Vol. 18(6), pp. 407-413, June, 2022
DOI: 10.5897/AJAR2020.15229
Article Number: D14FF3A69220
ISSN: 1991-637X

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African Journal of Agricultural Research

Full Length Research Paper

Maize intercropped between *Eucalyptus urophylla* in agroforestry systems in Brazil

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Received 28 September, 2020; Accepted 3 December, 2020

The objective of this work was to evaluate the agronomic characteristics of maize intercropping with *Eucalyptus urophylla* at agroforestry system in two triple row distance (alleys) at different sampling distances and positions in relation to the eucalyptus external row (transect), and three positions in relation to the cardinal points: east side, west side and middle. Eucalyptus (*E. urophylla*) seedlings were planted with spacing of 1.5 m between plants and 3.0 m between rows (triple rows) and two triple row distances: 16.5 and 37.1 m apart, with the spatial exposure of the rows towards north and south, ranging from 888 to 464 plants ha^{-1}. It was observed that treatments differed in relation to the number of ears ha^{-1} and grain yield in both seasons. In addition, in relation to the final plant density ha^{-1}, in the 2014/2015 season, the maize at 4.2 m distance from eucalyptus at 16.5 m triple row distance had lower number of ears ha^{-1} and grain yield, and maize at 8.2 m from eucalyptus at 37.1 m triple row distance had greater number of ears and grain yield. The cardinal positions (W/E) in relation to the eucalyptus did not influence the agronomic characteristics of the maize.

Key words: Cropping systems, integrated systems, *Zea mays*.

INTRODUCTION

The Cerrado biome (the Brazilian savanna), characterized by high Al content, low pH, and low P, covers 204 million hectares (24%) of the Brazilian land area and is one of the world's largest agricultural frontiers (Araujo et al., 2012; Mendes et al., 2012; Souza et al., 2016).

The integrated agricultural production systems, the

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purpose of which is to increase soil C and thus reestablish soil fertility, is increasingly implemented in the Brazilian Cerrado (Tonucci et al., 2017), and has been implemented mainly in sandy soils (Sarto et al., 2020a).

These systems are interesting options for approaching global issues such as food security, climate change and sustainable farming besides improving social conditions in the rural environment (Borges et al., 2019a).

Farmers and society as a whole can benefit from these systems, since maintaining soil fertility is critical for the conservation of natural resources and the provision of environmental services (Lemaire et al., 2014; Salton et al., 2014).

Agroforestry systems are a type of integrated agricultural production systems. They consist of the simultaneous cultivation of grain-producing plants, tree and forage in the same area, which allows increased yield, economic stability and crop diversity (Franzluebbers, 2007).

Maize cultivation intercropped with forest species are an interesting option for agroforestry systems. However, the degree of impact of the tree component on maize crop is still questioned.

Borges et al. (2019b) found that maize grown in an agroforestry system at 370 stems per hectare, with eight years-old eucalyptus, resulted in a lower plant density than the agro-pastoral system, and lower mass of one hundred grains than maize in an agro-pastoral and monoculture system in Northwestern São Paulo State, Brazil.

On the other hand, Bravin and Oliveira (2014) did not find any competition of maize cultivation for Xaraés grass (*Urochloa brizantha* cultivar Xaraés) and the mulateiro forest species (*Calycophyllum spruceanum*), in agroforestry system. They also reported that maize yield was not affected by the intercropping with the trees because of the characteristics of the species, which have a high canopy, with vertical and thin elliptical shape (Andrade et al., 2012), and by the extensive alleys in the system (20 m), which did not promote excessive shading in the area. Tree density was 125 stems ha^{-1} and the trees were four years-old.

The objective of this work was to evaluate the agronomic characteristics of maize intercropping with *Eucalyptus urophylla* at agroforestry system in two triple row distance (alleys) at different sampling distances and positions in relation to the eucalyptus external row (transect), and three positions in relation to the cardinal points: east side, west side and middle.

