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JP Panchal

Assistant Research Scientist,
 Bidi Tobacco Research
 Station, AAU, Anand, Gujarat,
 India

JC Shroff

Professor, Dept. of Agronomy,
 B. A. College of Agriculture,
 AAU, Anand, Gujarat, India

CF Makwana

Farm Manager, Krishi Vigyan
 Kendra, AAU, Devataj, Gujarat,
 India

DR Padheriya

Assistant Research Scientist,
 Regional Cotton Research
 Station, AAU, Viramgam,
 Gujarat, India

To evaluate the effect of spacing and nitrogen level on yield and quality of castor and post-harvest soil properties under middle Gujarat agro-climatic zone

JP Panchal¹, JC Shroff², CF Makwana³, DR Padheriya⁴

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ABSTRACT

The pooled results of two years of experimentation revealed that crop geometries and nitrogen levels significantly influenced seed yield, oil yield, nitrogen content and nitrogen uptake of hybrid castor. Among the crop geometries, 120 x 45 cm (S₄) recorded the highest seed yield (3783 kg/ha) and oil yield, whereas the closer geometry of 90 x 45 cm (S₂) recorded the lowest seed yield (2729 kg/ha). Oil content remained statistically unaffected by crop geometry. Application of 140 kg N/ha (N₃) significantly increased seed and oil yields, nitrogen content and uptake in both seed and stalk, although it remained statistically at par with 120 kg N/ha (N₂) for most parameters. The interaction of crop geometry and nitrogen levels indicated that S₄N₃ (120 x 45 cm with 140 kg N/ha) recorded higher seed and oil yield and nitrogen uptake in seed. Nitrogen content in seed and stalk was also enhanced with increasing nitrogen levels. Post-harvest soil chemical properties, including pH, EC, organic carbon, available phosphorus and available potassium were not significantly influenced by crop geometry or nitrogen levels, whereas available nitrogen in soil increased significantly with increasing nitrogen application. Thus, sowing hybrid castor at 120 x 45 or 120 x 60 cm spacing with 120 kg N/ha can be recommended for achieving higher productivity and economic returns under irrigated conditions.

Keywords: Hybrid castor, Crop geometry, Nitrogen levels, Seed yield, Oil yield, Post-harvest soil properties

Introduction

Castor (*Ricinus communis* L.) is an important non-edible oilseed crop valued for its adaptability and industrially important oil, particularly its high ricinoleic acid content. Castor oil is widely used in lubricants, pharmaceuticals, cosmetics, polymers, paints and other industries. India is a major producer and exporter of castor, necessitating efficient agronomic practices for improving productivity and resource-use efficiency.

Crop spacing regulates plant population, spatial distribution and competition for light, water and nutrients. Appropriate spacing facilitates efficient resource utilization and canopy development, thereby influencing biomass production, nutrient acquisition, seed formation and yield. Nitrogen is a major nutrient governing crop growth and productivity through its role in chlorophyll formation, protein synthesis, photosynthesis and biomass accumulation. Recent studies have demonstrated that nitrogen management can substantially influence nitrogen uptake, seed yield and oil yield in castor.

Nitrogen content and uptake reflect crop nutritional status, while post-harvest soil properties indicate nutrient removal, residual fertility and sustainability of nitrogen management. Recent research under North Gujarat conditions has specifically evaluated nutrient content, nutrient uptake and post-harvest soil fertility in castor, highlighting the importance of nutrient management for maintaining soil productivity (Patel *et al.*, 2024) [1]. Oil content is an important quality trait that may respond differently to agronomic practices than seed yield. Recent findings have shown that nitrogen management can enhance nitrogen uptake and oil yield, although changes in oil concentration may be comparatively limited (Gato *et al.*, 2024; Chaudhary *et al.*, 2025) [3, 2].

Although the effects of spacing and nitrogen on castor growth and yield have been widely studied, their combined influence on nitrogen nutrition, post-harvest soil properties and oil content under irrigated conditions remains comparatively less documented. Hence, the present study was undertaken to evaluate the effects of different crop spacings and nitrogen levels on yield and quality of castor and post-harvest soil properties under the agro-ecological conditions of middle Gujarat, with a view to identifying an efficient and sustainable production strategy.

