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Row spacing for pigeon pea sowing and its influence on the recovery of degraded pasture

Abstract – The objective of this work was to evaluate the effect of row spacing for sowing of 'BRS Mandarim' pigeon pea (*Cajanus cajan*) on soil fertility and on the yield and nutritional values of brachiaria (*Urochloa decumbens*) pasture. Pigeon pea was sown in an area in the initial stage of degradation and cultivated with brachiaria. Four row-spacing treatments were evaluated for pigeon pea sowing, using the following row spacing: single rows spaced at 40, 80, and 120 cm; and a double-row with 40 cm between rows, spaced at 120 cm. In addition, a reference area treatment without pigeon pea was used. The nutritive parameters of the total available forage and of the pigeon pea plants were measured at three following development stages of pigeon pea plants: vegetative stage, at 79 days after sowing (DAS); beginning of the reproductive stage, with green pods, at 157 DAS; and final stage of grain production (dry pods), at 281 DAS. The use of the legume provided an economy of up to R$ 1,716.30 ha^{-1} in the application of nitrogen fertilizers. Pigeon pea used as green manure provides a significant increase of 53.5 to 140% in the dry matter yield of brachiaria.

Index terms: *Cajanus cajan*, *Urochloa decumbens*, green manure, legume, organic matter, sustainability.

Espaçamento entre linhas para semeadura de guandu e sua influência na recuperação de pastagens degradadas

Resumo – O objetivo deste trabalho foi avaliar o efeito do espaçamento entre linhas para plantio de guandu (*Cajanus cajan*) 'BRS Mandarim' sobre a fertilidade do solo e sobre a produtividade e o valor nutricional de pastagem de braquiária (*Urochloa decumbens*). O guandu foi semeado em área com estágio inicial de degradação e cultivada com braquiária. Quatro tratamentos foram avaliados para a semeadura de guandu, tendo-se utilizado os seguintes espaçamentos entre linhas: fileiras únicas espaçadas em 40, 80 e 120 cm; e fileira dupla com 40 cm entre as fileiras, espaçadas em 120 cm. Além disso, foi utilizada uma área de referência de tratamento sem guandu. Os parâmetros nutritivos da forragem total disponível e das plantas de guandu foram mensurados nos três seguintes estágios de desenvolvimento das plantas de guandu: estágio vegetativo, aos 79 dias após a semeadura (DAS); início do estágio reprodutivo, com vagens verdes, aos 157 DAS; e estágio final de produção de grãos (vagens secas), aos 281 DAS. O uso da leguminosa proporcionou economia de até R$ 1.716,30 ha^{-1} na aplicação de fertilizantes nitrogenados. O guandu como adubação verde proporciona um aumento significativo de 53,5 a 140% na produtividade de matéria seca da braquiária.

Termos para indexação: *Cajanus cajan*, *Urochloa decumbens*, adubação verde, leguminosa, matéria orgânica, sustentabilidade.

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Introduction

Brazilian livestock is based mainly on pasture production, in an area of over 160 million hectares (ABIEC, 2023). Pasture areas between 50 and 70% in Brazil are estimated to have some degree of degradation (Dias-Filho, 2014), which makes the recovery of these areas strategic for the country.

A sustainable strategy for the recovery of degraded pastures – with less dependence on external inputs, and with conservation of natural resources – requires the adaptation of agroecosystems with greater species diversity and production stability, to intensify nutrient recycling and minimize losses by protecting the soil from erosion, avoiding soil tillage or, at least, using minimum tillage (Souza & Resende, 2006). In this context, the introduction of legume species into the production system can bring benefits, such as a greater interaction with nitrogen-fixing bacteria (Oliveira et al., 2017).

Pigeon pea [*Cajanus cajan* (L.) Millspaugh] belongs to the legume family. It is a shrub of great agricultural importance in several countries in Asia, Africa, and Latin America, where its popularity is justified by its wide variety of uses and its robustness (Ayenan et al., 2017). Its plants are used as green manure, both in rotation (Godoy & Godoy, 2008) and in association with other crops (including grasses in pastures), as an intercrop with other perennial crops, in animal feed (in the form of protein banks, hay, silage, direct grazing, and grains) and in human food (dry or green grains, and pods) (Souza et al., 2007).

The nitrogen-fixing capacity of pigeon pea is about 280 kg N ha^{-1} per year (Purcino et al., 2005), which is equivalent to 636 kg urea ($CO(NH_2)_2$) or 1,400 kg ammonium sulfate ($(NH_4)_2SO_4$). In addition, due to its vigorous and deep root system, pigeon pea is especially suitable for regions with water deficiency, and has the capacity to penetrate compacted sub-surface soil layers, which allows of its use as a bio-decompactor (Rodrigues et al., 2004; Souza et al., 2007).

