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Effect of Planting Geometry on Seed and Oil Yield of Jatropha

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Abstract: The present study was carried out for two consecutive years (2010 and 2011) at Student's Experimental Farm, Sindh Agriculture University, Tandojam. The experiment was laid out in randomized complete block design factorial with three replications. Three Jatropha varieties i.e Thailand, Malaysian and Indian were used in the experiment under different planting geometries (2.15×2.15 m, 2.50×2.50 m and 2.15×3.00 m). The results revealed that effect of planting geometry on plant height, branches plant^{-1}, days to harvest, fruits plant^{-1}, seeds fruit^{-1}, seed weight plant^{-1}, seed index, seed yield (kg ha^{-1}) and oil content (%) was found significant ($P<0.05$) statistically. The crop performance was maximum in planting geometry of 2.15m × 3.00 m with 524.9 fruits plant^{-1}, 1661 kg ha^{-1} seed yield and 31.00 % oil content. Among varieties, Thai performed better than Malaysian and Indian varieties with highest values for plant height (255.7 cm), fruits plant^{-1} (533.2), seed yield (1905 kg ha^{-1}) and oil content (32.6 %) respectively. The interactive effect of planting geometry 2.15×3.00 m × variety Thai × 2011 resulted in markedly higher crop performance as compared to rest of the treatment combinations, with maximum fruits plant^{-1} (697.5), seed weight plant^{-1} (1547 g), seed yield (2398 kg ha^{-1}) and oil content (35.5 %). Being a perennial crop, overall, performance was better during the second year (2011) as compared to first year (2010) which is mainly associated with the one year increased age and development of the crop.

Keywords: Jatropha, planting geometry, seed yield and oil content percetage

1. INTRODUCTION

Jatropha (*Jatropha curcas* L.) is a small tree or shrub with a height 3-10 meters and can have a life span of 40-50 years. Jatropha called wild castor in English is a perennial plant belonging to *Euphorbiaceae* family and has many social, ecological and economic advantages. It bears black caster like seeds from which production of oil is possible through processing. Climatically, it is found in the tropics and subtropics. It likes heat but can withstand some amount of frost (Tadesse and Tadesse, 2017). It has received significant interest of researchers as an important source of biodiesel. Jatropha has diverse uses as a source of enhancing rural economy by generating huge employment of peoples during many stages of its cultivation and further processing makes it as a potential candidate for large-scale cultivation on marginal lands (Kochhar *et al*., 2008; Rao *et al.*, 2008; Sunil *et al*., 2008;; Atta, 2009; Kheira and Mishra, 2009; Behera *et al*., 2010). Jatropha has emerged as one of the major sources of biofuel due to its ability to thrive in marginal areas and produce low-cost alternative of fuel (Salé and Dewes, 2009). Currently, the whole world is faced with critical fuel shortages accompanied with high prices as well as the global warming issue (Pratt *et al*., 2002). This situation has prompted world organizations to search for alternative sources of energy which are renewable, safe and non-polluting (Achten *et al.*, 2008; Gohil and Pandya, 2009; Jimu *et al*., 2009). Biodiesel is most feasible for the countries like Pakistan due to its agricultural base and suitable climatic condition. Research on *Jatropha curcas* are limited specially for cultivation and propagation in Pakistan (Harun, 2008). However, there is need of complete package of production technology including proper date of sowing and proper plant population on the basis of demonstration plots under different ecologies (Chakraborty *et al.,* 2017).Whereas 2,500 trees are best for unmanaged and marginal farming (Kheira *et al.*, 2009). In one acre, at a spacing of 2 m x 2 m 1000 plants can be planted (Zaidman *et al.*, 2010). The recommended spacing for planting *Jatropha curcas* ranges in between 2 m x 1.5 m to 3 m x 3 m (Miller, 1992). In this way 1,600 to 2,200 plants are needed for planting one hectare area. The wider space gives larger fruit yield, 318 g shrub^{-1} and 794 kg ha^{-1} (Heller, 1996). The recommended inter intra row spacing for monoculture of Jatropha is 3 m x 2.5 m, it gives about 1333 plants ha^{-1} for the first few years of cultivation and makes possible for intercropping of food crops (Franken, 2010).