MATERIALS AND METHODS

The experiment was carried out in the 2013/2014 and 2014/2015 seasons on the Nelson Guerreiro farm, located in Brotas, São Paulo State, Brazil (22°10'57.14" S and 48°15'43.18" W, 567 m above sea level). The soil in the experimental area was classified as Yellow Red Latosol according to SiBCS (Santos et al., 2013) with a slope of 8.7% and with the following particle size characteristics: 90.2% sand, 6.9% clay and 2.8% silt in the 0-0.10 m depth layer; 88.1% sand, 8.8% clay and 3.1% silt in the 0.10-0.20 m depth layer; 86.3% sand, 10.6% clay and 3.1% silt in the 0.20-0.40 m depth layer.

Data on rainfall (mm) and monthly average temperature (°C) over the experimental period, from October 2013 to May 2015, are as shown in Figure 1. The study used data from the municipality of São Manuel, São Paulo State as it is the nearest weather station to the municipality of Brotas, São Paulo State.

The agroforestry system was established in April 2011, in an area of 12.52 ha, using the species *E. urophylla*, in the triple rows, with spacing of 1.5 m between trees in a row and 3.0 m between rows, distanced 16.5 or 37.1 m apart. The triple rows were oriented north to south, ranging from 888 to 464 plants ha^{-1}. The succession of crops in the 2011/2012 and 2012/2013 season were (first and second seasons, respectively): maize silage/maize silage; maize silage/*Lupinus albus* L. The average height of eucalyptus was 14.31 and 18.77 m in the 2013/2014 and 2014/2015 seasons, respectively.

The experimental design used was randomized blocks with three replications. The treatments were defined by the combination of triple row distances (16.5 and 37.1 m), with different sampling distances in relation to the eucalyptus external row (transect), and three positions in relation to the cardinal points: east side (shading applied by eucalyptus in the afternoon), west side (shading applied by eucalyptus in the morning) and middle (with lower shading period throughout the day). The treatments are described in Table 1.

Soil in the 0-0.20 m layer was randomly sampled before the establishment of the experiment. The analysis showed the following average values: Organic Matter: 15 g kg^{-1}; pH ($CaCl_2$): 4.5; P (resin): 31 mg dm^{-3}; K: 1 mmol$_c$ dm^{-3}; Ca: 13 mmol$_c$ dm^{-3}; Mg: 6 mmol$_c$ dm^{-3}; Bases saturation (V): 56%.

In the 2013/2014 season, soil liming (September 2013) was carried out using dolomitic limestone, with relative power total neutralizing (RPTN) of 86%, 600 kg ha^{-1}, to reach V of 70%, according to the recommendation of the Technical Bulletin 100 (van Raij et al., 1997).

The area was desiccated in October 2013, using glyphosate at a dosage of 3 L ha^{-1} of commercial product (c.p.) and flumioxazine at a dosage of 68 g ha^{-1} of c.p. Then the AL Bandeirantes maize variety (no-tillage) was sown at a density of 5.3 seeds m^{-1} at a spacing of 0.8 m between lines, targeting the final population of 60000 plants ha^{-1}.

The fertilization was performed as formulated fertilizer NPK 08-28-16 at a dosage of 150 kg ha^{-1} at sowing, and at a dosage of 500 kg ha^{-1} of the formulated fertilizer NPK 20-00-10 in topdressing, according to the recommendation of Technical Bulletin 100 (Raij et al., 1997).

Maize was harvested on April 25, 2014. The Department of Seeds, Seedlings and Matrices (Departamento de Sementes, Mudas e Matrizes - DSMM), of the Coordination of Integral Technical Assistance (Coordenadoria de Assistência Técnica Integral - CATI), cites that the average grain yield for AL Bandeirante variety, considering low to high fertility soils, is 7000 kg ha^{-1} in the harvest, with a plant density of 60000 plants ha^{-1} and 4000 kg ha^{-1} in the off-season, with a plant density of 40000 plants ha^{-1} (DSMM /CATI, 2019).

