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Biomass of *Crotalaria juncea* as a function of plant densities in the semiarid region of Northeastern Brazil

Biomasa del *Crotalaria juncea* en función de la densidad de plantas en la región semiárida del Noreste de Brasil

Neyton de Oliveira Miranda^{1*}, Giulliana Mairana Moraes de Sousa Vanomark², Isabel Giovanna Costa e Melo³, and Glêidson Bezerra de Góes⁴

ABSTRACT

An increase in the production per area of sunn hemp (*Crotalaria juncea* L.) biomass in order to expand its beneficial effects as green manure is an objective for the agronomic management of this species. Three experiments were performed during consecutive years to test the following plant densities per m²: 10, 20, 30, and 40; 25, 35, 50, and 100; 25, 50, 75, and 100. For each density the spacing between the sowing rows and within the rows was equal. The experiments were conducted at Mossoro, RN, Brazil, with a randomized complete block design of four replicates. For each experiment, we determined the shoot dry mass and root dry mass per hectare and the ratio between the values per hectare of shoot dry mass and seed rate. Data were subjected to analysis of variance (F test) and regression analysis. The increasing linear behavior of shoot and root biomass of sunn hemp as a function of plant density establishes a recommendation of 100 plants m⁻² with equal spacing in the sowing row and between rows. However, the amount of dry mass produced by each kg of seeds decreased to the density of 90 plants m⁻². The amount of biomass produced was limited by the length of the vegetative phase of sunn hemp during day length conditions at Mossoro.

Key words: sunn hemp, green manure, cover crops, soil management.

RESUMEN

El incremento de la producción por área de biomasa de cáñamo de la India (*Crotalaria juncea* L.) para aumentar sus efectos beneficiosos como abono verde es un objetivo en el manejo agronómico de esta especie. En este sentido, se realizaron tres experimentos en años consecutivos para probar las siguientes densidades de plantas por metro cuadrado: 10, 20, 30 y 40; 25, 35, 50 y 100; 25, 50, 75 y 100. En cada densidad, el espaciado entre las filas de siembra y dentro de las filas fue igual. Los experimentos se realizaron en Mossoró, RN, Brasil, en un diseño de bloques completos al azar con cuatro repeticiones. En cada experimento se determinaron la materia seca de la parte aérea y la materia seca de la raíz, ambas por hectárea, y la relación entre los valores por hectárea de materia seca de la parte aérea y la tasa de semillas. Los datos se sometieron a análisis de varianza (prueba F) y análisis de regresión. El comportamiento lineal creciente de la biomasa de la parte aérea y raíces de *C. juncea* en función de la densidad de plantas permite la recomendación de 100 plantas m⁻² con el mismo espacio en la hilera de siembra y entre hileras, pero la cantidad de materia seca producida por cada kg de semillas disminuyó hasta la densidad de 90 plantas m⁻². La cantidad de biomasa producida se vio limitada por la duración de la fase vegetativa de *C. juncea* en las condiciones de duración del día en Mossoró.

Palabras clave: cáñamo de la india, abono verde, cultivos de cobertura, manejo del suelo.

Introduction

The need for intensifying food production together with inadequate agricultural practices cause soil degradation. This affects the soil's chemical, physical and biological attributes, accelerates the mineralization of soil organic matter (SOM) and causes a decline in the soil productive potential. These processes occur throughout the season

of agricultural production and are of concern in small de-capitalized farms (Xavier *et al.*, 2017).

In the Northeast region of Brazil, this problem is aggravated by unfavorable chemical characteristics of soils, such as acidity, deficiency of some nutrients and low cation exchange capacity, as well as the sandy texture of many soils (Cavalcante *et al.*, 2012; Teodoro *et al.*, 2018). Because

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of this, obtaining a satisfactory crop yield requires large amounts of expensive fertilizers. Low-income farmers tend to substitute chemical fertilizers with manure, but the amount their animals produce is insufficient for the needs of the crops (Silva *et al.*, 2007; Cavalcante *et al.*, 2012).

