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Response of *Jatropha curcas* Grown on an Ultic Paleustalf to Chemical Fertilizers and Compost

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ABSTRACT

The field experiment was conducted on an Ultic Haplustalf in Kanchanaburi Research Station, Muang district, Kanchanaburi province, west of Thailand for a period of one year (July 2009 to June 2010). A Randomized Complete Block Design (RCBD) was employed with eight treatments and four replications. The treatments consisted of no fertilizer as a control (F1) and others with different fertilizer managements (F2-F8). The study aimed at investigating the response of *Jatropha curcas* L. (Euphorbiaceae) to applied fertilizers. *Jatropha curcus* (KUBP 78-9 Var.) was planted using direct seed at a spacing of 2×2 m. Drip irrigation was used to apply water at the rate of 2 L tree^{-1} in every 2 days for whole period of the study. *Jatropha curcus* began flowering in October 2009, three months after planting and capsule cluster was detected a month after. Seed yield measured at 15% moisture was highest in the first month of harvest in February 2010 and decreased until June 2010. The application of 25 kg N+75 kg P_2O_5+75 kg K_2O ha^{-1} together with compost at the rate of 6.25 t ha^{-1} statistically gave the highest oil yield of 456.9 kg ha^{-1}. This amount was highly significantly greater than those obtained from other treatments including the control. There was no influence of applied fertilizer on all plant nutrient concentrations in *J. curcus* leaf collected at 2 and 6 months of age. A positive correlation between Mn concentration in 2 months old leaf and seed yield was found. The concentration of Mg and Fe in 2 months old leaf negatively correlated with seed yield and Fe and Zn concentrations in 6-month old leaf with oil yield.

Key words: *Jatropha curcus*, Jatropha, fertilization, Ultic Haplustalf

INTRODUCTION

Jatropha curcas L. (Jatrpha or Physic nut) is a wild plant. The plant that belongs to the family Euphorbiaceous, is classified as one of the plant oil similar to palm oil (Anderson and Ingram, 1993; Sricharoenchaikul *et al.*, 2008). What distinguishes *J. curcus* from many other biofuel crops are the benefits it can offer to relatively small rural areas in less developed countries. In recent years, *J. curcus* has widely been planted using artificial management. However, soil water and plant nutrients are the most important factors affecting the growth and water use of this plant. The plant is commercially rather new to Thailand. There is very scarce information about fertilizer needed for improving yield of *J. curcus* grown in the country. General recommendation of fertilizer use for growing *J. curcus* is based on those used in other plants such as cassava. The ratio, 1:1:1, of plant major nutrients is broadly recommended for cassava which the plant is in the same family as *J. curcus*. Recent study indicated that application of nitrogen and phosphorus increased the growth, seed yield and oil yield of *J. curcus* (Patolia *et al*., 2007; Yin *et al*., 2010). The results are also in conformity with the findings of Yong *et al*. (2010) and Kalannvar (2008). A pot experiment was conducted in the greenhouse and obtained that the optimal nitrogen supply is 288 kg ha^{-1} which can increase photosynthetic rate and growth of *J. curcus* under mild drought condition (Yin *et al*., 2011). Nitrogen addition significantly promotes the growth of main stem and added P or K fertilizer can obviously increase the yield of *J. curcus* (Liu *et al*., 2009; Gu *et al*., 2011). Previous study also showed that the following recommendation is sufficient to optimize the yield for India degraded soils: Irrigation frequency at a 30 day as water required and 2 kg of farmyard manure and N, P and K at 10, 20 and 10 g $plant^{-1}$, respectively (Singh *et al*., 2013). In addition, nitrogen fertilization improves photosynthesis at 80% of water holding capacity (Yin *et al*., 2010). Nitrogen addition also increased total dry mass, whole plant water storage capacity, total evapotranspiration and water use efficiency (Yang *et al*., 2013). A study in coarse-textured soils of northwest India (Tikkoo *et al*., 2013) showed that *J. curcus* seed yield increased significantly at 60 kg N ha^{-1} with no irrigation whereas seed yield increased significantly up to 90 kg N ha^{-1} with one and two irrigations. The significant effect of potassium application on seed yield was found up to 45 K_2O ha^{-1} in the absence of irrigation but its effect was significant up to 60 kg K_2O ha^{-1} with one and two irrigations. As mentioned earlier, additional information about fertilization for growing *J. curcus* are importantly essential, particularly in tropical region where this plant has a potential to be grown for use as sources of energy. Thus, this study was undertaken to preliminarily investigate the response of Jatropha grown on an Ultic Haplustalf of western Thailand to different fertilizer managements.

