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Bio-agronomic efficiency indices of eggplant and tomato intercropping

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ABSTRACT

The successful intercropping with vegetables depends on the type of crops grown and on the proper handling of tested treatments, such as the time of transplanting a crop in relation to transplanting another crop, among others. Thus, the objective of this work was to evaluate the bio-agronomic performance of eggplant and tomato for industry, in intercropping, in relation to their single crops, as a function of the transplanting time of the eggplant in relation to the tomato and of the cultivation season (summer or winter). The experimental design used was a randomized complete block with ten treatments and four replications, implanted in two growing seasons (from February to September and from August to February), where the treatments consisted of ten eggplant transplanting times (-30, -25, -20, -15, -10, -5, 0, +5, +10 and +15 days in relation to tomato transplantation). In each block, plots of eggplant monocultures were planted in each transplanting time, as well as a plot in tomato monoculture in order to obtain the bio-agronomic indices. The competition and bio-agronomic efficiency indices of the crops and of the intercropped systems were evaluated. The variation in the transplanting time of eggplant in relation to tomato significantly interferes in the bio-agronomic performance of both species. Eggplant transplanting performed between -20 and -15 days compared to tomato transplantation reduces the dominance of one crop over the other and the interspecific competition for environmental resources. The intercropped system has greater land equivalent ratio when the eggplant is transplanted at +15 days after transplanting the tomato.

Keywords: *Solanum melongena*, *Solanum lycopersicum*, crop sowing times, intercropping system.

RESUMO

Índices de eficiência bio-agronômica do consórcio de berinjela e tomate

O êxito da consorciação de culturas com hortaliças depende do tipo de culturas cultivadas e da manipulação adequada de tratamentos testados, como época de transplante de uma cultura em relação ao transplantio da outra, entre outros. Assim, o objetivo deste trabalho foi avaliar o desempenho bio-agronômico da berinjeleira e do tomateiro para indústria, em cultivo consorciado, em relação a seus cultivos solteiros, em função da época de transplante da berinjeleira em relação ao do tomateiro, em duas épocas de cultivo (verão ou inverno). O delineamento experimental usado foi de blocos completos casualizados com dez tratamentos e quatro repetições, implantados em duas épocas de cultivo (de fevereiro a setembro e de agosto a fevereiro), onde os tratamentos consistiram de dez épocas de transplante da berinjela (-30, -25, -20, -15, -10, -5, 0, +5, +10 e +15 dias em relação ao transplante de tomate). Em cada bloco, foram plantadas parcelas em monocultivos de berinjela em cada época de transplantio, bem como, uma parcela em monocultivo de tomate com o objetivo de permitir a obtenção dos índices bio-agronômicos. Foram avaliados os índices de competição e eficiência bio-agronômica das culturas e dos sistemas consorciados. Pode-se concluir que a variação na época de transplantio da berinjeleira em relação ao tomateiro interfere de forma significativa no desempenho bio-agronômico de ambas as espécies. O transplantio da berinjeleira realizado entre -20 e -15 dias em relação ao transplantio do tomateiro reduz a dominância de uma cultura sobre a outra e a competição interespecífica por recursos do meio ambiente. O sistema consorciado apresenta maior eficiência de uso da terra quando a berinjeleira é transplantada aos +15 dias após o transplantio do tomateiro.

Palavras-chave: *Solanum melongena*, *Solanum lycopersicum*, épocas de semeadura de culturas, cultivo consorciado.

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The intercropping, simultaneous cultivation of more than one plant species in the same area has proven to be a viable strategy for small and medium producers, as it allows them to maximize production and diversify the income of agricultural activity, especially in the cultivation of vegetables (Guerra *et al.*, 2021). The adoption of this cultivation system enables the reduction of production costs, ensures greater efficiency in the use of agricultural inputs and labor (Sediyama *et al.*, 2014; Wang *et al.*, 2015), in addition to causing less environmental impact (Cecílio Filho *et al.*, 2019; Pereira *et al.*, 2021).

The success of the intercropping system depends directly on the species used and the management practices employed (Maitra *et al.*, 2019). Thus, for crop intercropping, it is important to know the agronomic characteristics and edaphoclimatic needs of each species, in order to understand the relationship of complementarity of these with the use of environmental resources (Cecílio Filho *et al.*, 2013; Silva *et al.*, 2021; Guerra *et al.*, 2022). Such information helps to determine the right time for the establishment of the intercropping, minimizing the negative interferences of interspecific interaction and competition for natural resources (water, light and nutrients) (Cecílio Filho *et al.*, 2013; Guerra *et al.*, 2021).

Agronomic and production factors must be considered to determine the efficiency of the intercropping. However, for a better understanding, indices that discuss the competition between species should be considered, such as the relative crowding coefficient (K), aggressivity of crops (A), competitive ratio (CR) of crops, actual yield loss (AYL) and land equivalent ratio (LER). Such indices allow evaluating the effectiveness and characterizing the intercropping systems, as they reflect the influence of competition between the cultures that make up the system. Thus, its values can help to plan and manage the association between cultures (Cecílio Filho *et al.*, 2013).

Among the factors that can affect productivity and the indices for determining success in the intercropping is the period of coexistence between the species used, determined by the time of installation of the cultures. Assessing the intercrops between tomato and lettuce (Cecílio Filho *et al.*, 2013) and between cucumber and lettuce, Cecílio Filho *et al.* (2015) concluded that the greatest bio-agronomic efficiency between intercropping and these in relation to their monocultures occurred when the transplantation of the main (tomato or cucumber) and secondary (lettuce) cultures were carried out on the same time.

Although the intercropping of tomato and eggplant with other vegetables has already been studied, no reports were found in the literature on the interaction of these two cultures in the same intercropping. Thus, the objective of this study was to evaluate the bio-agronomic performance of eggplant and tomato for industry, in intercropping, in relation to their single crops, as a function of the transplanting time of the eggplant in relation to the tomato and of the cultivation season (summer or winter).

MATERIAL AND METHODS

Two experiments were carried out in the field in two growing seasons, the first being from February 12th to September 5th, 2009 and the second from August 8th, 2009 to February 20th, 2010. The experiments were carried out in the experimental area of UNESP, campus of Jaboticabal, São Paulo, Brazil (21°15'22"S; 48°18'58"W and altitude of 575 m).