2. MATERIALS AND METHODS

The study was conducted at Student's Farm, Sindh Agriculture University Tandojam for two years during 2010 to 2011. Three different planting geometries viz (2.15×2.15 m), (2.15×2.50 m) and (2.15×3.00 m) within and between rows under three varieties i.e Thailand, Malaysian and Indian were evaluated for the growth and oil content of Jatropha. The crop was sown on 25th Julty, 2009. The experiment was conducted in a randomized complete block design factorial with three replications in a plot size of 12.5 m x 9 m (112.5 m^2). The data for 1st year crop was recorded during 2010, whereas for 2nd

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year crop during 2011. After seed bed preparation, ring basins were prepared all around each plant at radii of one and half feet distance to facilitate better storage of water and efficient utilization of nutrients. Seedlings were transplanted 75 days after planting from nursery bed to experimental field and planted manually as per requirement of above mentioned treatment of planting geometry. First irrigation was applied after planting and subsequent irrigations were applied keeping in view the soil moisture condition and plant need at the interval of 15 days. All the inputs were applied as recommended for Jatropha. To investigate effect of planting geometry, the data was recorded for plant height, branches plant^{-1}, days to harvest, fruits plant^{-1}, seeds fruit^{-1}, seed weight plant^{-1}, seed index/1000 seed weight, seed yield kg ha^{-1} and oil content in percentage. For taking the observations, five plants randomly from each treatment were selected and tagged for recording data. The average values of these five plants were considered for further analysis. The collected data was statistically analyzed using statisix 8.1 computor software (statisix, 2006). The value of P less than 0.05 were considered statistically significant and the LSD was applied to compare treatment means superiority. Meteorological data for the crop growth period was collected from Regional Agro- Metrological Centre, Tandojam, Sindh Pakistan on maximum and minimum temperature (^{0}C), relative humidity (%) and rain fall (mm).

3. RESULTS AND DISCUSSION

Effect of varieties under different planting geometry of Jatropha

The performance of Jatropha in relation to different varieties as influenced by planting density was investigated for consecutive two years (2010 and 2011) and the data is given in Table-1. The analysis of variance illustrated that growth and yield of Jatropha was significantly ($P<0.05$) affected by the planting geometry. On average, the Jatropha variety Thai performed better than Malaysian and Indian varieties with highest values for plant height (255.7 cm), branches plant^{-1} (25.59), fruits plant^{-1} (533.2), seeds fruit^{-1} (2.79), seed weight plant^{-1} (1045 g), seed index/1000 seed weight (730.1 g), seed yield (1905 kg ha^{-1}) and oil content (32.64 %) with lowest number of days to harvest (246.5), respectively. The Malaysia Jatropha variety ranked second in plant height (226.6 cm), branches plant^{-1} (19.63), days to harvest (246.5), fruits plant^{-1} (471.7), seeds fruit^{-1} (2.28), seed weight plant^{-1} (872.5 g), seed index/1000 seed weight (679.9 g), seed yield (1587 kg ha^{-1}) and oil content (27.92 %). The Indian Jatropha variety ranked third with minimum values for plant height (196.1 cm), branches plant^{-1} (15.23), fruits plant^{-1} (425.5), seeds fruit^{-1} (1.6), seed weight plant^{-1} (744.6 g), seed index/1000 seed weight (631.0 g), seed yield (1357 kg ha^{-1}) and oil content (24.95 %). with maximum days to harvest (321.2), respectively. The consolidation of results from planting geometry experiment indicated that Thai Jatropha variety proved to be superior in overall plant traits. Regardless the planting geometry, this variety has shown its utmost suitability under the environment of Tandojam area and the performance of this variety has been found far better than Malaysian and Indian Jatropha varieties, respectively. Near similar to our findings, (Kalhoro, 2011) proved that among varieties, Indian Jatropha variety showed its superiority with 62.23% germination, 8.54 days to seedling emergence, 10.67 cm root length, 12.28 cm shoot length and 7.59 leaves plant^{-1}, while Thai variety ranked second with 61.11% germination, 9.22 days to seedling emergence, 9.46 cm root length, 11.79 cm shoot length and 7.16 leaves plant^{-1}. However, Malaysian variety ranked 3rd in position. These results are in confirmation with Ginwal *et al.* (2005) who also evaluated Jatropha curcas varieties Gondia, Bichia, Balaghat, Niwas, Khandwa, Burhanpur, Nasik, Chindwara, Kundam and Jabalpur for their growth performance, and they found that varieties varied significantly for agronomic performance as well as oil content percentage.

