Extinction coefficient and interception efficiency of the photosynthetic photon flux density in cherry tomato under levels of nitrogen in greenhouse conditions

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Abstract

Cherry tomato (*Perinha Água Branca* cultivar) was cultivated under organic management in greenhouse conditions set up in the municipality of Seropédica, Rio de Janeiro state, Southeastern Brazil. The crop was subjected to different nitrogen doses (N) ranging from 0 to 400% based on the reference value for the crop (100 kg ha^{-1}) applied by means of dairy cattle wastewater. In order to estimate the extinction coefficient (k) and interception efficiency (ε_{int}), weekly measurements of the photosynthetic photon flux density (PPFD) were performed below (PPFD$_b$) and above the canopy (PPFD$_a$) and the Leaf Area Index (LAI) was estimated. The extinction coefficient k for each treatment was obtained based on the model proposed by Monsi and Saeki. ε_{int} was estimated by the quotient between PPFD absorbed by the canopy (PPFD$_{abs}$ = PPFD$_a$ – PPFD$_b$) and PPFD$_a$. Statistical tests were applied to k and ε_{int} to evaluate the distribution of data (Kolmorogov-Smirnov) and their significance (Kruskal-Wallis), considering the treatments applied. No statistically significant differences were observed for k ($p<0.05$), which indicated canopy structure uniformity. The median k value was 0.792. Similar to k, ε_{int} showed no statistically significant differences ($p<0.05$) between treatments; however, the highest interception efficiency was achieved by treatment with 300% N (ε_{int} = 0.825), which coincided with the highest leaf area index and the lowest by treatment with 100% N (ε_{int} = 0.521). The nitrogen did not interfere in the plant canopy architecture; however, it provided greater leaf area index to plants submitted to nitrogen doses two and three times above that recommended for the crop. Treatment with three times the recommended nitrogen dose reached in a shorter time interval the maximum efficiency value

Keywords: Organic management; Light attenuation; *Solanum lycopersicum var. cerasiforme*; Solar radiation; Vegetal canopy; Vegetative growth.
Abbreviations: BOD_ biochemical oxygen demand; COD_ chemical oxygen demand; DAT_days after transplanting; DCW_dairy cattle wastewater; k_extinction coefficient; LAI_leaf area index; N_nitrogen; N-NH4$^+$_ammonium; PAR_photosynthetically active radiation; pH_ hydrogen potential; PPFD_photosynthetic photon flux density; PPFD$_a$_photosynthetic photon flux density above the canopy; PPFD$_{abs}$_photosynthetic photon flux density absorbed by the canopy; PPFD$_b$_photosynthetic photon flux density below the canopy; T_nitrogen doses treatment; VC_variation coefficient; ε_{int}_interception efficiency.

Introduction

In Brazil, tomato (*Solanum lycopersicum*) stands out among vegetables due to its high production, which in the 2012/2013 harvest season was 3.04 million tons in a planted area of 68,867 ha (Agroanalysis, 2013). Among the tomato varieties marketed fresh, cherry tomato (*Solanum lycopersicum* var. *cerasiforme*) stands out for having a high commercial value. In the state of Rio de Janeiro, cherry tomato cultivation is associated with small producers and family farms (Lumbreras et al., 2003). The cultivation of tomato in a greenhouse allows obtaining micrometeorological conditions suitable for the growth and production of plants (e.g., reduction of negative effects of temperature, relative air humidity and solar radiation) and allows the introduction of efficient agricultural techniques in the production of vegetables, which results in increased production (Duarte et al., 2010). Solar radiation stands out for its performance in the growth and yield of plants through the process of photosynthesis, in which photosynthetically active radiation (PAR), within wavelength from 0.4 to 0.7 μm, is absorbed by chlorophyll molecules and carotenoids (Björkman and Demmig-Adams, 1995). The PAR fraction corresponds to the average energy along the visible band divided by the energy of photons in the green wavelength, whereas the photosynthetic photon flux density (PPFD) considers the whole visible band that is used by plants in the photosynthetic process (Campbell and Norman, 1998).

