Agriculture and Natural Resources 50 (2016) 454–459

Contents lists available at ScienceDirect

Agriculture and Natural Resources

journal homepage: http://www.journals.elsevier.com/agriculture-and-natural-resources/

Original Article

Effects of soil moisture conservation practice, irrigation and fertilization on *Jatropha curcas*

Aran Phiwngam, Somchai Anusontpornperm,* Suphicha Thanachit, Worachart Wisawapipat

Department of Soil Science, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand

ARTICLE INFO

Article history:
Received 23 March 2016
Accepted 13 October 2016
Available online 3 January 2017

Keywords:
Fertilization
Irrigation
Jatropha curcas
Soil moisture conservation practice
Ultic Haplustalf

ABSTRACT

A field experiment was conducted on an Ultic Haplustalf at the Kanchanaburi Research Station, Muang district, Kanchanaburi province, western Thailand between July 2011 and June 2012. Split plots in a randomized complete block design with four replications were employed, having eight main plots (soil moisture conservation practice and irrigation, W1–W8) and 2 sub plots (fertilization, F1 and F2). *Jatropha curcas* (KUBP 78-9 Var.), having been planted at 2 × 2 m spacing, was aged 2 yr when the experiment was commenced. The highly significantly heaviest 100-seed weight of 42 g was obtained 1 mth after water irrigation which had been applied at the rate of 16 L/plant, particularly in the treatment with crop residue mulching (W8) but there were no significant differences among the other treatments where irrigation had been applied (W5–W7). Fertilization and a combination between different fertilizers and soil moisture conservation schemes plus irrigation showed no different effect on the weight of 100 seeds throughout the year of measurement. Growing *J. curcas* with drip-irrigated water at the rate of 16 L/plant applied every 2 d and crop residue mulching (W8) significantly gave the highest seed yield of 1301.3 kg/ha at 15% moisture content. There were no significant differences among the seed yields from the plots applied with the same amount of irrigated water but with no mulching (W7) and half that amount of irrigated water with crop residue mulching (W6), producing yields of 1112.0 kg/ha and 1236.3 kg/ha, respectively. Three-year-old *J. curcas* gave inferior seed yield when grown with no irrigated water supply (W1–W4). The application of 50–150–150 kg/ha of N–P_2O_5–K_2O significantly induced a higher amount of seed yield (933.9 kg/ha) than did the addition of 93.75–93.75–93.75 kg/ha of N–P_2O_5–K_2O (786.3 kg/ha). The interaction between soil moisture conservation plus irrigation and fertilizer was clear. Applying 50–150–150 kg/ha of N–P_2O_5–K_2O together with water irrigation at the rate of 16 L/plant (W7F2) significantly promoted the greatest seed yield of 1415.2 kg/ha. However, irrigated water can be reduced to 8 L/plant in combination with crop residue mulching and the addition of 50–150–150 kg/ha of N–P_2O_5–K_2O (W6F2) and the plants still performed well, producing a seed yield of 1356.4 kg/ha. In addition, with no irrigation, none of the moisture conservation practices (W2–W4) showed any significant effects regardless of the different fertilizers applied.

Introduction

Jatropha curcas L. (Jatropha or Physic nut) is a wild plant that has been cultivated as a result of variety research and belongs to the family Euphorbiaceae being classified as having plant oil similar to palm oil (Anderson and Ingram, 1993; Sricharoenchaikul et al., 2008). What distinguishes *J. curcas* from many other bio fuel crops are the benefits it can offer to relatively small rural areas in less developed countries. In recent years, *J. curcas* has been planted widely, using artificial management (Openshaw, 2000). However, soil water and plant nutrients are the most important factors affecting the growth and water use of this plant (Heller, 1996). The plant is commercially rather new to Thailand so that there is scarce information about fertilization to improve the yield of *J. curcas* grown in the Kingdom. General recommendations for fertilizer use when growing *J. curcas* are based on those used in other plants such as cassava, where a ratio of 1:1:1 for the plant major nutrients is broadly recommended (Chinawong, 2006). Recent study has indicated that the application of nitrogen and phosphorus

* Corresponding author.
E-mail address: somchai.a@ku.ac.th (S. Anusontpornperm).

http://dx.doi.org/10.1016/j.anres.2016.10.006

increased the growth, seed yield and oil yield of *J. curcas* (Patolia et al., 2007; Yin et al., 2010). These results also conformed with the findings of Yong et al. (2010) and Kalannvar (2008). A pot experiment was conducted in the greenhouse and the result showed that the optimal nitrogen supply was 288 kg/ha, which can increase the photosynthetic rate and growth of *J. curcas* under mild drought conditions (Yin et al., 2011). Nitrogen addition significantly promotes the growth of the main stem, and added P or K fertilizer can clearly increase the yield of *J. curcas* (Liu et al., 2009; Gu et al., 2011). Previous study also showed that to optimize the yield for degraded soils in India, the recommended regime was an irrigation frequency at 30 d as water is required, 2 kg of farmyard manure and N, P and K at 10 g, 20 g and 10 g per plant, respectively (Singh et al., 2013). In addition, nitrogen fertilization improved photosynthesis at 80% of water holding capacity (Yin et al., 2010). Nitrogen addition also increased the total dry mass, whole plant water storage capacity, total evapotranspiration and water use efficiency (Yang et al., 2013). A study in the coarse-textured soils of northwest India (Tikkoo et al., 2013) showed that *J. curcas* seed yield increased significantly at 60 kg/ha N with no irrigation whereas seed yield increased significantly up to 90 kg/ha N with one and two irrigation events. A significant effect of potassium application on seed yield was found up to 45 kg/ha K_2O in the absence of irrigation but its effect was significant up to 60 kg/ha K_2O with one and two irrigation events. As mentioned earlier, additional information on fertilization for growing *J. curcas* is essential, particularly in tropical regions where this plant has the potential to be grown for use as a source of energy. Thus, the current study was undertaken as a preliminary investigation into the yield response of *Jatropha* grown on an Ultic Haplustalf soil in western Thailand to different types of soil moisture conservation practice, irrigation and fertilization.

