NARROW PLANT SPACING AND MODEST NITROGEN APPLICATION IMPROVED SEED AND OIL YIELDS OF CASTOR BEAN

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Abstract: Castor bean has a significant ability to regulate its yield components in response to the alteration in the plant population. The enhanced production of castor bean is possible mainly through maintaining optimum plant spacing and nitrogen (N) application. A two factor experiment, which included plant spacing (50, 75, 100 and 125 cm) and N levels (0, 60, 90 and 120 kg ha^{-1}) was conducted in Peshawar. Maximum plant height (194 cm), capsule plant^{-1} (139), grain yield (1518 kg ha^{-1}), biological yield (9222 kg ha^{-1}), oil yield (701 kg ha^{-1}), nitrogen use efficiency (21.1 kg kg^{-1}) and agronomic efficiency (16.2 kg kg^{-1}) were obtained at plant spacing of 50 cm, while maximum branches plant^{-1} (9), thousand grain weight (254 g) and capsule plant^{-1} (58) were recorded in wider plant spacing of 125 cm. In case of nitrogen levels, 120 kg N ha^{-1} resulted in taller plants (192 cm), higher number of branches plant^{-1} (10), capsule plant^{-1} (222), thousand grain weight (254 g) and biological yield (8753 kg ha^{-1}) of castor bean but application of 90 kg N ha^{-1} resulted in maximum grain yield (1568 kg ha^{-1}), harvest index (20%), oil content (48.8%) and oil yield (766 kg ha^{-1}), while at 60 kg N ha^{-1}, the maximum nitrogen use efficiency (22.4) and agronomic efficiency (12.6) were recorded. Thus, plant spacing of 50 cm produced maximum seed and oil yields, nitrogen use efficiency and agronomic efficiency and application of nitrogen at the rate of 90 kg ha^{-1} resulted in higher seed and oil yields.

Keywords: Plant spacing; Nitrogen levels; Yield; Oil content; AUE; NUE

I. INTRODUCTION

Castor bean (*Ricinus communis* L.) belongs to family *Euphorbiaceae*, is the most useful non-edible oil seed crop. It is cultivated in subtropical and tropical areas of the world for oil production and ornamental purposes (Radhamani et al., 2012). In 2016, castor production in Pakistan was 2.3 thousand tons on an area of 2.25 thousand hectares (Yosaf et al., 2018). This plant is mainly important for the production of best quality lubricant due to the occurrence of unusual fatty acid (ricinoleic acid) in high amount. As it is oil containing crop, it is getting attention for biodiesel production to lower the fossil fuel utilization, and performs as alternative source of energy (Nahar, 2015). Castor oil has two exciting phenomena as raw material for biodiesel. It does not need high inputs for cultivation and on other hand it does not show competition with most of the edible oil crops (Saez-Bastante et al., 2015). Beside this that it contains uniform amount of ricinoleic acid, its oil is used in medicines, cosmetics, paints and has much more other industrial uses (Cheema et al., 2013). Economically, it is well known because of its utilization as highly usable castor oil as well as its use as laxative (Kamal and Joshi, 2000).

Castor bean has a significant ability to regulate its yield components in the direction to the alteration in the plant population through changes in racemes numbers plant-1, seeds in each raceme and its weight (Severino et al., 2017). Due to this reason, it is general to locate small and contradictory effect of castor bean plant population density on yield production (Bizinoto et al., 2010). Therefore, accurately counting cannot be done for plant population, only an opinion of a certain value can be made (Lopes et al., 2013). Some literatures focus on finding the best row spacing for variety of crops. As the rows spacing decreases in a place, then the competition for nutrients and water among plants rise rapidly and on the other side when there is small spacing, then the absorption of light is large, there is no light for weeds in earlier stage, which stop their growth and showing a useful effect on yield of the crops (Magalhaes et al., 2013). Among the important factors which limit the castor yield is poor (inadequate) plant density (Soratto et al., 2011).

Among all agronomic techniques, fertilization is considered as most important to enhance profits and increase yield (Marinho et al., 2010). Among the nutrients, nitrogen is considered as vital nutrient due to its significance for development and growth of plants and also part of plant structure and amino acids which are building blocks of proteins, enzymes, DNA, RNA, chlorophyll, ATP and others (Marschner, 1995). The plant response to the nitrogen fertilization is of great importance in agriculture. Combination of genetic improvement and management strategies such as nitrogen application increased the crop yield steadily over last 60 years (Stewart et al., 2005). Under field conditions, the growth of some crop species and its development are restricted by nitrogen commonly (Roggatz et al., 1999).

The major lacking nutrient in the soil is nitrogen. For attaining the higher productivity of crop, it is important to provide nitrogen in adequate amount. Farahani and Aref (2008) found that nitrogen application at the rate of 80 kg ha-1 gave maximum dry matter, oil yield and seed yield of castor bean while, higher thousand seed weight was attained through 120 kg ha^{-1} nitrogen application. The effect of various nitrogen levels was studied by many researchers on the castor bean seed yield. They found that yield of castor bean was considerably high when the level of nitrogen was increased, while higher yield was obtained by applying nitrogen at 120 kg ha^{-1} (Taylor et al., 2005). Keeping the importance of plant spacing and nitrogen levels, this experiment was carried out to find the effect of various plant spacing and nitrogen levels on yield attributes of castor bean.