Table 1. Effect of varieties on growth and yield of Jatropha different planting Geometries

Traits	S.E.	LSD 0.05	Varieties		
			Thai	Malaysian	Indian
Plant height (cm)	3.225	9.268	255.7 a	226.6b	196.1 c
Branches plant^{-1}	0.2339	0.6723	25.59 a	19.63 b	15.23 c
Days to harvest	3.829	11.01	246.5 c	287.9 b	321.2 a
Fruits plant^{-1}	3.205	9.210	533.2 a	471.7 b	425.5 c
Seeds fruit^{-1}	0.0365	0.1049	2.70 a	2.20 b	1.60 c
Seed weight plant^{-1}(g)	11.60	33.33	1045 a	872.5 b	744.6 c
Seed index (1000 seed wt g)	11.58	33.28	730.1 a	679.9 b	631.0 c
Seed yield (kg ha^{-1})	28.94	83.16	1905 a	1587 b	1357.0 c
Oil content (%)	0.4095	1.177	32.64 a	27.92 b	24.95 c

Effect of planting geometry on various traits of Jatropha

The crop performance in Jatropha for growth and yield as affected by different planting geometries for a consecutive period of two years was examined and the analysis of variance suggested significant ($P<0.05$). The data (Table-2) showed that the crop performance was linearly superior in plots kept at the planting geometry 2.15 x 3.00 m over 2.15 x 2.50 m and 2.15 x 2.15 m planting geometries except plant height, produced maximum values for branches plant^{-1} (25.60), fruits plant^{-1} (524.9), seeds fruit^{-1} (2.90), seed weight plant^{-1} (1072 g), seed index/1000 seed weight (745.7g), seed yield (1661 kg ha^{-1}) and oil content (31.0%) , with minimum days to harvest (247.6) and plant height (193.2), respectively.The plant geometry 2.15×2.15 m showed similar seed yield, maximum plant height but oil content and other traits decreased considerably. Produced plant height (258.5 cm), branches plant^{-1} (15.11), days to harvest (323.8), fruits plant^{-1} (428.4), seeds fruit^{-1} (1.70), seed weight plant^{-1} (768 g), seed index/1000 seed weight (614.6 g), seed yield (1661 kg ha^{-1}) and oil content (26.67 %), respectively whereas planting geometry 2.15x2.50 m performed better but decreased in plant height and seed yield.,produced plant height (226.6 cm), branches plant^{-1} (19.75), days to harvest (284.3) fruits plant^{-1} (477.1), seeds fruit^{-1} (1.90), seed weight plant^{-1} (822.8 g), seed index/1000 seed weight (680.7 g), seed yield (1528 kg ha^{-1}) and oil content (27.84 %). The results from plant geometry experiment indicated that the planting geometry 2.15 x 3.00 m proved to be superior in overall plant traits except plant height. The plant density 2.15 × 2.15 m showed similar seed yield but decreased oil content (%) and other plant traits considerably, whereas planting geometry 2.15 x 2.50 m performed better but decreased in seed yield as compared to planting geometry 2.15 m × 3.00 m and 2.15 m × 2.15m, respectively. Similar to present results, (Vazquez *et al.,* 2013) also noted that wider spacing increases crop yield and oil content. Distance of 8.8 by 8.8 ft (2.7 by 2.7 m) may be more desirable for commercial cultivation because, plant geometry of 1,012 plants acre^{-1} (2500 plants. ha^{-1}) is more acceptable. While (Santosh *et al.,* 2013) observed that seed yield per plant was maximum at the spacing of 3 m×3 m followed by 3 m × 2 m spacing.

Table 2. Effect of planting geometry on growth and yield of Jatropha

Traits	SE	LSD 0.05	planting geometry		
			2.15 × 2.15 m	**2.15 × 2.50 m**	**2.15 × 3.00 m**
Plant height (cm)	3.225	9.268	258.5 a	226.6 b	193.2 c
Branches plant^{-1}	0.2339	0.6723	15.11 c	19.75 b	25.60 a
Days to harvest	3.829	11.01	323.8 a	284.3 b	247.6 c
Fruits plant^{-1}	3.205	9.210	428.4 c	477.1 b	524.9 a
Seeds fruit^{-1}	0.0365	0.1049	1.70 c	1.90 b	2.90 a
Seed weight plant^{-1}(g)	11.60	33.33	768.0 c	822.8 b	1072. a
Seed index (1000 seed wt g)	11.58	33.28	614.6 c	680.7 b	745.7 a
Seed yield (kg ha^{-1})	28.94	83.16	1661.0 a	1528. b	1661.0 a
Oil content (%)	0.4095	1.177	26.67 b	27.84 b	31.0 a