In the 2014/2015 season, liming was performed in August 2014 using dolomitic limestone, RPTN of 86%, at a dose of 700 kg ha^{-1}, aiming at V of 70%, according to the recommendation of Technical Bulletin 100 (van Raij et al., 1997). The area was then desiccated using glyphosate at a dosage of 5 L ha^{-1} c.p. and in October 2014 the area was harrowed in an attempt to control a *Digitaria insularis*

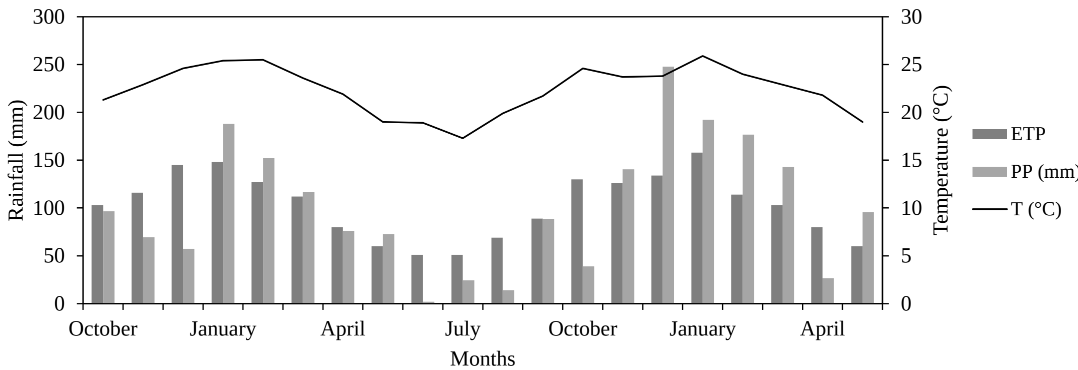

Figure 1. Data on potential evapotranspiration potential (ETP), rainfall (PP) and average temperature (T) in São Manuel, in the evaluated period from October 2013 to May 2015.
Source: Ciiagro (2015).

Table 1. Description of the treatments used in the experiment.

Treatment	Triple row distance (m)	Distance from the eucalyptus (m)	Position in relation to the rows
1	37.1	5.8	East side - E
2	37.1	8.2	East side
3	37.1	11.4	East side
4	37.1	5.8	West side - W
5	37.1	8.2	West side
6	37.1	11.4	West side
7	16.5	4.2	East side
8	16.5	5.8	East side
9	16.5	4.2	West side
10	16.5	5.8	West side
11	16.5	7.4	Middle

infestation. At this time the area was fertilized with 6000 kg ha^{-1} poultry litter.

In December 2014, the forage *U. brizantha* cultivar Marandu was broadcast sown, followed by the sowing of the BM 207 maize hybrid, at a density of 5.3 seeds m^{-1} at a spacing of 0.8 m between lines, targeting the population of 60000 plants ha^{-1}. For sowing fertilization, the formulated fertilizer NPK 10-15-05 was used at a dosage of 540 kg ha^{-1} and topdressing fertilization was performed in January 2015, using formulated fertilizer NPK 20-00-10 at a dosage of 280 kg ha^{-1} according to the recommendation of Technical Bulletin 100 (Raij et al., 1997).

Maize was harvested on 6 February 2015. The BM 207 maize hybrid was used in the second season as AL Bandeirantes maize variety was not available. After maize harvest, beef cattle were introduced in the system (silvopastoral system).

In order to characterize maize production, the insertion height of the first ear, plant height, final plant density ha^{-1}, number of ears and grain yield were evaluated at maize harvest. Sampling of the insertion height of the first ear and plant height was carried out in seven plants in each plot, and the sampling of the final plant density ha^{-1} and grain yield was carried out in 10 m of each plot. The ears were threshed in a mechanical thresher. After threshing, the grains were weighed and their moisture was measured to calculate grain yield, with grain moisture standardized to 13% (wet basis).