II. MATERIALS AND METHODS

Experimental Detail

The field trial was carried out at Agronomy Research Farm, The University of Agriculture Peshawar, in summer 2019. The experiment was laid out in randomize complete block design (RCBD) replicated three times. The experiment was consisted of two factors, i.e. four plant spacing (50, 75, 100 and 125 cm) and four nitrogen levels (0, 60, 90 and 120 kg ha^{-1}). Plot size was 6.5 m by 3.75 m having five rows with inter row distance of 75 cm. Nitrogen application was done in split doses from urea i.e. half at the time of seeding and half at panicle stage whereas phosphorus application was done in the form of DAP at 60 kg ha^{-1} at sowing time. Total five irrigations were given to the crop after the emergence i.e. first irrigation given after two weeks of emergence, second after four weeks, third after six weeks, fourth at flowering and fifth at fruiting setting stages. Weeds were controlled manually by hoeing. First hoeing was done on fourth week after sowing and the second was done on eighth week after sowing.

Procedure for maintaining plant population

The plant population was maintained according to each treatment through plant spacing (PS). Three seeds per hole were sown at desired plant spacing and later thinned to single plant per hole to achieve the required plant population. The desired plant population for treatments PS 1 (50 cm), PS 2 (75 cm), PS 3 (100 cm), PS 4 (125 cm) were 13, 8, 6, 5 plants in each row of the plot, respectively.

Methodology of Data Recording

Plant height was measured from base at earth level to the plant tip at maturity. Total numbers of branches and capsules plant^{-1} were determined by calculating the number of branches and capsules in five plants randomly at maturity stage in all plots. Grain sample taken from each experimental unit was counted through grain counter and was weighed for thousand grain weight through electronic balance.

Grain yield and biological yield data were recorded through drying, cleaning and threshing the three rows harvested for biomass. For grain yield or biological yield these three rows were harvested when it reached to maturity and were left in the field for 10 days for sun drying. For recording biological yield, when plants completely dried, they were weighed through balance and converted into kg ha^{-1}and for seed yield only seeds were weighed and then converted into kg ha^{-1}.

Harvest index was calculated by dividing grain yield by biological yield and multiplying with hundred. Data regarding oil content were obtained through Soxhelt tool method AOAC, (1990). The data for oil yield were calculated by multiplying oil content with grain yield and then dividing by hundred.

Nitrogen use efficiency was determined by dividing total seed yield of plot by amount of nitrogen applied to that plot whereas, Agronomic use efficiency was calculated through subtracting grain yield of nitrogen treated plots from control plots and then divided by the amount of nitrogen applied to that plots.

Statistical analysis

Data were analyzed statistically as described by Steel and Torrie, (1996). Through LSD test, the means were compared at a probability level of 5% where the F values were significant.

III. RESULTS

Plant height (cm)

Plant spacing (PS) and nitrogen (N) levels significantly affected plant height of castor bean (Table 1). Interaction between PS × N was found non-significant. Taller plants (193.9 cm) were recorded in plots having plant spacing of 50 cm followed by 75, 100 and 125 cm having plant height of 177, 173 and 168 cm, respectively. Application of nitrogen at the rate of 120 kg ha^{-1} resulted in taller plants (192 cm) followed by nitrogen application at the rate of 90 and 60 kg ha^{-1} having plant height of 190, 183 cm, respectively. The lowest plant height (70 cm) was noted in control plots.

Branches $plant^{-1}$

Data concerning branches $plant^{-1}$ are shown in Table 2. Analysis of the data revealed that plant spacing (PS) and nitrogen (N) levels significantly affected branches $plant^{-1}$. The interaction among plant spacing and nitrogen (PS x N) for branches $plant^{-1}$ was also found significant. Maximum branches $plant^{-1}$ (9) were recorded in plots having plant spacing of 125 cm followed by plant spacing of 100 cm (8), 75 cm (7) and 50 cm (8), respectively which were statistically similar with each other. Likewise, maximum branches $plant^{-1}$ of 9 and 10 were obtained with nitrogen addition of 120 and 90 kg ha^{-1} followed by nitrogen application at the rate 60 kg ha^{-1} (8). The lowest branches $plant^{-1}$ (5) was noted in control plots. The PS x N interaction indicated that higher branches $plant^{-1}$ (12) was recorded in plots having 125 cm plant spacing with nitrogen fertilization of 120 kg ha^{-1}.

