Ciência Rural, Santa Maria, v.49:12, e20190338, 2019 http://dx.doi.org/10.1590/0103-8478cr20190338

ISSNe 1678-4596
CROP PRODUCTION

Intercropping garlic in strawberry fields improves land equivalent ratio and gross income

Fernando Teruhiko Hata[1*] **Mauricio Ursi Ventura**[1] **Maria Tereza de Paula**[1] **Gabriel Danilo Shimizu**[1] **Jean Carlo Baudraz de Paula**[1] **Deise Akemi Omori Kussaba**[1] **Nicholas Vieira de Souza**[1]

[1]Departamento de Agronomia, Universidade Estadual de Londrina (UEL), 86060070, Londrina, PR, Brasil. E-mail: hata.ft@hotmail.com. [*]Corresponding author.

ABSTRACT: *Studies showed that intercropping garlic reduced pests in strawberry field crops. However, influence of intercropping on yield was not tested. The objective of the study was to evaluate the strawberry pseudofruit and garlic bulb productions in monocropping and intercropping systems. Assessments of the yields and calculation of the land equivalent ratio, competition ratio and gross income were performed. The experiments were conducted in three areas (two open field and one greenhouse) in Londrina municipality. Treatments in the field experiments were garlic or strawberry in monocrops (controls), strawberry (S) + one garlic row (GR), S + 2GR or S + 3GR per plot. In the greenhouse experiment, plants were grown in pots with following treatments: garlic or strawberry in monocrops, 2S + 2 garlic plants per plot (GPP), 2S + 4GPP or 2S + 5GPP. Similar yields (garlic bulbs and strawberry pseudofruits) were observed among the treatments. Intercropping garlic among strawberry plants increased the land equivalent ratio. The intercrop land equivalent ratio index ranged from 1.34 to 2.55. An increasing in gross income were observed when increasing garlic plant densities in intercropping with strawberry. Results showed that intercropping garlic with strawberry increases land equivalent ratio and gross income. Production of strawberry pseudofruits and garlic bulbs were not influenced by intercropping systems compared to monocropping.*
Key words: *Allium sativum, companion planting, competition ratio, Fragaria* x *ananassa, land equivalent ratio*.

Cultivo consorciado de alho e morangueiro aumenta a razão equivalente de terra e a receita bruta

RESUMO: *Estudos demonstram que o cultivo consorciado de alho em lavouras de morangueiro reduz a população de pragas. No entanto, a influência do consórcio na produção destas culturas não foi testada. O objetivo do trabalho foi avaliar a produtividade de pseudofrutos de morango e bulbos de alho em monocultivo e em sistema de cultivo consorciado. Foram realizadas avaliações dessa produção, razão equivalente de terra, razão de competição e receita bruta. Os experimentos foram realizados em três áreas de cultivo (dois a céu aberto e uma em cultivo protegido) no município de Londrina. Os tratamentos nas áreas de cultivo a céu aberto foram: alho ou morangueiro em cultivo solteiro (controles); morangueiro em consórcio com uma, duas ou três linhas de cultivo de alho por parcela. Em experimentos em cultivo protegido, as plantas foram cultivadas em vasos com os seguintes tratamentos: alho ou morangueiro em cultivo solteiro, duas plantas de morangueiro (2M) + duas plantas de alho por parcela (2 PAP), 2M+4PAP e 2M+5PAP. Produções semelhantes tanto de alho, quanto de morangos, foram obtidas entre os tratamentos. O cultivo consorciado aumentou a eficiência no uso da terra. O índice razão equivalente de terra variou entre 1,34 a 2,55. A receita bruta aumentou com aumento da densidade de cultivo de alho. Os resultados demonstram que o cultivo consorciado de alho e morangueiro aumenta o uso eficiente da terra e a receita bruta. As produções de pseudofrutos de morangueiro e bulbos de alho não foram influenciadas pelos sistemas de cultivo consorciado, comparado ao monocultivo destas culturas.*
Palavras-chave: *Allium sativum, plantas companheiras, razão de competição, Fragaria* x *ananassa, razão equivalente de terra*.

INTRODUCTION

Monocrops predominate in farming practices due to the simplicity of their management to achieve agricultural yields. However, the concentration of resources under monocropping increases the incidence of diseases and pests, which may reduce crop productivity. In contrast, if intelligently designed, plant diversification schemes may reduce the number of crop pests and increase the number of their natural predators, as shown by a meta-analysis including 552 experiments (LETOURNEAU et al., 2011, GREENOP et al., 2018). In general, these cropping systems are mostly suitable for small farmers whose main income source is the cultivation of vegetables. A wide range of combinations of plants

Received 04.30.19 Approved 10.15.19 Returned by the author 11.01.19
CR-2019-0338.R1

are possible due to the vast number of horticultural crops available.