The climate at the place where the experiments were conducted is classified as Aw (Köppen and Geiger), with rains in summer and little rain in winter. During the conduct of the experiments, the recorded average values of minimum, mean and maximum temperatures, relative humidity, precipitation and sun hours for the first growing season (S1), February 12th to September 5th were respectively: 5.4, 21.7 and 33.3°C; 73.0%; 688.2 mm and 1493.4 hr, and for second growing season (S2), August 8th to February 20th were respectively: 17.5, 26.7 and 34.8°C; 71.0%; 896.3 mm and 1595.8 hr.

The experiments were carried out in a randomized complete blocks experimental design with ten treatments and four replications implanted in two growing seasons (S1 and S2). The treatments consisted of ten eggplant transplanting times (-30, -25 , -20, -15, -10, -5, 0, +5, +10 and +15 days in relation to tomato transplant). The transplanting dates are presented in Table 1. In each block, plots in eggplant monocultures were planted in each transplanting time, as well as a plot in tomato monoculture in order to allow calculations to be made to obtain the evaluated bio-agronomic indices. Both, in the monoculture and intercropping, eggplant was planted at 1.30 x 1.00 m spacing and tomato at 1.30 x 0.33 m spacing. The experimental plot in both experiments had a total area of 9.10 m^2 (1.30 x 7.0 m), consisting of a cultivation line with seven eggplant plants and 21 tomato plants (Figure 1). The plants in the central area of the plots (harvest area) were used in the evaluations defined in the study, and five eggplant plants and 15 tomato plants were collected in each evaluation.

The soil in the area is classified as a typical Eutroferric Red Latosol with a very clayey texture (Santos *et al.*, 2018). For soil preparation in the experiments, a plowing, a harrowing and a subsequent formation of beds were performed. Before soil preparation, soil samples were collected in the 0 to 20 cm layer and the values of the chemical attributes in the areas of experiments 1 and 2 were: pH 5.7 and 5.2, organic matter = 32.0 and 16.3 g dm^{-3}, Presin = 129.0 and 80.7 g dm^{-3}, K = 3.6 and 5.3 $mmol_c$ dm^{-3}, Ca = 25.8 and 24.7 $mmol_c$ dm^{-3}, Mg = 16.8 and 12.3 $mmol_c$ dm^{-3}, H+Al = 17.0 and 35.3 $mmol_c$ dm^{-3}, sum of bases = 45.2 and 42.3 $mmol_c$ dm^{-3}, CCE = 62.2 and 77.6 $mmol_c$ dm^{-3}, and base saturation of soil = 72.7 and 54.5%. According to the chemical analysis of the soil, lime was applied throughout the area (PRNT 126%, CaO 48% and MgO 16%), aiming to increase the base saturation of the soil to 80%, as recommended by Trani *et al.* (1997a,b). Due to the lack of studies recommending planting fertilization for intercropped eggplant-tomato crops, planting fertilization was carried out as a function of the recommendation for

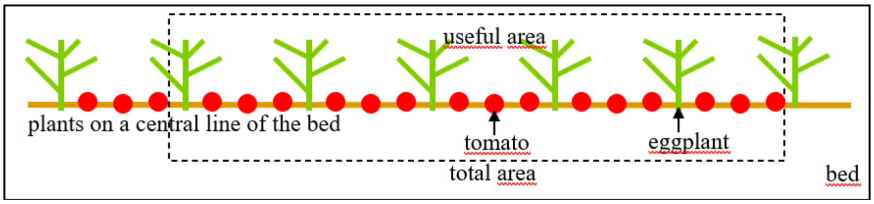

Figure 1. Schematic of an eggplant-tomato intercrop plot and the useful area used for data collection. Jaboticabal, UNESP, 2009-2010.

the most demanding crop, i.e., eggplant. Thus, in the planting fertilization in the intercropping plots, were applied the fertilizer doses recommended for eggplant by Trani *et al.* (1997a), i.e., 40 kg ha^{-1} N, 160 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} K_2O in each cropping season. For eggplant monoculture plots, planting fertilization followed the same recommendation for intercropping plots. For tomato monoculture plots, planting fertilization followed the recommendation for industry tomato by Trani *et al.* (1997b), which corresponded to 30 kg ha^{-1} N, 100 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} K_2O, in each cropping season. Top dressing was also carried out according to the recommendation for each species (Trani *et al.* 1997a,b). Thus, for eggplant and tomato in monoculture and intercropping, in both crop seasons, were applied for each species, 120 kg ha^{-1} N and 120 kg ha^{-1} K_2O. The doses for eggplant were divided into six applications every 15 days after transplanting, while for tomato into two applications at 25 and 50 days after transplanting. At planting, fertilizers were applied in furrows, in the 0.2 m layer. In coverage, they were applied about 5 cm from the plants, for both species.

The eggplant hybrid Napoli F1 (Sakata) and the industry tomato hybrid AP 529 (Seminis) were used. Seeds from both cultures were sown in trays containing 128 cells for the formation of seedlings, which were kept in greenhouse until transplanting to beds. In both experiments, the eggplant was sown on dates that provided adequate seedlings (four-leaf seedlings) for transplanting at the times established in the treatments, as well as for tomato.

Weed control was carried out through manual weeding and for phytosanitary control spraying with insecticides (deltamethrin and imidacloprid), fungicides (methyl thiophanate + chlorothalonil and mancozeb) and acaricide (propargite) suitable for the crops was carried out. Irrigation was performed using a sprinkler system. The fruit harvests took place three times a week for three months for the eggplant. The start dates and harvest period for eggplant in the first and second growing seasons are presented in Table 1. Tomato harvests began after 66 and 79 days after transplanting in the growing seasons 1 and 2, respectively. Two harvests per week were conducted for one month in both experiments. After harvesting, the crop productivities and the following bio-agronomic indices were determined:

a) Relative Crowding Coefficient (K): This coefficient estimates the relative dominance of one crop over the other in intercropped systems. The component culture with the highest ‘K’ is dominant. This K index also allows us to identify whether intercropping is advantageous in relation to monocultures of the species. It was calculated by the following expression (Pinto *et al.*, 2011):

$$K = K_t * K_e$$

and

$$K_t = \frac{Y_{te}Z_{et}}{(Y_t - Y_{te})Z_{te}}$$

and

$$K_e = \frac{Y_{et}Z_{te}}{(Y_e - Y_{et})Z_{et}}$$

where K_t and K_e are the relative crowding coefficients of tomato (K_t) and eggplant (K_e); Y_e and Y_t are the productivities of eggplant (Y_e) and tomato (Y_t) in single cultivation; Y_{te} and Y_{et} are the productivities of tomato and eggplant in the association and Z_{te} and Z_{et} are the proportions of planting of tomato (Z_{te}) and eggplant (Z_{et}) in intercropping.