Number of capsules $plant^{-1}$

Number of capsules $plant^{-1}$ was significantly affected plant spacing and nitrogen levels (Table 2). The interaction between PS x N was not significant. The plant spacing of 125 cm had maximum number of capsules $plant^{-1}$ (190) followed by 100 and 75 cm having 164, 155 number of capsules $plant^{-1}$, respectively while 50 cm had lower capsules $plant^{-1}$ (139). In response to various levels of nitrogen, the highest capsules $plant^{-1}$ (222) were obtained with 120 kg ha^{-1} followed by 90 and 60 kg N ha^{-1} having 179, 146 capsules $plant^{-1}$, respectively. The minimum capsules $plant^{-1}$ (100) was obtained from control plots.

Thousand grains weight (g)

The thousand grain weight was significantly affected by plant spacing and nitrogen levels (Table 2). The highest thousand grain weight (254.1 g) was measured in the plots having plant spacing of 125 cm followed by plant spacing of 100 cm having thousand grain weights of 242.8 g, while lower thousand grain weight (213.4 g) was recorded in 50 cm plant spacing. Likewise, the highest thousand grain weight (254.3 g) was recorded in the plots having nitrogen application of 120 kg ha^{-1} followed by 90 kg ha^{-1} with thousand grain weight of 248.3 g and 60 kg ha^{-1} having thousand grain weight of 239.7 g. Minimum thousand seed weight (202.3 g) was noted in the control plots. The interaction between plant spacing and nitrogen (PS x N) indicated that the highest thousand grain weight was noted in plots having plant spacing of 125 cm along with application of 120 kg ha^{-1}.

Grain yield (kg ha^{-1})

Data on grain yield are shown in Table 3. Plant spacing and nitrogen levels significantly affected the grain yield of castor bean. The interaction between plant spacing and nitrogen was also found significant. The maximum grain yield (1518 kg ha^{-1}) was obtained in plots having plant spacing of 50 cm followed by 75, 100 and 125 cm having grain yield of 1407, 1069, 1076 kg ha^{-1}, respectively. Similarly, the maximum grain yield (1568 kg ha^{-1}) was produced in plots with nitrogen fertilization of 90 kg ha^{-1} followed by nitrogen application of 120 kg ha^{-1} having grain yield of 1445 kg ha^{-1} and 60 kg ha^{-1} having grain yield of 1344 kg ha^{-1}. The lowest grain yield of 712 kg ha^{-1} was noted in control plots. The interaction between plant spacing and nitrogen (PS x N) indicated that the maximum grain yield was noted in plot having plant spacing of 50 cm along with the nitrogen application of 90 kg ha^{-1}.

Table 1. Days to tasseling, days to silking, days to physiological maturity, leaf area plant^{-1}, and leaf area index of maize as affected by humic acid and foliar salicylic acid application.

	Parameters				
Plant spacing (cm)	Plant height (cm)	Branches plant^{-1}	Capsules plant^{-1}	Thousand grains weight (g)	Grain yield (kg ha^{-1})
50	194 a	8 b	139 c	213.3 d	1518 a
75	177 b	7 b	155 b	234.3 c	1407 a
100	173 b	8 b	164 b	242.8 b	1068 b
125	169 b	9 a	190 a	254.1 a	1076 b
LSD $_{(0.05)}$	13	0.64	12	5.1	156
Nitrogen levels (kg ha^{-1})					
0	147 b	5 c	100 d	202.3 d	712 c
60	183 a	8 b	146 c	239.7 c	1344 b
90	190 a	10 a	179 b	248.3 b	1568 a
120	193 a	9 a	222 a	254.3 a	1445 ab
LSD $_{(0.05)}$	13	0.64	12	5.1	156
Interaction					
PS × N	NS	**	NS	**	**

