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# NUTRIENT REQUIREMENT OF *JATROPHA* CULTIVARS OF DIVERSIFIED ORIGIN

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## ABSTRACT

Jatropha is a plant that produces biodiesel and possesses great economic significance due to its characteristics of growing on barren, eroded lands under harsh climatic conditions, demanding low moisture and resulting in productive harvests. The experiment was conducted for consecutive two years (2010 to 2011) in a three replicated Strip Plot Design to examine the nutrient requirements using four N-P-K levels @ 0-0-0, 40-40-40, 60-60-60 and 80-80-80 g plant$^{-1}$ or three jatropha cultivars (Malyasian, Thai and Indian). The results obtained on the effect of NPK levels on growth, seed yield and oil content of these Jatropha varieties. The NPK @ 60-60-60 kg ha$^{-1}$ showed appropriate result with 524.9 fruits plant$^{-1}$, 1827 kg ha$^{-1}$ seed yield and 30.97% oil content, followed by NPK @ 80-80-80 kg ha$^{-1}$ and minimum values for all the traits were observed under control. The response of Thai variety to NPK was more remarkable than Malasian and Indian varieties. The interactive effect of NPK @ 60-60-60 kg ha$^{-1}$ × Thai variety × 2011 produced maximum crop performance over rest of the treatment combinations. Statistically, the effect of NPK levels on growth, seed yield and oil content of all the varieties was significant ($P<0.05$). It was concluded that for successful crop production, Jatropha may be cultivated under an appropriate NPK level of 60-60-60 kg ha$^{-1}$.

**Keywords:** *Jatropha*, cultivars, fertilizer requirement, NPK, growth, seed yield, oil content.

## INTRODUCTION

Rising petroleum prices, declining fossil fuel reserves and ever-increasing consumption of petroleum items would evidently results in increasing the costs of crude oil in future. According to (Shahinur, 2012) all the world resources of Fossil fuels will be finished up to 2040. And the most realistic way to deal with increasing demand is utilizeing alternative fuel sources. Biodiesel a monoalkyl esters and precious form of renewable power is the most excellent nominee as diesel fuel that can be utilized directly in any existing and unmodified diesel engines. Biodiesel is environmental friendly and flames similar to petroleum diesel but it has relative (HHVs) Higher Heating Values (Demirbas, 2007). Jatropha plant (*Jatropha curcas* L.) is commercially known as a biodiesel plant which grows well on waste and dry lands have potential upon which the industry could be built. Due to its capability to flourish in marginal areas and generate low-cost alternative energy, Jatropha has emerged as one of the major sources of biofuel (Salé and Dewes, 2009). As many peoples were encouraged and they expanding their farms and venturing into commercial farming but organizing extensive *Jatropha* production demands large scale management strategies (PCARRD, 2010).

Due to agricultural base and appropriate climatic provisions biodiesel is most reasonable for Pakistan, 30% of its total geographical area is under cultivation this situation encourages for fuel crops such as *Jatropha*, Castor, etc. Currently country's per annum of petroleum consumption is more than 8 million tons and half demand is imported, but with 10-20 % blend of biodiesel, a large amount of foreign exchange savings can be achieved and poor farmer communities receive earnings (Anonymous, 2009), but research on development, propagation and cultivation of *Jatropha curcas* is inadequate, especially in Pakistan (Harun *et al.*, 2006).

In one acre, 1000 Jatropha plants can be planted at certain spacing (Zaidman *et al.*, 2010). Four thousand trees hectare$^{-1}$ is best for commercial irrigated farming while 2,500 trees are best for unmanaged and marginal farming (Kheira and Atta, 2009). Franken (2010) reported that Jatropha seed yields can differ between 250 and 6000 kg hectare$^{-1}$ year$^{-1}$, depending on water supply and soil fertility.

*Jatropha* is a nutrient reactive plant; their requirement varies with the soil fertility and availability of irrigation water (Rijssenbeek, 2010). In addition to the N, P, K, Zn and B fertilizers, there are certain substances which affect the growth of plants and to grow to full size and to produce seeds (Franken, 2010, Mohapatra and Panda, 2011). The *Jatropha* seed yield is significantly influenced by N and $P_2O_5$ fertilization, which promotes growth and oil yields

(Patolia *et al*., 2007). Lea (2009) argues that nitrogen (N) is to be given at the beginning of the growing season, and potassium (K) plays important role therefore it should be given before flowering. Franken (2010) proposed that in the first four years NPK fertilization build up the plant architecture like roots, stem and leaves, and also flower and fruit production and the needed amounts of nutrients for jatropha plant is 14.3-34.3 kg $ha^{-1}$ N; 0.7-7-0 kg $ha^{-1}$ P and 14.3-31.6 kg $ha^{-1}$ K (Achten *et al*., 2008). After the first four years the jatropha plant residues like press cake, fruit shells, husk from the oil production or residue from biogas production if put back into the field hardly any fertilizer is needed. If these materials are not returned to the field, nutrients like nitrogen (N), phosphorous (P), potassium (K) and micronutrients have to be added. Five-year-old standing crop plantation was treated with two levels of N (60 and 50 g $plant^{-1}$), P (80 and 100 g $plant^{-1}$) and K (75 and 60 g $plant^{-1}$), either alone or in combination. Application of N fertilizer proved to be beneficial for Jatropha under tropical agroclimatic conditions in an Aeric Tropaquept of eastern India (Mahapatra and Panda, 2011). Yong *et al.* (2010) found no significant difference in the oil content of *Jatropha* seeds with the increase in nitrogen levels. Tchobsala *et al.* (2013) recommended NPK @15-20-15 + cow dung for achieving desired crop yields in Jatropha. The present study was mainly aimed at identifying the nutrient requirement of Jatropha cultivars of diversified origin.