The transmission of solar radiation from the top of the plant canopy to its interior is mainly conditioned by the plant architecture. Most direct solar radiation occurs in the upper part of the canopy; however, the diffuse radiation is responsible for the dissipation of light inside the canopy and in the lower parts of the plant (Fagan et al., 2013). In the greenhouse conditions, increases of the diffuse radiation fraction in relation to the direct one due to the plastic cover, or its structure, which alters the relationships between radiation and the vegetal canopy in comparison to field crops (Reis et al., 2012).

The light attenuation by the vegetal canopy can be represented by the mathematical model proposed by Monsi and Saeki (2005), which describes the vertical profile of radiation inside the canopy, as a function of the leaf area index and a dimensionless coefficient (light extinction coefficient). This coefficient integrates the decrease in the radiation flux density within the canopy. The efficiency with which plants intercept solar radiation depends on the incident radiation, leaf area distribution in time (along the cycle) and in space, the optical properties of the canopy (reflection, transmission and absorption) and leaf angle (Monteith, 1965; Hirose, 2005; Monsi and Saeki, 2005). In tomato, the elevation in the nitrogen level (N) supplied to plants up to the optimum physical point increases plant height, leaf number and leaf area (Ferreira et al., 2010), which contributes to the interception efficiency.

In view of the complex interactions between solar radiation and vegetal canopy, the present work had the objective of evaluating the influence of nitrogen doses applied by means of dairy cattle wastewater (DCW), in the relationships between photosynthetic photon flux density and the canopy of cherry tomato (*Solanum lycopersicum* var. *cerasiforme*) cultivated in protected environment.

Results

Leaf area index

Leaf area indexes showed normal distribution, according to the Kolmorogov-Smirnov test (p<0.05). Despite the variation in the LAI values among treatments (minimum LAI = 1.07; maximal LAI = 2.25), the Kruskal-Wallis test (p≤0.05) did not show statistically significant differences among data analyzed for each campaign.

Plants submitted to treatment T3 (100% N) presented the lowest vegetative growth, with LAI of 1.07, when compared to plants of the other treatments (Table 1). This lower LAI value obtained by treatment T3 (100% N) may not be associated to the nitrogen doses applied, considering that the same N doses were applied in all campaigns. Maximum LAI (2.25) was obtained for treatment with 300% of the recommended N dose (T5), at 71 DAT (Table 1).

It was verified that the culture reached its maximum LAI at 71 DAT for treatments with 100 to 400% of the N recommendation (T3, T4, T5 and T6). From this date, plants began the senescence process, indicated by the decrease of LAI values. This same pattern was not observed for plants submitted to N doses of 0 and 50% (T1 and T2 respectively), which continued to grow until the last measurement campaign (78 DAT). Plants submitted to T5 (300% N), except for campaign at 57 DAT, reached LAI values higher than those submitted to T6 (400% N).

Extinction coefficient

By the Kolmogorov-Smirnov test (p<0.05), the extinction coefficients did not present a normal distribution frequency. Therefore, the medians of k were determined for the treatments considered (Table 2). The median of k was 0.79 for all treatments except for T1 (control - 0% N) and T2 (50% N), whose k was respectively 0.78 and 0.77. Although the highest percentage difference (2.5%) in k values was found for plants of treatment with 100% N (T3), the non-parametric Kruskal-Wallis test result (p<0.05) showed no statistically significant differences of medians k among treatments during the evaluated period. The relative differences between median k of treatments were lower than the variation coefficients (VC), which indicated low dispersion of data, regardless of treatment. VC values ranged from 3.5% for treatment T1 (0% N) to 6.5% for treatment T3 (100% N).

