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Competitive Ability and Physiological Aspects of Single and Intercropped Arugula (*Eruca sativa* Miller)

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Abstract

The aim of this study was to evaluate the competitive ability and physiological aspects of arugula intercropped with different aromatic condiment species. The study was carried out at the Teaching Garden of the Federal University of Ceará, Brazil. A randomised complete block design was used, with four replications and seven treatments: T1 (single arugula), T2 (arugula intercropped with coriander), T3 (arugula and parsley), T4 (arugula and garlic chives), T5 (single coriander), T6 (parsley) and T7 (garlic chives). A physiological evaluation was made of the arugula only. Competitive ability was obtained by calculating the aggressivity index, simplified aggressivity, competitive ratio and compensation ratio. The leaf area index and specific leaf area were calculated. No difference was seen between the treatments with arugula for the physiological factors net photosynthesis, stomatal conductance, rate of transpiration and instant carboxylation efficiency under evaluation within each crop cycle, but there was a difference between the two cycles. The coriander showed the highest aggressivity index and competitive ratio, and was considered more competitive than the arugula, with a higher compensation ratio. As an intercrop, the arugula showed greater competitive ability than the parsley and garlic chives. The greatest leaf area and leaf area index in the arugula plants were seen when intercropped with coriander.

Keywords: *Allium tuberosum* (garlic chives), *Coriandrum sativum* (coriander), *Petroselinum crispum* (parsley), aggressivity index, competitive ratio

1. Introduction

Intercropping is a production system that aims to provide greater yields with less impact on the environment due to greater efficiency in the use of natural resources and inputs involved in the production process, bringing benefits to agricultural production of greater yields and better quality crops (Cecílio Filho et al., 2015; Cecílio Filho et al., 2017; Hendges et al., 2019; Wen et al., 2019; He et al., 2019; Barros Júnior et al., 2020).

Although with intercrops the aim is to maximise the use of environmental and local resources, crops grown under such a production system, even when not sown at the same time, develop simultaneously, which forces them to interact (Batista et al., 2016; Dodiya et al., 2018; Silva et al., 2021). Intercropped plants are usually subject to various types of interaction, which have been described as interactions of complementarity, competition and allelopathy, and which have also been seen as a form of communication under this cropping system (Costa, 2014; Callaway et al., 2020).

When considering an intercropping system, the ideal is to choose companion crops that between them display some type of complementarity. This is possible when the intercropped species present different complementary ecological niches, which can result in the better use of soil and climate factors compared to cultivating only one crop in the area (Cecílio Filho et al., 2008; Porto et al., 2011). As such, the efficiency or advantage of an intercropping system depends on the complementarity between the component crops.

In addition to complementarity, influences on the growth and development of intercrops, in both intra- and interspecific combinations, are the result of competition for resources such as water, light and nutrients, and the competitive ability of each species (Oliveira et al., 2012; Camili et al., 2013; Raza et al., 2019). In general, competitive interactions between plants are complex, with interaction occurring between the competition above and below ground (Zanine and Santos, 2004; Brooker et al., 2015). Such competition is better understood from physiological evaluations of gas exchange and leaf area that can demonstrate competitive ability above the ground as a function of the luminous environment. This can also happen through the observation of various indices that evaluate the individual performance of the intercropped species in relation to its behaviour as a single crop and/or in relation to the other intercropped species (Batista et al., 2016; Ribas et al., 2020). These indices allow the degree of competitiveness between crops to be quantified, and their aggressivity and dominance in the system, i.e. their competitive ability, to be determined.

Considering that intercropping involves specific biological interactions and competitive relationships which can have a significant impact on crop performance and on the efficiency of the intercropping systems (Hendges et al., 2019; Nassary et al., 2020), studies to evaluate different species are of great importance, since they can define which species are the most productive when submitted to intercropping. Based on the above, the aim of this study was to evaluate the physiological aspects and effects on the competitive ability of arugula intercropped with different aromatic condiment species.