PS: plant spacing, N: nitrogen, NS: non-significant

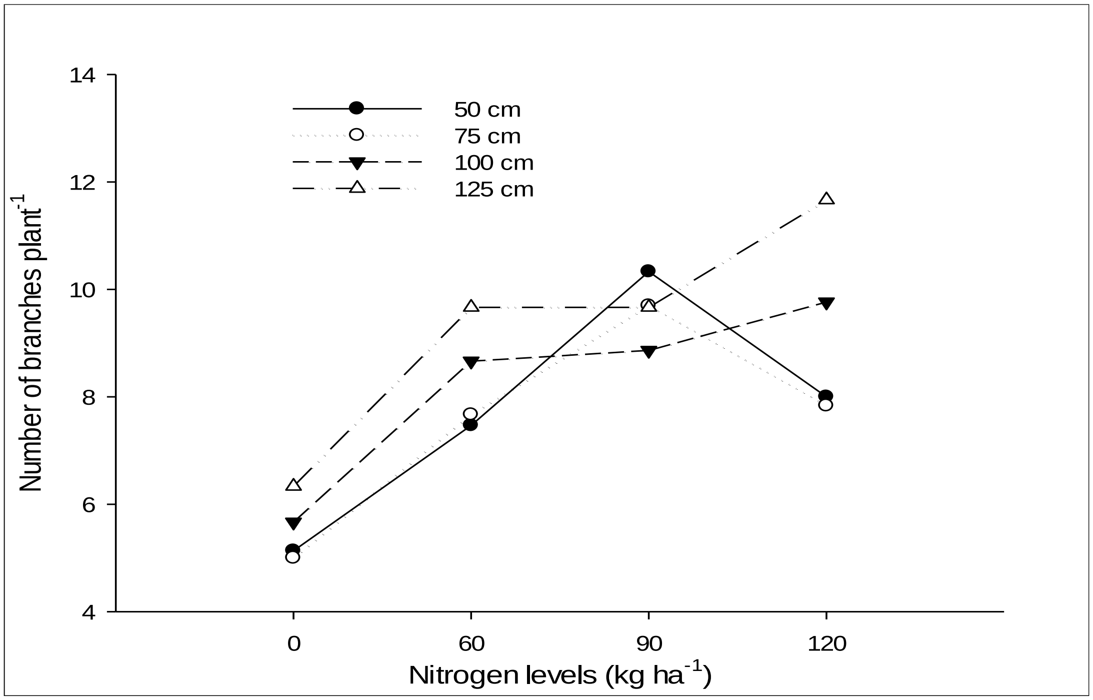

Fig. 1. Interaction between plant spacing and nitrogen levels for branches plant^{-1} of castor bean.

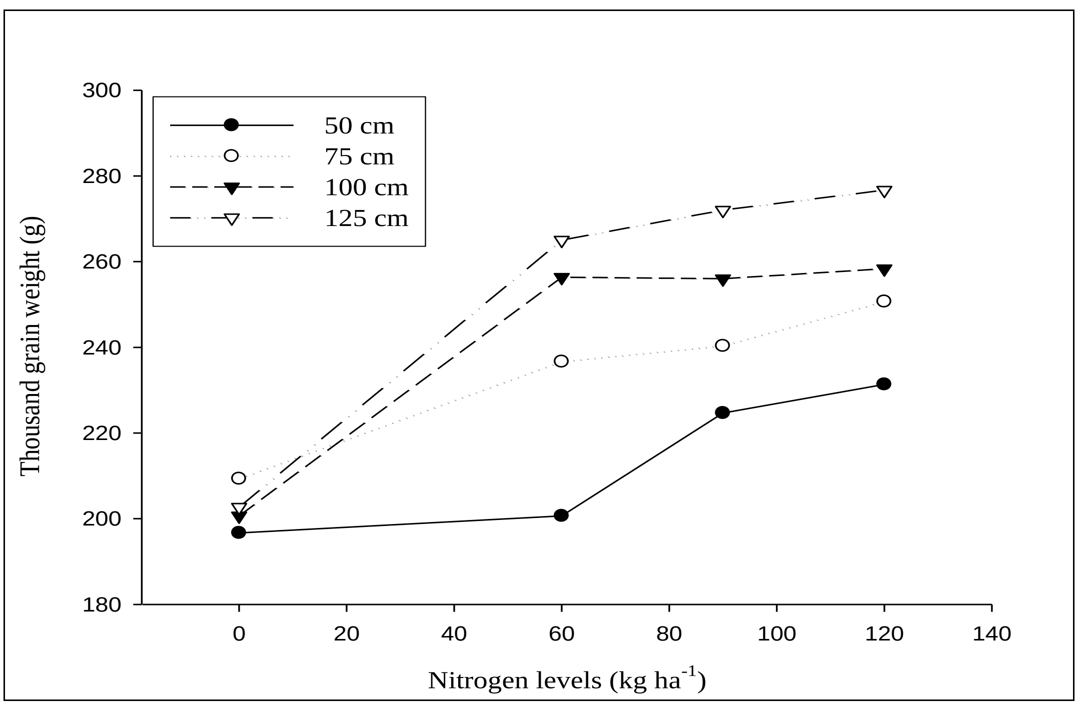

Fig. 2. Interaction between plant spacing and nitrogen levels for thousand grain weight (g) of castor bean.

