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Beetroot production using *Calotropis procera* as green manure in the Brazilian Northeast semiarid

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Abstract

The use of green manures in vegetable crop production systems has increased, but there is still a lack of information about the correct handling of the species for better use by culture. Two field experiments were conducted in Serra Talhada in the semiarid of Pernambuco state, Brazil, to evaluate the effects of amounts of biomass and times of *Calotropis procera* incorporation into the soil in the agronomic performance of the beetroot 'Early Wonder' in two growing seasons (fall and spring-summer). The experimental design was a randomized block in three replications. The treatments were arranged in a 4 x 4 factorial scheme, with the first factor corresponding to the quantities of *C. procera* biomass (5.4, 8.8, 12.2, and 15.6 Mg ha^{-1} on a dry basis) and the second to the times of incorporation into the soil (0, 10, 20, and 30 days before sowing of beetroot). The following characteristics were assessed in the beetroot: plant height, number of leaves per plant, root diameter, total productivity, commercial productivity, and dry mass of roots. The amount of *C. procera* as well as the time of incorporation and growing season directly influenced the agronomic performance of beetroot. Regardless of the assessed agronomic characteristics, increasing amounts, and decreasing the time of incorporation proportionally influenced the performance of beetroot. The best agronomic performance of the beetroot was obtained by fertilization with 15.6 Mg ha^{-1} of *C. procera*. The ideal time of incorporation of green manure coincided with the date of the sowing of beetroot. The cultivation in the fall season resulted in higher total and commercial productivity of beetroots fertilized with *C. procera*.

Keywords: *Beta vulgaris* L.; *Calotropis procera* (Ait.) R. Br.; green fertilizer; organic fertilization; soil and climate conditions.
Abbreviations: DBS – days before sowing.

Introduction

The beetroot (*Beta vulgaris* L.) is a vegetable crop belonging to the *Quenopodiaceae* family, widely cultivated throughout Brazil (Filgueira, 2008). To obtain the maximum yield of the beetroot, the proper management of the factors that influence the growth and development of culture, such as its water and nutritional needs, is necessary (Barlog et al., 2013). In nutritional terms, beetroot is considered a demanding crop in a balanced fertilizer. According to Granjeiro et al. (2007), the nutrients accumulated by beetroot, in decreasing order, are (N), potassium (K), magnesium (Mg), calcium (Ca), and phosphorus (P).

Green manures contain important sources of plant nutrients, and their use can reduce the amount of manure applied in organic production systems and contribute directly to the replacement of nutrient reserves in the soil (Linhares et al., 2009; Linhares et al., 2012; Sediyama et al., 2014). The use of green manure in the soil has promoted varied effects on the agronomic performance of the crops depending on the species used, the management of the biomass, the planting season of the crop, length of time on the ground, local climatic conditions, and the interaction between these factors (Alcântara et al., 2000). The spontaneous species of the Caatinga biome, hairy *Merremia aegyptia* L., *Calotropis procera* (Ait.) R. Br., and *Senna uniflora* L., have contributed so positive when used as green manure in organic systems of production of lettuce (Góes et al., 2011), coriander (Linhares et al., 2012), arugula (Souza et al., 2016), beetroot (Batista et al., 2016; Silva et al., 2011), carrot (Bezerra Neto et al., 2014; Oliveira et al., 2011), and radish (Batista et al., 2013).

The *C. procera* belongs to the *Apocynaceae* family, with wide geographical distribution, particularly in arid and semi-arid conditions (Souto et al., 2008; Carvalho Júnior et al., 2010). This species remains lush and green throughout the year, forming a shrub that is fast growing and exhibits vigorous regrowth, with a production capacity of approximately 700 kg of dry matter per hectare within 60 days after cutting (Andrade et al., 2008). The content of nitrogen, phosphorus, and corresponding potassium is 17.4, 4.4, and 23.5 g kg^{-1} dry weight, respectively, and their C/N ratio is 25/1, which favors the mineralization process of organic matter. Some studies have shown the potential of this type to be used as green manure with various crops, such as carrot (Silva et al., 2013), radish (Silva et al., 2017), lettuce (Souza et al., 2017), and arugula (Souza et al., 2016). Cultivation of beetroot with *C. procera* provided total and commercial root productivity of 18.74 Mg ha^{-1} and 16.33 Mg ha^{-1}, respectively (Batista et al., 2016).

In general, vegetable crops require large amounts of nutrients in a short time, considering their nutritional needs. The amount as well as the time of biomass incorporation directly influences the availability of nutrients for crops (Bezerra Neto et al., 2011; Oliveira et al., 2011). Biomass decomposition is controlled by soil microorganisms, environmental conditions, and the chemical composition of the material (Xu and Hirata, 2005; Batista et al., 2013, 2016). If there is a high rate of mineralization of the nutrients of the biomass used as green manure outside the period of high nutrient demand of the crop, leaching losses can occur, resulting in no absorption of nutrients in the stage of higher nutritional requirements (Crews and People, 2005).

In addition to fertilization, local climatic conditions are one of many pre-harvest factors affecting the yield of vegetables. In Brazil, there are few studies that demonstrate the productive potential of beetroot grown under different meteorological conditions. The sertão of the state of Pernambuco presents two climatic conditions, in which, in the spring-summer, the average air temperatures (above 25 ºC) and the photoperiod (above 12h) are higher than in autumn-winter, which can affect the productive response of beetroot and the mineralization of green manure.