Interactive effect of varieties × planting geometry on various traits of Jatropha

The interactive effect of varieties × planting geometry on growth and yield of Jatropha was examined and the analysis of variance showed that such effect on plant height, branches plant^{-1},days to harvest, fruits plant^{-1}, seeds fruit^{-1}, seed weight plant^{-1}, seed index/1000 seed weight, seed yield ha^{-1} and oil content was significant ($P<0.05$). The data (Table-3) indicated that on the basis of seed and oil yield , the interaction between variety Thai and 2.15 m × 3.00 m planting geometry proved to be superior combination in relation to plant height (217.9 cm), branches plant^{-1} (31.85), fruits plant^{-1} (589.0), seeds fruit^{-1} (3.50), seed weight plant^{-1} (1265 g), seed index/1000 seed weight (794.9 g), seed yield (1960 kg ha^{-1}) and oil content (35.47%) with lowest days to harvest (204.1), respectively. Interaction between variety Thai and 2.15 m × 2.15 m plant geometry showed similar seed yield but oil yield decreased considerably; while interaction between variety Thai and 2.15 m x 2.50 m planting geometry resulted in a decreased seed yield. The interaction between variety Malaysian and 2.15 x 3.00 m planting geometry showed better performance in regards to plant height (193.6 cm), branches plant^{-1} (24.95), days to harvest (247.0), fruits plant^{-1} (515.3), seeds fruit^{-1} (2.96), seed weight plant^{-1} (1053 g), seed index/1000 seed weight (745.7 g), seed yield (1632 kg ha^{-1}) and oil content (30.15%), respectively. Interaction between variety Malaysian and 2.15 m ×2.15 m planting geometry showed similar seed yield but decreased oil content; while interaction between variety Malaysian and 2.15 m × 2.50 m planting geometry resulted in a lowest seed yield. The interaction between variety Indian and 2.15 m × 3.00 m planting geometry produced 168.1 cm plant height, 20.00 branches plant^{-1}, 291.6 days to harvest, 470.5 fruits plant^{-1}, 2.31 seeds fruit^{-1}, 897.5 seed weight plant^{-1}, 696.6 g seed index/1000 seed weight, 1391 kg ha^{-1} seed yield and 27.38% oil content, respectively. Interaction between variety Indian and 2.15 m × 2.15 m planting geometry produced same seed yield but reduced oil yield; while interaction between variety Indian and 2.15 m x 2.50 m planting geometry resulted in a minimum seed yield. It was concluded that the seed yield and oil content (%) was higher in Jatropha under 2.15 m x 3.00 m planting geometry as compared to 2.15 m x 2.15 m or 2.15 x 2.50 m planting geometry regardless the varieties of Jatropha. These results are in consonance with those of (Vaknin *et al.* 2018) who suggested planting density of 3m × 2 m for Jatropha plantation which produced a seed yield of 0.911 kg TS plant^{-1} (1 kg total weight) with an oil content of 35 % providing an annual oil yield of 1.42 tons year^{-1}. While Zaidman *et al.* (2010) suggested spacing of 2m × 2.5m.

Table 3. Interactive effect of varieties × planting geometry on growth and seed yield of Jatropha

Traits	S.E.	LSD 0.05	Varieties × planting geometry								
			Thai			Malaysian			Indian		
			2.15 x 2.15 m	2.15 x 2.50 m	2.15 x 3.00 m	2.15 x 2.15 m	2.15 x 2.50 m	2.15 x 3.00 m	2.15 x 2.15 m	2.15 x 2.50 m	2.15 x 3.00 m
Plant height (cm)	5.586	16.05	293.8 a	255.2 b	217.9 c	258.2 b	228.0 c	193.6 d	223.4 c	196.7 d	168.1 e
Branches plant^{-1}	0.4052	1.164	19.68 c	25.25 b	31.85 a	14.77 d	19.17 c	24.95 b	10.87 e	14.83 d	20.00 c
Days to harvest	6.633	19.06	289.1 c	246.2 d	204.1 e	331.1 b	285.6 c	247.0 d	351.1 a	321.0 b	291.6 c
Fruits plant^{-1}	5.550	15.95	480.5 c	530.0 b	589.0 a	425.5 d	474.1 c	515.3 b	379.1 e	427.1 d	470.5 c
Seeds fruit^{-1}	0.0632	0.1818	2.37 c	2.50 c	3.51 a	1.82 e	2.05 d	2.96 b	1.16 g	1.44 f	2.31 c
Seed weight plant^{-1}(g)	20.08	57.72	906.1 d	965.4 c	1265 a	754.5 e	810.0 e	1053 b	643.3 f	693.0 f	897.5 d
Seed index (1000 seed wt g)	20.05	57.64	665.0def	730.5 bc	794.9 a	613.0 fg	680.9 cde	745.7 ab	565.8 g	630.6 ef	696.6 bcd
Seed yield (kg ha^{-1})	50.12	144.0	1960 a	1796 b	1960 a	1632 c	1498 cd	1632 c	1391de	1289 e	1391 de
Oil content (%)	0.7093	2.039	30.03 c	32.42 b	35.47 a	26.57 d	27.05 d	30.15 c	23.42 e	24.05 e	27.38 d