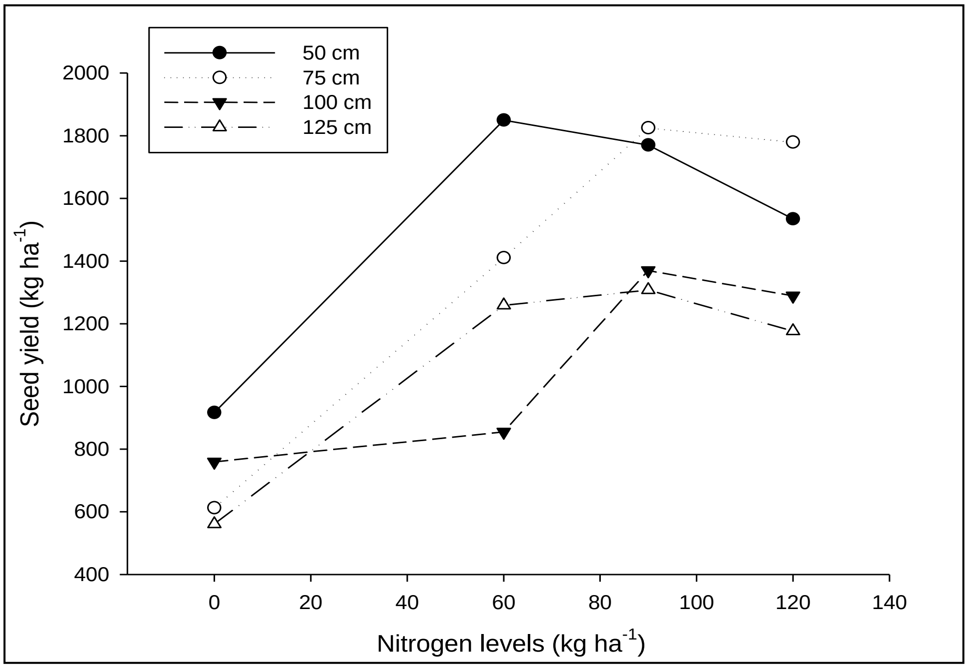

Fig. 3. Interaction between plant spacing and nitrogen levels for seed yield (kg ha^{-1}) of castor bean.

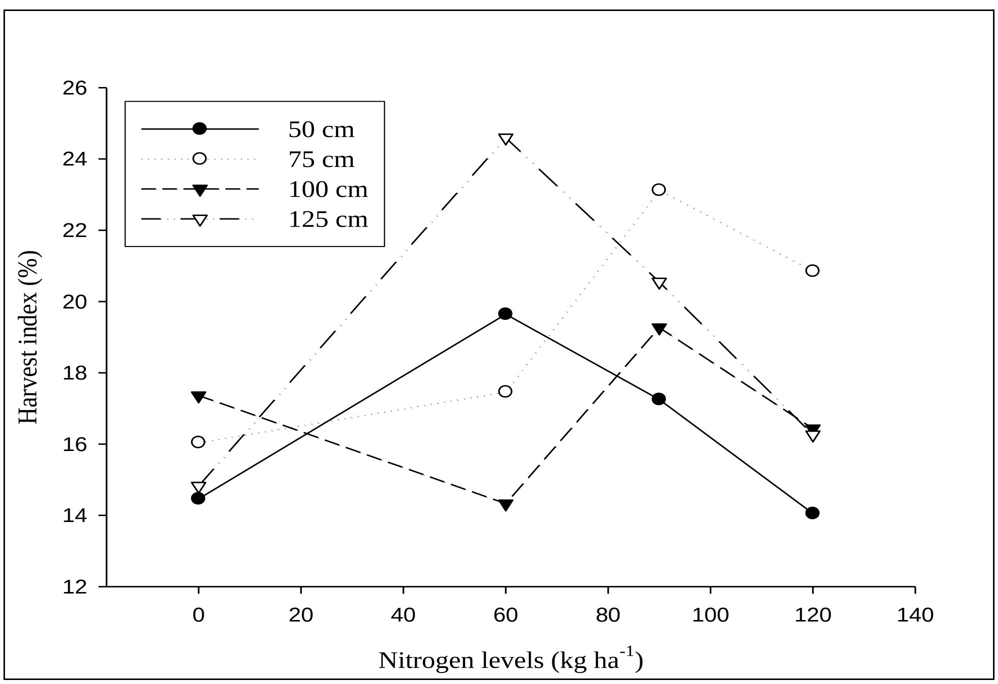

Fig. 4. Interaction between plant spacing and nitrogen levels for harvest index (%) of castor bean.

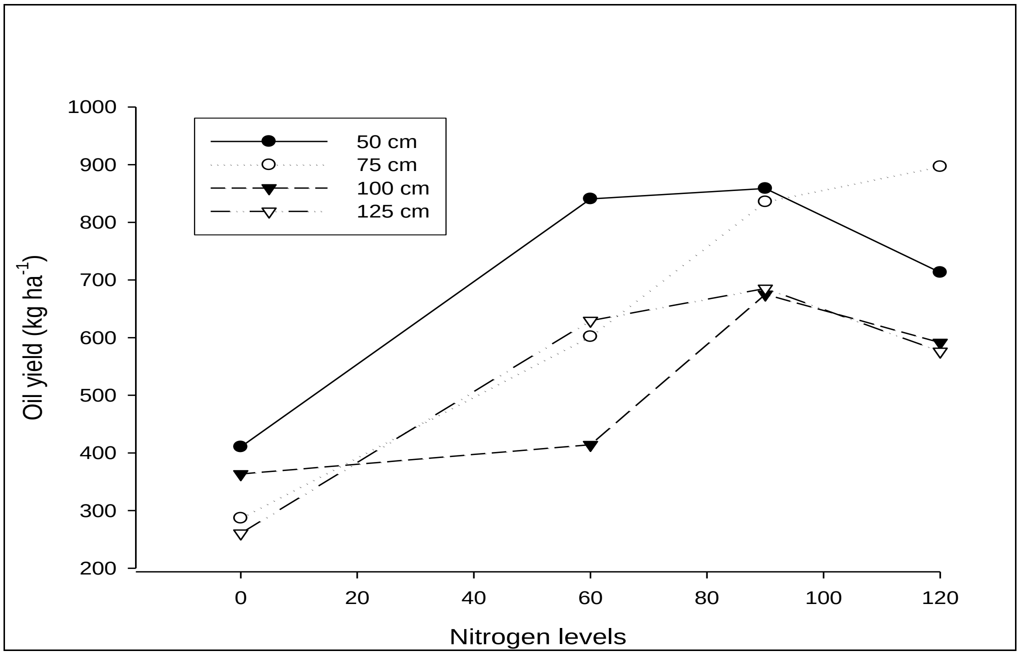

Fig. 5. Interaction between plant spacing and nitrogen levels for oil yield (kg ha^{-1}) of castor bean.