MATERIALS AND METHODS

Experimental site description: The experiment was conducted in Kanchanaburi Research Station, Muang district Kanchanaburi province, west of Thailand (47 535142E 1561440N). The area is under tropical climate with average annual rainfall of 1,026.5 mm, having bimodal pattern and mean annual rainfall of 27.7°C. The average rainfall is slightly lower than normal because the station is located on the lee side of a mountainous area (away from the wind). The mountains block the passage of rain-producing weather systems and cast a "Shadow" of dryness behind them, so called rain shadow area. Soil representing the experimental site is an Ultic Paleustalf formed on nearly flat surface on dissected footslope of a limestone mountain. The soil has loam and clay loam textures in topsoil and subsoil, respectively, while clay particle increasing with increasing depth. Soil chemical properties are shown in Table 1. Soil pH values slightly vary throughout soil profile in the range between 4.8 and 5.3. Soil organic matter clearly accumulates in topsoil layers, 21.6 and 11.0 g kg^{-1} for Ap1 and Ap2 and considerably decreases with depth. Total nitrogen content of the soil is low to very low while available phosphorus being moderately low in the topsoil and very low in subsoils. An amount of available potassium in the top 20 cm of the soil is high (116.8 mg kg^{-1}), the content reduces slightly in Ap2 and becomes low in layers underneath. Calcium is dominant among bases in the soil with the amount varying from 1.77-3.26 $cmol_c$ kg^{-1}, however, the content of sum bases in this soil is still low. Cation exchange capacity of the soil is also low.

Experimental trial design and crop management: *Jatropha curcus* (KUBP 78-9 Var.) or Jatropha was planted in June 2009, using direct seed at a spacing of 2×2 m having

Table 1: Properties of an Ultic Paleustalf

Soil properties	Topsoil: Ap1 (0-20 cm)	Topsoil: Ap2 (20-35 cm)	Subsoil: Bt1 (35-54 cm)	Subsoil: Bt2 (54-78 cm)	Subsoil: Bt3 (78-103 cm)
pH (1:1 H_2O)	4.90	5.10	4.80	5.00	5.30
Organic matter (g kg^{-1})	21.60	11.00	4.70	6.80	0.70
Total N (g kg^{-1})	1.40	1.05	1.05	0.98	0.91
Available P (mg kg^{-1})	10.50	5.60	3.00	2.10	2.10
Available K (mg kg^{-1})	116.80	85.40	44.20	44.50	41.90
Extractable Ca ($cmol_c$ kg^{-1})	3.26	2.74	1.77	2.43	3.05
Extractable Mg ($cmol_c$ kg^{-1})	1.00	0.79	0.49	0.56	0.72
Extractable K ($cmol_c$ kg^{-1})	0.30	0.22	0.11	0.11	0.11
Extractable Na ($cmol_c$ kg^{-1})	0.21	0.20	0.21	0.24	0.24
Sum bases ($cmol_c$ kg^{-1})	4.80	3.90	2.60	3.30	4.10
CEC ($cmol_c$ kg^{-1})	3.30	3.30	4.00	3.20	4.00

Table 2: Properties of compost used in the experiment

Properties	Vlaues
pH (H_2O 1:2)	6.20
Organic matter (g kg^{-1})	24.59
Total N (g kg^{-1})	5.12
Available phosphorus (P_2O_5) (g kg^{-1})	4.72
Available potassium (K_2O) (g kg^{-1})	0.93
Total calcium (g kg^{-1})	0.52
Total magnesium (g kg^{-1})	0.29
Total sodium (g kg^{-1})	0.08
Total iron (mg kg^{-1})	1.03
Total zinc (mg kg^{-1})	0.84
Total copper (mg kg^{-1})	0.21
Total manganese (mg kg^{-1})	0.11

2,500 plants ha^{-1}. Basal dressing fertilization using 18.5 g $hole^{-1}$ for each of N, P and K fertilizers and 2.5 kg $hole^{-1}$ of compost that its properties are presented in Table 2, was done before placing *J. curcus* seeds (three seeds per hill). Growing plant was tipped at 50 cm height to allow the plant to branch laterally at the beginning of its growth. Drip irrigation was performed throughout whole period of growth at the rate of 2 L per plant every two days. Pest and weed controls were performed according to general local practices and recommendations. All other necessary operations were kept normal and uniform for all treatments.

