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Radiation use efficiency in maize as a function of sowing dates and plant densities

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ABSTRACT

The objective of this work was to evaluate the radiation use efficiency (RUE) for the accumulated biomass and for grain yield in the irrigated maize crop according to sowing dates (SOW) and plant densities (D) in Rio Largo, state of Alagoas, Brazil, in the year 2013. SOW were SOW 1 (6/28/13), SOW 2 (7/8/13), SOW 3 (7/18/13), SOW 4 (7/28/13) and the plant densities were D1 = 125,000, D2 = 87,500, D3 = 50,000, D4 = 37,500 plants ha^{-1}. Sowing dates and the interaction of these dates with plant densities did not have significant effects on grain yield and RUE, but plant densities were significant. The highest average grain yield (6067.3 kg ha^{-1}) occurred in D3, decreasing in the highest densities. RUE increased from 2.98 g MJ^{-1} in low density (D4) to 4.72 g MJ^{-1} in higher density (D1). The maize plants with higher densities showed a higher index of leaf area and dry biomass. At low plant density, the solar radiation incident is less intercept because the leaf area index is poorly distributed among the plant lines. The effect of plant density on RUE for the accumulation of biomass was the opposite to that of the RUE for grain yield (RUEy), so that lower RUEy was found at lower densities.

Introduction

Maize is widely planted in Brazil but has a low yield (average grain yield in 2019 was 6.2 Mg ha^{-1}) (Conab, 2019) concerning the United States of America (average grain yield in 2018 was 11.7 Mg ha^{-1}) (USDA-NASS, 2019). The lower yield (average grain yield in 2019 was 4 Mg ha^{-1}) (Conab, 2019) observed in northeastern Brazil is a result of poor distribution or concentration of rainfall in a few months and the low technological level of management of small farmers (Silva et al., 2005; Ferreira Junior et al., 2014; Andrea et al., 2018).

The improvement in maize yield in northeastern Brazil leads to research related to crop management seeking to mitigate the gaps between current and potential yields. The potential yield of a crop depends on intercepted solar radiation by the canopy when thermal, water, nutritional, and phytosanitary are in optimum condition (Monteith, 1977). Photosynthetic active radiation (PAR) is the energy that plants use to carry out photosynthesis at wavelengths from 400 to 700 nm, while global solar radiation range from 305 to 2800 nm. Radiation use efficiency (RUE) is a parameter used to quantify the relationship between solar radiation and biomass production, which is the input basis for growth and yield models. Solar radiation incident on the canopy is absorbed, transmitted and reflected in varying amounts depending on the angle of incidence of solar rays and the quantitative (leaf area and volume) and qualitative (optical and geometric) characteristics of the canopy (Hirose, 2005). The optical and geometric properties of vegetation are represented by the radiation extinction coefficient (k), which, associated with the leaf area occupying a particular ground area (Leaf Area Index, LAI), resulting in the transmittance of solar radiation (Monteith, 1973; Campbell, 1986).

Increasing the density of plants changes the distribution and angle of leaves, raising the interception of solar radiation. However, the degree of intra-specific competition caused by increased plant density causes a reduction in the plant part of interest, such as the grain (Demétrio et al., 2008). Thus, targeted studies using different population densities are needed to define the best use of solar radiation, water and nutrients (Mundstock, 1977; Argenta et al. 2001; Kunz et al., 2007).

Most of the maize cultivation in the coastal region of Alagoas is rainfed, where rains are concentrated from April to August (Souza et al., 2005), allowing only one growth cycle per year. Water stress reduces the maize yield, obtaining a direct consequence in the absorption of solar radiation, causing leaf curl and smaller leaf area (Earl & Davis, 2003; Müller et al., 2005). Therefore, this study aimed to evaluate the RUE in the production of biomass and grain yield of maize in response to sowing dates and plant densities in Rio Largo, in the coastal region of Alagoas.

Material and Methods

The research was conducted in the region of Rio Largo, state of Alagoas, Northeast of Brazil (09°28'02"S; 35°49'43"W; 127 m) in an area of 2,736 m². According to the classification of Thornthwaite, the region is classified as humid climate, megathermic, with moderate water deficiency in summer and sizeable excess of water during winter (Thornthwaite & Mather, 1955). The local receive 70 percent of their total annual precipitation (1818 mm) during the months of April to August. Air temperature varies from 19.3 (August) to 31.7 °C (January) with an annual average of 25.4 ºC and average monthly air humidity above 70% (Souza et al., 2005).

