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RESPOSTA DA ALFACE EM SISTEMA AGROFLORESTAL IRRIGADO POR GOTEJAMENTO

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1 RESUMO

Os sistemas agroflorestais (SAFs) proporcionam comumente uma otimização da área de cultivo, mão-de-obra, insumos e água, com maior estabilidade e diversificação da produção, maior eficiência no controle de plantas espontâneas e proteção do solo contra a erosão. Contudo, atualmente são escassos os estudos sobre SAFs irrigados. Desta forma, este trabalho teve como objetivo avaliar a produção da cultura da alface (*Lactuca sativa* L.) em cultivo solteiro e consorciado com rúcula (*Eruca sativa* L.) e rabanete (*Raphanus sativus* L.), no interior de um SAF e a pleno sol, sob irrigação por gotejamento. O estudo foi conduzido no Sítio Agroecológico da Embrapa Meio Ambiente, em Jaguariúna, SP. Os resultados demonstraram que o sistema de condução não influenciou o diâmetro horizontal da alface, enquanto o cultivo a pleno sol promoveu maior produção de massa seca e número de folhas de alface e rúcula. O rabanete apresentou folhas mais longas no SAF quando comparado ao pleno sol. O policultivo aumentou a produção por unidade de área, em 129,5% em média, em relação ao monocultivo no SAF e pleno sol. Estes resultados demonstraram que a consorciação foi vantajosa em relação ao monocultivo, ao produzir uma maior quantidade de hortaliças por unidade de área e insumos.

Palavras-chave: sistema de cultivo, otimização de cultivos, irrigação localizada.

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RESPONSE OF LETTUCE UNDER AGROFORESTRY SYSTEM WITH DRIP IRRIGATION

2 ABSTRACT

Agroforestry systems (SAFs) commonly provide optimization of the cultivation area, labor, inputs and water, with yield diversification and stability, greater efficiency in weed control and soil protection against erosion. However, studies on irrigated SAFs are currently scarce. Thus, this work aimed to evaluate the production of lettuce (*Lactuca sativa* L.) in single cultivation and intercropped with arugula (*Eruca sativa* L.) and radish (*Raphanus sativus* L.), grown in an

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agroforestry system and in full sun. The study was conducted at the Sítio Agroecológico of Embrapa Meio Ambiente (experimental farm), in the city of Jaguariúna, in the state of São Paulo, Brazil. The results showed that the conduction system did not influence the horizontal diameter of lettuce, while cultivation in full sun promoted greater production of dry mass and number of lettuce and arugula leaves. The radish showed longer leaves in SAF compared to full sun. Polyculture increased production per unit area, by 129.5% on average, compared to monoculture in SAF and full sun. These results showed that intercropping was advantageous in relation to monoculture, as it produced a greater number of vegetables per unit area and inputs.

Keywords: farming system, crop optimization, localized irrigation system.

3 INTRODUCTION

Among sustainable agricultural production practices, the use of intercropping has currently been suggested, in which two or more species coexist in the same planting area for a given period of time.

Intercropping systems are generally employed by family farmers, who have a relatively low technological level, to make most of the available resources, such as cultivation areas, inputs and labor, minimize the risk of monoculture failure by promoting the diversity of agricultural production and sources of income (NASCIMENTO *et al*., 2018; HATA *et al*., 2019).

Generally, this cultivation system allows for better use of the area and the different strata, both aerially and underground, enabling greater biological diversity and optimization of labor, inputs, land and water, in addition to promoting greater production stability, increasing efficiency in the control of invasive plants and improving soil protection against erosion (LELES *et al*., 2015; KOEFENDER *et al*., 2016; OLIVEIRA *et al*., 2019).

In agroforestry systems (SAFs), the consortium of agricultural crops and tree species, native or exotic, also allows for better exploration of different aerial and underground strata, producing food, fibers, oils, medicinal essences, wood, and ornamental plants, as well as milk, meat and eggs when combined with animal husbandry, as well as ecotourism, among other benefits, with additional benefits, such as environmental improvements (DANELLI; FISCH; VIEIRA, 2016; KHADKA *et al*., 2021).

