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Establishment and Early Field Performance of *Jatropha Curcas* L at Bindura University Farm, Zimbabwe

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ABSTRACT

The performance of J. curcas propagated through pre-cultivated seedlings, non-rooted cuttings and direct seeding, established at 3333, 2500, 1333 stems/ha and subjected to spot weeding, slashing and both spot weeding and slashing was evaluated. The trial was established on the 20th of December 2006, in a 3^3 factorial completely randomized block design with three replications. Each plot consisted of 16 trees. Data were collected from the entire population. Height, root collar diameter (RCD) and survival were determined using standard forestry procedures. Data were analysed through one-way analysis of variance (ANOVA) at 95% confidence level using SPSS version 15 (2003). Jatropha curcas established through pre-cultivated seedlings outperformed ($P<0.05$) non-rooted cuttings and direct seeded plants in terms of survival. There were no significant differences ($P>0.05$) among saplings established at 3333, 2500 and 1333 stems/ha planting densities as well as among those subjected to spot weeding, slashing and both spot weeding and slashing in terms of survival and growth in height and RCD. This research concludes that pre-cultivated J. curcas seedlings perform better in percentage survivals than non-rooted cuttings and direct seeded plants in agro-ecological conditions similar to those of the study site.

Key Words: *Jatropha curcas*, propagation method; weed management method, planting density, root collar diameter.

INTRODUCTION

The crude oil crisis of the 1970s and the subsequent shortages of petro-fuels on the world market have seen the recognition of the limitations of world oil resources (Grimm, 1996; Heller, 1996; Henning, 2000; Pratt *et al*., 2002). Currently, the whole world is faced with critical fuel shortages accompanied with high prices as well as the global warming issue. This has prompted governmental and non-governmental organizations (NGOs) to search for alternative sources of energy, which are renewable, safe and non-polluting. In this regard, renewable vegetable fuels have assumed top-priority. Special interest has been shown in the cultivation of the tropical physic nut (*Jatropha curcas* L., Euphorbiaceae) for oil extraction (Grimm, 1996; Heller, 1996).

The Concept of Bio-diesel

According to Biswas *et al.* (2006), the concept of bio-fuel dates back to 1885 when Dr. Rudolf Diesel built the first bio-diesel engine. In 1912, he predicted the potential of bio-diesel, "The use of vegetable oils for engine fuels may seem insignificant today. But such oils may in the course of time become as important as petroleum and the coal tar products of present time" (Biswas *et al*., 2006).

In the early 1970s, scientists discovered that the viscosity of vegetable oils could be reduced by a simple chemical process and that it could perform as petro-diesel in a modern engine (Biswas *et al*., 2006). Since then, technical developments have come a long way and plant oil has been highly established as a bio-fuel, equivalent to diesel. Recent environmental (e.g. Kyoto Protocol) and economic concerns have prompted the resurgence of bio-diesel throughout the world.

World Distribution of *J. curcas*

Jatropha curcas is a shrub, which originated in the Caribbean, Central America and was spread by Portuguese traders as a valuable hedge plant via the Cape Verde Islands and former Portuguese Guinea (Guinea Bissau) (Henning, 2008) to countries in Africa, Asia and India (Jepsen *et al.,* 2006). *Jatropha curcas* grows under a variety of conditions, which makes its cultivation possible across the world's agro-ecological regions. Today, the species is cultivated in almost all tropical and sub-tropical countries as live fences.

Botanical Description of *J. curcas*

According to Leon (1987), Mabberley (1987), and Rehm and Espig (1991), the Euphorbiaceae family contains oil crops of economic importance among them *J. curcas*, *Ricinus communis* and *Sapium sebiferum*. The genus *Jatropha* belongs to the tribe *Joannesieae* of *Crotonoideae* in the *Euphorbiaceae* family (Henning, 2008). The term *Jatropha* was derived from the Greek words *jatros* (doctor) and *trophe* (food), which means medicinal uses (Heller, 1996). *Curcas* is the common name for physic nut in India (Correll and Correll, 1982).

Jatropha curcas grows up to a height of 3 to 5 metres and its average life, with effective yield is about 50 years (Singh *et al*., 2007). It bears fruits from the second year of its establishment and the economic yield stabilizes from the fourth or fifth year onwards (Makkar *et al*., 2001). It gives about 2 kg of seed per plant. In poor soils, the yields have been reported to be about 1 kg seed per plant (Singh *et al*., 2007).

Sustainability of *J. curcas* Oil as an Alternative to Petro-diesel

In the present scenario, the appropriate answer to the current oil crisis is to explore the possibility of bio-diesel. Bio-diesel is an eco-friendly, alternative fuel prepared from vegetable oils (edible or non edible) and animal fat which are renewable (Singh *et al*., 2007). The non-edible *J. curcas* oil has requisite potential of providing a promising and commercially viable alternative to petro-diesel. *Jatropha curcas* bio-diesel has the desired physio-chemical and performance characteristics comparable to petro-diesel (Kureel, 2006). It has a higher cetone number (51) than other vegetable oils and petro-diesel (46 to 50) (Kureel, 2006). This makes it an ideal alternative fuel and requires no special modification in the engine.

The initial flash point of *J. curcas* oil is 100 ^{0}C as compared to 50 ^{0}C of petro-diesel (Kureel, 2006). This creates initial engine starting problem. Similarly, the higher viscosity of *J. curcas* oil may affect the smooth flow of oil in the engine. However, these problems can easily be overcome by esterification (Kureel, 2006).

Other Uses of *J. curcas*

The bark of the plant produces a dark blue dye, which is used for coloring cloth, fishing nets and lines (Singh *et al*., 2007). *Jatropha curcas* oil cake contains about 6 % nitrogen, 2.75 % phosphate and 0.94

% potassium and thus can be used as organic manure (Makkar *et al*., 2001). The seed cake or seeds can be used as animal feed (Makkar *et al*., 2001). The leaves can be used as food for tussler silkworms. Burnt root ashes are used as a salt substitute (Morton, 1981). Latex, which contains alkaloids (*jatrophine, jatrophan, jatrophone*, and *curcain*) has anticancerous properties and is inhibitory to watermelon mosaic virus (Tewari and Shukla, 1982). According to Agaceta *et al.* (1981), the latex can be used as a remedy for alopecia, anasorca, burns, dropsy, eczema, inflammation, paralysis and yellow fever. The most exploited uses of oil pressed from the seed in rural-industrial development include lubrication, soap and candle making (Tigere *et al*., 2006). In China, the oil is used to produce furniture varnish after boiling it with iron oxide (Ochse, 1931).