Data were submitted to ANOVA (F test) and the averages were compared by the Tukey test (P< 0.05) using the software Assistat (Silva and Azevedo, 2016).

RESULTS

There were no differences (P< 0.05) observed regarding the insertion height of the first ear and plant height but, on the other hand, the treatments differed from each other (P<0.05) in relation to the number of ears ha^{-1} and grain yield in the two seasons, also, in relation to the final plant density ha^{-1}, in the 2014/2015 season (Tables 2 and 3). It is emphasized that different cultivars were used in the two seasons and in the second season, maize was grown intercropped with *U. brizantha*.

Furthermore, there was no significant difference found in any variable studied for treatments with the same triple

Table 2. Maize crop agronomic characteristics, Brotas, São Paulo State, Brazil, 2013/2014 season.

Treatment	Ear insertion height (m)	Plant height (m)	Final plant density ha^{-1}	Number of ears ha^{-1}	Grain yield (kg ha^{-1})
1: 37.1*-5.8**-E***	0.78	1.60	52469	35802^{ab}	1389^{ab}
2: 37.1-8.2-E	0.75	1.63	58641	31481^{ab}	1096^{ab}
3: 37.1-11.4-E	0.79	1.64	51234	31481^{ab}	1111^{ab}
4: 37.1-5.8-W	0.81	1.65	50000	41358^{ab}	1652^{ab}
5: 37.1-8.2-W	0.96	1.78	56172	45679^{a}	2607^{a}
6: 37.1-11.4-W	0.71	1.56	56790	42592^{ab}	1620^{ab}
7: 16.5-4.2-E	0.84	1.63	55555	29012^{ab}	865^{b}
8: 16.5-5.8-E	0.93	1.83	53086	32716^{ab}	1311^{ab}
9: 16.5-4.2-W	0.84	1.68	50000	24074^{b}	833^{b}
10: 16.5-5.8-W	0.87	1.78	53703	30864^{ab}	1080^{ab}
11: 16.5-7.4-M	0.93	1.81	49382	35185^{ab}	1652^{ab}
SMD	0.27	0.43	16560	20139	1713
CV	11.00	8.66	10.52	19.75	38.93

Means followed by the same letter in the column are not different from each other (Tukey. P< 0.05). SMD - significant minimum difference; CV - Coefficient of variation (%), *Triple row distance (m); **Distance from the eucalyptus (m); ***Position in relation to the rows.

Table 3. Maize crop agronomic characteristics, Brotas, São Paulo State, Brazil, 2014/15 season.

Treatment	Ear insertion height (m)	Plant height (m)	Final plant density ha^{-1}	Number of ears ha^{-1}	Grain yield (kg ha^{-1})
1: 37.1*-5.8**-E***	0.82	2.02	30556^{cde}	27083^{abc}	2209^{ab}
2: 37.1-8.2-E	0.75	1.87	52083^{abcd}	43750^{ab}	2019^{ab}
3: 37.1-11.4-E	0.80	2.00	36111^{abcde}	31944^{abc}	2050^{ab}
4: 37.1-5.8-W	0.80	1.87	52778^{abc}	46528^{ab}	2411^{ab}
5: 37.1-8.2-W	0.88	1.93	59722^{ab}	50694^{a}	3800^{a}
6: 37.1-11.4-W	0.90	1.99	55556^{abc}	49306^{a}	2951^{ab}
7: 16.5-4.2-E	0.87	2.10	61111^{a}	47222^{ab}	2143^{ab}
8: 16.5-5.8-E	0.87	1.95	51389^{abcde}	38819^{abc}	2266^{ab}
9: 16.5-4.2-W	0.75	1.75	22917^{e}	14583^{c}	750^{b}
10: 16.5-5.8-W	0.81	1.82	23611de	19444^{bc}	1036^{b}
11: 16.5-7.4-M	0.89	2.07	31944^{bcde}	29167^{abc}	1882^{ab}
SMD	0.20	0.58	29083	27838	2298
CV	8.30	10.16	22.70	26.04	36.44