Mitigation of soil degradation can be achieved by more sustainable management practices, such as crop rotation and cultivation of species for green manuring and soil cover (Lima *et al.*, 2010; Eiras and Coelho, 2012). Green manures, incorporated into soil management or used to cover the soil (Espíndola *et al.*, 2005) protect and enrich the soil with SOM and nutrients and reduce the use of industrialized inputs while mitigating environmental degradation (Mateus and Wütke, 2006). This makes agriculture more socially, economically, and environmentally sustainable, and benefits crop productivity and farmers' income (Cavalcante *et al.*, 2012; Xavier *et al.*, 2017; Teodoro *et al.*, 2018).

Among the species used for green manuring and soil cover, the legumes (Fabaceae) stand out because they form a symbiotic association with bacteria that perform biological nitrogen fixation. As a result, after the cultivation of legumes the plants provide a substantial amount of nitrogen for crops in succession (Espíndola *et al.*, 2005). An important characteristic of plants that improve the soil (Xavier *et al.*, 2017) is that they promote the economic viability and sustainability of production systems by reducing the use of synthetic nitrogen fertilizers (Perin *et al.*, 2010).

After cutting and decomposition, green manures release to the successor crop the nutrients absorbed by their roots from the deep soil layers and that have been accumulated in their shoots (Espíndola *et al.*, 2005). This nutrient cycling reduces the use of chemical fertilizers in the main crop and preserves the environment. Other consequences are the increase in soil cation exchange capacity (Cavalcante *et al.*, 2012), and higher availability of nitrogen (nitrates) and phosphorus, because the increased SOM can decrease soil phosphorus retention (Espíndola *et al.*, 2005).

Among the benefits of biomass added to the soil by green manures are weed control, maintenance of soil moisture and temperature, the promotion of biological diversity, and remediation of degraded areas. An increase in SOM improves soil aggregation, which benefits soil density, soil porosity and water infiltration, while soil cover slows rainwater runoff, reducing soil and water losses by erosion (Espíndola *et al.*, 2005; Teodoro *et al.*, 2016; Pereira *et al.*, 2017).

Sunn hemp (*Crotalaria juncea* L.) is one of the main species of green manure and is adapted to the different soil and climatic conditions in Brazil. It stands out for its large capacity of biomass production, nutrient accumulation and the high quality of its residues, which are important for protecting the soil from erosion and for enriching the soil with nutrients (Xavier *et al.*, 2017). Sunn hemp is characterized by rapid growth, tolerance to water stress, low soil fertility requirements, and it is able to fix from 78 to 183 kg ha⁻¹ of nitrogen into nitrogen oxides that produce ammonia, nitrites and nitrates. In addition, it can control nematodes and weeds (Espíndola *et al.*, 2005; Silva *et al.*, 2007; Teodoro *et al.*, 2016; Facco *et al.*, 2018). Sunn hemp is indicated for remediating degraded areas, including compacted soils (Pacheco *et al.*, 2015; Pereira *et al.*, 2017).

The increase in sunn hemp biomass production can improve its benefits as green manure such as in weed control and SOM accumulation that are directly related to biomass production per area. Additionally, nitrogen accumulation in the shoots accompanies an increase in biomass (Pereira *et al.*, 2005). Perin *et al.* (2010) and Teodoro *et al.* (2016) show that phosphorus and magnesium accumulation by sunn hemp is more influenced by the amount of biomass produced than by the content of these nutrients in the biomass, while calcium accumulation is influenced by both higher biomass production and its higher content in biomass.

The objective of this work was to test increasing sunn hemp plant densities to identify the densities producing maximum shoot and root biomass and to determine sunn hemp densities that provide the maximum biomass production per kilogram of seed used.

Materials and methods

This research was carried out in the vegetable garden of the Federal Rural University of the Semi-arid Region (5°12'26" S, 37°24'06" W), in the municipality of Mossoro, located in the state of Rio Grande do Norte, in northeastern Brazil. The climate of the region, using the classification of Thornthwaite, is semiarid, megathermal with a water deficit during the year. The mean annual precipitation is 673.9 mm of which about 550 mm occur in the period from February to May.