Jatropha curcas Production in Zimbabwe

Jatropha curcas was introduced into Zimbabwe in the 1940s (Makkar *et al*., 2001). Since then, it has spread to many parts of the country, with known concentrations in the northeastern districts of Mutoko, Wedza, Chiweshe, Mudzi and Nyanga (Jepsen *et al.,* 2006), among small scale farmers. Efforts are under way to establish jatropha plantations across the country.

The government of Zimbabwe together with NGOs has initiated research on *J. curcas* oil for bio-diesel production. The institutions involved include Harare and Masvingo polytechnic colleges (experiments on *J. curcas* bio-diesel running engines), the Scientific and Industrial Research and Development Centre (SIRDC), the National Oil Company of Zimbabwe (NOCZIM) as well as Environment Africa (Jepsen *et al.,* 2006). The efforts of these organizations have seen the mushrooming of small scale oil pressing mills in areas like Harare, Guruve, Mutoko and Masvingo (Jepsen *et al.,* 2006). An extensive *J. curcas* oil extraction plant is under construction in Mutoko. Its completion may see a significant number of vehicles running on bio-diesel.

Traditionally, *J. curcas* was propagated through cuttings especially in the establishment of live fences around homesteads, kraals, fields, gardens and along roads. Planting density was dependent upon individual farmers depending on their objectives for instance to keep out livestock or as a boundary line. Once planted, the species required little or no management since it can tolerate harsh conditions and is capable of out-competing weeds. Its toxicity deters livestock thereby requiring less attention as compared to other trees. The need to grow the tree for bio-diesel means that the productivity has to be improved. Widespread research on agronomic techniques to optimize yield of *J. curcas* is therefore pertinent.

Little has been done both on the species productivity and processing resulting in substantially less benefit from the plant's potential uses. Although *J. curcas* is commonly planted in Zimbabwe, research on cultivation and propagation is limited (Jepsen *et al.*, 2006). The areas in which there is inadequate information include fertilizer requirement, intercropping, irrigation requirements, effects of management practices, propagation methods and the use of seed cake as a feed to livestock (Tigere *et al*., 2006). This research sought to determine region and situation specific propagation method, planting density and weed management method for the cultivation *J. curcas* for seed production in Zimbabwe.

MATERIALS AND METHODS

Study Site

The trial was conducted at Bindura University farm (17^{o}.18′S, 31^{o}.18′E), about 7 km north-east of Bindura town. The site has red clay soils, classified as Chromic Luvisol (FAO) or Ustalfs (USDA). They were formed from maffic rocks and have a crumb microstructure. Mean annual precipitation ranges from 700 to 1050 mm and occurs during a single rainy season extending from November to April. Mean annual temperatures range from 25^{o}C to 30^{o}C. The area experiences frost from May to July.

The study area is dominated by *Rottboellia exaltata* with some pockets of *Cynodon dactylon, Heteropogon contortus* and *Hyparrhenia filipendula* as well as isolated occurrences of *Solanum sp*. The surrounding area partly consist of a mixed forest characterised by *Acacia polyacantha, Anona senegalensis, Brachystegia sp, Bauhinia petersiana, Bauhinia thonningii, Combretum sp, Dichrostachys cineria, Diplorhychus condylocarpon, Flacourtia indica, Julbernardia globiflora, Lonchocarpus capassa, Rhus sp, Terminalia sericea* and *Strychnos sp*.

Experimental Design

The research was conducted in a 3^3 factorial randomized complete block design with three replications, involving three propagation methods (transplanting pre-cultivated seedlings, non-rooted cuttings and direct seeding), three planting densities (3333, 2500 and 1333 stems/ha) and three weed management methods (spot weeding, slashing and both slashing and spot weeding). The planting densities were chosen after Singh *et al*. (2007) and Heller (1996) recommendations that *J. curcas* planting densities for plantations be between 3333 and 1111 stems/ha. Blocking was done perpendicular to the soil (colour) gradient and slope. Soil colour varied from red at the upper part of the experimental site to dark brown at the lower part.

Nursery Tending

Three beds, each of 3 m x 1 m, were pegged, dug to a depth of 20 cm using a hoe and the soil removed using a shovel. The volume created was filled with a mixture of top soil and decayed organic matter collected from the floor of Acacia woodlands (dominated by *Acacia polyacantha*) at Bindura University farm. The floor of the bed was underlain with a polyethylene layer to avoid seedling roots growing deeper in the soil. This was after Kureel (2006) who reported the polythene bag method to give inferior seedlings as compared to the open rooted system. The seeds were sown on the first of September 2006. Sowing depth was 3 cm (Henning, 2000) with an average seed to seed distance of 10 cm. Emergence was first recorded on the eighth day of planting and on the tenth day an average germination of 92% was recorded. The seedlings were watered once everyday for a period of 8 weeks. Thereafter, watering was gradually reduced to once every two days and finally once every three days to progressively harden the seedlings. Weeds were controlled manually by hand pulling. The seedlings were monitored for growth in root collar diameter (measurements were done using a veneer caliper) and height (using a height rod and a tape measure).

Land Preparation and Planting

The research area was disced to a depth of 0.2 m using a tractor drawn disk plough. Marking and pitting were done using a tape measure and manually respectively. Each research plot consisted of 16 planting stations and ranged in size from 27 m^2 (for the 3333 stems/ha planting density), 36 m^2 (for the 2500 stems/ha planting density) and 67.5 m^2 (for the 1333 stems/ha planting density). The planting stations measured about 20 cm in depth and 15 cm in diameter.

Transplanting of seedlings from the nursery to the research site, planting of cuttings and seeds were done on the 20th of December following precipitation amounting to 20 mm. Seedlings had attained an average height of 45 cm and a root collar diameter of 11 mm. The seedlings were planted using a garden fork. Care was taken to avoid 'J' and 'L' rooting.

Cuttings were collected from, one year old branches and were about 5 cm in diameter, 25 cm long, with 4 to 5 buds. These specifications were adapted from Singh *et al.* (2007). The cuttings were planted at 10 cm depth.