The use of intercropping with vegetable species, such as aromatic or spicy plants, has high potential to improve land equivalent ratio (ANJUM et al., 2015; ISLAM et al., 2016; SCHMITT et al., 2016). These cropping systems collaborated to save production resources such as water and fertilizer, and manpower usage becomes more efficient, which contributed to the development of agroecosystem sustainability. For example, intercropping garlic (*Allium sativum* L.), onion (*Allium cepa* L.) or coriander (*Coriandrum sativum* L.) in mustard (*Brassica napus* L.) field reduced aphid incidence (NOMAN et al., 2013). Although the mustard seed production was diminished, the income generated by the intercropped plants was very high (three times more than the monocrops) (NOMAN et al., 2013).

The candidates used in intercropping systems must have similar agronomic and climatic requirements. Strawberry (*Fragaria* × *ananassa* Duch.) plants are herbaceous and perennial, and their edible part is formed by a fleshy receptacle (pseudofruit) (FILGUEIRA, 2008). The strawberry pseudofruit production is affected by temperature, photoperiod, soil conditions and the phytosanitary conditions (ZEIST and de RESENDE, 2019). Garlic plants have narrow and elongated leaves (FILGUEIRA, 2008). In general, garlic bulbs receive good prices, which suggested that growers could consider them as a suitable candidate to be included in intercropping systems.

Although intercropping garlic in strawberry fields has been successfully used for the management of arthropod pests, twospotted spider mite (TSSM) *Tetranychus urticae* Koch (Acari: Tetranychidae) (HATA et al., 2016) and *Neopamera bilobata* Say (Hemiptera: Rhyparochromidae) (HATA et al., 2018), we did not find reports of studies regarding the feasibility of intercropping in terms of the yields of the two crops. Since the maximization of land use efficiency may be achieved by using intercropping (SINGH et al., 2018), we hypothesized that this would be possible for strawberry + garlic designs.

The objective of the study was to evaluate the strawberry pseudofruit and garlic bulb productions in monocropping and intercropping systems. Assessments of garlic and strawberry yields and calculation of the land equivalent ratio (LER), competition ratio (CR) and gross income (GI) indexes were performed.

MATERIALS AND METHODS

The experiments were conducted in three areas. In area I, the experiment was conducted in open field beds in Warta (District of Londrina municipality), Paraná (23°12’40.6”S, 51°12’16.4”W; 580 m.) in the area of Eloi Müller, a traditional strawberry grower in the region. In the area II, the experiment conducted in a greenhouse located at Universidade Estadual de Londrina (UEL) (23°19’44.5”S, 51°12’17.3”W; 585 m.) with the plants grown in plastic pots (7 L, top diameter: 27 cm, bottom diameter: 19 cm and pot height: 22 cm) filled with soil. In area III, the experiment conducted in open field beds at the UEL experimental farm in Londrina municipality (23°20’28.1”S, 51°12’34”W; 547 m.). The climate type was Cfa (Köppen classification), and the soil was classified as red ferralsol (EMBRAPA, 2018), with clay texture in all areas of the study.

The soil fertility analysis showed the following values: Area I: pH_{H2O}= 7.10, P= 7,80 mg/dm^3, K^+= 1.11 cmol$_c$/dm^3, Ca^{+2}= 10.0 cmol$_c$/dm^3, Mg^{+2}= 4.1 cmol$_c$/dm^3, Al^{+3}= 0.0, H+Al^{+3}= 2.73 cmol$_c$/dm^3, Cation exchange capacity, CEC = 17.94 cmol$_c$/dm^3, V= 84.67%, and Organic matter, OM= 1.90%. Area II: pH_{H2O}= 5.10, P= 6.00 mg/dm^3, K^+= 0.75 cmol$_c$/dm^3, Ca^{+2}= 1.35 cmol$_c$/dm^3, Mg^{+2}= 1.20 cmol$_c$/dm^3, Al^{+3}= 0.0, H+Al^{+3}= 2.10 cmol$_c$/dm^3, CEC = 5.40 cmol$_c$/ dm^3, V= 61.11%, and OM= 1.80%. Area III: pH_{H2O}= 5.50, P= 12.90 mg/dm^3, K^+= 0.78 cmol$_c$/dm^3, Ca^{+2}= 7.6 cmol$_c$/dm^3, Mg^{+2}= 1.6 cmol$_c$/dm^3, Al^{+3}= 0.0, H+Al^{+3}= 4.61 cmol$_c$/dm^3, CEC = 9.97 cmol$_c$/ dm^3, V= 68.0%, and OM= 2.14%.