A Randomized Complete Block Design (RCBD) with eight treatments each replicated four times giving a total of 32 plots was employed. Detail of treatments were as follows; F1: No fertilization, F2: Applied 6.25 t compost ha^{-1}, F3: 46.88 kg N+46.88 kg P_2O_5+46.88 kg K_2O ha^{-1}, F4: 93.75 kg N+93.75 kg P_2O_5+93.75 kg K_2O ha^{-1} (equally split application), F5: F2+F3, F6: 25 kg N+75 kg P_2O_5+75 kg K_2O ha^{-1}, F7: 50 kg N+150 kg P_2O_5+75 kg K_2O ha^{-1} (equally split application), F8 = F2-F6. Fertilizers were applied at two months after planting with *J. curcus* in treatments F4 and F7 being were given again with the same amount of fertilizer as in the first time at four months after planting. Compost was applied at two months of age. All fertilizers were applied on the circle line at the rim of plant canopy.

Soil and plant sampling and analyses: Composite soil sample was collected prior to conducting the experiment and soil properties were analyzed. The 5th fully mature leave was randomly corrected from twelve plants per each plot when the plant was 2 and 5 months old (one month after applying fertilizer) for the analysis of plant nutrient concentration. Numbers of inflorescence and capsule cluster were counted every month while seed yield was measured every month and weighed at 15% moisture content, starting from February 2010. Oil yield was analyzed using composite seed samples collected for one year, counting from the first day of planting.

Soil and plant analyses were carried out based on standard methods. For plant samples, total nitrogen was extracted by digestion mixture (H_2SO_4-Na_2SO_4-Se) and determined by Kjeldahl method (Jackson, 1965). Total phosphorus was extracted by digestion mixture (HNO-H_2SO_4-$HClO_4$) (Johnson and Ulrich, 1959) and determined by Vanado-molybyellow colour method (Westerman, 1990) and then measured by spectrophotometer at 440 nm wavelength (Murphy and Riley, 1962). Total potassium, calcium, magnesium, iron, zinc, manganese and copper were analyzed by using digestion acid mixture extraction (HNO_3-H_2SO_4-$HClO_4$) (Johnson and Ulrich, 1959) and determined by atomic absorption spectrophotometer (Westerman, 1990). Total sulphur was analyzed by digestion with acid mixture (HNO_3-$HClO_4$) (Johnson and Ulrich, 1959) and determined turbidimetrically as $BaSO_4$ and the amount was determined by spectrophotometer with 450 nm wavelength (Bardsley and Lancaster, 1965).

Statistical analysis: Analysis of variance (ANOVA) was performed by using SPSS Statistics 17.0 software package. Data was analyzed using the General Linear Model (GLM). Means among treatments were compared using Duncan's Multiple Range Test (DMRT) (SAS Institute, 2003) with differences being tested at 0.05 probability ($p<0.05$) (Steel and Torrie, 1987).

RESULTS AND DISCUSSION

***Jatropha curcus* fluorescence and capsule cluster:** *Jatropha curcus* started to produce the first fluorescence in October 2009 (four months after planting). The average number per month increased rather steadily from this month and peaked in April 2010 (Fig. 1). However, the number decreased drastically in May and June 2010. The highest monthly number of fluorescence per plant was 17.4 obtained from the plot applied with compost at the rate of 6.25 t ha^{-1} together with 46.88 kg N+46.88 kg P_2O_5+46.88 kg K_2O ha^{-1} (F5). The lowest number of 15.5 $plant^{-1}$ was found in the control plot with no fertilizer applied and F6 (25 kg N+75 kg P_2O_5+75 kg K_2O ha^{-1}). *Jatropha curcus* started to produce less number of inflorescence in May 2010 onwards because it was the beginning of rainy season when high amount of rain induced the plant to have more vegetative growth. By that mean, the plant tended to stop flowering.