Sowing was carried out during the months of August, September and October of the years 2009, 2010 and 2011. The climatological normals for these months for the municipality of Mossoro are presented in Table 1.

TABLE 1. Climatological normals for months of the second semester in the municipality of Mossoro, RN, Brazil.

Parameter	August	September	October	November	December
Potential evapotranspiration (mm)	186.1	202.2	223.7	218.2	234.7
Mean temperature (°C)	27.7	28.3	28.7	28.7	29.0
Maximum temperature (°C)	34.3	35.0	35.1	34.9	34.8
Minimum temperature (°C)	21.7	22.6	23.5	23.7	24.2
Relative humidity (%)	61.7	60.1	61.7	64.5	65.1
Monthly sunshine duration (h)	8.9	9.6	9.9	9.8	8.8
Rainfall accumulated (mm)	7.2	1.8	2.4	1.7	14.3
Wind speed (m s ⁻¹)	4.7	5.2	5.3	5.1	5.0

Source: INMET (2018).

The soil of the area is classified as an eutrophic red-yellow argisol (Santos *et al.*, 2013) whose main characteristics are: pH - 6.22; CE - 0.07 dS m⁻¹; Ca - 1.42 cmolc dm⁻³; Mg - 0.93 cmolc dm⁻³; K - 21.57 mg dm⁻³; Na - 3.85 mg dm⁻³; P - 22.73 mg dm⁻³; N - 0.27 g kg⁻¹; Sand - 900 g kg⁻¹; Silt - 70 g kg⁻¹; Clay - 30 g kg⁻¹.

The experiments were set up as a randomized complete block design with four replicates. The experimental plots had a useful area of one m². The treatments consisted of plant densities of sunn hemp m⁻² that changed each year according to the previous results. The plant densities in each year were: 10, 20, 30, and 40; 25, 35, 50, and 100; 25, 50, 75, and 100 plants m⁻². For each plant density, the hills were arranged at equal distances in the row and between rows as follows: 10 - 31.6 x 31.6 cm, 20 - 22.4 x 22.4 cm, 25 - 20.0 x 20.0 cm, 30 - 18.3 x 18.3 cm, 35 - 16.9 x 16.9 cm, 40 - 15.8 x 15.8 cm, 50 - 14.1 x 14.1 cm, 75 - 11.5 x 11.5 cm, and 100 - 10.0 x 10.0 cm. This arrangement was made possible by a cardboard template in which holes were drilled according to each plant density.

Seeds were purchased from a commercial seed producing company and the mass of 1000 seeds was 45 g. The second experiment was fertilized with one kg of chicken manure m⁻², mixed superficially. The manure had N, P and K contents of 9.19, 1.85 and 3.04 g kg⁻¹, respectively.

Control of weeds was performed manually whenever necessary, and irrigation was performed daily using a microsprinkler system. Irrigation depths applied were 270 mm in the first experiment, 310 mm in the second, and 330 mm in the third experiment.

Biomass production was determined at full flowering, at which time all plants in the plot were removed with the aid of a cutting shovel to a depth of 30 cm, in order to promote

minimum loss of the root system. Posteriorly, the plants were cut at the stem base to separate the shoot from the root system, which were weighed separately. Five plants were randomly withdrawn from each plot. These were dried in a forced air circulation oven (model TE-394/500L, Tecnal Equipamentos Científicos in Piracicaba, SP, Brazil) at 65°C until a constant weight was obtained. The calculated dry mass per plot of roots and shoot was expressed in t ha⁻¹.

The ratio between the shoot dry mass and the seed rate, was determined in kg ha⁻¹ considering the following densities in plants m⁻² and seed rates: 10 - 4.50 kg ha⁻¹, 20 - 9.00 kg ha⁻¹, 25 - 11.25 kg ha⁻¹, 30 - 13.50 kg ha⁻¹, 35 - 15.75 kg ha⁻¹, 40 - 18 kg ha⁻¹, 50 - 22.50 kg ha⁻¹, 75 - 33.75 kg ha⁻¹, and 100 - 45 kg ha⁻¹.