## MATERIALS AND METHODS

Introduction of *Jatropha* in Pakistan as a source of bio-diesel is in initial stage; hence with its cultivation on commercial scale, the general production practices right from the nursery raising, land preparation, required inputs and farm operations till harvest would be in question among the farming communities. Thus, this study was carried out to establish production technology for *Jatropha*, using field experiement related to effect of different NPK fertilizer levels on seed and oil yield of *Jatropha* for two years consecutively (2010 and 2011). The experiment was conducted in a three replicated Strip Plot Design. After preparation of furrows and pits, seedlings were shifted from nursery bed to experimental field by planting manually at the distance of (2.15 m x 3.00 m) from row to row and plant to plant. All P, K and half N were applied in the well prepared pits at the time of 1$^{st}$ irrigation. The remaining N was split applied during 3$^{rd}$ and 5$^{th}$ irrigations.

### Agronomic observations:

Agronomic observations were recorded as, Plant height (cm), Branches / $plant^{-1}$, Days to maturity, Fruits / $plant^{-1}$, Seeds / $fruit^{-1}$, Seed weight / $plant^{-1}$ (g), 1000 seed weight (g), Oil yield (litre $ha^{-1}$), Seed yield (kg $ha^{-1}$) . The seed yield (kg $ha^{-1}$) was recorded by applying following formula.

Seed yield (kg $ha^{-1}$) =Total weight (Kg $plant^{-1}$) x total No of plants ($ha^{-1}$)

### Statistical analysis of data

The collected data were 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.

## RESULTS AND DISCUSSION

Analysis of the results revealed significant differences in growth as well as yield characteristics due to application of inorganic fertilizers. While maximum seed yield was recorded in $N_{60}$ treatment, the seed oil content varied significantly under various regimes of N:P:K applications. Treatment with $N_{50}$ $P_{100}$ $K_{60}$ and $N_{60}$ resulted in consistent higher yield of seed oil. On the Basis of results growth and yield, N fertilizer proved to be beneficial for *Jatropha*.

### 1. Varietal effect:

Varietal performance of Jatropha for growth, yield and oil content during 2010 and 2011 was studied and the analysis of variance suggested significant agronomic performance of Jatropha varieties. The results (Table 1) revealed that Thai variety proved better than Malaysian and Indian varieties, with maximum values for plant height (236.6 cm), branches $plant^{-1}$ (25.33), fruits $plant^{-1}$ (498.0), seeds $fruit^{-1}$ (2.642), seed weight $plant^{-1}$ (856.1 g), seed index/1000 seed weight (699.4 g), seed yield (1852 kg $ha^{-1}$) and oil content (30.92%) with minimum days to harvest (235.0), respectively. Where Malaysian variety ranked 2$^{nd}$ in plant height (207.1 cm), branches $plant^{-1}$ (20.58), days to harvest (262.5), fruits $plant^{-1}$ (445.6), seeds $fruit^{-1}$ (2.073), seed weight $plant^{-1}$ (709.8 g), seed index/1000 seed weight (651.1 g), seed yield (1535 kg $ha^{-1}$) and oil content (26.28%). However, Indian variety ranked 3$^{rd}$ in performance with maximum days to harvest (290.1), and minimum values for plant height (179.3 cm), branches

plant$^{-1}$ (15.80), fruits plant$^{-1}$ (403.7), seeds fruit$^{-1}$ (1.388), seed weight plant$^{-1}$ (588.2 g), seed index/1000 seed weight (602.8 g), seed yield (1272 kg ha$^{-1}$) and oil content (23.39%). Mahapatra and Panda (2010) also studied 20 different accessions and observed significient difference between them for different traits like growth, flowering, fruiting, seed length, seed breadth, single seed weight, test weight and oil content. Chengxin *et al.* (2014) stated that *Jatropha* variety "JO S2" has higher seed production, early flowering, better branching, more fruits per bunch and better uniformity of plants. Tripathi *et al.* (2015) evaluated 72 different clonal accessions for 13 characters and observed significient difference between them for traits like growth, yield and seed characteristics except for number of primary branches plant$^{-1}$.