If the value of K= 1, it means that intercropping was indifferent to monocultures; if K<1, it means that the intercropping was not advantageous over monocultures; if K>1, the intercropping was advantageous over monocultures.

b) Competitive Ratio (CR): This index allows the identification of the crop present in the intercropping that had the greatest capacity to use the resources of the environment, that is, the crop with the highest CR. Crops CR indices were calculated by the following equations (Machiani *et al.*, 2018):

$$CR_t = \left[\frac{\frac{Y_{te}}{Y_t}}{\frac{Y_{et}}{Y_e}}\right]\frac{Z_{et}}{Z_{te}}$$

and

$$CR_e = \left[\frac{\frac{Y_{et}}{Y_e}}{\frac{Y_{te}}{Y_t}}\right]\frac{Z_{te}}{Z_{et}}$$

where CR is the competitive ratio of the intercropping; CR_t is the tomato competitive ratio; CR_e is the eggplant competitive ratio; Y_e and Y_t are the productivities of eggplant (Y_e) and tomato (Y_t) in single cultivation; Y_{te} and Y_{et} are the productivities of tomato (Y_{te}) and eggplant (Y_{et}) in the intercropping; Z_{te} and Z_{et} are the proportions of tomato (Z_{te}) and eggplant (Z_{et}) planting in intercropping.

c) Aggressivity (A): This index is often used to indicate the degree of competitiveness between cultures

Table 1. Transplanting dates, start dates and harvest period for eggplant in the first and second growing seasons (S). Jaboticabal, UNESP, 2009-2010.

Treatment (DATT[1])	Transplanting dates		Start of harvest (date)		Harvest period (days)	
	S1	S2	S1	S2	S1	S2
-30	2/12	8/27	4/13	10/09	90	90
-25	2/17	8/31	4/18	10/09	90	90
-20	2/22	9/05	4/23	10/09	90	90
-15	2/27	9/10	4/29	10/23	90	90
-10	3/04	9/15	5/06	10/23	90	90
-5	3/09	9/20	5/11	10/23	90	90
0	3/14	9/25	5/27	11/09	90	90
+5	3/19	9/30	6/03	11/09	90	90
+10	3/24	10/05	6/03	11/20	90	90
+15	3/29	10/10	6/15	11/20	90	90

[1]DATT: days after tomato transplant.

(Machiani *et al.*, 2018). If A equals to 0, both crops are equally competitive, if A_t is positive, the tomato crop is dominant; if A_t is negative, the tomato crop is the dominated one. The same principle applies for A_e. The values of the A indices were obtained from the following equations:

$$A_t = \left(\frac{Y_{te}}{Y_t Z_{te}}\right) - \left(\frac{Y_{et}}{Y_e Z_{et}}\right)$$

and

$$A_e = \left(\frac{Y_{et}}{Y_e Z_{et}}\right) - \left(\frac{Y_{te}}{Y_t Z_{te}}\right)$$

where A_t is the tomato aggressivity; A_e is the eggplant aggressivity; Y_e and Y_t are the productivities of eggplant (Y_e) and tomato (Y_t) in single cultivation; Y_{te} and Y_{et} are the productivities of tomato (Y_{te}) and eggplant (Y_{et}) in the intercropping; Z_{te} and Z_{et} are the proportions of tomato (Z_{te}) and eggplant (Z_{et}) planting in intercropping;

d) Actual Yield Loss (AYL): This index refers to the proportional yield loss or gain of the intercropped crops compared to the respective monoculture, that is, it takes into account the real sown proportion of the component crops of the intercropping with its stand in the monoculture. Positive or negative, the value of AYL indicates that there is an advantage or disadvantage of the intercropping, respectively (Gebru, 2015). In addition, the actual yield loss (AYL_t or AYL_e) represents the proportional yield loss or gain of each species when cultivated as an intercropping in relation to its monoculture yield. The values of the AYL indices were obtained through the following equations:

$$AYL_t = \left\{\left[\left(\frac{Y_{te}}{Z_{te}}\right) / \left(\frac{Y_t}{Z_t}\right)\right] - 1\right\}$$

and

$$AYL_e = \left\{\left[\left(\frac{Y_{et}}{Z_{et}}\right) / \left(\frac{Y_e}{Z_e}\right)\right] - 1\right\}$$

where AYL is the actual yield loss of intercropping; AYL_t is the tomato actual yield loss; AYL_e is the eggplant actual yield loss; Y_{te} and Y_{et} are the productivities of tomato (Y_{te}) and eggplant (Y_{et}) in the intercropping; Y_e and Y_t are the productivities of eggplant (Y_e) and tomato (Y_t) in single cultivation; Z_{te} and Z_{et} are the proportions of tomato (Z_{te}) and eggplant (Z_{et}) planting in intercropping; Z_t and Z_e are the proportions of tomato planting (Z_t) and eggplant (Z_e) in monoculture.

e) Land Equivalent Ratio (LER): This index expresses the area needed in a monoculture to equal the same productivity produced in the intercropping, measured in hectares: This index is calculated by the following expression (Bantie *et al.*, 2014; Diniz *et al.*, 2017):

$$LER = LER_t + LER_e = \left(\frac{Y_{te}}{Y_t}\right) + \left(\frac{Y_{et}}{Y_e}\right)$$

where LER_t is the tomato land equivalent ratio and LER_e is the eggplant land equivalent ratio. Y_{te}, Y_{et}, Y_t and Y_e are described in the previous index.

Values of LER = 1.0 indicate that productivity in the intercropping area was similar to the productivity of monocultures. When LER>1.0 indicates productivity gain per area, that is, more area of the monoculture would be needed to have productivity similar to the intercropping. If LER<1.0 indicates that there is no viability in the intercropping.

The competition and bio-agronomic indices of the crops were analyzed using univariate analysis of variance for a randomized block design, using SAS software (Dewiche & Slaughter, 2003). After that, a joint analysis of variance over the growing seasons was performed in order to check whether or not there was a significant interaction between growing seasons and the transplanting times of the component crops. A response curve fit for each index at the times of transplantation of each crop was performed using the Table Curve 2D software (Systat Software, 2021). The obtained response functions were evaluated based on the following criteria: biological logic, significance of the mean square of the regression residual (QMRr), high value of the coefficient of determination (R^2) and significance of the regression parameters, using the t test to 5% probability level.

Table 2. F values for relative crowding coefficient (K), competitive ratio (CR) and aggressivity (A) as a function of eggplant transplanting times in relation to tomato transplanting and growing seasons of each experiment. Jaboticabal, UNESP, 2009-2010.

