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Seed yield and yield components of castor influenced by irrigation

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ABSTRACT

An understanding of yield components is critical to the successful development of castor cultivars (*Ricinus communis* L.) adapted for different cropping systems (such as mechanical harvest) and growing regions. A detailed study was made on the changes occurring in the castor oil yield components in response to irrigation. The experiments were conducted in Lubbock, TX in 2009 and 2010. Six castor cultivars highly divergent in seed weight, plant height, and number of racemes were cultivated on a subsurface irrigation system with total water (including precipitation) varying from 188 to 897 mm. Seeds were harvested, counted, and weighed from individual racemes. Irrigation increased seed yield in all the cultivars. The largest increase in seed yield was observed in the cv. BRS Nordestina which was raised from 232 kg ha^{-1} under 188 mm (rainfed) to 2758 kg ha^{-1} under 897 mm of precipitation + irrigation. There were large differences in the magnitude of yield components among cultivars; however, in all cultivars most of the variation in the oil yield was explained by the number of racemes, followed by the number of seeds per raceme, and then by the seed weight. The changes in seed oil content had negligible importance for the determination of the oil yield. For example, comparing plants of the cv. BRS Energia under rainfed and maximum irrigation, the number of racemes increased by 151% (from 7.5 to 18.8 raceme plant^{-1}), the number of seeds decreased 17% (from 72 to 60 seed raceme^{-1}), the seed weight increased 23% (from 235 to 289 mg), but the seed oil content increased only 7% (from 462 to 493 g kg^{-1}). Three quarters of the seeds matured in 42 days prior to 130 days after planting, while only 8% matured in the following 45 days. A discussion was made on the trade-offs between yield components and the ability of castor plants to adapt to the environment, and how this information can be used to improve the crop management and breeding of this oilseed crop.

1. Introduction

The response of yield components to environmental stress in castor (*Ricinus communis* L.) is dependent on many factors. While measuring yield components is relatively easy, the use of this information to improve oil yield is complex because the components are influenced by not only environment, but also genetic and physiological controls and evolutionary constraints (Sadras and Slafer, 2012). A detailed understanding of the factors controlling the yield components in castor plants would support the optimization of management practices and the development of cultivars with increased oil yield potential.

Historically, selecting for a specific yield component has had limited influence on final seed yield because of compensation among yield components. Yield components are interdependent, and they change in response to current or anticipated environmental conditions. Because negative correlations among yield components are very common (Kumar et al., 1997; Rajala et al., 2009; Sadras and Slafer, 2012; Soratto et al., 2011), optimum productivities will not be obtained by selecting for increments in an individual component, but by promoting a set of yield components with which the plant will optimize the utilization of environmental resources.

The oil yield components in castor plants are (1) number of racemes, (2) number of seeds per raceme, (3) seed weight, and (4) seed oil content. In some studies, the number of seeds per raceme was broken down to number of fruits per raceme and number of seeds per fruit; however, these two components are preferably analyzed together because there is negligible variation in the number of seeds per fruit (Fanan et al., 2009; Machado et al., 2009; Soratto et al., 2011, 2012; Souza-Schlick et al., 2011, 2012). After the reproductive phase begins, the castor plant is able to continually initiate new racemes. Consequently, seeds in each raceme grow under a different set of environmental conditions (Severino and

Abbreviations: cv, cultivar; DAP, days after planting; PET, potential evapotranspiration.

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Auld, 2013). The number of seeds in each raceme can also be highly variable, but the factors controlling this yield component are not clear. Environmental factors seem to have limited influence on the seed weight and seed oil content (Nagabhushanam and Raghavaiah, 2005; Soratto et al., 2011, 2012; Souza-Schlick et al., 2011, 2012). Special attention has been given to seed oil content because the oil is the primary commercial product.

Water is the environmental factor with the highest impact on the plant growth and the most frequent factor limiting seed yield. For castor, water is particularly important because the most important regions cultivating this oilseed are semi-arid (Anjani, 2010; Severino et al., 2012a). The response to drought stress is very different between determinate and indeterminate plants. In determinate plants, anthesis provides a clear division between the vegetative and reproductive phases. The plant responds with a reduced seed number if a drought stress occurs before anthesis or with a reduced seed weight if it occurs after anthesis (particularly during seed filling) (Rajala et al., 2009, 2011). In castor, the response to drought stress is complicated because the plant initiates racemes at different times, and each raceme can adjust both the seed number and seed weight according to environmental conditions and plant source-sink status.

The objective of this study was to measure the changes in oil yield components in six cultivars of castor highly divergent regarding yield components in response to a variation in the water availability controlled by irrigation treatments. The changes in yield components over time and the accumulated oil yield along the growing season were also investigated.

