicadas em cobertura (0, 100, 200 e 300 kg ha⁻¹). Em 2014/2015, o cultivo mínimo apresentou a maior produtividade comercial de 70,2 Mg ha⁻¹. Em 2015/2016, não houve diferenças quanto à produção entre os tratamentos de preparo de solo; porém, a produção diferiu entre os tratamentos com N. As maiores produtividades comerciais de 64,1 e 31,1 Mg ha⁻¹ foram obtidas com as doses de 253 e 209 kg ha⁻¹ de N em cobertura, respectivamente, em 2014/2015 e 2015/2016. A melancia pode ser cultivada em áreas de renovação de canal, e a demanda de N pela planta não depende do sistema de preparo de solo.

Termos para indexação: *Citrullus lanatus*, cultivo conservacionista, rotação de culturas, adubação nitrogenada.

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Introduction

Brazil is the world's largest producer of sugarcane, with the annual harvest of 684 million tons in the 2016/2017 harvest (Acompanhamento..., 2016). After planting, crop productivity decreases year after year, until replanting is done after an average of 5 years. This agricultural practice is known as crop rotation (Santiago & Rossetto, 2008). This practice is usually performed in periods of higher rainfall, and it involves processes such as grazing and subsoiling, which causes soil losses owing to erosion (Bolonhezi et al., 2007). The adoption of mechanized sugarcane harvesting stimulated the gradual elimination of fires that resulted in the deposition of a large amount of straw and dry matter on the soil surface. Most of the replanting areas remain unoccupied from the end of the harvest to the beginning of replanting, allowing of the implementation of planting practices for the conservation management (Bolonhezi et al., 2007) of sugarcane straw by crop rotation. Previous studies evaluated sugarcane crop rotation with peanuts (Bolonhezi et al., 2007; Barbosa et al., 2014), soybean (Finoto et al., 2015), and green manure (Ambrosano et al. 2011). However, to the best of our knowledge, no studies have evaluated crop rotation with vegetables until present. Therefore, watermelon (*Citrullus lanatus*) cultivation, which has a high socioeconomic importance in tropical regions, provides an option of encouraging the cultivation of food crops in sugarcane regeneration areas. Watermelon is one of the main cucurbits cultivated in Brazil; it is planted in a 94,375 ha area, and its yield is 2,171,448 Mg per year (FAO, 2014). Watermelon is grown in the state of São Paulo, primarily in sandy soils (Branco et al., 2014), in degraded pasture lands. Watermelon cultivation requires N as one of the most important nutrients whose deficiency limits this crop productivity (Grangeiro & Cecílio Filho, 2004; Leão et al., 2008). The recommended fertilizer application for watermelon growth in São Paulo state is from 80 to 130 kg ha⁻¹ N (Trani et al., 1997) during the crop cycle.

Few studies have evaluated the conservation management of watermelon cultivation. Rocha et al. (2011) compared the use of conventional tillage, minimum tillage, and no-tillage systems with a scarifier, and observed that the highest yield occurred in conventional tillage (126.5 Mg ha⁻¹), whereas that in the no-tillage treatment was lower (74.1 Mg ha⁻¹). In no-tillage systems, the presence of straw on the soil

surface changes the physical, chemical, and biological soil properties, leading to an higher soil fertility and yield than those in the conventional tillage system (Bernoux et al., 2006; Tivelli et al., 2010). The use of straw in no-tillage systems facilitates the colonization by microorganisms, in contrast to conservation tillage systems (Simpósio..., 2007). Therefore, different soil tillage systems may differently affect the flow of water and nutrients, including N.

Predicting N dynamics in soils under no-tillage systems is difficult because this dynamics depends on the rate of straw decomposition and on the amount of available N for the rotation crop. Therefore, the N concentration supply to the crop depends on the N level available in the soil. The amount of N released from the straw during the next cycle of sugarcane cultivation may vary from 3 to 30% (Vitti et al., 2008, 2010). However, studies show that the N incorporation by the mineralization of straw increases significantly with longer cultivation periods, and decreases with shorter cultivation periods (Vitti et al., 2011; Fortes et al., 2013); this may be the case with watermelon cultivation. Because of changes in the physical, chemical, and biological soil properties under different tillage systems, complementary nutritional studies are necessary to ensure adequate rates and periods of N application to avoid excess or lack of nutrients to the crops.