**2. Effect of NPK levels:**

The *Jatropha* crop performance was affected by different NPK levels, analysis of variance suggested that the effect of various NPK levels on the plant traits was significant ($P<0.05$). The data (Table 2) exhibited that N-P-K @ 60-60-60 kg ha$^{-1}$ resulted in highest overall performance of Jatropha as compared to rest of the treartments and control, with plant height of (226.7 cm), branches plant$^{-1}$ (25.87), fruits plant$^{-1}$ (524.9), seeds fruit$^{-1}$ (2.8), seed weight plant$^{-1}$ (844.7 g), seed index/1000 seed weight (745.7 g), seed yield (1827 kg ha$^{-1}$) and oil content (30.97%) with minimum days to harvest (247.2) respectively. *Jatropha* fertilized with NPK level @ 80-80-80 kg ha$^{-1}$ ranked 2$^{nd}$ with maximum, plant height (258.6 cm), branches plant$^{-1}$ (22.18), days to harvest (302.5), fruits plant$^{-1}$ (477.0), seeds fruit$^{-1}$ (1.978), seed weight plant$^{-1}$ (773.0 g), seed index/1000 seed weight (680.7 g), seed yield (1672 kg ha$^{-1}$) and oil content (27.84%). The NPK fertilizers applied @ 40-40-40 kg ha$^{-1}$ ranked 3$^{rd}$ with relative lesser days to harvest (247.2), plant height (193.3 cm), branches plant$^{-1}$ (20.68), fruits plant$^{-1}$ (428.5), seeds fruit$^{-1}$ (1.8), seed weight plant$^{-1}$ (695.7 g), seed index/1000 seed weight (614.6 g), seed yield (1505 kg ha$^{-1}$) and oil content (26.67%), respectively.

The *Jatropha* having no NPK fertilizers application (control) ranked least with lowest values for plant height (152.2 cm), branches plant$^{-1}$ (13.56), days to harvest (226.7), fruits plant$^{-1}$ (366.0), seeds fruit$^{-1}$ (1.4), seed weight plant$^{-1}$ (558.8 g), seed index/1000 seed weight (563.4 g), seed yield (1209 kg ha$^{-1}$) and oil content (21.97%). Ige *et al.* (2011) indicated that the increase of NPK fertilizer with organic fertilizer enhances the growth and yield of J. curcas. Yong *et al.* (2010) indicated that high N nutrition improves the overall plant oil yield by increasing the total number of fruits/seeds produced per plant, while not affecting the intrinsic seed oil content but nitrogen at higher levels hastened the flowering process in *Jatropha curcas*. Mahapatra and Panda (2011) achieved maximum seed yield (427.21 kg ha$^{-1}$) in $N_{60}$ treatment, and the seed oil content varied significantly from 32.00% to 35.69% under various regimes of N:P:K applications.

**3. Interactive effect of varieties x NPK levels on various traits of *Jatropha*:**

The interactive effect of NPK levels × varieties was studied and the data is given in Table 3. The treatment interaction (variety Thai×60-60-60 NPK kg ha$^{-1}$) proved to be most effective combination in relation to plant height (255.4 cm), branches plant$^{-1}$ (31.52), fruits plant$^{-1}$ (589.0), seeds fruit$^{-1}$ (3.625), seed weight plant$^{-1}$ (985.5g), seed index/1000 seed weight (794.9 g), seed yield (2131 kg ha$^{-1}$) and oil content (35.40%) with minimum days to harvest (245.5). Variety Thai × 80-80-80 NPK kg ha$^{-1}$ interaction ranked 2$^{nd}$ for plant height (294.4 cm), branches plant$^{-1}$ (27.55), days to harvest (274.6), fruits plant$^{-1}$ (529.3), seeds fruit$^{-1}$ (2.633), seed weight plant$^{-1}$ (911.0g), seed index/1000 seed weight (730.3 g), seed yield (1970 kg ha$^{-1}$) and oil content (32.42%). Variety Malaysian × 60-60-60 NPK kg ha$^{-1}$ interaction ranked 3$^{rd}$ for plant height (227.7 cm), branches plant$^{-1}$ (25.53), days to harvest (273.2), fruits plant$^{-1}$ (515.4), seeds fruit$^{-1}$ (3.017), seed weight plant$^{-1}$ (835.8g), seed index/1000 seed weight (745.8 g), seed yield (1808 kg ha$^{-1}$) and oil content (30.10%).

Variety Thai × 40-40-40 NPK kg ha$^{-1}$ interaction ranked 4$^{th}$ in plant height (218.1 cm), branches plant$^{-1}$ (25.40), fruits plant$^{-1}$ (480.3), days to harvest (218.3), seeds fruit$^{-1}$ (2.342), seed weight plant$^{-1}$ (832.4g), seed index/1000 seed weight (665.4 g), seed yield (1800 kg ha$^{-1}$) and oil content (30.03%). The interactive effect of Indian variety with different NPK levels could not result satisfactorily. Under 60-60-60 kg NPK ha$^{-1}$ the *Jatropha* seed yield in varieties Thai, Malaysian and Indian was 2131, 1808 and 1542 kg ha$^{-1}$, respectively. Mohapatra and Panda (2011) who concluded that Jatropha is a nutrient responsive plant and generally higher amounts of N in addition to P and K produced higher agronomic performance under field conditions. Sarhan *et al.* (2010) reported that the Jatropha plants fertilized by 100:50 and 75:37.5 g plant$^{-1}$ $P_2O_5$:$K_2O$ gave the highest values for vegetative growth, fruit yield and oil percentage as compared to other fertilizer treatments. Akbarian *et al*. (2011) studied the effect of fertilizer on yield, dry matter and oil content. They concluded that 70-120-150 NPK kg ha$^{-1}$ gave highest values for these traits.