Means followed by the same letter in the column are not different from each other (Tukey. P< 0.05). SMD - significant minimum difference; CV - Coefficient of variation (%),*Triple row distance (m); ** Distance from the eucalyptus (m); *** Position in relation to the rows.

row distance (1 to 6 and 7 to 11) in the 2013/2014 season. Treatment 5 (37.1 m triple row distance; 8.2 m distant from eucalyptus; W) had the largest number of ears ha^{-1} and the highest grain yield and differed from treatment 7 (16.5 m triple row distance; 4.2 m distant from eucalyptus; E), in relation to number of ears, and from treatment 9 (16.5 m triple row distance; 4.2 m distant from eucalyptus; W), in relation to number of ears and grain yield. That is, at least up to 4.2 m away from eucalyptus, at the shortest triple row distance, no matter the position (E/W) in relation to the row, maize yield was impaired. This loss of yield may be tolerated or the planting of more shade tolerant species (such as *Vigna unguiculate*) could be considered.

In the 2014/2015 season, treatment 5 had the largest maize ears and the highest grain yield once more and differed from treatments 9 and 10 (16.5 m triple row distance; 4.2 and 5.8 m away from the eucalyptus; W).

Treatment 7 had the highest final plant density ha^{-1} and differed from treatments 1 (37.1 m triple row distance; 5.8 m distant from eucalyptus; E) and from narrower triple row distance (16.5 m): 9 and 10 (4.2 and 5.8 m distant from eucalyptus; W) and 11 (7.4 m distant from eucalyptus; middle).

DISCUSSION

Borges et al. (2020) also found no difference along a transect between eucalyptus' rows in the insertion height of the first ear and final plant density ha^{-1} of maize intercropped with *U. brizantha*, in agroforestry system with *E. urograndis* (*E. grandis* × *E. urophylla*) H-13 (eight years-old), after thinning the trees. On the other hand, they verified greater plant height 6 m away from the eucalyptus rows, with 50% thinning, in relation to 2 and 4 m away from the eucalyptus planting lines.

Mendes et al. (2013) also verified higher height of maize plants as the distance from *Cordia oncocalyx* trees increased, and taller plants were found in the treatment 4 m away from the trees, which were completely out of the canopy. They also reported that such result can be attributed to the fact that maize is a species that does not grow well under shading (Kho, 2000; Reynolds et al., 2007). Muthuri et al. (2005) also verified a difference in maize height only 1 m away from the stem of *Grevillea robusta* trees, where maize in agroforestry system was smaller than in monoculture.

Macedo et al. (2006) observed that the different distance length in relation to the eucalyptus planting rows did not present significant differences regarding the number of maize plants; however, eucalyptus (two years-old) were planted in a single row system in this study, at a density of 250 stems ha^{-1}.

On the other hand, when evaluating the productive and nutritional characteristics of the pasture in agroforestry system, Paciullo et al. (2011) described the influence of the tree component on many pasture features, as a function of its distance from the tree row in an agroforestry system; they considered the effect to be consistent with the importance of radiation in the photosynthetic processes of C4 plants, such as maize.

According to Oliveira et al. (2007), incident solar radiation under the canopy becomes a major determinant of the possibility of a successful insertion of agricultural and/or forage crops in production systems associated with the forest component. The lower incidence of solar radiation associated with low natural soil fertility should be responsible, at least in part, for the low yield of maize in all treatments over the two experimental years.

