Industrial Crops & Products xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Industrial Crops & Products

journal homepage: www.elsevier.com/locate/indcrop

Plant density does not influence every castor plant equally

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ARTICLE INFO

Keywords:
Ricinus communis
Plant density
Dominance
Hierarchy
Leaf area

ABSTRACT

Castor (*Ricinus communis*) is an oilseed crop, which oil is used in the chemical industry for several products. There are attempts to adjust the plant density of castor aiming to increase its seed yield. This study discusses how plant density influences seed yield of individual castor plants. It explores the concept that neighboring plants establish an interplant hierarchy, and that the hierarchy changes along the cropping season. Two field experiments were performed under contrasting environmental conditions. One experiment was run under irrigation in a temperate region (Lubbock, TX, USA), with plant density varying randomly. The other experiment was run without irrigation in a tropical and semiarid region (Balsas, MA, Brazil), with plants placed in previously defined in-row distance. Data from individual plants was taken on leaf area and plant height at two-week intervals and on seed yield in 48 plants in the temperate and 84 plants in the tropical location. Plant hierarchy was calculated as the leaf area or plant height of a given plant divided by the average of the two neighboring plants in the same row. It was observed that in the temperate environment, as early as 10 days after emergence, the plant hierarchy in leaf area was correlated with the final seed yield ($r = 0.36$). Plant density did not influence seed yield in the temperate location, but in the tropical conditions, higher productivity was found under higher plant density. In both environments, the interplant hierarchy changed considerably along the cropping season, and the plants that dominated around flowering time had higher seed yield than the plants that became dominating later. Seed yield had the highest correlation with the plant leaf area and height at the beginning of reproductive phase.

1. Introduction

Plant density is regarded as an important component of the cropping system because it influences many farming protocols and the seed yield. Attempts to define an optimum plant density for castor (*Ricinus communis* L.) are failing because such optimal density depends on many factors such as plant architecture, soil characteristics, crop management (fertilization, weed control, plant growth regulators), and on the environmental conditions along the cropping season (rains, temperature, luminosity, air humidity). For instance, the cultivar BRS Nordestina was tested in different locations, and the optimal plant density for each experiment varied from 4200 plant/ha(Severino et al., 2006a) and 5000 plant/ha (Severino et al., 2006b) to 12,500 plant/ha (Carvalho et al., 2010).

Castor plants have a considerable capacity to adjust the yield components in a way that a given change in the plant density is compensated by adjustments in the number of racemes, number of seeds per raceme, and seed weight. For that reason, it is common to find negligible or inconsistent effect of plant density on castor seed yield (Bizinoto et al., 2010; Diniz et al., 2009; Petinari et al., 2012; Severino and Auld, 2013; Soratto et al., 2011, 2012; Souza-Schlick et al., 2011; Souza-Schlick et al., 2012).

The complex interaction of factors related to the plant density is reflected in the fact that a broadly accepted optimal plant density is not defined even for major crops such as corn (*Zea mayz* L.), cotton (*Gossypium hirsutum* L.), peanut (*Arachis hypogaea* L.), and soybean (*Glycine max* L.) (Boquet, 2005; Duncan, 1986; Egli, 1988; Lanier et al., 2004; Maddonni and Otegui, 2004; Rossini et al., 2011; Weber et al., 1966; Wells, 1991). Extensive experimentation with soybean for more than 50 years failed to generate a general hypothesis to explain the association of seed yields and planting patterns (Duncan, 1986).

This study adds some information to the debate on how plant density influences castor seed yield. The approach of this study considers that each individual plant in the plant community is influenced by plant density in a different way. The influence of plant density depends on three factors: i) the intensity of competition made by neighboring plants, ii) environmental conditions, and iii) the competition for assimilates between vegetative growth and seed production. This

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http://dx.doi.org/10.1016/j.indcrop.2017.05.061
Received 29 January 2017; Received in revised form 29 May 2017; Accepted 29 May 2017
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Please cite this article as: Severino, L.S., Industrial Crops & Products (2017), http://dx.doi.org/10.1016/j.indcrop.2017.05.061

approach is opposite to the assumption that all the plants in the community respond equally to the intensity of competition defined by plant density. This discussion is important because the seed yield results from the integration of many factors acting together, and the seed yield depends on the interaction of all those factors rather than from any of the factors isolated. When only the average seed yield is measured, those interactions occurring at single-plants level are ignored. As suggested by Maddonni and Otegui (2004), the study of plant-to-plant variability within a stand add some information to understand the interplant interference and the establishment of hierarchies.

This study had the objective to investigate the variability in the response of castor plants to plant density and how it influences seed yield. The study was made by measuring plant-to-plant variability in leaf area, plant height, and seed yield being influenced by within-row spacing in temperate and tropical environments.