The objective of this work was to evaluate the watermelon cultivation in regeneration areas of a sugarcane field under different soil management systems and N fertilization regimes.

Materials and Methods

Two experiments were carried out during the 2014/2015 and 2015/2016 harvest seasons in sugarcane fields, in the municipality of Andradina, in the state of São Paulo, Brazil. The geographic coordinates of this municipality are 20°45' and 20°46'S and 51°22' and 51°22'W, at 379 m altitude.

Both sugarcane crops, each in a 30 ha area, were replanted after the seventh consecutive harvest, when the yield of sugarcane 'RB 83 5486' was less than 60 Mg ha⁻¹. In the year before the installation of both experiments, weeds in the ratoon cane were managed in September with herbicides, using 1 L ha⁻¹ clomazone, and 1.5 kg ha⁻¹ diuron with hexazinone.

The soil was classified as Latossolo Vermelho (Santos et al., 2006). The soil chemical analyses at 0–0.20 m soil depth, before starting the experiments in the 2014/2015 and 2015/2016 seasons, were respectively the following ones: $\text{pH}_{(\text{CaCl}_2)}$, 5.1 and 5.9; P_{resine} , 26 and 10 mg dm^{-3} ; organic matter, 10 and 12 g dm^{-3} ; base saturation (V), 64 and 63%; H+Al, 16 and 16 $\text{mmol}_c \text{dm}^{-3}$; K, 1.0 and 1.1 $\text{mmol}_c \text{dm}^{-3}$; Ca, 24 and 17 $\text{mmol}_c \text{dm}^{-3}$; Mg, 3 and 9 $\text{mmol}_c \text{dm}^{-3}$; sum of bases (SB), 28 and 27 $\text{mmol}_c \text{dm}^{-3}$; cation exchange capacity (CEC), 44 and 43 $\text{mmol}_c \text{dm}^{-3}$. No liming was performed in the experimental areas, and chemical fertilization was applied in the crop rows using 30 kg ha^{-1} N (urea), 240 kg ha^{-1} P_2O_5 (triple superphosphate), and 150 kg ha^{-1} K_2O (potassium chloride). Cover fertilization was performed using 100 $\text{kg K}_2\text{O ha}^{-1}$ divided into three applications at 15, 30, and 50 days after emergence.

After harvest, sugarcane crop regrowth was dried using glyphosate (3 kg ha^{-1} i.a.), and the soil was tilled. For watermelon planting, 'Olímpia' hybrid was manually sown on October 6, 2014 and October 6, 2015. Cultivation practices were adopted considering the needs of the crop, and irrigation was performed by sprinkling, using the central pivot system.

Four replicates of each treatment were arranged in a randomized complete block design. The main plots, with 192 m^2 , included three tillage systems: conventional, minimum, and no-tillage. Conventional tillage involved the incorporation of sugarcane straw into the soil, after harvest, using a disk plow, and later, a disk harrow. Minimum tillage was performed by subsoiling at 0.60 m soil depth in the crop rows, and no-tillage, by opening crop rows to 0.03 m soil depth using a seeder for direct seeding of grains. In the minimum tillage and no-tillage systems, most of the area was covered with sugarcane straw. The subplots corresponded to different N concentrations (0, 100, 200, and 300 kg ha^{-1}) in the soil cover, in the form of ammonium nitrate (33.5% N), divided into three treatments at 15, 30, and 50 days after plant emergence. Spacing was 3.0 m between rows and 1.0 m between plants within each row. Each subplot was composed of two rows of eight plants each, with 8.0 m length by 6.0 m width, totaling 48.0 m^2 . A border plant was left at each end of the subplots, and 10.0 m space was left between the plots to prevent the main rows from overlapping.

One week before watermelon planting, 10 sugarcane straw samples were collected from the experimental area where straw had not been incorporated in the soil. This procedure was repeated biweekly until 75 days after sowing (DAS), next to the experimental area. The straw samples were collected, using a 0.25 m^2 template (0.5x0.5 m), and dried in a forced-circulation air oven at 65°C, for determining the mass of straw dry matter. These measurements were subjected to regression analysis.