Materials and methods

Experimental site description

The experiment was conducted at the Kanchanaburi Research Station, Muang district Kanchanaburi province in western Thailand (47 535142° E, 1561440° N). The area has a tropical climate with an average annual rainfall of 1114.3 mm (2012–2014), having a bimodal pattern and a mean annual temperature of 27.7 °C (National Statistical Office, 2014). The average rainfall is slightly lower than normal for the area 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 “rain shadow” behind them. Soil at the experimental site is an Ultic Haplustalf, having been formed on a nearly flat surface on the dissected footslope of a limestone mountain. The soil has loam and clay loam textures in the topsoil and subsoil, respectively, with clay particle increasing with increasing depth. Table 1 summarizes the properties of soil prior to conducting the experiment. The soil pH values varied slightly within 60 cm from the mineral soil surface, in the range 5.1–5.4. Soil organic matter had clearly accumulated in the topsoil layers (10.5 g/kg) and decreased in the layers below (6.81 and 2.72 g/kg). The total nitrogen content of the soil was very low (0.63–0.84 g/kg), while available phosphorus was very low to low (2.54–4.52 mg/kg). The range of available potassium content in the top 60 cm of the soil was low (41.2–54.1 mg/kg).

Experimental trial design and crop management

J. curcas (KUBP 78-9 Var.) was planted in June 2009, using direct seeding at a spacing of 2 × 2 m, giving a total population of 2500 plants/ha. Basal dressing fertilization was applied using 56.25 g/plant consisting of equal amounts of N, P and K chemical fertilizer with 2.5 kg compost per hole; the compost properties are presented in Table 2. Then, three *J. curcas* seeds per hole were sown. The growing plant was tipped at 50 cm height to allow the plant to branch laterally at the beginning of its growth in the first year. Drip irrigation at the rate of 2 L/plant every 2 d was performed throughout the whole period of growth in the first year. In the second year, the plants were irrigated in accordance with the treatments described below. The same amount of fertilizer (93.75–93.75–93.75 kg/ha of N–P_2O_5–K_2O) was applied to all plots in both years.

The current study utilized data gathered from the same experiment but was commenced when the plants were fully two years old. It began with hard pruning being done for all plants in July 2010. A split plot in a randomized complete block design with four replications was employed for the experiment. The main plots consisted of: W1 = control, W2 = crop residue mulching (mainly local weeds), W3 = vetiver grass grown between rows of *J. curcas* and the vetiver leaves were slashed twice a year and then mulched around the *J curcas* plants, W4 = jack bean grown as ground cover, W5 = drip irrigation applied at the rate of 8 L/plant every 2 d, W6 = drip irrigation applied at the rate of 8 L/plant every 2 d with crop residue mulching as in W2, W7 = drip irrigation applied at the rate of 16 L/plant every 2 d and W8 = drip irrigation applied at the rate of 16 L/plant every 2 d with crop residue mulching as in W2. Crop residue mulch was composed mainly of rice straw and a layer approximately 2.5 cm thick of the residue was placed to wholly cover all designed plots at the beginning of the rainy season in each year. Vetiver grass was grown using a spacing between tillers of 30 cm in the first year at the time when the *J. curcas* plants were aged 2 mth and their leaves were slashed at a height of 20 cm twice a year during the rainy season for mulching purposes. Jack bean was grown using direct seeding at a rate of 62.5 kg/ha at the same time as the vetiver grass and it was re-sown each year at the beginning of the rainy season. Irrigation was performed during the drought period, starting from October 2011 until the end of April 2012. Subplots comprised two rates of chemical fertilizer: F1 = 93.75–93.75–93.75 kg/ha of N–P_2O_5–K_2O and F2 = 50–150–150 kg/ha of N–P_2O_5–K_2O. These fertilizer rates were based on the result of the response of *J. curcas* grown on an Ultic Paleustalf to chemical fertilizers and compost previously studied nearby (Saikaew et al., 2014) where the characteristics of the soil and its fertility level were rather similar to those in this experiment. Split applications of equal amounts of these

Table 1
Properties of soil prior to conducting the experiment (before placing seedbed).

Depth (cm)	Textural class	pH 1:1 (H_2O)	OM (g/kg)	Total N (g/kg)	Avail. P (mg/kg)	Avail. K (mg/kg)
0–20	Silt loam	5.1	10.52	0.84	4.52	54.1
20–40	Clay loam	5.2	6.81	0.70	3.52	49.9
40–60	Clay loam	5.4	2.72	0.63	2.54	41.2

Note: Avail. P = available P, Avail. K = available K.

Table 2
Properties of compost used in the experiment.

Parameter	Analysis	Unit	Parameter	Analysis	Unit
pH (H_2O 1:2)	6.20	–	Total Mg	0.29	g/kg
Organic matter	24.59	g/kg	Total Na	0.08	g/kg
Total N	5.12	g/kg	Total Fe	1.03	mg/kg
Total P_2O_5	4.72	g/kg	Total Zn	0.84	mg/kg
Total K_2O	0.93	g/kg	Total Cu	0.21	mg/kg
Total Ca	0.52	g/kg	Total Mn	0.11	mg/kg

chemical fertilizers were applied in July and September 2011. 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.