The objective of this study was to evaluate the effects of different amounts of *C. procera* biomass and ground incorporation times in two cropping seasons (fall and spring-summer) in the agronomic performance of beetroot.

Results

Joint analysis of variance

There was interaction between growing seasons and amounts of *C. procera* biomass, as well as between seasons and incorporation times of green manure for plant height, number of leaves per plant, and root diameter. Interaction between the three factors (growing seasons, amounts of biomass, and incorporation times) occurred for total and commercial productivity and dry mass of roots.

Plant height, number of leaves per plant, and diameter of the beetroots

The plant height and the number of leaves per plant were higher in the fall season compared to the spring-summer cultivation, regardless of the amount of biomass and the incorporation time (Tables 1 and 2). The diameter of the beetroots planted in the spring-summer was smaller than to the fall in all amounts of biomass, except dose 15.6 Mg ha^{-1}.

In both growing seasons, the height of beetroot plants increased with increasing amounts of *C. procera* biomass, reaching maximum values of 26.56 (fall) and 24.11 cm (spring-summer), when the fertilizing consisted of 14.65 and 15.6 Mg ha^{-1}, respectively (Fig. 1A). In contrast, linear reductions were observed in the plant height between the lowest and the highest ground incorporation time for the green manure, with differences of 3.73 cm in the fall and 1.92 cm in the spring-summer (Fig. 1B).

The number of leaves per beetroot plant increased linearly with increasing amounts of *C. procera* incorporated into the soil, reaching maximum values of 11.80 (fall) and 9.88 (spring-summer) of leaves per plant with the amount of 15.6 Mg ha^{-1} of *C. procera* (Fig. 2A). Partitioning the interaction by times of incorporation within growing seasons, it was observed that the number of leaves per plant was reduced with the increase in the time that the green manure stayed in the ground, independent of the planting period of the crop (Fig. 2B).

The root diameter increased linearly with increasing amounts of green manure (Fig. 3A). Each ton of *C. procera* added to the soil caused increase of 0.06 (fall) and 0.26 (spring-summer) in the root diameter. Similar to what occurred for the height and number of leaves per plant, the diameter of beetroot was reduced when it was fertilized later in relation to the sowing, with larger differences in spring-summer cultivation (Fig. 3B).

Total productivity of beetroots

The increased amount of *C. procera* biomass increased the total productivity of beetroots, with maximum values of 46.48 Mg ha^{-1} (fall) and 40.99 Mg ha^{-1} (spring-summer) with the amounts of 14.08 and 15.6 Mg ha^{-1} of green manure, respectively, associated with 0 days before sowing (DBS) (Fig. 4AB).

Maximum values of total productivity were obtained when the green manuring was held on the beetroot planting day (Fig. 4CD). This time of incorporation along with the amount of 15.6 Mg ha^{-1} of *C. procera* yielded the highest values of total root productivity, both in fall cropping (46.56 Mg ha^{-1}) and in spring-summer cultivation (41.48 Mg ha^{-1}).

Commercial productivity of beetroots

In the fall, it was estimated the commercial productivity of beetroots of 35.53 Mg ha^{-1} using 14.23 Mg ha^{-1} of *C. procera* added to the soil 10 days before planting of the crop (Fig. 5A). In the second period, the amount of 15.6 Mg ha^{-1} of green manure at 0 DBS resulted in commercial productivity of 33.78 Mg ha^{-1}, followed by the treatments at 10 (29.52 Mg ha^{-1}), 20 (28.54 Mg ha^{-1}), and 30 (26.96 Mg ha^{-1}) DBS (Fig. 5B).

Regarding the interaction partition of ground incorporation times within the amounts of *C. procera*, there were no adjustments of the regression equations for the first growing season (fall) in the amounts of 5.4 Mg ha^{-1}, 12.2 Mg ha^{-1}, and 15.6 Mg ha^{-1}, but the average productivity of these amounts were 25.86 Mg ha^{-1}, 32.23 Mg ha^{-1}, and 34.22 Mg ha^{-1}, respectively (Fig. 5C). For the spring-summer, the estimated incorporation time of 1.26 days associated with 15.6 Mg ha^{-1} of *C. procera* yielded the maximum value of 33.64 Mg ha^{-1} of commercial beetroot productivity (Fig. 5D).

Dry mass of beetroots

For all periods of soil incorporation, the increase in the supply of the green manure increased the dry mass yield of beetroots, with maximum values of 7.73 (fall) and 4.15 Mg ha^{-1} (spring-summer) with the amount of 15.6 Mg ha^{-1} of *C. procera* deposited on the soil on the same day as planting (Fig. 6A and 6B). In the reverse breakdown of the interaction, it was observed that treatment related to fertilization with 15.6 Mg ha^{-1} of *C. procera*, associated with the incorporation time of 0 DBS, allowed the beetroot to achieve averages of 7.77 (fall) and 4.13 (spring-summer) (Fig. 6C and 6D).

Table 1. Plant height, number of leaves per plant, and diameter of beetroots in two growing seasons (fall and spring-summer) and different amounts of *Calotropis procera* biomass.