Interception efficiency

For ε_{int} estimates, the statistical tests described above were also applied, which demonstrated the non-normality of the distribution (p<0.05) and the absence of statistically significant differences (p<0.05) of ε_{int} among treatments. Increasing ε_{int} values for all treatments up to 71 DAT were observed, except for treatments T1 (0% N) and T6 (400% N). From this period, there was a decrease in ε_{int} for T4 (200% N) and T5 (300% N), while for treatments T1 (0% - control), T2 (50% N) and T3 (100% N), ε_{int} had not yet reached its maximum value. In T6, the maximum efficiency occurred at 64 DAT; however, with a lower value compared to that obtained by T5 (Table 3).

When comparing the LAI and ε_{int} results (Tables 1 and 3, respectively) it was verified that the maximum efficiency was obtained at 71 DAT (ε_{int} = 0.825) by T5 (300% N), with LAI equal to 2.25. However, for the same period, T4 (200% N) showed near-maximum intercept efficiency (ε_{int} = 0.823) with LAI equal to 2.16. The lower interception efficiency (ε_{int} = 0.521) was observed at 57 DAT for T3 (100% N), the same treatment that resulted in the lowest LAI.

Analyzing the correlation between LAI and ε_{int}, it was found that increasing LAI, ε_{int} tended to increase until it reached its maximum value, when LAI value was maximum. Thereafter, LAI decreased, which indicated the beginning of the senescence stage of the crop. This could be observed in T4 (200% N) and T5 (300% N).

It was observed, therefore, that only T4 (200% N) and T5 (300% N) showed reduction in ε_{int} concomitant to the senescence process. The same reduction was not observed for T3 (100% N) and T6 (400% N) due to the non-expressive decrease in the LAI value between campaigns at 71 and 78 DAT. ε_{int} was graphically fitted according to LAI based on the equation of Monsi and Saeki (2005). From the extrapolated values, it was observed that when LAI reached value equal to 3.0, ε_{int} reached 91%. However, for LAI values greater than 3.0, the efficiency variation rate as a function of LAI tended to decrease significantly (Figure 1). This demonstrated that for tomato crop to maximize ε_{int}, LAI should be equal to 3.0. However, none of the treatments reached this LAI value since the maximum LAI obtained in the experiment was 2.25 by treatment T5 (300% N).

Table 1. Average leaf area index (LAI) as a function of treatments (nitrogen doses - N) with dairy cattle wastewater (DCW) for each period evaluated.

Campaigns	DAT	Treatments (% N)					
		T1 0%	T2 50%	T3 100%	T4 200%	T5 300%	T6 400%
Jul/25	57	1.16_{ns}	1.42_{ns}	1.07_{ns}	1.39_{ns}	1.39_{ns}	1.67_{ns}
Ago/01	64	1.53_{ns}	1.59_{ns}	1.25_{ns}	1.85_{ns}	2.03_{ns}	1.95_{ns}
Ago/08	71	1.52_{ns}	1.88_{ns}	1.55_{ns}	2.16_{ns}	2.25_{ns}	1.96_{ns}
Ago/15	78	1.59_{ns}	1.97_{ns}	1.44_{ns}	1.95_{ns}	1.87_{ns}	1.82_{ns}

ns - not significant ($p < 0.05$).

Table 2. Extinction coefficient (k) medians and their respective statistical analyses of standard deviation and variation coefficient (VC).

Treatments (% N)	k (median)	Standard deviation	VC (%)
T1 - 0%	0.780_{ns}	0.03	3.5
T2 - 50%	0.798_{ns}	0.03	5.0
T3 - 100%	0.770_{ns}	0.05	6.5
T4 - 200%	0.796_{ns}	0.03	4.0
T5 - 300%	0.794_{ns}	0.03	4.3
T6 - 400%	0.791_{ns}	0.05	5.9
Mediana	0.792	-	-

ns - not significant ($p < 0.05$).