Biological yield (kg ha^{-1})

Plant spacing and nitrogen levels significantly affected biological yield of castor bean. The plant spacing and nitrogen levels interaction (PS x N) was found non-significant (Table 3). The highest biological yield (9222 kg ha^{-1}) was noted in plots having plant spacing of 50 cm followed by plant spacing of 75, 100 and 125 cm with biological yield of 7083, 6423 and 5749 kg ha^{-1}, respectively. In case of the nitrogen application, maximum biological yield (8753 kg ha^{-1}) was obtained through nitrogen application of 120 kg ha^{-1} followed by 90 kg ha^{-1} having biological yield of 7954 kg ha^{-1} and 60 kg ha^{-1} with the biological yield of 7162 kg ha^{-1}. The lowest biological yield (4609 kg ha^{-1}) was obtained from control plots.

Harvest index (%)

The harvest index was significantly affected by plant spacing and nitrogen levels. The interrelation between plant spacing and nitrogen (PS × N) was significant (Table 3). The highest harvest index

(19.4 and 19.1%) was calculated in plots having a plant spacing of 75 cm and 125 cm which were statistically at par with each other, while lower harvest index (16.4, 16.8%) was obtained at 50 cm and 100 cm. In case of nitrogen, the highest harvest index (20%) was recorded in the plots having nitrogen application of 90 kg ha^{-1} followed by 60 kg ha^{-1} having harvest index of 19% and 120 kg ha-1 having harvest index of 16.9%. Minimum harvest index (15.7%) was noted in control plots. In case of PS × N interaction the highest harvest index was obtained in the plots having plant spacing of 125 cm along with the addition of 60 kg N ha^{-1}.

Oil content (%)

The data regarding oil content are presented in Table 4. The oil content was significantly affected by nitrogen levels but plant spacing had no effect on oil content of castor bean. The interaction between plant spacing and nitrogen (PS × N) was non-significant. The maximum oil content (48.8%) was produced in plots having nitrogen application of 90 kg ha^{-1} while lower oil content (45%) was obtained from control plots.

Oil yield (kg ha^{-1})

Plant spacing and nitrogen levels had significant influence on oil yield of castor bean. The interaction between PS × N was found non- significant. The highest oil yield (701 and 655 kg ha^{-1}) was measured in plots having plant spacing of 50 and 75 cm which were statistically at par with each other. Lower oil yields of 515 and 501 kg ha^{-1} were obtained from plots having plant spacing of 125 and 100 cm, respectively. Likewise, nitrogen application at 90 kg ha^{-1} resulted in higher oil yield (766 kg ha^{-1}) followed by nitrogen application at the rate of 120 and 60 kg ha-1 having oil yield of 670 and 628 kg ha^{-1}, respectively. The lowermost oil yield (319 kg ha^{-1}) was obtained from control plots. In case of PS × N interaction, the highest oil yield was noted from plots having plant spacing of 75 cm along with 90 kg N ha^{-1}.

Nitrogen use efficiency (kg kg^{-1})

The data concerning nitrogen use efficiency (NUE) are presented in Table 4. The NUE was significantly affected by plant spacing and nitrogen levels. The interaction between plant spacing and nitrogen was also found significant. The maximum NUE (21.1 and 19.5 kg kg^{-1}) was recorded in plots having plant spacing of 50 and 75 cm which were statistically at same level. Lower NUE

(15.1 and 13.4 kg kg^{-1}) was measured in plots having plant spacing of 125 cm and 100 cm, respectively. In case of nitrogen, maximum NUE (22.4 kg kg^{-1}) was obtained from application of 60 kg N ha^{-1} while, minimum was obtained at 125 kg N ha^{-1}. In case of PS × N interaction, the highest NUE was noted from plots having plant spacing of 50 cm along with 60 kg N ha^{-1}.

Agronomic use efficiency (kg kg^{-1})

The data related to agronomic use efficiency (AUE) are presented in Table 4. Plant spacing and nitrogen levels had a major impact on the AUE. The relationship of plant spacing and nitrogen (PS × N) was also significant. The results showed that AUE increased with decreasing nitrogen levels. The highest AUE (16.2) was obtained in plots with plant spacing of 50 cm followed by 75 cm and 125 cm plant spacing having AUE of 12.2 and 8.4, respectively, while lowest AUE (4.3) was obtained in plots with plant spacing of 125 cm. In the case of nitrogen, the highest AUE (12.6) was obtained by applying 60 kg N ha^{-1}, while the minimum (7.2) was obtained by applying 120 kg N ha^{-1}. In the case of PS × N interaction, plots with plant spacing of 50 cm and 60 kg N ha^{-1} had the maximum AUE.

