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Research Article

Effect of spacing and cutting on pigeon pea development under subtropical conditions[1]

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ABSTRACT

Depending on the purpose of its cultivation, pigeon pea can be grown under different spacings and cuts, since it quickly resprouts. This study aimed to assess the pigeon pea growth, forage production and quality, considering two spacings and one cut. A field experiment using a completely randomized design, with three treatments [1.0 × 0.2 m spacing (between rows and plants, respectively), without cuts; 0.5 × 0.1 m, without cuts; and 0.5 × 0.1 m, with cut at 90 days after emergence (DAE)], was carried out. The spacings did not affect the plant height. The 0.5 × 0.1 m spacing showed an individual plant growth worse, but a forage yield (kg ha^{-1}) higher than the 1.0 × 0.2 m treatment, from 120 to 180 DAE. The 0.5 × 0.1 m spacing was more advantageous than the 1.0 × 0.2 m, with the highest forage yield obtained by harvesting at 150 DAE. It is better to harvest the forage at 90 DAE and harvest it again at 180 DAE than maintaining a continuous plant growth and harvest it at 180 DAE. In each sampling date, there was no difference for stem and leaf crude protein and starch content as a function of the treatments. The forage harvested from 90 to 180 DAE showed similar crude protein and starch contents. So, for this period, the forage quality is not a limiting factor for establishing the harvest time.

KEYWORDS: *Cajanus cajan*, plant density, forage production.

RESUMO

Efeito do espaçamento e corte no desenvolvimento de guandu sob condições subtropicais

Dependendo da finalidade, o guandu pode ser cultivado sob diferentes espaçamentos e cortes, pois rebrota rapidamente. Objetivou-se avaliar o crescimento, produção e qualidade de forragem de guandu, considerando-se dois espaçamentos e um corte. Um experimento de campo foi conduzido em delineamento inteiramente casualizado, com três tratamentos [espaçamento de 1,0 × 0,2 m (entre linhas e plantas, respectivamente), sem corte; 0,5 × 0,1 m, sem corte; e 0,5 × 0,1 m, com plantas cortadas aos 90 dias após a emergência (DAE)] e sete repetições. Os espaçamentos não influenciaram na altura das plantas. O espaçamento de 0,5 × 0,1 m apresentou pior crescimento individual das plantas, mas maior produtividade de forragem (kg ha^{-1}) do que o espaçamento de 1,0 × 0,2 m, dos 120 aos 180 DAE. O espaçamento de 0,5 x 0,1 m foi mais vantajoso que o de 1,0 x 0,2 m, sendo a maior produtividade de forragem obtida na colheita aos 150 DAE. É melhor colher a forragem aos 90 DAE e colher novamente aos 180 DAE do que manter o crescimento contínuo das plantas e colher somente aos 180 DAE. Em cada época de amostragem, não houve diferença nos teores de proteína bruta e amido do caule e folha em função dos tratamentos. A forragem colhida dos 90 aos 180 DAE apresentou teores de proteína bruta e amido semelhantes. Assim, nesse período, a qualidade da forragem não é um fator limitante para definir o momento da colheita.

PALAVRAS-CHAVE: *Cajanus cajan*, densidade de plantas, produção de forragem.

INTRODUCTION

Pigeon pea (*Cajanus cajan*) attracts substantial interest worldwide as a source of protein for human and animal feed and due to its high production capacity, when compared to other legumes, in environments subjected to high temperatures, water deficit and poor soil fertility (Obala et al. 2020, Zhao et al. 2020). In Brazil, pigeon pea stands out among forage legumes for its remarkable drought tolerance and good adaptation to poorly fertile soils, showing a considerable potential for forage production, even during drought conditions (Marangoni et al. 2017).