Growing seasons	Amounts of *Calotropis procera* (Mg ha^{-1})			
	5.4	8.8	12.2	15.6
	Plant height (cm)			
Fall	22.44 a[1]	24.03 a	26.18 a	26.42 a
Spring-summer	21.39 b	23.18 b	23.57 b	24.14 b
	Number of leaves per plant			
Fall	10.24 a	11.23 a	11.40 a	11.91 a
Spring-summer	9.22 b	9.40 b	9.70 b	9.87 b
	Root diameter (cm)			
Fall	8.01 a	8.22 a	8.39 a	8.68 a
Spring-summer	5.80 b	6.36 b	7.35 b	8.46 a

[1]Means followed by the same letter in the column do not differ by the Tukey test at 5% probability.

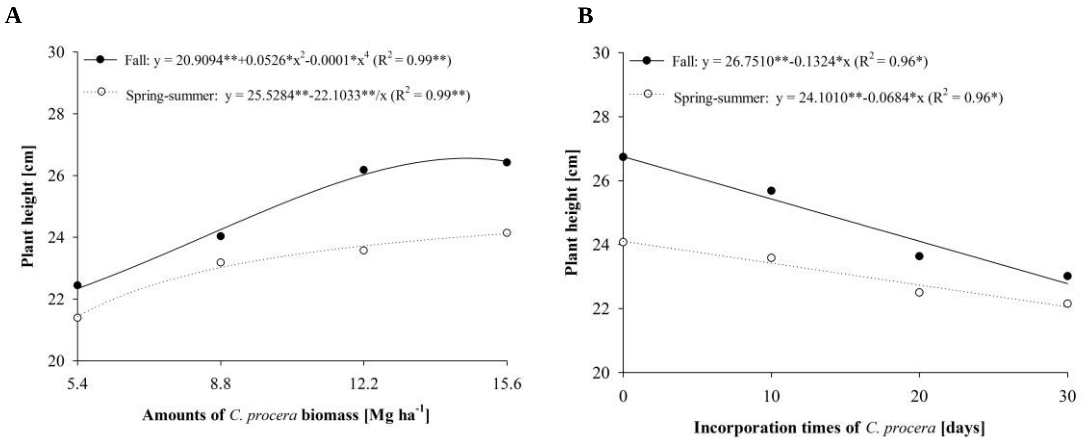


Fig 1. Height of beetroot plants in different amounts of *Calotropis procera* biomass (A) and incorporation times into the ground (B) in two growing seasons (fall and spring-summer).

Table 2. Plant height, number of leaves per plant, and diameter of beetroots in two growing seasons (fall and spring-summer) and different incorporation times of *Calotropis procera* into the soil.

Growing seasons	Incorporation times of *Calotropis procera* (days)			
	0	10	20	30
	Plant height (cm)			
Fall	26.74 a[1]	25.68 a	23.63 a	23.01 a
Spring-summer	24.07 b	23.57 b	22.49 b	22.15 b
	Number of leaves per plant			
Fall	12.04 a	11.41 a	10.92 a	10.39 a
Spring-summer	10.11 b	9.50 b	9.41 b	9.17 b
	Root diameter (cm)			
Fall	8.68 a	8.52 a	8.09 a	8.01 a
Spring-summer	8.12 b	7.16 b	6.62 b	6.07 b

[1]Means followed by the same letter in the column do not differ by the Tukey test at 5% probability.

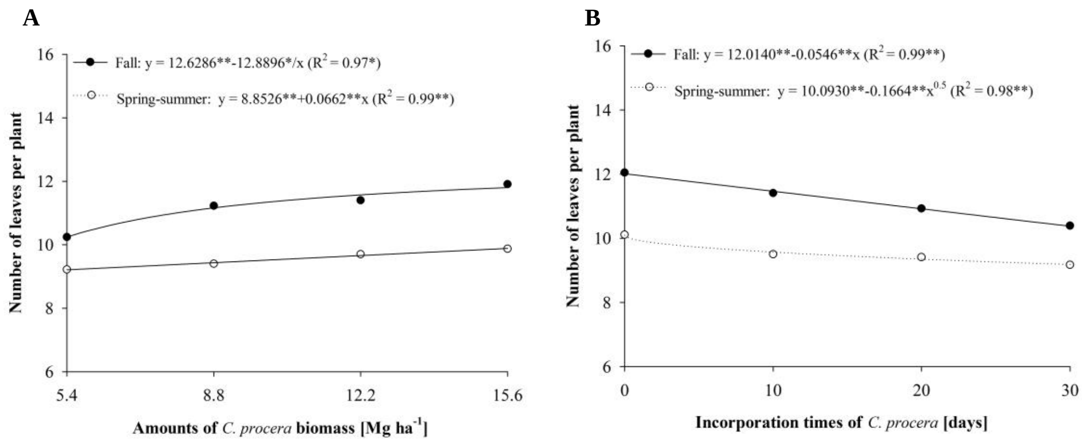


Fig 2. Number of leaves per plant of beetroot in different amounts of *Calotropis procera* biomass (A) and the incorporation times into the ground (B) in two growing seasons (fall and spring-summer).