Data of the shoot dry mass (SDM) and root dry mass (RDM), both expressed in t ha⁻¹, and the ratio between shoot dry mass and seed rate were subjected to an analysis of variance. The significance of the effect of plant densities was determined by the F test. In case of a significant effect, the data were subjected to a regression analysis, whose model was chosen by the highest coefficient of determination. The statistical software used was SISVAR (Ferreira, 2011).

Results and discussion

The flowering of sunn hemp occurred at 49, 55, and 63 days after plant emergence (DAE) in the first, second, and third experiments respectively. The plant density per area promoted a significant effect ($P < 0.01$) on sunn hemp shoot dry mass (SDM) in all three experiments. The averages obtained were 3.39 t ha⁻¹ in the first experiment, 4.92 t ha⁻¹ in the second and 2.07 t ha⁻¹ in the third experiment. These results are much lower than the biomass production potential mentioned by Wutke *et al.* (2014), which is greater than 15 t ha⁻¹.

The time to flowering and the SDM observed in our study were closer to those obtained in studies conducted in northeastern Brazil, where the day length differs little from that observed in Mossoro. In the state of Alagoas (9°45' S; 35°38' W), sunn hemp flowering occurred at 65 d and 3 t ha⁻¹ of SDM were obtained in a cycle between May and September (Cavalcante *et al.*, 2012). In the state of Paraíba (7°19' S; 33°51' W), flowering occurred between 50 and 55 d and the highest SDM obtained ranged from 5.4 to 6.7 t ha⁻¹ during five consecutive years with sowings between February and March (Silva *et al.*, 2007). In the state of Piauí (3°05' S; 41°46' W), Teodoro *et al.* (2018) observed a period of 67 d until flowering, but the SDM of 9.8 t ha⁻¹ was obtained because the plants were cut at 100 DAE. The higher SDM (12.82 t ha⁻¹) obtained by Pereira *et al.* (2016) in the state of Ceará (5°07' S; 37°05' W), at a distance of 90 km from Mossoro, is due to the harvesting of plants at the end of the cycle (78 DAE).

The previous discussion is confirmed by the fact that our results were closer to those obtained when the sowing was carried out in the autumn-winter season in southern regions of the country. The period until sunn hemp flowering in our study (49 to 63 d) was similar to the sowings in the month of March in São Paulo (24°35' S, 47°50' W), when days are decreasing in duration (Lima *et al.*, 2010). The SDM obtained by us was smaller than that obtained when the sowing occurred in November in that state (15.6 t ha⁻¹), and the time to flowering was 116 d. According to Lima *et al.* (2010), the greater day length in São Paulo between November and January delays flowering and allows greater accumulation of SDM. There is no time for further accumulation of SDM under the photoperiod conditions of the Northeast region, where flowering occurs earlier.

The effect of photoperiod variation on sun hemp development is confirmed by differences in SDM and time to flowering due to the sowing date in the state of Rio de Janeiro (22°46' S, 43°41' W). In this location, sowing in autumn-winter or spring-summer resulted in flowering at 60 or 125 d and SDM of 6.8 t ha⁻¹ or 10.7 t ha⁻¹, respectively (Pereira *et al.*, 2005). The variation was also seen in the state of Goiás (16°43' S, 49°07' W), when sowing in the months of November or March was compared (Amabile *et al.*, 2000), which resulted in decreasing the time until flowering from 118 to 67 d, with a consequent decrease in SDM from 17 t ha⁻¹ to 6 t ha⁻¹. This was slightly higher than that obtained in our study.

The possibility that the low sunn hemp SDM values in our study are due to the anticipation of flowering in our region

is confirmed by studies with sunn hemp in the state of Rio Grande do Sul. In one locality (29°42' S, 53°49' W), Facco *et al.* (2018) observes that the time until flowering increased from 97 to 110 d, when sowing is performed in October or December, months in which there is an increase in day length. In another location (29°05' S, 53°12' W), Pereira *et al.* (2017) observes 120 d until flowering and obtains SDM of 22.71 t ha⁻¹ when sowing is performed in December.