The pigeon pea forage production may vary depending on the plant physiological development, spacing and cultivation site, reaching 14 t ha^{-1} $year^{-1}$ when harvested at pod maturation (Skerman 1977). Amabile et al. (2000) reported a shoot dry weight

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production of 12.7 and 11.1 t ha^{-1} for planting in November and January, respectively, while Nascimento & Silva (2004) obtained 9.39 t ha^{-1} in crops planted in April using a spacing of 0.5 x 0.25 m, in Alagoinha, Paraíba state, Brazil. Additionally, Fernandes et al. (1999) observed an increase of approximately 3 t ha^{-1} in plant biomass production, when the population density increased from 100,000 to 200,000 plants ha^{-1}, in Lagarto, Sergipe state. This increase was not observed by Amabile et al. (2000), when comparing densities of 600,000 and 750,000 plants ha^{-1}, in Senador Canedo, Goiás state. In turn, Giomo et al. (2001) found no significant difference in the number of pods produced per plant under inter- and intra-row spacings of 75 and 100 cm, and 7 and 10 cm, respectively.

Plant height may also vary as a function of genotype, planting date and cultivation site. For example, plant height for the IAC-Fava Larga genotype can reach up to 270.0 cm (Miranda et al. 1989). This is better than the results described by Giomo et al. (2001), who reported 91 to 94 cm, with planting in March, and Marchi et al. (1984), 163 to 180 cm for planting in January.

According to Menegario (1966), pigeon pea is the most recommended legume for cutting, providing 3 to 4 cuts per year, with easy regrowth. Watkins & Severen (1951) submitted several grass and legume species to different cutting frequencies and heights and found that pigeon pea tolerates cutting at a height of 60 cm and three months between cuts.

On average, the pigeon pea dry weight contains 19.29 % of crude protein (Valadares Filho et al. 2010, Vieira 2011), but this concentration may vary depending on plant age and management, soil and other environmental conditions.

Pigeon pea has a strong woody stem that can store starch during the vegetative phase. When the reproductive phase begins, this reserve mobilizes to fill the pods (Godoy & Santos 2011). However, it is unclear if plant spacing and cutting affect protein content and accumulation in the stem and leaf tissue, mainly under subtropical conditions.

Given that plants respond differently depending on soil and climate conditions and the management practices used, and that information on pigeon pea cultivation under subtropical conditions is scarce, this study aimed to assess the effect of spacing regimes and cutting on the individual plant performance, forage yield and quality.

MATERIAL AND METHODS

The experiment was conducted under field conditions at the Universidade Estadual Paulista, in Jaboticabal, São Paulo state, Brazil (21º17'S, 48º18'W and altitude of 590 m), from November 2019 to June 2020.

According to the Köppen classification, the climate in the study area is Cwa, subtropical, with relatively dry winters and wet summers, and average annual temperature and rainfall of 22 ºC and 1,552 mm, respectively. The rainfall and maximum and minimum temperatures recorded daily during the experiment are presented in Figure 1.

The soil of the experimental area is classified as Typical Dystrophic Latosol, moderate A, clayey texture (Santos et al. 2018), corresponding to Oxisol (USDA 2014). The soil was previously plowed and harrowed, and showed the following characteristics: pH ($CaCl_2$) = 5.3; OM = 29 g dm^{-3}; P (resin) = 53 mg dm^{-3}; K = 4.2 mmol$_c$ dm^{-3}; Ca = 45 mmol$_c$ dm^{-3}; Mg = 18 mmol$_c$ dm^{-3}; H + Al = 38 mmol$_c$ dm^{-3}; SB = 67.2 mmol$_c$ dm^{-3}; V% = 69 (Raij et al. 2001). Given its good fertility, no liming or fertilization was needed.

Pigeon pea seeds (IAC-Fava larga) were planted in early December. A completely randomized design was used, with three treatments and seven replications, totaling 21 experimental units in the field. The first treatment used a spacing of 1.0 m (between rows) and 0.2 m (between plants) (MT1 = main treatment 1); the second treatment (MT2) inter- and intra-row spacing of 0.5 and 0.1 m; and the third treatment (MT2 + cut) applied the same spacing as MT2, with plants cut at a height of 60 cm, at 90 DAE. The plant densities were 50,000 and 200,000 plants ha^{-1}, respectively for MT1 and MT2.

Each experimental unit (plot) measured 10 m long by 6 m wide, with a total area of 60 m^2. Considering a 0.5 m border around each plot, the study area per plot was 45 m^2.

Manual weeding was carried out periodically, in order to keep the crop free of invasive plants.