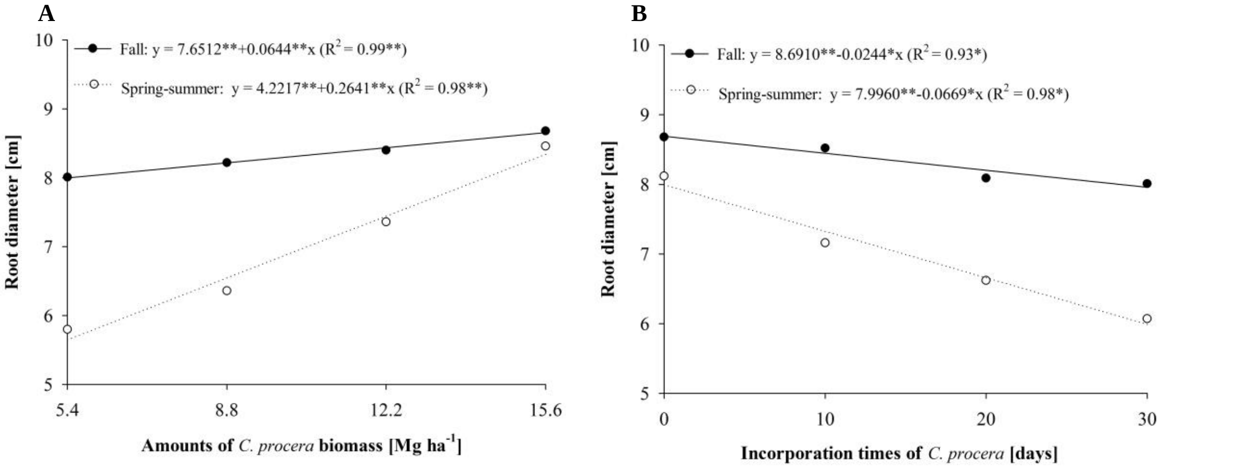


Fig 3. Diameter of beetroots in different amounts of *Calotropis procera* biomass (A) and the incorporation times into the ground (B) in two growing seasons (fall and spring-summer).

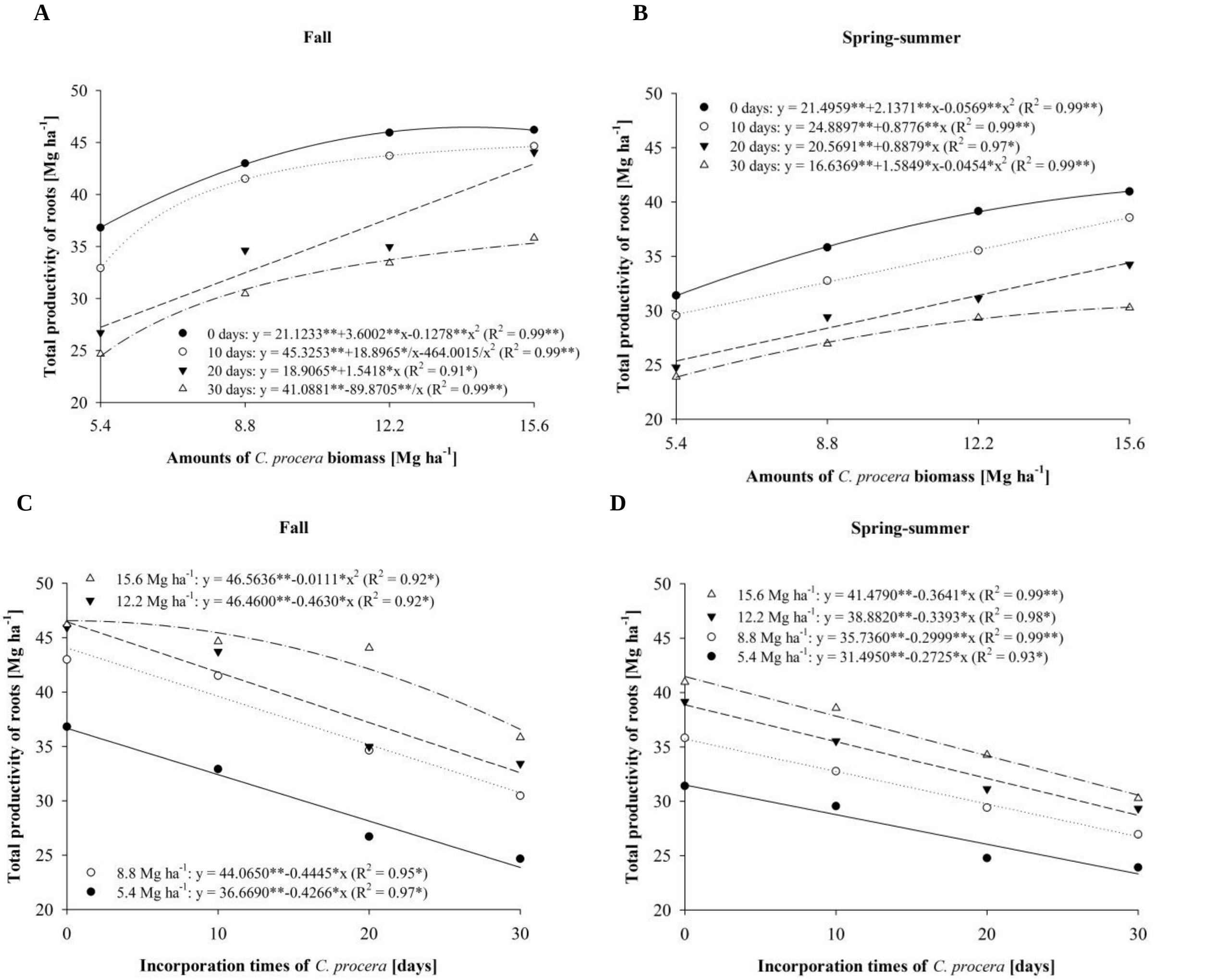


Fig 4. Total productivity of beetroots in different amounts of *Calotropis procera* biomass and incorporation times into the land of the green manure (A. fall; B. spring-summer) and of the converse (C. fall; D. spring-summer) within each growing season.