As for direct seeding propagation method, two seeds were sown per planting station. The planting depth was three times the diameter of the seed (3 to 4 cm) (Singh *et al*., 2007). 'Thinning to waste' was done 2 weeks after emergence. Slashing and spot weed management practices were done after two months of planting. The total plant population was 1296 and covered about 0.4 hectares of planted area.

Field Measurements and Data Collection

Measurements were done on all the trees in the plots. Tree survival was determined by use of Equation 1 and was done after seven months of planting.

$$\text{Survival (\%)} = \frac{\text{Total plants established-Total plants dead x 100}}{\text{Total plants established}} \qquad \textit{Eqn 1}$$

Growths in height and root collar diameter (RCD) were measured after one and seven months after planting, using a height rod and a veneer caliper, respectively. Plant height was measured as the distance in cm, between the RCD and the apical meristem. However, for some of the plants, the apical meristem was damaged by herbivores, frost or pathogens. In these cases, branch leader meristems were considered for height measurement (Balderrama and Chazdon, 2005).

Plant growth was evaluated as the mean relative growth rates in height (RGR_h) and RCD (RGR_d) over the total growth period using the formulae for classic plant growth analysis (Balderrama and Chazdon, 2005) as shown in Equations 2 and 3.

$$RGR_h = \frac{\log_e hf - \log_e hi}{t_2 - t_1} \qquad \textit{Eqn 2}$$

Where RGR_h =Relative growth rate in height,

hi = the initial (a month after establishment,' t_1 ') growths in height,

hf = the final (after ' t_2 ' months) growths in height.

$$RGR_d = \frac{\log_e df - \log_e di}{t_2 - t_1} \qquad \textit{Eqn 3}$$

Where RGR_d =Relative growth rate in RCD,

di = the initial (a month after establishment, ' t_1 ') growths in RCD,

df = the final (after ' t_2 ' months) growth in RCD,

Data Analysis

Data on survival were arcsine transformed before being analyzed. This was done to ensure normality. Geometric means were calculated for presentation. Plant survival, growth in height and RCD, RGR_h and RGR_d were tested for significance among treatments through a one way analysis of variance (ANOVA) using SPSS for Windows Version 15 (2006). Differences between means were tested using LSD post hoc tests at 5% level of significance. Equation 4 shows the model for the experiment.

$$Y_{ijkl} = \mu + S_i + P_j + W_k + SP_{ij} + SW_{ik} + PW_{jk} + SPW_{ijk} + e_{ijkl} \qquad \textit{Eqn 4}$$

Where: Y_{ijkl} = Response of trees planted at ith planting density, propagated through the jth method and with weeds managed through the kth method.

μ =Grand mean,

S_i =Response to the ith planting density (i=3333, 2500 or 1333 stems/ha),

P_j = Response to the jth propagation method (j=pre-cultivated seedlings, non-rooted cuttings or direct seeding).

W_k =Response to the kth weed management method (k=spot weeding; slashing and the two weed management methods combined),

SP_{ij} =Response to the effect of the interaction between planting density and propagation method,

PW_{jk} = Response to the effect of the interaction between propagation method and weed management technique,

SPW_{ijk} = Response to the effect of the interaction among planting densities, propagation methods and weed management techniques,

e_{ijkl} = the error term.

RESULTS

Relative Growth Rates in Height and RCD

Relative growth rates in height ($RGR_{h7months}$) and RCD ($RGR_{d7months}$) over a seven months period, of *J. curcas* saplings propagated through pre-cultivated seedlings and direct seeding, planted at densities 3333, 2500 and 1333 stems/ha and subjected to slashing, spot weeding and both slashing and spot weeding are shown in Table 1. Relative growth rates in height and $RGR_{d7months}$ for non-rooted cuttings are missing because the plants growth habit did not allow data on height and RCD to be collected.

Table 1: *Jatropha curcas* $RGR_{h7months}$ and $RGR_{d7months}$

Propagation Method	Planting Density (Stems/ha)	Weed Management Method	$RGR_{h7months}$ ±SE	$RGR_{d7months}$±SE
Pre-cultivated seedlings	3333	Slashing	0.018±0.011	0.035±0.009
		Spot & slashing	0.030±0.012	0.010±0.010
		Spot	0.031±0.012	0.016±0.010
	2500	Slashing	0.015±0.011	0.032±0.009
		Spot & slashing	0.015±0.011	0.039±0.009
		Spot	0.018±0.011	0.036±0.009
	1333	Slashing	0.017±0.011	0.063±0.009
		Spot & slashing	0.032±0.012	0.048±0.009
		Spot	0.016±0.011	0.053±0.009
Direct seeding	3333	Slashing	0.028±0.014	0.019±0.011
		Spot & slashing	0.018±0.011	0.015±0.016
		Spot	0.074±0.021	0.047±0.017
	2500	Slashing	0.015±0.021	0.020±0.018
		Spot & slashing	0.054±0.018	0.038±0.015
		Spot	0.051±0.018	0.046±0.015
	1333	Slashing	0.027±0.015	0.029±0.012
		Spot & slashing	0.028±0.016	0.060±0.013
		Spot	0.038±0.013	0.061±0.011
Significance	Propagation Method (Prop)		NS	NS
	Weed management (Weed Mgt)		NS	NS
	Planting Density (Density)		NS	NS
	Prop*Density		NS	NS
	Prop*Weed Mgt		NS	NS
	Density*Weed Mgt		NS	NS
	Prop*Weed Mgt*Density		NS	NS

NS= Not significantly different at P=0.05.

Plants established through pre-cultivated seedlings did not significantly differ ($P>0.05$) from those established by direct seeding in terms of $RGR_{h7months.}$ As for planting densities, $RGR_{h7months}$ did not vary ($P>0.05$) among plants established at 3333, 2500, and 1333 stems/ha. Similarly, $RGR_{h7months}$ did not significantly differ ($P>0.05$) among plants where slashing, spot weeding and both slashing and spot weeding were practiced. The interaction between propagation methods and planting densities as well as the one between planting densities and weed management techniques did not result in significant differences ($P>0.05$) on Jatropha's $RGR_{h7months.}$ Similarly, the interaction between propagation methods, planting densities and weed management techniques did not result in significant differences ($P>0.05$) on plants' $RGR_{h7months}$.

