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Optimized nitrogen fertilizer application enhances absorption of soil nitrogen and yield of castor with drip irrigation under mulch film

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ABSTRACT

Optimization of nitrogen fertilizer application is an important means of improving castor (*Ricinus communis* L.) yield. The method of nitrogen application with drip irrigation under mulch film (DI) differs from that of standard cultivation practices. A field experiment was conducted in 2013 and 2014 to investigate the effects of different nitrogen treatments (0, 100, 200, 300, and 400 kg N ha^{-1}) on castor yield, nitrogen use efficiency, and dynamic changes in the spatial distribution of roots under DI. The main objective was to determine the effectiveness of nitrogen fertilizer application for simultaneous improvement of the nitrogen use efficiency and productivity of castor. Yield showed a distinct increase with elevation in nitrogen application rate. The highest yields of 5939.3 and 5812.1 kg ha^{-1} were attained under nitrogen application of 300 kg N ha^{-1} in the 2013 and 2014 cropping seasons, respectively. However, application of 400 kg N ha^{-1} did not further increase yield. Root length increased gradually with increasing nitrogen application from 0 to 200 kg N ha^{-1}. Under 200 kg N ha^{-1}, maximum root length was observed and the root length density in the soil was most widely distributed in the entire soil profile, which may account for the high nitrogen use efficiency observed in this treatment (72.4% and 67.4% in 2013 and 2014, respectively). The difference in yield between the 300 kg N ha^{-1} and 200 kg N ha^{-1} treatments was not significant. The results suggest that the optimal nitrogen application for castor under DI is between 200 and 300 kg N ha^{-1} to improve yield and nitrogen use efficiency simultaneously.

1. Introduction

Castor (*Ricinus communis* L.) is an industrial crop cultivated for the oil contained in the seeds. Castor oil is predominantly used in the specialty chemical industry worldwide. Growth in consumption of castor oil is limited by insufficient and unreliable feedstock supply rather than by industrial demand (Severino et al., 2012). The majority of the global castor-seed crop (96%of world production as of 2009) is produced mostly by small farmers in only four countries: India, China, Brazil, and Mozambique (Severino and Auld, 2013).

In China, castor is mainly grown in Northeast and North China. However, in these regions, the most productive arable land is mainly planted in food crops. Given that castor oil is exclusively an industrial product, it is impossible for castor production to compete with food crops for cultivation on high-quality agricultural land. Consequently, castor cultivation in these regions is highly fragmented and produces an average yield of only 2700 $kgha^{-1}$. In inland areas of China, such as Xinjiang, although the land area is large, the climate is arid and soil salinity is high; thus, the planting area of grain crops is extremely small. Castor is tolerant to high salinity (Silva et al., 2005) and drought (Severino et al., 2012); therefore, inland areas maybe more suitable for large-scale cultivation of castor in China.

Xinjiang is a typical irrigated arid area. The drip irrigation under mulch film (DI) technology, developed as a water conservation measure, has been widely used in Xinjiang since the late 1990s (Hu and Li, 2003). The application of DI technology has been highly successful for cotton production in Xinjiang. For example, irrigation water and nitrogen applications were reduced by about one-third and one-fifth, respectively, under DI compared with flood irrigation (Zhang et al., 2002). Cotton production increased from 4500 kg ha^{-1} before the introduction of DI to 6750 kg ha^{-1} after the application

Abbreviations: DI, drip irrigation under mulch film; ANR, apparent nitrogen recovery; PFP_N, nitrogen partial factor productivity.

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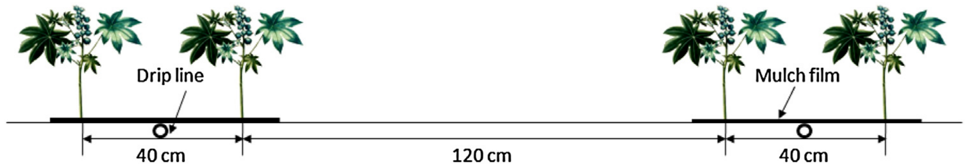

Fig. 1. Plant spacing and irrigation system used in the experiment.

of DI. Application of DI technology may be similarly beneficial for intensive castor production in arid areas.

Castor must be grown in soils of high fertility to attain good productivity. Nitrogen is the most important nutrient for castor growth (Torres et al., 2016). The quantity and method of nitrogen application under DI differ from those of standard cultivation practices, with the majority of nitrogen fertilizer (80%) applied to the soil via drip irrigation. Research on the optimal nitrogen application for castor is important to achieve high yields under DI.