Capsule cluster was counted one month after *J. curcus* initiated its flower. The number increased in quite the same pattern as the average monthly number of inflorescence (Fig. 2). Peak period of capsule cluster production was in April 2010 with the range between 13.5 and 16.3 numbers per plant. Again, the number started to drop in May and June 2010 with the ranges of 9.7-13.8 numbers per month in May 2010 and 7.5-11.9 numbers per plant in June 2010.

Seed and fruit weights of *J. curcus*: The average single seed and fruit weights were recorded monthly from the month in which *J. curcus* fruit started ripening. There was no statistical difference among treatments in both seed and fruit weights (Table 3). The seed of *J. curcus* in first harvest in March 2010 had the highest weight, ranging from 2.21-2.43 g per seed. The smallest

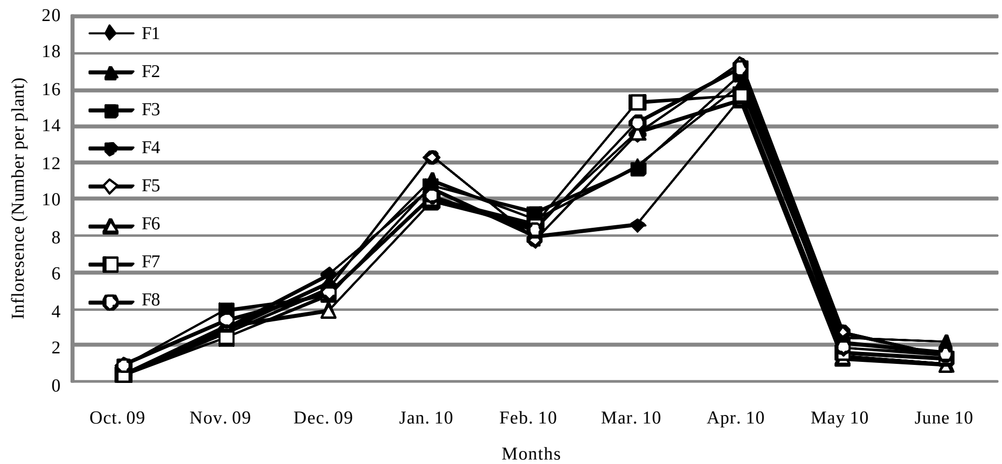

Fig. 1: Average monthly number of inflorescence per plant. F1 = No fertilization, F2 = Applied 6.25 t compost ha^{-1}, F3 = 46.88 kg N+46.88 kg P_2O_5+46.88 kg K_2O ha^{-1}, F4 = 93.75 kg N+93.75 kg P_2O_5+93.75 kg K_2O ha^{-1} (equally split application), F5 = F2+F3, F6 = 25 kg N+75 kg P_2O_5+75 kg K_2O ha^{-1}, F7 = 50 kg N+150 kg P_2O_5+75 kg K_2O ha^{-1} (equally split application) and F8 = F2-F6