Among the vegetables that perform well when grown in consortia for biological, nutritional, economic and social reasons are lettuce (*Lactuca sativa* L.), arugula (*Eruca sativa* L.) and radish (*Raphanus sativus* L.), with promising results (KOEFENDER *et al*., 2016; PEREIRA *et al*., 2016; OLIVEIRA *et al*., 2017; NASCIMENTO *et al*., 2018).

Intercropping systems, in general, modify the local microclimate, influencing the variability of evapotranspiration, soil water dynamics, carbon fixation, nutrient dynamics and soil enzymatic activities (SVOMA *et al*., 2016), and the biodiversity of AFSs tends to increase agricultural performance and the resilience of the system to stress conditions, such as water stress (BASCHE; EDELSON, 2017).

However, when water becomes a limiting factor in AFSs, whether in terms of total quantity or irregular distribution, supplementary irrigation becomes mandatory to ensure productivity, especially for plants that are less tolerant to water deficit and have less stomatal control and/or development of the root system, such as lettuce, arugula and radish, than do trees (STAGNARI *et al*., 2018; CUNHA *et al*., 2018; JESUS *et al*., 2018; SILVA *et al*., 2018).

Despite being widely practiced, plant intercropping has only recently begun to receive greater attention from researchers, with a demand for knowledge, especially in irrigated AFS conditions.

Therefore, the present study aimed to evaluate the production of lettuce in single cultivation systems intercropped with arugula and radish in an agroforestry system (SAF) and in full sun when irrigated by drip irrigation.

4 MATERIALS AND METHODS

This work was conducted between September and November 2019 at the Agroecological Site of the Brazilian Agricultural Research Corporation (Embrapa) Environment, which is located in the municipality of Jaguariúna, in the state of São Paulo, with a latitude of 22°43'28" S, a longitude of 47°56'08" W, and an average altitude of 646 meters.

According to the Köppen classification, the region's climate is of the Cwa mesothermal type, with hot summers, a dry season between May and September and a rainy season between October and April, with an average annual temperature of 19.9°C and an average annual rainfall of 1,314 mm.

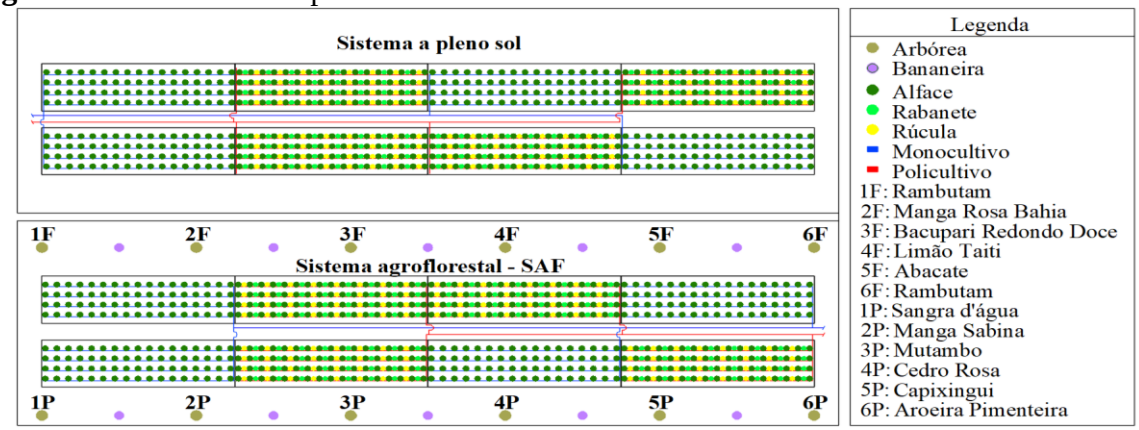
An automatic meteorological station, installed close to the experiment site, was used for daily monitoring of rainfall, temperature and relative humidity.