Soil and plant sampling and analyses

Composite soil samples were collected prior to conducting the experiment and the soil properties were analyzed. The numbers of inflorescence and capsule clusters were counted at the end of every month and seed yield was measured every month.

Soil analysis was carried out based on standard methods. The particle size distribution was determined using a combination of sieve and pipette analysis (Day, 1965). Bulk density was determined using a cold method (Blake and Hartge, 1986). Soil pH was determined for a 1:1 soil:water mixture using a pH meter (National Soil Survey Center, 1996). Organic carbon was determined according to the Walkley and Black wet oxidation and titration procedure (Walkley and Black, 1934; Nelson and Sommers, 1996). Total N was determined using Micro Kjeldahl digestion (Jackson, 1965). Soil was extracted using the Bray II method and subsequently the available phosphorus content was determined using the molybdate blue method (Bray and Kurtz, 1945). Available potassium was determined using NH_4OAc pH 7.0 (Pratt, 1965); K in the extract was measured using atomic absorption spectrometry (Peech, 1945). For compost analysis, pH and total nitrogen were determined using the same procedure as those for soil analysis. The compost was digested using digestion mixture (HNO_3–H_2SO_4–$HClO_4$) (Johnson and Ulrich, 1959). Total P_2O_5, was determined by vanado-molybyellow colour method (Westerman, 1990) and then measured by spectrophotometer with 440 nm wavelength (Murphy and Riley, 1962). Total K_2O, Ca, Mg, Na, Fe, Zn, Cu and Mn were determined by atomic absorption spectrophotometer (Westerman, 1990).

Statistical analysis

Analysis of variance was performed using the SPSS Statistics software package (version 17.0; SPSS; Chicago, IL, USA). Data were analyzed using a general linear model. Means among treatments were compared using Duncan's multiple range test (SAS Institute, Inc., 1990) with significant differences being tested at $p \leq 0.05$ (Steel and Torrie, 1987).

Results and discussion

J. curcas influorescence and capsule clustering

The first countable inflorescence of *J. curcas* was observed in September 2011. The average numbers per month increased rather steadily from this month and peaked in February and March 2012 depending on the treatment (Table 3). However, the numbers decreased slightly in April and considerably in May and June 2012. There were no statistical differences among treatments involving irrigation and the types of soil moisture conservation (W1–W8) except for those measured in March 2012. In this month, *J curcas* grown with jack bean ground cover (W4) highly significantly produced the highest number of inflorescence (28.7 inflorescence per plant) compared to W5, W6 and W7, but showed no difference from the control (W1), the treatment with crop residue mulching (W2) and the treatment with vetiver grass being grown between rows of *J. curcas* with where the leaves of the grass had been slashed and used for mulching (W3). The plants grown with the regular supply of water tended to produce lower amounts of inflorescence. However, it cannot be concluded that irrigation depressed the number of inflorescence of *J. curcas* but rather

Table 3
Effect of type of soil moisture conservation scheme, irrigation and fertilizer on average monthly number of inflorescence.

Treatment[†]	Inflorescence (number/plant)									
	2010				2011					
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
W1	9.0	2.2	0.8	0.2	6.0	24.3	21.5[ab‡]	15.2	7.9	5.6
W2	5.4	2.2	0.3	0.0	9.1	23.0	26.8[a]	15.7	7.0	2.6
W3	8.5	1.8	0.1	0.1	5.9	21.5	27.7[a]	11.8	9.4	4.7
W4	6.5	2.5	1.0	0.2	7.5	20.5	28.7[a]	16.4	8.3	3.5
W5	5.7	1.7	0.4	0.1	4.0	21.3	13.1[cd]	12.4	5.9	2.5
W6	7.8	1.2	0.2	0.1	6.2	25.9	14.9[bc]	9.4	6.3	3.7
W7	5.4	1.7	0.5	0.7	5.2	26.6	7.8[cd]	6.6	4.2	1.3
W8	7.3	0.8	0.4	0.4	10.3	30.3	5.8[d]	10.8	4.2	1.6
F-test (W)	ns[‡]	ns	ns	ns	ns	ns	**	ns	ns	ns
F1	6.6	1.7	0.5	0.2	7.3	24.1	17.4	11.9	6.2	3.1
F2	7.3	1.7	0.5	0.3	6.2	24.2	19.2	12.6	7.1	3.2
F-test (F)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
%CV	57.8	67.3	190.3	187.8	51.9	18.3	37.5	30.7	59.0	55.7

[†]W1 = control; W2 = crop residue mulching; W3 = vetiver grass grown between rows of *J. curcas* with vetiver leaves slashed and used as mulching material; W4 = jack bean as ground cover; W5 = drip irrigation at the rate of 8 L/plant every 2 d; W6 = drip irrigation at the rate of 8 L/plant every 2 d crop residue mulching; W7 = drip irrigation at the rate of 16 L/plant every 2 d; W8 = drip irrigation at the rate of 16 L/plant every 2 d with crop residue mulching; F1 = Fertilizer 93.75–93.75–93.75 kg/ha N–P_2O_5–K_2O; F2 = Fertilizer 50–150–150 kg/ha N–P_2O_5–K_2O; %CV = Coefficient of variation; No interaction at all, between W (soil moisture conservation plus irrigation) and F (fertilizer) in any month, thus results of the combination are not shown in the table.
[‡]ns = not significant; *, ** significantly different at 0.05 and 0.01 probability levels, respectively; means with different lowercase superscript letters within a column indicate a significant difference according to Duncan's multiple range test at $p \leq 0.05$.

capsule clusters (discussed in the next paragraph) were produced in much greater numbers in place of the inflorescence in the same month (Table 3). Neither different rates of applied chemical fertilizer (F1 and F2) nor combinations between chemical fertilizer added and types of soil moisture conservation scheme and irrigation had a significant impact on the number of inflorescence throughout the measuring months.