The field study was composed of four sowing dates: SOW 1 (28/06/13), SOW 2 (08/07/13), SOW 3 (18/07/13), SOW 4 (28/07/13) and four plant densities (D1 = 125,000, D2 = 87,500, D3 = 50,000, D4 = 37,500 plants ha^{-1}) with a fixed row spacing of 0.8 m. The sowing dates were established within the rainy season (Souza et al., 2004) aiming to take advantage of the greater availability of precipitation and less use of irrigation to meet the search for high yields. The values of plant densities evaluated were defined based on previous studies (Sangoi et al., 2005; Dourado Neto et al., 2003; Sangoi et al., 2011).

We used a randomized blocks design in split-plot-scheme (16 treatments). The sowing dates treatments were allocated on the plots and the plant densities in the subplots. Each treatment was replicated four times. The subplots consisted of five lines of seven meters.

The sowing of cultivar AL Bandeirantes from Embrapa (Brazilian Agricultural Research Corporation) was performed in the no-till system and the furrows were opened at a depth of 10 cm. The fertilizer was applied pre-planting with 30, 80 and 60 kg ha^{-1} of N, P_2O_5 and K_2O, respectively. Top-dressing fertilization was performed at 20 days after sowing (DAS) when the plants presented four expanded leaves (V4), according to the scale proposed by Ritchie et al. (1993). The N source used was urea, applying 120 kg ha^{-1} of N. Micronutrients were applied twice: at the four and eight leaves expanded stages (V4 and V8) as needed. Weed and pest control was carried out during cultivation.

The soil water content at the depth of the root zone (0.3 m) was maintained at more than 55% of the total available water necessary to obtain potential crop growth conditions (Doorenbos & Kassam, 1979). The drip irrigation was based on the reference evapotranspiration (daily average of 3.8 ± 0.4 mm) of the study region obtained from the agrometeorological station neighboring the experimental area, crop coefficient (Allen et al., 1998) and physical-hydro soil data (Magalhaes et al., 2017) volumetric water content in field capacity (0.2445 m^3 m^{-3}) and permanent wilting point (0.1475 m^3 m^{-3}).

The leaf area (LA) of twelve plants per plot was obtained weekly by the equation of Hermann & Câmara (1999): LA = L*W 0.75 (N + 2), where W is the width, L is the length of the 3rd fully expanded leaf from top each plant, N is number of green leaves fully, 0.75 is leaf shape factor and 2 is represents the area of the leaves not fully explanted (Montgomery, 1911; Francis et al., 1969). The LAI was calculated by the ratio between the LA and the soil area occupied by the plants.

Weekly sampling was performed in eight plants per sub-plot to obtain the dry mass (DM) through of a dry oven at

65 °C with forced ventilation (Benincasa, 1988). Harvesting was performed manually when the grains acquired a black layer formation, endosperm solidification line, and DM accumulation (Araújo et al., 2006). Grain yield (GY) was determined in the ears harvested in the three central lines of three meters of each treatment. The grains were dried in a forced circulation oven at 75 ºC, and the mass was corrected for 13% humidity (Pimentel & Fonseca, 2011). The harvest index (HI) was calculated by the ratio between the GY and the accumulated DM until physiological maturation (Demétrio et al., 2008).

The air temperature (HMP45C, Campbell Scientific, Logan, Utah) and global solar irradiance - Rg (Eppley, model 848, B&W, Newport, Rhode Island) were obtained from an automatic agrometeorological station near the experimental area. The values of incident photosynthetic solar irradiance (PAR, W m^{-2}) were estimated as 43% of Rg (Ferreira Junior et al., 2012). Global solar irradiation (Hg, MJ m^{-2} day^{-1}) and incident photosynthetic irradiation (H_{PAR}, MJ m^{-2} day^{-1}) were obtained by integration of the Rg and PAR values, respectively, during the daytime period.

The transmitted photosynthetic solar irradiance (TPAR, W m^{-2}) was measured four times in each sub-plot in the four sowing dates, from 10:00 to 14:00 hours, on clear sky days, using a linear quantum sensor (LI-191SA, LI-COR, Lincoln, Nebraska) adequately calibrated. These measurements were made diagonally on the crop line to install the sensor in the interline (Monteith, 1993; Maddonni et al., 2001). The flow densities of photosynthetic photons (μmol s^{-1} m^{-2}) and the conversion to photosynthetic irradiance (W m^{-2}) considered that 1 W m^{-2} is equal to 4.6 μmol s^{-1} m^{-2} (Mccree, 1972). The parameter k was estimated by exponential regression between the transmitted irradiance fraction (fTPAR = TPAR / PAR) and LAI (Flénet et al., 1996).