Table 3. Interception efficiency (ε_{int}) medians as a function of treatments with dairy cattle wastewater (DCW) for each period evaluated.

| Campaigns	DAT	Treatments (% N)					
		T1 0%	T2 50%	T3 100%	T4 200%	T5 300%	T6 400%
Jul/25	57	0.578_{ns}	0.674_{ns}	0.521_{ns}	0.670_{ns}	0.647_{ns}	0.714_{ns}
Ago/01	64	0.701_{ns}	0.693_{ns}	0.598_{ns}	0.764_{ns}	0.806_{ns}	0.781_{ns}
Ago/08	71	0.680_{ns}	0.741_{ns}	0.659_{ns}	0.823_{ns}	0.825_{ns}	0.754_{ns}
Ago/15	78	0.722_{ns}	0.785_{ns}	0.662_{ns}	0.778_{ns}	0.755_{ns}	0.762_{ns}

ns - not significant ($p < 0.05$).

Table 4. Characterization result of dairy cattle wastewater under organic management of the Integrated Agroecological Production System of Embrapa-Agrobiologia.

Characteristics	Units of measures	Values
pH	-	7.38
Electric conductivity	$dS\ m^{-1}$	2.55
Total solids	$mg\ L^{-1}$	22.100
COD	$mg\ L^{-1}$	20.080
BOD	$mg\ L^{-1}$	4.712
Total nitrogen	$mg\ L^{-1}$	486.50
$N-NH_4^+$	$mg\ L^{-1}$	117.50
Total phosphorus	$mg\ L^{-1}$	75.00

Table 5. Total blades values of dairy cattle wastewater (DCW) for each treatment corresponding to the respective doses of N used.

Treatments	Doses (% N)	DCW total blades (mm)
T1	0	0.00
T2	50	25.67
T3	100	51.34
T4	200	102.68
T5	300	154.02
T6	400	205.36
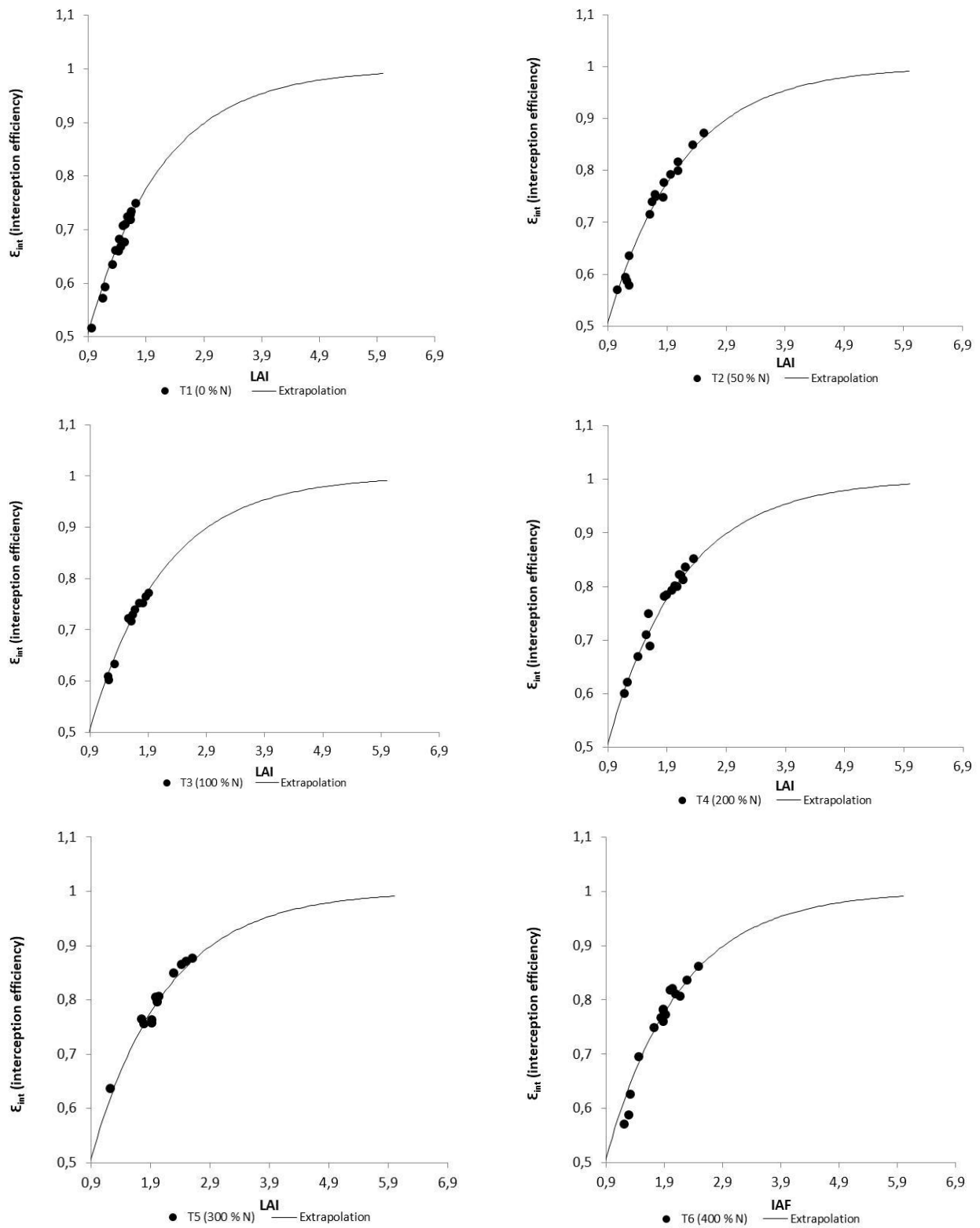
Fig 1. Extrapolation of interception efficiency values ($\mathcal{E}_{int}$) as a function of the Leaf Area Index (LAI) and comparison with $\mathcal{E}_{int}$ and LAI values obtained in each treatment with DCW (T1 = 0%, T2 = 50%, T3 = 100%, T4 = 200%, T5 = 300% and T6 = 400% N).

