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Physiological Efficiency and Yield of Prickly Pear and Gliricidia under Different Planting Configurations

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HIGHLIGHTS

- Dense cultivation of gliricidia up to 4,348 plants ha^{-1} increases its yield;
- Regardless of gliricidia density, prickly pear yield was not influenced.

Abstract: Physiological and yield evaluation of perennial forage plants grown in intercropping in the semiarid region is indispensable in the search for higher efficiency of the agricultural and livestock production systems. In this context, an experiment was carried out at the Experimental Station of the National Institute of the Semiarid Region – INSA, in the municipality of Campina Grande, Paraíba, Brazil, to evaluate the physiological efficiency and yield of prickly pear and gliricidia in intercropping. Treatments were distributed in randomized blocks, with six replicates, being represented by four spacings between gliricidia plants: S1 (1.0 m), S2 (1.5 m), S3 (2.0 m) and S4 (3.0 m) x 2.30 m between rows. Prickly pear was planted in double rows of 1.5 m x 0.8 m x 0.5 m. The analyzed variables were initial, maximum and variable fluorescence chlorophyll *a*, variable/initial fluorescence ratio, potential quantum yield and the fresh matter yield of both crops. Density planting of gliricidia up to 4,348 plants ha^{-1} increases its photochemical efficiency and yield, but reduces light energy capture by prickly pear in intercropping, whereas its yield is not influenced by cultivation density. Regardless of gliricidia density, prickly pear yield was not influenced.

Keywords: intercropping; *Gliricidia sepium* (Jacq.) Kunth ex Walp.; *Opuntia stricta* (Haw.) Haw.; production; quantum yield

INTRODUCTION

The Brazilian semiarid region, like the other dry areas of the world, stands out as an area with great suitability for livestock production, especially ruminants. In these regions, for adequate maintenance of yield levels, it is indispensable to grow perennial xerophilous plants, avoiding the uncertainty in forage harvesting [1].

In this context, prickly pear (*Opuntia* sp. or *Nopalea* sp.) is currently the main xerophyte cultivated in Brazil, standing out for its high forage production capacity, above 200 Mg ha^{-1} year^{-1}, being the food base of both beef and dairy cattle herds in this region, especially in the drought period [2]. This species has the Crassulacean Acid Metabolism (CAM), characterized by the opening of stomata only at night, avoiding high rates of transpiration and excessive loss of water to the atmosphere. This survival strategy, combined with the superficial root system, which allows it to make use of minimum levels of precipitation, enables this cactus species to obtain high water use efficiency [3].

Despite the numerous advantages of prickly pear, its high water content (about 90%) makes it deficient in fiber and protein. Hence, intercropped cultivation with perennial leguminous plants such as gliricidia [*Gliricidia sepium* (Jacq.) Kunth ex Walp.] becomes essential, mainly from the viewpoint of compensating for these deficiencies [4]. Gliricidia, in turn, is a drought-tolerant, tree leguminous species that has been cultivated as a source of forage and firewood in rural properties in the semiarid region [5]. In addition, the use of this leguminous plant in intercropping can bring other benefits, such as soil decompaction in deeper layers through its root system and also the increase in nitrogen content in soil via biological fixation, improving its chemical and physical quality [6]. Despite the number of studies conducted with these species regarding propagation, fertilization, spacings and frequencies of cut and irrigation, little has been studied about the physiological aspects of both, especially in intercropping system.

Determination of chlorophyll a fluorescence aims to measure the yield of photosystem II (PS II), i.e., how many moles of CO_2 are fixed or how many moles of O_2 are produced by each mol of photon that is absorbed by the energy-harvesting system in the thylakoids, which are used in the photochemical process [7]. Chlorophyll a fluorescence may be useful to understand the physiological dynamics of prickly and gliricidia in intercropped rainfed cultivation in the semiarid region, since the different managements given to the two intercropped species can directly interfere with their yield.

In this context, the objective of this study was to evaluate the physiological efficiency and yield of prickly pear and gliricidia under different planting configurations

MATERIAL AND METHODS

The experiment was conducted at the Experimental Station of the National Institute of the Semiarid Region – INSA, located in the municipality of Campina Grande, Paraíba, Brazil, in the Agreste Paraibano mesoregion, with 7º13'50"S latitude, 35º52'52"W longitude and 551 m altitude. The climate is classified as Aw' according to Köppen's climatic classification and is considered as sub-humid dry, with water deficit in most of the year [8]. The experimental period was from June 2016 to May 2018. The meteorological variation along the experimental period is presented in Table 1.