Table 1. Effecct of varieties on the growth and yield traits of *Jatropha* (Varieties x fertilizer doses (kg ha$^{-1}$).

| Traits | S. E. | LSD 0.05 | Varieties | | |
|---|---|---|---|---|---|
| | | | Thai | Malaysian | Indian |
| Plant height (cm) | 0.0536 | 0.1526 | 236.6 a | 207.1 b | 179.3 c |
| Branches plant$^{-1}$ | 0.0580 | 0.1654 | 25.33 a | 20.58 b | 15.80 c |
| Days to harvest | 0.0808 | 0.2302 | 235.0 c | 262.5 b | 290.1 a |
| Fruits plant$^{-1}$ | 0.0683 | 0.1945 | 498.0 a | 445.6 b | 403.7 c |
| Seeds fruit$^{-1}$ | 0.0182 | 0.0519 | 2.642 a | 2.073 b | 1.388 c |
| Seed weight plant$^{-1}$(g) | 0.0713 | 0.2030 | 856.1 a | 709.8 b | 588.2 c |
| Seed index (g) | 0.0851 | 0.2424 | 699.4 a | 651.1 b | 602.8 c |
| Seed yield (kg ha$^{-1}$) | 0.1473 | 0.4194 | 1852 a | 1535 b | 1272 c |
| Oil content (%) | 0.0413 | 0.1177 | 30.92 a | 26.28 b | 23.39 |

Table 2. Effect of NPK fertilizer levels on the growth and yield of *Jatropha* (Thai, Malaysian & Indian).

| Traits | S. E. | LSD 0.05 | Fertilizer (kg ha$^{-1}$) | | | |
|---|---|---|---|---|---|---|
| | | | 0-0-0 | 40-40-40 | 60-60-60 | 80-80-80 |
| Plant height (cm) | 0.06191 | 0.1762 | 152.2 d | 193.3 c | 226.7 b | 258.6 a |
| Branches plant$^{-1}$ | 0.06708 | 0.1910 | 13.56 d | 20.68 c | 25.87 a | 22.18 b |
| Days to harvest | 0.09339 | 0.2659 | 226.7 d | 247.2 c | 273.7 b | 302.5 a |
| Fruits plant$^{-1}$ | 0.07888 | 0.2245 | 366.0 d | 428.5 c | 524.9 a | 477.0 b |
| Seeds fruit$^{-1}$ | 0.02108 | 0.06001 | 1.403 d | 1.875 c | 2.881 a | 1.978 b |
| Seed weight plant$^{-1}$ (g) | 0.08233 | 0.2344 | 558.8 d | 695.7 c | 844.7 a | 773.0 b |
| Seed index (g) | 0.09832 | 0.2799 | 563.4 d | 614.6 c | 745.7 a | 680.7 b |
| Seed yield (kg ha$^{-1}$) | 0.1701 | 0.4843 | 1209 d | 1505 c | 1827 a | 1672 b |
| Oil content (%) | 0.04773 | 0.1359 | 21.97 d | 26.67 c | 30.97 a | 27.84 b |

Table 3. Interactive effect of varieties x NPK levels on various traits of *Jatropha* (2010 &2011).

| Traits (2010 & 2011) | LSD 0.05 | Varieties x fertilizer doses (kg ha$^{-1}$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Thai | | | | Malaysian | | | | Indian | | | |
| | | F1 | F2 | F3 | F4 | F1 | F2 | F3 | F4 | F1 | F2 | F3 | F4 |
| Plant height (cm) | 0.3053 | 178.7 i | 218.1 f | 255.4 c | 294.4 a | 149.1 k | 193.6 h | 227.7 d | 258.0 b | 128.9 l | 168.1 j | 196.9 g | 223.4 e |
| Branches plant$^{-1}$ | 0.3308 | 16.87 g | 25.40 c | 31.52 a | 27.55 b | 13.55 i | 21.20 e | 25.53 c | 22.02 d | 10.25 j | 15.43 h | 20.55 f | 16.98 g |
| Days to harvest | 0.4605 | 201.6k | 218.3j | 245.5 h | 274.6 e | 225.5 i | 245.6 h | 273.2 f | 305.5 b | 252.9 g | 277.6 d | 302.3 c | 327.5 a |
| Fruits plant$^{-1}$ | 0.3889 | 393.4 i | 480.3 d | 589.0 a | 529.3 b | 366.4 k | 425.8 h | 515.4 c | 474.7 e | 338.3 l | 379.4 j | 470.4 f | 426.9 g |
| Seeds fruit$^{-1}$ | 0.1039 | 1.967 e | 2.342 d | 3.625 a | 2.633 c | 1.243 f | 2.033 e | 3.017 b | 2.000 e | 1.000 g | 1.250 f | 2.000 e | 1.300 f |
| Seed weight Plant $^{-1}$ (g) | 0.4059 | 695.6 g | 832.4 d | 985.5 a | 911.0 b | 554.3 k | 689.4 h | 835.8 c | 759.8 e | 426.6 l | 565.2 j | 712.8 f | 648.1 i |
| Seed index (g) | 0.4848 | 607.0 i | 665.4 f | 794.9 a | 730.3 c | 565.4 j | 612.7 h | 745.8 b | 680.5 e | 517.7 k | 565.8 j | 696.4 d | 631.2 g |
| Seed yield (kg. Ha $^{-1}$) | 0.8388 | 1505 g | 1800 d | 2131 a | 1970 b | 1199 k | 1491 h | 1808 c | 1643 e | 922.8 l | 1222 j | 1542 f | 1402 i |
| Oil content (%) | 0.2353 | 25.85 g | 30.03 c | 35.40 a | 32.42 b | 21.40 j | 26.57 f | 30.10 c | 27.05 e | 18.67 k | 23.42 i | 27.42 d | 24.05 |