The Albion and Camarosa seedlings were purchased from a commercial nursery and transplanted on March 10 and April 7, 2015, for areas I and III, respectively. At the moment of transplanting the stolons were present with abundant rizomes and only the new leaf from crown were kept. A double line spacing of 0.35 x 0.35 m was used. Garlic (BRS Hozan and Cateto cultivars) was planted on April 2 and 28, respectively, for areas I and III (spacing was 0.10 m between plants and 0.35 m between rows). Each plot consisted of eight strawberry plants or eight garlic plants in monocrop or strawberry + garlic intercrops. For areas I and III, the treatments were as follows: monocrop of garlic or strawberry or strawberry (S) + one (S+1GR), two (S+2GR) or three (S+3GR) garlic rows (Figure 1 A, B, C and D).

For area II, Albion seedlings were purchased from a commercial nursery and transplanted on March 10, 2015. Garlic (BRS Hozan) was planted on April 8. At the moment of transplanting the stolons

Figure 1 - Experiment for testing strawberry and garlic intercropping yields with different densities: Strawberry monocrop (A) or strawberry + one (B), two (C) or three (D) garlic rows.

were present with abundant rizomes and only the new leaf from crown were kept. The plot consisted of two strawberry plants per pot. The treatments were as follows: monocrop of garlic (two plants per pot), monocrop of strawberry or strawberry + two (S+2GPP), four (S+4GPP) or five (S+5GPP) garlic plants per plot (Figure 2). This design was determined to simulate the density of the garlic plants in the one, two or three rows of garlic + strawberry intercropping fields, respectively.

Soil fertilization, fertigation, and pest and disease management were carried out according to the technical recommendations for strawberry crops (RONQUE, 2010). For area I, the grower management was realized. For area II and III, organic farming management was used (Rule 10.831/2003 and inputs allowed by Normative proceeding 46/2011 and Normative proceeding 17/2014).

Strawberry harvesting was performed three times per week to determine the mass of the commercial pseudofruits (perfect or with slight defects) (PBMH & PIMO, 2009). The non-commercial pseudofruits (with serious defects) were discarded. The garlic bulbs were harvested when the leaves showed signs of senescence.

The land equivalent ratio (LER) was calculated using the following formula (1) (MEAD & WILLEY, 1979):

LER Intercropping = LER (s) + LER (g) (1)

Where LER Intercropping = yield (kg/ha) with intercropping/yield (kg/ha) with monocropping. s = strawberry, and g = garlic. LER of each plant crop were calculated individually, and LER Intercropping was the sum of the strawberry crop LER + garlic crop LER.

The competition ratio (CR) was calculated using the following formula (2) (WILLEY & RAO, 1980):

CRg = (Pgs/Pg)/(Psg/Ps) × (Fg/Fs) or CRs = (PSg / Ps)/(Pgs/Pg) × (Fs/Fg) (2)

Where Pgs = yield of garlic (kg/ha) intercropped with strawberry; Pg = yield of garlic (kg/ha) in monocrop; Psg = yield of strawberry (kg/ha) intercropped with garlic; Ps = yield of strawberry (kg/ha) in monocrop; Fg = frequency of garlic intercropped with strawberry; and Fs = frequency of strawberry intercropped with garlic.

The financial indicator of gross income (GI) was also calculated using the following formula (3).

GI = ∑ (Pi × Qi) (3)

Where Pi= price (US$) and Qi= production.