Corresponding Author:

JP Panchal

Assistant Research
 Scientist, Bidi Tobacco
 Research Station, AAU,
 Anand, Gujarat, India

Materials and Methods

The field trial was conducted during the *kharif* seasons of 2023-24 and 2024-25 at Agronomy Farm, B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat on loamy sand soils. The study was designed to assess the influence of varying spacings and nitrogen levels on yield and quality of castor and post-harvest soil properties. The experimental location falls at 22°35' N latitude and 72°55' E longitude, with an elevation of 45.1 meters above mean sea level in the Middle Gujarat Agro-climatic Zone (AES-III). The climate is characterised by a semi-arid and sub-tropical conditions with a fairly cold winters and dry, hot summers. The area receives an average annual rainfall of approximately 880 mm, predominantly associated with the South-West monsoon. During 2023-24 cropping season, a

cumulative rainfall of 260.8 mm was recorded over 17 rainy days, whereas 668.6 mm of rainfall was received over 20 rainy days during 2024-25. The weekly mean maximum temperature varied from 25.7 to 38.2 °C in 2023-24 and from 26.8 to 40.1 °C in 2024-25. Correspondingly, the weekly mean minimum temperature ranged from 11.0 to 26.3 °C and 11.5 to 27.9 °C during the respective seasons.

Before commencement of the experiment, representative composite soil samples were collected from various locations within the experimental field at a depth of 0-15 cm using standard soil sampling procedures. The collected samples were processed and analyzed for their physical and chemical properties following standard laboratory methods, and the results are presented in Table 1.

Table 1. Physico-chemical properties of soil of the experimental plot (Initial)

Particulars	Value at 0-15 cm depth		Method followed
Physical Properties	2023-24		
I. Coarse sand (%)	0.55		International pipette method Piper (1966)
II. Fine sand (%)	83.30		
III. Silt (%)	10.23		
IV. Clay (%)	5.42		
V. Textural class	Loamy sand		
Chemical Properties	2023-24	2024-25	
I. pH (1:2.5 Soil: Water)	7.50	7.72	Potentiometric method (Jackson, 1973)
II. EC (1:2.5 Soil: Water) (dS/m)	0.23	0.26	Conductometric method (Jackson, 1973)
III. Organic carbon (%)	0.31	0.32	Walkley and Black method (Walkley and Black, 1934)
IV. Available N (kg/ha)	157.12	154.36	Alkaline KMnO ₄ method (Subbiah and Asija, 1956)
V. Available P ₂ O ₅ (kg/ha)	37.01	35.54	Olsen’s method (Olsen <i>et al.</i> , 1954)
VI. Available K ₂ O (kg/ha)	291.82	286.33	Flame photometric method (Jackson, 1973)

Well-decomposed Farm Yard Manure 5 t/ha was applied uniformly to the experimental field 10 days prior to sowing in both the cropping seasons. Gujarat Castor Hybrid 9 (GCH 9) was selected as the test hybrid for the investigation. The experiment was conducted in a Split Plot Design (SPD) with three replications. The experimental layout comprised 36 plots representing 12 treatment combinations arising from the interaction of four crop geometries and three nitrogen levels. The treatment details and their respective symbols are presented in Table 2.

Table 2. Treatment details with their symbols

A. Main Plot: Crop Geometries (S)	B. Sub Plot: Nitrogen levels (N)
S ₁ : 90 x 60 cm	N ₁ : 100 kg/ha
S ₂ : 90 x 45 cm	N ₂ : 120 kg/ha
S ₃ : 120 x 60 cm	N ₃ : 140 kg/ha
S ₄ : 120 x 45 cm	

Nitrogen was applied as per treatment through urea in three equal splits; 25% N at basal, 50% N at 35 DAS and remaining 25% N at 65 DAS. As per recommended practices, the entire quantity (25 kg/ha) of phosphorus was applied as basal uniformly to all treatments in the form of di-ammonium phosphate (DAP). The seeds were sown manually in previously opened furrows at a depth of 3.0-5.0 cm according to the respective crop geometry treatment in month of September. Harvesting of castor spikes was carried out manually in three successive pickings based on spike maturity. Matured spikes from the pre-tagged plants were harvested separately for recording observations. Afterwards, the produce from these plants was added back to the respective net plot yield to ensure accurate yield estimation.