There was no significant difference ($P>0.05$) between plants established through pre-cultivated seedlings and direct seeding in terms of $RGR_{d7months}$. As for planting densities, there were no significant differences ($P>0.05$) among plants established at 3333, 2500, and 1333 stems/ha in terms of $RGR_{d7months}$. Plants' response to weed management indicated no significant differences ($P>0.05$) in $RGR_{d7months}$ among those subjected to slashing, spot weeding and both slashing and spot weeding. Plants' response to the interaction between propagation methods and planting densities as well as planting densities and weed management techniques indicated no significant differences ($P>0.05$) in $RGR_{d7months}$. The interaction among propagation methods, planting densities and weed management techniques did not result in significant differences ($P>0.05$) on plants' response in terms of $RGR_{d7months}$.

Survivals and Growths Seven Months after Planting

Growth in height and RCD and survival percentages of *J. curcas* achieved in 7 months are shown in Table 2.

Table 2 Survivals, height and RCD of *J. curcas* after seven months

Propagation Method	Planting Density (Stems/ha)	Weed Management Method	Survival (%)	Mean Height (cm) ±SE	Mean RCD (cm) ±SE
Pre-cultivated Seedlings	3333	Slashing	83.33	64.33±2.18	2.73±0.10
		Spot & slashing	83.33	69.24±2.27	2.96±0.10
		Spot	78.17	75.28±2.27	3.30±0.10
	2500	Slashing	77.08	73.09±2.07	2.93±0.09
		Spot & slashing	83.33	76.24±2.01	3.07±0.09
		Spot	87.50	69.13±2.15	3.11±0.10
	1333	Slashing	77.08	81.88±2.05	3.60±0.09
		Spot & slashing	83.33	74.16±2.10	3.36±0.09
		Spot	78.17	70.66±2.21	3.27±0.10
Direct Seeding	3333	Slashing	51.39	16.63±2.62	1.28±0.12
		Spot & slashing	25.00	17.83±3.93	1.58±0.17
		Spot	49.67	15.21±3.63	1.41±0.16
	2500	Slashing	25.00	15.73±4.10	1.26±0.18
		Spot & slashing	31.25	16.47±3.51	1.35±0.16
		Spot	53.50	19.13±3.51	1.44±0.16
	1333	Slashing	29.17	16.96±2.90	1.41±0.13
		Spot & slashing	31.25	18.67±2.48	1.61±0.11
		Spot	47.92	17.58±3.12	1.71±0.14
Non-rooted Cuttings	3333	Slashing	10.42	-	-
		Spot & slashing	20.67	-	-
		Spot	24.92	-	-
	2500	Slashing	22.92	-	-
		Spot & slashing	16.67	-	-
		Spot	18.75	-	-
	1333	Slashing	14.58	-	-
		Spot & slashing	27.08	-	-
		Spot	18.67	-	-
Significance	Propagation Method (Prop)		***	***	***
	Weed management (Weed Mgt)		NS	NS	NS
	Planting Density (Density)		NS	NS	NS
	Prop*Density		NS	NS	NS
	Prop*Weed Mgt		NS	NS	NS
	Density*Weed Mgt		NS	NS	NS
	Prop*Weed Mgt*Density		NS	NS	NS

*** =Significant differences at P=0.001; NS=not significant (P>0.05) and '–'=missing value.

Survival

Survival Variation by Propagation Method

Arcsine transformed survival data showed that saplings established by means of pre-cultivated seedlings (81.42 %) outperformed ($P<0.05$) those established through direct seeding (38.07 %) and cuttings (19.41 %) when the three planting densities and weed management techniques were evaluated. In turn, *J. curcas* established through direct seeding outperformed ($P<0.05$) the ones propagated through non-rooted cuttings in terms of survival.

Survival Variation by Planting Density

Planting densities did not differ significantly ($P>0.05$) among themselves in terms of *J. curcas* survival. The overall survivals of saplings established at 3333, 2500 and 1333 stems/ha were 45.60 %, 46.28 % and 45.36 % respectively.

Planting densities showed no significant differences ($P>0.05$) among themselves in terms of the survival of saplings propagated by planting pre-cultivated seedlings, with 3333 stems/ha density recording 79.17 %; 2500 stems/ha, 83.50 % and 1333 stems/ha, 81.61 %.

Similarly, planting densities did not differ significantly ($P>0.05$) on the survivals of saplings propagated by direct seeding and recorded 40.14 % for those planted at 3333 stems/ha; 36.58 %, 2500 stems/ha and 36.11 %, 1333 stems/ha density. As for saplings propagated through non-rooted cuttings, there were no significant differences in percentage survivals ($P>0.05$) among cuttings established at 3333 stems/ha (18.67 %), 2500 stems/ha (19.44 %) and 1333 stems/ha (20.11 %).

Survival Variation by Weed Management Method

Weed management techniques did not differ significantly ($P>0.05$) among themselves in terms of *J. curcas* survival. The overall survivals of saplings subjected to slashing, spot weeding and both slashing and spot weeding were 43.44 %, 50.79 % and 42.74 % respectively.

Slashing (81.61 %), spot weeding (79.86 %) and both slashing and spot weeding (82.81 %) did not result in significant differences ($P>0.05$) on survivals of saplings propagated by planting pre-cultivated seedlings. Saplings propagated by direct seeding and subjected to spot weeding (50.19 %) recorded a higher (P<0.05) survival percentage when compared to those subjected to slashing (35.19 %) and both slashing and spot weeding (28.13 %). As for saplings propagated through non-rooted cuttings, weed management practices exhibited no significant differences (P>0.05) among themselves in terms of survival, with those subjected to slashing scoring 15.97 %, spot weeding, 20.78 % and both slashing and spot weeding (21.47 %).

Height and RCD

Saplings Propagated through Pre-cultivated Seedlings

In terms height, saplings propagated through pre-cultivated seedlings indicated no significant differences (P>0.05) among those subjected to slashing (Mean±SE; 73.45 cm±1.66), spot weeding (71.58 cm±1.24) and both slashing and spot weeding (73.56 cm±1.55). The same scenario was observed with RCD, recording no significant differences (P>0.05) among saplings which were subjected to slashing (3.10 cm±0.07), spot weeding (3.14 cm±0.06) and both slashing and spot weeding (3.22 cm±0.06).