The following production characteristics were evaluated: total and commercial number and total fruit per plant, diameter and length of commercial fruit (m), total and commercial production of fruit (grams per plant), and total and commercial yield (Mg ha^{-1}) of fruit. The data were subjected to the analysis of variance and F-test. The effect of N concentrations was evaluated using the regression analysis, and the criterion for choosing the model was the magnitude of the coefficients of regression. Tukey's test was used for analyzing the data on the soil preparation, at the 5% probability. Data obtained from the two harvests were analyzed in combination, when the relationship between the residual mean squares of the individual analyses of variance of each crop did not exceed the 7:1 ratio (Banzatto & Kronka, 2006). Software Sisvar version 5.3 (Ferreira, 2011) was used in the statistical analyses.

Results and Discussion

In the 2014/2015 and 2015/2016 harvest seasons, the conditions of the tests (genetic material, cultivation practices, soil and relief classifications) were similar, but the climatic conditions differed. In the 2014/2015 season, rainfall was 327.6 mm, which was similar to the historical average of the region, whereas in the 2015/2016 season, rainfall was 715 mm, which was 78% higher than the historical average of the region in the period (CIAGRO, 2016). The increased precipitation limited the control of fungal diseases and caused crop yield decrease (Figure 1). The mean maximum and minimum temperatures varied from 20.9 to 33.3°C in the first year, and from 20.8 to 34.5°C in the second year; these values are similar to the historical average of the region in the period (18.7–32.7°C) (CIAGRO, 2016).

One week before watermelon sowing, the mean yield of straw dry matter in the experimental areas, in 2014/2015 and 2015/2016 seasons, was 14.5 and 15.8 Mg ha⁻¹, respectively. These values are close to those (8–20 Mg ha⁻¹) found in the literature (Vitti et al., 2008; Trivellini et al., 2013).

The dry matter yield of sugarcane straw decreased over time in the biweekly harvests and fitted to the linear functions (Figure 2), indicating a decomposition rate of up to 9.4 and 7.5 Mg ha⁻¹ straw dry mass, at 75 days after sowing, in the 2014/2015 and 2015/2016 harvests, respectively.

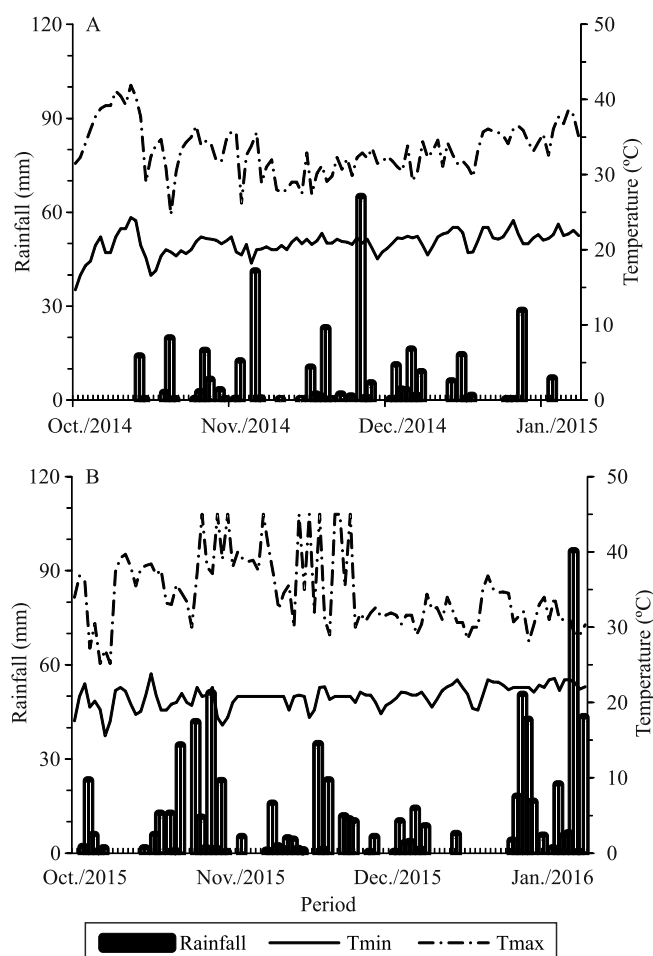


Figure 1. Rainfall, and maximum and minimum air temperatures recorded in two harvest seasons: A, 2014/2015; and B, 2015/2016, in the municipality of Andradina, in the state of São Paulo, Brazil.