RUE was determined by linear regression (with 0=0) between the DM of the accumulated aerial part and the intercepted photosynthetic irradiation (H_{IPAR}) accumulated (Monteith, 1977). H_{IPAR} (MJ m^{-2} day^{-1}) was calculated based on Beer's law (Hipps et al., 1983):

$$H_{IPAR} = H_{PAR} \left(1 - \exp(-k\, LAI)\right) \quad (1)$$

where, H_{PAR} is the photosynthetic incident irradiation (MJ m^{-2} day^{-1}). RUE for the grain yield (RUEy) was estimated by the relationship between the GY and the accumulated H_{IPAR}.

The statistical analyses were performed using SISVAR software, submitting the data to the analysis of variance (Anova), at 5% probability. Subsequently, for the quantitative variables, regressions were performed and for the qualitative variables mean comparison by the Tukey test (p≤0.05).

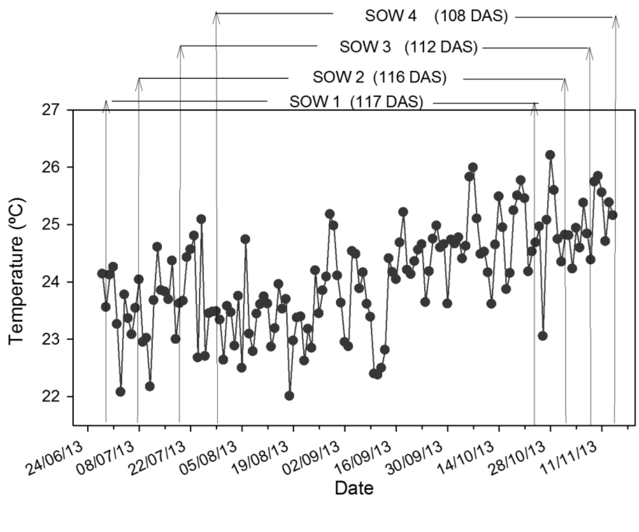
Results and Discussion

The air temperature was not a limiting factor for the maize studied, with the average values in the cycles ranging from 23.9 °C in SOW 1 to 24.2 °C in SOW 2 (Figure 1), since for the development of crop maize the thermal demand is between 8 and 44 °C, with maximum growth occurring between 26 and 34 °C (Kiniry, 1991).

Crop cycle decreased with the advance of the sowing dates due to the greater availability of daily thermal energy, ranging from 108 (SOW 4) to 117 days (SOW 1). The acceleration of chemical reactions together with the substrate availability (CO_2) and energy transport can shorter the Maize cycle (Andersson & Backlund, 2008), which is characteristic of C4 plants in a tropical environment. Thus, the shorter cycle of maize due to the increase in air temperature with the advance of sowing dates reduced the period of photosynthesis, resulting in less grains by the lower interception of solar radiation and biomass conversion (Tollenaar, 1977; Muchow et al, 1990; Andrade et al., 1993; Cirilo & Andrade, 1994; Bergamaschi, 2006). Similar results were highlighted in other studies (Didonet et al., 2002) regarding the duration of the phenological phase and grain yield.

The plants in the treatments D1, D2, D3, and D4 had an average radiation extinction coefficient (k) of 0.46, 0.58, 0.59, and 0.66, respectively (Figure 2). The k in treatments D2 and D3 were not significantly different, according to the SEE, thus considering that the architectures of the D2 and D3 plants are equivalent. The determination coefficients (R^2) of the relations between fTPAR and LAI were greater than 0.70 and significant at 95% probability (t-test). In low plant density, the incident radiation is less intercepted because the LAI is little distributed between the rows of

Figure 1. Air temperature in sowing dates (SOW 1 28Jun2013, SOW 2 08Jul2013, SOW 3 18Jul2013 and SOW 4 29Jul2013) of maize in Rio Largo, coastal region of Alagoas, 2013.



planting, i.e., more plant density takes more advantage of incident radiation.

Plants with horizontally arranged leaves and more open foliar architecture showed a k above 0.60. Lindquist et al. (2005) found a k (0.67) like ours in the period of grain filling. Maddonni & Otegui (1996), in research using different hybrids, at a density of 70,000 plants ha^{-1}, showed that k varied between 0.46 and 0.64 for different types of hybrids, in three different locations. The highest values of k were observed in hybrids with a more horizontal leaf architecture, while hybrids with more erect leaves showed a lower k. Tohidi et al. (2012) calculated k for five hybrids and three nitrogen levels in the semi-arid region of Iran, where k ranged from 0.56 to 0.60 for the highest and lowest nitrogen level and from 0.52 to 0.69 when comparing maize hybrids.

We found a strong relation between the k and the plant density (R^2 = 0.90), that is, the highest the density (D1) the lower the k, and higher k at low densities (Figure 3). The k found in this work serves as a tool to mechanistic models that use light interception of varieties with open canopy based on k and LAI.