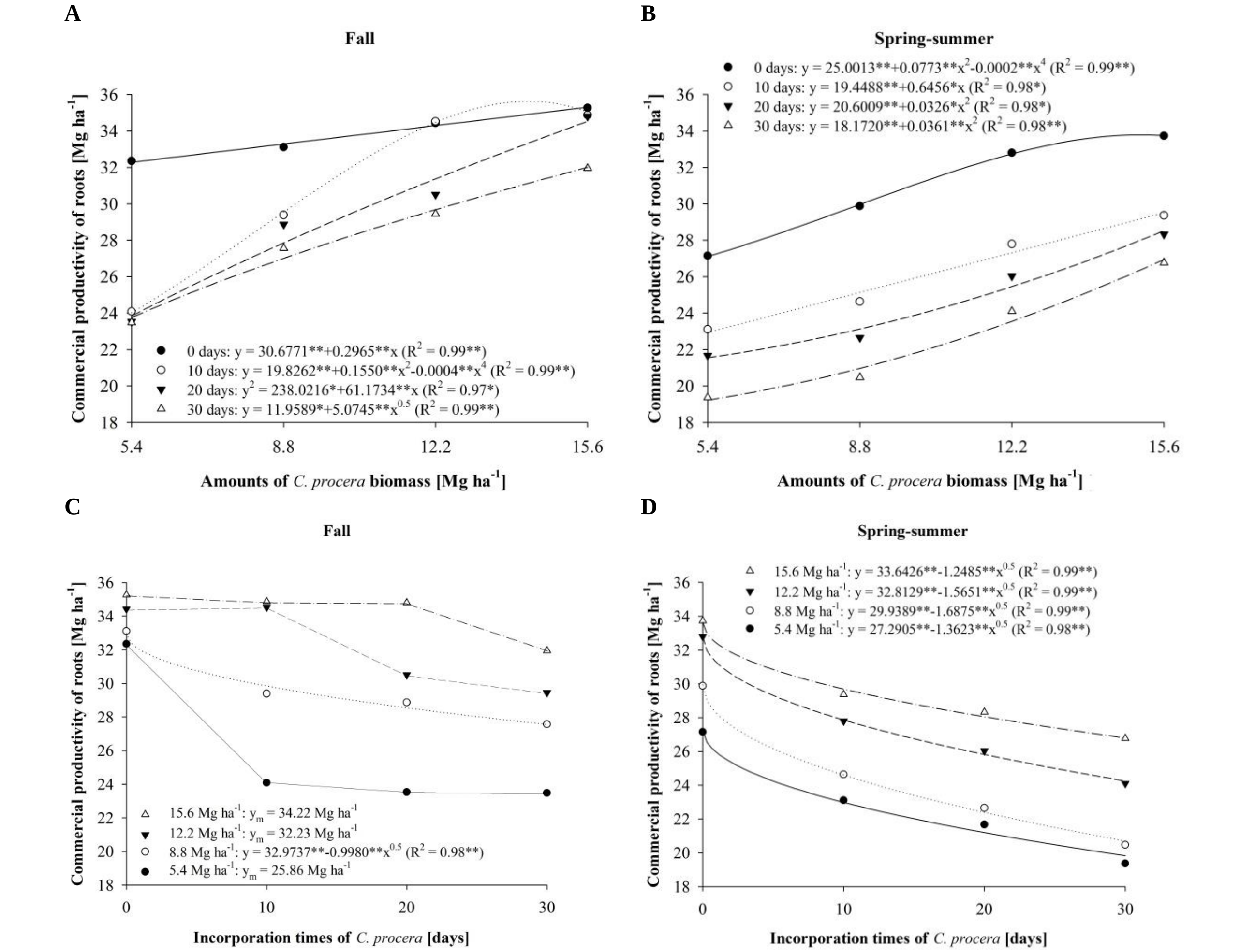
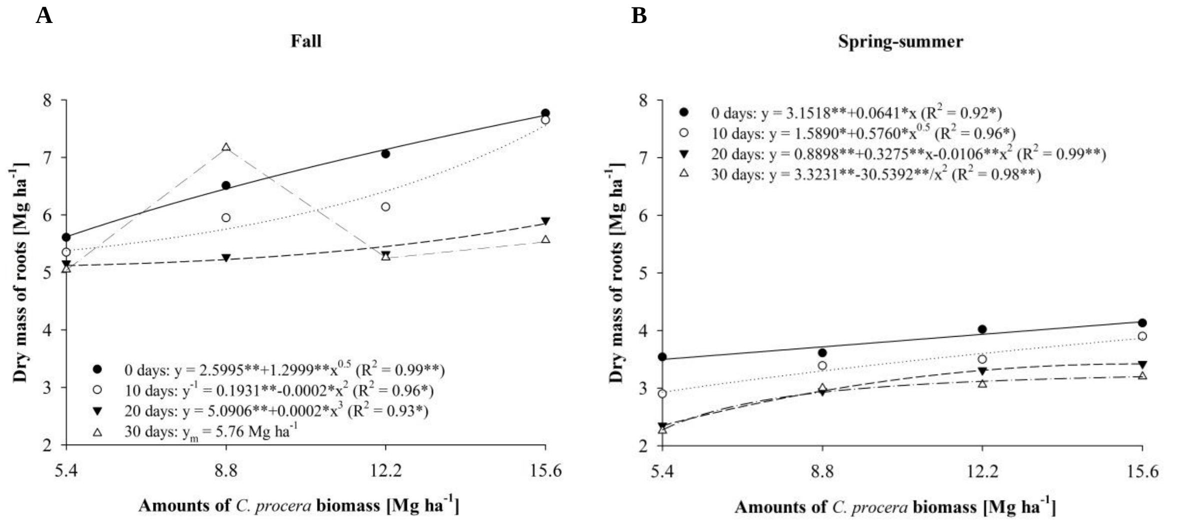