F1=0-0-0 (Control), F2=40-40- 40, F3=60-60-60, F4=80-80-80 kg ha$^{-1}$ NPK

**4. Effect of varieties and year of cultivation:**

The traits studied were influenced significantly ($P<0.05$) due to interactive effect of varieties x years under the NPK fertilizer trial. The data showed that during 2011, the treatment interaction (Year 2011 × variety Thai) showed highest performance with maximum values for plant height (255.2 cm), branches plant$^{-1}$ (28.30), fruits plant$^{-1}$

(614.0), seeds fruit$^{-1}$ (2.650), seed weight plant$^{-1}$ (1041 g), seed index/1000 seed weight (699.4 g), seed yield (2252 kg ha$^{-1}$) and oil content (30.89%) minimum days to harvest (235.0) . The treatment interaction (Year 2011 × variety Malaysian) ranked 2$^{nd}$ in plant height (225.0 cm), branches plant$^{-1}$ (23.89), days to harvest (262.5), fruits plant$^{-1}$ (571.5), seeds fruit$^{-1}$ (2.053), seed weight plant$^{-1}$ (914.2 g), seed index/1000 seed weight (651.2 g), seed yield (1977 kg ha$^{-1}$) and oil content (26.27%).

The treatment interaction (Year 2011 × variety Indian) ranked 3$^{rd}$ in plant height (192.2 cm), branches plant$^{-1}$ (18.65), days to harvest (290.2), fruits plant$^{-1}$ (531.6), seeds fruit$^{-1}$ (1.413), seed weight plant$^{-1}$ (797.2 g), seed index/1000 seed weight (602.8 g), seed yield (1724 kg ha$^{-1}$) and oil content (23.38%). In the year 2010, the overall crop performance was lower as compared to 2011. The treatment interaction (Year 2010 × variety Thai) showed better performance than rest of the treatment interactions with maximum values for plant height (218.1 cm), branches plant$^{-1}$ (22.37) , fruits plant$^{-1}$ (382.0), seeds fruit$^{-1}$ (2.633), seed weight plant$^{-1}$ (670.9g), seed index/1000 seed weight (699.5 g), seed yield (1451 kg ha$^{-1}$) and oil content (30.96%)with minimum days to harvest (235.0). while other treatment interactions showed lower overall performance as compared to interaction (Year 2010 × variety Thai). Chengxin *et al.* (2014) demonstrated Jatropha variety JO S2, on two sites India, which produced up to 2.95 ton/ha of dry seeds in the first year and up to 4.25 ton/ha of dry seeds in the second year, much better than the local variety control. According to the Zaman *et al.* (2010) maximum economic yield of jatropha starts from fifth year which is about 6.2 tons ha$^{-1}$ for average of first four years and 12.5 t ons ha$^{-1}$ fifth year, as it is planted on marginal land using marginal water the yield cannot exceed from 4 and 6 tons ha$^{-1}$.

Table 4. Effect of varieties and year of cultivation on the growth and yield of *Jatropha*.

| Traits | S.E. | LSD 0.05 | Varieties x year | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 2010 | | | 2011 | | |
| | | | Thai | Malaysian | Indian | Thai | Malaysian | Indian |
| Plant height (cm) | 0.07583 | 0.2159 | 218.1 c | 189.2 e | 166.4 f | 255.2 a | 225.0 b | 192.2 d |
| Branches plant$^{-1}$ | 0.08216 | 0.2339 | 22.37 c | 17.26 e | 12.96 f | 28.30 a | 23.89 b | 18.65 d |
| Days to harvest | 0.1144 | 0.3256 | 235.0 c | 262.5 b | 290.0 a | 235.0 c | 262.5 b | 290.2 a |
| Fruits plant$^{-1}$ | 0.09661 | 0.2750 | 382.0 d | 319.6 e | 275.8 f | 614.0 a | 571.5 b | 531.6 c |
| Seeds fruit$^{-1}$ | 0.02582 | 0.0735 | 2.633 a | 2.094 b | 1.362 c | 2.650 a | 2.053 b | 1.413 c |
| Seed weight plant$^{-1}$ (g) | 0.1008 | 0.2870 | 670.9 d | 505.4 e | 379.2 f | 1041 a | 914.2 b | 797.2 c |
| Seed index (1000 seed wt g) | 0.1204 | 0.3428 | 699.5 a | 651.1 b | 602.8 c | 699.4 a | 651.2 b | 602.8 c |
| Seed yield (kg ha$^{-1}$) | 0.2084 | 0.5931 | 1451 d | 1093 e | 820.2 f | 2252 a | 1977 b | 1724 c |
| Oil content (%) | 0.05845 | 0.1664 | 30.96 a | 26.28 b | 23.40 | 30.89 | 26.27 | 23.38 |