Discussion

The results showed that the elevation of nitrogen doses above the reference value for tomato favored the crop growth rate. However, the accumulation of N contents in plants (400% N) may have caused phytotoxicity. This N accumulation in plants was verified by Jorge et al. (2016), based on variables obtained in the same experiment considered in the present study. The authors verified by means of analysis of the nutritional contents of tomato leaves (dry mass), linear growth in the N accumulation in leaves as a function of the DCW dose applied.

When comparing the maximum LAI (LAI = 2.25) found in the present study at 71 DAT with LAI determined by Reis et al. (2013) in an experiment carried out with the tomato crop under protected environment conditions, there was a percentage difference of around 20%. The authors found maximum LAI value of 2.82 at 70 DAT, and from 70 DAT, LAI decreased and reached 2.70 at 80 DAT.

Comparing the median extinction coefficient among treatments (k = 0.792) and k determined by other authors also for tomato crop, values similar to the present study were observed. Higashide and Heuvelink (2009) used the equation of Monsi and Saeki (2005) and obtained for tomato plants light extinction coefficient of 0.75. These authors also verified that the coefficient is dependent on the morphological and physiological characteristics of the plant, and similar k values for the same crop should be observed.

Radin (2002) estimated the light extinction coefficient for tomato culture from the photosynthetically active radiation fraction by means of the linear regression between [ln (1-ε_{int})] and LAI and LAI derived from the transmissivity equation adapted from the Beer's Law. For all surveyed environments (greenhouse with screen, greenhouse without screen and area outside the greenhouse) the average extinction coefficient was 0.57. This represents a percentage difference of 32% of the median k value obtained in the present study (k = 0.792). This difference in k value occurred because the author used photosynthetically active radiation estimates as a function of the PAR fraction with global solar radiation to determine the extinction coefficient, whereas k in the present work was obtained with photosynthetic photon flux density measurements.