2. Method

The study was carried out at the Teaching Garden of the Department of Plant Science on the Pici Campus of the Federal University of Ceará (UFC), in Fortaleza, Ceará, Brazil, at 03º44' S and 38º34' W, and an altitude of 21 m. According to Köppen, the climate in the region is type As, defined as tropical with dry summers, a mean annual temperature greater than 26°C and mean annual rainfall of approximately 1,450 mm (Alvares et al., 2013).

During the study period the mean minimum temperature was 22.97ºC, the maximum was 31.57ºC, the relative humidity was 71.5% and the accumulated rainfall was 116.20 mm. The data were obtained from the weather station of the Department of Agricultural Engineering on the Pici Campus of UFC.

A randomised complete block design was used, with seven treatments and four replications. The treatments consisted of T1 - sole arugula, T2 - arugula intercropped with coriander, T3 - arugula intercropped with parsley, T4 - arugula intercropped with garlic chives, T5 – sole coriander, T6 – sole parsley, and T7 – sole garlic chives.

For both the sole and intercropped arugula, the spacing between plants was 0.2m x 0.2m, with five plants per crop row, giving a total of 35 single plants per plot or 20 intercropped plants per plot, for a plot size of 1.0m x 1.4m, with a total of 192.500 and 110.000 plants per hectare in single and intercropped crops respectively.

The sole and intercropped coriander, parsley and garlic chives were also spaced 0.2m between crop rows, in plots with an area of 1.0m x 1.4m; for the intercropped treatments, the companion vegetables were arranged across the bed in alternating rows with the arugula. For the coriander and parsley, 4 grams of seed were used per linear metre. The single coriander and parsley were grown in seven rows and the intercropped plants in three rows. Vegetative propagation was used for the garlic chives with tillers from plants grown in the teaching garden of UFC, at a spacing of 0.10m between plants, giving a total of 63 single plants and 27 intercropped plants per plot, with a total of 346.500 and 148.500 plants per hectare in single and intercropped crops respectively.

The working area for evaluating the treatments comprised the three central rows of arugula (fifteen plants) in both the single crops and the intercrops. For the intercropped aromatic condiment plants, all three crop rows were considered. To coincide with the consortium treatments, work was carried out on the monoculture treatments, the working area of the three central lines. For the coriander and parsley, all plants within a 0.30 m section were harvested and evaluated. For garlic chives, all plants in the three central rows were harvested for evaluation.

The following cultivars were used: arugula 'Cultivada', coriander 'Verdão' (Feltrin®), parsley 'Graúda Portuguesa' (Feltrin®) and garlic chives (Takii Seeds®). Preparation and fertilisation of the beds was carried out eight days before transplanting the arugula seedlings. Planting fertilisation was carried out by incorporating 12 $kg.m^{-2}$ organic compost produced at the site, whose analysis showed pH (water) = 6.9, P = 344.3 $mg.dm^{-3}$, K^+ = 230.0 $mg.dm^{-3}$; Ca^{2+} = 10.4 $cmol_c.dm^{-3}$, Mg^{2+} = 6.4 $cmol_c.dm^{-3}$, H+Al = 0.99 $cmol_c.dm^{-3}$, SB = 17.4 $cmol_c.dm^{-3}$, CEC = 17.4 $cmol_c.dm^{-3}$ and V = 95%. The coriander and parsley were planted directly in furrows prepared in the soil. The parsley was sown, and the garlic chives were transplanted seven days before transplanting the arugula. The coriander was sown on the same day the arugula was transplanted.

In order to maximise the productive efficiency of the intercrops, the period each species occupied the area was made to coincide, to enable a fair comparison between treatments. As such, usage of the area was established at 65 days, i.e. the time in days of one cycle for harvesting the parsley and garlic chives, since both had the longest occupation cycle in the soil. As a result, while for these two crops only one crop cycle was harvested for evaluation, in the treatments with coriander and arugula, with an average of 30 days occupation, two cycles (two crops) were harvested, regardless of whether they were produced as single crops or intercrops.

The arugula seedlings for the second production cycle were transplanted on the day following the first-cycle harvest, shortly after preparing and fertilising between the rows used in the previous crop. For the coriander, the second sowing took place six days after harvesting the first cycle, immediately after preparing the soil.