There was no significant interaction between soil tillage and N concentrations applied to the soil cover ($p < 0.05$) in the two evaluated seasons. Therefore, the demand of N in watermelon production was the same, regardless of the soil tillage system adopted, with or without the incorporation of sugarcane straw. Farinelli et al. (2006) and Farinelli & Lemos (2012) evaluated N fertilization in the soil cover in bean and maize crops, using conventional tillage and no-tillage treatments, respectively, and showed that beans required higher N concentrations in the no-tillage system because of the decreased straw decomposition. In contrast, the agronomic and nutritional characteristics of maize did not differ between tillage systems and N concentrations used, although the conventional tillage had caused higher losses of N, and N application to the soil cover had promoted an increase in the incorporation of this nutrient by maize.

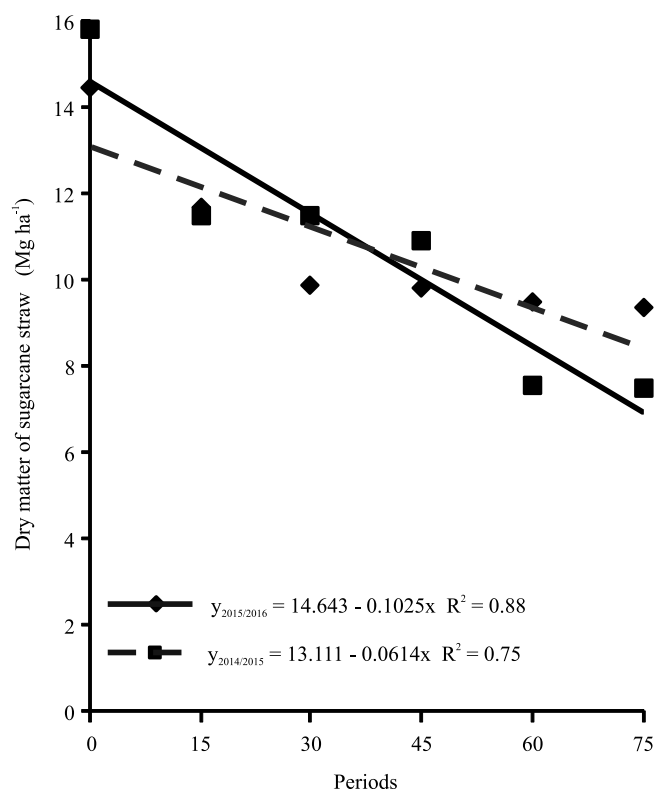


Figure 2. Effect of the collection time on the dry matter amount of sugarcane straw in the 2014/2015 and 2015/2016 harvest seasons, in the municipality of Andradina, in the state of São Paulo, Brazil.

There was a significant effect of the treatments when they were analyzed independently. In the 2014/2015 season, tillage strongly affected the production characteristics of watermelon, except for the total and the commercial number of fruit, with 2.3 and 1.5 fruit per plant, respectively. In minimum tillage, the mean fruit diameter and length were 0.82 and 0.48 m, respectively, which differed statistically from the means found for conventional tillage (0.76 and 0.46 m) and no-tillage (0.79 and 0.47 m) (Table 1). Moreover, the total and commercial production and total and commercial yield varied among the treatments, and the highest means were observed in the minimum tillage system, corresponding to 23.0 and 21.0 g per plant, and 76.8 and 70.2 Mg ha⁻¹, respectively. Commercial productivity in the minimum tillage system was 45 and 36% higher than that in the conventional tillage and no-tillage, respectively (Table 1). In the 2015/2016 season, the tillage system did not affect the evaluated production characteristics. The 2015/2016 season showed the following results: the mean total and commercial number of fruit per plant was 1.6 and 0.76 fruit, respectively; fruit diameter and length were 0.73 and 0.42 m, respectively; total and commercial production were 9.4 and 6.7 kg per plant, respectively; and total and commercial yield were 31.5 and 22.3 Mg ha⁻¹, respectively. Therefore, in the 2014/2015

season, the minimum tillage system showed the best results, with a mean commercial yield of 70.2 Mg ha⁻¹. By contrast, in the 2015/2016 season, there were no significant differences between the evaluated tillage systems, and the mean commercial yield was 22.3 Mg ha⁻¹.