The experiment was installed in beds located in full sun and between the lines of a biodiverse SAF implemented in December 2018 in a dystrophic Red–Yellow Latosol with a sandy-clay loam texture.

The design of the SAF in question was developed by the agroecology team at Embrapa Meio Ambiente and partner institutions such as Mutirão Agroflorestal, reproducing the SAFs implemented by this team in areas of family farmers.

This type of AFS features tree rows spaced 5 m apart, alternating between rows of economically productive trees, primarily fruit trees, and rows of native trees for biomass production from pruning. In these rows, the trees were spaced every 4 m, and one banana tree was spaced every 2 m, as illustrated in Figure 1.

Figure 1. Sketch of the experiment.



Source: Authors' results.

Among the SAF species are Rambutam (*Nephelium lappaceum*), Bahia Pink Mango (*Mangifera indica*), Sweet Round Bacupari (*Garcinia brasiliensis*), Tahiti Acid Lime (*Citrus latifolia*), Avocado (*Persea americana*), Water Lily (*Croton urucurana*), Sabine Mango (*Mangifera indica*), Mutambo (*Guazuma ulmifolia*),

Pink Cedar (*Cedrela fissilis*), Capixingui (*Croton floribundus*) and Peppercorn Tree (*Schinus terebinthifolia*).

The chemical attributes of the soil in the beds implemented in the SAF and in full sun are expressed in Table 1.

Table 1. Chemical attributes of the dystrophic Red–Yellow Latosol used in this study.

Location	Acidity	P	K^{+}	Ca^{2+}	Mg^{2+}	H+Al	SB
	pH -$CaCl^2$	mmol.dm^{-3}					
SAF	5.3	20	3.8	32	11	21	46.8
PS	4.8	9	3.8	20	8	24	31.8
	CTC	**B**	**Ass**	**Faith**	**Mn**	**Zn**	**V**
	mmol.dm^{-3}						%
SAF	67.8	0.2	1.4	51	19.5	2	69
PS	55.8	0.2	1.6	74	21.4	1	57

SAF - cultivation in agroforestry system, PS - cultivation in full sun, CTC - cation exchange capacity, SB - sum of bases and V% - base saturation.
Source: Authors' results.

The preparation of the beds aimed to make them uniform and consisted of weeding the area, subsoiling and organic fertilization.

Fertilization and soil correction were carried out according to Raij *et al*. (1996), resulting in the application of 0.25 kg.m^{-2} of yogurt, 0.042 kg.m^{-2} of camag, 0.15 kg.m^{-2} of castor bean cake, 1.0 kg.$m^{-2\ of}$ Provaso compost, and 1.0 kg.m^{-2} of cattle manure. These products were mixed and incorporated with a rotary hoe throughout the area of the beds 13 days before the implementation of the experiment. After the inputs were incorporated, the beds were covered with a 0.05-meter layer of mulch consisting of crushed tree branches from the urban afforested area of Jaguariúna.

The seedlings of 'Vanda' crisp lettuce, 'Astro' arugula and 'HS2030' radish, which are suitable for the region's soil and climate conditions, were transplanted to their final locations 29, 23 and 22 days after sowing, respectively, with a spacing of 0.3 × 0.3 m between the lettuce plants, with the arugula and radish seedlings inserted alternately between them, in the intercropped treatments (Figure 1), with regular selective weeding and supplementary irrigation.

This experiment included surface drip irrigation, with emitters spaced 0.3 m apart, at a flow rate of 1.3 Lh^{-1}, with one emitter row per row of plants. The plants were irrigated whenever the soil water tension approached -30 kPa, maintaining the soil near field capacity (FC). Soil water tension was monitored via tensiometer batteries installed at depths of 0.15 and 0.40 m, approximately 0.15 m from the dripperline, in each plot.