Pigeon pea can also be used as a forage crop, as it is a legume with a high protein content, and leaves and pods have good digestibility. Abebe (2022) observed that pigeon pea forage has a crude protein content ranging from 15% to 24%, and dry matter digestibility varies between 50% and 60%. When pastures are dry and of low nutritional quality (Hatfield & Fukushima, 2005), the use of pigeon pea during the dry season improves the diet digestibility, allowing of a greater consumption of total digestible nutrients by animals, and increasing cattle live weight gain, which allows of the reduction of the concentrated feed provision, and to reduce the cost of feeding, without impairing animal performance (Lourenço et al., 1994).

Studies on row spacing for pigeon pea have been reported in the literature to evaluate grain yield (Kaur & Saini, 2018; Leena et al., 2022) and forage production (Azevedo et al., 2023). The use of pigeon pea for pasture recovery has also been documented (Fernandes et al., 2006), mainly due to its status as a legume and its ability to form symbiosis with diazotrophic bacteria (Jorrin et al., 2021). However, limited information is available on the specific effect of planting row spacing on the recovery of degraded pastures.

The objective of this work was to evaluate the effect of row spacing for sowing of 'BRS Mandarim' pigeon pea on soil fertility and on the yield and nutritional values of brachiaria (*Urochloa decumbens*) pasture.

Materials and Methods

The experiment was carried out at Embrapa Pecuária Sudeste, in the municipality of São Carlos, in the state of São Paulo, Brazil (21°57'S, 47°50'W, at 860 m altitude). The climate is classified as tropical, Cwa, according to the Köppen-Geiger's classification, with two well-defined seasons: the rainy one from October to March, with average temperature and total precipitation of 23.0°C and 1100 mm, respectively; and the dry one from April to September, with average temperature and total precipitation of 19.9°C and 250 mm, respectively.

The experimental area soil is classified as a Typic Haplustox with sandy-loam texture (Soil Survey Staff, 1999), and the following soil texture: 601 g kg^{-1} sand, 57 g kg^{-1} silt, and 342 g kg^{-1} clay.

A flat and uniform area of soil physical and chemical properties, cultivated with brachiaria (*Urochloa decumbens*) since 1996, was used. This area was classified as level 1 of degradation, that is, pasture that is still productive, but already showing areas of bare soil or with weeds, according to Dias-Filho (2017). Four months after the liming process to increase base saturation to 50% (Rodrigues et al., 2004), the experiment was installed, on December 3, 2015. A direct-seeding seeder was used to sow pigeon pea seed, at 3 cm soil depth, immediately after brachiaria was mowed to a 5 cm height. The effect of row spacing on the sowing of 'BRS Mandarim' pigeon pea was evaluated, considering the following spacing: pigeon pea sown at row 40 cm; sown at 80 cm; sown at 120 cm; and a double-row of pigeon pea sown at 40 cm between rows, separated by 120 cm; and a reference area, without pigeon pea. For each spacing treatment and for the reference area, double disc openers performed a minimal soil disturbance, with a row spacing of 40 cm, and fertilization with 250 kg ha^{-1} of simple superphosphate (from 18% to 21% P_2O_5; 16% calcium; and from 10% to 12% sulfur). Therefore, the difference between the treatments was the row spacing sowed with pigeon pea. For each pigeon pea treatment, 24 rows of 60 m were seeded and 10 plants m^{-1} were cultivated. The adoption of a higher population density with the use of 10 plants m^{-1} aimed at producing plants with thinner stems, to facilitate their decomposition after cutting.

Total biomass yield is the variable composed of the combined production of pigeon pea and brachiaria plants obtained at each collection point. The populations of pigeon pea plants were estimated in 250,000 plants ha^{-1} for the row spacing of 40 cm, 125,000 plants ha^{-1} for the 80 cm, 83,333 plants ha^{-1} for 120 cm, and 125,000 plants ha^{-1} for the treatment with the pairs of double-rows spaced at 120 cm.

Forage biomass samples were collected at five distinct points of each treatment, by a cutting close to the ground, according to the following developmental stages of pigeon pea plants: vegetative stage, at 79 days after seeding (DAS); beginning of the reproductive stage, reaching the appearance of green pods, at 157 DAS; and final stage of grain production (dry pods), at 281 DAS. As samples, 2 m of total biomass yield were collected from two lines of each spacing treatment for subsequent separation between pigeon pea and brachiaria. Thus, the biomass components (grass and pigeon pea plants) and their respective nutritive value were measured.