Other studies reported different results for watermelon cultivation under different tillage systems. Rocha et al. (2011) compared watermelon crops cultivated on oat straw using conventional, minimum, and no-tillage systems, and performed scarification with one to four disks. They concluded that the conventional tillage system was the best treatment, with the mean crop yield of 126.5 Mg ha⁻¹. In this case, the higher soil mobilization increased the root surface area, resulting in a more homogeneous, horizontal, and deeper root system.

Silva et al. (2013) evaluated weed management of watermelon under no-tillage and conventional tillage systems. They concluded that the no-tillage system provided higher yield than the conventional tillage. Branco et al. (2014) compared watermelon cultivated on clover and oat straw under minimum tillage and no-tillage conditions, and observed that root development was restricted in the no-tillage system. However, commercial yield was similar between the treatments (27.4 Mg ha⁻¹), except for no-tillage using oat straw

Table 1. Total number of fruit per plant (TNF), number of commercial fruit per plant (NCF), fruit diameter, fruit length, total production (TP), and commercial production (CP), total yield, and commercial yield (CY) of watermelon 'Olimpia' (*Citrullus lanatus*), according to the tillage system used in the 2014/2015 and 2015/2016 harvest seasons⁽¹⁾.

Soil preparation	TNF (number per plant)	NCF	Fruit diameter ------(m)-----	Fruit length -----	TP -----(kg per plant)----	CP	Total yield ------(Mg ha ⁻¹)-----	CY
2014/2015 harvest season								
Conventional tillage	2.3a	1.4a	0.76c	0.46b	17.6b	14.4b	58.8b	48.2b
Minimum tillage	2.4a	1.9a	0.82a	0.48a	23.0a	21.0a	76.8a	70.2a
No-tillage	2.3a	1.3a	0.79b	0.47b	19.1ab	15.4b	63.7b	51.5b
DMS	-	-	0.89	1.10	5.13	4.39	17.09	14.63
F	0.47 ^{ns}	5.61 ^{ns}	180.03**	14.31**	5.52*	12.48**	5.52*	12.41**
CV (1) %	23.96	34.22	1.05	2.15	23.72	23.84	23.72	23.84
CV (2) %	22.78	34.80	2.81	4.79	24.81	26.80	24.80	26.80
2015/2016 harvest season								
Conventional tillage	1.7a	0.86a	0.74a	0.42a	10.3a	7.3a	34.4a	24.3a
Minimum tillage	1.5a	0.79a	0.74a	0.43a	9.4a	7.0a	31.3a	23.4a
No-tillage	1.4a	0.61a	0.70a	0.41a	8.6a	5.7a	28.6a	19.1a
DMS	-	-	-	-	-	-	-	-
F	1.90 ^{ns}	3.12 ^{ns}	1.10 ^{ns}	0.96 ^{ns}	2.30 ^{ns}	2.02 ^{ns}	2.32 ^{ns}	2.01 ^{ns}
CV (1) %	28.40	37.48	12.51	11.05	24.52	35.01	24.30	35.01
CV (2) %	26.90	37.37	14.51	15.17	25.56	33.07	25.63	33.10

⁽¹⁾Means followed by equal letters do not differ by Tukey's test, at 5% probability. * and **Significant at 5 and 1% probability, respectively. ^{ns}Nonsignificant.

(17.9 Mg ha⁻¹). The combined analysis of the crops indicated that the production variables were affected by the planting season, except for the fruit diameter and length, which did not meet the conditions for this type of analysis. The variables evaluated in 2014/2015 were approximately two-fold higher than in 2015/2016 (Table 2). This difference can be attributed to adverse climatic conditions, particularly the rainfall in the 2015/2016 season.

In the 2014/2015 season, the highest fruit diameter and length, commercial production and yield were affected by the different N concentrations, which fitted with the quadratic regression model (Figure 3). In the 2015/2016 season, all the production variables were affected by different N levels, except for the total number of fruit. The mean values of these variables also fitted with the quadratic regression model.