Planting density had no effect (P>0.05) on growth in height as well as RCD. The mean heights achieved were: 69.98 cm±1.31 for 3333 stems/ha, 72.98 cm±1.23 for 2500 stems/ha and 75.82 cm±1.81 for 1333 stems/ha. As for RCD, the 3333 stems/ha density recorded 2.99 cm±0.06; 2500 stems/ha, 3.04 cm±0.06 and 1333 stems/ha, 3.42 cm±0.66.

Saplings Propagated by Direct Seeding

Saplings propagated through direct seeding indicated no significant differences (P>0.05) in terms of mean height, among those subjected to slashing (16.58 cm±0.38), spot weeding (17.38 cm±0.63) and both slashing and spot weeding (17.91 cm±0.75). However, unlike height, RCD indicated significant differences (P<0.05) with saplings subjected to slashing (1.32 cm±0.04) being thinner when compared to those which were subjected spot weeding (1.54 cm±0.64) and both slashing and spot weeding (1.54 cm±0.06). There was no significant difference (P>0.05) between *J. curcas* saplings subjected to spot weeding and both slashing and spot weeding.

Planting densities showed no significant differences ($P>0.05$) on height with 3333 stems/ha recording 16.53 cm±0.39; 2500 stems/ha, 17.24 cm±0.70 and 1333 stems/ha, 17.85 cm±0.35. In terms of RCD, saplings established at 1333 stems/ha (1.57 cm±0.05) were thicker ($P<0.05$) than those established at 3333 stems/ha (1.38 cm±0.05) and 2500 stems/ha (1.36 cm±0.05).

DISCUSSION

Propagation Methods

In spite of the high expenses involved, results on survival percentages achieved by *J. curcas* in this research indicated the necessity of pre-cultivating seedlings in a nursery, prior to transplanting them. The high survival percentages observed on plants established by planting pre-cultivated seedlings were also reported by Kobilke (1989) and Heller (1992). This observation is scientifically sensible because the pre-cultivation of seedlings under closely monitored nursery conditions gives them a physiological advantage over plants established by direct planting of either seed or cuttings. The well developed root system and stem increase the potential to survive water and other stresses. Although the pre-cultivated seedlings were observed to initially lose leaves due to transplantation shock, the roots and stem organs enabled them to quickly develop new leaves thereby increasing chances of survival. Thus, pre-cultivated seedlings easily adapted to the harsh, less controlled field environment than non-rooted cuttings and seed. However, during winter, plants established by planting pre-cultivated seedlings were the most affected, losing their apical meristems to frost, forcing the plants to develop some shoots in response to the loss of apical dominance. This is consistent with observations by Wini *et al*. (2006) and Singh *et al*. (2007) that *J. curcas* cannot withstand frost.

Although the survivals of *J. curcas* propagated through pre-cultivated seedlings surpassed those by non-rooted cuttings and direct seeding, the mortality was high considering the maximum allowed during the first year of plantation establishment. The minimum percentage survival required to avoid blanking costs is 85% compared to 81.42% recorded in this study. The mortality was mainly attributed to frost which attacked the saplings' shoots during winter (Wini *et al*., 2006; Singh *et al*., 2007) and defoliation by mammals, rodents and locusts (Heller, 1992).

Unlike pre-cultivated seedlings, directly planted seed need to germinate and survive the critical, early stages of growth and development which occurs in an unpredictable natural environment characterized by harsh weather conditions and pests and diseases. This partly explains the high mortality observed on *J. curcas* established by direct seeding. Similar results were observed elsewhere (Kobilke, 1989; Heller, 1992; Kureel, 2006; Feike *et al*., 2007). Salisbury and Ross (1992) explained that the period from germination to the time the seedling becomes established as an independent organism constitute the most critical phase in the life history of the plant. During this period, the plant is most susceptible to injury by a wide range of insect pests and parasitic fungi and water stress can prove to be fatal. Direct field observations from this study attributed the high mortality to pests and diseases chief of which were damping off (Heller, 1992; Singh, 1983), defoliation by millipedes (Heller, 1992), locusts (Heller, 1996), termites and rodents (Kar and Das, 1988; Meshram and Joshi, 1994; Biswas *et al*., 2006; Rao, 2006). The high incidence of pests and diseases explains the high vulnerability of the tender, post germinated juvenile plants.

Perry (1980) reported plants established by direct planting of seed to give mixed results on survival. Besides, success in terms of survival percentage has been reported with plants established by direct seeding in Thailand (Sukarin *et al*., 1987). This inconsistence with the findings of this research is reasonable because the method, as explained above, is heavily influenced by critical factors (moisture availability, pests and diseases etc) which if favourable, give high survival percentages and vice-versa. Thus, the intra-specific variation in survival percentages, across agro-ecological regions, was not unusual in view of plants established by the direct planting of seed.

Surprisingly, survival percentages of *J. curcas* established by non-rooted cuttings which are generally thought to have a physiological advantage over plants established through direct seeding (Kobilke, 1989; Heller, 1992) were similarly low. However, cuttings may be argued to have no advantage over directly planted seed because they too need to develop some crucial organs prior to the commencement of growth and development. If the environment is not conducive, cuttings may find it difficult to root and develop shoots. The high mortality observed on plants established by means of non-rooted cuttings was mainly attributed to stem rot caused by high moisture levels and defoliation by locusts and millipedes during the early growth phase (Phillips, 1975; Singh, 1983; Kar and Das, 1988; Heller, 1992; Meshram and Joshi, 1994; Heller, 1996; Biswas *et al*., 2006). These findings agree with Heller (1996) who reported *J. curcas* plants established by non-rooted cuttings to have lower longevity, drought, pest and disease resistance compared to plants propagated by generative means. Additionally, Kureel (2006) reported large scale *J. curcas* mortality in non-rooted cuttings planted during the rainy season. This was attributed to the high moisture levels which promoted fungal infection.