All samples of grass and pigeon pea were oven dried at 60ºC with forced ventilation until constant weight was attained. After the dry weight obtention, the following variables were evaluated: dry matter of total biomass yield (kg ha^{-1}), dry matter of pigeon pea (kg ha^{-1}) and dry matter of *U. decumbens* (kg ha^{-1}). The dried samples were milled in a Willey-type knife mill with a 1 mm sieve, to perform the nutritive value analysis, using the reflectance spectroscopy by the near-infrared (NIR) technique. The following variables were obtained in percentage: crude protein content (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin content (LIG), in vitro digestibility (IVD), and the concentration of macrominerals (g kg^{-1}) and microminerals (mg kg^{-1}), respectively.

Average heights and thicknesses of pigeon pea stems were obtained based on five representative plants from each treatment. The stem thickness values were obtained at 30 cm from the ground. The nutritive value of the pigeon pea plants was also measured at these three developmental stages, considering the evaluation of the whole plant. The effect of row spacing on pigeon pea grain yield was also observed, for the harvest performed at 281 DAS. After the harvest, pigeon pea plants were cut close to the ground and left on the pasture for natural degradation.

The statistical analyses involving the variables height of plants, stem thickness, dry matter, grain yield, and nutritive value were performed using the SAS statistical package (SAS Institute Inc., Cary, NC, USA), based on the generalized linear models procedure (PROC GLM), using a completely randomized design with five replicates, in a factorial arrangement n=2 (three developmental stages of pigeon pea plants, and four spacing treatments and the reference area). The analyses involving the variables related to soil fertility, dry matter yield, and nutritive value of brachiaria, measured at 180 days after cutting (DAC) of pigeon pea plants, were performed based on the completely randomized statistical design with five replicates.

To calculate the nitrogen (N) content from the protein content, a conversion factor of 6.25 was employed. This factor is based on the average N content of proteins, which is approximately 16% (Krul, 2019). To calculate estimated biological nitrogen fixation (eBNF), a conservative extrapolation was performed, considering that 90% of the N content in the plants derived from biological fixation. This value is based on the work of La Favre & Focht (1983), who report that from 91% to 94% of the N content in the plants is derived from biological fixation.

After 180 days of cutting the pigeon pea plants, during the rainy season, samples of brachiaria forage were obtained to evaluate their yield and nutritive value (whole plant), according to the row spacing used.

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For this purpose, a standardization mowing of the brachiaria plants was carried out and, after a 28-day interval, forage and soil samples were collected from each treatment.

Simulations of the economic benefits of using pigeon pea were performed. The calculations were carried out for the main fertilizers used in Brazil – urea and ammonium sulfate (Mariano et al., 2019). The urea simulations were conducted based on the study by Rochette et al. (2009) who established a volatilization rate of 50%. Consequently, the amount of urea applied was doubled, to achieve the same eBNF efficiency.

The equivalence of urea in relation to eBNF was calculated based on the percentage composition of N present in urea, as well as the degree of purity of the substance. Urea has the molecular formula CH_4N_2O and a molar mass of 60.06 g mol^{-1}, containing 46.6% N, which represents 28.0134 g mol^{-1} N, according to the periodic table (N = 14.0067 g mol^{-1}, totaling 28.0134 g mol^{-1} N in the urea formula). With a purity level of 96.5%, urea contains 45% nitrogen. To the ammonium sulfate, with a 132.14 g mol^{-1} molar mass, the calculated N percentage was 21.2%. However, to account for potential impurities in the ammonium sulfate formulation, a value of 21% was applied to the calculations (Bernardi et al., 2014).

Results and Discussion

The interactions between spacing and development stage factors for the variables pigeon pea plant height and stem thickness were not significant (p=0.64 and p=0.96, respectively), resulting in comparisons between independent means between the factors. Spacing did not interfere with pigeon pea plant height and stem thickness, which varied from 134 to 144 cm, and from 0.70 to 0.77 cm, respectively. However, plant age affected the pigeon pea plant height and stem thickness (Figure 1). The maximum height was obtained at the reproductive stage. At of dry pod stage, the average height reduced due to the pod weight, as branches were bent downward.

The developmental stages of pigeon pea plants provided significant interactions with the row spacing for the variables total biomass yield and pigeon pea plants yield, and the comparisons between means were performed in a dependent way between the factors (Table 1). Populations of pigeon pea plants per hectare provided significant variations for the total biomass yield and for the proportions of pigeon pea plants in the total biomass. In all evaluated spacing treatments, the total biomass yield in the consortium increased until the reproductive stage, while the single pasture stopped accumulating forage from 79 days.