The importance of the length of day and night in determining vegetative growth and induction of sunn hemp flowering is stated by Teodoro *et al.* (2018). The development of species like this one is influenced by the interaction between photoperiod and temperature, the sowing date and the latitude (Amabile *et al.*, 2000). Sunn hemp is a photoperiod-sensitive species and its flowering is induced by the shortening of day length, resulting in a decrease in biomass production (Lima *et al.*, 2010; Eiras and Coelho, 2012). In Mossoro, the length of the day varies slightly, ranging from 11.8 h in June to 12.4 h in December, which is the photoperiod range in which Santos and Campelo Júnior (2003) observe the shortest time until sunn hemp flowering.

The SDM of sunn hemp presented positive linear behavior ($P < 0.01$) as a function of plant density per area (Fig. 1). This result is corroborated by other studies, like that of Eiras and Coelho (2012), who observe an increase in SDM as plant density increased from 20, 30, 40, 50 and 60 plants m⁻², keeping 50 cm between rows. With the same spacing, Teodoro *et al.* (2016) obtain an increase in SDM with higher densities of 20, 40 and 60 plants m⁻². In the study by Pereira *et al.* (2005), the highest SDM is obtained both by increasing the number of plants in the row (5, 10, 20 and 40) as well as by decreasing the row spacing (120, 60 and 30 cm). As plant densities tested by Eiras and Coelho (2012) result in similar dry mass per plant, the increase in plant density per area is determinant for the increase in SDM, as stated by Teodoro *et al.* (2016). Similarly, in our study the SDM increased with higher plant density per area, but SDM per plant decreased.

The fact that the highest SDM observed by Pereira *et al.* (2005) in autumn-winter (6.8 t ha⁻¹) is obtained with 133 plants m⁻², while in spring-summer the highest SDM (10.7 t ha⁻¹) is obtained with 100 plants m⁻², indicates that in spring-summer the plants develop more, and from the density of 100 plants m⁻² the competition among them for water, light and nutrients limits the development. This is explained by Lima *et al.* (2010), who point out that the interception of solar radiation by the leaves of the crop canopy and the use of this intercepted radiation are the main