Compared with phosphorus and potassium, nitrogen in the soil is highly mobile. Soil nutrients are taken up by plant roots, thus the effectiveness of nitrogen application is mainly dependent on interception by roots and accessibility to the plant, that is, the biological and spatial efficiency of nutrient use. However, owing to the influence of soil heterogeneity and fertilization, the nutrient distribution in the soil is usually non-uniform. The root systems of crop plants often detect the uneven distribution of nutrients and make an adaptive response because soil nutrients closest to the roots are always absorbed preferentially. Therefore, the spatial distribution of the crop root system and the contact area with the soil are important for nutrient absorption. Revealing the spatial distribution of nitrogen and characteristics of the root system in the soil and their interactions, and regulation of root growth, morphology, and absorption activity to enhance nutrient availability in the rhizosphere, will be beneficial to meet the nitrogen demand of castor at different growth stages.

Previous studies on the effects of nitrogen fertilizer application on castor have mainly concentrated on the yield response (Moro et al., 2011; Severino et al., 2006a, 2006b; Silva et al., 2007), and have not considered the nitrogen utilization efficiency. Similarly, biological knowledge of castor root systems, especially the spatial and temporal distribution characteristics of the root system in the soil, is also deficient (Severino and Auld, 2013). Furthermore, no information is available on the effects of nitrogen fertilizer application on castor grown in an arid environment under DI.

The aim of the present study was to determine the effects of nitrogen fertilizer application on yield, nitrogen use efficiency, and dynamic changes in the spatial distribution of roots of castor under DI. The overall objective is to establish whether nitrogen fertilizer regulation is an effective approach to improve nitrogen use efficiency and castor productivity simultaneously through application of nitrogen fertilizer.

2. Materials and methods

2.1. Experimental design

The field experiment was carried out at the Xiaoguai Experimental Station of the Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences in Urumqi, China, in the 2013 and 2014 cropping seasons. The site has an arid climate typical of the area with average annual rainfall of 105.3 mm, annual evaporation of 2692 mm, annual sunshine hours of 2705 h, accumulated temperature ≥10 °C of 3760 °C, and 232 frost-free days per annum.

The soil type at the study site is a gray desert soil typical of the region. The soil was analyzed before sowing. The chemical properties of the 0–30 cm soil layer were as follows: extracted mineral nitrogen 16.7 mgkg^{-1}, pH (H_2O) 8.1, soil density 1.33 g cm^{-3}, Olsen phosphorus 3.1 mg kg^{-1}, NH_4OAc-extracted potassium 208.9 mg kg^{-1}, and organic matter 5.3 g kg^{-1}.

The experiment included five nitrogen treatments: 0, 100, 200, 300, and 400 kg N ha^{-1}. A randomized block design with three replicates was used. Thus, in total there were 15 plots, each 16 m × 10 m in area. Border plots were included on the margins of the experimental field to eliminate border effects. Weed growth on the plots was controlled with pre-emergence herbicides and cultivation.

Seeds of the castor hybrid 'Nongfeng' were sown on 23 April, 2013 and 20 April, 2014 at an identical density of 31,250 plants ha^{-1}. Two rows (40 cm apart) were sown on either side of the irrigation drip line. The distance between two drip lines was 160 cm, with 40 cm spacing between plants within a row (Fig. 1).

The total volume of water supplied by DI was 4000 m^3 ha^{-1}.

Nitrogen fertilizer was applied in the form of urea, of which 20% was applied before sowing as a basal dressing, and the remainder was applied with drip irrigation. In addition, 150 kg P_2O_5 ha^{-1} (as superphosphate) and 150 kg K ha^{-1} (as potassium sulfate) were applied before sowing as a basal dressing.

The specific applications of water and topdressing of nitrogen fertilizer in each treatment are summarized in Table 1.

2.2. Plant harvest

Plants were harvested at 158 days after sowing (DAS) in 2013 and at 161 DAS in 2014, respectively. On each sampling date, six whole plants were harvested from each plot (two plants each from three adjacent rows). The shoots were divided into leaves, stems, and reproductive organs. All samples including roots were killed at 105 °C for 30 min, then dried at 70 °C until a constant weight was attained. The dry weight was recorded and subsamples were taken to measure the nitrogen content using the Kjeldahl method (Nelson and Somers, 1973).

To study in detail the spatial distribution of roots and available nitrogen in the soil, a monolith method (Böhm, 1979) was used to harvest roots at 118 and 123 DAS in 2013 and 2014, respectively, at which date the castor plants were at the grain-filling stage. From the limited information currently available, a sigmoidal pattern of growth is evident for root length, and have the largest root system (e.g., root length) at the grain-filling stage (Peng et al., 2010). Soil cubes with 13-cm sides (2740 cm^3) were dug individually in a soil volume of 78 cm × 39 cm and to a depth of 52 cm surrounding one plant (Fig. 2). The total number of monoliths per plant was 72. Each soil block was placed in a separate plastic bag and labeled with the spatial coordinates. Roots were sieved with a stainless steel mesh (1-mm diameter) and rinsed with water, then stored at −20 °C until measurement of the root length. Soil samples were collected from each soil block after the roots were sieved, then dried for analysis of soil available nitrogen by continuous flow analysis (TRAACS 2000; Bran and Luebbe, Norderstedt, Germany).