The experiment was conducted over a period of 180 DAE, and seven plant samplings were performed, considered secondary treatments (for statistical purposes). The first and second samplings occurred at 15 and 30 DAE, respectively, and the remainder monthly. Three plants were collected per plot in each sampling. The samples were washed

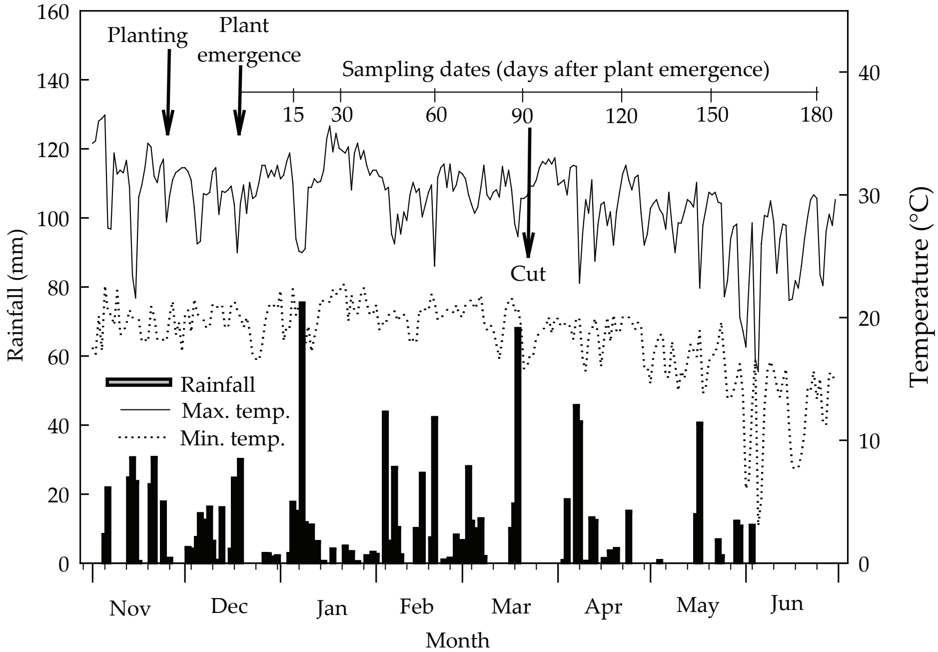

Figure 1. Climate conditions during the experimental period (November 2019 to June 2020), and when planting, plant emergence, cutting and assessments occurred (Jaboticabal, São Paulo state, Brazil).

with tap water in the laboratory and separated into leaves and stems.

The assessed variables were plant height, number of leaves per plant, leaf area per plant, stem, leaf and shoot (stem + leaves) dry weight per plant, and equivalent forage production (kg ha^{-1}). The forage production was calculated by multiplying the corresponding dry weight per plant by 50,000 or 200,000 plants ha^{-1} for MT1 and MT2, respectively.

The plant height was measured from the ground to the main apical bud and the leaf area according to Keatinge & Eughes (1980). To determine the dry weight production, the plant material was dried in a forced air oven at 65-70 ºC, until constant weight, and the dry weight determined using a scale accurate to 1 g. In dried samples, crude protein and starch contents were determined by using the AOAC (1990) procedures.

The results were analyzed in a 3 x 7 factorial scheme, with the factors consisting of the three main treatments (MT1, MT2 and MT2 + cut) and the 7 sampling times considered secondary treatments (split plot). The data were submitted to analysis of variance by the F test, and the means compared by the Tukey test at 5 % of probability. Coefficients of variation for the main and secondary treatments were also determined. Statistical analyses were performed using the AgroEstat software (Barbosa & Maldonado Júnior 2015).