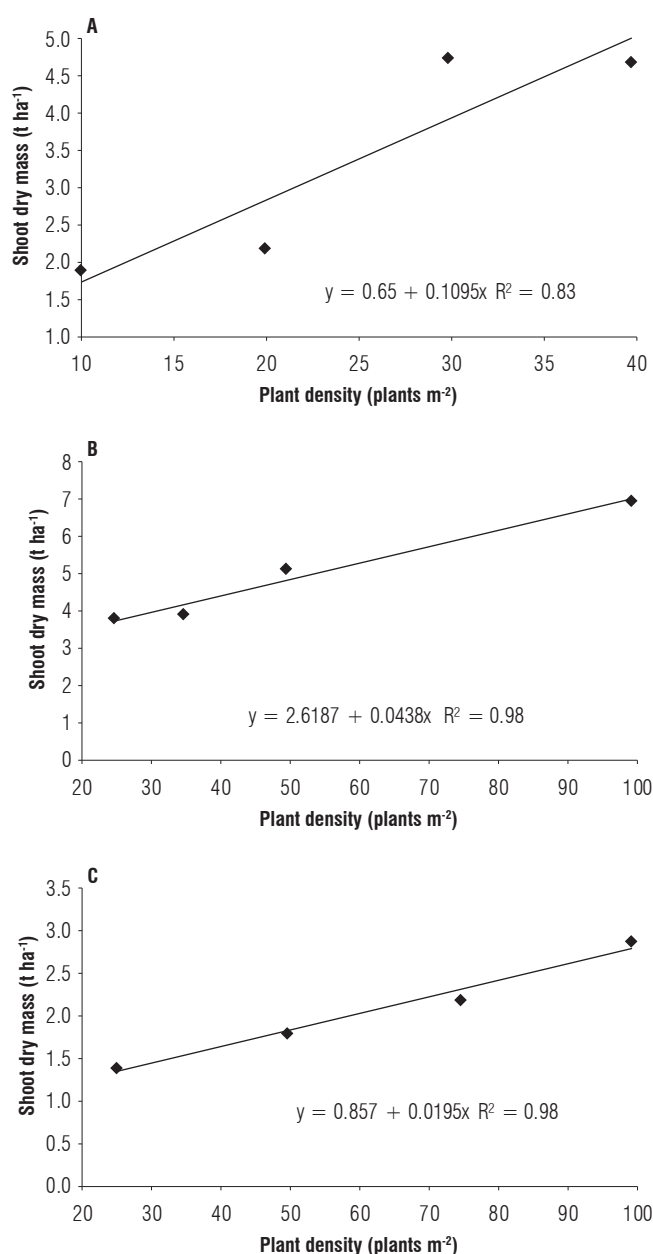


FIGURE 1. Shoot dry mass of sunn hemp as a function of the plant density per area in the first (A), second (B), and third (C) experiments.

factors determining the accumulation of SDM. According to Pereira *et al.* (2005), a higher SDM can be obtained with higher plant density in the row and lower row spacing. This supports the results obtained in our study, in which the row and in-row spacing were equal. In addition, the early flowering may have limited plant growth, so that in none of the densities studied by us did the plant development cause competition for solar radiation or impaired its interception.

In relation to our work, in which the increase in plant density per area promoted an increase in SDM, the importance

of maintaining equal spacing in the row and between rows was demonstrated in two papers in which densities of 50 or 62.5 plants m⁻² were tested, which were obtained with a row spacing of 50 or 40 cm and 25 plants m⁻¹ of row. In the study of Lima *et al.* (2010), the increase in plant density per area causes a reduction in SDM, while no effect of increasing density is observed by Amabile *et al.* (2000), who explain that the arrangement of plants studied did not influence competition between plants for light, water and nutrients.

The even interception and use of solar radiation throughout the sunn hemp canopy in our study may have played an important role in dry mass accumulation, even with increasing plant densities. In this sense, Lima *et al.* (2010) argue that the smaller row spacing favors shading within the canopy affecting leaf area. This may impair the accumulation of dry mass by sunn hemp plants. These authors reduce row spacing to obtain an increase in plant density from 50 to 62.5 plants m⁻² and obtain a reduction in SDM from 15.6 t ha⁻¹ to 14.3 t ha⁻¹. However, they do not obtain differences in SDM when the same density (50 plants m⁻²) is obtained by varying the row spacing (50 or 40 cm) and the number of plants m⁻¹ of row (25 or 20).

Plant density per area also promoted a significant effect ($P < 0.01$) on sunn hemp root dry mass (RDM) in all three experiments. The averages obtained were 0.91 t ha⁻¹ in the first experiment, 0.83 t ha⁻¹ in the second, and 0.26 t ha⁻¹ in the third. The values of RDM obtained in our study were smaller than those obtained by Teodoro *et al.* (2016), which range from 1.0 to 1.16 t ha⁻¹ at the end of the cycle. In the study by Teodoro *et al.* (2018), the RDM that they obtain (1.70 t ha⁻¹) with a density around 50 plants m⁻² is considered underestimated because roots are removed only up to 20 cm due to the difficulty of collecting the entire root system. In our research, the excavation sought to reach the depth of greater root concentration, around 30 cm, where 79% of the sunn hemp roots are located, according to Teodoro *et al.* (2018).

The results obtained in the three experiments indicated a linear increase in sunn hemp root dry mass (Fig. 2) with the increase in plant density per area. Similarly, although not statistically significant, Teodoro *et al.* (2016) obtains an increase in RDM as they progressively increase the density of 10, 20 and 30 plants m⁻¹ of row, maintaining a row spacing of 50 cm.