Maddonni et al. (2001) determined k using also exponential equations in the region of Argentina and found a value of 0.55 at the density of 9 plants m^{-2} (maximum LAI = 6). However, at densities of 3 and 12 plants m^{-2}, they found different values than in this research, probably a result of different characteristics of the hybrid canopy used. The treatment may have affected the distribution and growth of hybrid leaves through morphological changes in the leaves before radiation competition. Borrás et al. (2003) obtained similar results to those of Maddonni et al. (2001), with increasing k as a function of plant density.

Figure 3. Extinction coefficient (k) of solar radiation as a function of maize plant density in Rio Largo, coastal region of Alagoas, 2013.

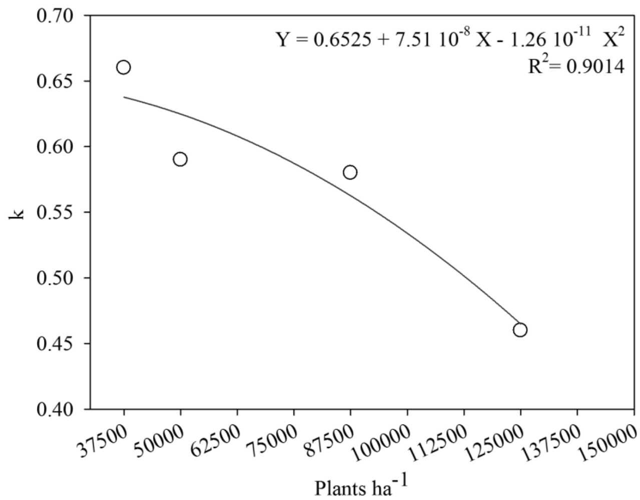
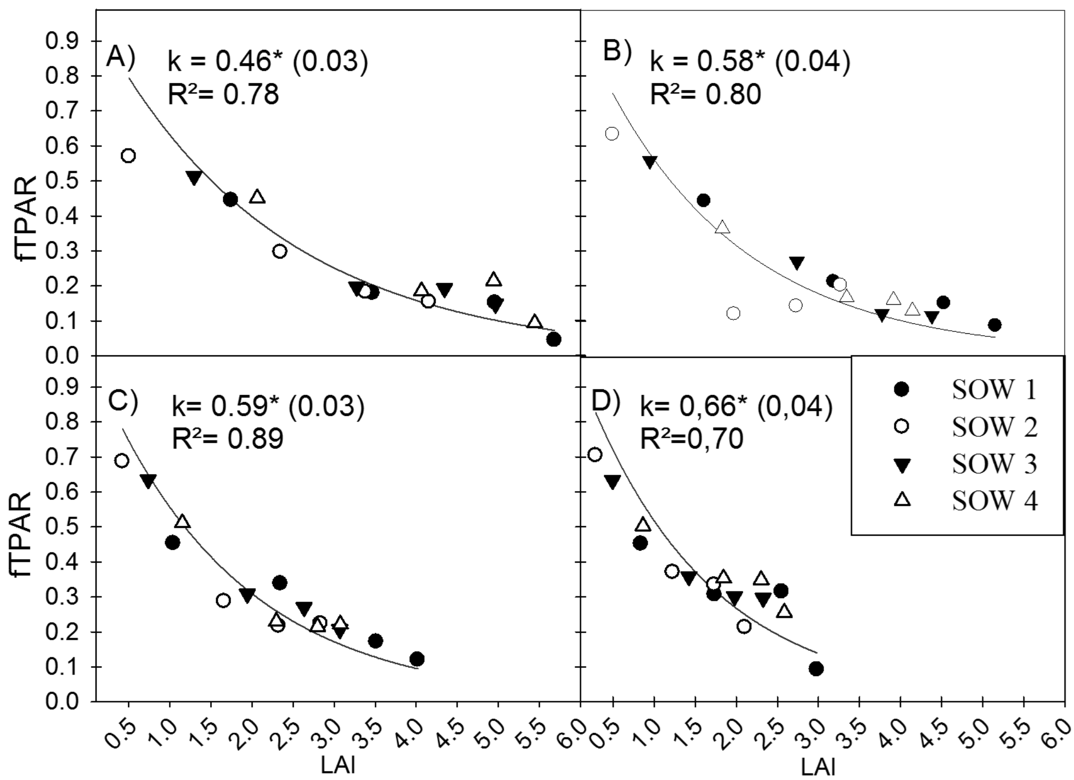


Figure 2. Relationship between the transmitted irradiance fraction (fTPAR) and the leaf area index (LAI) for plant densities of maize in Rio Largo, coastal region of Alagoas, 2013. A) D1 = 125000 plants ha^{-1}; B) D2 = 87500 plants ha^{-1}; C) D3 = 50000 plants ha^{-1}; D) D4 = 37500 plants ha^{-1}. Notes *significant coefficients at 5% probability of error, by the t test; Value between parenthesis represents the standard error of estimate (SEE).