Table 1. Precipitation (mm) in the experimental field, along the studied period.

Months	**Years**		
	2016	**2017**	**2018**
January	-	0.6	48.7
February	-	0.0	87.1
March	-	16.0	61.7
April	-	54.1	56.9
May	-	47.2	83.9
June	12.9	47.2	-
July	6.9	115.4	-
August	6.6	0.7	-
September	5.1	14.7	-
October	0.2	8.2	-
November	0.0	0.0	-
December	50.0	0.0	-
Total	**81.7**	**304.1**	**338.3**

Prior to planting, a composite soil sample was collected in the 0-20 cm layer of the experimental area and sent to the soil laboratory of the Rural Engineering Department of the Center for Agrarian Sciences, Federal University of Paraíba in Areia-PB, for fertility characterization (Table 2). Soil samples were collected at this depth because approximately 75% of the prickly pear root system is located in the first centimeters of the soil [9].

Table 2. Chemical attributes of the soil with respect to fertility in the 0-20 cm layer.

pH	P	K^+	Na^+	$H^+ + Al^{+3}$	Al^{+3}	Ca^{+2}	Mg^{+2}	V%	CEC	OM
H_2O (1:2.5)	----mg/dm³----		----------------------cmolc/dm³--------------------------							g/kg
5.4	3.30	98.09	0.11	3.37	0.20	3.34	0.32	54.4	7.39	6.46

P, K, Na: Mehlich^{-1} Extractor; H + Al: 0.5 M Calcium Acetate Extractor, pH 7.0; H + Al: .5 M Calcium Acetate Extractor, pH 7.0; Al, Ca, Mg: 1 M KCl Extractor; OM: Organic Matter – Walkley-Black; V%: base saturation; CEC: cation exchange capacity.

Tillage in the area was carried out with harrowing and subsequent opening of holes to plant the prickly pear, obtained from a multiplication field of the Experimental Station of INSA and left in the shade for eight days, for healing the cuts. Gliricidia seedlings were grown from seeds in the nursery of the Experimental Station, with substrate from soil of the experimental area and addition of 5% bovine manure. Cultivation practices such as the control of spontaneous herbs were carried out by weeding and/or mowing, whereas pest and disease control was performed according to the needs of both crops.

For the study, an intercropping system with 'Orelha de Elefante Mexicana' prickly pear (*Opuntia stricta* Haw) and gliricidia (*G. sepium*) was planted in a randomized block experimental design with four treatments and six replicates. The treatments applied were four spacings between gliricidia plants: S1 (1.0 m), S2 (1.5 m), S3 (2.0 m) and S4 (3.0 m) × 2.30 m between rows, which respectively correspond to the densities of 4,348, 2,899, 2,174 and 1,450 plants ha^{-1}. Prickly pear was planted in double rows of 1.5 m × 0.8 m × 0.5 m, while gliricidia was planted in its interrows. The experimental plots had a total dimension of 92.4 m^2 (12 × 7.7 m), each of which composed of 200 prickly pear plants and 39, 27, 21 and 15 gliricidia plants for the treatments S1, S2, S3 and S4, respectively, which corresponded to a total area of 2,371.4 m^2 (28.4 x 83.5 m). For yield evaluations, 10 prickly pear plants and four gliricidia plants were marked in each plot.

At two years after planting, chlorophyll *a* fluorescence emissions were determined between 09:00 and 11:00 a.m. in two plants of each species per plot, and the readings were taken in two mature cladodes of prickly pear and in two leaves of one of the intermediate branches of gliricidia. A portable continuous excitation fluorimeter (Sciences Inc. - model OS-30p, Hudson, USA) was used and, before measurement, the areas of the cladodes and leaves were dark-adapted for 30 minutes using the fluorometer's own clips [10,11].

The physiological variables analyzed were initial (F0), maximum (Fm) and variable (Fv) chlorophyll a fluorescence, Fv/F0 ratio and the potential quantum yield (Fv/Fm). Subsequently, prickly pear plants were harvested, preserving the primary cladodes, and gliricidia plants were cut at 0.5 m from the ground level in order to measure the fresh matter yields (FMY) in Mg/ha^{-1} of both crops, considering the average weight of the plot and then multiplying it by the plant population per hectare. After obtaining and tabulation, the data were subjected to analysis of variance and statistically different means were compared by Tukey test at 5% probability level, using the program Statistical Analysis System – SAS [12].