In the 2014/2015 season, the highest fruit diameter and length, and the estimated commercial production and yield were 0.81 m, 0.48 m, 18.9 kg per plant, and 64.1 Mg ha⁻¹, respectively, and these values were obtained using 195, 178, 241, and 253 kg ha⁻¹ N applications to the soil cover, respectively. In the 2015/2016 season, the highest total production and yield were 11.4 kg per plant and 37.5 Mg ha⁻¹, respectively, using 233 and 185 kg ha⁻¹ N applications to the soil cover, respectively. In the 2015/2016 season, the highest estimated number of commercial fruit, fruit diameter and length, and commercial production and yield were 1.0 fruit per plant, 0.78 m, 0.45 m, and 8.9 kg per plant, and 31.1 Mg ha⁻¹, respectively, using 195, 219, 227, 174, and 209 kg ha⁻¹ N application to the soil cover, respectively. In the state of São Paulo, the official recommendation for watermelon cultivation is

the total application from 80 to 130 kg ha⁻¹ N (Trani et al., 1997). Barros et al. (2012) studied the effect of different N concentrations in the planting of watermelon 'Crimson Sweet'. They found that the highest yield (40.4 Mg ha⁻¹) was achieved using 144.4 kg ha⁻¹ N, and this value is close to the official recommendation. In contrast, Soares et al. (2002) analyzed different doses of N for the growth of watermelon 'Crimson Sweet', and found that the highest yield (64.9 Mg ha⁻¹) was obtained using 229.8 kg ha⁻¹ N, which was close the value found in the present study.

Therefore, in the present work, the mean total N level (fertilization of crop and cover crop) that resulted in the highest yield was 93% higher than the highest recommended concentration, and some of the applied N was probably leached, volatilized, and immobilized by microorganisms. The amount of N leachate is particularly dependent on the amount of the applied N, type of soil, and volume of precipitation (Nielsen et al., 1982). The residual sugarcane straw promotes changes in the production environment and increases the C:N ratio. Fortes et al. (2012) observed that the C:N ratio of sugarcane straw initially varied from 70:1 to 108:1 but decreased along the harvests. The release of N by straw is slow, and its use by the subsequent crop is also low, according to Vitti et al. (2008), primarily because of the high initial C:N ratio of sugarcane straw, which favors the immobilization of N by soil microorganisms (Jingguo & Bakken, 1997). Therefore, as compared with the official recommendations, the high-N concentrations applied for higher productivity in the present work may be related to the competition for this nutrient between plants and microorganisms.

Table 2. Comparison of total number of fruit per plant (TNF), number of commercial fruit per plant (NCF), fruit diameter (FD), fruit length (FL), total production (TP), and commercial production (CP), total yield (TY), and commercial yield (CY) of watermelon 'Olímpia' (*Citrullus lanatus*), in the 2014/2015 and 2015/2016 harvest seasons⁽¹⁾.

Harvest seasons	TNF ---(number per plant)---	NCF	FD ------(m)-----	FL	TP ------(kg per plant)-----	CP	TY ------(Mg ha ⁻¹)-----	CY
2014/2015	2.3a	1.5a	-	-	20.0a	17.0a	66.5a	56.6a
2015/2016	1.6b	0.7b	-	-	9.4b	6.7b	31.5b	22.3b
DMS	0.24	0.16	-	-	1.80	1.59	5.91	5.30
F	38.59**	106.07**	-	-	159.63**	190.64**	159.44**	189.89**
CV (1) %	28.97	32.40	-	-	27.72	30.38	27.75	30.93
CV (2) %	25.64	30.35	-	-	26.55	30.18	26.50	30.25

⁽¹⁾Means followed by equal letters do not differ by Tukey's test, at 5% probability. * and **Significant at 5 and 1% probability, respectively.
^{ns}Nonsignificant.