Besides the shoot dry mass, it is important to consider the root system of green manure species, which is rarely quantified because even species that do not stand out for

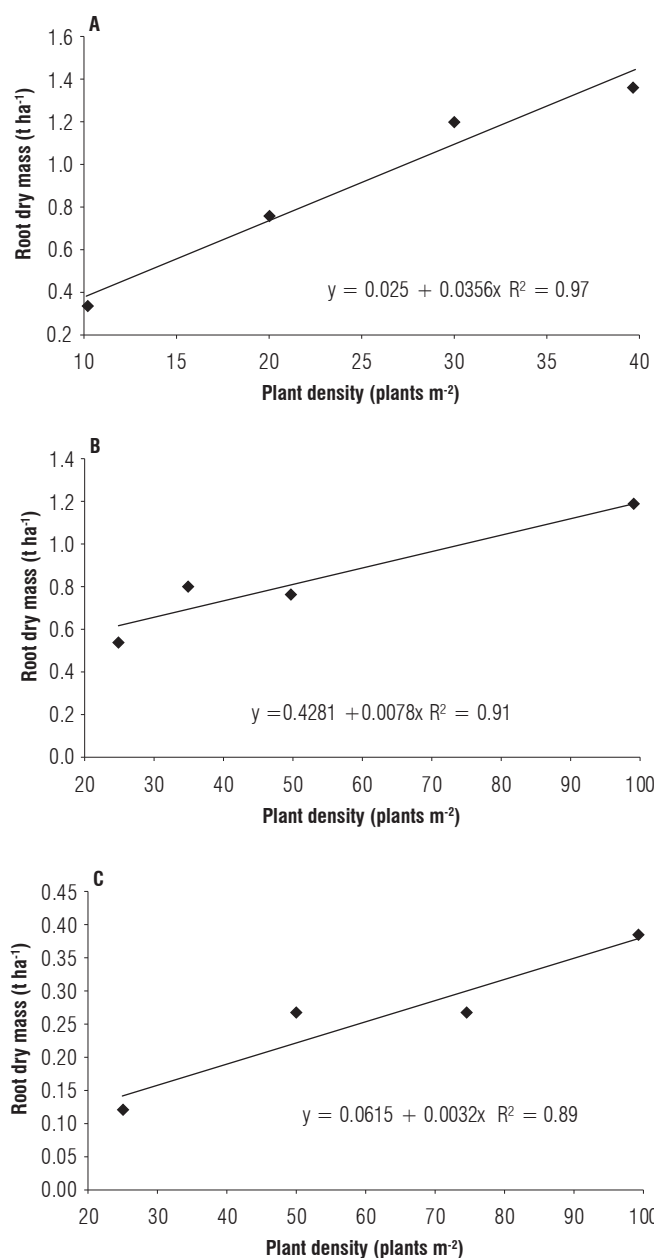


FIGURE 2. Dry mass of roots of sunn hemp as a function of the plant density per area in the (A) first, (B) second and (C) third experiments.

the production and quality of the shoot biomass can be very efficient in improving the physical quality of the soil due to a well-developed root system (Xavier *et al.*, 2017). Species with high root growth benefit agricultural production in compacted soils because they form channels in the soil profile that favor the root growth of crops in succession (Pacheco *et al.*, 2015).

When analyzing the ratio between the shoot dry mass and seed rate in the second and third experiments, we observed a significant effect of plant density per area ($P < 0.01$) and