At the vegetative stage of pigeon pea, total biomass was similar between spacing treatments. However, in the two subsequent stages – flowering and pod production –, the total biomass with 40 cm between-row spacing was significantly higher than the mean of the other pigeon pea treatments at reproductive stage (33% higher) and at dry pod stage (45.7% higher).

At the reproductive stage, the differences between the effects of row spacing were significant. Considering the total biomass production, the presence of pigeon plants had a major impact, reaching yield up to 223% higher than the reference. At dry pod stage, the results of total biomass yield were very similar to those obtained at the reproductive stage. At this third stage, the yield from the 40 cm row spacing was distinct from the other treatments.

The interaction between the factors development stage of pigeon pea plants and row spacing was not significant for all nutritive variables of pigeon pea. The spacing used showed no significant effects for practically all nutritive variables. However, the development stage of pigeon pea plants had a significant effect on all variables related to their nutritional quality (Table 2).

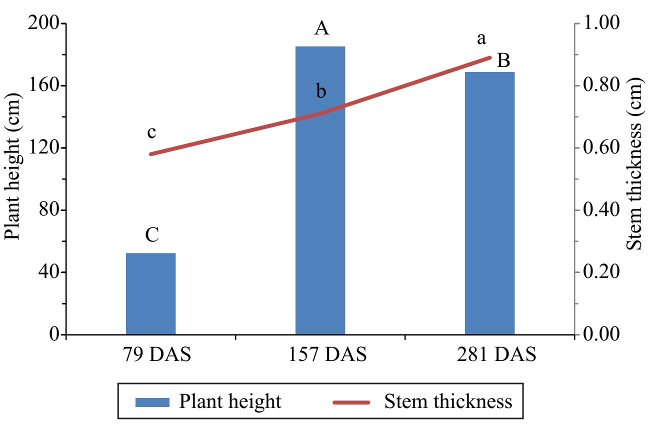

Figure 1. Plant height and stem thickness of pigeon pea (*Cajanus cajan*) according to the three developmental stages of plants. Means followed by equal letters, uppercase for plant height and lowercase for stem thickness, do not differ by Tukey's test, at 5% probability.

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Although the protein content was higher during the vegetative period, digestibility and NDF content were greater at the pod production stage. The NDF content was higher at the 0.4 m spacing than at 0.8 m. Considering that the NDF content has a direct influence on dry matter intake rate and on satiety function, through the ruminal load signal, and therefore, on the grazing time (Baumont et al., 2004), this result indicates that the 0.4 m spacing and the pod production stage are the best factors to be applied, to obtain a better use for animal feed.

Higher macro and micronutrient contents were observed for juvenile plants, except for iron (Fe), which showed higher values in the most advanced developmental stages. The concentration decrease of macro and microminerals in pigeon pea plants can be justified by the recognized translocation process during the grain filling stage in various cultivations. Working with soybean, Bender et al. (2015) reported that at the beginning of plant growth the nutrient uptake is relatively higher than the dry matter accumulation, which leads to an increase of their concentration in different parts of the plant. However, at later stages, when nutrient translocation to seed production begins, the concentration starts to decrease, which explains the higher contents of macro and micronutrient in juvenile plants.

If pigeon pea is used as forage, both its nutritional quality and its proportion of total biomass should be taken into account according to the development stage of the plants. It is worth noting that the use of pigeon pea improves the digestibility of the diet, allows of a greater consumption of total digestible nutrients by the animal, and increases the live weight gain (Rodrigues et al., 2004).

The eBNF benefits at the reproductive stage can be of advantage for animals which would feed on this associated pasture, eliminating the need for protein supplementation, with economic advantages related

Table 1. Interaction between growth stages (vegetative, 79 days after sowing (DAS); reproductive, 157 DAS; and dry pod, 281 DAS) and row spacing for the dry matter yield (DMY) of total biomass of pigeon pea (*Cajanus cajan*) plants(1).