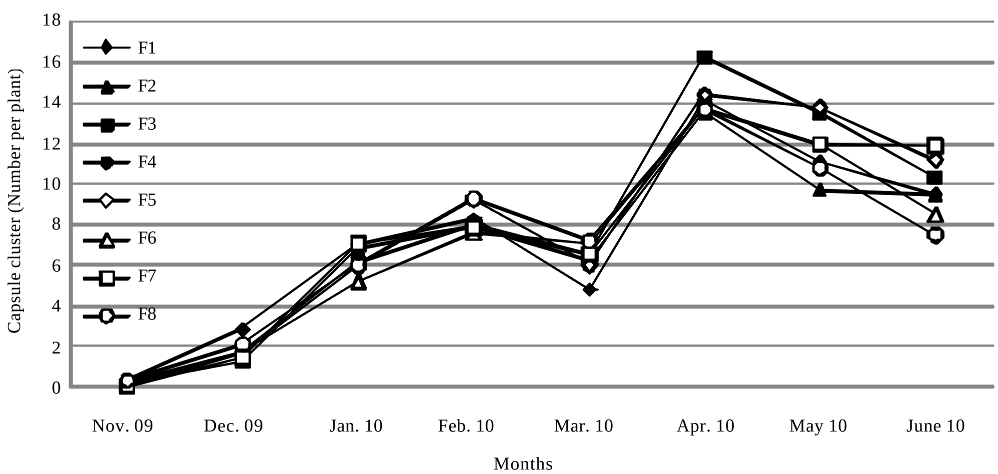

Fig. 2: Average monthly number of capsule cluster per plant. F1 = No fertilization, F2 = Applied 6.25 t compost ha^{-1}, F3 = 46.88 kg N+46.88 kg P_2O_5+46.88 kg K_2O ha^{-1}, F4 = 93.75 kg N+93.75 kg P_2O_5+93.75 kg K_2O ha^{-1} (equally split application), F5 = F2+F3, F6 = 25 kg N+75 kg P_2O_5+75 kg K_2O ha^{-1}, F7 = 50 kg N+150 kg P_2O_5+75 kg K_2O ha^{-1} (equally split application) and F8 = F2-F6

seed was found in May 2010 with the values ranging between 1.24 and 1.40 g per seed. The weight of a single fruit was nearly the same in every month with the highest weight of 6.0 g per fruit and the lightest weight of 5.4 g per fruit. The mean of seed and fruit weights was in the ranges between 1.90-1.96 g per seed and 5.8-5.9 g per fruit.

Table 3: Average single jatropha seed and fruit weights measured at 15% moisture content

	March 10		April 10		May 10		June 10		Mean	
	Seed	Fruit	Seed	Fruit	Seed	Fruit	Seed	Fruit	Seed	Fruit
Treatment	(g)									
F1	2.23	5.8	2.03	6.0	1.25	6.0	2.11	5.4	1.90	5.8
F2	2.30	5.9	2.00	6.0	1.33	5.9	2.08	5.5	1.93	5.8
F3	2.29	5.8	2.05	5.9	1.39	6.0	2.14	5.5	1.96	5.8
F4	2.26	5.8	2.06	5.9	1.33	6.0	2.18	5.5	1.96	5.8
F5	2.29	5.8	2.02	5.9	1.24	6.0	2.05	5.6	1.90	5.8
F6	2.43	6.0	2.06	5.8	1.39	5.9	2.03	5.4	1.98	5.8
F7	2.27	5.8	2.05	6.0	1.32	6.0	2.08	5.6	1.93	5.9
F8	2.21	5.7	2.00	6.0	1.40	6.0	2.15	5.6	1.94	5.8
F-test	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	5.54	2.5	5.61	2.8	11.39	2.3	4.51	3.5	4.62	1.3

ns: Non significant

Table 4: Seed yield of Jatropha as influenced by different fertilizers applied (measured at 15% moisture content)

	February 10	March 10	April 10	May 10	June 10	Total
Treatment	(kg ha^{-1})					
F1	265.6	240.0	263.1	77.5	150.0	996.3
F2	366.3	256.9	321.9	90.0	158.1	1,193.1
F3	413.1	190.0	269.4	120.0	224.4	1,216.9
F4	373.1	218.8	355.6	1319.0	240.0	1,319.4
F5	293.8	193.8	256.3	96.3	206.3	1,046.3
F6	445.0	140.6	290.0	188.8	236.3	1,300.6
F7	272.5	170.6	291.9	115.0	226.9	1,076.9
F8	408.1	229.4	297.5	187.5	284.4	1,406.9
F-test	-	-	-	-	-	ns
CV (%)	-	-	-	-	-	17.6

ns: Non significant, -: Not performed

Seed and oil yields of *J. curcus*: The first harvest was in February 2010 (7 months after planting). When the highest monthly seed yield of which the amount was illustrated with 15% moisture content was gained. The yield harvested after that was rather fluctuated. There were no statistical difference among seed yields both in monthly harvest and total seed yield of the first year of planting. Without statistical difference, the figures obtained from control plot showed the lowest amount of monthly and total seed yields. The highest amount of seed yield per month was in February 2010 with the value of 408.1 kg ha^{-1} obtained from the plot that applied 25 kg N+75 kg P_2O_5+75 kg K_2O ha^{-1} together with 6.25 t compost ha^{-1} (F8). The highest total seed yield also obtained from the same treatment (F8) with the amount of 1,406.9 t ha^{-1} (Table 4).