2. Material and methods

2.1. Temperate environment

The experiment was run in 2012 at field conditions in the Experimental Farm of Texas Tech University in Lubbock, TX, USA (33°36′ N; 101°54′W, 990 m of elevation). The plant material was castor cv. Brigham, which is the first commercial variety with reduced ricin content (Auld et al., 2001). The experiment was planted in 12 June 2012 in a spacing of 0.9 m between rows. Irrigation was applied with a subsurface drip irrigation system with tapes buried 30 cm below the soil surface. Irrigation was applied at a rate of 5 mm/day from planting through 9 September 2012. After irrigation was withheld, precipitation supplied additional 69 mm of water. Data on mean air temperature, accumulated degree-days, and supplied water (irrigation + precipitation) are presented at 30-days intervals (Table 1). The soil had a pH of 8.6, 11 g/kg of organic matter, 45 mg/kg of P, and 520 mg/kg of K. Nitrogen was applied through irrigation water at the rate of 67 kg/ha at 30 days after planting (DAP). Weeds were controlled by hoeing, and no treatment for disease or pest was required.

Data was collected in plants in a row chosen randomly in a field planted for seed production. Plant spacing was naturally uneven due to the planting equipment and occasional failures of seedling emergence. The lateral rows were cultivated with similar variety, random plant density, and crop management. Beginning just after seedling emergence, data was taken on 50 contiguous plants in the selected row, but the data from the first and last plants was used only for calculation of hierarchy. Plant spacing was assumed as half of the distance between the preceding and the following plant. The plant spacing varied randomly from 0.14 to 1.26 m (equivalent to 8818–79,365 plant/ha), with an average of 0.48 m and a CV of 52.2%. All the plants in the row survived to harvest.

Data on plant height and leaf area was taken every two weeks (approximately) beginning at 10 DAP. The leaf area was calculated using the equation $Leaf\ area = 0.262 \text{ x } V^{2425}$, in which V is the length of the main vein that was measured in each leaf of the plant (Severino et al., 2004). The plant leaf area was calculated as the sum of the area of each individual leaf. Fruits that turned from green to brown were harvested every week, oven dried (105 °C, 1 day), hand threshed, and seeds were weighed. The killing frost occurred in 27 October 2012 (at 137 DAP). Two days after the killing frost, the remaining fruits were harvested and processed as previously described.

2.2. Tropical environment

The experiment was made in 2014 in the farm Fazenda Modelo, Balsas, MA, Brazil (7°31′ S; 46°02′W, 250 m of elevation). The plant material was castor cv. BRS Energia. The experiment was planted in 19 February 2014 and terminated in 16 July 2014 (147 DAP). Plants were rainfed, and total precipitation was 303 mm. The rain was poorly distributed, as 173 mm occurred in the first 30 days, and only 130 mm occurred in the following 118 days. Data on mean air temperature, accumulated degree-days, and precipitation are presented at 30-days intervals (Table 1). Fertilization was made with 40 kg/ha of nitrogen (urea, 1/3 at planting and 2/3 at 45 DAP), 60 kg/ha of P_2O_5 (MAP), and 60 kg/ha of potassium (KCl). The fertilizer was distributed in the planting row. Weeds were controlled by hoeing, and no treatment for disease or pest was required. Because of the intensive drought, some plants did not survive until 147 DAP. Some plants died beginning at 115 DAP.

Row spacing was constant at 0.75 m, while the distance between plants was carefully controlled in a way that for each plant the distance to the previous plant was 9.1% smaller than to the next. Plant spacing was assumed as half of the distance between the preceding and the following plant. Within-row spacing varied from 0.19 to 1.09 m (equivalent to 12,232 to 66,666 plant/ha), and each plant density was replicated four times. The experiment was planted in three rows following the same spacing in the neighboring plants. Data was taken only in the central row on leaf area, plant height, and seed yield following the same procedures as described in the Section 2.1 in the experiment in the temperate environment. Because the plants were under severe drought stress and because castor plant has large leaves, in some cases the leaf area of individual plants changed substantially between measurements. When the experiment was terminated, the fruits in all plants had turned brown and the leaves were senesced due to intensive drought stress.

2.3. Statistical procedures

Leaf area index (LAI) was calculated for individual plants as $LAI = LA/(S_r \text{ x } S_i)$, in which LAis the plant leaf area, S_r is the row spacing, and S_i is the in-row plant spacing. The hierarchy among plants was determined as dominance index (D) which was calculated as $D = 2 \text{ x } P_i/(P_{i-1} + P_{i+1})$, in which D is the dominance index, P_i is the

Table 1
Mean air temperature, accumulated degree-days, and supplied water (precipitation + irrigation) at 30-days intervals in the temperate and tropical environments.

Days after planting	Lubbock, TX, USA			Balsas, MA, Brazil		
	Mean air temperature (°C)	Accumulated degree-days[1]	Irrigation + precipitation (mm)	Mean air temperature (°C)	Accumulated degree-days[1]	Precipitation (mm)
1–30	28.0	390	194	26.7	351	173
31–60	29.1	813	158	27.0	711	74
61–90	25.6	1131	164	27.7	1092	51
91–120	18.6	1239	64	27.8	1476	5
121-end[1]	18.0	1287	5	28.0	1814	–
Total water	–	–	585	–		303

[1]Base temperature = 15 °C.
[2]The experiment ended at 137 DAP in Lubbock, TX, USA and at 147 DAP in Balsas, MA, Brazil.

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