Monsi & Saeki (1953) reported k with a value equal to 1.0 for ideally distributed horizontal leaves and 0.44 for leaves with lower inclination angle at insertion. For Müller et al. (2005), the smallest k occurred in treatments less efficient at interception, due to more erect and smaller leaves that reduce the capacity of light interception between leaf layers. The authors attribute the result to unadjusted plant population density and/or row spacing.

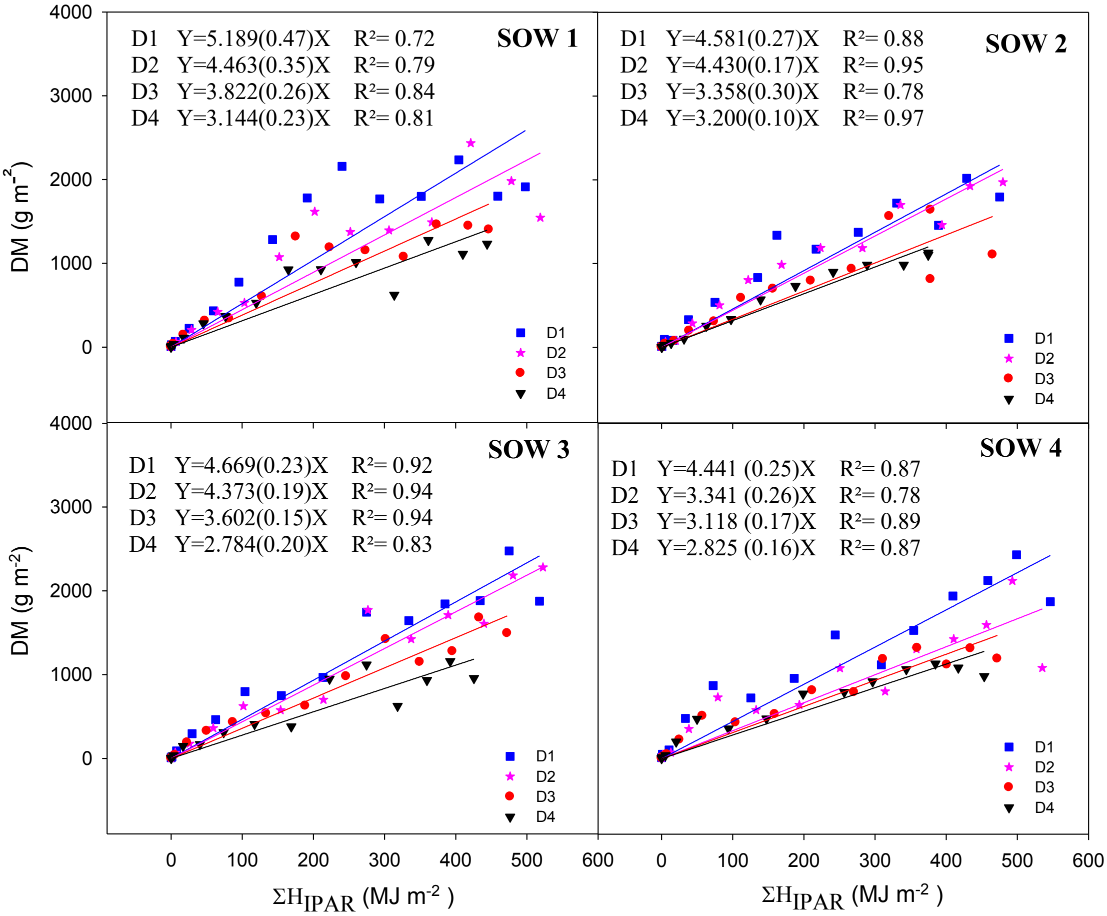
The solar radiation is more intercepted in crop with higher density and more erect leaves. Thus, the structure of the canopy of plants, population density and types of hybrids/maize varieties modify light interception. Genotypes with most erect foliar structure in higher plant density use better the solar radiation and experience lower competition on the canopy. Thus, the larger the k the smaller the fraction of radiation intercepted by the leaf structure by the densification of the plants.

The density of plants and their architecture influence the quantity and quality of light allowing a better use and conversion into biomass (Monteith, 1973; Campbell, 1986). The RUE for biomass increased with plant density, however the sowing dates had varied values of RUE (Figure 4), due to the difference in solar irradiance.