Kobilke (1989) and Heller (1992) reported non-rooted *J. curcas* cuttings to give more than 80 % survivals. The inconsistence with the findings of this research could be a result of a complex interaction of factors among them agro-ecological differences, different cutting morphologies. Unlike the cuttings used in this research which despite being 5 cm thick and 25 cm long recorded low percentage survivals; Thitithanavanich (1985) reported cuttings of 3 cm diameter and 30 cm length to form more roots than those of 1 and 2 cm diameter and 15 cm length. Heller (1996) reported the rooting potential of cuttings to be influenced by the nature of the rooting media, aeration and drainage. Thus, the medium to poor aeration and drainage associated with the soils on the trial site caused water logging, a condition conducive for *Phytophthora spp, Pythium spp* and *Fusarium spp* which caused stem and root rot (Heller, 1992) and contributed to the low survivals recorded for non-rooted cuttings. Further, the anaerobic conditions could have limited aerobic respiration (Salisbury and Ross, 1992) since the cuttings had less or no leaves for oxygen absorption, thus retarding the growth process, culminating in the death of the cuttings. Although not specific, Hartmann and Kester (1983) reported the age of the plant from which cuttings are taken as well as the position of the cutting on the plant to determine rooting and hence survival percentage. This could have impacted less on the survival of cuttings in this research since the cuttings were collected from one year old branches (Heller, 2006; Singh *et al.,* 2007).

The lack of significant differences in $RGR_{h7months}$ and $RGR_{d7months}$responses of pre-cultivated seedlings and direct seeding could be explained by environmental and physiological factors. The loss of the physiological advantage associated with saplings established through pre-cultivated seedlings could be explained by transplanting shock as well as the harsh climatic and edaphic conditions on the field. Transplanting seedlings from the closely monitored nursery to the field, characterized mainly by episodes of moisture deficiency could have significantly lowered the plants' external water potential which could have caused a decrease in cellular growths (Sakurai and Kuraishi, 1988) and thus negatively impacted on $RGR_{h7months}$ and $RGR_{d7months}$ resulting in the lack of significant difference between *J. curcas* established by pre-cultivated seedlings and seedlings. It may be possible that the effect of the transplanting shock was prolonged enough to overshadow the established root system and shoot advantage characteristic of pre-cultivated seedlings.

Planting Densities

Premature to the widely publicized inverse relationship between planting density and tree survival (Lahani, 1980) as well as the one between planting density and growth in height and RCD (Bhatia, 1980; Lohani, 1980; Jamroenpruscksa, 1989; Effendi and Bachtiar, 1994; Nilsson, 1994; Kohani, 1997; Taurins, 1997; Jaeghagen, 1997; Loutfy *et al*., 1998), findings from this research indicated planting density to have no effect on *J. curcas* survival and growth in height and RCD in the first season of establishment mainly because of the lack of intra-specific competition. This is reasonable considering the growth rate of *J. curcas* which in the favourable conditions for instance those of Thailand, is averaged at 1 m in height and 0.75 m crown diameter after 5 months of establishment (Heller, 1996) as well as the planting density treatments which were low enough to avoid canopy closure during the first season of establishment. However, depending on climatic conditions and management prescriptions later in the life cycle of *J. curcas*, canopy closure would suppress and eliminate weaker trees. Until then, none of the three planting densities can be considered ideal for the establishment of a *J. curcas* plantation for seed production in conditions similar to those at Bindura University farm.

Weed Management Techniques

Vegetation management is a routine practice in plantation forests and is essential for achieving high rates of productivity (Richardson, 1993). It has been shown to be critical immediately after plantation establishment, with some researchers reporting substantial growth benefits from weed control (Morris, 1994; Little and Rolando, 2001; South *et al*., 2001; Little and Staden, 2003). In most resource poor developing countries, spot weeding and slashing provide the foundation of weed management wherever intensive plantation management has developed.

In this study, weed management treatments caused the same survival and growth responses although spot weeding and both spot weeding and slashing were expected to give outstanding outcomes compared to slashing (Richardson, 1993; Kyato and Okamoto 2002; Coll *et al*., 2005; Kagombe and Gitanga, 2005). Since spot weeding and slashing liberated *J. curcas* saplings by removing the aboveground weed biomass with slashing leaving 5 cm high stumps, it may be argued that the effect was the same, resulting in the lack of significant differences among the weed management treatments in terms of survival and growth in height and RCD. Thus, the ability of spot weeding to damage the weed's root system was overshadowed by the removal of aboveground biomass and hence had no visible effect on *J. curcas* survival and growth. In support, Schwinning and Weiner (1998) reported aboveground weed competition to strongly affect seedlings than belowground competition hence the lack of significant difference between spot weeding and slashing.

Additionally, the fact that the weed management treatments were prescribed once, basing on financial constraints than on weed re-growth and re-infestation potential could have contributed to the lack of differences among *J. curcas* saplings subjected to spot weeding, slashing and both spot weeding and slashing. This is reasonable considering the fast re-growth vigour associated with *Rottboellia exaltata* which dominated the study site. *Rottboellia exaltata* is characterized by long and horizontally oriented leaf blades which together with the observed high density of the weed shaded the *J. curcas* saplings from sunlight thus negatively impacting on the process of photosynthesis. Thus, the initial effects of the weed management treatments on *J. curcas* survival and growth in height and RCD could have been overshadowed by weed re-growths as the season progressed.

The survival and growth responses of *J. curcas* saplings was not a function of weed management alone but many factors a combination of which could have led to the observed results. Thus, the lack of significant differences among the weed management treatments could be explained by the ability of *J. curcas* to tolerate weed competition as well. In support, Jongschaap *et al*. (2007) reported *J. curcas* to be weed tolerant and to have low nutrient requirements. Basing on the later, it may be argued that the degree of competition after either spot weeding or slashing was low to cause water, nutrient and light deficiencies to affect the *J. curcas* saplings' survivals and growths in height and RCD.

However, unlike the findings of this research, Kyato and Okamoto (2002) and Coll *et al.* (2005), reported trees subjected to spot weeding to achieve better heights and RCDs than those subjected to slashing. This is sound since spot weeding entirely removes the weeds' aerial biomasses unlike slashing which leaves stumps and juvenile weeds below the 5 cm slashing height thus leaving a certain degree of competition for light, water, nutrients and space. Further, spot weeding damages the weeds' root systems thus reducing root competition compared to slashing. Wilson (1988), Parker *et al*. (1993), Gerry and Wilson (1995), Weiner *et al*. (1997), Davis *et al*. (1999), and Rikala and Sajala (2002) reported root competition to have a greater impact than shoot competition on the survival and growth of saplings since the roots of both the tree crop and weeds particularly grass and shrubs use water and nutrients from the same layers. Casper and Jackson (1997) reported belowground competition to cause water and mineral nutrient deficiencies to saplings.