Row spacing	DMY of total biomass (kg ha^{-1})			DMY of pigeon pea plants (kg ha^{-1})		
(cm)	Vegetative	Reproductive	Dry pod	Vegetative	Reproductive	Dry pod
Reference(2)	2,292.03±222.09aA	2,993.20±193.76cA	2,964.60±239.00cA	-	-	-
40	2,861.98±357.11aB	9,673.54±680.79aA	9,551.13±727.35aA	978.16±163.81aB	7,751.78±739.97aA	7,596.52±818.81aA
80	2,432.18±352.95aB	7,543.27±303.39bA	6,210.63±744.44bA	629.24±95.38aC	5,255.94±456.37bA	3,576.83±458.13bB
120	2,253.27±333.64aB	7,889.72±1279.75bA	6,460.14±590.78bA	369.54±49.33aC	5,298.44±1137.85bA	3,656.36±327.07bB
Double-row	2,333.16±163.49aB	6,251.30±685.66bA	6,995.76±708.45bA	436.52±26.32aB	4,578.28±403.44bA	4,397.63±557.85bA

(1)Means and standard errors followed by equal letters, lowercase in each column and uppercase in each row, by variable, do not differ by Tukey's test, at 5% probability. (2)Reference: only brachiaria.

Table 2. Nutritive parameters of pigeon pea (*Cajanus cajan*) according to the plant developmental stages (vegetative, 79 days after sowing (DAS); reproductive, 157 DAS; and dry pod, 281 DAS) of the plants and row spacing(1).

Factor	Level	Nutritive parameter(2)													
		CP	NDF	ADF	LIG	IVD	Ca	Mg	P	K	S	Cu	Fe	Mn	Zn
		------(%)------					------(g kg^{-1})------					------(mg kg^{-1})------			
Spacing	0.4 m	12.59a	63.71a	53.03a	13.27a	36.11a	5.64a	1.86a	1.17a	8.43a	0.97a	8.15a	196.92a	30.01a	16.49a
	0.8 m	12.88a	60.20b	50.64a	13.40a	36.63a	5.78a	1.80a	1.12ab	7.82a	0.98a	8.14a	194.94a	28.97a	16.05a
	1.2 m	11.85a	62.10ab	52.57a	13.22a	38.21a	6.10a	2.01a	1.03ab	6.76a	0.88a	6.94a	221.94a	26.06a	14.64a
	Double-row	11.60a	62.20ab	49.94a	11.91a	37.38a	5.67a	1.93a	0.99b	7.21a	0.87a	6.92a	185.73a	30.67a	14.65a
Stage	Vegetative	18.06A	57.31C	51.03B	14.42A	32.41C	8.20A	2.57A	1.41A	9.29A	1.22A	8.11A	112.27B	33.02A	15.94A
	Reproductive	11.14B	60.71B	49.69B	13.16A	37.18B	5.06B	1.72B	1.05B	8.09A	0.86B	8.04A	240.49A	33.93A	16.98A
	Dry pod	7.48C	68.11A	53.91A	11.27B	41.90A	4.14C	1.41C	0.78C	5.29B	0.70C	6.46B	246.89A	19.83B	13.44B

(1)Means followed by equal letters, lowercase for spacing factor and uppercase for growth stage factor, do not differ by Tukey's test, at 5% probability. (2)CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; LIG, lignin content (acid detergent lignin method); IVD, in vitro digestibility; Ca, calcium; Mg, magnesium; K, potassium; S, sulfur; Cu, copper; Fe, iron; Mn, manganese; and Zn, zinc.

to the exclusion of another input from the production system (Oliveira et al., 2017).

Therefore, the results of the present study show that the best treatment for recovering pastures is the spacing of 0.4 m between rows of pigeon pea and the cutting of the plants at the beginning of flowering and at beginning of pod production. These cutting procedures would allow of the use of the highest available biomass for degradation; besides, these are the stages with the highest amount of eBNF. Considering animal feeding, 0.4 m between rows of pigeon pea is the best spacing treatment, as it allows of the animal release to the pasture during the beginning of flowering and the beginning of pod production, and to leave the animals until the end of the pigeon pea production cycle, at the stage of dry pod production.

In general, soil fertility was enhanced by the application of pigeon pea. An increase of phosphorus (P) content was observed even at 20–40 cm soil depth (Table 3). This result can be explained by the increase of soil aggregation under pigeon pea cultivation, which substantially reduces the losses of organic P from occluded aggregate fractions and its subsequent sorption as inorganic P to silt and clay particles (Garland et al., 2018).

Interaction was not significant between the development stage of pigeon pea plants and row spacing for the nitrogen input via aerial part of pigeon pea. The results found in the present study corroborate those obtained by La Favre & Focht (1983), in which nitrogen fixation showed a peak of activity between the beginning of flowering and pod production, which would be the stage observed at reproductive stage in the present study (Table 4).