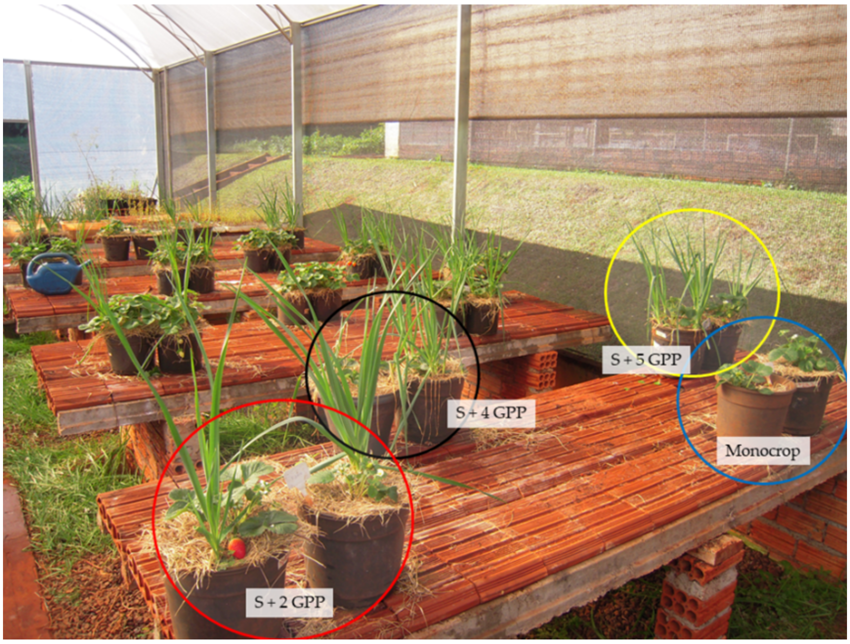

Figure 2 - Experiment for testing strawberry and garlic intercropping yields with different densities: Strawberry monocrop (blue circle), Strawberry + 2 garlic plant per plot - GPP (red circle), S+4GPP (black circle) and S+5GPP (yellow circle).

Prices were obtained from the Ceagesp distribution center (www.ceagesp.gov.br), the greatest in Brazil. Mean market prices were collected from October 2014 to October 2017. At the moment of the prices survey the conversion of 1 Dollar to Brazilian Real was R$ 3.22. We chose this indicator because only garlic seed bulbs were included as an additional input in the intercropping designs, and growers, in general, produce their own seed bulbs.

A completely randomized block design with five replicates for areas I and II and with four replicates for area III was used. The data were submitted to a homoscedasticity test (Hartley's F test) and normality test (Shapiro-Wilk test). Thereafter, analysis of variance was performed, and the means were compared with Tukey's test ($p<0.05$). Data was not transformed. Data from CR were compared between garlic and strawberry to know what plant were the most competitive.

RESULTS

Results of greenhouse and open field studies showed that there were no differences between of strawberry or garlic yields among the treatments in the three growing areas (Table 1) (*p* valor for strawberry in areas I, II and III are, respectively: 0.93; 0.66; 0.14; *p* valor for garlic in areas I, II and III are, respectively: 0.22; 0.70; 0.95).

Although not different, the average yield of garlic bulbs varied from 29.22 (Strawberry plants [S] +3 garlic rows [GR]) to 33.30 g (control) for area I, 22.06 (S+5 garlic plant per plot [GPP]) to 25.50 g (control) for area II and 10.89 (S+2GR) to 15.06 g (S+3GR) for area III. For strawberry, the yield of the pseudofruits per plant ranged from 376.96 g (S+2GR) to 454.48 g (S+3GR) for area I, 211.46 (S+2GPP) to 256.31 g (control) for area II, and 121.27 (S + 3GR) to 145.64 g (S + 2GR) for area III (Table 1).

Intercrop LER indexes higher than one were observed (Table 2), which means that intercropping production (taking in account bulb production + pseudofruit production) is higher than monocropping (bulb or pseudofruit in sole production, monocrop), in the same area. The values ranged from 1.34 (S+2GPP, area II) to 2.55 (S+3GR, area III). In areas I and III, the LER with the S+3GR treatment was higher than that with the other treatments (F = 14.96 and 24.57, *p* valor<0.01, for areas I and III, respectively). For area II, higher LER indexes were observed with the

Table 1 - Means of garlic bulbs and strawberry pseudofruits yield (g) per plant, on three intercropping designs (densities of garlic intercropped with strawberry) and strawberry or garlic monocrops. Londrina, 2017.

	--------------------------Garlic----------------------			-------------------------------Strawberry--------------------------		
Treatments	Area I	Area II	Area III	Area I	Area II	Area III
Monocrop	33.30$^{n.s.}$	25.50$^{n.s.}$	14.91$^{n.s.}$	425.33$^{n.s.}$	256.31$^{n.s.}$	131.24$^{n.s.}$
S+1GR or 2GPP	29.66	22.38	11.65	392.20	211.46	131.40
S+2GR or 4GPP	31.70	25.13	10.89	376.96	236.41	145.64
S+3GR or 5GPP	29.22	22.06	15.06	454.48	227.68	121.27
C.V. (%)	35.74	20.40	22.16	14.75	19.29	44.15
p valor	0.93	0.66	0.14	0.22	0.70	0.95

C.V. = Coefficient of variation; n.s. = non-significant by Anova (p>0.05). Strawberry (S) + 1GR or 2GPP, one garlic row or two plants per plot; S+2GR or 4GPP, two garlic rows or four garlic plants per plot; S+3GR or 5GPP, three garlic rows or five garlic plants per plot). The GPP denomination was used for area II, only.

S+4GPP or S+5GPP treatments ($F = 13.61$; $p<0.01$) than with S+2GPP.