The intercepted photosynthetic irradiation (H_{IPAR}) in the SOW 1 cycle varied according to the planting densities, in which D1 and D2 were higher (563.6 and 564.0 MJ m^{-2}) and D3 and D4 were 475.5 and 480.8 MJ m^{-2}, respectively. In SOW 2, the H_{IPAR} in the cycle for D2 was the highest (522.3 MJ m^{-2}) about 14% than in D4 (450.1 MJ m^{-2}). D1 and D3 accumulated H_{IPAR} of 517.2 and 509.9 MJ m^{-2}, respectively. SOW 3 accumulates radiation intercepted by crops in D2, D1, D3 and D4 ranging from 437.2 (D4) to 537.5 MJ m^{-2} (D2). In the last sowing date (SOW 4), the accumulated H_{IPAR} values decreased from 542.1 (D1) to 450.3 MJ m^{-2} (D4).

The daily H_{IPAR} t increased in all treatments up to the maximum LAI (at the end of the vegetative phase of the crop) when the translocation of photoassimilates to the ears, leaf senescence and decrease of LAI began (in the reproductive phase of the plant), and consequently lower light interception. LAI values decreased with the decrease in plant densities, but it does not mean that the density with higher LAI intercepts more radiant energy. The interception also depends on the architecture of plants, that is, spatial arrangements of planting densities –

Figure 4. Relation between the accumulation of dry matter (DM) and cumulative intercepted photosynthetic irradiation (ΣH_{IPAR}) for sowing dates (SOW) and plant densities (D, plants ha^{-1}) of maize crop in Rio Largo, coastal region of Alagoas, 2013. Notes: SOW 1 - 28Jun2013; SOW 2 - 08Jul2013; SOW 3 - 18Jul2013; SOW 4 - 29Jul2013. D1 - 125000; D2 - 87500; D3 - 50000; D4 37500 plants ha^{-1}). Value between parenthesis represents the standard error of estimate (SEE).



depends, therefore, on LAI, k and the angle of incidence of solar radiation.

Marchão et al. (2006) showed a correlation between plant densities and interception of radiation in maize crop. The higher plant density allows greater interception of photosynthetic radiation and higher grain yield. In the present study, the highest densities of plants had the highest interception of radiant energy, however, concerning the two highest densities, D2 intercepted lighter than D1. The higher plasticity of the leaves in the lower density crop may explain the lower interception of radiant energy. Similar results were found by Sangoi et al. (2011).

We did not find an effect of sowing dates and interaction between sowing dates and plant densities on the grain yield (GY) (F-test, $p < 0.05$). However, the grain yield was significantly affected by plant density. The highest mean of GY (mean of the dates) occurred at D3 treatment (6067.3 kg ha^{-1}), with a maximum of 6409.2 kg ha^{-1} in SOW 2 (Figure 5) and a minimum of 4656.5 kg ha^{-1} at D1 treatment. The quadratic regression explained 89% of the GY values as a function of plant densities.

We observed the highest ratio of GY and accumulated biomass (harvest index - HI) in D4 (0.46) and was 56% higher than D1 (0.20, the lowest HI) and the average HI was 33%. The results show that when the density of plants increased the accumulation of biomass increased but the GY decreased, likely due to the self-shading of the leaves and the low capacity to translocate the photoassimilates to fill the grains of this maize reached. Yang et al. (2004) also observed decreasing HI due to the increase in plant population, ranging from 0.49 (113,000 plants ha^{-1}) to 0.53 (70,000 plants ha^{-1}) in the 1999 survey and from 0.50 (110,000 plants ha^{-1}) to 0.54 (69,000 plants ha^{-1}) in the 2000 survey. Argenta et al. (2001) found different HI but unaffected by plant density. According to the authors for a population of 50 thousand plants ha^{-1}, the HI ranged between 0.42 and 0.50. Demetrio et al., (2008) found a maximum value of 0.44 for the population of 58 thousand plants per hectare.

The SOW 1 had the highest RUE (4.09 g MJ^{-1}) and SOW 4 the lowest (3.71 MJ m^{-1}). SOW 2 showed the highest value of RUEy (1.15 g MJ^{-1}) and a difference of about 15 % of SOW 4, which was the lower (1.01 g MJ^{-1}) (Table 1) but the RUE and RUEy of maize plants sown in different dates tested did not differ by the F-test ($p<0.05$). We also not found effect of the interaction between sowing dates x plant densities. The coefficients of variation showed good experimental accuracy, both for RUE and for RUEy (Scapim et al., 1995) (Table 2).

The highest RUEy occurred at D3 and the lowest at D1. Plant densities significantly affected the RUE and RUEy (F-test $p<0.05$), only for linear regression, indicating that the 1st degree equation explains the characteristic of the RUE and RUEy as a function of the increase in plant density. Plant density significantly increased the RUE from 2.98 at low density (D4) to 4.74 at higher densities (D1). The effect of plant density on RUE was the opposite for RUEy, so that lower RUEy were found at lower plant densities (Figure 6). The high RUE for maize crop is associated with high light saturation point and higher CO_2 capture at high temperatures. This is a result of the high efficiency of the enzyme phosphoenolpyruvate carboxylase in the fixation of CO_2 in the sheath beam cells. While the enzyme ribulose-1.5-biphosphate carboxylase oxygenase is present in the mesophilic foliar cells unable to exercise oxygenase function.