Capsule clusters (Table 4) were detected and counted 1 mth after *J. curcas* initiated flowering. The numbers increased in the same pattern as the average monthly number of inflorescence (Table 3). The peak period of capsule cluster production began in March and lasted until May 2012. Significant differences in the numbers of capsule clusters among treatments were recorded in February, March and May 2012. In February 2012, irrigation tended to induce capsule clustering, especially when applied at the rate of 16 L/plant every 2 d with no mulching (W7) and with crop residue mulching (W8). Both treatments produced highly significantly more capsule clusters with 5.4 capsule clusters per plant and 6.5 capsule clusters per plant, respectively. A similar pattern was found in March 2012. However, the treatments with no irrigation (W1–W4) tended to produce greater numbers of capsule clusters later in May 2012. By the end of the experiment (June 2012), the numbers of capsule clusters were not significantly different among treatments. The application of 93.75–93.75–93.75 kg/ha of N–P_2O_5–K_2O (F1) induced highly significantly better formation of capsule clusters than did the addition of 50–150-150 kg/ha of N–P_2O_5–K_2O (F2) only in February 2012, while in the other months, there were no significant differences. Nonetheless, there was no interaction between soil moisture conservation practices plus irrigation and applied fertilizer in terms of capsule clusters produced throughout the period of measurement.

Table 4
Effect of type of soil moisture conservation scheme, irrigation and fertilizer on average monthly number of capsule clusters.

Treatment†	Capsule cluster (number/plant)									
	Year 2011				Year 2012					
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
W1	0.0	6.3	1.3	1.0	0.4	$1.8^{bc\ddagger}$	7.5^{cde}	11.5	13.5^{ab}	4.3
W2	0.0	6.3	1.9	0.9	0.0	1.9^{bc}	9.5^{bcd}	8.1	17.8^{a}	2.0
W3	0.1	8.0	1.8	1.0	0.1	1.2^{bc}	5.4^{de}	16.0	19.5^{a}	1.9
W4	0.0	5.3	1.2	1.0	0.3	0.84^{c}	2.6^{d}	6.4	16.0^{ab}	4.4
W5	0.1	4.8	2.1	0.5	0.4	2.3^{bc}	13.6^{bc}	9.3	14.2^{ab}	1.5
W6	0.1	7.2	1.6	1.1	0.3	3.0^{b}	12.5^{bc}	10.5	14.0^{ab}	2.9
W7	0.0	4.4	2.1	1.7	0.3	5.4^{a}	15.7^{ab}	13.4	8.5^{b}	0.7
W8	0.0	6.6	1.3	0.7	0.1	6.5^{a}	21.2^{a}	12.4	8.7^{b}	1.5
F-test (W)	ns‡	ns	ns	ns	ns	**	*	ns	*	ns
F1	0.0	5.8	1.5	1.0	0.2	3.8^{a}	12.2	11.1	14.0	2.1
F2	0.0	6.3	1.7	1.0	0.3	1.9^{b}	9.8	10.7	14.0	2.7
F-test (F)	ns	ns	ns	ns	ns	**	ns	ns	ns	ns
%CV	417.7	63.1	71.1	114.0	154.4	62.7	55.1	38.5	46.7	80.3

†W1 = control; W2 = crop residue mulching; W3 = vetiver grass grown between rows of *J. curcas* with vetiver leaves slashed and used as mulching material; W4 = jack bean as ground cover; W5 = drip irrigation at the rate of 8 L/plant every 2 d; W6 = drip irrigation at the rate of 8 L/plant every 2 d crop residue mulching; W7 = drip irrigation at the rate of 16 L/plant every 2 d; W8 = drip irrigation at the rate of 16 L/plant every 2 d with crop residue mulching; F1 = Fertilizer 93.75–93.75–93.75 kg/ha N–P_2O_5–K_2O; F2 = Fertilizer 50-150-150 kg/ha N–P_2O_5–K_2O; %CV = Coefficient of variation; No interaction at all, between W (soil moisture conservation plus irrigation) and F (fertilizer) in any month, thus results of the combination are not shown in the table.
‡ns = not significant; *, ** significantly different at 0.05 and 0.01 probability levels, respectively; means with different lowercase superscript letters within a column indicate a significant difference according to Duncan's multiple range test at $p \leq 0.05$.

Table 5
Effect of type of soil moisture conservation scheme, irrigation and fertilizer on weight of 100 seeds (15% moisture).