Oil content in different parts of seed was analyzed using composite samples having been collected from those all harvested in the first year of planting. Seed cake weight percentage ranged from 35.1-39.7 while the range of kernel weight percentage being between 60.3 and 64.9. The percentage of oil in kernel and in seed seemed to show a response of *J. curcus* to fertilizers applied although there was no statistical analysis performed. The greatest oil percentage in kernel of 54.5% can be obtained when applied 25 kg N+75 kg P_2O_5+75 kg K_2O ha^{-1} together with 6.25 t compost ha^{-1} (F8). The same story was found in the case of oil in seed with the highest value

Table 5: Oil content in different parts of Jatropha seed and total oil yield as influenced by different fertilizers applied

Treatment	Seed cake weight (%)	Kernel weight (%)	Oil in kernel (%)	Oil in seed (%)	Total oil yield (kg ha^{-1})
F1	39.3	60.7	28.1	17.0	153.1^{d}
F2	37.6	62.4	47.3	29.5	317.5^{bc}
F3	37.9	62.1	46.4	28.8	315.0^{bc}
F4	37.3	62.7	45.5	28.5	340.0^{bc}
F5	36.3	63.7	41.3	26.3	248.1^{c}
F6	39.0	61.0	51.2	31.2	366.3^{b}
F7	39.7	60.3	48.9	29.5	286.3^{bc}
F8	35.1	64.9	54.5	35.3	456.9^{a}
F-Test	-	-	-	-	**
CV (%)	-	-	-	-	18.3

**Significant at 0.01 probability levels, means followed by different letters in column are significantly different according to Duncan's Multiple Range Test (DMRT), -: Not performed

of 35.3% (Table 5). *Jatropha curcus* can hardly produce high oil content when grown without fertilization. Although, there was no difference among seed yields as influenced by fertilizers applied, total oil yield demonstrated different matters when compared among treatments that had different fertilizer managements. Applying 25 kg N+75 kg P_2O_5+75 kg K_2O ha^{-1} together with 6.25 t compost ha^{-1} (F8) statistically gave the highest total oil yield of 456.9 t ha^{-1} which was highly significantly higher than other treatments. The application of 25 kg N+75 kg P_2O_5+75 kg K_2O ha^{-1} without compost added also gave a satisfactory total oil yield of 366.3 kg ha^{-1}. Surprisingly, this amount of oil yield was statistically significantly higher than the yield obtained from F5 that 46.88 kg N+46.88 kg P_2O_5+46.88 kg K_2O ha^{-1} plus compost were applied. Sole application of compost at the rate of 6.25 t ha^{-1} (F2) gave rather identical amount of total oil yield as of the soil application of chemical fertilizer (F3: 46.88 kg N+46.88 kg P_2O_5+46.88 kg K_2O ha^{-1}). It was not surprising that growing *J. curcus* without the addition of fertilizer had the lowest total oil yield of 153.1 kg ha^{-1}.

According to fertilizer ratio used in this experiment and taking total oil yield into consideration, 1:1:1 was inferior to 1:3:3 fertilizer ratios. Increased rate of these two ratios of fertilizer to doubling amount (F4 and F7) showed no positive response in the total oil yield of *J. curcus* even the application was split. The sole application of compost at the rate of 6.25 t ha^{-1} gave the same result as the applications of chemical fertilizer and combination between the compost and chemical fertilizer with the exception of applying it together with 25 kg N+75 kg P_2O_5+75 kg K_2O ha^{-1}. It can be said that major plant balance plays a role in the yield of one year old *J. curcus* as oil content in treatments 6, 7 and 8 that used 1:3:3 ratio, giving higher content than that of 1:1:1. The amount of nitrogen used in this experiment is far lower than that reported by Tikkoo *et al*. (2013) which seed yield increased significantly when nitrogen up to 90 kg ha^{-1} was applied. This might be because of age difference of *J. curcus*.