Sources of variation	DF	K_e	K_t	K	CR_e	CR_t	A_e	A_t
Blocks (growing seasons)	6	0.69^{ns}	0.80^{ns}	1.31ns	3.62**	2.46*	4.79**	4.79**
Growing seasons (S)	1	17.46**	13.17**	30.40**	0.21^{ns}	0.96^{ns}	6.59*	6.59*
Eggplant transplanting times in relation to tomato transplanting (T)	9	24.95**	98.94**	15.64**	510.59**	51.05**	1974.49**	1974.49**
S x T	9	6.65**	6.33**	5.53**	12.72**	3.67**	14.27**	14.27**
CV (%)		60.97	41.02	39.48	9.45	9.89	-8.31	8.31
Growing seasons								
S1		1.18 b	5.54 b	2.36 b	0.69 a	2.78 a	-1.05 a	1.05 b
S2		2.12 a	7.75 a	3.88 a	0.70 a	2.84 a	-1.11 b	1.11 a

** = P<0.01; * = P<0.05; ns = P>0.05. S1 = Experiment 1 growing season (February 12th to September 5th); S2 = Experiment 2 growing season (August 8th to February 20th).

RESULTS AND DISCUSSION

In the first growing season, commercial yields of eggplant reduced from 69.7 to 26.6 t ha^{-1} and from 62.2 to 9.9 t ha^{-1} when single and in a tomato intercrop, respectively. In the second growing season, when in a single crop, the commercial yield of eggplant was not influenced by transplanting time and the average yield was 94.6 t ha^{-1}. In intercropping, commercial yield decreased from 96.5 to 32.2 t ha^{-1} when eggplant transplanting went from -30 to 15 DATT. For tomato, commercial yields in first and second growing seasons increased from 6.7 to 53.5 and 7.4 to 55.6 t ha^{-1}, respectively, when eggplant transplanting time changed from -30 to 15 DATT (Cecílio Filho *et al.*, 2022). A significant interaction was observed between transplanting times of eggplant in relation to tomato and growing seasons of each experiment in the relative crowding coefficients of crops (K_e and K_t) and system (K), in the competitive ratio of crops (CR_e and CR_t) and in the aggressivity of cultures (A_e and A_t) evaluated (Table 2).

Studying the interaction of eggplant transplanting times within each growing season of the experiments, the same biological behavior of these indices was recorded as a function of eggplant transplanting times between growing seasons (Figures 2 to 6). The relative crowding coefficient (K_e) of the eggplant decreased the later was the transplantation of the eggplant plant in relation to the tomato plant, both in the first and in the second growing season. The maximum estimated values were 3.27 and 6.52, when the eggplant was transplanted at 30 days before tomato transplant (DBTT), and the minimum estimated values were 0.03 and 0.11 when the eggplant was transplanted at 15 DATT in first and second growing season, respectively (Figures 2A and 2B).

This decrease in K_e values with the delay in transplanting eggplant compared to tomato is due to increased interspecific competition for environmental resources, especially light, due to the larger size of tomato plants shading the eggplant plants at the

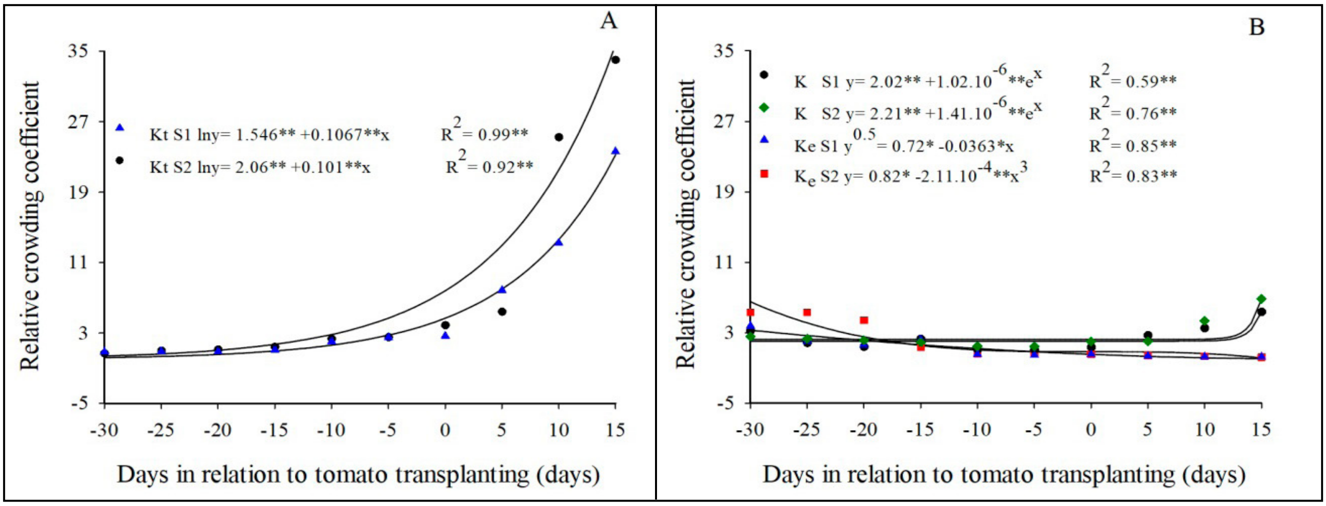

Figure 2. Relative crowding coefficients of the tomato plant (K_t) in the first (S1) and second growing season (S2) (A), and of eggplant plant (K_e) and of intercropping system (K) in the first (S1) and in the second growing season (S2) (B), as a function of transplanting times of the eggplant plant in relation to tomato plant. Jaboticabal, UNESP, 2009-2010.