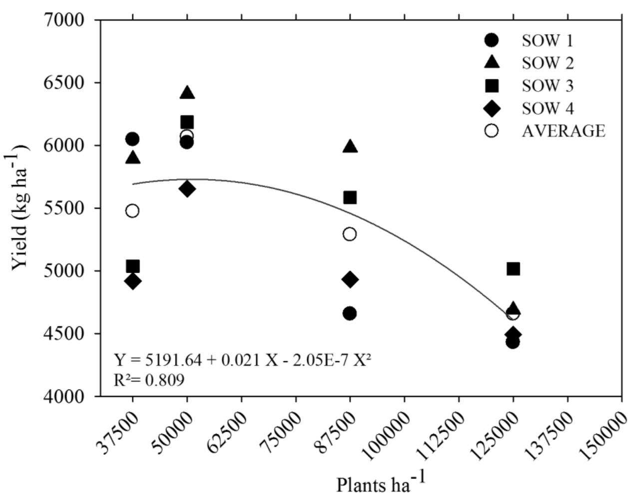
The high plant density increased LAI and interception of solar radiation. The spatial arrangement of the plants changed the distribution of leaves enhancing the use of solar radiation and biomass conversion. This effect was negative for grain production, very likely because the increased density of plants raised the competition causing physiological limitation (Mundstock, 1977). Stressed plants can absorb the same amount of solar radiation as unstressed plants but have a lower photosynthetic rate

Table 1. Effect of sowing dates on the radiation use efficiency (RUE) for biomass production and (RUEy) grain yield of maize (*Zea mays* L.) in Rio Largo, coastal region of Alagoas, 2013.

Treatments	RUE (g MJ-1)	RUEy (g MJ-1)
SOW 1	4.09 a	1.05 a
SOW 2	3.56 a	1.15 a
SOW 3	3.96 a	1.10 a
SOW 4	3.71 a	1.01 a

Notes: Mean followed by the same lowercase letter in a column do not differ by the Tukey test ($p <0.05$).

Figure 5. Quadratic regression for grain yield as a function of the maize plant density in Rio Largo, coastal region of Alagoas, 2013.



Notes *Significant coefficients at 5% probability, according to the t test.

Table 2. Mean squares of the analysis of the variance of the effects of sowing dates and plant densities of the variables: radiation use efficiency (RUE) for biomass, radiation use efficiency for grain yield (RUEy) and grain yield (GY) of maize in Rio Largo, coastal region of Alagoas, 2013.

Source de variation	GL	RUE	RUEy	GY
		Mean Squares		
Block	3	-	-	-
SOW	3	0.93ns	0.06ns	1550444,50ns
Residue (a)	9	0.34	0.03	699213,88
Densities	(3)	9.74*	0.49*	5401316,36*
Linear	1	28.69*	1.36*	11485231,3*
Quadratic	1	0.44ns	0.002ns	1633298,27ns
Cubic	1	0.09ns	0.12ns	-
Densities X SOW	9	0.27ns	0.02ns	642168,22ns
Residue (b)	36	0.25	0.01	445815,74
Total	63			
Coefficient of variation a (%)		15.21	15.27	15.57
Coefficient of variation b (%)		13.04	11.63	12.43
Overall average		3.83	1.08	5371,37

Notes: nsNot significant at $p<0.05$ by F-test; *Significant at $p<0.05$ by F-test; Significant at $p<0.01$ by F- test; GL = Graus of freedom.

and yield conversion (Kunz et al., 2007).

Ferreira Junior et al. (2014) found similar value (maximum RUE 3.85 g MJ^{-1}) using a cultivar BR 106 from EMBRAPA for a population of 62500 plants ha^{-1}. Kunz et al. (2007) found RUE values of 3.2 g MJ^{-1}, for crops with 70,000 plants ha^{-1}, under irrigated conditions and 0.8 m row spacing. When the authors decreased the row spacing to 0.4 m, RUE increased (4.0 g MJ^{-1}), concluding that at the same density there was an increase in the intercept efficiency of PAR with a reduction in the row spacing, due to a more equidistant distribution between plants. Still, allowing better leaf architecture favoring the interception of photosynthetic radiation.