RESULTS AND DISCUSSION

By analyzing the initial fluorescence (F0) of the different species, it can be noted that, regardless of spacing, gliricidia plants reached the highest values. However, when cultivated at density of 2,174 plants ha^{-1}, the maximum mean values obtained were 77.5 and 45.3 electrons quantum^{-1} for gliricidia and prickly pear, respectively, with a 71% increase in the F0 of the leguminous plant in comparison to that of the cactus (Figure 1A and 1B). The F0 values of prickly pear observed in this study corroborate those reported by Souza and coauthors (2019) [1], who evaluated different genotypes of this species in the semiarid region of Paraíba and observed variation from 43.8 to 58.8 electrons quantum^{-1}.

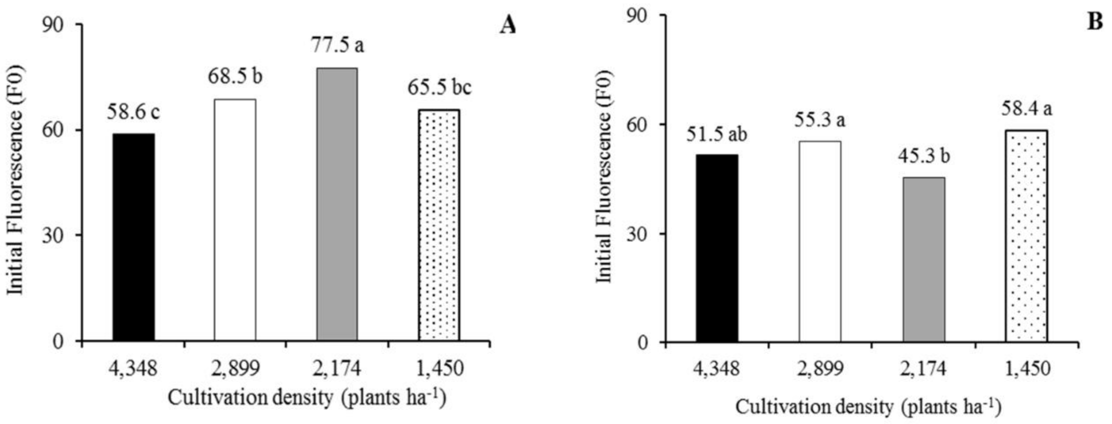

Figure 1. Initial fluorescence (F0) of gliricidia (A) and prickly pear (B) in intercropping under different densities of gliricidia.

Baker & Rosenqvst (2004) [13] point out that F0 is defined as the intensity of fluorescence when all PSII reaction centers and photosynthetic membranes are open. In other words, increase in its values indicates destruction of PSII reaction center or decrease in the energy transfer capacity, due to the detachment of the light-harvesting complex from the central complex of this photosystem [14]. Considering the evaluation time, from 9:00 to 11:00 a.m., such lower energy transfer by gliricidia plants possibly occurs due to the difference in metabolism between the two species because, for being a C_3 plant, gliricidia requires greater environmental and especially thermal comfort to perform its metabolic activities efficiently, while prickly pear, for having CAM metabolism, has greater rusticity and consequently lower sensitivity to environmental variations such as high temperature, insolation and water stress.

Figure 2 shows an inverse behavior as a function of the different spacings of intercropped gliricidia for maximum fluorescence (Fm); while the leguminous species had its maximum mean value (332 electrons quantum^{-1}) when cultivated at density of 4,348 plants ha^{-1} (Figure 2A), the prickly pear obtained its highest Fm when the gliricidia cultivation density was reduced to 2,174 and 1,450 plants ha^{-1}, reaching the mean values of 233.3 and 240.3 electrons quantum^{-1}, respectively (Figure 2B). Nunes and coauthors (2017) [11] emphasize that Fm represents the maximum intensity of fluorescence, when virtually all quinone is reduced and the reaction centers reach their maximum capacity for photochemical reactions.