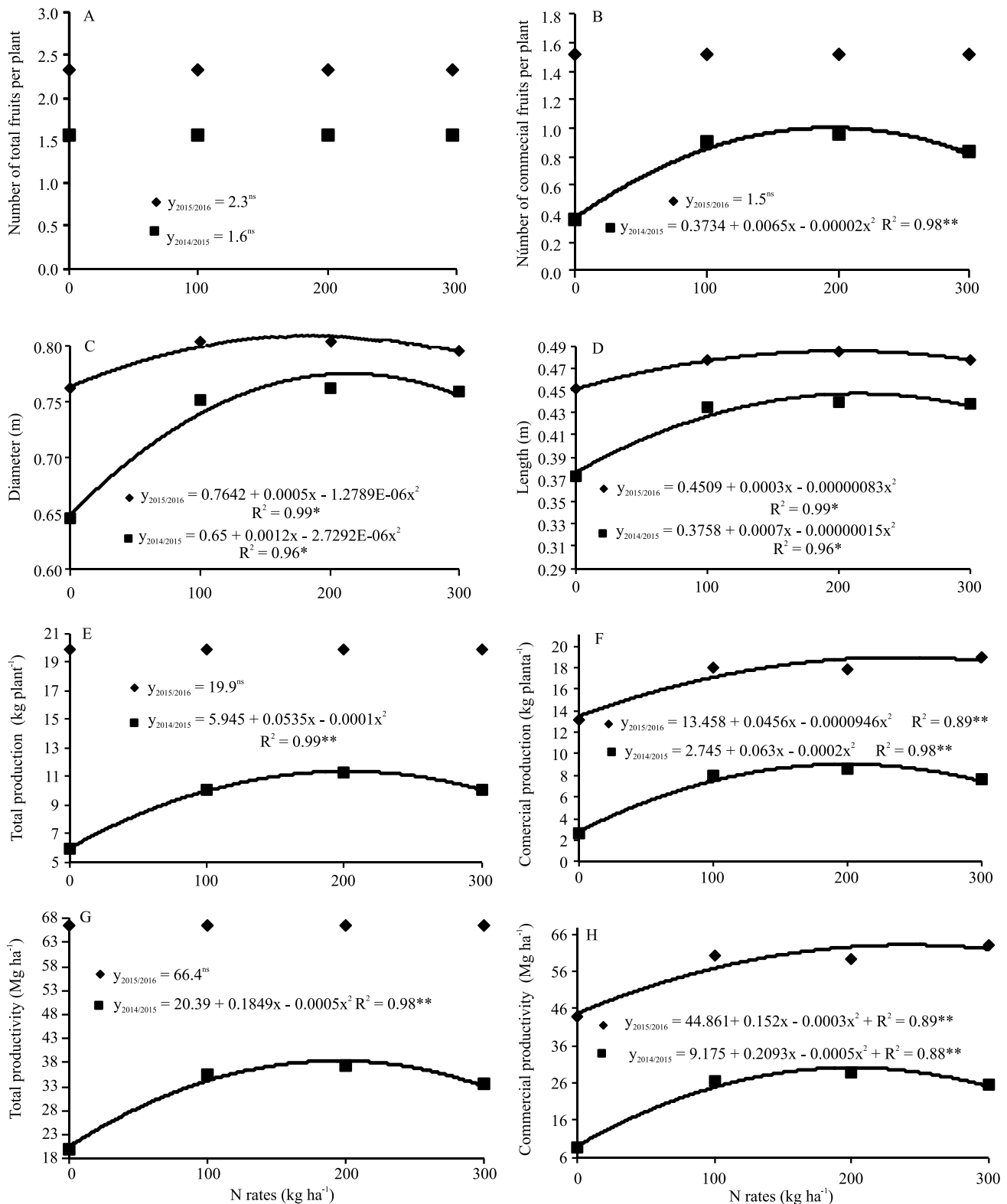


Figure 3. Effect of N concentrations in the soil cover on the total and commercial number of fruit (A, B), fruit length (C), fruit diameter (D), total and commercial production (E, F), and total and commercial yield (G, H) of watermelon 'Olímpia' (*Citrullus lanatus*), in the 2014/2015 and 2015/2016 harvest seasons (equations 1 and 2, respectively) in the municipality of Andradina, in the São Paulo state, Brazil.

Conclusions

1. Watermelon (*Citrullus lanatus*) may be cultivated in regeneration areas of sugarcane field.

2. Watermelon yield in the no-tillage system is similar to that of conventional tillage in the two evaluated harvest seasons.

3. In the 2014/2015 harvest, minimum tillage presented higher commercial yield than other tillage systems.

4. Watermelon yield varied with the increase in N concentration but was similar between the soil tillage systems evaluated.

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