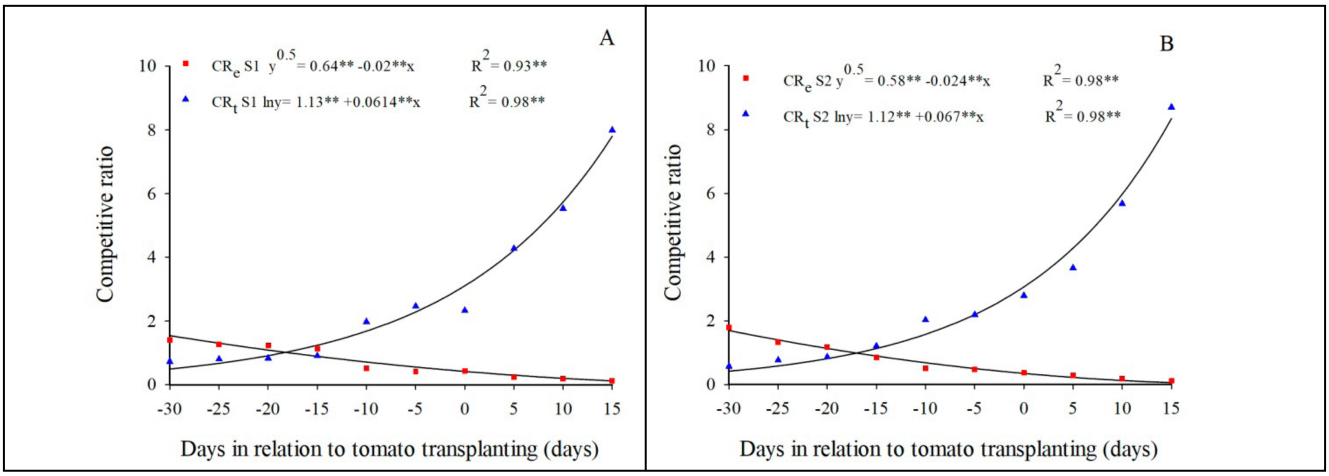

Figure 3. Competitive ratio of eggplant plant (CR_e) and of the tomato plant (CR_t) in the first growing season (S1), (A), and in the second growing season (S2), (B), as a function of transplanting times of eggplant plant in relation to the tomato plant. Jaboticabal, UNESP, 2009-2010.

Table 3. F values for actual yield loss (AYL) and land equivalent ratio (LER) as a function of eggplant transplanting times in relation to tomato transplanting and growing seasons of each experiment. Jaboticabal, UNESP, 2009-2010.

Sources of variation	DF	AYL_e	AYL_t	AYL	LER_e	LER_t	LER
Blocks (growing seasons)	6	1.33^ns^	5.27**	4.30**	1.33^ns^	5.24**	2.80*
Growing seasons (S)	1	36.64**	32.57**	61.20**	36.56**	32.53**	86.00**
Eggplant transplanting times in relation to tomato transplanting (T)	9	402.43**	1662.35**	871.77**	402.98**	1664.14**	121.26**
S x T	9	8.40**	13.28**	10.49**	8.40**	13.26**	8.75**
CV (%)		- 36.38	8.23	10.04	4.20	4.06	2.90
Growing seasons							
S1		-0.13 b	0.93 b	0.80 b	0.65 b	0.48 b	1.13 b
S2		-0.08 a	1.02 a	0.95 a	0.69 a	0.51 a	1.20 a

** = P<0.01; * = P<0.05; ns = P>0.05. S1 = Experiment 1 growing season (February 12th to September 5th); S2 =Experiment 2 growing season (August 8th to February 20th).

time of transplanting. These results can be explained as a function of the change in the light spectrum, which, due to shading, affects the morphogenesis and physiological processes of the shaded species (Fan *et al.*, 2018).

Differently from what was observed for eggplant, the relative crowding coefficients of tomato plant (K_t) and of the intercropped system (K) increased the later the transplantation of eggplant plant (before or after) was carried out in relation to tomato plant. The minimum K_t values of 0.19 and 0.37 and K values of 2.02 and 2.21 and the maximum K_t values of 23.25 and 35.69 and K of 5.35 and 6.82 observed, in first and second growing season were obtained when the eggplant was transplanted at 30 DBTT and 15 DATT, respectively (Figures 2A and 2B).

Since the K values, which weight the relative crowding coefficient of the two crops, were greater than 1, it can be inferred that the intercropping resulted in biological efficiency (Nedunchezhiyan *et al.*, 2010), that is, it presented a yield advantage for intercropping system in relation to single crops (Diniz *et al.*, 2017).

In both growing seasons, eggplant competitive ratios (CR_e) decreased the later the eggplant was transplanted in relation to tomato. The maximum CR_e values observed were 1.54 and 1.69, when transplanted at 30 DBTT, in the first and second season, respectively. Minimum values of 0.12 and 0.05 were observed when transplantation was performed at 15 DATT, respectively for the first and second season. When eggplant plant was transplanted at 20 and 15 DBTT, the CR values for eggplant and tomato were similar in both growing seasons (Figures 3A and 3B).

On the other hand, the CR of tomato plant (CR_t) increased with the delay in transplanting eggplant compared to tomato plant, with maximum values observed equal to 7.78 and 8.37, when the eggplant was transplanted at 15 DATT, and minimum values of 0.49 and 0.41, when the eggplant was transplanted at 30 DBTT, respectively, in the first and second growing seasons (Figures 3A and 3B).

Cultures that have higher CR values in relation to each other have a greater ability to use environmental resources (Machiani *et al.*, 2018). Thus, the mean CR_t values in the different eggplant plant transplanting times were higher than the mean CR_e values, by 4.03 to 4.06 times between the first and last eggplant transplantation time, indicating how much more competitive the tomato plant was than the eggplant (Figures 3A and 3B). This result is confirmed when the CR values of the tomato plant are compared to the intercropping, with the crop showing higher values.

The intercropping showed CR values greater than 1.0, indicating a detrimental effect of one crop on another (Bantie *et al.*, 2014). When studied in relation to the transplantation period of the eggplant seedlings, it was observed that the highest levels of CR_t occurred in the latest periods of transplantation. These results point to a negative effect of tomato plant on eggplant production and development.

The biological behaviors of eggplant (A_e) and tomato (A_t) aggressivity were inversely proportional to the progression of the eggplant transplant period in relation to tomato plant, in both growing seasons, that is, there was a reduction in the A_e index while A_t values increased, both quadratically in relation to transplantation times. For eggplant plant, the maximum values observed for A_e were 0.35 and 0.48 when the eggplant plant was transplanted at 30 DBTT and the minimum values of -3.59 and -3.67 when the eggplant plant was transplanted at 15 DATT, respectively, in the first and second growing season. In relation to tomato plant, the maximum values observed for A_t were 3.59 and 3.66 at 15 DATT and minimum values of -0.33 and -0.48 at 30 DBTT, for the first and second growing season, respectively (Figures 4A and 4B). Furthermore, the values of A_e and A_t were similar when the eggplant plant was transplanted at 18 and 17 DBTT, at both times (Figures 4A and 4B). The increase in A_t and the decrease in A_e were approximately 3.93 in the first season and 4.14 in the second growing season and this relationship