The harvests were carried out according to the marketing pattern for each species in the growing region. The arugula was harvested at the end of each vegetative cycle, 55 days after sowing (DAS), or 30 days after transplanting (DAT) the seedlings. For the coriander, the harvest took place at 30 DAS for each of the cultivated crops. The parsley and garlic chives were harvested 65 DAS and 65 DAT respectively.

A physiological evaluation was carried out for the arugula only, on one fully expanded leaf, exposed to light and located on the upper third of the plant. For the analysis, the LI6400XT portable infrared gas analyser (IRGA), (LI-COR Biosciences Inc., Lincoln, Nebraska, USA) was used, and the following physiological factors were determined: 1) Stomatal conductance (gs - µmol H_2O m^{-2} s^{-1}), 2) Rate of transpiration (E - mmol H_2O m^{-2} s-1), 3) CO_2 concentration in the substomatal chamber (Ci - µmol CO_2 mol^{-1}), 4) Net photosynthesis (A - µmol CO_2 m^{-2} s-1), 5) Ratio between the CO_2 concentration in the substomatal chamber and the CO_2 concentration of the environment (Ci/Ca), and 6) Instant carboxylation efficiency (A/Ci). The physiological IRGA evaluation was carried out at 30 DAT, before harvesting the arugula seedlings in both crop cycles.

The leaf area (LA) was determined directly, using a LI-COR® LI3100 leaf area integrator. From the LA the leaf area index (LAI) was calculated: LAtotal.AS^{-1} (area of soil, spacing of 0.20 m^2 $plant^{-1}$) and specific leaf area (SLA): LA.$DMleaves^{-1}$ (dm^2 g^{-1}) (Benincasa, 2003).

The competitive ability between the components of the intercropping systems was obtained by calculating the aggressivity index (A), simplified aggressivity index (SA), competitive ratio (CR) and compensation ratio (CoR), for which the crop yields were used; for the arugula and coriander that were grown in two cycles, the sum of the yield of each cycle was used. To estimate crop productivity, a working area of 7,700 m² per hectare was considered, corresponding to the actual cultivated area of the beds.

Aggressivity (A) measures interspecific competition in the intercrop from the ratio between crop yields (WILLEY; RAO, 1980), and indicates how much one crop in an intercropping system is superior in productivity to the other. The greater its numerical value, the greater the difference between the species in terms of competitive ability (Pinto et al., 2011; Pinto; Pinto, 2012). The index was proposed by Mcgilchrist and Trenbath (1971):

$$\mathbf{Aab} = \frac{\mathbf{Yab}}{(\mathbf{Yaa} * \mathbf{Zab})} - \frac{\mathbf{Yba}}{(\mathbf{Ybb} * \mathbf{Zba})}$$

$$\mathbf{Aba} = \frac{\mathbf{Yba}}{(\mathbf{Ybb} * \mathbf{Zba})} - \frac{\mathbf{Yab}}{(\mathbf{Yaa} * \mathbf{Zab})}$$

where: Y_{ab}: yield of species 'a' intercropped with species 'b';

Y_{aa}: yield of species 'a' as a monocrop;

Z_{ab}: proportion at planting of species 'a' intercropped with species 'b';

Y_{ba}: yield of species 'b' intercropped with species 'a';

Y_{bb}: yield of species 'b' as a monocrop;

Z_{ba}: proportion at planting of species 'b' intercropped with species 'a'.

Simplified aggressivity (SA) was proposed by Yates and Dutton (1988), who suggested a way to simplify the aggressivity index. A simpler model of aggressivity is adopted, based only on the ratio of the yield of each component in the intercropped plots, using the formula:

$$ASab = \frac{100 * Yab}{(Yab+Yba)}$$

$$ASba = \frac{100 * Yba}{(Yba+Yab)}$$

where: Y_{ab}: yield of species 'a' intercropped with species 'b';

Y_{ba}: yield of species 'b' intercropped with species 'a';