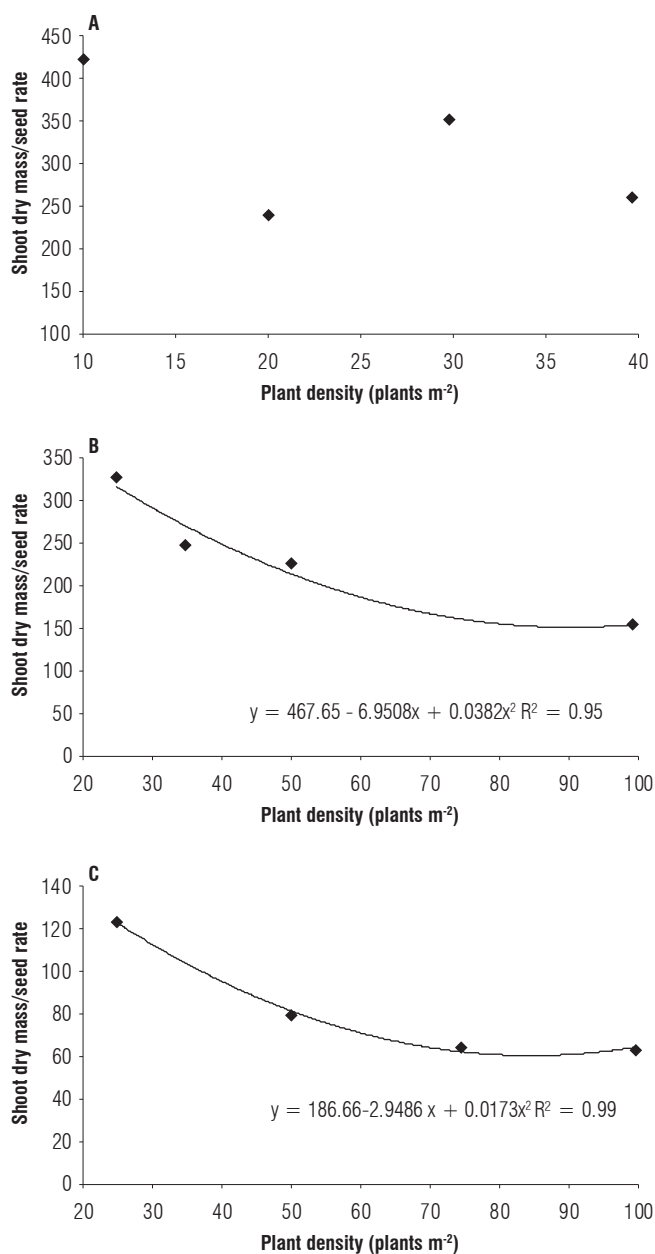


FIGURE 3. Ratio between shoot dry mass and the seed rate of *Crotalaria juncea* in the (A) first, (B) second and (C) third experiments.

a non-significant effect in the first experiment. Each kilogram of seed produced an average of 319.75, 239.90, and 83.54 kg of dry mass in the first, second and third experiments, respectively.

Analyzing Figure 3, in which the seed rate is represented by the corresponding number of plants m⁻², we observed that the shoot dry mass produced by each kg of seeds decreased in a quadratic way as a function of the plant density in the second and third experiments. The point of inflection is at 90 plants m⁻². Eiras and Coelho (2012) observe that, in spite

of the increase of dry mass per area of sunn hemp due to the increase in plant density, the dry mass of each plant is similar among the densities, while in our work there was a decrease in dry mass of each plant as the density increased up to 90 plants m^{-2} . Therefore, taking into account the possibility of increasing biomass production by increasing plant density, it is important to consider seed availability and cost (Mateus and Wutke, 2006).

The small return in biomass production relative to the higher seed cost when increasing sowing density can discourage small and medium farmers from using higher sunn hemp plant densities. Therefore, it would be important for farmers to produce their own seed (Eiras and Coelho, 2012). In this sense, Pereira *et al.* (2011) comment that the practice of green manuring, despite its advantages, has been little-used by farmers. The lack of immediate economic return and the area that must be occupied by these crops are among the main causes for the lack of adoption.

Conclusion

The increasing linear behavior of shoot and root biomass of sunn hemp as a function of plant density supports a recommendation of 100 plants m^{-2} with equal spacing in the sowing row and between rows.

The amount of shoot dry mass produced by each kilogram of seeds decreased up to the density of 90 plants of sunn hemp m^{-2} .

The amount of biomass produced was limited by the length of the vegetative phase of sunn hemp at day length conditions found at Mossoro, RN, Brazil.

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