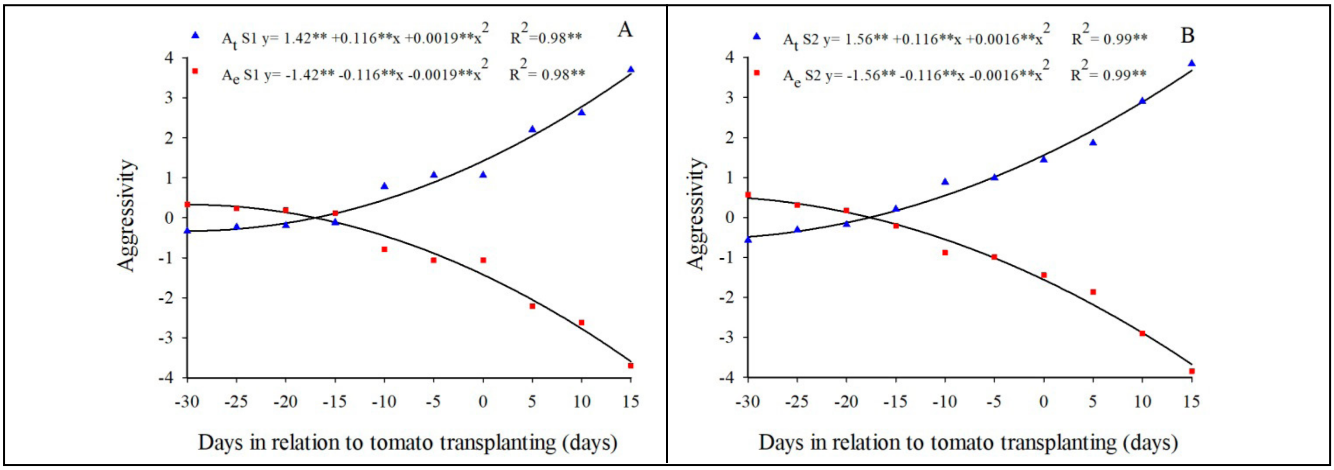

Figure 4. Aggressivity of eggplant plant (A_e) and of the tomato plant (A_t) in the first growing season (S1), (A), and in the second growing season (S2), (B), as a function of transplanting times of eggplant plant in relation to the tomato plant. Jaboticabal, UNESP, 2009-2010.

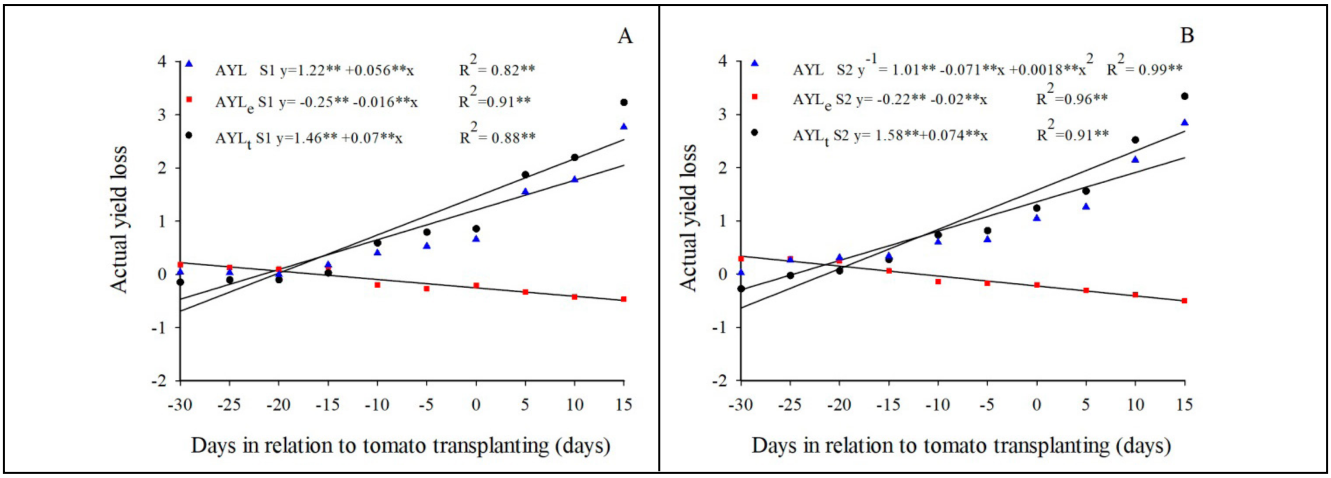

Figure 5. Actual yield loss of eggplant plant (AYL_e) and of the tomato plant (AYL_t) and of intercropping system (AYL) in the first growing season (S1), (A), and in the second growing season (S2), (B), as a function of transplanting times of eggplant plant in relation to the tomato plant. Jaboticabal, UNESP, 2009-2010.

indicates that tomato was the dominant crop in the intercropping.

To measure the dominance of one crop over another in intercropping, the aggressivity index (A) was used. Higher values in this index reflect a greater competitive capacity of a crop and a greater difference between actual and expected yields for crops. Thus, the increase in A_t and the decrease in A_e in the two growing seasons indicate that tomato was the dominant crop due to the delay in planting eggplant.

Thus, given the results of the CR and A indexes obtained for the crops, it can be said that tomato plant responds positively to the delay in eggplant plant transplantation (Figures 3A and 3B; 4A and 4B), skilfully using available environmental resources. These results corroborate with the K index, which indicates that tomato was the dominant crop in the intercropping. Although the eggplant crop has negatively interfered in the productive performance of tomato plant, the CR_t was little affected.

Significant interactions were observed between transplanting times of eggplant plant in relation to tomato plant and growing seasons of each experiment in the actual yield loss (AYL_e and AYL_t) and in the system (AYL) and in the land equivalent ratio of crops (LER_e and LER_t) and of the system (LER) evaluated (Table 3).