RESULTS AND DISCUSSION

The effects of the treatments on plant height, number of leaves per plant and leaf area are shown in Table 1. The MT1 and MT2 treatments, which did not involve cutting, did not differ in height, except at 60 DAE, when plants with the largest spacing obtained the lowest values. These results corroborate those by Giomo et al. (2001), who studied two inter (75 and 100 cm) and intra-row spacings (7 and 10 cm) and found no significant difference in plant height. In the present study, the tallest plants were observed from 120 to 180 DAE, with values varying from 254.3 to 257.5 cm in MT1 and 259.0 to 260.7 cm in MT2. These values are similar to the 270.0 cm reported by Miranda et al. (1989) for the IAC-Fava Larga cultivar and the 163 to 180 cm reported by Marchi et al. (1984) for planting carried out in January, but are higher than the 91 to 94 cm described by Giomo et al. (2001) for planting in March. From 150 DAE, in the aforementioned treatments, the height remained constant at flowering, when the apical bud becomes a floral bud and growth stops. The plant height was similar among the treatments until 90 DAE, when

Table 1. Height, number of leaves and leaf area of pigeon pea plants in different treatments and evaluated from 15 to 180 days after plant emergence (DAE).

Treatment*	Sampling (DAE)						
	15	30	60	90	120	150	180
				Height (cm)			
MT1	14.7 Ae**	42.7Ad	121.0 Bc	190.7 Ab	254.3 Aa	257.3 Aa	257.5 Aa
MT2	14.7 Af	42.0 Ae	128.7 Ad	194.7 Ac	251.7 Ab	259.0 Aa	260.7 Aa
MT2 + cut	15.0 Ag	41.7 Af	129.7 Ab	193.7 Aa	77.0 Be	86.3 Bd	99.7 Bc
CV treatments = 4.30 %				CV samplings = 1.77 %			
				Number of leaves per plant			
MT1	6.0 Ae	16.3 Ae	96.3 Ad	188.0 Ac	287.3 Ab	351.7 Aa	79.0 Bd
MT2	5.7 Ad	14.0 Ad	59.3 Bc	89.7 Bb	143.0 Ba	152.3 Ba	85.7 Bbc
MT2 + cut	5.3 Ac	14.3 Ac	60.7 Bb	78.7 Bb	68.3 Cb	75.7 Cb	113.3 Aa
CV treatments = 19.77 %				CV samplings = 11.56 %			
				Leaf area per plant (cm^2)			
MT1	52.3 Ae	239.7 Ae	588.7 Ad	5172.0 Aa	12,796.3 Ab	9,884.0 Ac	1,842.7 Ad
MT2	51.3 Ad	215.3 Ad	1921.0 Ac	6573.0 Ba	5,211.7 Ba	3,611.7 Bb	992.7 Acd
MT2 + cut	52.7 Ad	204.3 Ad	1863.0 Ab	6876.7 Ba	418.3 Ccd	1,020.0 Cbcd	1,789.7 Abc
CV treatments = 18.32 %				CV samplings = 15.93 %			

* MT1: main treatment 1 (1.0 x 0.2 m); MT2: main treatment 2 (0.2 x 0.1 m); MT2 + cut: main treatment 2 with plants cut at a height of 60 cm, at 90 DAE. ** Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ according to the Tukey test at 5 % of probability.

the first cut occurred in MT2 + cut, period in which the maximum height was observed, with a value of 194.7 cm.

The number of leaves per plant in the MT1 and MT2 treatments increased from 15 to 150 DAE, varying from 6.0 to 351.7 (MT1) and from 5.7 to 152.3 (MT2) (Table 1). From 150 to 180 DAE, these values decreased in both the treatments due to natural drying and leaf drop. From 60 to 150 DAE, MT1 exhibited a higher number of leaves than the other treatments due to the larger spacing, which allowed a greater light incidence on the leaves, thus increasing the photosynthetic capacity and resulting in a better plant development in MT1, when compared to MT2 and MT2 + cut. The MT2 + cut treatment showed the same trend as MT2 until 90 DAE, and the lowest value observed at 120 DAE is due to the decrease in leaves caused by the cutting carried out immediately after the 90 DAE assessment. However, from 120 to 180 DAE, the number of leaves tended to increase in MT2 + cut plants, mainly from 150 to 180 DAE, due to sprout growth, reaching an average of 113.3 leaves per plant at 180 DAE, corresponding to 32.2 and 43.4 % more leaves than for MT2 and MT1 plants, respectively.

The maximum leaf area was reached at 90 DAE (Table 1). At this time, the plants had not yet reached the maximum number of leaves, because, as the number of leaves increases, their size tends to decrease. At 90 DAE, the densest plants (MT2 and MT2 + cut) showed a larger leaf area, which decreased from 120 DAE onwards, in relation to MT1 plants, due to leaf drop caused by self-shading as a result of the higher plant density.