Additionally, compost could not combine well with the addition of 46.88 kg N+46.88 kg P_2O_5+46.88 kg K_2O ha^{-1} as the total oil yield was lowest among treatments that involved added fertilizers. This can be because the amount of nitrogen applied in the form of chemical fertilizer and that stored in compost may be in excess of a requirement for growth of *J. curcus*. It may be in favour of vegetative growth of *J. curcus* rather than reproductive growth. Although, it was found that seed oil content responded positively to increased nitrogen supply as nitrogen plays the central role in many physio-logical and biochemical processes in plant which ultimately affects the amount of oil in *J. curcas* (Akbariana *et al*., 2012). In the case of growing *J. curcus* in semi-arid region, a contrast result was reported (Patolia *et al*., 2007). The seed yield of *J. curcus* was significantly influenced by application of nitrogenous and phosphate fertilizers at the rates of 60 kg N ha^{-1} and 30 kg P_2O_5 ha^{-1}, giving the highest seed yield of 518.5 kg ha^{-1} in the second year of their study.

Plant nutrient concentration in *J. curcus* leaf: *Jatropha curcus* leaf was collected at 2 and 6 months of age for the analysis of plant nutrient concentration. The concentration of major and minor plant nutrients in leaf is presented in Table 6 while Table 7 shows the concentration of plant micronutrients in leaf. There were no statistical differences in the concentration of all plant nutrients as influenced by different fertilizer managements. *Jatropha curcus* had the highest concentration of nitrogen in leaf and the contents in leaf at both ages were quite similar in the range of 3.06-4.05%. Phosphorus was in the lowest content in leaf compared among plant major nutrients. The concentrations at both ages were also almost identical, varying between 0.26-0.41%. The content of potassium in leaf increased with increasing age. The range of 1.28-1.68% was in leaf at younger age (2 months old) whereas the range of 2.13-2.64% was detected when the plant was

Table 6: Plant major and minor nutrient concentration in Jatropha leaf collected at 2 and 6 months of age

	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (%)	
	2	6	2	6	2	6	2	6	2	6	2	6
Treatment	(Months)											
F1	3.89	3.21	0.31	0.39	1.45	2.13	1.54	1.70	0.72	0.80	0.09	0.11
F2	3.85	3.06	0.40	0.37	1.64	2.45	1.70	1.91	0.76	0.95	0.11	0.13
F3	3.85	3.37	0.33	0.35	1.42	2.44	1.64	1.85	0.70	0.74	0.08	0.10
F4	3.76	3.40	0.32	0.41	1.68	2.42	1.78	1.93	0.75	0.77	0.07	0.09
F5	3.96	3.16	0.33	0.36	1.61	2.42	1.71	1.91	0.83	0.82	0.09	0.10
F6	4.05	3.42	0.31	0.36	1.28	2.64	1.63	1.75	0.77	0.65	0.10	0.10
F7	3.92	3.33	0.31	0.31	1.35	2.32	1.53	1.66	0.73	0.74	0.10	0.10
F8	3.76	3.47	0.26	0.32	1.36	2.30	1.85	1.99	0.79	0.80	0.12	0.13
F-test	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	6.80	15.6	19.8	15.3	18.2	11.9	13.9	14.2	12.5	18.0	12.5	15.3

ns: Non significant

Table 7: Plant micronutrient concentration in Jatropha leaf collected at 2 and 6 months of age

	Cu (mg kg^{-1})		Fe (mg kg^{-1})		Zn (mg kg^{-1})		Mn (mg kg^{-1})	
	2	6	2	6	2	6	2	6
Treatment	(Months)							
F1	14.5	8.4	137.3	213.5	26.7	18.7	391.9	180.4
F2	14.0	8.2	121.2	177.2	30.3	15.5	349.0	216.1
F3	13.6	9.0	115.0	139.5	30.0	16.1	404.7	175.0
F4	16.9	7.6	115.9	139.5	26.8	16.5	395.3	223.1
F5	15.6	9.1	117.6	128.7	33.5	15.5	399.2	184.9
F6	15.9	10.9	129.7	185.7	32.0	14.1	499.5	210.5
F7	15.3	9.9	113.4	186.3	27.9	14.2	444.4	217.3
F8	14.3	10.7	138.1	137.7	30.1	10.0	385.9	204.4
F-test	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	16.2	17.0	16.1	15.2	13.1	18.5	19.4	24.8

ns: Non significant

Table 8: Correlation between plant nutrient concentrations in Jatropha leaf collected at 2 and 6 months of age and seed yield and oil yield (n = 32)