Table 5. Interactive effect of NPK levels and year of cultivation on the growth and yield of *Jatropha*.

| Traits | S. E. | LSD 0.05 | Fertilizers (kg ha$^{-1}$) x year | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2010 | | | | 2011 | | | |
| | | | F1 | F2 | F3 | F4 | F1 | F2 | F3 | F4 |
| Plant height (cm) | 0.087 | 0.249 | 138.8 h | 174.9 f | 209.4 e | 241.8 c | 165.6 g | 211.6 d | 244.0 b | 275.3 a |
| Branches plant$^{-1}$ | 0.094 | 0.270 | 11.11 h | 17.49 f | 22.91 d | 18.60 e | 16.00 g | 23.87 c | 28.82 a | 25.77 b |
| Days to harvest | 0.132 | 0.376 | 226.5 d | 247.2 c | 273.7 b | 302.5 a | 226.8 d | 247.2 c | 273.6 b | 302.5 a |
| Fruits plant$^{-1}$ | 0.111 | 0.317 | 240.8 h | 305.4 g | 405.2 e | 351.9 f | 491.2 d | 551.6 c | 644.7 a | 602.0 b |
| Seeds fruit$^{-1}$ | 0.029 | 0.084 | 1.403 d | 1.867 c | 2.878 a | 1.972 b | 1.403 d | 1.883 c | 2.883 a | 1.983 b |
| Seed weight plant$^{-1}$ (g) | 0.116 | 0.331 | 393.9 h | 494.5 g | 630.5 e | 555.2 f | 723.8 d | 896.8 c | 1059 a | 990.8 b |
| Seed index (g) | 0.139 | 0.395 | 563.4 d | 614.6 c | 745.7 a | 680.7 b | 563.3 d | 614.7 c | 745.7 a | 680.7 b |
| Seed yield (kg ha$^{-1}$) | 0.240 | 0.684 | 852.1 h | 1070 g | 1364 e | 1201 f | 1565 d | 1940 c | 2290 a | 2143 b |
| Oil content (%) | 0.067 | 0.192 | 22.02 d | 26.67 c | 31.00 a | 27.83 b | 21.92 d | 26.68 c | 30.94 a | 27.84 b |

F1=0-0-0 (Control), F2=40-40- 40, F3=60-60-60, F4=80-80-80 kg ha$^{-1}$ NPK

Table 6. Interactive effect of varieties x fertilizer x years on the growth and yield of *Jatropha*.