A randomized block design was adopted, with four replicates per treatment, for a total of 16 plots. The treatments consisted of lettuce in sole cultivation in full sun (T1), lettuce intercropped with arugula and radish in full sun (T2), lettuce in sole cultivation within SAF (T3) and lettuce intercropped with arugula and radish within SAF (T4), which were randomly distributed according to Figure 1.

Lettuce was harvested between 35 and 36 days after transplanting (DAT), arugula was harvested between 28 and 30 DAT, and radish was harvested between 29 and 33 DAT.

After being harvested, the plants were measured as described below, dried in an ovens at 65°C until their dry mass stabilized, and then weighed.

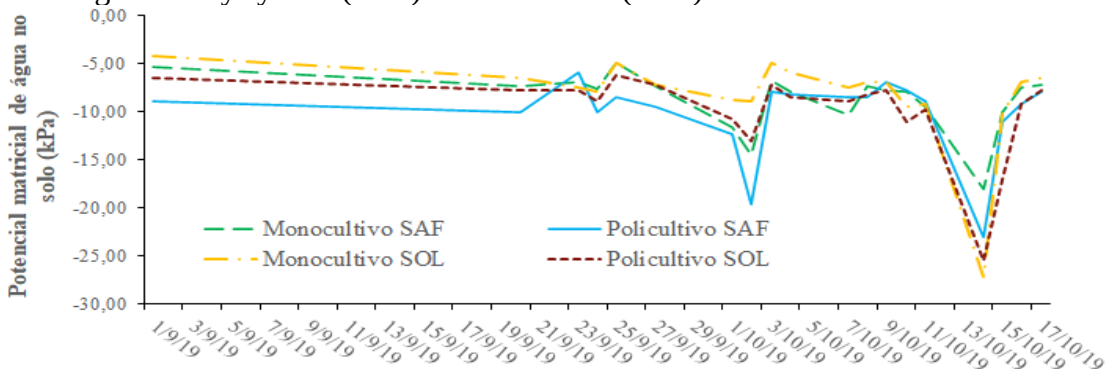
During harvest, lettuce and arugula were cut close to the ground to quantify shoot dry mass and leaf number, as were the lettuce head diameter and arugula leaf length. All the radish samples were harvested to measure the transverse width of the fresh tuberous roots, leaf length, and, after oven drying, shoot and root dry mass.

The results obtained for each response variable were subjected to analysis of variance (ANOVA) via the F test with a significance level of 0.10. In the case of a significant effect of one factor, the means were compared via the Tukey test, with a significance level of 0.10. The analyses were performed via the GLM *procedure* of the statistical software SAS/STAT (STATISTICAL ANALYSIS SYSTEM, 2011) from the *Statistical Analysis System* (SAS).

5 RESULTS AND DISCUSSION

As shown in Figure 2, during the experiment, the soil water tension was maintained between -4.3 and -27 kPa in layers 0.00 to 0.25 m deep.

Figure 2. Water matrix potential in the soil of lettuce monocultures and polycultures in the agroforestry system (SAF) and in full sun (SOL).



Source: Authors' results.

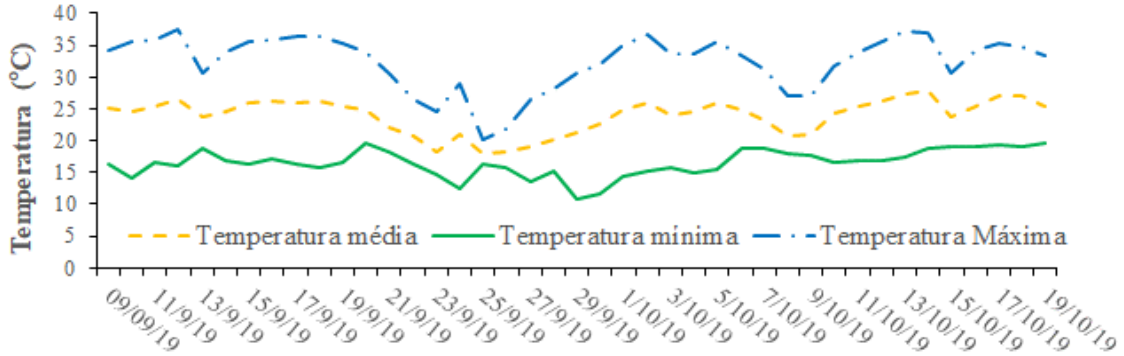
For drip-irrigated vegetables to perform better, maintaining soil water tensions close to field capacity, that is, approximately -10 and -30 kPa for coarse- and fine-textured soils, respectively, is recommended (BERNARDO *et al*., 2019).