CONCLUSION

From this study, pre-cultivated seedlings can be concluded to be the ideal method for establishing *J. curcas* plantations compared to non-rooted cuttings and direct seeding in agro-ecological conditions similar to those of Bindura University farm. The study demonstrated *J. curcas* planting density treatments to have no effect on the survival and growth of saplings during the first season of establishment. Data to be collected in future may help determine the most ideal planting density. As for weed management, the results indicated spot weeding, slashing and both spot weeding and slashing to have the same effect on *J. curcas* survival and growth in height and RCD.

REFERENCES

Agaceta, L.M., Dumag, P.U. and Batolos, J.A. (1981). Studies on control of snail vectors of fascioliasis: Molluscicidal activity of some indigenous plants. *NSDB Technology Journal; Abstracts on Tropical Agriculture 6:2:30-34.*

Balderrama, S.I.V. and Chazdon, R.C. (2005). Light-dependent seedling survival and growth of four tree species in Costa Rican second-growth rain forests. *Journal of Tropical Ecology 21: 383-395.*

Bhatia, K.S. (1980). The growth of Eucalyptus hybrid on eroded alluvial soils of Uttah Pradesh in relation to spacing, irrigation and manuring. *Indian Forester 106(10): 738-743.*

Biswas, S., Kaushik, N. and Srikanth, G. (2006). Biodiesel : Technology and Business Opportunities – An Insight. Papers presented at the Biodiesel Conference Towards Energy Independence – Focus on *Jatropha,* Rashtrapati Nilayam, Bolaram, Hyderabad, India.

Casper, B.B. and Jackson, R.B. (1997). Plant competition underground. *Annu Rev Ecol Syst 28: 545–570.*

Coll, L., Messier, C., Delagrange, S. and Berninger, F. (2005). Effect of different vegetation control techniques on hybrid poplar development in plantations establishment on previously logged forest sites. Paper presented on the Fifth International Conference on Forest Vegetation Management, Oregon, USA.

Correll, D.S. and. Correll, H.B. (1982). Flora of the Bahama Archipelago. *J. Cramer, Vaduz.18: 567-578.*

Davis, M.A., Wrage, K.J., Reich, P.B., Tjoelker, M.G., Schaeffer, T. and Muermann, C. (1999). Survival, growth and photosynthesis of tree seedlings competing with herbaceous vegetation along a water-light-nitrogen gradient. *Plant Ecol 145: 341–350*.

Effendi, R. and Bachtiar, A. (1994). The influence of spacing against the diameter and tree height growth of bakau (Rhizophora apiculata) in Tembilahan, Riau. Bulletin Penelitian Hutan. *Forest Reseach Bulletin no. 540: 35-44.*

Feike, T., Weis, K., Claupein, W. and Mueller, J. (2007). Propagation of physic nut (*Jatropha curcas* L.) on Leyte Island, Philippines. Conference contribution, Tropentag, Witzenhausen, Germany.

Gerry, A.K. and Wilson, S.D. (1995). The influence of initial size on the competitive responses of six plant species. *Ecology 76: 272–279.*

Grimm, C. (1996). The Jatropha project in Nicaragua. Bagani Tulu (Mali) 1: 10-14.

Hartmann, H.T. and Kester, D.E. (1983). Plant Propagation. Principles and Practices. 4th edition. Prentice-Hall Inc., Englewood Cliffs.

Heller, J. (1992). Studies on genotypic characteristics and propagation and cultivation methods for physic nuts (*Jatropha curcas* L.)]. Kovac, Hamburg.

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.

Henning, R.K. (2000). *The Jatropha Booklet*. A Guide to the Jatropha System and its Dissemination in Zambia. GTZ-ASIP Support Project Southern Province. Bagani GbR.

Henning R.K. (2008). Jatropha curcas L. in Africa. An evaluation. Global Facilitation Unit for Underutilised Species (GFUUS), Weissensberg, Germany.

Jaeghagen, K. (1997). Impact of competition on survival, growth and tree characteristics of young conifers. Umeaa (Sweden). SLU. p 29.

Jamroenprucksa, K. (1989). Effect of thinning on growth and production of poplar under intensive management. *Lesnictvi-UZPI (Czech Republic) vol. 43(8): 203- 215.*

Jepsen, J..K., Henning, R.K. and Nyati, B. (2006). Generative propagation of *Jatropha curcas* L. on Kalahari Sand. Environment Africa. Zimbabwe

Jongschaap, R.E.E., Corre, W.J., Bindraban, P.S. and Brandenburg, W.A. (2007). Claims and facts on Jatropha curcas. Global Jatropha curcas evaluation, breeding and propagation programme. Plant Research International Report 158, Wageningen, The Netherlands.

Kagombe, J.K. and Gitonga, J. (2005). Plantation establishment in Kenya. The Shamba system case study. Kenya Forests Working Group, Nairobi, Kenya.

Kar, A.K. and Das, A. (1988). New records of fungi from India. *Indian Phytopathol. 41(3):505.*

Kobilke, H. (1989). *Jatropha curcas* a promising agroforestry crop. Shree Offset Press, Nashik.

Kureel, R.S. (2006). Prospects and Potential of *Jatropha Curcas* for Biodiesel Production. Papers presented at the Biodiesel Conference Towards Energy Independence – Focus on *Jatropha,* Rashtrapati Nilayam, Bolaram, Hyderabad, India.

Kyato, E. and Okamoto, K. (2002). Effects of different weeding techniques on the survival of selected tree species in arid and semi-arid lands. Kenya Forestry Research Institute (KEFRI), Nairobi, Kenya.

Leon, J. (1987). Botanica de los cultivos tropicales. Instituto Interamericano de Cooperacionpara la Agricultura, San José, Costa Rica.

Liang, Y., Chen, H., Tang, M.J., Yang, P.F. and Shen, S.H. (2007). Responses of *Jatropha curcas* seedlings to cold stress: photosynthesis-related proteins and chlorophyll fluorescence characteristics. *Physiologia Plantarum 131: 508–517.*

Little, K.M. and Rolando, C.A. (2001). The impact of vegetation control on the establishment of pine at four sites in the summer rainfall region of South Africa. *South. Afr. For. J. 192 , 31 – 40*.