The competitive ratio (CR) indicates the number of times that one species is more competitive than the other (Costa, 2014). Interpretation of the competitive ratio (CR) is given by: CR<1 there is a positive benefit, and the crop can grow as an intercrop; if CR>1, there is a disadvantage for the other crop, and its cultivation as an intercrop is not indicated (Egbe; Bar-Anyam, 2010; Pinto; Pinto, 2012). The CR was calculated based on the equation (Willey; Rao, 1980):

$$RCa = \frac{\frac{Yab}{Yaa * Zab}}{\frac{Yba}{Ybb * Zba}} = \frac{UETa}{UETb} * \frac{Zba}{Zab}$$

$$RCb = \frac{\frac{Yba}{Ybb * Zba}}{\frac{Yab}{Yaa * Zab}} = \frac{UETb}{UETa} * \frac{Zab}{Zba}$$

where: Y_{ab} and Y_{ba} represent the yield of crop ‘a’ intercropped with crop ‘b’;

Y_{aa} and Y_{bb}: yield of crops ‘a’ and ‘b’ as monocrops;

UET_a and UET_b: land use efficiency index of crop 'a' and 'b' respectively;

Z_{ab} and Z_{ba}: proportion at planting of species 'b' intercropped with species 'a'.

The compensation ratio (CoR) indicates whether the yield of the most competitive crop compensated for its competitive effect on the dominated species (Pinto; Pinto; Pitombeira, 2012). When CoRab>1, the competitive effect of species 'a' on species 'b' is balanced by the substantial gain in species 'a'. When CoRba>1, the competitive effect of species 'b' on species 'a' is balanced by the substantial gain in species 'b' (PINTO; PINTO; PITOMBEIRA, 2012). While CoRab = 1 indicates that the loss in yield of species 'b' intercropped with species 'a' is equal to the yield of species 'a' intercropped with species 'b', there being no compensation. When CoRab = 0, this indicates that there is no competitive effect from species 'a' on species 'b', as the yield of species 'b' intercropped with species 'a' remains equal to that of the single crops, with no need for compensation. When CoRab<1, this indicates that the yield of species 'b' intercropped with species 'a' is higher than for the single crop, with no need for compensation. CoR was calculated as per Ntare and Williams (1992):

$$RCoab = \frac{Yab}{Ybb - Yba}$$

$$\mathbf{RCoba} = \frac{\mathbf{Yba}}{\mathbf{Yaa} - \mathbf{Yab}}$$

where: Y_{ab} e Y_{ba}: yield of crop 'a' intercropped with crop 'b';

Y_{aa} e Y_{bb}: yield of crops ‘a’ and ‘b’ as monocrops.

The results of the physiological evaluations were submitted to analysis of variance (F-test), with the mean values compared by Tukey’s test a level of 5% using the SSA software (SSA Institute, 2002). For the variables with two mean values (single crop and intercrop), the Kolmogorov test of normality was used, with the mean values compared by t-test (Satterthwaite method: inequality of variance) (PROC TTEST, SSA Institute 2002).

3. Results

The chemical characteristics of the cultivated soil, obtained by analysing the fertility of the 0 to 20 cm layer, showed pH (water) = 7.3, P = 304.5 mg.dm-3, K+ = 430.0 mg.dm-3, Ca2+ = 4.7 cmolc.dm-3, Mg2+ = 3.4 cmolc.dm-3, H+Al = 1.2 cmolc.dm-3, SB = 9.2 cmolc.dm-3, CEC = 9.2 cmolc.dm-3, V = 88% and OM = 4.8 g.kg-1.

The competitive ability between the intercropped species indicates positive aggressivity in the arugula intercropped with the parsley and garlic chives, being characterised as dominant for these combinations. The arugula plants showed negative aggressivity when intercropped with coriander, i.e. less competitive ability, and were therefore considered as the dominated species under those conditions (Table 1).