As shown in Figure 2, there was a trend toward lower water consumption for most of the experiments in the lettuce monoculture treatment under full sun. This fact can be explained, in part, by the lower evapotranspiration resulting from the smaller number of leaves and roots, that is, from the lower plant density in the monoculture system than in the polyculture system.

Figure 2 also shows that the soil experienced the greatest water deficit on October 14, 2019, as evidenced by the highest water tension in the soil.

This date coincides with the period in which the highest air temperatures were recorded, between October 12 and 14, 2019, as shown in Figure 3, which also demonstrates the considerable thermal variability throughout the experiment.

Figure 3. Average, minimum and maximum air temperatures recorded at the Agroecological site of Embrapa Meio Ambiente, located in the municipality of Jaguariúna, SP.



Source: Authors' results.

Generally, the efficiency of intercropping depends fundamentally on the level of competition and complementarity, spatially and temporally, between the component crops, that is, their ability to maximize productivity and the use of available resources locally (NASCIMENTO *et al*., 2018; PAIVA *et al*., 2016).

In this study, no significant interaction effect between monoculture and polyculture systems, in full sun or inside the AFS, was identified on the horizontal diameter of lettuce, which was approximately 0.3 m in all the treatments (Table 2).

Table 2. Horizontal diameter (DIAM_H), dry mass (MS) and number of leaves (N_FLH) of lettuce grown in full sun (SOL) and inside the SAF (SAF), monoculture (MONO) and polyculture (POLI) systems.

Variable	Unit	Shading	Systems		EP
			MONO	POLY	
DIAM_H	(cm)	SAF	28.23 Aa	35.68 Aa	3.35
DIAM_H		SUN	29.02 Aa	30.30 Aa	0.06
MS	(g.plant $^{-1}$)	SAF	7.58 Aa	10.04 Ab	1.07
MS		SUN	10.82 Ba	9.30 Aa	0.24
N_FLH	(leaves.plant $^{-1}$)	SAF	18.85 Aa	21.00 Aa	1.03
N_FLH		SUN	28.26 Ba	23.62 Bb	0.56

Means followed by lowercase letters compare systems, whereas uppercase letters compare different shading conditions. The same letters do not differ statistically according to Tukey's test at the 10% significance level. SE - standard error.

Source: Authors' results.

Similar results were reported by Paiva *et al*. (2016), who also reported that the presence of intercropped species, such as coriander, arugula, radish and beetroot, would not negatively influence the profitability of lettuce.

Table 2 shows that, compared with the SAF treatment, the single lettuce cultivation treatment in full sun promoted greater accumulation of dry mass and a greater number of leaves.

These results can probably be explained by the microclimatic conditions in full sunlight, in which the plants received a higher flux density of solar radiation owing to the lack of physical barriers to radiation,

unlike the plants grown in the SAF, which had part of the flux of incident solar radiation retained by the tree species present.

Table 2 also shows that, in the polyculture treatments, the highest number of leaves was obtained from crops grown in full sun, although the same behavior did not occur with the dry mass variable, which was not significantly different under the different shading conditions.

These results are consistent with those reported by Dalastra *et al*. (2016), who studied the effects of different levels of shading on lettuce production, concluded that cultivation in full sun resulted in relatively high values of fresh mass and number of leaves.

Considering the dry mass of lettuce (Table 2) grown in monocultures and polycultures within the SAF system, a positive interaction was observed, with polycultures producing greater quantities of this variable, which did not occur in the full-sun system.