The plants with the densest spacing (MT2 and MT2 + cut) had fewer leaves and a smaller leaf area due to mutual shading, which causes leaves in the lower plant sections to abort, dry or drop. Self-shading also prevented leaf and branch development in the lower stem. The higher value recorded for MT1 is due to the greater spacing used, which enabled less competition among plants and, consequently, improved their development.

The results obtained for stem and leaf dry weight showed that a denser spacing (MT2 and MT2 + cut) limited the dry weight accumulation in the stems and leaves from 90 DAE onwards, when compared to MT1 (Table 2).

The stem dry weight tended to increase in all the treatments until 150 DAE, followed by a decline from 150 to 180 DAE. However, MT1 plants always obtained a higher stem dry weight than those in the other treatments. In general, MT2 and MT2 + cut plants did not differ at each sampling date (Table 2).

In uncut plants, the leaf dry weight increased up to 90 DAE, when they reached maximum values of 65.63 and 27.88 g $plant^{-1}$, respectively for MT1 and MT2 (Table 2). These values decreased from

Table 2. Stem, leaf and shoot dry weight during the crop cycle of pigeon pea plants under different treatments assessed from 15 to 180 days after emergence (DAE).

Treatment*	Sampling (DAE)						
	15	30	60	90	120	150	180
			Stems (g plant^{-1})				
MT1	0.12 Ad**	0.81 Ad	13.63 Ad	86.02 Ac	125.90 Ab	181.75 Aa	168.86 Aa
MT2	0.12 Ac	0.77 Ac	12.17 Ac	41.01 Bb	53.82 Bab	75.25 Ba	69.27 Ba
MT2 + cut	0.12 Ab	0.71 Ab	10.20 Abc	40.12 Ba	14.67 Cbc	17.03 Cabc	23.55 Cab
MT2 + cut/ac	0.12 Ac	0.71 Ac	10.20 Ac	40.12 Bb	54.79 Bab	57.15 Bab	63.67 Ba
CV treatments = 21.94 %				CV samplings = 20.42 %			
			Leaves (g plant^{-1})				
MT1	0.32 Ad	1.45 Ad	15.31 Ac	65.63 Aa	62.95 Aab	56.68 Ab	10.57 Bc
MT2	0.28 Ac	1.30 Ac	11.36 Ab	27.88 Ba	25.26 Ba	20.42 Ca	5.61 Cbc
MT2 + cut	0.32 Ad	1.23 Acd	11.02 Ab	29.17 Ba	2.03 Ccd	4.93 Cbcd	8.64 Cbc
MT2 + cut/ac	0.32 Ad	1.23 Ad	11.02 Ac	29.17 Bb	31.20 Bab	34.09 Bab	37.81 Aa
CV treatments = 19.75 %				CV samplings = 17.04 %			
			Shoots: stems + leaves (g plant^{-1})				
MT1	0.44 Ad	2.26 Ad	28.94 Ad	151.65 Ac	188.86 Ab	238.43 Aa	179.43 Abc
MT2	0.40 Ab	2.07 Ab	23.53 Ab	68.89 Ba	79.08 Ba	95.68 Ba	74.88 Ca
MT2 + cut	0.44 Ac	1.95 Ac	21.22 Abc	69.29 Ba	16.70 Cbc	21.96 Cbc	32.20 Db
MT2 + cut/ac	0.44 Ac	1.95 Ac	21.22 Ac	69.29 Bb	85.99 Bab	91.25 Bab	101.48 Ba
CV treatments = 20.12 %				CV samplings = 18.57 %			

* MT1: main treatment 1 (1.0 × 0.2 m); MT2: main treatment 2 (0.2 × 0.1 m); MT2 + cut: main treatment 2 with plants cut at a height of 60 cm, at 90 DAE; MT2 + cut/ac: cumulative value in the main treatment 2 with plants cut at 60 cm, at 90 DAE. ** Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ according to the Tukey test at 5 % of probability.