Interactive effect of varieties × years under different planting geometries of Jatropha

The interactive effect of varieties × years on various traits for growth andyield of Jatropha was assessed in a planting density experiment and the data are presented in Table-4. The analysis of variance showed that the interactive effect of varieties x years on traits examined in this study were significant (P<0.05). The interaction (Year 2011 × variety Thai) resulted in superior Jatropha performance, produced highest values for plant height (275.2 cm), branches plant^{-1} (30.47), fruits plant^{-1} (648.9), seeds fruit^{-1} (2.78), seed weight plant^{-1} (1279g), seed index/1000 seed weight (730.0 g), seed yield (2330 kg ha^{-1}) and oil content (32.61%) with lowest days to harvest (245.1), respectively. The interaction (Year 2011 × variety Malaysian) ranked 2nd with plant height (245.0 cm), branches plant^{-1} (22.72), days to harvest (288.5), fruits plant^{-1} (598.2), seeds fruit^{-1} (2.25), seed weight plant^{-1} (1124.0 g), seed index/1000 seed weight (680.2 g), seed yield (2048.0 kg ha^{-1}) and oil content (27.96%). The interaction (Year 2011 × variety Indian) ranked 3rd in plant height (210.5 cm), branches plant^{-1} (17.39), days to harvest (321.5), fruits plant^{-1} (551.0), seeds fruit^{-1} (1.70), seed weight plant^{-1} (995.8 g), seed index/1000 seed weight (631.0 g), seed yield (1815.0 kg ha^{-1}) and oil content (24.96 %), respectively. Apart from the varieties, poor crop performance was observed during the first year of experiment (2010) probably due to age of the plant and due to non-existence of production technologies for the particular agro-ecological condition. The treatment interaction (Year 2011 × variety Thai) showed better performance than rest of the interactions in 2010, with maximum values for plant height (236.1 cm), branches plant^{-1} (20.72), fruits plant^{-1} (417.4), seeds fruit^{-1} (2.80), seed weight plant^{-1} (812.1g), seed index/ 1000 seed weight (730.3 g), seed yield (1480.0 kg ha^{-1}) and oil content (32.67 %) with lowest days to harvest (247.8), respectively. The interactions of Year 2010 × variety Malaysian and Year 2011 × variety Indian showed lower overall performance as compared to interaction (Year 2010 × variety Thai). The results concluded that the crop performance on average for the year (2010) was not upto the mark; however, during year (2011) tremendous improvement in the growth, seed yield and other parameters was noted. That might be due to increase one year age and size of the plant. Irrespective of styudy years, Thai variety proved to be superior over Malaysian and Indian for all the growth and yield traits, as well as this variety also proved to be an early maturing. Similarly present findings confimed by Pandey *et al.* (2007) who conducted progeny evaluation experiment and studied morphological characteristics of many Jatropha genotypes and a highly significant variation among varieties for all the characters was observed.

Table 4. Interactive effect of varieties × years on growth and yield under different planting geometries of Jatropha