Table 3 shows the average dry mass, number and length of arugula leaves grown in full sun and AFS.

Table 3. Dry mass (DM), number of leaves (N_FLH) and leaf length (CF) of arugula grown in full sun (SOL) and AFS (SAF).

Variable	Unit	Shading	Averages*	EP**
MS	(g.plant $^{-1}$)	SAF	5.13a	0.51
MS		SUN	13.43b	0.51
N_FLH	(leaves.plant $^{-1}$)	SAF	41.52a	3.55
N_FLH		SUN	84.47b	3.55
CF	(cm)	SAF	29.81a	0.39
CF		SUN	34.17b	0.39

* Means followed by the same letters do not differ from each other, according to the Tukey test at a significance level of 0.10.
** EP - Standard error.
Source: Authors' results.

According to Table 3, arugula presented relatively high values of dry mass, number of leaves, and leaf length when grown in full sun. This response suggests that the reduced flux density of incident solar radiation in the AFS negatively influences arugula production, likely due to the lower tolerance of the crop to shade.

Similar results were obtained by Gadum *et al*. (2006), who reported that arugula varieties respond negatively to shading in terms of dry and fresh biomass production.

Table 4 presents the average values of dry mass of the aerial part, dry mass of the tuberous root, transverse width of the tuber and length of leaves of the radish grown in full sun and within the AFS.

Table 4. Average production of aerial part dry mass (MSPA), tuberous root dry mass (MSRT), tuber transverse width (LT) and leaf length of radish (CF) grown in full sun (SOL) and within the AFS (SAF).

Variable	Unit	Shading	Averages*	EP**
MSPA	(g.plant $^{-1}$)	SAF	1.21a	0.19
MSPA		SUN	1.08a	0.19
MSRT	(g.plant $^{-1}$)	SAF	1.97a	0.38
MSRT		SUN	2.46a	0.38
LT	(cm)	SAF	40.83a	3.9
LT		SUN	44.13a	3.9
CF	(cm)	SAF	21.18a	1.34
CF		SUN	16.5b	1.34

* Means followed by the same letters do not differ from each other, according to the Tukey test at a significance level of 0.10.
** EP - Standard error.
Source: Authors' results.

With respect to radish production (Table 4), there was no effect of cultivation in full sun or within the SAF, with the exception of leaf length, which presented higher values in the shaded environment, that is, in the SAF.

In fact, studies on plant shading have shown that the highest growth rates are generally found in plants kept under conditions of lower solar radiation incidence than in those that grow in full sun, which can be partially explained by the need for these plants to develop a larger stem and/or leaf area to capture solar radiation in an environment of competition between individuals (BINOTTI *et al*., 2019; WHATLEY; WHATLEY, 1982; YAZICI; GUNES, 2018).

The comparative analysis of the total dry mass production of plants cultivated in the single lettuce cultivation (T1 and T3) and lettuce intercropped with arugula and radish (T2 and T4) treatments revealed that intercropping increased the dry mass production per unit area to 132.8% in full sun and 126.1% in AFS, with an average increase of 129.5% in relation to that of the monoculture.

In this way, the intercropping of vegetable species allowed for better use of available resources, becoming advantageous in relation to the single cultivation of lettuce, by producing a greater quantity of vegetables per unit of area with the same quantities of inputs.

6 CONCLUSION

The training system, whether single, intercropped, SAF or full-sun, did not influence the horizontal diameter of the lettuce.

Cultivation in full sun promoted greater production of dry mass and a greater number of lettuce leaves in monocultures and polycultures, as well as arugula.

Cultivation within the SAF favored the emergence of longer leaves in the radish crop.

The association of crops allowed an increase in production per unit area inside and outside the SAF in relation to single crops inside and outside the SAF.

The monoculture system showed a positive interaction in the SAF, which was advantageous in relation to the single cultivation of lettuce because it produced a

greater quantity of vegetables per unit of area with the same quantity of inputs.

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