120 to 180 DAE, likely due to the end of the growth phase and beginning of the reproductive phase. In the MT2 + cut treatment, there was a drastic reduction in leaf dry weight immediately after the first cutting at 90 DAE. After cutting, the dry weight production per plant increased over time as a function of sprouting and regrowth. Considering the harvested material plus regrowth (MT2 + cut/ac), cut plants produced a higher leaf dry weight at 180 DAE, in relation to the other treatments.

Data on the dry weight production (kg ha^{-1}) of stems, leaves and shoots (stems + leaves) are shown in Table 3. The shoot dry weight production increased in MT1 and MT2 up to 150 DAE, reaching 11,921 and 19,135 kg ha^{-1}, respectively, and declined from 150 to 180 DAE due to leaf drying and dropping (Tables 2 and 3). Fernandes et al. (1999) also reported a greater dry weight production by increasing density from 100,000 to 200,000 plants ha^{-1}, what is consistent with the results obtained in the present study.

The highest stem dry weight (150 DAE), leaf dry weight in MT1 and MT2 (90 DAE) and shoot dry weight values recorded (150 DAE) for pigeon pea (Table 3) were similar to those observed for *Crotalaria juncea* (135 to 150 DAE), but occurred later than those of *Crotalaria spectablis* (Barbosa et al. 2020). Furthermore, at 150 DAE, pigeon pea in the MT1 treatment produced 2,279 kg ha^{-1} less and 4,781 kg ha^{-1} more than *Crotalaria juncea*, and 4,935 kg ha^{-1} and 11,995 kg ha^{-1} more than *Crotalaria spectablis*, which were grown at densities of 500,000 and 650,000 plants ha^{-1}, respectively (Barbosa et al. 2020).

In the present study, in fertile soil and subtropical conditions, the dry weight production at 150 DAE (Table 3) in MT1 (11921.5 kg ha^{-1}) and MT2 (19135.1 kg ha^{-1}) corresponded to -744 kg ha^{-1} (MT1) and +6,470 kg ha^{-1} (MT2), when compared to the highest production (12,655.6 kg ha^{-1}) recorded in plants grown at densities of 600,000 plant ha^{-1} in an Aw (Köppen classification) climate in the Savannah of the Goiás state, Brazil (Amabile et al. 2000). In relation to the plant density of 80,000 plants ha^{-1} in the low-fertility soil and dry climate conditions of the Brazilian Northeast (Nascimento & Silva 2004), the dry matter production in the present study was +2,531 kg ha^{-1} (MT1) and +9,745 kg ha^{-1} (MT2).

The cumulative dry weight production increased in cut plants throughout the study period, with values similar to those of MT2, except at 150 DAE, when lower values were recorded (Table 3).

Table 3. Dry weight production of pigeon pea plants submitted to different treatments and average cumulative values for cut plants assessed from 15 to 180 days after emergence (DAE).

Treatment*	Sampling (DAE)						
	15	30	60	90	120	150	180
	Stems (kg ha^{-1})						
MT1	5.9 Ad**	40.7 Ad	681.5 Bd	4,300.9 Bc	6,295.2 Bb	9,087.7 Ba	8,443.0 Ba
MT2	23.7 Ae	153.2 Ae	2,434.2 Ad	8,202.0 Ac	10,763.1 Ab	15,050.7 Aa	13,853.2 Aa
MT2 + cut	23.6 Ad	142.9 Ad	2,039.1 Ac	8,023.7 Aa	2,934.0 Cc	3,407.1 Cbc	4,710.7 Cb
MT2 + cut/ac	23.6 Ae	142.9 Ae	2,039.1 Ad	8,023.7 Ac	10,957.7 Ab	11,430.7 Bab	12,734.4 Aa
CV treatments = 8.39 %				CV samplings = 12.49 %			
	Leaves (kg ha^{-1})						
MT1	16.1 Ac	72.4 Ac	765.5 Ab	3,281.4 Ba	3,147.7 Ca	2,883.8 Ca	528.4 Dbc
MT2	56.6 Ae	259.9 Ae	2,272.2 Ac	5,575.7 Aa	5,052.1 Ba	4,084.4 Bb	1,122.5 Cd
MT2 + cut	64.7 Ad	246.7 Ad	2,203.9 Ab	5,833.5 Aa	406.1 Dcd	985.1 Dc	1,728.5 Bb
MT2 + cut/ac	64.7 Ae	246.7 Ae	2,203.9 Ad	5,833.5 Ac	6,239.2 Abc	6,818.7 Ab	7,562.0 Aa
CV treatments = 11.23 %				CV samplings = 12.45 %			
	Shoots: stems + leaves (kg ha^{-1})						
MT1	22.1 Ac	113.1 Ac	1,446.9 Bc	7,582.3 Bb	9,442.8 Bb	11,921.5 Ba	8,971.4 Cb
MT2	80.3 Ae	413.1 Ae	4,706.4 Ad	13,777.7 Ac	15,815.1 Ab	19,135.1 Aa	14,975.7 Bbc
MT2 + cut	88.3 Ac	389.7 Ac	4,243.0 Ac	13,857.2 Aab	3,340.1 Cc	4,392.1 Cc	6,439.2 Cb
MT2 + cut/ac	88.3 Ae	389.7 Ae	4,243.0 Ad	13,857.2 Ac	17,197.3 Ab	18,249.3 Aab	20,296.4 Aa
CV treatments = 7.86 %				CV samplings = 11.73 %			