Treatment†	100-seed weight (g)								
	Year 2011		Year 2012						Mean
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
W1	0.48	0.48	0.38	$0.41^{abc\ddagger}$	0.29^{c}	0.28	0.27	0.28	0.36
W2	0.46	0.46	0.33	0.33^{c}	0.33^{bc}	0.32	0.31	0.26	0.35
W3	0.48	0.48	0.36	0.35^{bc}	0.32^{bc}	0.30	0.30	0.28	0.36
W4	0.45	0.45	0.38	0.34^{bc}	0.33^{bc}	0.30	0.30	0.26	0.35
W5	0.48	0.48	0.41	0.42^{ab}	0.37^{ab}	0.30	0.30	0.26	0.37
W6	0.47	0.47	0.42	0.46^{a}	0.37^{ab}	0.30	0.30	0.27	0.37
W7	0.50	0.50	0.42	0.46^{a}	0.39^{ab}	0.31	0.31	0.26	0.37
W8	0.47	0.47	0.41	0.37^{bc}	0.42^{a}	0.32	0.32	0.25	0.37
F-test	ns‡	ns	ns	**	**	ns	ns	ns	ns
F1	0.47	0.43	0.38	0.41	0.36	0.31	0.31	0.26	0.36
F2	0.47	0.43	0.39	0.38	0.35	0.29	0.29	0.27	0.36
F-test	ns	ns	ns	ns	ns	ns	ns	ns	ns
%CV	5.5	6.0	16.1	5.9	12.2	11.5	11.0	11.6	8.3

†W1 = control; W2 = crop residue mulching; W3 = vetiver grass grown between rows of *J. curcas* with vetiver leaves slashed and used as mulching material; W4 = jack bean as ground cover; W5 = drip irrigation at the rate of 8 L/plant every 2 d; W6 = drip irrigation at the rate of 8 L/plant every 2 d crop residue mulching; W7 = drip irrigation at the rate of 16 L/plant every 2 d; W8 = drip irrigation at the rate of 16 L/plant every 2 d with crop residue mulching; F1 = Fertilizer 93.75–93.75–93.75 kg/ha N–P_2O_5–K_2O; F2 = Fertilizer 50-150-150 kg/ha N–P_2O_5–K_2O; %CV = Coefficient of variation; No interaction at all, between W (soil moisture conservation plus irrigation) and F (fertilizer) in any month, thus results of the combination are not shown in the table.
‡ns = not significant; *, ** significantly different at 0.05 and 0.01 probability levels, respectively; means with different lowercase superscript letters within a column indicate a significant difference according to Duncan's multiple range test at $p \leq 0.05$.

Weight of 100 J. curcas seeds

The average 100-seed weight was recorded monthly, starting from November 2011 until June 2012 as shown in Table 5. There were highly significant different 100-seed weights in February and March 2012. The heaviest 100-seed weight was found when water at both rates was applied with crop residue mulching (W6) and without mulching (W7), giving a 100-seed weight of 0.46 g per 100 seeds, although this was not significantly different from the control (0.41 g per 100 seeds). Differences were evident in the month after irrigation was applied at the rate of 16 L/plant, particularly in the treatment with crop residue mulching (W8) resulting in highly significantly the heaviest 100-seed weight of 0.42 g compared to no irrigation treatments (W1, W2, W3 and W4). However, the weight was not clearly different from other treatments involving irrigation (W5–W7). Again, fertilization and a combination of different fertilizer and soil moisture conservation schemes plus irrigation showed no significant differences in the 100-seed weight throughout the year of measurement.

Seed yields of J. curcas

J. curcas flowered and produced significant amounts of fruit twice a year (September–December and March–May) as indicated by the results from this study. Soil moisture conservation practices and irrigation clearly affected the yield of *J curcas*, particularly in the second peak and the total yield for a whole year. In the first peak where the plants received some rain for a few months, mulching (W2, W6 and W8) could effectively induce a good seed yield (363.8 t/ha, 350.5 t/ha and 286.1 t/ha, respectively) although there was no statistical difference among treatments (Table 6). A clearer difference was evident in the second peak (the drought period, especially in April 2012). The *J. curcas* plants produced significantly better seed yield when they received irrigated water at both rates with or without mulching (W5–W8). The yields were far greater than those without irrigation (W1–W4). Drip irrigation at the rate of 16 L/plant significantly gave the highest seed yield of 377.9 kg/ha which was in clear contrast to the lowest amount of 9.6 kg/ha gathered from the plot covered with jack bean (W4). The result was consistent with a study in southern Haryana, India by Tikkoo et al. (2013) that found increased irrigation events (that is, the amount of irrigated water applied) can increase the seed yield of *J. curcas* and was also in conformity with the findings of Kheira and Atta (2009). Comparisons among soil moisture conservation practices without irrigation applied were rather surprising, since the control with no conservation practice tended to give the highest seed yield of 147.7 kg/ha.

The total seed yield per year indicated some complexity in the data but the overall results seemed reasonable. The highest seed yield measured at 15% moisture content was obtained when *J. curcas* was grown with 16 L of drip water per plant every 2 d and mulching (W8), producing 1301.3 kg/ha/yr. Nevertheless, there was no statistical difference among treatments involving the use of irrigated water with the exception of W5. The lesser amounts among these treatments were in following order—W6, W7 and W5—with the seed yields gained being 1236.3 kg/ha/yr, 1112.0 kg/ha/yr and 810.2 kg/ha/yr, respectively. Comparing between mulching and no mulching with both rates of water supplied, despite there being no statistical difference, mulching with water addition enhanced the yield and was likely to give a higher seed yield than irrigation without mulching.

Data retrieved from this study also illustrated that growing *J. curcas* without irrigation can produce a satisfactory annual seed

Table 6
Effect of type of soil moisture conservation scheme, irrigation and fertilizer on seed yield at 15% moisture content.