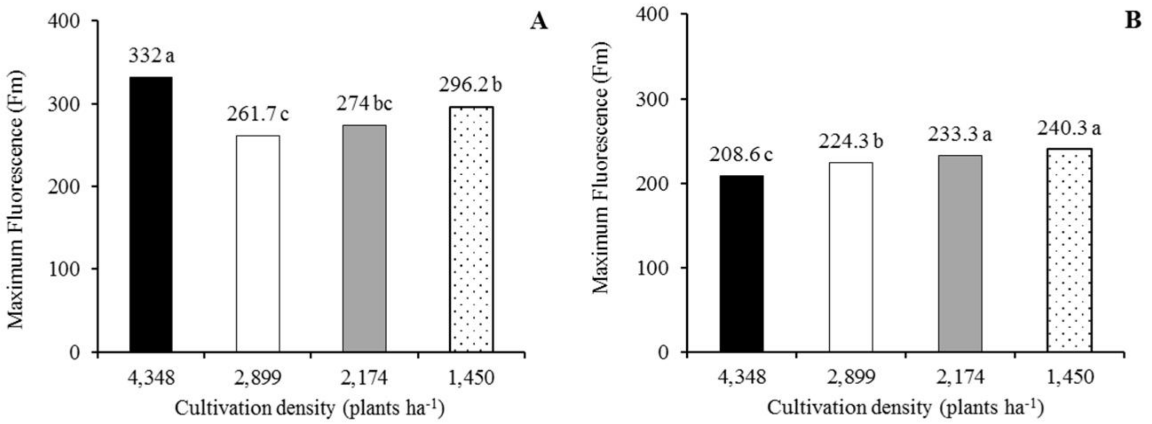

Figure 2. Maximum fluorescence (Fm) of gliricidia (A) and prickly pear (B) in intercropping under different densities of gliricidia.

This variable confirms the importance of studying the intercropping between plants, especially in the semiarid region, which has more than 2,000 hours of insolation year^{-1}. The results efficiently point to the behavioral differences between the species; gliricidia shows no damage to the capacity of photochemical reactions when grown at higher densities (4,348 plants ha^{-1}). This possibly occurs due to the good crown formation by this species, as well as by the presence of a microclimate between the aerial part of the plants and the soil, which facilitates the capture of energy and maintenance of its photochemical potential. However, the cultivation of this leguminous species at this density in intercropping with prickly pear reduced the efficiency of Fm of the cactus, which is probably due to the greater shading provided by the smallest spacings between gliricidia plants, reducing the area of photochemical capture by prickly pear.

Variable fluorescence (Fv) is the difference between Fm and F0, so the dynamics of these values represents a relevant adaptation of the photosynthesizing tissue to the dark. Thus, increases in Fv represent elevation in the plant's capacity to transfer energy of electrons ejected from the molecules of photosynthetic pigments to form the reducing agent NADPH and ATP [15]. The trend observed for F0 and Fm also occurs for Fv, as it is observed that gliricidia populations of 2,899 and 4,348 plants ha^{-1} reduce the electron transfer capacity in the photosystem II by this leguminous species and by prickly pear to 193.3 (Figure 3A) and 157.1 (Figure 3B) electrons $quantum^{-1}$, respectively, indicating lower stabilization of these crops at these densities of gliricidia cultivation.

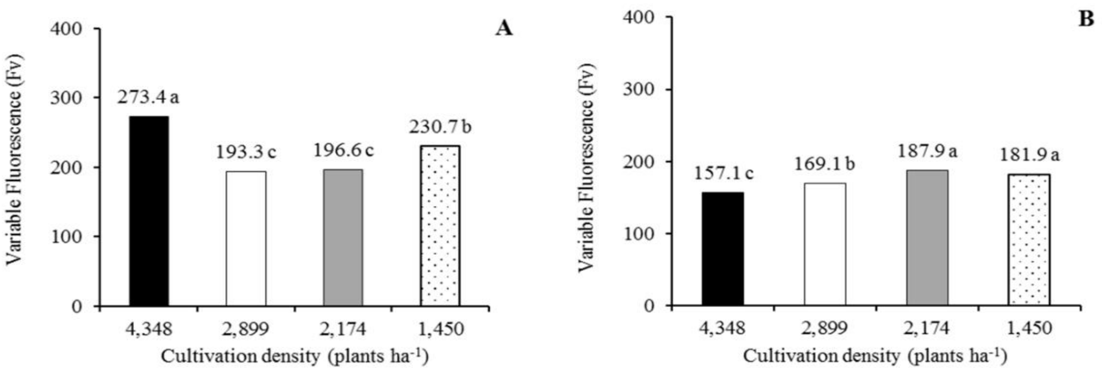

Figure 3. Variable fluorescence (Fv) of gliricidia (A) and prickly pear (B) in intercropping under different densities of gliricidia.