Low light extinction coefficients are more effective in the transfer of radiation into the canopy and thus result in better utilization of radiation by the canopy as a whole when the canopy is completely closed. According to Allen et al. (1998), this occurs with LAI equal to 2.88. However, high k values indicate that only a small fraction of radiation can be transmitted to the surface below the canopy and thus result in higher radiation absorption. This occurs because when the extinction coefficient is low, higher transmissivity coefficient value is obtained, which favors the transmission of radiation into the canopy. The k value tends to be lower for predominantly erect leaves (more upright canopy architecture), while it is higher for horizontally-arranged leaves (Lambers et al., 1998).

Although some authors such as Daymond et al. (2002) highlight the canopy structure as the most influential factor in the light extinction coefficient, Zhang et al. (2014) reported that k is determined by the inclination angle of leaves and by the zenith solar angle, and therefore, implicitly, k undergoes temporal and spatial influences. In the present study, however, no statistically significant differences were found between samplings of the same treatment evaluated over the four campaigns. However, the period of the campaigns was one month and the measurements were always carried out at the same time, that is, the same zenith angle.

The ability of the plant to absorb the intercepted radiation depends on the light extinction coefficient in the canopy. However, the radiation available to the plant is a function of the interception efficiency of it by the crop. When intercepting the photosynthetically active radiation, the plant canopy transmits it to its interior, where it is then absorbed by the leaves. The higher the intercepted radiation, the greater the availability of radiation to the plant, however, not all radiation intercepted by the canopy is effectively used by plants in metabolic processes. Part of the intercepted radiation is lost by reflection or by transmission to the surface by the canopy itself.

Comparing the maximum interception efficiency observed (ε_{int} = 82%) with the work of Oliveira et al. (2013) for irrigated tomato under field conditions, the authors obtained maximum value of 88%. The result is close to that reached in the present study for tomato crop.

Ferreira et al. (2010) stated that the elevation of nitrogen supply to plants causes an increase in photosynthetic potential and contributes to greater production of carbon skeletons in leaves, increasing the source potential and, consequently, the supply to the drain, represented by tomato fruits. Studies have shown that the weight and number of marketable tomato fruits per plant increased with increasing N levels in the soil. Therefore, increased ε_{int} and LAI parameters tend to increase crop productivity.

As result of the analyses performed, it was verified that ε_{int}, LAI and k are correlated with each other and are variables of fundamental importance in understanding solar radiation and plant canopy interaction. The larger the leaf area, the greater the solar radiation interception by the plant canopy. However, the best use of intercepted radiation will also depend on the canopy structure characteristics (Gomes et al., 2005). In the case of plants with more horizontally-oriented leaves and with larger leaf area, there is shading of leaves that are located in the lower parts of the canopy. This causes a decrease of the photosynthetic rate by leaves that are located in the lower parts of the canopy. In plants whose leaves are more upright, the radiation is intercepted and distributed through the plant canopy more evenly.

In the case of greenhouse cultivation, the environment provided greater dispersion of the solar radiation inside it, and thus, it caused an increase in the diffuse solar fraction with greater contribution in the photosynthetic radiation, which increased the amount of radiation transmitted inside the canopy and increased the interception efficiency of the photosynthetic radiation.

Materials and methods

Experimental site

The study was carried out in a greenhouse located in the municipality of Seropédica (22°48'S, 43°41'W and 33 m asl), Rio de Janeiro state, Southeastern Brazil, from May 29 to September 20, (autumn-winter). According to the Köppen classification, the climate of the region is Aw type, tropical

climate, with dry winter. The greenhouse, with an area of 160 m², was built in a wooden structure, being of "chapel" cover type, covered with low density polyethylene of 150 µm and thermo-reflective aluminet® mesh, and sides covered with 50% shading screen.