Fig 5. Commercial productivity of beetroots in different amounts of *Calotropis procera* biomass and incorporation times into the land of green manure (A. fall; B. spring-summer) and the converse (C. fall; D. spring-summer) within each growing season.

B



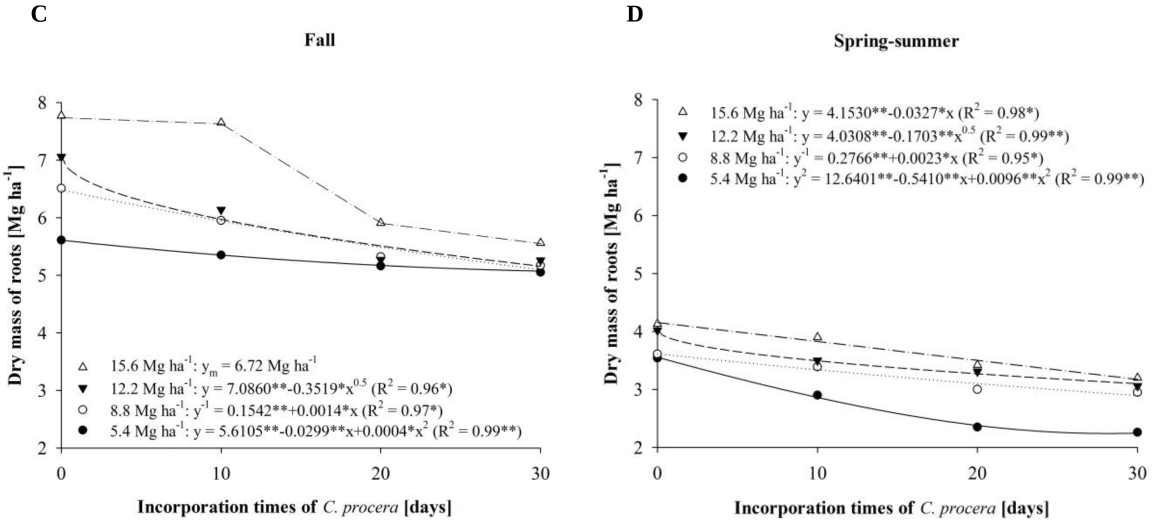


Fig 6. Dry mass of beetroots in different amounts of *Calotropis procera* biomass and incorporation times into the land of the green manure (A. fall; B. spring-summer) and of the converse (C. fall; D. spring-summer) within each growing season.

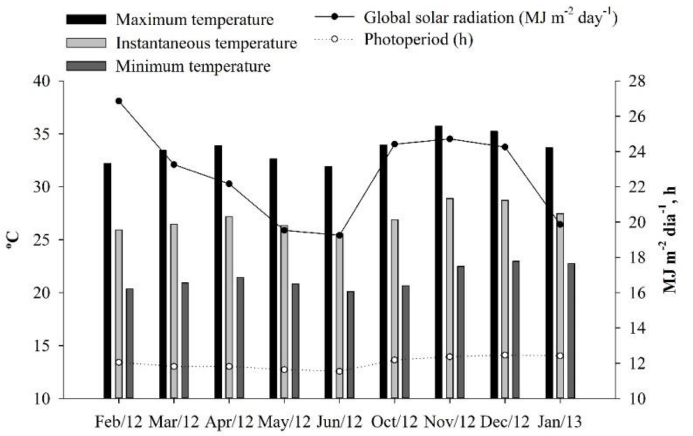


Fig 7. Average values of instantaneous temperatures (ºC), maximum and minimum solar radiation (MJ m^{-2} day^{-1}), and photoperiod (h) in each of the beetroot growing season (2012-2013).