Table 2. Dry matter partitioning at silking and physiological maturity stage of maize as affected by humic acid and foliar salicylic acid application.

	Parameters					
Plant spacing (cm)	Biological yield (kg ha^{-1})	Harvest index (%)	Oil content (%)	Oil yield (kg ha^{-1})	NUE (kg kg^{-1})	AUE (kg kg^{-1})
50	9222 a	16.4 c	45.8	701.5 a	21.1 a	16.2 a
75	7083 b	19.4 a	46.5	665.2 a	19.5 a	12.2 b
100	6424 bc	16.8 bc	46.7	501.8 b	13.4 b	4.3 d
125	5749 c	19.1 a	47.7	515.8 b	15.1 b	8.4 c
LSD $_{(0.05)}$	741	2.3	NS	81.6	2.2	2.4
Nitrogen levels (kg ha^{-1})						
0	4609 d	15.7 c	45.0 c	319.1 c	-	-
60	7162 c	19.0 ab	46.9 b	628.7 b	22.4 a	12.6 a
90	7954 b	20.0 a	48.8 a	766.1 a	17.4 b	10.9 a
120	8753 a	16.9 bc	46.2 b	670.2 b	12.0 c	7.2 b
LSD $_{(0.05)}$	741	2.3	1.5	81.6	2.2	2.4
Interaction						
PS × N	NS	**	NS	**	NS	**

PS: plant spacing, N: nitrogen, NS: non-significant

IV. DISCUSSION

Maintaining plant spacing of 50 cm resulted in 15% highest plant height as compared to 125 cm due to increase in competition among plants under narrow spacing for light which eventually resulted in a rapid meristematic activity thus enhance in size of cells occurred and so as increased in plant height (Lakshamma et al., 2003). These findings also match with the outcomes of Kathirvelan (2017) who reported that closer spacing of 120 × 120 cm resulted in higher plant height and seed yield as compared to wider spacing in castor bean. Among various nitrogen levels, greater dose of nitrogen 120 kg ha^{-1} led to an increase of 31% in plant height over control. The plant height increased with the rise in fertility levels may be attributed that nitrogen is important nutrient for vegetative growth primarily. Nitrogen increases elasticity of cell wall and thus size of the cell which finally contributes to cell division and cell elongation (Nahar and Pan, 2015).

Plant spacing of 125 cm produced 13% more branches $plant^{-1}$ than 50 cm plant spacing. This is because in wider plant spacing there is better utilization of light, water, nutrients and space which as a result provides favorable environmental conditions for maximum growth and development. While in denser plant spacing, intra-crop-competition increases and thus reduces number of branches which results in poor growth due to limited resources. Our results are in line with Aruna and Sagar (2016) who found that number of branches $plant^{-1}$ of castor bean increased in both years with increase in plant spacing, because closer planting negatively affect growth of the plants due to less availability of space for each plant under reduced resources. Nitrogen application of 120 kg ha^{-1} produced 100% maximum branches $plant^{-1}$ as compared to control plots because there is escalation in vegetative growth and sprouting with addition in nitrogen amount (Srinivas et al., 2005; Vanaja et al., 2008; Bakht et al., 2011). The results are supported by Jamil et al. (2017) who reported that higher amount of nitrogen is responsible for increased photosynthesis which as result increases all growth related aspects of plant including branches $plant^{-1}$.

The plant spacing of 125 cm resulted in 37% more capsules $plant^{-1}$ as compared to 50 cm plant spacing. Our results are in agreement with those of Daisy and Thavaprakaash (2019) who revealed that plant and row spacing of 150 × 150 cm in castor bean resulted in maximum number of capsules $plant^{-1}$, which might be due to effective utilization of above and below ground resources due to large area availability to the individual plant. Among different levels of nitrogen, the maximum capsules plant^{-1} was recorded with application of 120 kg N ha^{-1} which was 122% higher as compared to control plot. The increase in capsules plant^{-1} might be due to nitrogen which favorably influenced flowering and fruiting. Our results are in line with Shinde et al. (2018) who found that NPK application at the rate 80:50:40 kg ha^{-1} significantly improved all growth and yield parameters of castor bean than 40:30:20 kg ha^{-1} and 60:40:30 kg ha^{-1}.

The highest thousand seed weight was recorded in plots having plant spacing of 125 cm which was 19% higher than plant spacing of 50 cm. This may be due to wider plant spacing that may have improved photosynthetic activity and thus increased amount of metabolites which showed positive impact on seed weight. Our results are in line with Kathirvelan (2017) who resulted that test weight of castor bean increased with increase in plant spacing. In comparison to control plots, nitrogen at a rate of 120 kg ha^{-1} resulted in a 26% increase in thousand seed weight. The probable reason may be the nitrogen which plays key role in assimilates production, thus as a result higher translocation towards grains occurs which may lead to bold and heavy grains. Our result agrees with the findings of Farahani and Aref, (2008) and Chatzakis et al. (2011) who reported that nitrogen also positively affected thousand grain weight of castor bean.