Description of the experimental characteristics

Cherry tomato, cv. *Perinha Água Branca*, was cultivated in an organic system in 12 L pots arranged in a greenhouse with spacing of 0.6 m between rows and 0.7 m between plants. Plants were tutored with the use of loops fixed in wires on the tomato rows at a height of 3 m. The sowing of tomato was performed on 04/17/12, in polystyrene trays, where each cell received three seeds. Fifteen days after sowing, the thinning of seedlings was performed and plants were transplanted to pots on 05/29/12. The experiment was concluded on 09/20/12 (114 days after transplanting - DAT). The cultivation soil (substrate) was prepared from the mixture of clay, sand and commercial Top Garden® substrate at a ratio of 3:2:1. Soil chemical corrections were performed according to recommendations of Campos et al. (2013) for the state of Rio de Janeiro. Tomato was irrigated using irrigation system located by drippers with flow of 2.4 L h^{-1} and one emitter per plant. Irrigations were carried out daily in pulses lasting two minutes at a time and repeated throughout the day according to soil moisture conditions, verified by tensiometers distributed in pots. Thus, soil moisture was kept close to field capacity.

The experiment was carried out with a randomized block design of 192 pots, with one plant each, divided into 32 pots per treatment, with a total of six treatments (eight plots per treatment with four plants each). In addition, 68 bordered pots were also used. Thus, pots were distributed in 10 culture lines with 26 pots per line.

Treatments consisted of different nitrogen doses applied to tomato (T1 = 0%, T2 = 50%, T3 = 100%, T4 = 200%, T5 = 300% and T6 = 400%), based on the reference value for the crop of 100 kg ha^{-1}, according to Matos (2006). The N doses were applied by means of dairy cattle wastewater (DCW), consisting of the mixture of 30% fresh manure with 70% water. The characterization result of dairy cattle wastewater is presented in Table 4. DCW slides were calculated according to guidelines of Macedo et al. (2010):

$$TA_{AR} = 1000 \cdot \frac{\left[N_{abs} - \left(T_{m1} \cdot MO \cdot \rho_s \cdot p \cdot 10^7 \cdot 0,05 \cdot \frac{n}{12} \right) \right]}{\left[T_{m2} \cdot \frac{n}{12} \cdot N_{org} + \left(N_{ammoniacal} + N_{nitric} \right) TR \right]}, \qquad (1)$$

where: T_{AR} - application rate (m³ ha^{-1}); N_{abs} - nitrogen absorption, recommended for Matos (2006), according to the crop to obtain the desired yield; T_{m1} - annual rate of mineralization of organic matter previously present in the soil (0,01 – 0,15 kg kg^{-1}); MO - content of organic matter present in the soil (kg kg^{-1}), according to soil characterization; ρ_s - soil specific density (t m^{-3}), according to the soil physical characterization; p - depth of soil considered (m), according to Matos (2006), the organic layer is restricted to the first 20 cm of soil; n - number of months of crop cultivation; T_{m2} - annual rate of mineralization of organic nitrogen (kg kg^{-1} year^{-1}), recommended for Matos (2006); N_{org} - organic nitrogen provided by the applied residue (mg L^{-1}); $N_{ammoniacal}$ - ammoniacal nitrogen provided by the applied residue (mg L^{-1}); N_{nitric} - nitric nitrogen provided by the applied residue (mg L^{-1}); TR - rate of recovery of mineral nitrogen by the crop that varies between 0.70 - 0.85 kg kg^{-1} year^{-1}; 10^7 - unit conversion coefficient; and 0,05 - unit conversion coefficient. The dairy cattle wastewater determined for each treatment (Table 5) was divided into applications that occurred every 15 days, with applications beginning 45 days after the transplanting of the seedlings. The application of the different doses of the wastewater in the soil was done manually, using containers with different volume graduations for the differentiation of the treatments. The irrigation system was not used for the application of the effluent because of the potential obstruction of the emitters; in addition, the system was set up in such a way that the application of water was identical for all plants, making it impossible to differentiate the doses. Foliar fertilization was also carried out in all plants using Agrobio® organic fertilizer, in order to supply micronutrients to plants.