2. Materials and methods

The experiment was run on the Texas Tech University Experimental Farm at Lubbock, TX, United States (33°36′ N; 101°54′ W, 990 m.a.s.l.) in 2009 and 2010. Six castor cultivars (AL Guarany, BRS Energia, BRS Nordestina, Campinas, Divela, and Hale) were cultivated under seven levels of irrigation (varying from 0.0 to 6.0 mm day^{-1}, with increments of 1 mm day^{-1} between treatments). These cultivars were selected for wide divergence in plant height, raceme number, raceme size, and seed weight. The cv. AL Guarany was developed in Brazil by CATI. It has medium height, large fruits and seed, and it usually initiates a large primary raceme (Freire et al., 2001). The cv. BRS Energia was developed in Brazil by Embrapa. It is a medium-height plant, adapted to mechanical harvest, and it usually produces many medium-sized racemes (Milani et al., 2007). The cv. BRS Nordestina was developed in Brazil by Embrapa. It produces a large and black seed, and it is not appropriate for mechanical harvest due to the height and wide stem (Freire et al., 2001). The cv. Campinas was developed in Brazil by IAC. It has a medium to short height, with medium-sized seeds and some degree of dehiscence in the fruits (Banzatto et al., 1976). Divela was a genotype in the castor breeding program of Texas Tech University registered as the PI 183078 (USDA repository) that was introduced from India. It is a tall plant, with easily shattering fruits (due to braking of the petioles rather than due to dehiscence), with very small seeds, and large number of small racemes. The cv. Hale was developed in the U.S.A. by USDA/ARS and Texas A&M University (Brigham, 1970). It has short height, small seeds, and it can be mechanically harvested. Except for Hale, all the cultivars were developed in tropical regions, but previous evaluations in the same region confirmed that their seed yields were compared to the local cultivar (Oswalt, 2011).

Irrigation was applied with subsurface drip irrigation spaced 0.9 m apart and buried 30 cm below the soil surface. The experiments were planted on 28 May 2009 and 24 May 2010. In 2009, the irrigation was applied from 10 days after planting (DAP) through 116 DAP. In 2010, it was applied from 28 DAP through 107 DAP. The period of irrigation was adjusted based on the precipitation and crop development. In 2009, precipitation totaled 188 mm (Table 1), and a 15-mm rain at 65 DAP was followed by 39 days with only 3.3 mm of precipitation. In 2010, precipitation totaled 259 mm, but 135 mm occurred in only three days (after 41 DAP). Irrigation (35 mm) was applied just after planting to allow germination. An 18-mm precipitation at 49 DAP was followed by 49 days with only 7.5 mm of rain. Any precipitation occurring after 150 DAP (25 October, 2009 and 21 October, 2010) was not considered to influence the final oil yield because of the low air temperatures (Table 1) and the short time before killing frost. The precipitation was considerably smaller than the potential evapotranspiration (PET), particularly in the first half of the growing season, when the plants have an intensive photosynthetic activity and a higher water demand. On average between June and August, the precipitation was only 15 and 36% of the PET in 2009 and 2010, respectively.

The soil had a pH of 8.6, 11 g kg^{-1} of organic matter, 45 mg kg^{-1} of P, and 520 mg kg^{-1} of K. Nitrogen was applied at the rate of 67 kg ha^{-1} at 30 DAP. Weeds were controlled by hand, and no disease or pest requiring control was observed. A randomized block design was used with irrigation treatments applied in strips. Blocks were orthogonal to the irrigation strips. Seeds were mechanically planted at 0.9 m between rows. The seedlings were thinned to 0.9 m between plants at 10 DAP to establish a plant population of 12,346 plant ha^{-1} for all cultivars. The plant population was not adjusted to the characteristics of each genotype. For that reason, the cultivars probably were not able to express their full yield potential, and for this reason, comparisons of oil yield among cultivars were not made in this study. However, the main objective of this study (measuring the yield components) was not impaired by the equal plant population. Each plot had 4 rows with 8 plants per row. Racemes were individually harvested and analyzed in one plant per plot.

Along the growing season, racemes were hand harvested at maturity in one plant randomly selected in each plot. They were considered mature when all the fruits had hard spines and brownish color (up to two fruits close to maturation was tolerated). Four days before the anticipated killing frost, racemes with two thirds of mature fruits were harvested to prevent them from being mixed with the more immature racemes to be harvested after the plants were frost killed. In 2010, data was also taken on the harvest date of each raceme. The capsules were oven dried (75 °C, for at least 7 days). Two weeks after the killing frost, the fruits in all the plants in the two central rows were harvested, and weighed. A 200-g sample of fruits was collected for each cultivar, manually threshed, and the seeds were weighed. The proportion of fruit to seed weight in the samples was used to convert the fruit weight to seed weight.

The seeds from individual racemes were manually threshed, counted, and weighed. The seed oil content of each individual raceme was measured on wet base in 50-g samples by Nuclear Magnetic Resonance (Minispec mq10, Brucker Optics, Billerica, MA). The oil yield was broken down in the following components:

$$\text{Oil yield (g plant}^{-1}) = \{\text{raceme plant}^{-1}\} \times \{\text{seed raceme}^{-1}\} \times \{\text{seed weight}\} \times \{\text{seed oil content}\}.$$

The calculations of yield components in each plant were made as follows. The raceme $plant^{-1}$ was the counting of the racemes harvested in each plant. The seed $raceme^{-1}$ was the total number of seeds divided by the number of racemes in the plant. The seed weight was the weight of all seeds divided by the number of seeds in the same plant. The oil yield was calculated as the sum of the seed weight of each raceme multiplied by its seed oil content. The