Discussion

Effect of the C. procera *biomass amounts*

In both growing seasons (fall and spring-summer), plant height, number of leaves per plant, diameter, total and commercial productivity, and dry mass of roots showed increasing responses with the increased amount of *C. procera* provided to the culture via green manure. These positive results are probably due to the higher availability of macro (N, P, K, Ca, and Mg) and micro-nutrients (B, Cu, Fe, Mn, Zn, and Na) in the soil, which, when released by *C. procera*, can promote the improvement or maintenance of soil fertility. Alves et al. (2008) emphasize that the omission of macronutrients, particularly N, P, K, and Ca, caused losses in the development of the beetroot, decreasing height, number of leaves, and dry weight (shoot and roots) and affecting the nutrition of vegetable crop, which was reflected in morphological changes.

In addition to the mineralization of the constituents of *C. procera* biomass, the fertilization with plant species that occur spontaneously in the semiarid region also favors the microbiological aspects of soil, with an increase in the number of actinomycetes, fungi, and beneficial bacteria to plant growth since they operate in the solubilization of nutrients of the green manure (Batista et al., 2013). The constant irrigation and occurrence of medium temperatures above 26 °C during the experiments (Fig. 7) may have been stimulant conditions for this microbial activity.

A study in semiarid Potiguar (Mossoró-RN) demonstrated that the best productive performance of the beetroot was obtained when fertilized with *C. procera* in the amount of 21.0 Mg ha^{-1}, achieving total and marketable root productivity 18.74 Mg ha^{-1} and 16.33 Mg ha^{-1}, respectively (Batista et al., 2016). In the same city as the previous study, Silva et al. (2011) found that beetroot fertilized with 15.6 Mg ha^{-1} of hairy woodrose biomass reached commercial root productivity of 9.60 Mg ha^{-1} and a dry mass yield of 2.14 Mg ha^{-1}, thus strengthening the potential of the *C. procera* as an alternative to green manuring with spontaneous species of Caatinga.

Effect of the incorporation times of C. procera

The study of the incorporation time of *C. procera* into the soil allowed us to identify the moment of synchronization between the mineralization of the vegetable residue and the period of maximum nutritional requirements of beetroot (Myers et al., 1994); i.e., the green manure, when incorporated to the soil on the planting day of the crop, had the perfect time to make available in the soil solution the nutrients present in its chemical composition.

The higher demand of nutrients by beetroot takes place in the period 50 to 60 days after sowing for nitrogen, 30 to 50 days for phosphorus, and 30 to 40 days for potassium (Grangeiro et al., 2007), so about 45 days total of incubation of the green manure are needed for greater productivity for this vegetable crop. It is important to note that this recommended time did not change between growing seasons, perhaps because the variation in temperature and in solar radiation (Fig. 7) was unable to promote changes in the speed of the reactions between the microbiota and soil organic matter. Torres et al. (2005) found that most mineralization of N in crops used as green manures occurred in the first 42 days after being desiccated, relating it to the low C/N ratio of the plant material (20-25/1). A similar proportion was also observed in the chemical composition of the *C. procera* (25/1).

Corroborating this result, Silva et al. (2011) obtained the maximum productivity of beetroots when they were fertilized with hairy woodrose on the sowing day of the crop. This green manure, as well as the *C. procera*, had carbon/nitrogen ratio of 25/1.

Effect of growing seasons

To assess the influence of climatic conditions on the growth and development of vegetable crops, experiments must be conducted in different growing seasons, that is, from a different approach from previous studies conducted in individual situations or under controlled conditions (Kenter et al., 2006). This influence was observed in different cultural cycles of beetroots in the fall (85 days) and spring-summer (80 DBS), as well as in the higher agronomic yield obtained in the first growing season. Probably, average temperatures close to 26 °C and a reduced photoperiod (under 12 h) favored vegetative growth and the accumulation of photoassimilates in the culture roots in the fall (Fig. 7).

Moreover, the high temperatures, higher radiation, and prolonged photoperiod in the spring-summer (Fig. 7) may have contributed to a reduction in the accumulation of biomass by the roots of the beet; this condition has a direct influence on the development of species, causing a decrease in the growth cycle of the culture (Taiz and Zeiger, 2013; Barlog et al., 2013; Kenter et al., 2006). High temperatures can also decrease the dry mass accumulation in C3 species because of increasing photorespiration (Polley, 2002).

Similarly, Souza et al. (2016) observed that the green mass yield of arugula fertilized with *C. procera* was higher in the fall compared to the spring-summer cropping. Silva et al. (2017), studying fertilization with *C. procera* in radish culture, also obtained maximum productivity of commercial roots in the fall-winter compared to spring-summer planting. According to Fontanétti et al. (2004), the green manuring reduces the thermal and water variations in the surface layer of the soil and provide the formation and stabilization of aggregates, with improvement in aeration conditions, infiltration, and moisture retention in the soil.

Materials and Methods

Study site

The experiments were conducted in Serra Talhada-PE (7º57'15" south latitude, 38º17'41" west longitude, and altitude of 461 m) in two growing seasons: fall (March 27 to June 20, 2012) and spring-summer (October 31 to January 19, 2013). The local climate, according to Köppen, is Bwh, called semiarid, warm, and dry, with summer rains, a thermal annual average of 24.7 °C, and average annual rainfall of 642.10 mm (SUDENE, 1990; Medeiros et al., 2005). The average meteorological data from the conducting period of the experiments are shown in Fig. 7.