Table 1. Indicators of competitive ability, aggressivity (A), simplified aggressivity (SA), competitive ratio (CR) and compensation ratio (CoR) in single arugula and intercropped with aromatic condiment plants, at 35 days after transplanting

Treatment[1]	A		SA%		CR		CoR	
	Arugula	Companion	Arugula	Companion	Arugula	Companion	Arugula	Companion
T2	-0.40	0.40	33.94	66.06	0.68	1.48	0.51	1.97

T3	0.49	-0.49	70.11	29.89	1.48	0.67	1.58	3.59
T4	0.15	-0.15	78.11	21.89	1.12	0.89	3.62	1.55

[1]T1 – Monocrop of arugula; T2 - Arugula intercropped with coriander; T3 - Arugula intercropped with parsley and T4 - Arugula intercropped with garlic chives.

In the arugula and coriander intercrop, the coriander contributed 66.06% of the aggressivity in the system according to the simplified aggressivity index (SA). In the intercrops with parsley and garlic chives where the arugula was dominant, this species contributed 70.11% and 78.11% respectively of the aggressivity in each system.

For the Competitive Ratio (CR), in the intercrop of arugula with coriander, the first species presented a low competitive ratio (0.68). The coriander showed a CR of 1.48, proving to be more competitive than the arugula. The relative aggressivity between the species agrees with the above indices, in which the arugula also presented a higher competitive ratio in the intercrops with parsley and garlic chives.

Despite the coriander showing aggressivity and competition in the intercrop with arugula, it also afforded a greater compensation ratio (1.97), satisfactorily compensating for possible productive losses in the principal crop due to the established competition.

Even though parsley is less competitive and is dominated by arugula, it also afforded satisfactory gains to the system, with a higher value for CoR (3.59). The interference seen between the arugula and parsley, demonstrate that the crops achieved satisfactory productive gains (mutual cooperation) in the intercrop compared to the single crops. In the intercrop of arugula with garlic chives, the competitive effect of the arugula on the garlic chives was reflected in more satisfactory compensation in the arugula (3.62).

For the physiological characteristics evaluated in the arugula, no differences were seen between plants grown as a single crop or as intercrops, at 30 days after transplanting (DAT; Table 2).

Table 2. Mean values for net photosynthesis (A), stomatal conductance (gs), CO_2 concentration in the substomatal chamber (Ci), rate of transpiration (E), ratio between the CO_2 concentration in the substomatal chamber and the CO_2 concentration of the environment (Ci/Ca), and instant carboxylation efficiency (A/Ci), in arugula grown as a single crop and intercropped with aromatic condiment plants, 30 days after transplanting

	1º cycle					
Treatment[1]	**Photo (A)**	**Cond (gs)**	**Ci**	**Transp (E)**	**Ci/Ca**	**A/Ci**
	µmol $CO_2 m^{-2} s^{-1}$	mol $H_2O\ m^{-2} s^{-1}$	µmol $CO_2\ mol^{-1}$	mmol H2O $m^2 s^{-1}$		

T1	24,76^{ns}	0,83 ^{ns}	319,55 ^{ns}	0,011 ^{ns}	0,84 ^{ns}	0,078 ^{ns}
T2	27,12	0,91	316,85	0,011	0,84	0,086
T3	27,96	0,82	304,37	0,011	0,80	0,092
T4	27,96	0,9	315,8	0,011	0,83	0,089
C.V. (%)	**9,5**	**17,49**	**4,11**	**14,77**	**4,11**	**11,29**
			2º cycle			
Treatment[1]	**Photo (A)**	**Cond (gs)**	**Ci**	**Transp (E)**	**Ci/Ca**	**A/Ci**
	µmol $CO_2 m^{-2} s^{-1}$	mol $H_2O\ m^{-2} s^{-1}$	µmol $CO_2\ mol^{-1}$	mmol $H_2O\ m^2 s^{-1}$		
T1	20,9 ^{ns}	0,69 ^{ns}	321,31 ^{ns}	0,009 ^{ns}	0,84 ^{ns}	0,042 ^{ns}
T2	18,57	0,56	313,54	0,008	0,81	0,059
T3	17,02	0,42	305,73	0,007	0,79	0,055
T4	16,75	0,46	308,06	0,007	0,80	0,054
C.V. (%)	**21,61**	**25,48**	**5,81**	**13,14**	**5,66**	**26,82**

[1]T1 – Monocrop of arugula; T2 - Arugula intercropped with coriander; T3 - Arugula intercropped with parsley and T4 - Arugula intercropped with garlic chives.