The cultivation densities of 4,348 and 2,174 gliricidia plants ha^{-1} promote minimum increments of 31.3 and 33.2% in the Fv/Fm ratio of this leguminous plant and of prickly pear, respectively (Figure 4A and B). This demonstrates the high requirement for sunlight of 'Orelha de Elefante Mexicana' prickly pear (*O. stricta*), characterizing itself as a heliophyte of excellent rusticity. Additionally, its intercropping with shrub leguminous species, as is the case here, should be performed in smaller populations of the latter, so that there is greater photosynthetic conversion by the cactus species, especially due to its growth habit, which is more horizontal than vertical after it reaches 0.7 to 1.0 m height, unlike those of *Opuntia ficus-indica* Mill. and even *Nopalea cochenillifera*. These values are similar to those obtained by Souza and coauthors (2019) [1], who evaluated different prickly pear genotypes in the semiarid region of Paraíba and observed that reductions in this ratio may occur in response to the conditions of lower growth and/or capacity for absorption and conversion of light energy, indicating photoinhibitory damage to plants.

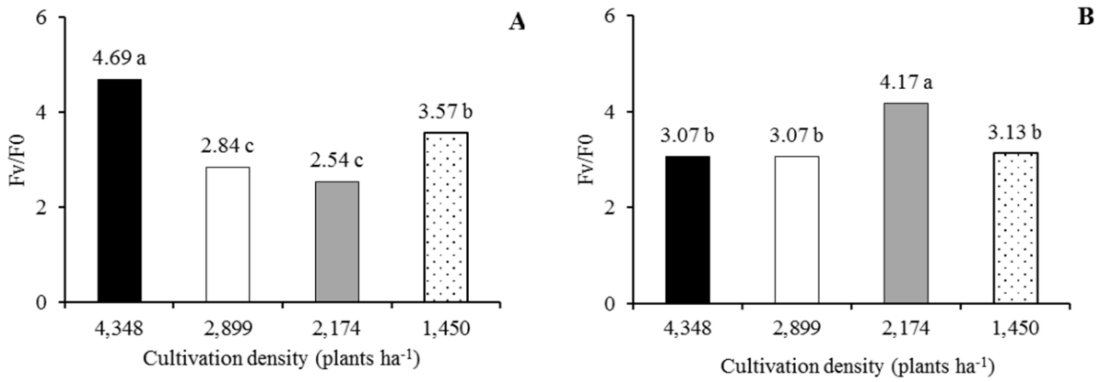

Figure 4. Fv/F0 ratio of gliricidia (A) and prickly pear (B) in intercropping under different densities of gliricidia.

Shao and coauthors (2014) [16] state that light restriction directly influences ATP production and consequently carbon fixation by the plant, i.e., with reduced levels of photon flux density the biosynthesis of carbohydrates is also hampered, which can greatly affect the nocturnal CO_2 fixation of CAM plants. Evaluating *O. ficus-indica*, Nobel and Hartsock (1983) [17] found that for CAM plants the requirement reaches 25 photons per molecule of CO_2 captured, whereas in C_3 and C_4 plants this ratio is around 11 and 22 photons/CO_2 captured, respectively, indicating that the high requirement of photons per CO_2 captured seems to be common for CAM plants, corroborating the higher energy requirement (ATP) by these plants [7].

The behavior of the potential quantum yield of both species was similar to that of Fv/F0 ratio, where the highest efficiency in capturing excitation energy by the PSII reaction centers, 0.82 and 0.81 electrons quantum^{-1} for gliricidia and prickly pear, respectively, occurred when this leguminous species was cultivated at population densities of 4,348 and 2,174 plants ha^{-1} (Figure 5A and 5B). Reis and Campostrini (2011) [15] point out that plants with Fv/Fm values between 0.75 and 0.85 electrons quantum^{-1} have an intact photosynthetic apparatus, while those with values below 0.75 electrons quantum^{-1} have their photosynthetic potential reduced. This indicates that densities of 2,899 and 2,174 gliricidia plants ha^{-1} hampered the capture of energy by this species. For prickly pear, it is noted that the plants maintained their quantum yield at adequate values, regardless of gliricidia spacing.