Chemical analysis

Oil content (%)

A representative seed sample from each net plot was used for determination of oil content. Oil percentage was estimated by the Nuclear Magnetic Resonance (NMR) technique using an IBM DC/20 Series Minispec NMR Analyzer, following Tiwari *et al.* (1974) [4].

Oil yield (kg/ha)

Oil yield was calculated from seed yield and oil content by using following formula.

$$\text{Oil Yield (kg/ha)} = \frac{\text{Oil content in seed (\%)} \times \text{Seed yield (kg/ha)}}{100}$$

Soil status after harvest

After harvest, soil samples were collected from each plot at the prescribed depth, air-dried, powdered and passed through a 2-mm sieve. The processed samples were analyzed for pH, electrical conductivity (EC), organic carbon and available N, P₂O₅ and K₂O using standard analytical methods, as detailed in Table 1.

Nitrogen content (%)

Representative seed and stalk samples from each treatment were collected after harvest, dried separately, finely ground and analyzed for nitrogen concentration using the modified Micro-Kjeldahl method of Piper (1966) [5]. Nitrogen content was expressed as percentage on a dry-weight basis.

Nitrogen uptake (kg/ha)

Nitrogen uptake by seed and stalk was calculated separately from their respective nitrogen concentration and yield.

$$\text{Nitrogen uptake by seed/stalk (kg/ha)} = \frac{\text{Nitrogen content in seed/stalk (\%)} \times \text{Seed/stalk yield (kg/ha)}}{100}$$

Statistical analysis

The data recorded on various parameters of the castor crop studied in investigation were subjected to statistical analysis following the procedure for split plot design described by Cochran *et al.* (1957) [6]. The significance of treatment effects was tested using the *F*-test at the 5% probability level. Standard error of the mean (*S.E.m*[±]) and coefficient of variation (CV%) were computed to assess the precision and experimental variability.

Results and Discussion

Seed yield (kg/ha)

The results for seed yield of castor presented in Table 3, revealed that seed yield was significantly influenced by both spacing and nitrogen levels. Among the spacing treatments, 120 x 45 cm (S₄) recorded the highest seed yield (3783 kg/ha) which was significantly superior to 90 x 45 cm (S₂) (2729 kg/ha) but remained statistically at par with 120 x 60 cm (S₃) (3598 kg/ha) and 90 x 60 cm (S₁) (3514 kg/ha). The lowest seed yield was recorded under S₂. The higher seed yield under S₄ may be attributed to optimum plant spatial arrangement which provided adequate space for individual plants and reduced inter-plant competition for light, moisture and nutrients, thereby promoting better growth and reproductive development. In contrast, the closer geometry of 90 x 45 cm possibly intensified competition among plants resulting in reduced assimilate availability and consequently lower seed production per unit area. Similar findings were reported by Raju *et al.* (2019) [7], Arutchenthil *et al.* (2020) [8] and Thanki *et al.* (2020) [9]. Nitrogen application significantly enhanced seed yield. Application of 140 kg N/ha (N₃) produced the highest seed yield (3542 kg/ha) followed by 120 kg N/ha (N₂) with 3465 kg/ha, whereas the lowest seed yield (3211 kg/ha) was obtained with 100 kg N/ha (N₁). The higher seed yield with increasing nitrogen supply could be attributed to improved vegetative growth, leaf area development and photosynthetic activity which enhanced assimilate production and translocation towards reproductive sinks. Adequate nitrogen availability also favours the development and filling of reproductive structures, ultimately increasing seed yield. These findings are consistent with Silva *et al.* (2020) [10], Ramanjaneyulu *et al.* (2021) [11] and Chaudhari *et al.* (2025) [12]. The interaction effect of crop geometry x nitrogen level on seed yield was significant (Table 3.1). The highest seed yield (4042 kg/ha) was recorded with S₄N₃ (120 x 45 cm with 140 kg N/ha), followed by S₁N₃ (3892 kg/ha), S₃N₂ (3848 kg/ha) and S₄N₂ (3825 kg/ha), while the lowest seed yield (2557 kg/ha) was obtained under S₂N₁ (90 x 45 cm with 100 kg N/ha).