| Years | Varieties | NPK levels (kg ha$^{-1}$) | Plant traits | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Days to harvest | Plant height (cm) | Branches plant$^{-1}$ | Fruits plant$^{-1}$ | Seeds fruit$^{-1}$ | Seed weight plant$^{-1}$ (g) | Seed index (g) | Seed yield (kg ha$^{-1}$) | Oil content (%) |
| 2010 | Thai | 0-0-0 | 201.6 l | 162.8 r | 14.00 m | 277.3 s | 1.933 e | 545.5 p | 607.2 i | 1180 p | 25.87 g |
| | | 40-40-40 | 218.3 k | 195.6 l | 22.47 g | 360.2 p | 2.333 d | 654.6 m | 665.5 f | 1416 m | 30.07 c |
| | | 60-60-60 | 245.6 i | 235.1g | 28.57 c | 480.2 l | 3.600 a | 780.2 j | 795.0 a | 1688 j | 35.40 a |
| | | 80-80-80 | 274.5 e | 278.7b | 24.43 e | 410.3 n | 2.667 c | 703.5 l | 730.2 c | 1522 l | 32.50 b |
| | Malaysian | 0-0-0 | 225.5 j | 133.1u | 11.33 o | 242.2 u | 1.277 f | 385.5 u | 565.5 j | 833.8 u | 21.50 j |
| | | 40-40-40 | 245.6 i | 173.5p | 17.83 j | 300.9 r | 2.067 e | 478.8 s | 612.5 h | 1036 s | 26.53 f |
| | | 60-60-60 | 273.3 f | 209.8j | 22.53 g | 390.3 o | 3.033 b | 621.0 n | 745.7 b | 1343 n | 30.10 c |
| | | 80-80-80 | 305.5 b | 240.3ef | 17.33 k | 345.2 q | 2.000 e | 536.2 q | 680.6 e | 1160 q | 27.00 e |
| | Indian | 0-0-0 | 252.4 h | 120.5 v | 8.000 p | 203.0 v | 1.000 g | 250.8 w | 517.6 k | 542.5w | 18.70 k |
| | | 40-40-40 | 277.6 d | 155.6 s | 12.17 n | 255.0 t | 1.200 f | 350.0 v | 565.7 j | 757.0 v | 23.40 i |
| | | 60-60-60 | 302.2 c | 183.2 n | 17.63 jk | 345.0 q | 2.000 e | 490.3 r | 696.3 d | 1060 r | 27.50 d |
| | | 80-80-80 | 327.6 a | 206.6 k | 14.03 m | 300.3 r | 1.250 f | 425.8 t | 631.5 g | 920.9 t | 24.00 h |
| 2011 | Thai | 0-0-0 | 201.6 l | 194.6 m | 19.73 h | 509.5 i | 2.000 e | 845.7 i | 606.9 i | 1829 i | 25.83 g |
| | | 40-40-40 | 218.4 k | 240.7 e | 28.33 c | 600.3 e | 2.350 d | 1010 d | 665.4 f | 2185 d | 30.00 c |
| | | 60-60-60 | 245.4 i | 275.6 c | 34.47 a | 697.8 a | 3.650 a | 1191 a | 794.8 a | 2575 a | 35.40 a |
| | | 80-80-80 | 274.6 e | 310.1 a | 30.67 b | 648.3 b | 2.600 c | 1119 b | 730.5 c | 2419 b | 32.33 b |
| | Malaysian | 0-0-0 | 225.4 j | 165.0 q | 15.77 l | 490.6 k | 1.210 f | 723.1 k | 565.3 j | 1564 k | 21.30 j |
| | | 40-40-40 | 245.7 i | 213.6 h | 24.57 e | 550.7 h | 2.000 e | 900.0 g | 612.9 h | 1947 g | 26.60 f |
| | | 60-60-60 | 273.2 f | 245.6 d | 28.53 c | 640.5 c | 3.000 b | 1051 c | 745.9 b | 2272 c | 30.10 c |
| | | 80-80-80 | 305.5 b | 275.6 c | 26.70 d | 604.2 d | 2.000 e | 983.3 e | 680.5 e | 2127 e | 27.10 e |
| | Indian | 0-0-0 | 253.3 g | 137.3 t | 12.50 n | 473.5 m | 1.000 g | 602.5 o | 517.8 k | 1303 o | 18.63 k |
| | | 40-40-40 | 277.7 d | 180.6 o | 18.70 i | 503.7 j | 1.300 f | 780.3 j | 565.8 j | 1688 j | 23.43 i |
| | | 60-60-60 | 302.3 c | 210.7 i | 23.47 f | 595.7 f | 2.000 e | 935.4 f | 696.4 d | 2023 f | 27.33 de |
| | | 80-80-80 | 327.4 a | 240.2 f | 19.93 h | 553.5 g | 1.350 f | 870.5 h | 631.0 g | 1883 h | 24.10 h |
| SE | | | 0.2288 | 0.1517 | 0.1643 | 0.1932 | 0.05164 | 0.2017 | 0.2408 | 0.4167 | 0.1169 |
| LSD 0.05 | | | 0.6512 | 0.4317 | 0.4678 | 0.5500 | 0.1470 | 0.5741 | 0.6856 | 1.186 | 0.3328 |

**5. Interactive effect of NPK levels x years:**

Studied traits were influenced significantly ($P<0.05$) due to year x NPK interaction. The treatment interaction (Year 2011 × 60-60-60 NPK kg ha$^{-1}$) resulted in a maximum crop performance with reference to plant height (244.0 cm), branches plant$^{-1}$ (28.82), fruits plant$^{-1}$ (644.7), seeds fruit$^{-1}$ (2.883), seed weight plant$^{-1}$ (1059 g), seed index/1000 seed weight (745.7 g), seed yield (2290 kg ha$^{-1}$) and oil content (30.94%) with lowest days to harvest (273.6). The treatment interaction (Year 2011 × NPK @80-80-80 kg ha$^{-1}$) ranked 2$^{nd}$ with plant height (275.30 cm), reduced values for branches plant$^{-1}$ (25.77), days to harvest (302.5), fruits plant$^{-1}$ (602.0), seeds fruit$^{-1}$ (1.983), seed weight plant$^{-1}$ (990.80 g), seed index/1000 seed weight (680.7 g), seed yield (2143 kg ha$^{-1}$) and oil content (27.84%). The treatment interaction (Year 2011 × NPK@40-40-40 kg ha$^{-1}$) ranked 3$^{rd}$ in days to harvest (247.2), plant height (211.6 cm), branches plant$^{-1}$ (23.87), fruits plant$^{-1}$ (551.6), seeds fruit$^{-1}$ (1.883), seed weight plant$^{-1}$ (896.8 g), seed index/1000 seed weight (614.7 g), seed yield (1940 kg ha$^{-1}$) and oil content (26.68%). While during 2010, all the traits examined were significantly ($P<0.05$) lower than the year 2011. However, the treatment interaction (Year 2010