França et al. (1999) obtained a value of 2.6 g MJ^{-1} for a population of 67 thousand plants per hectare. Values between 2.5 and 2.8 g MJ^{-1} were found for sorghum crop and at a mean of 2.2 for other crops (sunflower, rice and wheat) (Muchow & Davis, 1988; Kiniry et al., 1989). Cirilo & Andrade (1994) show for maize crop values up to 4.2 g MJ^{-1} in a period of higher solar radiation and similar values were found by (Bonhomme et al., 1982; Muchow & Davis, 1988; Kiniry et al., 1989). Thus, the RUE has values between 2.5 and 4.6 g MJ^{-1}, varying with plant density and lea f architecture.

Conclusions

The maize plants at higher densities showed higher leaf area index and dry biomass. In low plant density, the incident radiation is less intercepted because the leaf area index is little distributed between the rows of planting. The increase in leaf area index decreased the transmitted solar irradiance. The radiation extinction coefficient was lower at higher plant densities in the evaluated maize. We found a unimodal relationship between crop yield and plant density, with higher yield at density of 50,000 plants per hectare. The effect of plant density on Radiation use efficiency for the accumulation of biomass (increase) was the opposite to that of the Radiation use efficiency for grain yield.

Acknowledgments

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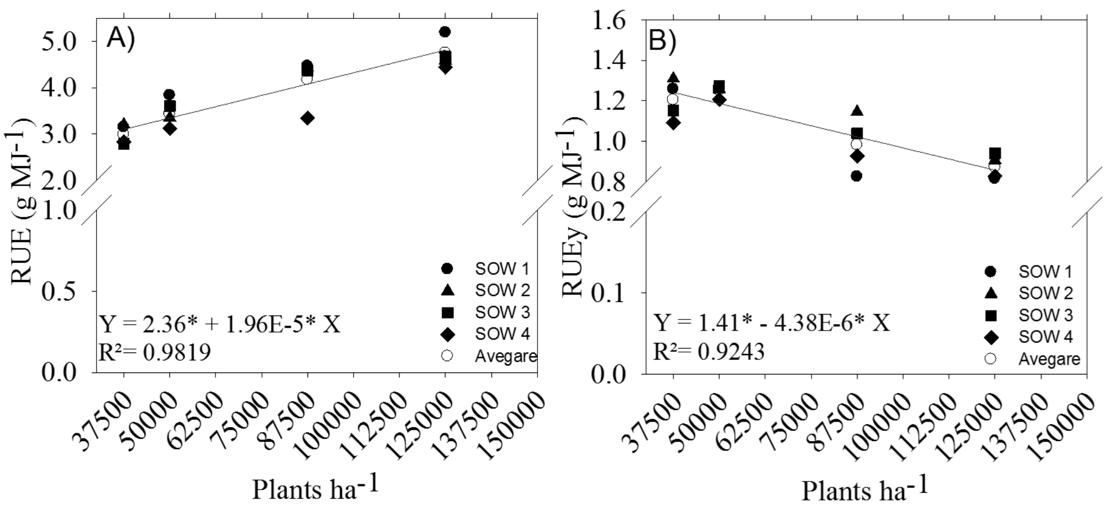
Figure 6. A) Radiation use efficiency for aerial dry biomass (RUE) and B) for grain yield (RUEy) as a function of the maize plant density in Rio Largo, coastal region of Alagoas, 2013.



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Eficiência no uso da radiação no milho em função de datas de semeadura e de densidades de plantas

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RESUMO

O Objetivo deste trabalho foi avaliar a eficiência do uso de radiação (EUR) para a biomassa acumulada e para o rendimento de grãos na cultura do milho irrigado em função de datas de semeadura (DS) e de densidades de plantas (D) em Rio Largo, Alagoas, no ano de 2013. As DS foram DS 1 (28/06/13), DS 2 (08/07/13), DS 3 (18/07/13), DS 4 (28/07/13) e as densidades de plantas foram D1 = 125.000, D2 = 87.500, D3 = 50.000, D4 = 37.500 plantas ha^{-1}. As datas de semeaduras e a interação dessas datas com as densidades de plantas não tiveram efeitos significativos na produtividade de grão e na EUR, porém a densidades de plantas teve significância. A maior média de produtividade de grãos (6067,3 kg ha^{-1}) ocorreu na D3 diminuindo nas maiores densidades. A EUR aumentou de 2,98 g MJ^{-1} em baixa densidade (D4) para 4,72 g MJ^{-1} em densidade mais alta (D1). As plantas de milho com maiores densidades apresentaram maior índice de área foliar e biomassa seca. Em baixa densidade de plantas, a radiação solar incidente é menos interceptada porque o índice de área foliar está mal distribuído entre as linhas de plantas. O efeito da densidade de planta na EUR para a acúmulo de biomassa foi o oposto para a EUR para rendimento de grãos (EURr), de modo que foram encontrados menores EURr em densidades mais baixas.

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