Traits	SE	LSD 0.05	Varieties × years					
			2010			2011		
			Thai	Malaysian	Indian	Thai	Malaysian	Indian
Plant height (cm)	4.561	13.11	236.1 b	208.2 c	181.7 d	275.2 a	245.0 b	210.5 c
Branches plant^{-1}	0.3308	0.9508	20.72 c	16.53 d	13.08 e	30.47 a	22.72 b	17.39 d
Days to harvest	5.416	15.56	247.8 c	287.2 b	320.9 a	245.1 c	288.5 b	321.5 a
Fruits plant^{-1}	4.532	13.02	417.4 d	345.1 e	300.1 f	649.0 a	598.2 b	551.0 c
Seeds fruit^{-1}	0.0516	0.1484	2.80 a	2.30 b	1.50 d	2.70 a	2.20 b	1.70 c
Seed weight plant^{-1}(g)	16.40	47.13	812.1 d	621.2 e	493.4 f	1279 a	1124 b	995.8 c
Seed index (1000 seed wt g)	16.37	47.06	730.3 a	679.6 b	631.1 b	730.0 a	680.2 b	631.0 b
Seed yield (kg ha^{-1})	40.92	117.6	1480 d	1127 e	899.2 f	2330 a	2048 b	1815 c
Oil content (%)	0.5792	1.665	32.67 a	27.89 b	24.94 c	32.61 a	27.96 b	24.96 c

Interactive effect of planting geometry × years on various traits of Jatropha

The interactive effect of planting geometry × years was investigated on growth and yield of Jatropha and the data for all the traits are consolidated in Table-5. The analysis of variance showed significant (P<0.05) effect on traits studied during 2010 and 2011. It is evident from the data that during 2010, the crop condition was although satisfactory, but not upto the desired level. During 2011, the age and size of the crop increased and the crop produced better results as compare to previous year 2010. The treatment interaction (Year 2011 × 2.15 m × 3.00 m planting geometry) resulted in a maximum crop performance with reference to plant height (211.5 cm), branches plant^{-1} (29.20), fruits plant^{-1} (644.7), seeds fruit^{-1} (2.90), seed weight plant^{-1} (1369 g), seed index/1000 seed weight (745.8 g), seed yield (2121 kg ha^{-1}) and oil content (31.00 %) with lowest days to harvest (247.6), respectively. The treatment interaction (Year 2011 × 2.15 × 2.50 m) ranked 2nd with plant height (243.9 cm), branches plant^{-1} (23.33), days to harvest (283.7), fruits plant^{-1} (602.0), seeds fruit^{-1} (2.00), seed weight plant^{-1} (1049 g), seed index/1000 seed weight (680.6 g), seed yield (1951 kg ha^{-1}) and oil content (27.84 %), respectively. The treatment interaction (Year 2011 × 2.15 × 2.15 m planting geometry) ranked 3rd except seed yield and plant height attained plant height (275.3cm), branches plant^{-1} (18.04), days to harvest (323.3), fruits plant^{-1} (551.5), seeds fruit^{-1} (1.7), seed weight plant^{-1} (980.8 g), seed index/1000 seed weight (614.7 g), seed yield (2121 kg ha^{-1}) and oil content (26.68%), respectively. It was further observed that during 2010, the values for all the traits examined were significantly (P<0.05) lower than the year 2011. However, on the basis of seed yield and its contributing traits, the treatment interaction (Year 2010 × 2.15 m × 3.00 m planting geometry) ranked 1st with reference to plant height (175.0 cm), branches plant^{-1}(22.0), days to harvest (247.6), fruits plant^{-1} (405.1), seeds fruit^{-1} (2.80), seed weight plant^{-1} (774.7 g), seed index/1000 seed weight (745.7 g), seed yield (1201 kg ha^{-1}) and oil content (31.00%), respectively. The interaction Year 2010 × 2.15 × 2.50 m planting geometry ranked 2nd and year 2010 × 2.15 m × 2.15 m planting geometry ranked least for all the growth and yield contributing traits except seed yield and plant height. The results concluded that during 2011, the Jatropha plantation remained better as compared to the year 2010. Howevr, on the basis of interactive effect, 2.15 m × 3.00 m planting geometry can be assumed as an appropriate plant population for Jatropha production. However our findings has also been supported by G.T.Z (2009) who also noted that the recommended spacing for Jatropha plantation is 3 m × 2.5 m for monoculture of Jatropha which produced a seed yield of 1 kg plant^{-1} with an oil content of 35 % and providing an annual oil yield of 1.42 tons year^{-1}. The wider spacing leads to larger and taller trees and need better pruning for easily harvesting, balance water and nutrient supply. However (Nahar and Hampton, 2017) evaluated that distance of 8.8 by 8.8 ft (2.7 by 2.7 m) with plant geometry of 1,012 plants acre^{-1} (2500 plants. ha^{-1}) may be more desirable for commercial cultivation because wider spacing is reported to increase crop yield by increasing fruit size

Table 5. Interactive effect of Planting Geometry × years on growth and yield of Jatropha.