For the characteristics under evaluation related to leaf area (Table 3), the intercrop with coriander gave the highest mean values for the leaves of arugula in both cycles, 1,495.8 and 1,184.9 $cm^2.plant^{-1}$ for the first and second cycle, respectively. The other intercrops did not differ between themselves or the single crop of arugula.

Table 3. Mean values for leaf area (LA), leaf area index (LAI) and specific leaf area (SLA) in arugula grown as a single crop and intercropped with aromatic condiment plants, 30 days after transplanting

	Cycle 1			**Cycle 2**		
Treatment[1]	**AF**	**IAF**	**AFE**	**AF**	**IAF**	**AFE**

	cm^2		cm^2.g^{-1}	cm^2		cm^2.g^{-1}
T1	1.052,2 b	0,13 b	256,32 a	820,18 b	2,63 b	127,06 b
T2	1.495,8 a	0,19 a	178,75 b	1.184,90 a	3,74 a	182,57 a
T3	1.235,7 b	0,15 b	141,48 b	784,69 b	3,09 b	113,72 b
T4	737,2 b	0,09 b	115,08 b	750,33 b	1,84 b	121,51 b
C.V. (%)	**10,64**	**16,30**	**13,40**	**11,08**	**17,80**	**15,90**

[1]T1 – Monocrop of arugula; T2 - Arugula intercropped with coriander; T3 - Arugula intercropped with parsley and T4 - Arugula intercropped with garlic chives. Means followed by the same letters in column do not differ by Tukey test at 5% probability.

For the leaf area index (LAI), as well as LA, intercropping arugula with coriander made it possible to obtain plants with the highest mean values in both cycles, 0.19 and 3.74 for the first and second cycle, respectively. For specific leaf area (SLA), the results show the single crop of arugula with the highest mean value in the first cycle, 256.32 cm^2.g^{-1}.

4. Discussion

The competitive ability of coriander in relation to arugula, measured by means of the aggressivity and simplified aggressivity indices, and the competitive ratio, may be related to two main factors. First to the fact that coriander has the faster initial growth. Second, the fact that the two crops were grown in two concurrent cycles to simulate a similar occupation time to the other crops with a longer cycle. In the latter case, the parallel growth of the two crops favours competition for environmental factors in the crop that shows faster initial growth. However, although these indices measure interspecific competition in the intercrops, i.e. between different species, in general, this type of competition does not necessarily harm the intercropped plants. If the negative effect of competition is not sufficiently strong, it can happen that both crops together produce more than their respective single crops and as such the intercrop becomes advantageous (Pinto; Pinto, 2012; Brooker et al., 2015), exactly as seen in this study. Although individual crop yields were lower in the intercrops, the combined yields of the intercropped species were positive, especially in the arugula and coriander intercrop, suggesting efficiency in the system.

The efficiency of intercropped systems is often dependent on the complementarity between crops. When the period of greatest demand for environmental resources of the intercropped plants does not coincide, the competition between them may be minimised, this situation being known as temporal complementarity. When the differences in plant architecture favour the best use of available light, water and nutrients, so-called spatial complementarity occurs, with sharing and the efficient use of resources (Montezano; Peil, 2006; Nassary et al., 2020).

For the arugula intercropped with parsley, although the arugula was dominant, temporal complementarity occurred, with environmental and nutritional demands at different times, given that initial growth is slow in the parsley, and in the first cycle of arugula there was little competition between the species. In the intercrop with garlic chives, spatial complementarity was seen, as the upright architecture of the garlic chives did not hinder light capture by the arugula. Intercropping is therefore a technique of intensive cultivation in space and time, where competition between crops can occur over part or all of the cultivation period (Dodiya et al., 2018).