Oil content (%) and oil yield (kg/ha)

Oil content was not significantly affected by spacing or nitrogen levels (Table 3). The oil content varied from 45.96% under S₃ to 47.64% under S₄, while among nitrogen levels it ranged from 46.35% with N₁ to 47.83% with N₃. Oil yield followed a trend similar to seed yield and was significantly influenced by spacing and nitrogen levels, as presented in Table 3. Among spacings, S₄ recorded the maximum oil yield (1804 kg/ha) followed by S₁ (1670 kg/ha) and S₃ (1655 kg/ha). The greater oil yield under S₄ was mainly associated with its higher seed yield, as oil content did not differ significantly among spacing treatments. Similarly, application of 140 kg N/ha (N₃) resulted in higher oil yield (1695 kg/ha) followed by N₂ (1624 kg/ha). The increase in oil yield with nitrogen application was therefore largely a consequence of increased seed yield rather than changes in oil concentration. A similar result was also reported by Pisal *et al.* (2018) [13] and Kachhadiya *et al.* (2025) [14]. The interaction effect of spacing x nitrogen level on oil yield was significant (Table 3.2). The highest oil yield (1987 kg/ha) was recorded under S₄N₃ (120 x 45 cm with 140 kg N/ha) followed by S₁N₃ (1881 kg/ha), whereas the lowest oil yield (1191 kg/ha) was observed under S₂N₁ (90 x 45 cm with 100 kg N/ha).

Nitrogen content (%) and uptake (kg/ha) in seed and stalk

The data pertaining to nitrogen content and nitrogen uptake in seed and stalk of hybrid castor as influenced significantly by different crop geometries and nitrogen levels are presented in Table 4. The results revealed that different crop geometries did not exert any significant influence on nitrogen content in either seed or stalk. In contrast, crop geometry significantly affected nitrogen uptake in both seed and stalk. The maximum nitrogen uptake in seed (160.07 kg/ha) was recorded under S₄ (120 x 45 cm), which was significantly superior to S₁ (90 x 60 cm), S₂ (90 x 45 cm) and S₃ (120 x 60 cm). The lowest nitrogen uptake in seed (112.07 kg/ha) was observed under S₂ (90 x 45 cm). Similarly, nitrogen uptake in stalk was significantly higher under S₄ (120 x 45 cm), recording 131.55 kg/ha, while the minimum uptake (91.48 kg/ha) was recorded under S₂ (90 x 45 cm). The higher nitrogen uptake under S₄ may be attributed mainly to the greater seed and stalk biomass production under this crop geometry, coupled with comparatively higher nitrogen concentration in plant tissues.

With regard to nitrogen levels, nitrogen content in seed increased progressively with increasing nitrogen application and was recorded as 4.06, 4.16 and 4.23 per cent under N₁ (100 kg N/ha), N₂ (120 kg N/ha) and N₃ (140 kg N/ha), respectively. Similarly, nitrogen content in stalk increased from 1.73 per cent under N₁ to 1.76 per cent under N₂ and 1.79 per cent under N₃. Thus, increasing nitrogen availability resulted in greater accumulation of nitrogen in both seed and stalk. Nitrogen uptake in seed and stalk was also significantly enhanced by

increasing nitrogen levels. The maximum nitrogen uptake in seed (150.23 kg/ha) was recorded with N₃ (140 kg N/ha), followed by N₂ (120 kg N/ha) with 144.49 kg/ha, while the minimum value (130.24 kg/ha) was recorded under N₁ (100 kg N/ha). Similarly, nitrogen uptake in stalk increased from 108.97 kg/ha under N₁ to 117.45 and 121.65 kg/ha under N₂ and N₃, respectively. The increased nitrogen uptake with higher nitrogen application could be attributed to improved nitrogen availability in the soil, enhanced vegetative growth and greater dry matter production, which ultimately increased the amount of nitrogen absorbed and accumulated by the crop.