The CR showed how much the plant is more competitive than other. Values were similar among treatments (Table 3). In most cases, the CR indexes showed that the strawberry plants had a higher competition potential compared to the garlic plants (F = 9.31, 14.64, 33.58, *p* valor<0.01, respectively, for S+1, 2 or 3GR, area I); (F = 20.72, *p* valor<0.05; 18.04, *p* valor<0.01, respectively for S+4 or 5GPP, area II); (Table 3). The CR indexes for the garlic plants ranged from 0.28 (S + 2GR, area III) to 0.57 (S + 2 or 5GPP, area II). For the strawberry plants, the CR indexes ranged from 1.82 (S+5GPP, area II) to 3.70 (S+2GR, area III).

An increase in GI ranging from US$ 2,390 (2 GPP, area II) to 21,815 (S+3GR, area I) per hectare was obtained by intercropping garlic in strawberry fields (Table 4). The GI increased with the garlic plant densities (8.4, 17 and 19%; 5, 10 and 13%; 9.7, 15 and 31% for 1, 2 or 3 GR in areas I, II and III, respectively).

DISCUSSION

Our results showed that intercropping garlic and strawberry did not reduce both crops yield, therefore, improving land equivalent ratio and gross income to farmers. Previous studies have shown that the average weight of the Hozan garlic variety bulbs in monocrop ranged from 7.60 g (30

Table 2 - Land Equivalent Ratio (LER) of strawberry or garlic in monocrop or different designs of strawberry plus garlic (three plant densities) intercropping in three areas, Londrina, 2017.

---------------------Area I--------------------				---------------------Area II*------------------				-------------------------Area III-------------------			
Treatments	LER G	LER S	LER I	Treatments	LER G	LER S	LER I	Treatments	LER G	LER S	LER I
S+1GR	0.47 b	0.93 a	1.40 b	S+2GPP	0.44 b	0.90 a	1.34 b	S+1GR	0.41 b	0.99 a	1.41 b
S+2GR	0.96 a	0.89 a	1.86 b	S+4GPP	0.98 ab	1.04 a	2.02 a	S+2GR	0.77 b	1.15 a	1.92 ab
S+3GR	1.37 a	1.07 a	2.43 a	S+5GPP	1.33 a	0.98 a	1.93 a	S+3GR	1.54 a	1.01 a	2.55 a
C.V.	27.04	35.53	15.84	C.V.	30.69	39.15	12.17	C.V.	30.77	29.97	24.57
p value	0.01	0.19	0.02	*p* value	0.01	0.92	0.05	*p* value	0.01	0.85	0.05

C.V. = Coefficient of variation; Means within a column followed by the same letter are not significantly different based on Tukey's test (p>0.05). Strawberry (S) + 1GR or 2GPP, one garlic row or two plants per plot; S+2GR or 4GPP, two garlic rows or four garlic plants per plot; S+3GR or 5GPP, three garlic rows or five garlic plants per plot). LER G (Garlic) + LER S (Strawberry) = LER I (Intercrop). The GPP denomination was used for area II, only.

Table 3 - Competition rate (CR) of strawberry or garlic in monocrop or different designs of strawberry plus garlic (three plant densities) intercropping in three areas, Londrina, 2017.

---------------------Area I---------------------					-----------------------Area II---------------------					--------------------Area III ---------------------				
Treatments	CR G	CR S	C.V.	*p* value	Treatments	CR G	CR S	C.V.	*p* value	Treatments	CR G	CR S	C.V.	*p* value
S+1GR	0.39 aB	2.84 aA	65. 03	0.01	S+2GPP	0.57 aB	2.18 aA	74. 10	0.04	S+1GR	0.37 aB	3.09 aA	58.00	0.02
S+2GR	0.45 aB	2.59 aA	58. 27	0.01	S+4GPP	0.56 aB	2.23 aA	28. 94	0.05	S+2GR	0.28 aB	.70 aA	22.88	0.01
S+3GR	0.34 aB	3.23 aA	49. 68	0.01	S+5GPP	0.57 aB	1.82 aA	34. 65	0.01	S+3GR	0.42 aB	2.45 aA	28.58	0.01
C.V.	35.72	35.53			C.V.	34.67	39. 15			C.V.	30.77	26.09		
p value	0.56	0.69			*p* value	0.99	0.85			*p* value	0.21	0.18		

C.V. = Coefficient of variation; Means ± SD within a column followed by the same lowercase letter, or uppercase within a line, are not significantly different based on Tukey's test (p>0.05). Strawberry (S) + 1GR or 2GPP, one garlic row or two plants per plot; S+2GR or 4GPP, two garlic rows or four garlic plants per plot; S+3GR or 5GPP, three garlic rows or five garlic plants per plot). The GPP denomination was used for area II, only.

days of vernalization) to 17.88 g (non-vernalized bulbs) (LUCENA et al., 2016). The previously reported average bulb mass for this variety was 25.5 g in southeastern Brazil (BIESDORF et al., 2015). In the present study, the average mass of this variety of garlic bulbs varied from 22.06 to 33.30 g, which was above the averages reported previously. However, the bulbs were weighed immediately after harvest without a curing process, while in previous studies, a curing process of 7 (LUCENA et al., 2016) or 25 days (BIESDORF et al., 2015) was carried out, which may have reduced the mass of the bulbs (3 to 10% reduction in bulb weight) (LIMA & RESENDE, 2007).