Traits	SE	LSD 0.05	Planting geometry × years					
			2010			2011		
			2.15 × 2.15 m	**2.15 × 2.50 m**	**2.15 × 3.00 m**	**2.15 × 2.15 m**	**2.15 × 2.50 m**	**2.15 × 3.00 m**
Plant height (cm)	4.561	13.11	241.7 b	209.4 c	174.9 d	275.3 a	243.9 b	211.5 c
Branches plant^{-1}	0.3308	0.9508	12.17 f	16.17 e	22.00 c	18.04 d	23.33 b	29.20 a
Days to harvest	5.416	15.56	323.6 a	284.8 b	247.6 c	323.9 a	283.7 b	247.6 c
Fruits plant^{-1}	4.532	13.02	305.3 f	352.2 e	405.1 d	551.5 c	602.0 b	644.7 a
Seeds fruit^{-1}	0.0516	0.1484	1.80 c	1.90 b	2.80 a	1.70 c	2.00 b	2.90 a
Seed weight plant $^{-1}$(g)	16.40	47.13	555.2 e	596.7 e	774.7 d	980.8 c	1049 b	1369 a
Seed index (1000 seed wt g)	16.37	47.06	614.6 c	680.7 b	745.7 a	614.7 c	680.6 b	745.8 a
Seed yield (kg ha^{-1})	40.92	117.6	1201 c	1104 c	1201 c	2121 a	1951 b	2121 a
Oil content (%)	0.5792	1.665	26.67 b	27.83 b	31.00 a	26.68 b	27.84 b	31.00 a

Interactive effect of varieties ×planting geometry× years on various traits of Jatropha

The interactive effect of varieties × planting geometry × years on growth and yield of Jatropha was examined and such interactive effect on the parameters such as plant height, branches plant^{-1}, days to harvest, fruits plant^{-1}, seeds fruit^{-1}, seed weight plant^{-1}, seed index/1000 seed weight, seed yield kg ha^{-1} and oil content was significant (P<0.05) statistically. It is evident from the data **(Table-6)** that during year 2011 crop performance was superior in the treatment interaction Thai variety under 2.15 m × 3.00 m planting geometry with maximum branches plant^{-1} (37.27), fruits plant^{-1} (697.5), seeds fruit^{-1} (3.40), seed weight plant^{-1} (1547 g), seed index/1000 seed weight (794.7 g), seed yield (2398 kg ha^{-1}) and oil content (35.50 %) with lowest plant height (240.3 cm) and days to harvest (245.1), respectively. The interaction (variety Thai × 2.15 m × 2.50 m planting geometry) ranked 2nd and the interaction (variety Malaysian × 2.15m × 3.00m planting geometry) ranked 3rd for all the growth and yield parameters studied. During 2010, the overall growth and yield performance of Jatropha was relatively inferior as compared to the year 2011. However, during this year of study, the treatment interaction (variety Thai ×2.15m×3.00m planting geometry) resulted maximum performance with 195.5 cm plant height, 26.43 branches plant^{-1}, 205.0 days to harvest, 480.5 fruits plant^{-1}, 3.60 seeds fruit^{-1}, 982.3 g seed weight plant^{-1}, 795.1 g seed index/1000 seed weight, 1522 kg ha^{-1} seed yield and 35.43% oil content, respectively. The interaction (variety Thai × 2.15 m × 2.50 m planting geometry) ranked 2nd; and the interaction (variety Thai ×2.15m× 2.15 m planting geometry) ranked 3rd for all the growth and yield parameters studied. It was concluded that that planting geometry 2.15 m × 3.00 m proved to be an appropriate level for all the Jatropha varieties examined. Similarly, Thai variety showed its superiority over Malaysian and Indian varieties regardless the impact of planting geometry and years of study. However, the crop performance was remarkably higher during 2011 as compared to 2010 without consideration of varieties and planting geometry that might be due to increased age and size of the plant hence, seed yield and other plant traits gradually improved. Similarly our result are supported by (Ouwens *et al*., 2007 Nahar and Hampton, 2017) who noted that Jatropha yields increase with age and development of tree; therefore, the NPK fertilizer rates are increased with the development of plant age.