The economic gains for eBNF with the application of urea and ammonium sulfate were from 40.40 kg ha^{-1} urea at the vegetative stage, in 120 cm spacing, to 553.6 kg ha^{-1} urea in 40 cm spacing at the reproductive stage (Table 5). The national market value of urea in February 2023 was R$ 3,100.00 Mg^{-1}, according to the website of the Companhia Nacional de Abastecimento (Conab, 2023). Regarding fertilizers that could be applied to the soil, in the present experiment, the eBNF provided R$ 1,716.30 ha^{-1} saving for urea application, and R$ 1,551.19 ha^{-1} for ammonium sulfate application at the reproductive stage, at 40 cm spacing.

After the pigeon pea degradation process, no interference of row spacing was observed on the height of brachiaria plants, which ranged from 36.4 cm to 50.2 cm. The effect of pigeon pea as green manure on the yield of brachiaria is unquestionable. The highest production of brachiaria occurred for the 40 cm spacing (4,436 kg ha^{-1}), the lowest one took place on the single pasture area (1,850 kg ha^{-1}), and the remaining spacing showed intermediate results (Figure 2). It is worth reporting the significant effect of the P level on the nutritive variables of brachiaria grass (Table 6). This result can be explained by the increase of soil fertility

Table 3. Soil fertility in the 0–20 and 20–40 cm depth layers after 180 days of cutting the pigeon pea (*Cajanus cajan*) plants for each planting row spacing treatment[(1)].

Row spacing (cm)	pH (water)	pH ($CaCl_2$)	SOM ---(g dm^{-3})---	TC	Pres (mg dm^{-3})	Kres ---(mmol$_c$ dm^{-3})---	Ca	Mg	Al	H+Al	SB	CEC	BS ---(%)---	m	$S\text{-}SO_4$ ---(mg dm^{-3})---	B	Cu	Fe	Mn	Zn
0–20 cm depth layer																				
Reference[(2)]	5.52a	4.82a	27.2bc	15.8bc	2.2b	1.36a	18.0a	8.8b	1.4a	33.2a	28.2a	61.2a	46.0b	4.6a	21.0a	0.352ab	0.84a	87.4a	3.78ab	0.66ab
40	5.92a	5.22a	19.6c	11.6c	4.6a	1.42a	24.2a	11.8a	0.0b	26.4b	37.4a	63.8a	58.6a	0.0b	25.0a	0.408ab	0.98a	68.2b	2.48b	0.44b
80	5.74a	5.00a	28.0bc	16.4abc	3.8ab	1.38a	20.6a	10.2ab	0.8ab	29.2ab	32.0a	61.2a	52.8ab	2.4ab	7.2a	0.406ab	0.92a	81.0ab	3.06ab	0.46b
120	5.80a	5.04a	37.6a	21.8a	3.6ab	1.28a	21.6a	9.6ab	1.0ab	29.8ab	32.4a	62.2a	51.4ab	3.4ab	17.4a	0.430a	0.82a	84.4ab	3.10ab	0.58ab
Double-row	5.68a	4.94a	34.2ab	20.0ab	2.8ab	1.32a	18.4a	9.2ab	0.8ab	30.4ab	28.8a	59.2a	48.8b	2.8ab	15.2a	0.332b	0.88a	79.6ab	4.74a	1.20a
20–40 cm depth layer																				
Reference	5.40a	4.70a	17.6c	10.2c	2.0b	1.00a	15.6a	6.8a	3.0a	32.2a	23.2a	55.6a	42.0a	11.6a	27.2a	0.328ab	0.84ab	85.0a	6.08a	0.32ab
40	5.68a	5.02a	14.4c	8.6c	3.2a	1.06a	19.0a	9.0a	0.6b	26.0a	29.0a	55.0a	53.0a	2.2b	17.0a	0.352a	0.92a	68.0a	3.24a	0.24ab
80	5.64a	4.90a	17.6c	10.2c	3.2a	0.76a	17.0a	8.4a	1.0ab	29.8a	26.2a	56.2a	46.6a	3.8ab	16.6a	0.332ab	0.88ab	84.0a	4.18a	0.22b
120	5.62a	4.86a	31.4a	18.2a	2.8ab	0.58a	18.8a	8.4a	1.8ab	30.2a	27.8a	58.2a	46.8a	7.0ab	15.8a	0.348ab	0.78b	81.0a	3.76a	0.22b
Double-row	5.52a	4.78a	23.2b	13.4b	2.0b	0.72a	15.6a	7.6a	1.2ab	29.8a	24.0a	53.8a	44.8a	4.8ab	20.0a	0.292b	0.78b	66.0a	4.42a	0.44a

[(1)]Means followed by equal letters for each depth, do not differ by Tukey's test, at 5% probability. [(2)]Reference: only brachiaria. SOM, soil organic matter; TC, total carbon; Pres, phosphorus by the resin method; Kres, potassium by the resin method; Ca, calcium; Mg, magnesium; Al, exchangeable acidity; H+Al, potential or total acidity; SB, sum of exchangeable bases; CEC, potential cation exchange capacity; BS, percentage of base saturation; m, percentage of aluminum saturation; $S\text{-}SO_4$, sulfur in the form of the sulfate ion; B, boron; Cu, copper; Fe, iron; Mn, manganese; Zn, zinc.

provided by pigeon pea as explained by Garland et al. (2018).