The interaction between crop geometry and nitrogen levels was found significant for nitrogen uptake in seed, whereas it was non-significant for nitrogen content in seed and stalk and nitrogen uptake in stalk. The highest nitrogen uptake in seed (174.57 kg/ha) was recorded under S₄N₃ (120 x 45 cm spacing with 140 kg N/ha) and was remained at par with S₁N₃ (164.04 kg/ha). The lowest nitrogen uptake in seed (103.00 kg/ha) was observed under S₂N₁ (90 x 45 cm spacing with 100 kg N/ha).

Soil chemical properties after harvest

The effect of different spacings and nitrogen levels on the chemical properties of soil after harvest is presented in Table 5. The parameters studied included EC, organic carbon, pH, available N, P₂O₅ and K₂O. Different spacings did not cause any significant variation in the soil chemical properties after harvest. Nitrogen application did not significantly influence soil EC, organic carbon, pH, available P₂O₅ or available K₂O after harvest. In contrast, available nitrogen in soil was significantly affected by nitrogen application. It increased consistently with an increase in the applied nitrogen level. Higher available nitrogen (163.62 kg/ha) was recorded under N₃ (140 kg N/ha) and remained at par with N₂ (120 kg N/ha) with 156.32 kg/ha. The increase in available nitrogen under higher nitrogen application may be attributed to the greater amount of nitrogen added to the soil through fertilizer, resulting in a higher residual nitrogen pool after crop removal. The interaction between spacing and nitrogen levels did not produce any significant effect on any of the soil chemical properties studied.

Table 3. Seed yield, oil content and oil yield as influenced by spacing and nitrogen level

Treatments	Seed Yield (kg/ha)	Oil content (%)	Oil Yield (kg/ha)
Main Plot: Spacing (S)			
S ₁ : 90 x 60 cm	3514	47.44	1670
S ₂ : 90 x 45 cm	2729	47.01	1281
S ₃ : 120 x 60 cm	3598	45.96	1655
S ₄ : 120 x 45 cm	3783	47.64	1804
S.E.m. +	89	0.54	44
CD (<i>P</i> = 0.05)	274	NS	134
CV %	11.1	4.9	11.5
Sub plot: Nitrogen level (N)			
N ₁ : 100 kg/ha	3211	46.35	1489
N ₂ : 120 kg/ha	3465	46.86	1624
N ₃ : 140 kg/ha	3542	47.83	1695
S.E.m. +	46	0.46	26
CD (<i>P</i> = 0.05)	129	NS	75
<i>S</i> x <i>N</i>	Sig.	NS	Sig.
CV %	6.6	4.8	8.1

Table 3.1. Seed yield as influenced by the interaction effect of spacing and nitrogen level

Nitrogen level Spacing	Seed yield (kg/ha)		
	N ₁ : 100 kg/ha	N ₂ : 120 kg/ha	N ₃ : 140 kg/ha
S ₁ : 90 x 60 cm	3297	3352	3892
S ₂ : 90 x 45 cm	2557	2835	2794
S ₃ : 120 x 60 cm	3506	3848	3441
S ₄ : 120 x 45 cm	3484	3825	4042
S.E.m. +		92	
CD (<i>P</i> = 0.05)		259	
CV %		6.6	

(continued on next page)

Table 3.2. Oil yield as influenced by the interaction effect of spacing and nitrogen level