Table 6. Interactive effect of varieties × Planting Geometry × years on growth and yield of Jatropha

Years	Varieties	Planting geometry	Plant traits								
			Plant height (cm)	Branches plant^{-1}	Days to harvest	Fruits plant^{-1}	Seeds fruit^{-1}	Seed weight plant^{-1}(g)	(1000 seed wt g)	Seed yield (kg ha^{-1})	Oil content (%)
2010	Thai	2.15 x 2.15 m	277.8 b	15.57 j	289.7 d	360.6 h	2.35 cde	703.7 i	665.5 bc	1522 ef	30.07 bc
		2.15 x 2.50 m	234.9 cd	20.17 g	248.7 e	411.2 g	2.50 c	750.3 i	730.3 ab	1396 f	32.50 ab
		2.15 x 3.00 m	195.5 ef	26.43 d	205.1 f	480.5 f	3.58 a	982.3 fg	795.1 a	1522 ef	35.43 a
	Malaysian	2.15 x 2.15 m	240.6 c	11.93 k	330.7 abc	300.7 i	2.00 f	536.1 jk	612.6 cd	1160 g	26.53 d-g
		2.15 x 2.50 m	210.4 e	16.00 ij	285.2 d	344.7 h	2.00 f	579.5 j	680.7 bc	1061 gh	27.00 c-f
		2.15 x 3.00 m	173.6 fg	21.67 fg	245.9 e	389.8 g	2.93 b	747.9 i	745.4 ab	1159 g	30.13 bc
	Indian	2.15 x 2.15 m	206.7 e	9.000 l	350.5 ab	254.7 j	1.06 i	425.7 l	565.6 d	920.8 h	23.40 g
		2.15 x 2.50 m	182.8 f	12.33 k	320.5 c	300.7 i	1.46 gh	460.4 kl	631.2 cd	856.2 h	24.00 fg
		2.15 x 3.00 m	155.6 g	17.90 h	291.8 d	345.1 h	2.16 def	594.0 j	696.5 bc	920.7 h	27.43 cd
2011	Thai	2.15 x 2.15 m	309.8 a	23.80 e	288.5 d	600.5 c	2.40 cd	1108 de	664.6 bc	2397 a	30.00 bc
		2.15 x 2.50 m	275.5 b	30.33 b	243.7 e	648.8 b	2.50 c	1181 cd	730.6 ab	2196 ab	32.33 b
		2.15 x 3.00 m	240.3 c	37.27 a	203.2 f	697.5 a	3.45 a	1547 a	794.7 a	2398 a	35.50 a
	Malaysian	2.15 x 2.15 m	275.8 b	17.60 hi	331.6 abc	550.3 d	1.65 g	973.0 fg	613.5 cd	2105 bc	26.60 d-g
		2.15 x 2.50 m	245.6 c	22.33 ef	286.0 d	603.6 c	2.10 ef	1040 ef	681.1 bc	1935 cd	27.10 c-f
		2.15 x 3.00 m	213.5 de	28.23 c	248.0 e	640.8 b	3.00 b	1358 b	745.9 ab	2105 bc	30.17 bc
	Indian	2.15 x 2.15 m	240.1 c	12.73 k	351.6 a	503.5 e	1.26 hi	860.8 h	565.9 d	1862 d	23.43 g
		2.15 x 2.50 m	210.6 e	17.33 hi	321.4 bc	553.5 d	1.41 gh	925.7 gh	630.0 cd	1721 de	24.10 efg
		2.15 x 3.00 m	180.7 f	22.10 ef	291.5 d	595.8 c	2.46 c	1201 c	696.7 bc	1862 d	27.33 cde
SE			7.899	0.5730	9.380	9.380	0.08944	28.40	28.36	70.88	1.003
LSD 0.05			22.70	1.647	26.96	26.96	0.2571	81.63	81.51	203.7	2.883

4. CONCLUSION

The effect of planting geometry for growth, seed yield and oil content was examined and the crop planted unnder 2.15m×3.00m planting geometry showed maximum performance with (524.9) fruits plant^{-1}, (1661 kg ha^{-1}) seed yield and (31.00 %) oil content, followed by 2.15m×2.15m and 2.15m×2.50m planting geometry respectively. Among varieties Thai performed better than Malaysian and Indian varieties with highest values for plant height (255.7 cm), fruits plant^{-1} (533.2), seed yield (1905 kg ha^{-1}) and oil content (32.64 %) respectively. The interactive effect of 2.15m×3.00m planting geometry × Thai variety × 2011 was distinctly higher as compared to rest of the treatment combinations, with maximum fruits plant^{-1} (697.5), seed weight plant^{-1} (1547 g), seed yield (2398 kg ha^{-1}) and oil content (35.50 %). Being a perennial crop, overall, performance was better during the second year (2011) as compared to first year (2010) which is apparantly associated with the one year increased age and development of the crop.

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