The row spacing produced similar grain yields for the treatments with spacing between rows at 40 cm (856.95 kg ha^{-1}), 80 cm (917.03 kg ha^{-1}), and 120 cm (999.50 kg ha^{-1}). However, the double-row planting produced 1,251.75 kg ha^{-1} grainn yield, which is significant by Tukey's test, at 5% probability, and which is about 46.0% higher than the value showed by the densest spacing of 40 cm between rows.

As pigeon pea 'BRS Mandarim' has an indeterminate growth habit, the production of new flowers, pods, and seed maturation occur simultaneously (Saxena et al., 2017). Thus, the ideal time for grain harvest is when from 80% to 90% of the pods are straw-colored, which indicates the completion of the seed maturation process (Souza et al., 2007). However, in our experiment, the grain harvest began late, and seed dehiscence was already observed, mainly in older pods during the hottest hours of the day. Therefore, the data of grain yield values were underestimated.

During the hand harvesting of mature pods, all treatments with pigeon pea had a plant population greater than the minimum of 40,000 plants ha^{-1} recommended by Souza et al. (2007). However, if the

Table 4. Estimated biological nitrogen fixation (eBNF) input via aerial part to the production system, according to the development stage of pigeon pea (*Cajanus cajan*) plants and the row spacing used, in plants mowed at the indicated stages[(1)].

Stage	Row spacing (cm)	Dry matter (kg ha^{-1})	Crude protein (CP, %)	eBNF[(2)] (kg ha^{-1})
	40	978.16	18.57	26.16cd
Vegetative	80	629.24	19.10	17.31cd
79 days after sowing (DAS)	120	369.54	17.08	9.09d
	Double-row	436.52	17.52	11.01d
	40	7,751.78	11.16	124.57a
Reproductive	80	5,255.94	11.89	89.99b
157 DAS	120	5,298.44	10.87	82.94b
	Double-row	4,578.28	10.63	70.08b
	40	7,596.52	8.03	87.84b
Dry pod	80	3,576.83	7.65	39.40c
281 DAS	120	3,656.36	7.60	40.02c
	Double-row	4,397.63	6.65	42.11c

[(1)]Means followed by equal letters, do not differ by the Tukey's test, at 5% probability. [(2)]eBNF, considering that 90% of N content in the plants was derived from BNF, according to La Favre & Focht, 1983.

Table 5. Estimation of economic saving with nitrogen fertilizers per hectare, for each maturation stage and row spacing of pigeon pea (*Cajanus cajan*), by biological nitrogen fixation in the experiment.

Stage	Row spacing (cm)	Urea (kg ha^{-1})	Economic saving with urea (R$ ha^{-1})	$(NH_4)_2 SO_4$ (kg ha^{-1})	Economic saving with $(NH_4)_2 SO_4$ (R$ ha^{-1})
	40	116.27	360.43	124.57	325.75
Vegetative	80	76.93	238.49	82.43	215.55
79 days after sowing (DAS)	120	40.40	125.24	43.29	113.19
	Double-row	48.93	151.69	52.43	137.10
	40	553.64	1716.30	593.19	1,551.19
Reproductive	80	399.96	1239.86	428.52	1,120.59
157 DAS	120	368.62	1142.73	394.95	1,032.80
	Double-row	311.47	965.55	333.71	872.66
	40	390.40	1210.24	418.29	1,093.82
Dry pod	80	175.11	542.84	187.62	490.62
281 DAS	120	177.87	551.39	190.57	498.34
	Double-row	187.16	580.18	200.52	524.37

$(NH_4)_2 SO_4$: ammonium sulfate.