Little, K.M. and Staden, J. (2003). Inter-specific competition affects early growth of a *Eucalyptus grandis* × *E. camaldulensis* hybrid clone in Zululand, South Africa. *S. Afr. J. Bot. 69 , 505 – 513.*

Lohani, D.N. (1980). Studies on spacing of Eucalyptus plantations. Uttah Pradesh Department Bulletin No 42, Research and Development Circle, Uttah Pradesh, India.

Loutfy, I., Juhany, E. and Aref, I.M. (1998). Spacing effects on relative growth rates of height, diameter and biomass production of Leucaena leucocephala (Lam .) before and after pruning.King Saudi University, Saudi Arabia.

Mabberley, D..J. (1987). The Plant Book. Cambridge University Press, Cambridge.

Makkar, H.P.S., Becker, K. and Schmook, B. (2001). Edible provenances of Jatropha curcas from Quintna Roo state of Mexico and effect of roasting on antinutrient and toxic factors in seeds. Institute for Animal Production in the Tropics and Subtropics (480), University of Hohenheim, Stuttgart, Germany.

Meshram, P.B. and Joshi, K.C. (1994). A new report of *Spodoptera litura* (Fab.) Boursin (Lepidoptera: Noctuidae) as a pest of *Jatropha curcas* Linn. *Indian Forester 120(3):273-274.*

Morris, A. (1994). Species × weeding × fertilizer interaction: results at five years. *Forest* Research Document 15/94, Usutu Pulp Co., Swaziland.

Morton, J..F. (1981). Atlas of medicinal plants of Middle America. Bahamas to Yucatan. C.C. Thomas, Springfield.

Nilsson, U. (1994). Development of growth and stand structure in Picea abies stands planted at different initial densities. *Scandinavian J. of Forest Research, vol. 9(2): 135-142.*

Ochse, J.J. (1931). Vegetables of the Dutch East Indices. Reprinted 1980. Asher and Co, Amsterdam.

Parker, M.L., Hull, J. and Perry, R.L. (1993). Orchard floor management effects on peach rooting. *J Amer Soc Hort Sci 118: 714-718.*

Perry, L.M. (1980). Medicinal plants of east and south-east Asia: attributed properties and uses. MIT Press, South East Asia.

Phillips, S. (1975). A new record of *Pestalotiopsis versicolor* on the leaves of *Jatropha curcas*. *Indian Phytopathol 28 (4):546.*

Pratt, J.H., Henry, E.M.T., Mbeza, H.F., Mlaka, E. and Satali, L.B. (2002). Malawi Agroforestry Extension Project Marketing & Enterprise Program Main Report. Publication No. 47. Malawi Agroforestry.

Rao, V.R. (2006). The *Jatropha* Hype : Promise and Performance. Papers presented at the Biodiesel Conference Towards Energy Independence – Focus on *Jatropha,* Rashtrapati Nilayam, Bolaram, Hyderabad, India.

Rehm, S. and Espig, G. (1991). The cultivated plants of the Tropics and Subtropics. Verlag Josef Margraf, Weikersheim.

Richardson, B. (1993). Vegetation management practices in plantation forests of Australia and New Zealand. *Can. J. For. Res. 23 , 1989 – 2005.*

Rikala, R. and Sarjala, T. (2002). Tree-cover crop interactions: Birch growth, competition and soil properties. 0ulu University Press.

Sakurai, N. and Kuraishi, S. (1988). Water potential and mechanical properties of the cell wall of hypocotyls of dark-grown squash under water stress conditions. *Plant Cell Physiol. 29(8): 1337-1343.*

Salisbury, F.B. and Ross, C.W. (1992). Plant Physiology. 4th Edition, Wadsworth Publishing Company, Belmont, California.

Schwinning, S. and Weiner, J. (1998). Mechanisms determining the degree of size asymmetry in competition among plants. *Oecologia 113: 447-455.*

Singh, RA., Munish, K. and Haider, E. (2007). Synergistic cropping of summer groundnut with Jatropha curcas. A new two-tier cropping system for Uttar Pradesh. *ICRISAT journal 5(1): 1-2.*

Singh, I.D. (1983). New leaf spot diseases of two medicinal plants. *Madras Agric. J. 70(7):490.*

South, D.B., Zwolinski, J.B. and Kotze, H. (2001). Early growth responses from weed control and planting larger stock of *Pinus radiata* are greater than that obtained from mechanical soil cultivation. *NewForests 22 , 199 – 211.*

Sukarin, W., Yamada, Y., and Sakaguchi, S. (1987). Characteristics of physic nut, Jatropha curcas L. as a new biomass crop in the Tropics. *Jpn. Agric. Res. Quart. (Japan) 20(4):302-303.*

Taurins, J. (1997). Development of scotch pine growth and spatial increase in stands of different initial density. The agricultural science on the way to the 21 century. P 124-126.

Tewari, J.P. and Shukla, I.K. (1982). Inhibition of infectivity of two strains of watermelon mosaic virus by latex of some angiosperms. *Geobios. (Jodhpur, India), 9(3): 124-126.*

Thitithanavanich, B. (1985). The effect of diameter and length of stem-cuttings on root production of physic nut (*Jatropha curcas* L.) in Thailand. Kasetsart University, Bangkok, Thailand.

Tigere, T.A., Gatsi, T.C., Mudita, I.I., Chikuvire, T.J., Thamangani, S., and Mavunganidze, Z.(2006). Potential of Jatropha curcas in improving smallholder farmers' livelihoods in Zimbabwe. An exploratory study of Makosa ward, Mutoko District. *J Sus Dev Africa*

Weiner, J., Wright, D.B and Castro, S. (1997). Symmetry of below-ground competition between *Kochia scoparia* individuals. *Oikos 79: 85–91*.

Wilson, J.B. (1988). Shoot competition and root competition. *J Appl Ecol 25: 279–296*.

Wini, S.P., Osman, M., Emmanuel, D.S., and Sreedevi., T.K. (2006). Improved livelihoods and environmental protection through biodiesel plantations in Asia. *Asian Biotechnology and Development Review 8(2): 11-29*.