The highest seed yield was obtained in plots having plant spacing of 50 cm which was 29% higher than plots in which 125 cm plant spacing were maintained. Our results were also confirmed by Kathirvelan (2017) who concluded that castor seed yield was the highest in plots maintained with higher population as result of narrow spacing. The possible cause is the increased reproductive units per unit area. Seed yield increased by 55% as nitrogen levels rose from 0 to 90 kg ha^{-1}, while further addition in the nitrogen amount (120 kg ha^{-1}) did not enhance but reduced yield by 8%. This might be due addition of N at the rate of 90 kg ha^{-1}. These results are in line with the findings of Farahani and Aref (2008) and Jamil et al. (2017) and Aruna and Sagar (2016) who found that castor yield increased with increase in nitrogen from 0 to 80 kg ha^{-1}.

Higher biological yield was noted in those plots where 50 cm plant spacing was maintained which was 23, 30 and 38% higher than plots in which plant spacing of 75, 100 and 125 cm were maintained, respectively. This may be due to high plant density as a result of narrow plant spacing and thus more the number of plants which are directly related with higher biomass. Vala et al.

(2000) reported that maintaining optimum plant stand as a result of proper plant spacing could probably increase plant biomass due to availability of favorable environmental conditions. Similar findings are reported by Saeed et al. (2017) who stated smaller plant spacing of 10 cm resulted in the maximum biological yield of maize than the wider plant spacing of 20 cm and 30 cm during both years. Castor bean showed 47% increase in biological yield over control plot by increasing amount of nitrogen from 0 to 120 kg ha^{-1}. The reason might be nitrogen which is important for plant vegetative growth and biomass production. Our results agree with Ahmad et al. (2018) who found that extending amount of nitrogen can significantly increase maize biological yield.

Castor bean oil content (%) was not significantly affected by plant spacing. Our findings are in line with Anbarasu et al. (2018) who concluded that the spacing between and among rows did not positively affect the oil content of castor bean and that there were no significant differences between the treatments. Higher oil content was obtained at 90 kg ha^{-1}, while low oil content was obtained at control treatment. These results are supported by Pashazadeh et al. (2012) who stated that nitrogen is a crucial nutrient for plants developmental phases and other metabolic processes so its incorporation for oil crop can effectively increase oil content of crop.

Oil yield was the highest in plots having plant spacing of 50 cm which was 29% higher than 125 cm of plant spacing. Our findings are similar to Anbarasu et al. (2018) who concluded that optimum plant spacing in castor bean can effectively increase oil yield due the fact that plant can have favorable environment in order to carry different metabolic processes which are necessary for the development and growth of plants such as photosynthesis and nutrients absorption. The highest oil yield was documented at 90 kg ha^{-1} nitrogen application, which was 213% greater than control plots. Nitrogen at optimum level enhanced oil content of castor seed because application of optimum nitrogen to oil seed crops increases their oil content over control plants. Our findings are consistent with those of Pashazadeh et al. (2012) who stated that nitrogen applied plots in contrast to control resulted in higher oil content of castor seed.

Nitrogen use efficiency (NUE) and agronomic efficiency (AE) of castor bean were significantly affected by plant spacing and nitrogen levels. Higher NUE and AE were obtained with plant spacing of 50 cm while lower NUE and AE were obtained at 125 cm plant spacing. It might be due to increased plant density in narrow plant spacing which increased nitrogen utilization. Our findings are not in line with Nadeem et al. (2010) who determined that the NUE of cotton improved with increase in plant spacing. Increased nitrogen levels resulted in a steep linear decrease in nitrogen usage. Higher NUE and AE were obtained at 60 kg ha^{-1} but decreased as N level increased. The lowest NUE and AE were obtained at 120 kg N ha^{-1}. This may be attributed to the plants' efficient use of adequate nitrogen. Since there could be losses of nitrogen due to volatilization and leaching, nitrogen absorption efficiency and nitrogen usage efficiency decreased as the volume of nitrogen increased from 60 to 120 kg ha^{-1}, respectively. These results are supported by Khattak et al. (2017) who concluded that NUE and AE in wheat crop showed linear decrease with increase in nitrogen level.

V. CONCLUSION

On the basis of the results it was concluded that narrow plant spacing of 50 cm reduced most of the yield components like branches plant^{-1}, racemes plant^{-1} and thousand seed weight but improved plant height, seed, biological and oil yields, NUE and AUE as compared to wider plant spacing of 125 cm. Similarly, nitrogen application at the rate of 90 kg ha^{-1} increased branches plant^{-1}, seed, biological, and oil yields and harvest index, whereas nitrogen level of 120 kg ha^{-1} had maximum thousand grain weight of castor bean. However, NUE and AUE were higher at reduced level of 60 kg N ha^{-1}.

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