Nitrogen level Spacing	Oil yield (kg/ha)		
	N ₁ : 100 kg/ha	N ₂ : 120 kg/ha	N ₃ : 140 kg/ha
S ₁ : 90 x 60 cm	1528	1602	1881
S ₂ : 90 x 45 cm	1191	1287	1364
S ₃ : 120 x 60 cm	1600	1817	1547
S ₄ : 120 x 45 cm	1635	1789	1987
S.E.m. +		53	
CD (<i>P</i> = 0.05)		149	
CV %		8.1	

Table 4. Nitrogen content and uptake in seed and stalk as influenced by spacing and nitrogen level at harvest

Treatments	Nitrogen content (%)		Nitrogen uptake (kg/ha)	
	Seed	Stalk	Seed	Stalk
Main Plot: Spacing (S)				
S ₁ : 90 x 60 cm	4.13	1.76	145.31	125.06
S ₂ : 90 x 45 cm	4.11	1.73	112.07	91.48
S ₃ : 120 x 60 cm	4.15	1.76	149.16	116.01
S ₄ : 120 x 45 cm	4.22	1.78	160.07	131.55
S.E.m. +	0.04	0.01	4.29	2.41
CD (<i>P</i> = 0.05)	NS	NS	13.23	7.42
CV %	4.6	2.7	12.9	8.8
Sub plot: Nitrogen level (N)				
N ₁ : 100 kg/ha	4.06	1.73	130.24	108.97
N ₂ : 120 kg/ha	4.16	1.76	144.49	117.45
N ₃ : 140 kg/ha	4.23	1.79	150.23	121.65
S.E.m. +	0.03	0.01	2.17	1.45
CD (<i>P</i> = 0.05)	0.08	0.03	6.12	4.10
S x N	NS	NS	Sig.	NS
CV %	3.2	2.5	7.5	6.1

Table 4.1. Interaction effect of spacing and nitrogen level on nitrogen uptake in seed after harvest

Nitrogen uptake in seed (kg/ha)			
Nitrogen level Spacing	N ₁ : 100 kg/ha	N ₂ : 120 kg/ha	N ₃ : 140 kg/ha
S ₁ : 90 x 60 cm	132.08	139.80	164.04
S ₂ : 90 x 45 cm	103.00	116.48	116.72
S ₃ : 120 x 60 cm	142.11	159.81	145.57
S ₄ : 120 x 45 cm	143.79	161.87	174.57
S.E.m. +		4.34	
CD (<i>P</i> = 0.05)		12.24	
CV %		7.5	

(continued on next page)

Table 5. Soil properties as influenced by spacing and nitrogen level after harvest of the crop

Treatments	After harvest soil properties					
	EC (ds/m)	Organic carbon (%)	pH	Available N (kg/ha)	Available P ₂ O ₅ (kg/ha)	Available K ₂ O (kg/ha)
Main Plot: Spacing (S)						
S ₁ : 90 x 60 cm	0.26	0.312	7.82	153.51	35.33	287.08
S ₂ : 90 x 45 cm	0.25	0.297	7.81	153.17	35.14	285.43
S ₃ : 120 x 60 cm	0.27	0.312	7.85	159.05	36.52	290.75
S ₄ : 120 x 45 cm	0.27	0.305	7.84	161.24	35.36	287.95
S.Em. +	0.01	0.004	0.05	2.17	0.41	2.12
CD (<i>P</i> = 0.05)	NS	NS	NS	NS	NS	NS
CV %	5.2	5.2	2.8	5.9	4.9	3.1
Sub plot: Nitrogen level (N)						
N ₁ : 100 kg/ha	0.26	0.302	7.79	150.28	35.18	286.08
N ₂ : 120 kg/ha	0.26	0.307	7.83	156.32	35.78	287.74
N ₃ : 140 kg/ha	0.27	0.310	7.87	163.62	35.80	289.59
S.Em. +	0.004	0.002	0.03	1.66	0.27	1.59
CD (<i>P</i> = 0.05)	NS	NS	NS	4.78	NS	NS
<i>S</i> x <i>N</i>	NS	NS	NS	NS	NS	NS
CV %	4.9	3.7	1.7	5.2	3.8	2.7

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