The yield of the Albion variety of strawberry was similar to that obtained in a previous monocrop study in Dois Vizinhos, PR, County, in which values ranged from 319.50 to 386.50 g per plant (MAZARO et al., 2013) and were inferior compared to that obtained in Guarapuava in first cycle (784.3 g per plant) (ZEIST et al., 2019). For the Camarosa variety, similar yields were observed in studies conducted in Pouso Alegre - MG (137 g per plant) (PÁDUA et al., 2015) and Curitiba, PR Counties (117.70 g per plant) (LEMINSKA et al., 2014) and were inferior compared to that obtained in Guarapuava in first and second cycles (482.0 and 410.7 per plant for first and second cycles, respectively) (ZEIST et al., 2019).

Intercropping did not significantly reduce the yields of both crops. Similar results were previously observed for strawberry - lettuce, onion or radish intercrops (KARLIDAG & YILDIRIM, 2009), in which the strawberry plants had similar yields in monocrop (422 and 375 g per plant, for first and second cycle, respectively) and in strawberry-onion intercropping in two production cycles (405 and 386 g per plant, for first and second cycle, respectively). Our results also corroborated with previous studies in which a LER index above 1.90 was reported for the strawberry-onion intercropping (KARLIDAG & YILDIRIM, 2009). In addition, the lettuce-onion intercropping also showed a LER index higher than 1.0, between 1.84 and 1.89, but the head diameter, fresh mass, and number of lettuce leaves were not altered by intercropping (KOEFENDER et al., 2016).

Intercropping with *Amaryllidaceae* family plants apparently does not reduce the yields of the strawberry crop. Both garlic, as observed in the present study, and onion have agronomic characteristics that may not negatively influence strawberry in intercropping. Leaves of garlic and onion plants are filiform and partially shade the strawberry plants. Although, in general, both strawberry and garlic crops are described as highly demanding of soil fertility (FILGUEIRA, 2008), the fertilizers provided for the monocrop were also enough for both crops (similar yields to monocrops), which suggested that nutrients were efficiently used.

The higher strawberry CR index was triggered by early planting (22, 28 and 21 days, for areas I, II and III, respectively) in relation to the

Table 4 - Gross income (USD/ha) of strawberry (S) or garlic (G) in monocrop or different designs of strawberry plus garlic (three plant densities) intercropping (I) in three areas, Londrina, 2017.

	------------------Area I----------------			--------------Area II--------------			----------------Area III--------------		
Treatments	G	S	I	G	S	I	G	S	I
Monocrop	8,287	86,898	-	2,723	52,366	-	3,710	26,813	-
S+1GR or 2GPP	7,381	80,130	87,511	2,390	43,203	45,593	2,899	26,846	29,745
S+2GR or 4GPP	15,777	77,016	92,793	5,366	48,300	53,667	5,420	29,755	35,175
S+3GR or 5GPP	21,815	92,854	114,668	7,066	46,517	53,583	11,243	24,776	36,020

Mean market prices from October 2014 to October 2017 (USD/kg) of garlic = 3.36 and strawberry = 3.22. Strawberry (S) + 1GR or 2GPP, one garlic row or two plants per plot; S+2GR or 4GPP, two garlic rows or four garlic plants per plot; S+3GR or 5GPP, three garlic rows or five garlic plants per plot). The GPP denomination was used for area II only.

planting time of the garlic plants. In a previous study with a garlic-peas intercropping system, the garlic plants also presented lower competitiveness, and the authors also found a comparable CR index (0.36) (ANJUM et al., 2015) to that in the present study. On other study, garlic plants showed a higher CR than eggplant (between 1.02 and 1.82) without causing a decrease in eggplant yield (ISLAM et al., 2016). Apparently, garlic plants initially develop faster than eggplants, which allowed their higher competitiveness.

The higher gross income in intercropping designs comes mainly from the higher density of garlic cultivation which provided a higher biomass production on the same area, and; consequently, greater income. For example, in area I the gross income from garlic in S+2GR treatment was higher than monocrop (USD 15,777 and 8,287, respectively, Table 4) even with lower garlic bulb production in S+2GR treatment (31.70 g per plant) versus garlic monocrop (33.30 g per plant) (Table 1). The same occurred in other production areas.