Studying the interaction between eggplant plant transplanting times within each growing season of the experiments, the same biological behavior of these indices was recorded as a function of eggplant transplanting times between growing seasons (Figures 5 and 6). The actual yield loss of eggplant (AYL_e) decreased linearly with the progression of transplanting days of eggplant in relation to tomato, in both growing seasons. The maximum values of AYL_e observed when the eggplant was transplanted at 30 DBTT, were 0.23 and 0.38, for the first and second growing season, respectively. The minimum values observed were -0.48 and -0.50 and occurred when the eggplant was transplanted at 15 DATT (Figures 5A and 5B). In relation to tomato plant, AYL_t and AYL increased linearly as a function of transplanting times, in

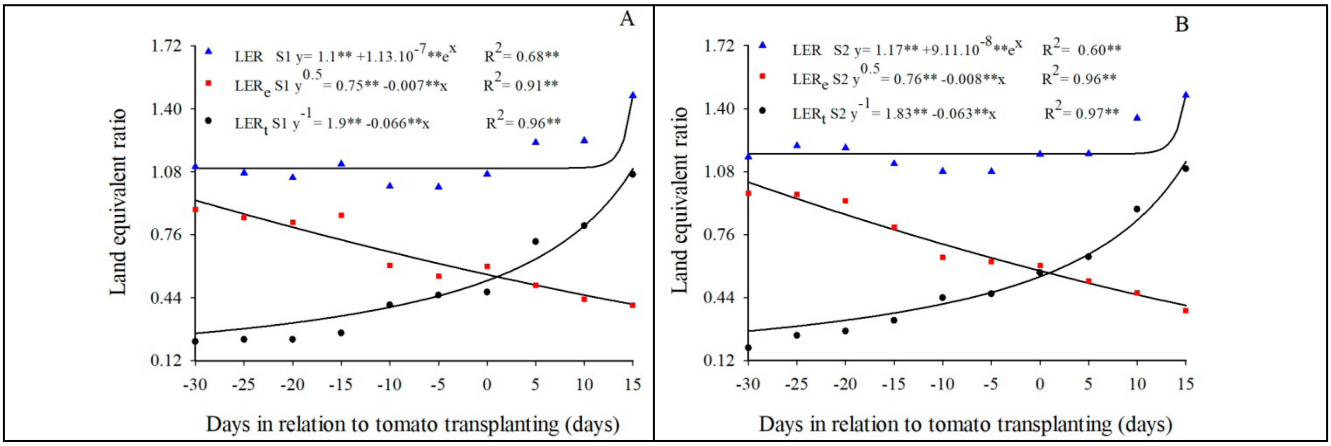

Figure 6. Land equivalent ratio of eggplant plant (LER_e) and of the tomato plant (LER_t) and of intercropping system (LER) in the first growing season (S1), (A), and in the second growing season (S2), (B), as a function of transplanting times of eggplant plant in relation to the tomato plant. Jaboticabal, UNESP, 2009-2010.

both growing seasons. The maximum values of these indices were 2.51 and 2.69 for AYL_t and 2.06 and 2.86 for AYL, observed when the eggplant was transplanted at 15 DATT, in first and second growing seasons, respectively. The minimum values recorded in these indices were -0.68 and -0.50 for AYL_t and -0.46 and 0.21 for AYL when the eggplant was transplanted at -30 DBTT, respectively, for the first and second season of cultivation (Figures 5A and 5B).

To evaluate the effects of competitiveness of crops on their productivity, the AYL index was used, which compares productivity of intercropped crops with productivity in monoculture. Thus, it can more accurately present the effects of inter- and intraspecific competition and the behavior of these species (Gebru, 2015; Pinto *et al.*, 2011). The AYL results obtained for tomato plant were positive and with a higher value than those obtained for eggplant plant, which had negative values. These values reflect the aggressiveness of the tomato plant, corroborating the CR, A and K indices obtained, in addition to considering factors such as morphology, physiology and nutrient requirements.

There was a linear reduction in the land equivalent ratio for eggplant plant (LER_e) as eggplant transplantation was performed later than tomato plant transplantation, in both growing seasons. The maximum LER_e values observed were 0.92 in the first season and 1.00 in the second season, obtained when the eggplant was transplanted at 30 DBTT, while the minimum values were 0.41 in the first season and 0.40 in the second season, were obtained when the eggplant transplanting was performed at 15 DATT (Figures 6A and 6B).

LER values remained more or less constant until 10 days after the eggplant transplantation, increasing until 15 days after eggplant transplantation in both growing seasons. On the other hand, there was an increase in the tomato plant LER_t as a function of the progression in the dates of transplantation of eggplant in relation to tomato, in both growing seasons. The maximum values of 1.07 and 1.09 for LER_t and 1.47 and 1.47 for LER in the first and second seasons were obtained when the eggplant plant was transplanted at 15 DATT. The minimum values were 0.26 and 0.27 for LER_t and 1.10 and 1.17 for LER in the first and second season, when the eggplant was transplanted at 30 DBTT (Figures 6A and 6B).

The LER of the intercrops established with different eggplant transplanting times were greater than 1, indicating a production advantage over the single system due to better land use and the use of environmental resources (Diniz *et al.*, 2017). According to Jagannath & Sunderaraj (1987), in any comparison of benefits between intercropped systems with different land occupation areas, the advantage of intercropping via LER results from two different sources, which are generally confused: a) the land factor (area occupied by each component crop) and b) of the biological/agronomic factor (coming from the tested treatment-factors). This advantage in the LER in the studied intercropping systems ranged from 1.47 to 1.09, in the first season, and from 1.47 to 1.17, in the second growing season, and came from the biological/agronomic factor resulting from the transplanting times tested, since the area occupied by each crop in the different systems was the same.

According to the indices presented for the tomato crop, it was observed that these increased with the delay in transplanting the eggplant. This behavior indicates a decrease in the interference of eggplant in the productive performance of tomato. On the other hand, the indices obtained for the eggplant plant decreased, evidencing that the tomato plant interferes in the productive performance of the eggplant plant as its transplantation took place later.

Regarding the growing seasons, significant differences were observed between them, with the second growing season standing out from the first, except for A_e, where there was an inverse behavior and for CR_e and CR_t, where no significant differences were observed between the growing seasons (Tables 2 and 3). This better performance of the second growing season is due to the climatic conditions of temperature in relation to the first season, which presented low temperatures, delaying the physiological process of fruit maturation and, consequently, eggplant and tomato productivity.

Finally, based on these evaluated indices, it is possible to conclude that the variation in transplanting date of eggplant plant in relation to tomato plant significantly interferes in the bio-agronomic performance of both species. Eggplant plant transplanting performed between -20 and -15 days compared to tomato plant transplantation reduces the dominance of one crop over the other and the interspecific competition for environmental resources. The intercropping had greater land use efficiency when the eggplant was transplanted at +15 days after transplanting the tomato plant. Based on this behavior, perhaps greater efficiency of land use could be achieved in eggplant transplantation performed after 15 days of tomato transplantation.

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REFERENCES

BANTIE, YB; ABERA, FA; WOLDEGIORGIS, TD. 2014. Competition indices of intercropped lupine (local) and small cereals in additive series in west Gojam, north western Ethiopia. *American Journal of Plant Sciences* 5: 1296-1305.