Treatment[†]	Seed yield at 15% moisture content (kg/ha)								
	Year 2011		Year 2012						Sum
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
W1	165	87	19	12.7	40	148^{bcd}[‡]	208	25	624^{b}
W2	364	88	32	28.4	59	61^{cd}	111	20	697^{b}
W3	275	102	21	3.4	66	73^{cd}	286	22	726^{b}
W4	206	71	11	5.2	66	9.6^{d}	99	68	374^{c}
W5	182	64	29	7.6	61	223^{abc}	243	28	810^{b}
W6	351	77	28	7.4	88	292^{ab}	370	41	1236^{a}
W7	181	63	47	21.8	74	378^{a}	341	43	1112^{a}
W8	286	91	13	1.9	118	323^{ab}	445	32	1301^{a}
F-test	ns[‡]	ns	ns	ns	ns	*	ns	ns	*
F1	173^{b}	76	28	12.3	77	184	269	32	786^{b}
F2	330^{a}	85	22	9.9	66	199	257	37	934^{a}
F-test	*	ns	ns	ns	ns	ns	ns	ns	*
W1F1	161	107	18	7.0	49	212	233	27	738^{cdef}
W2F1	268	108	44	36.6	68	86	180	19	738^{cdef}
W3F1	182	76	12	3.6	58	85	285	17	594^{def}
W4F1	91	48	15	7.8	66	9	53	86	253^{f}
W5F1	101	59	32	9.8	63	212	204	23	675^{cdef}
W6F1	237	66	21	9.8	115	309	348	32	1116^{abcd}
W7F1	90	53	66	20.7	86	291	246	18	809^{bcdef}
W8F1	252	92	15	2.5	112	271	603	35	1368^{ab}
W1F2	168	67	21	18.4	32	84	184	23	511^{ef}
W2F2	459	68	20	20.1	51	58	42	21	656^{cdef}
W3F2	369	128	31	3.2	74	94	287	26	858^{bcde}
W4F2	322	94	8	2.6	66	10	145	49	495^{ef}
W5F2	262	70	25	5.4	59	235	283	33	945^{abcde}
W6F2	464	88	34	4.9	60	275	391	50	1356^{ab}
W7F2	271	74	27	22.9	62	465	437	68	1415^{a}
W8F2	321	91	11	1.3	125	374	286	29	1235^{abc}
F-test	ns	ns	ns	ns	ns	ns	ns	ns	*
%CV	48.9	41.0	70.2	184.1	55.8	61.9	59.0	63.3	25.2

[†]W1 = control; W2 = crop residue mulching; W3 = vetiver grass grown between rows of *J. curcas* with vetiver leaves slashed and used as mulching material; W4 = jack bean as ground cover; W5 = drip irrigation at the rate of 8 L/plant every 2 d; W6 = drip irrigation at the rate of 8 L/plant every 2 d crop residue mulching; W7 = drip irrigation at the rate of 16 L/plant every 2 d; W8 = drip irrigation at the rate of 16 L/plant every 2 d with crop residue mulching; F1 = Fertilizer 93.75–93.75–93.75 kg/ha $N-P_2O_5-K_2O$; F2 = Fertilizer 50-150-150 kg/ha $N-P_2O_5-K_2O$; %CV = Coefficient of variation.
[‡]ns = not significant; *, ** significantly different at 0.05 and 0.01 probability levels, respectively; means with different lowercase superscript letters within a column indicate a significant difference according to Duncan's multiple range test at $p \leq 0.05$.

yield to some degree but it does require mulching using crop residue (W2; 696.9 kg/ha/yr) or with vetiver grass grown between *J. curcas* rows where mulching occurred from the regular slashing of the leaves of the vetiver grass (W3: 726.1 kg/ha/yr). This is quite practical in terms of the materials available on site (vetiver leaves), whereas crop residues will be costly unless they are close at hand. In addition, further investigation regarding W3 with irrigation applied will be of interest to see how much the yield of this plant can be increased based on the demand on the available water supply by the vetiver grass for its rapid growth and leaf production for later use in mulching. In addition, this practice will be much more practical where *J. curcas* is grown on a sloping surface because vetiver grass is well known for its ability to protect soil loss due to water erosion. The use of jack bean as ground cover for *J. curcas* produced an inferior annual seed yield (even when compared to the control without soil moisture conservation practice), with the significantly lowest yield of 374.1 kg/ha/yr. While not conclusive, this may have been due to this ground cover plant competing successfully with *J. curcas* for soil moisture stored on the surface and for the fertilizer applied, resulting in poor performance of the major crop plant.

The results of the study on the influence of two different rates of nitrogen, phosphorus and potassium showed that the application of 50–150–150 kg/ha of $N-P_2O_5-K_2O$ (F2) gave significantly better seed yield (933.9 kg/ha/yr) than did the addition of 93.75–93.75–93.75 kg/ha of $N-P_2O_5-K_2O$ (F1) with a yield of 786.3 kg/ha/yr. A significant difference between the effect of fertilizers applied was also found in the first harvest in November 2011 where F2 produced almost twice as much seed than did F1 (329.8 kg/ha compared to 172.8 kg/ha). The higher amounts of phosphorus and potassium applied in F2 were likely, with phosphorus contributing to enhanced inflorescence and capsule cluster formation and potassium improving the seed quantity and quality of the plant. In addition, soil analytical data prior to conducting this experiment showed that the soil lacked these two plant nutrients as the amounts were very low to low. This was consistent with the study by Saikaew et al. (2014) in one year old *J. curcas* even though other studies involving high nitrogen and phosphorus addition showed otherwise (Patolia et al., 2007; Kalannvar, 2008; Yin et al., 2010; Yong et al., 2010). This study and the study of Saikaew et al. (2014) also reaffirmed that the recommended use of 15N–15P–15K chemical fertilizer for *J. curcas* may not be suitable, particularly when grown on Ultic Paleustalf soils that contain low amounts of the major plant nutrients.