Experiments were carried out in soil with a sandy loam texture. Chemical characteristics at a depth of 0-0.20 m before installing the experiments were, in the fall, pH = 7.2; P = 14.0 mg dm^{-3}; K^+ = 0.6 $cmol_c$ dm^{-3}; Al^{3+} = 0.0 $cmol_c$ dm^{-3}; Ca^{2+} = 3.9 $cmol_c$ dm^{-3}; Mg^{2+} = 1.2 $cmol_c$ dm^{-3}; total porosity 47.6%; density 1.3 g cm^{-1}; clay = 11.6%; sand = 78.36%; and organic matter content of 12.8 g kg^{-1} and, in the spring-summer, pH = 6.6; P = 150.0 mg dm^{-3}; K^+ = 0.7 $cmol_c$ dm^{-3}; Al^{3+} = 0.0 $cmol_c$ dm^{-3}; Ca^{2+} = 3.4 $cmol_c$ dm^{-3}; Mg^{2+} = 2.0 $cmol_c$ dm^{-3}; total porosity 47.6%; density 1.3 g cm^{-1}; clay = 11.6%; sand = 78.4%; and organic matter content of 8.4 g kg^{-1}.

Experimental design, treatments, and plant material

The experimental design was a randomized complete block with three replications. The treatments were arranged in a factorial 4 x 4, with the first factor consisting of four amounts of *C. procera* biomass (5.4, 8.8, 12.2, and 15.6 Mg ha^{-1} on a dry basis) and the second factor being four times of biomass incorporation into the soil (0, 10, 20, and 30 DBS). The biomass amounts of *C. procera* were based on those used by Silva et al. (2011) in the production of beetroot fertilized with *M. aegyptia* in semiarid conditions.

Each experimental unit had total area of 1.44 m^2, with a harvest plot of 0.80 m^2. The beetroot cultivar used was 'Early Wonder', recommended for the semiarid conditions of northeast Brazil.

Conduction of experiments and use of C. procera

The soil preparation consisted of manual cleaning of the experimental area with the aid of a hoe, followed by harrowing and the construction of the beds. Six planting rows were arranged transversely in each plot, spaced at 0.20 m x 0.10 m.

The *C. procera* biomass was collected next to the experiment site and then crushed in a conventional forage machine to yield fragments of two or three centimeters that were dried until hay conditions arose (10% humidity). From samples of this material was determined the nutrient content in the dry matter: N = 17.4 g kg^{-1}; P = 4.4 g kg^{-1}; K = 23.5 g kg^{-1}; Ca = 14.3 g kg^{-1}; Mg = 23.0 g kg^{-1}; Fe = 463.0 mg kg^{-1}, Zn = 40.0 mg kg^{-1}; Cu = 29.0 mg kg^{-1}; Mn = 90.0 mg kg^{-1}; B = 71.0 mg kg^{-1}; Na = 1,640.0 mg kg^{-1}, M.O. = 764.0 mg kg^{-1}; and C/N = 25/1.

The manure was incorporated in the layer of 0-0.20 m soil in the experimental plots, according to the treatments. Daily irrigations (micro-sprinkler system) were carried out in two shifts to promote the microbial activity of the soil in the mineralization process of organic matter.

Direct seeding was conducted two centimeters deep, seeding three seedlings per hill. After ten days of emergence, thinning occurred, leaving one plant per hole. Hand weedings were carried out whenever necessary.

Growing seasons

Planting of beetroot in the first growing season (fall) was done on March 27, 2012, while the spring-summer planting was held on October 31, 2012. The beetroot harvest in the fall was performed 85 days after sowing, while in the spring-summer, it was done after 80 days.

Measured characteristics

At the time of harvest, the following characteristics were evaluated: plant height (cm), obtained by using a ruler to measure a sample of twenty plants from the ground level to the tip of the highest leaf; number of leaves per plant, determined in a sample of twenty plants by directly counting the number of leaves larger than three centimeters in length, starting from the basal leaves until the last open sheet; root diameter (cm), determined in the same sample of twenty plants using a digital caliper; total root yield (Mg ha^{-1}), determined from the fresh weight of all roots of the useful area; and the commercial productivity of roots (Mg ha^{-1}), determined from the fresh mass of plant roots of the harvest area free of cracks, bifurcations, nematodes, and mechanical damage; and dry mass of roots (Mg ha^{-1}), estimated from the weight of the mass of twenty plants of the harvest area after drying in an oven with forced air, with the temperature set at 65 °C, until constant mass was achieved.

Statistical analysis

Data were subjected to analysis of variance by the F test at 5% probability. The comparison of the two experiments was conducted using a joint analysis with the aid of the SISVAR software (Ferreira, 2011). A response curve fitting procedure was done between assessed traits and quantitative factors through the SigmaPlot 12.0 software (Systat Software, 2011). The Tukey test ($p<0.05$) was used to compare means between growing seasons.

Conclusion

From the results of this work, it can be seen that the agronomic performance of the beetroot is subject to variations according to the amount and incorporation time of the green biomass of *C. procera*. The growing season also affected the culture performance, possibly by the influence of climate variations. The best agronomic performance of the beetroot was obtained by fertilization with 15.6 Mg ha^{-1} *C. procera*. The ideal time of incorporation of green manure coincided with the date of the sowing of beetroot. Cultivation in the fall resulted in higher total and commercial productivity of the roots of beetroot fertilized with *C. procera*.

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