	Two month of age		Six month of age	
Plant nutrient concentration	Seed yield	Oil yield	Seed yield	Oil yield
N (%)	-0.326	-0.260	0.257	0.257
P (%)	-0.080	-0.118	0.078	-0.111
K (%)	-0.233	-0.267	0.242	0.292
Ca (%)	0.174	0.266	0.028	0.140
Mg (%)	-0.037	0.067	-0.395*	-0.317
Na (%)	0.015	-0.091	0.107	0.088
Fe (mg kg^{-1})	-0.094	-0.007	-0.411*	-0.440*
Cu (mg kg^{-1})	-0.302	-0.232	0.152	0.287
Zn (mg kg^{-1})	-0.222	-0.055	-0.231	-0.467**
Mn (mg kg^{-1})	0.352*	0.288	0.264	0.274

*, **Significant at 0.05 and 0.01 probability level, respectively

older (6 months old). Calcium concentrated highest in leaf among plant minor nutrients while sulfur being found in the lowest amount. The concentrations were identical in both ages. Among plant micronutrients, manganese clearly had the highest concentration followed by iron. *Jatropha curcus* contained very little amount of copper in leaf. The concentration of manganese decreased when *J. curcus* was older (2 compared to 6 months of age).

Based on ranges of plant nutrient concentration in leaf (Mattana *et al.*, 2005; Chaudharry *et al.*, 2007; Wan *et al.*, 2007) gathered from a number of sources by Jongschaap *et al.* (2007), nitrogen, phosphorus and potassium concentrations in leaf in this study was in the range reported (1.23-6.40, 0.15-0.34 and 0.90-3.77%, respectively). Calcium and magnesium concentrations were also in the ranges reported but sulfur concentration was slightly lower than the range. For micronutrients, it looked as if zinc and manganese concentrations in 2 months old leaf were excessive compared to reported ranges of 9-28 and 39-211 mg kg^{-1}, respectively.

Correlation between plant nutrient concentrations in *J. curcus* leaf and yields: Number of data used for a correlation analysis was 32. There were correlations between the concentration of some plant nutrients in leaf and yield of *J. curcus* as shown in Table 8. At two months of age, manganese concentration in leaf significantly correlated with seed yield (0.352) with no other correlations between plan nutrient concentration an oil yield. Magnesium and iron concentrations in six-month old leaf significantly had a negative correlation with seed yield (-0.395 and -0.411, respectively). The latter also showed the negative correlation with oil yield (-0.440) at the same age of plant. Zinc concentration in 6-month old leaf highly significantly had the negative correlation with oil yield of *J. curcus*.

CONCLUSION

Jatropha curcus responded to applied fertilizer differently on an Ultic Haplustalf. Although, there was no difference in terms of seed yield and other plant parameters, the plant received 1:3:3 ratio of chemical fertilizer at the rate of 25 kg N+75 kg P_2O_5+75 kg K_2O ha^{-1} gave better oil yield than 1:1:1 ratio applied at the rate 46.88 kg N+46.88 kg P_2O_5+46.88 kg K_2O ha^{-1}. The higher rate of these fertilizers showed no influence on the yields. Compost added at the rate of 6.25 t ha^{-1} had the identical effect on the oil yield as of sole application of chemical fertilizer. The combination between compost applied at the rate of 6.25 t ha^{-1} and 25 kg N+75 kg P_2O_5+75 kg K_2O ha^{-1} gave the highest oil yield and can be recommended for 1st year *J. curcus* whereas growing *J. curcus* without fertilization gave unsatisfactorily very low oil yield. The study also demonstrated no different plant nutrient concentrations in leaf of *J. curcus* as influenced by different fertilizer managements. Seed and oil yields had correlations with magnesium, manganese, iron and zinc concentrations in leaf at different ages of growth.

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