There was no monthly interaction of the effect between soil moisture conservation practice and irrigation, and chemical fertilizer on seed yield of *J. curcas* due to the fluctuations in the yield collected each month (Table 6). However, the total seed yield demonstrated a significant difference which is rare for experiments conducted on-farm. This interaction result revealed that the practice comprising irrigated water applied at the rate of 16 L/plant together with the addition of 50–150–150 kg/ha $N-P_2O_5-K_2O$ (W7F2) gave the highest seed yield of *J. curcas* of 1415.2 kg/ha/yr. This result also indicated that water supply and mulching were more pivotal than fertilization as the application of 93.75–93.75–93.75 kg/ha $N-P_2O_5-K_2O$ together with the supply of irrigated water at both rates together with crop residue mulching (W6F1 and W8F1) showed no significant differences in the annual seed yield from those irrigated together with the application of 50–150–150 kg/ha $N-P_2O_5-K_2O$/ha (W5F2, W6F2, W7F2 and W8F2). Growing *J. curcas* without irrigation resulted in an irregular trend in the seed yield no matter what type of fertilizer was applied owing to the plant water needs limiting growth as just mentioned. However, without irrigation, none of the moisture conservation practices (W2–W4) showed any significant effects, regardless of fertilizer practice.

In addition, the use of 93.75–93.75–93.75 kg/ha $N-P_2O_5-K_2O$ with the higher rate of irrigated water and no mulching (W7F1) was significantly less effective in the context of seed yield of *J. curcas* than the application of 50–150–150 kg/ha $N-P_2O_5-K_2O$ with the same irrigation practice with no mulching (W7F2). A rather similar result was also found in the case of the lower rate of irrigated water supply with no mulching (W5F1 and W5F2). These results demonstrated that the latter rate of nitrogen, phosphorus and potassium was more suitable when drip irrigation was performed with no soil moisture conservation against evaporation in the topsoil by using crop residue mulching. In the other words, the plant required greater amounts of chemical fertilizer in total, especially phosphorus and potassium. The balance of NPK fertilizer or the fertilizer ratio may also exert some notable influence on seed yield production. This also suggested that crop residue mulching positively enhanced the efficiency of fertilizer on seed yield, or in the other words, mulching helped lower the fertilizer rate necessary to achieve a desired yield.

J. curcas responded well to soil moisture conservation practice, irrigation and fertilization when grown on Ultic Paleustalf soil that had very low total nitrogen and available phosphorus and low available potassium. The peaks of inflorescence were in February and March while capsule clusters flourished a month later after until May in the same year. There was an indifferent effect of different treatments on 100-seed weight. Plants produced a greater annual seed yield with irrigation than without irrigation, particularly when combined with crop residue mulching. In the case of no irrigation, *J. curcas* was more productive under mulching conditions as well as growing vetiver grass between *J. curcas* rows and using the slashed vetiver leaves for mulching. The application of 50–150–150 kg/ha $N-P_2O_5-K_2O$ induced better seed yield than did the addition of 93.75–93.75–93.75 kg/ha $N-P_2O_5-K_2O$. Irrigation at the rate of 16 L/plant together with fertilization using 50–150–150 kg/ha $N-P_2O_5-K_2O$ was the best practice for gaining the highest seed yield, while water supply in the form of drip irrigation at the rate of 8 L/ha was preferable from an economic viewpoint because it halved the amount of water required. Further trials on growing vetiver grass between rows of *J. curcas* together with irrigation supply should be undertaken, especially where cultivation is on sloping ground for the purpose of conserving soil moisture by applying slashed vetiver leaves as mulch on site since the vetiver plant itself can help to prevent soil erosion.

Conflict of interest

The author declare that there are no conflicts of interest.

Acknowledgements

We gratefully acknowledge the Graduate School of Kasetsart University, Bangkok, Thailand, the Kasetsart University Biodiesel Project and PTT Public Company Limited for the financial support of the study.

References

Anderson, J.M., Ingram, J.S.I., 1993. Tropical Soil Biological and Fertility: A Handbook of Methods, second ed. CAB International, Wallingford, UK.

Blake, G.R., Hartge, K.H., 1986. Bulk density. In: Klute, A. (Ed.), Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods, second ed. ASA and SSSA, Madison, WI, USA, pp. 363–375.

Bray, R.H., Kurtz, L.T., 1945. Determination of total, organic and available forms of phosphorus in soils. Soil Sci. 59, 39–46.

Chinawong, S., 2006. Physic Nut and Value-added from its Wastes. Office Extension and Training Kamphaengsaen, Kasetsart University, Kamphaengsaen, Thailand (in Thai).

Day, P.R., 1965. Particle fraction and particle size analysis. In: Black, C.A. (Ed.), Methods of Soil Analysis, vol. 9. American Society of Agronomy, Madison, WI, USA, pp. 545–567.

Gu, Y., Yin, Y., Wu, H., Chen, X.Y., Huang, X.B., Dong, P., 2011. Effects of fertilization on growth, fruit yield and soil fertility of *Jatropha curcas* plantations. J. Northeast For. Univ. 39, 56–59.