* MT1: main treatment 1 (1.0 × 0.2 m); MT2: main treatment 2 (0.2 × 0.1 m); MT2 + cut: main treatment 2 with plants cut at a height of 60 cm, at 90 DAE; MT2 + cut/ac: cumulative value in the main treatment 2 with plants cut at 60 cm, at 90 DAE. ** Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ according to the Tukey test at 5 % of probability.

These data reveal that, in general, cutting did not influence the amount of dry weight accumulated by pigeon pea plants under subtropical conditions.

The results indicate that the stem crude protein content (Table 4) exhibited the same behavior for all the treatments, decreasing from 15 to 30 DAE, followed by an increase from 30 to 60 DAE (maximum protein content) and then a sharp drop (about 80 %) from 60 to 80 DAE, remaining low until 180 DAE. There was no difference in the leaf crude protein content among the treatments for the different sampling times, except at 150 DAE, when it was 9.1 and 23.6 % higher for MT2 and MT2 + cut plants, respectively, than those in MT1. The greater plant density in MT2 and cutting in MT2 + cut delayed flowering, when compared to MT1, what may justify the differences observed at 180 DAE. This corroborates other studies that demonstrated that plant growth is adversely affected by increasing plant densities, and that N yield (and consequently, crude protein) tends to increase at greater plant densities

Table 4. Leaf and stem crude protein content in the dry matter of pigeon pea plants submitted to different treatments assessed from 15 to 180 days after emergence (DAE).

Treatment*	Sampling (DAE)						
	15	30	60	90	120	150	180
	Stem crude protein content (g kg^{-1})						
MT1	136.5 Aa**	87.9 Ab	48.7 Ac	51.5 Ac	71.7 Ac	81.7 ABb	71.0 Ac
MT2	139.6 Aa	88.4 Ab	43.1 Ac	64.2 Ac	70.4 Ac	94.0 Abc	76.0 Ac
MT2 + cut	133.5 Aa	78.3 Ab	44.4 Ac	65.4 Ac	88.6 Abc	55.8 Bc	67.7 Ac
CV treatments = 15.71 %				CV samplings = 16.65 %			
	Leaf crude protein content (g kg^{-1})						
MT1	326.9 Aa	245.0 Ab	277.3 Aab	277.9 Aab	255.2 Ab	251.5 Bb	259.6 Ab
MT2	324.4 Aa	278.1 Aab	243.1 Ab	259.2 Ab	264.2 Ab	274.6 ABab	254.6 Ab
MT2 + cut	301.9 Aa	249.6 Ab	248.9 Ab	274.6 Aab	246.9 Ab	310.0 Aa	263.2 Aab
CV treatments = 4.75 %				CV samplings = 7.34 %			

* MT1: main treatment 1 (1.0 × 0.2 m); MT2: main treatment 2 (0.2 × 0.1 m); MT2 + cut: main treatment 2 with plants cut at a height of 60 cm, at 90 DAE. ** Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ according to the Tukey test at 5 % of probability.