One of the factors that may have favoured gains in the intercrop systems evaluated in this experiment is possibly related to the spacing and arrangement adopted for the plants in the field (Viana et al., 2021). According to Nascimento et al. (2011), a spacing of 0.20 m between the crop rows of coriander can also be considered ideal for obtaining maximum productivity in the arugula, with planting in bands, described as wide enough to allow the management of each crop and narrow enough for interaction between them. Zanine and Santos (2004) state that an equidistant arrangement of plants minimises self-shading and can also delay the start of intraspecific competition for soil resources, leading to maximum efficiency in the capture and use of the resources, and improving the competitive ability of the plants (Joseph et al., 2018).

When comparing the two arugula production cycles, it can be seen in Table 2 that the physiological factors, liquid photosynthesis (A), stomatal conductance (gs), transpiration rate (E) and instant carboxylation efficiency (A / Ci), in arugula cultivated in monoculture and produced in consortium, they presented lower values in the second cycle.

These results may be related to the environmental differences that occurred during the experiment, since during the first arugula production cycle, less rain and longer insolation period (315.95 h.month-1) were observed, in comparison with the second cycle. production (227.75 h.month-1). The greater volume of rain in the second cycle, together with clouds, were the main factors that contributed to the reduction of insolation. Such climatic conditions may have influenced the physiological responses of the crop.

For the physiological factors, the net photosynthesis, i.e. the balance between what is produced inside the chloroplasts and what is consumed by the respiratory process (Peixoto et al., 2011; Pedò et al., 2014), indicated similar photosynthetic efficiency in plants grown under both cropping systems in each cycle. This performance can be explained by the regular interception of radiation by the plants (Ribas et al., 2020). Such a result shows that the population density used for single crops and for the intercropping systems with arugula was adequate and did not cause competition among the plants, at least in terms of luminosity.

However, when comparing the two production cycles of arugula, lower values are seen in the second cycle, which can be explained by the environmental differences that took place during the experiment. A reduction in the light incident on the leaves can cause reductions in net photosynthesis, stomatal conductance, the rate of transpiration and consequently, in instant carboxylation efficiency (Taiz et al., 2017).

For the leaf area and leaf area index (LAI), the arugula intercropped with coriander afforded plants with the highest mean values in both cycles. The LAI represents the total leaf area per unit area of land, and functions as an indicator of the surface area available for light interception and absorption (Guerreiro et al., 2011).

According to Moraes et al. (2013), the LAI may be related to the productivity of a plant ecosystem, and possibly directly related to leaf growth and development. According to Figueiredo et al. (2010), as photosynthesis depends on the leaf area, the crop yield will be higher the faster the plant can reach the maximum leaf area index. As such, the greatest LAI and the largest leaf area, can together promote better use of solar energy, thereby producing more photoassimilates and, consequently, generating an increase in crop production (Borges et al., 2014).

The results for specific leaf area (SLA) show the single arugula to have the highest mean values in the first cycle. This result means that for the single crop in the first cycle the arugula leaves had less biomass than the intercrops, as this parameter is the result of the ratio between leaf area and leaf dry weight. For the intercropped plants, the smaller SLA indicates greater accumulation of photoassimilates per leaf area, which increases the thickness of the leaves (Matos et al., 2015). In the second cycle, despite the arugula having the highest SLA when intercropped with coriander compared to the other treatments, the result was similar to that seen in the first cycle.

From the above, it follows that arugula intercropped with the above-mentioned species, despite having an effect on the indices under study, showed no negative behaviour in physiology, which demonstrates the importance of this study for a better understanding of the interaction between species during the period of coexistence under intercropping systems.

5. Conclusions

The physiological similarity seen between the arugula plants grown under the monocrop system compared to those produced as intercrops is related to the conditions of this study, i.e. the spacing, plant density and suitable period of occupation. The difference in climate seen during the two production cycles interfered in the physiology and quantitative aspects of production in the arugula. Due to the use of environmental resources, the arugula was dominated by the faster-growing coriander, and for the same reason, was dominant when intercropped with parsley and garlic chives. The productive yield of the coriander made it possible to offset its competitive effects on the arugula. The parsley had a less competitive effect than the arugula, even so, it contributed significantly to the compensation of the system. The competitive effect of the arugula relative to the garlic chives, made satisfactory compensation possible, balancing the gains.

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