Experimental evaluations

In the period from July 25 to August 15, 2012, four weekly measurements of the photosynthetic photon flux density (PPFD) were performed with a ceptometer (AccuPAR LP80, Decagon Devices Inc.) below (PPFD$_b$, µmol m^{-2} s^{-1}) and above the canopy (PPFD$_a$, µmol m^{-2} s^{-1}) and leaf area index (LAI) estimates. LAI estimates by the ceptometer were based on measurements of PPFD$_b$, PPFD$_a$ and other variables associated with plant canopy architecture (leaf area distribution) and solar radiation (fraction of direct solar irradiance and irradiance from other sources, such as diffuse or even reflected by other surfaces) (Decagon Devices, Inc., not dated). During the period of the agrometeorological evaluations, the crop was at the phenological stage of flowering and fruiting (07/25/12) and maturation of fruits and harvest (August 01 to 15, 2012). Evaluations (campaigns) included two portions of each treatment and were always carried out in the same plots. In each evaluation, PPFD measurements were performed in eight different positions below the canopy of each plot and in the same position above the canopy. At each four samplings, the mean of PPFD PPFD$_b$, PPFD$_a$ and LAI values was calculated. Measurements were always performed at noon to avoid the influence of other factors in measures such as, for example, solar elevation angle and structure shading. The extinction coefficient (k) was obtained for each treatment based on the radiation extinction model in the Beer's Law (1852) and applied to a plant canopy by Monsi and Saeki (2005):

$$PPFD_b = PPFD_a \times e^{-k.LAI} \qquad (2)$$

$$k = \frac{\ln(PPFD_a) - \ln(PPFD_b)}{LAI} \qquad (3)$$

where PPFD$_b$, PPFD$_a$, k and LAI were photosynthetic photon flux density below the canopy (µmol m^{-2} s^{-1}), photosynthetic photon flux density above the canopy (µmol m^{-2} s^{-1}), light extinction coefficient in the plant canopy (dimensionless) and leaf area index (dimensionless), respectively. The interception efficiency (ε_{int}) of the photosynthetic photon flux density by the plant canopy was estimated by the

quotient between the photosynthetic photon flux density absorbed by the culture and the photosynthetic photon flux density above the canopy:

$$\varepsilon_{int} = \frac{PPFD_{abs}}{PPFD_a} = 1 - \frac{PPFD_b}{PPFD_a} \qquad (4)$$

where ε_{int} and $PPFD_{abs}$ were the interception efficiency (dimensionless) and photosynthetic photon flux density absorbed by the canopy ($\mu mol\ m^{-2}\ s^{-1}$), respectively.

The median k among treatments and the $PPFD_a$ and $PPFD_b$ measures were applied to Equations 1 and 3 combined to estimate ε_{int} as a function of LAI obtained by the ceptometer. Thus, the maximum interception efficiency and from which LAI values, ε_{int} tends to remain constant were observed.

Data analysis

The Kolmorogov-Smirnov distribution normality test (p<0.05) was applied to the parameters evaluated, which allowed defining the trend measures to be used to obtain the estimates. The Kruskal-Wallis nonparametric test was used to evaluate the significance of data in multiple comparisons (p<0.05).

Conclusion

Tomato plants had a uniform canopy structure, regardless of nitrogen doses provided by the different dairy cattle wastewaters. The nitrogen did not interfere, therefore, in the plant canopy architecture; however, it provided greater leaf area index to plants submitted to nitrogen doses two and three times above that recommended for the crop. Above these doses, the elevation of nitrogen at four times the recommended value exceeds the limit of assimilation of this nitrogen nutrient by the plant. In terms of interception efficiency, treatment with three times the recommended nitrogen dose is the most effective, since it reached in a shorter time interval the maximum efficiency value when compared to the other treatments. From the agronomic point of view, treatment with three times the reference nitrogen dose for tomato provides crop cycle advancement.
Acknowledgements

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