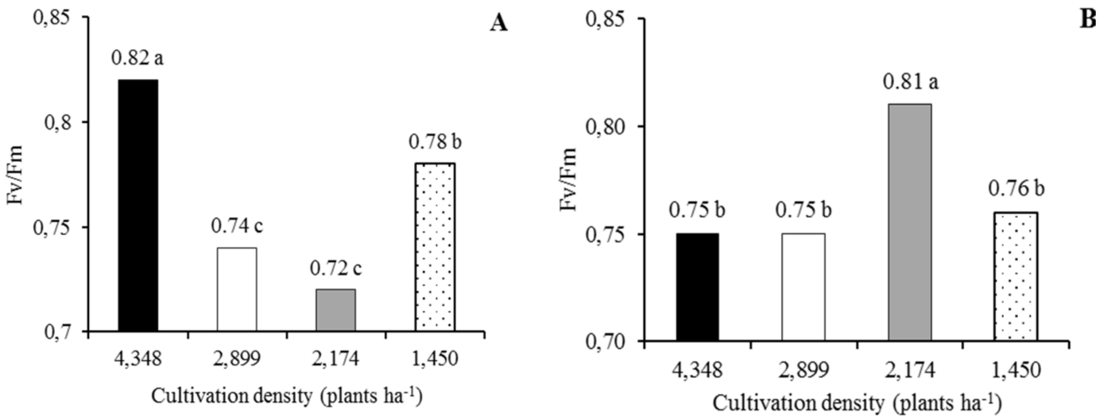

Figure 5. Potential quantum yield (Fv/Fm) of gliricidia (A) and prickly pear (B) in intercropping under different densities of gliricidia.

Dense cultivation of gliricidia, besides increasing the capture of light by plants, promoted higher fresh matter yield (FMY). By comparing the treatments with 4,348 and 2,899 plants ha^{-1}, it can be noted that a 33% increment in plant density increased FMY by 66.1% (Figure 6A). These results show that increases in the photochemical activity of chlorophyll a fluorescence can positively influence the yields of C_3 xerophytes such as gliricidia. Its capacity to adapt to smaller spacings, associated with the obtaining of higher yields, is extremely positive in areas such as the Brazilian semiarid region, where most properties are small. The FMY of prickly pear did not differ statistically as a function of the spacing in gliricidia cultivation (Figure 6B), and there was also no influence of fluorescence variation on the yield of cactus species, possibly because of its high rusticity and adaptability to the different densities of the intercropping system, especially over longer periods, such as the two years of study.

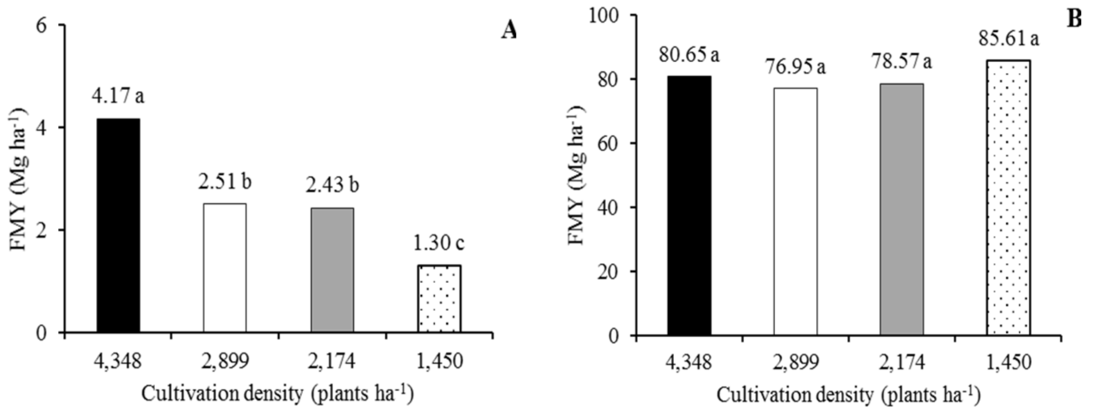

Figure 6. Fresh matter yield (FMY) of gliricidia (A) and prickly pear (B) in intercropping under different densities of gliricidia.

Although the FMY of prickly pear was not affected by gliricidia cultivation densities, it is important to be aware of the yield gains that this leguminous species can provide in intercropping, since it can supply the fiber and protein deficiency existing in prickly pear, which consists of approximately 90% of water, being also abundant in energy and mineral salts. This type of cultivation demonstrates that both prickly pear and gliricidia are characterized as biological elements compatible with the semiarid region because, besides the advantage of not relying on the use of artificial irrigation, they produce energy and protein at low cost, which is decisive for the rural producer to raise the animal support capacity of the property, producing with financial efficiency, whether the activity is milk or beef production.

CONCLUSION

Dense cultivation of gliricidia up to 4,348 plants ha^{-1} increases its photochemical efficiency and yield, but reduces the light energy capture by prickly pear in intercropping. Regardless of gliricidia density, prickly pear yield was not influenced.

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