Table 5. Insoluble carbohydrate content and starch equivalent in the dry matter of pigeon pea during the crop cycle under different treatments and assessed from 15 to 180 days after emergence (DAE).

Treatment*	Sampling (DAE)						
	15	30	60	90	120	150	180
	Stem (g kg^{-1})						
MT1	91.7 Acd**	41.9 Ad	2.6 Abcd	106.3 Abcd	241.2 Aa	248.1 Aa	198.2 Aab
MT2	93.5 Acd	56.4 Ad	157.3 Aabc	104.2 Abcd	242.9 Aa	214.0 Aa	187.8 Aab
MT2 + cut	101.9 Ab	78.8 Ab	166.3 Ab	90.2 Ab	249.7 Aa	214.0 Aa	202.6 Aa
CV treatments = 16.66 %				CV samplings = 23.66 %			
	Leaves (g kg^{-1})						
MT1	37.1 Ac	85.4 Abc	76.0 Ac	48.4 Acd	128.2 Aa	122.3 Aab	117.5 Aab
MT2	29.3 Ad	78.4 Abc	53.7 Bcd	40.3 Ad	124.4 Aa	119.1 Aa	110.5 Aab
MT2 + cut	33.6 Ad	74.3 Abc	31.9 Bd	40.0 Acd	133.0 Aa	119.1 Aa	107.1 Aab
CV treatments = 5.66 %				CV samplings = 18.09 %			

* MT1: main treatment 1 (1.0 × 0.2 m); MT2: main treatment 2 (0.2 × 0.1 m); MT2 + cut: main treatment 2 with plants cut at a height of 60 cm, at 90 DAE. ** Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ according to the Tukey test at 5 % of probability.

(Ahlawat & Saraf 1981). Moreover, the leaf crude protein content in all the treatments (Table 4) was between 243.1 and 326.9 kg ha^{-1} (corresponding to 24.31 and 32.69 %, respectively), what is higher than the average of 19.29 % reported by Valadares Filho et al. (2010) and Vieira (2011). As the plant age increased, the forage crude protein tended to decrease (Table 4), what is in agreement with Tenakwa et al. (2022), who stated that, as forage mature, tissues become more fibrous, and protein and energy levels decrease.

For insoluble carbohydrates (starch equivalent) in the stem and leaf (Table 5), there was no statistical difference among the treatments. However, the starch increased for MT1 and MT2 from 15 to 150 DAE, and then decreased from 150 to 180 DAE. In the MT2 + cut treatment, the insoluble carbohydrate levels decreased after cutting and then increased.

The forage harvested from 90 to 180 DAE showed similar crude protein and starch contents, in spite of exhibiting less crude protein and more starch content than younger plants (15 to 60 DAE).

According to Taiz et al. (2017), the greatest accumulation of insoluble carbohydrates is expected in the flowering phase. Godoy & Santos (2011) also reported that the strong woody stem of pigeon pea plants can store starch during the vegetative phase, which mobilizes to fill the pods when the reproductive phase begins. This is consistent with our observations, whereby the insoluble carbohydrate content tended to increase until 150 DAE, when the flowering phase started, and then decreased at 180 DAE, when the kernel formation began.

CONCLUSIONS

1. The studied spacing regimes (1.0 × 0.2 m and 0.5 × 0.1 m) did not influence plant height;
2. The 0.5 × 0.1 m regime showed a worse individual plant performance, but higher forage yield (kg ha^{-1}) than the 1.0 × 0.2 m treatment, from 120 to 180 days after emergence (DAE). Thus, aiming at forage production, the 0.5 × 0.1 m spacing was more advantageous than the 1.0 × 0.2 m, with the highest yield obtained by harvesting at 150 DAE;
3. Under the 0.5 × 0.1 m treatment, the dry weight production of cut plants was higher than that of plants with continuous development. Therefore, it is better to harvest forage at 90 DAE and harvest again at 180 DAE than leaving a continuous plant growth to harvest at 180 DAE;
4. In each sampling date, there was no difference for stem and leaf crude protein and starch content, as a function of the treatments. The forage harvested from 90 to 180 DAE showed similar crude protein and starch contents. So, in this period, the forage quality is not a limiting factor to define the harvest time.

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