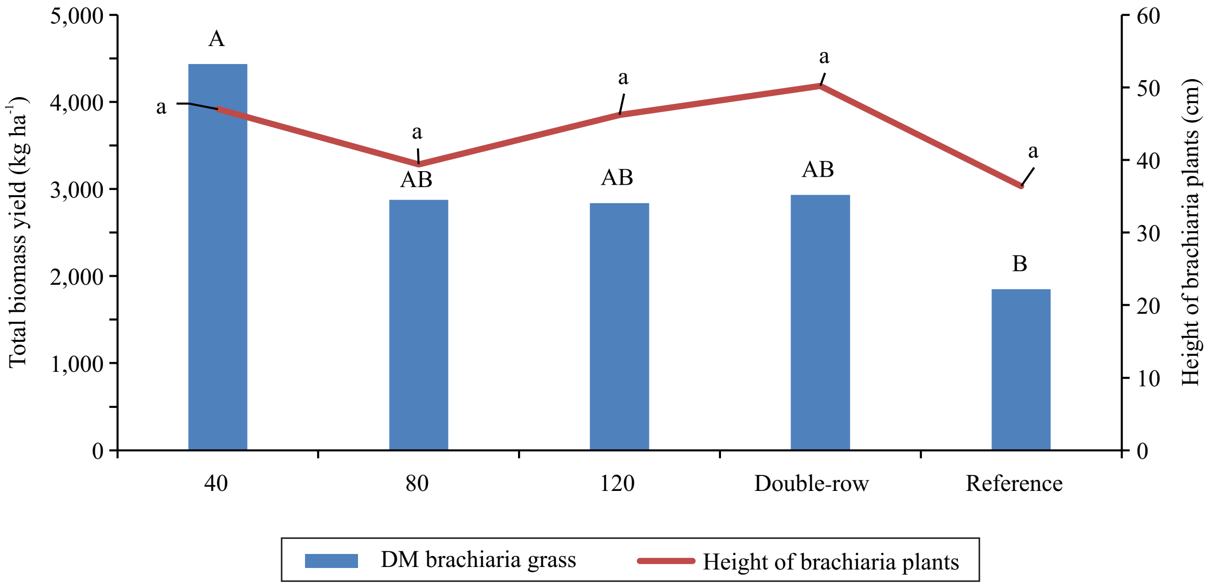

Figure 2. Total biomass yield (DM, dry matter) and plant height of brachiaria (*Urochloa decumbens*) grass at 180 days after the cutting of pigeon pea (*Cajanus cajan*). Means followed by equal letters, uppercase for plant height and lowercase for brachiaria DM yield, do not differ by Tukey's test, at 5% probability.

Table 6. Nutritive parameters for brachiaria (*Urochloa decumbens*) grass collected after 180 days of cutting of pigeon pea (*Cajanus cajan*) plants(1).

Row spacing	CP	NDF	ADF	LIG	IVD	Ca	Mg	P	K	S	Cu	Fe	Mn	Zn
(cm)	(%)					(g kg^{-1})					(mg kg^{-1})			
Reference(2)	6.8a	75.8a	46.7a	5.1a	47.0a	8.5b	7.3a	1.0b	19.8c	10.6a	2.9a	117.5a	325.8a	26.6a
40 cm	8.3a	75.4a	47.9a	5.3a	47.3a	9.2ab	8.0a	1.5a	30.8a	11.1a	1.8bc	79.0a	152.5a	32.0a
80 cm	7.3a	74.1a	45.6a	5.0a	48.3a	10.9ab	8.2a	1.5a	29.9ab	12.0a	1.7c	111.5a	173.5a	26.3a
120 cm	6.9a	73.2a	47.4a	4.9a	47.6a	11.4a	8.8a	1.0b	25.2abc	10.7a	2.6ab	125.5a	186.4a	27.84a
Double-row	7.2a	74.0a	45.8a	4.4a	47.7a	8.7b	7.7a	1.2b	21.6bc	10.6a	2.9a	126.2a	212.8a	27.3a

(1)Means followed by equal letters, do not differ by Tukey's test, at 5% probability. (2)Reference: only brachiaria. Parameters: CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; LIG, lignin (acid detergent lignin method); IVD, in vitro digestibility; Ca, calcium; Mg, magnesium; K, potassium; S, sulfur; Cu, copper; Fe, iron; Mn, manganese; and Zn, zinc.

goal were grain production, a lower population density would be better (Souza et al., 2007).

Conclusions

1. Soil fertility can be enhanced by the inclusion of pigeon pea (*Cajanus cajan*) in area cultivated with brachiaria (*Urochloa decumbens*).
2. Pigeon pea as green manure provides relevant gains in the dry matter productivity of brachiaria.
3. The best treatment for recovering pastures is the 0.4 m spacing between rows of pigeon pea, together with the cutting of the plants at the beginning of flowering and the beginning of pod production.

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