CECÍLIO FILHO, AB; ALVES, AU; GALATI, VC; BEZERRA NETO, F; BARBOSA, JC; MACHADO, BQV. 2022. Intercropping of eggplant and tomato as function of times of transplant and cropping season. *Revista Caatinga* 35: 276-287.

CECÍLIO FILHO, AB; BEZERRA NETO, F; REZENDE, BLA; BARROS JÚNIOR, AP; LIMA, JSS. 2015. Indices of bio-agroeconomic efficiency in intercropping systems of cucumber and lettuce in greenhouse. *Australian Journal of Crop Science* 9: 1154-1164.

CECILIO FILHO, AB; BEZERRA NETO, F; REZENDE, BLA; GRANGEIRO, LC; LIMA, JSS. 2013. Indices of competition and bio-agroeconomic efficiency of lettuce and tomato intercrops in greenhouses. *Australian Journal of Crop Science* 7: 809-819.

CECÍLIO FILHO, AB; REZENDE, BLA; DUTRA, AF. 2019. Yield of intercropped lettuce and cucumber as a function of population density and cropping season. *Revista Caatinga* 32: 943-951.

DEWICHE, LD; SLAUGHTER, SJ. 2003. *The little SAS book: A Primer*. 3rd edition. Cary, NC: SAS Institute Inc. 354p.

DINIZ, WJS; SILVA, TGF; FERREIRA, JMS; SANTOS, DC; MOURA, MSB; ARAÚJO, GGL; ZOLNIER, S. 2017. Forage cactus-sorghum intercropping at different irrigation water depths in the Brazilian semiarid region. *Pesquisa Agropecuária Brasileira* 52: 724-733.

FAN, Y; CHEN, J; CHENG, Y; RAZA, MA; WU, X; WANG, Z; LIU, Q; WANG, R; WANG, X; YONG, T; LIU, W; LIU, J; DU, J; SHU, K; YANG, W; YANG, F. 2018. Effect of shading and light recovery on the growth, leaf structure, and photosynthetic performance of soybean in a maize-soybean relay-strip intercropping system. *PLoS ONE* 13: e0198159.

GEBRU, H. 2015. A review on the comparative advantages of intercropping to mono-cropping system. *Journal of Biology, Agriculture and Healthcare* 5: 1-13.

GUERRA, NM; BEZERRA NETO, F; LIMA, JSS; SANTOS, EC; NUNES, RLC; PORTO, VCN; QUEIROGA, RCF; LINO, VAS; SÁ, JM. 2021. Productive and agro-economic benefits in beet-lettuce intercropping under organic manuring and population densities. *Research, Society and Development* 10: 01-25.

GUERRA, NM; BEZERRA NETO, F; LIMA, JSS; SANTOS, EC; NUNES, RLC; PORTO, VCN; QUEIROGA, RCF; LINO, VAS; SÁ, JM. 2022. Agroeconomic viability of lettuce-beet intercropping under green manuring in the semi-arid region. *Horticultura Brasileira* 40: 078-087.

JAGANNATH, MK; SUNDERARAJ. N. 1987. Productivity equivalent ratio and statistical testing of its advantage in intercropping. *Journal of the Indian Society of Agricultural Statistics* 39: 289-300.

MACHIANI, MA; JAVANMARD, A; MORSHEDLOO, MR; MAGGI, F. 2018. Evaluation of competition, essential oil quality and quantity of peppermint intercropped with soybean. *Industrial Crops and Products* 111: 743-754.

MAITRA, S; PALAI, JB; MANASA, P; KUMAR, DP. 2019. Potential of intercropping system in sustaining crop productivity. *International Journal of Agriculture, Environment and Biotechnology* 12: 39-45.

NEDUNCHEZHIYAN, M; RAO, KR; SATAPATHY, BS. 2010. Productivity potential, biological efficiency and economics of sweet potato (*Ipomoea batatas*) - based strip intercropping systems in rainfed Alfisols. *The Indian Journal of Agricultural Sciences* 80: 321-324.

PEREIRA, BJ; CECÍLIO FILHO, AB; LA SCALA, N. 2021. Greenhouse gas emissions and carbon footprint of cucumber, tomato and lettuce production using two cropping systems. *Journal of Cleaner Production* 282: 124517.

PINTO, CM; SIZENANDO FILHO, FA; CYSNE, JRB; PITOMBEIRA, JB. 2011. Produtividade e índices de competição da mamona consorciada com gergelim, algodão, milho e feijão caupi. *Revista Verde*, 6: 75-85.

SANTOS, HG; JACOMINE, PKT; ANJOS, LHC; OLIVEIRA, VA; LUMBRERAS, JF; COELHO, MR; ALMEIDA, JA; ARAÚJO FILHO, JC; OLIVEIRA, JB; CUNHA, TJF. 2018. *Sistema Brasileiro de Classificação de Solos*. 5.ed. rev. e ampl. Brasília: Embrapa. 356p.

SEDIYAMA, MAN; NASCIMENTO, JLM; LOPES, IPC; LIMA, PC; VIDIGAL, SM. 2014. Tipos de poda em pepino dos grupos aodai, japonês e caipira. *Horticultura Brasileira* 32: 491-496.

SILVA, JN; BEZERRA NETO, F; LIMA, JSS; CHAVES, AP; NUNES, RLC; RODRIGUES, GSO; LINO, VAS; SÁ, JM; SANTOS, EC. 2021. Sustainability of carrot-cowpea intercropping systems through optimization of green manuring and spatial arrangements. *Ciência Rural* 51: 1-13.

SYSTAT SOFTWARE Inc. 2021. *TableCurve 2D - Curve fitting made fast and easy*. San Jose, CA: Systat Software Inc.

TRANI, PE; MELO, AMT; PASSOS, FA; TAVARES, M; NAGAI, H; SCIVITTARO, WB. 1997a. Berinjela, jiló, pimenta-hortícola e pimentão. In.: RAIJ, B; CANTARELLA, H; QUAGGIO, JA; FURLANI, AMC (eds). *Recomendações de adubação e calagem para o estado de São Paulo*. Campinas: IAC. p.173.

TRANI, PE; NAGAI, H; PASSOS, FA. 1997b. Tomate rasteiro (industrial) irrigado. In.: RAIJ, B; CANTARELLA, H; QUAGGIO, JA; FURLANI, AMC. *Recomendações de adubação e calagem para o estado de São Paulo*. Campinas: IAC. p. 185.

WANG, M; WU, C; CHENG, Z; MENG, H. 2015. Growth and physiological changes in continuously cropped eggplant (*Solanum melongena* L.) upon relay intercropping with garlic (*Allium sativum* L.). *Frontiers in Plant Science* 6: 262.