× 60-60-60 NPK kg ha$^{-1}$) ranked 1$^{st}$ with reference to plant height (209.4 cm), branches plant$^{-1}$ (22.91), days to harvest (273.7), fruits plant$^{-1}$ (405.2), seeds fruit$^{-1}$ 2.878), seed weight plant$^{-1}$ (630.5 g), seed index/1000 seed weight (745.7 g), seed yield (1364 kg ha$^{-1}$) and oil content (31.00%). The treatment interaction (Year 2010 × NPK @80-80-80 kg ha$^{-1}$) ranked 2$^{nd}$ and year 2010 × NPK@40-40-40 kg ha$^{-1}$, ranked 3$^{rd}$ and control ranked least for all the growth and yield contributing traits of *Jatropha*.

It suggests that during 2011, the jatropha plantation thrive better as compared to the year 2010. Suriharn , *et al.* (2011) conducted a trial to observe effect of fertilizer on growth and yield of *Jatropha* for three years and concluded that NPK fertilizer increase branch number and branch length especially at the rate of 312.5 kg ha$^{-1}$, whereas the second year gave higher yield (1,559 kg ha$^{-1}$) than did in the first year (1,180 kg ha$^{-1}$) Fagam *et al.* (2012) conducted a Field experiment for three years and investigated that he 350kg NPK/ha produced the highest leaf area index, leaf area ratio, net assimilation rate, relative growth rate and crop growth rate in 2009 and 2010 seasons. However, in 2011, 2500kg/ha of cow dung produced the highest results.

**6. Interactive effect of varieties x fertilizer levels x years:**

The analysis of variance demonstrated statistically significant ($P<0.05$) results for this interactive effect. During 2011, the crop performance was superior in the treatment interaction (variety Thai × 60-60-60 kg ha$^{-1}$ NPK x 2011) taking 245.4 275.6 cm plant height, 34.47 branches plant$^{-1}$, days to harvest, 697.8 fruits plant$^{-1}$, 3.65 seeds fruit$^{-1}$, 1191g seed weight plant$^{-1}$, 794.8 g seed index/1000 seed weight, 2575 kg ha$^{-1}$ seed yield and 35.40% oil content. The interaction (variety Thai × 80-80-80 kg ha$^{-1}$ NPK x 2011) ranked 2$^{nd}$; and the interaction (variety Malaysian × 60-60-60 kg ha$^{-1}$ NPK x 2011) ranked 3$^{rd}$ for all the growth and yield parameters studied. Where during 2010, the overall growth and yield performance of jatropha was relatively inferior as compared to the year 2011. The treatment interaction (variety Thai × 60-60-60 kg ha$^{-1}$ NPK x 2010) resulted in maximum performance with 235.1 cm plant height, 28.57 branches plant$^{-1}$, 245.6 days to harvest, 480.21 fruits plant$^{-1}$, 3.6 seeds fruit$^{-1}$, 780.2 g seed weight plant$^{-1}$, 795 g seed index/1000 seed weight, 1688 kg ha$^{-1}$ seed yield and 35.40% oil content. The interaction (variety Thai × 80-80-80 kg ha$^{-1}$ NPK x 2010) ranked 2$^{nd}$; and the interaction (variety Thai × 40-40-40 kg ha$^{-1}$ NPK x 2010) ranked 3$^{rd}$ for all the growth and yield parameters studied. Krishna *et al.* (2008) also studied the growth performance of Jatropha and stated that response of unpruned crop to fertilizer application was of a higher magnitude and the plant height, stem girth and number of branches per plant of unpruned Jatropha increased significantly in the third year by the application of 46:50:25 kg ha$^{-1}$ NPK and 5 kg FYM per plant. Tikkoo *et al.* (2013) studied three years consecutively impacts of irrigation and nutrients on seed and oil yield of *J. curcas* in semi-arid conditions of India. and concluded that *Jatrophas* seed yield increased from 163.71 kg ha$^{-1}$ with no irrigation to 472.51 kg ha$^{-1}$ at 90 kg N and 60 kg $K_2O$ ha$^{-1}$ with two irrigations. The maximum oil content (34.52%) and oil yield (163.31 kg ha$^{-1}$) was recorded at 90 kg N and 60 kg $K_2O$ ha$^{-1}$ with two irrigations.

**Conclusion**

The effect of NPK levels on growth, seed yield and oil content of *Jatropha* varieties indicated that NPK @ 60-60-60 kg ha$^{-1}$ showed maximum growth with 524.9 fruits plant$^{-1}$, 1827 kg ha$^{-1}$ seed yield and 31 % oil content, followed by NPK @ 80-80-80 kg ha$^{-1}$ and 40-40-40 kg ha$^{-1}$. The interactive effect of NPK @ 60-60-60 kg ha$^{-1}$ × Thai variety produced maximum crop over rest of the treatment combinations. The *Jatropha* may be cultivated under NPK levels of 60-60-60 kg ha$^{-1}$ on the basis of better results as compared to 80-80-80 and 40-40-40 kg ha$^{-1}$.

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