Borges et al. (2020) also observed no difference, along the row transect, in maize grain yield intercropped with *U. brizantha*, in an agroforestry system with *E. urograndis* H-13 (eight years-old), after differential thinning of the trees. On the other hand, they verified greater grain yield after total tree felling, in relation to 0 and 50% thinnings, and they reported a clear competition for water, light and nutrients between eucalyptus and soybean and maize crops, mainly in the sampling position at 2 m from the eucalyptus rows. This competition by water also was found by Sarto et al. (2020b), that observed a gradient of soil water in an agroforestry system with fast growing trees (*E. urograndis* H-13 and *E. grancam* (*E. grandis* × *E. camaldulensis*) 1277) intercropped with *U. brizantha*, with lower soil water in and near the eucalyptus planting line.

This competition for water, light and nutrients between eucalyptus and maize also verified by Borges et al. (2017), reported lower maize grain yield at the studied agroforestry systems (at 370 stems ha^{-1}), with maize sowed after fourteen months of planting the tree component, which had a height greater than 4.5 m, than the agropastoral system and no-tillage system with maize cultivation in monoculture under full sun, indicating the need for management of the established competition.

Intervention in integrated production systems is necessary whenever competition prejudices the dynamic balance observed among the target components (Jose et al., 2004).

Sarto et al. (2020c) also described this competition at an agroforestry system with eucalyptus (*E. urograndis* H-13 and *E. grancam* 1277) intercropped with *U. brizantha:* grass root and shoot biomass were lower in the agroforestry system compared to the monoculture pasture, mainly in the vicinity of eucalyptus.

Macedo et al. (2006) also reported a higher maize grain yield in the central planting lines of systems intercropped with eucalyptus clones. However, in the present experiment, it did not occur, because in the two seasons, there was no significant difference in the yield in treatment 11 (planting center line, 7.4 m distant from eucalyptus) from the other positions (treatments 7 to 10). It is possible that the narrow distance between the triple rows was not enough to control competition, and reduced the yield in the treatment 11.

Ding and Su (2010) found a reduced yield of shaded maize plants compared to those completely exposed to the sun, and reported that such drop was related to changes in incident photosynthetically active radiation, air temperature and CO_2 concentration. In addition, Kang et al. (2008) noted reductions in photosynthetically active radiation when maize plants were closer to trees, especially at 60 days after sowing, which, according to the authors, resulted in a decreased maize yield.

On the other hand, Santos et al. (2015) also did not find any negative effects on maize yield in intercropping with *E. urograndis* and *Acacia mangium,* in 12 m row distance, with 2 m between plants, in agroforestry system in the first year of cultivation; possibly the low size of the trees until maize was harvest precluded competition at this point.

According to Paciullo et al. (2010), the intensity of shading decreases with the distance from the tree row, unless the distance between the tree rows are narrow, in which case competition may dominate the relationship across the planted area. Sarto et al. (2020d) found that establishing *E. urograndis* H-13 and *E. grancam* 1277 in pasture reduced forage yield close to the trees and that the forage yield increased along the row transect from 1.7 mg ha^{-1} close to trees to 4.45 mg ha^{-1} at 6.0 m away from the eucalyptus.

Vieira and Schumacher (2011) also verified that the total biomass production of maize intercropped with monospecific and mixed plantations of the forest species did not differ between the evaluated treatments. The authors reported that the same yield between treatments could be attributed to the fact that forest species did not compete with maize as it was sown one month after the tree planting. It is noteworthy that in this study the density was high, at 1667 trees ha^{-1}.

In addition to the likely competition with trees in the first season, unfavorable weather conditions in the early stage of maize crop development, with low rainfall and high potential evapotranspiration (Figure 1), also contributed to the low yields observed in the study. According to the IAC/CATI/Companies System Report (2014), grain yield of the AL Bandeirante variety in the central region of São Paulo State in the 2013/2014 season was 3271 kg ha^{-1}. The sum of stresses (competition + drought) can significantly affect the final result.

Conclusions

Short row distances (16.5 m vs. 37.1 m) can reduce the production of maize, expressed as the number of ears ha^{-1} and maize grain yield. Competition between trees and crops was more severe at short distances from the eucalyptus of low distance rows. Maize characteristics did not differ relative to their position relative to cardinal points (W/E).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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