The garlic yields were not affected by competition and the production of the main crop (strawberry) was not reduced. In addition, a LER index above one was obtained for the intercropping system, which indicated that there is greater efficiency in the use of land than with monocrops. Garlic was initially proposed and succeed as an intercropping plant for pest reduction in strawberry crops (HATA et al., 2016; HATA et al., 2018) and may provide an additional source of income without increased inputs (except garlic bulbs seeds). To produce garlic in a strawberry intercropping system, the same crop management was used. There was also no increase in expenses for soil preparation, control of weeds, etc. As suggested, intercropping schemes may be particularly suitable for organic farmers that have limitations on using pesticides in their crops.

In summary, there were no statistically significant changes in strawberry yields when intercropping garlic in this crop; the garlic yields were not affected by strawberry; the strawberry-garlic intercropping provided higher land equivalent ratio than the monocrops; and the gross income was higher from intercropping than from strawberry monocropping.

ACKNOWLEDGEMENTS

The authors would like to thank Eloi Müller's Family and Universidade Estadual de Londrina for the research areas, and the research funding agencies Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), for the scholarships granted.

DECLARATION OF CONFLICT OF INTERESTS

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study, in the collection, analyses, or interpretation of data, in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

FTH conceived, designed and performed the experiments, revised the manuscript and performed the statistical analysis. MUV conceived and designed the experiments and revised the manuscript. MTP. GDS, JCBP, DAOK and NVS performed the experiments.

REFERENCES

ANJUM, M.A. et al. Assessment of advantages of pea and non-legume winter vegetable intercropping systems through competition and economic indices. **Experimental Agriculture**, v.51, n.3, p.327-343, 2015. Available from: <https://doi.org/10.1017/S0014479714000337>. Accessed: Oct. 26, 2019. doi: 10.1017/S0014479714000337

BIESDORF, E.M. et al. Performance of garlic cultivars vernalizated and non-vernalizated in Southeast of the Mato Grosso. **Revista de Agricultura Neotropical**, v.2, n.3, p.44-48, 2015. Available from: <https://periodicosonline.uems.br/index.php/agrineo/article/download/281/713 >. Accessed: Oct. 26, 2019.

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária**. Sistema brasileiro de classificação de solos**. 5º ed. Embrapa Solos, 356p., 2018.

FILGUEIRA, F.A.R. **Novo manual de olericultura**. Viçosa: UFV, 2008, 421p.

GREENOP, A. et al. Functional diversity positively affects prey suppression by invertebrate predators: a meta-analysis. **Ecology**, v.99, n.8, p.1771-1782, 2018. Available from: <https://doi.org/10.1002/ecy.2378>. Accessed: Oct. 26, 2019. doi: 10.1002/ecy.2378.

HATA, F.T. et al. Intercropping garlic plants reduces *Tetranychus urticae* in strawberry crop. **Experimental and Applied Acarology**, v.69, n.3, p.311-321, 2016. Available from: <https://doi.org/10.1007/s10493-016-0044-3>. Accessed: Oct. 26, 2019. doi: 10.1007/s10493-016-0044-3.

HATA, F.T. et al. Chinese chives and garlic in intercropping in strawberry high tunnels for *Neopamera bilobata* Say (Hemiptera: Rhyparochromidae) control. **Bulletin of Entomological Research**, v.109, n.4, p-419-425, 2018. Available from: <https://doi.org/10.1017/S0007485318000299>. Accessed: Oct. 26, 2019. doi: 10.1017/S0007485318000299

ISLAM, M.R. et al. Outcome of intercropping garlic with brinjal for the small holder farmers of Bangladesh. **Indian Journal of Agricultural Research**, v.50, n.2, p.177-182, 2016. Available from: <https://doi.org/10.18805/ijare.v0iOF.9428>. Accessed: Oct. 26, 2019. doi: 10.18805/ijare.v0iOF.9428

KARLIDAG, H.; YILDIRIM, E. Strawberry intercropping with vegetables for proper utilization of space and resources. **Journal of Sustainable Agriculture**, v.33, n.1, p.107-116, 2009. Available from: <https://doi.org/10.1080/10440040802587462>. Accessed: Oct. 26, 2019. doi: 10.1080/10440040802587462

KOEFENDER, J. et al. Consorciação entre alface e cebola em diferentes espaçamentos. **Horticultura Brasileira**, v.34, n.4, p.580-583, 2016. Available from: <https:// dx.doi.org/10.1590/s0102-053620160419>. Accessed: Oct. 26, 2019. doi: 10.1590/s0102-053620160419.