Heller, J., 1996. Physic Nut, *Jatropha curcas* L. Promoting the Conservation and Use of Underutilized and Neglected Crops. Institute of Plant Genetics and Crop Plant Research, Gatersleben International Plant Genetic Resources Institute, Rome, Italy.

Jackson, M.L., 1965. Soil Chemical Analysis – Advanced Course. Department of Soils, University of Wisconsin, Madison, WI, USA.

Johnson, C.M., Ulrich, A., 1959. Analytical methods for use in plant analysis. Calif. Agri. Exp. Stat. Bull. 767, 25–78.

Kalannvar, V.N., 2008. Response of *Jatropha curcas* to Nitrogen Phosphorus and Potassium Levels in Northern Transition Zone of Karnataka. MSc. thesis submitted to the University of Agricultural Sciences. Dharwad, India.

Kheira, A.A.A., Atta, N.M.M., 2009. Response of *Jatropha curcas* L. to water deficits: yield, water use efficiency and oil seed characteristics. Biomass Bioenerg. 33, 1343–1350.

Liu, S., He, C.J., He, S.B., 2009. Effects of different fertilization treatments on the sapling growth of *Jatropha curcas*. J. Sichuan For. Sci. Technol 30, 53–56.

Murphy, J., Riley, J.P., 1962. A modified single solution method for determination of phosphate in natural waters. Anal. Chim. Acta 27, 31–36.

National Statistical Office, 2014. Rainfall and Temperature of Kanchanaburi Province. Source: http://service.nso.go.th/nso/web/statseries/statseries27.html, 16 May 2014.

National Soil Survey Center, 1996. Soil Survey Laboratory Methods Manual. Soil Survey Investigations Report No. 42, Version 3.0, Natural Conservation Service, USDA. Washington, DC, USA.

Nelson, D.W., Sommers, L.E., 1996. Total carbon, total organic carbon and organic matter. In: Sparks, D.L. (Ed.), Methods of Soil Analysis, Part 3: Chemical Methods. American Society of Agronomy, Inc., Madison, WI, USA, pp. 961–1010.

Openshaw, K., 2000. A review of *Jatropha curcas*: an oil plant of unfulfilled promise. Biomass Bioenerg. 19, 1–15.

Patolia, J.S., Ghosh, A., Chikara, J., Chaudharry, D.R., Parmar, D.R., Bhuva, H.M., 2007. Response of *Jatropha curcas* L. Grown on Wasteland to N and P Fertilization. Paper Presented at the FACT Seminar on *Jatropha curcas* L. Article No. 34. Agronomy and Genetics, March 26–28, 2007. Wageningen, the Netherlands.

Peech, M., 1945. Determination of exchangeable cations and exchange capacity of soils-rapid micromethods utilizing centrifuge and spectrophotometer. Soil Sci. 59, 25–38.

Pratt, P.E., 1965. Potassium. In: Black, C.A. (Ed.), Method of Soil Analysis, Part II: Chemical and Microbiological Properties. Agron. No. 9. Amer. Soc. of Agron. Inc, Madison, WI, USA, pp. 1023–1031.

Saikaew, W., Anusontpornperm, S., Thanachit, S., Suddhiprakarn, A., 2014. Response of *Jatropha curcas* grown on an Ultic Paleustalf to chemical fertilizers and compost. Asian J. Crop Sci. 6, 362–372.

SAS Institute Inc, 1990. SAS/STAT User's Guide, Version 6, fourth ed. SAS Institute, Cary, NC, USA.

Singh, B., Kripal, S., Rao, G.R., Chikara, J., Kumar, D., Mishra, D.K., 2013. Agro-technology of *Jatropha curcas* for diverse environmental conditions in India. Biomass Bioenerg. 48, 191–202.

Sricharoenchaikul, V., Pechyen, C., Aht-ong, D., Atong, D., 2008. Preparation and characterization of activated carbon from the pyrolysis of physic nut (*Jatropha curcas* L.) waste. Energ. Fuel 22, 31–37.

Steel, R.G.D., Torrie, J.H., 1987. Principles and Procedures of Statistics. McGraw-Hill Book Co. Int, New York, NY, USA.

Tikkoo, A., Yadav, S.S., Kaushik, N., 2013. Effect of irrigation, nitrogen and potassium on seed yield and oil content of *Jatropha curcas* in coarse textured soils of northwest India. Soil Till. Res. 134, 142–146.

Walkley, A., Black, I.A., 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37, 29–37.

Westerman, R.L., 1990. Soil Testing and Plant Analysis, third ed. American Society of Agronomy and Soil Science Society of America, Madison, WI, USA.

Yang, Q., Li, F., Zhang, F., Liu, X., 2013. Interactive effects of irrigation frequency and nitrogen addition on growth and water use of *Jatropha curcas*. Biomass Bioenerg. 59, 234–242.

Yin, L., Hu, T.X., Liu, Y.A., Xie, C.Y., Feng, Y., Yan, Z., 2011. Effect of nitrogen application rate on growth and leaf photosynthetic characteristics of *Jatropha curcas* seedlings. Acta. Ecol. Sin. 31, 4977–4984.

Yin, L., Hu, T.X., Liu, Y.A., Yao, S.F., Ma, J., Liu, W.T., 2010. Effects of drought stress on photosynthetic characteristics and growth of *Jatropha curcas* seedlings under different nitrogen addition. China J. Appl. Ecol. 21, 569–576.

Yong, J.W.H., Ng, Y.F., Tan, S.N., Chew, A.Y.L., 2010. Effect of fertilizer application on photosynthesis and oil yield of *Jatropha curcas* L. Photosynthetica 48, 208–218.