LEMISKA, A. et al. Produção e qualidade da fruta do morangueiro sob influência da aplicação de boro. **Ciência Rural**, v.44, n.4, p.622-628, 2014. Available from: <https:// dx.doi.org/10.1590/S0103-84782014000400008>. Accessed: Oct. 26, 2019. doi: 10.1590/S0103-84782014000400008.

LETOURNEAU, D.K. et al. Does plant diversity benefit agroecosystems? A synthetic review. **Ecological Applications**, v.21, n.1, p.9–21, 2011. Available from: <https://doi.org/10.1890/09-2026.1>. Accessed: Oct. 26, 2019. doi: 10.1890/09-2026.1.

LIMA, M.A.C.; RESENDE, G.M. **Cultivo da cebola no Nordeste**. Sistemas de produção, n.3, Embrapa Semi-árido, 2007.

LUCENA, R.R. et al. Productive performance of vernalizated semi-noble garlic cultivars in western Rio Grande do Norte state, Brazil. **Revista Caatinga**, v.29, n.2, p.327-337, 2016. Available from: <https://dx.doi.org/10.1590/1983-21252016v29n209rc>. Accessed: Oct. 26, 2019. doi: 10.1590/1983-21252016v29n209rc.

MAZARO, S.M. et al. Produção e qualidade de morangueiro sob diferentes concentrações de calda bordalesa, sulfocálcica e biofertilizante supermagro. **Semina: Ciências Agrárias**, v.34, n.6, (suplemento 1), p.3285-3294, 2013. Available from: <https://dx.doi.org/10.5433/1679-0359.2013v34n6Supl1p3285>. Accessed: Oct. 26, 2019. doi: 10.5433/1679-0359.2013v34n6Supl1p3285.

MEAD, R.; WILLEY, R.W. The concept of land equivalent ratio and advantages in yields from intercropping. **Experimental Agriculture**, v.16, p.217–228, 1980. Available from: <https://doi.org/10.1017/S0014479700010978>. Accessed: Oct. 26, 2019. doi: 10.1017/S0014479700010978.

NOMAN, M. S. et al. Intercropping mustard with four spice crops suppresses mustard aphid abundance, and increases both crop yield and farm profitability in central Bangladesh. **International Journal of Pest Management**, v.59, n.4, p.306-313, 2013. Available from: <https://doi.org/10.1080/09670874.2013.863408 >. Accessed: Oct. 26, 2019. doi: 10.1080/09670874.2013.863408.

PÁDUA, J. G. et al. Desempenho agronômico e comportamento de cultivares de morangueiro quanto à mancha-de-Pestalotiopsis e às podridões dos frutos. **Revista Agrogeoambiental**, v.7, n.1, p-65-74, 2015. Available from: <http://dx.doi.org/10.18406/2316-1817v7n12015544>. Accessed: Oct. 26, 2019. doi: 10.18406/2316-1817v7n12015544.

PBMH e PIMO – **Programa Brasileiro para Modernização da Horticultura e Produção Integrada de Morango**. Normas de Classificação de Morango. São Paulo: CEAGESP. (Documentos, 33), 2009.

RONQUE, E.R.V. **A Cultura do Morangueiro**. Instituto Emater Curitiba – Brasil, 2010.

SINGH, S.K. et al. Vegetable crops as most efficient and economical intercrops: a brief review. **Plant Archives**, v.18, n.1, p.923-929, 2018.

SCHMITT, O.J. et al. Consórcio de salsa e cebolinha para produção de maços comerciais mistos de cheiro-verde. **Horticultura Brasileira**, v.34, n.1, p.114-120, 2016. Available from: <http://dx.doi.org/10.1590/S0102-053620160000100017>. Accessed: Oct. 26, 2019. doi: 10.1590/S0102-053620160000100017.

WILLEY, R.W.; RAO, M.R. A competitive ratio for quantifying competition between intercrops. **Experimental Agriculture**, v.16, p.117-125, 1980. Available from: <https://doi.org/10.1017/S0014479700010802>. Accessed: Oct. 26, 2019. doi: 10.1017/S0014479700010802.

ZEIST, A.R.; de RESENDE, J.T.V. Strawberry breeding in Brazil: current momentum and perspectives. **Horticultura Brasileira**, v.37, p.7-16, 2019. Available from: <http://dx.doi.org/10.1590/s0102-053620190101>. Accessed: Oct. 26, 2019. doi: 10.1590/s0102-053620190101.

ZEIST, A.R. et al. Phenology and agronomic components of first and second-cycle strawberry. **Horticultura Brasileira**, v.37, p.29-34, 2019. Available from: <http://dx.doi.org/10.1590/s0102-053620190104>. Accessed: Oct. 26, 2019. doi: 10.1590/s0102-053620190104.