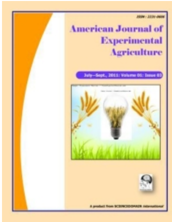


American Journal of Experimental Agriculture
4(1): 101-113, 2014

SCIENCEDOMAIN *international*
www.sciencedomain.org

Performance of Maize and Beans under Castor-based Intercropping System

Charles Obiero[1*], Rhoda Birech[1], Joyce Maling'a[2], Kibet Ngetich[3] and Bernhard Freyer[4]

[1]Department of Crops, Horticulture and Soil Science, Egerton University, P. O. Box 536 - 20115, Egerton, Kenya.
[2]Kenya Agricultural Research Institute (KARI – Kakamega), P. O. Box Private Bag, Kakamega, Kenya.
[3]Department of Peace, Security and Social Studies, Egerton University, P.O. Box 536 – 20115, Egerton, Kenya.
[4]University of Natural Resources and Life Sciences (BOKU), Division of Organic Farming, Gregor Mendel Straße 33, 1180 Vienna, Austria.

Authors' contributions

Author CO designed the study, laid and monitored the field experiment, collected data, performed the statistical analysis and wrote the first draft of the manuscript under the supervision of authors RB, JM and KN. Author BF through the PROBIOFUEL Project financed all the field experiment and proof red the draft. In addition all authors read and approved the final manuscript.

Research Article

Received 12th July 2013
Accepted 21st August 2013
Published 24th October 2013

ABSTRACT

Castor (*Ricinus communis* L.) has attracted a lot of attention all over the world as a potential crop targeting on-farm biofuel production. In Kenya smallholder farmers are already growing castor with maize (*Zea mays* L.) and beans (*Phaseolus vulgaris* L.) under an intercrop system in spite of the limited knowledge that such a system would have on growth and yield. The aim of this research was to investigate the possible effect of castor-based intercropping system on the performance of maize and beans. A 3 × 3 × 2 factorial experiment randomized in complete block design with three levels of crops, three levels of cropping system and two levels of spacing was laid-out at Egerton University farm, Njoro campus; for three seasons in 2010 to 2012. Results at *P* =.0001 level of significance indicated high seed yield for castor monocrops ranging from 2.0 - 3.0 tons seeds ha^{-1} yr^{-1}

**Corresponding author: Email: otycha@gmail.com;*

while castor with beans intercrop were shown as the best intercrop combination with resultant yields levels reported in the range of 2.15 - 2.43 and 0.3 - 0.83 tons seeds ha^{-1} yr^{-1} for an intercrop of castor (1.5 m × 1.0 m) with beans (0.5 m × 0.2 m) respectively. In contrast, castor with maize intercrop gave low maize grain yield of between 0.0 – 0.25 tons ha^{-1} yr^{-1}. It was concluded that castor could be grown successfully with beans without straining food crop production. In addition an intercrop of castor with maize and beans would not have significant effect on the yield performance of castor.

Keywords: Biofuel; cropping system; productivity; seed yield; smallholder farmer; spacing.

ABBREVIATIONS

ANOVA – Analysis of variance
CAN – Calcium ammonium nitrate
DAP – Di-ammonium phosphate
DAS – Days after sowing
DMRT – Duncan multiple range test
LER – Land equivalent ratio
LH3 – Lower highland zone III
RCBD – Randomized complete block design

1. INTRODUCTION

Castor (*Ricinus communis* L.) is a wild shrub from the Euphorbiaceous family and has been shown to appear in many farming systems of the world [1,2]. This crop grows widely and wildly from high, medium to low rainfall areas with reports indicating that arable sites under high altitude areas generally record high seed yield per tree [3]. The oil is the most important product of this plant and has been reported to have several industrial applications varying from aviation lubricant, biofuel and medicinal properties; moreover, there have been reports that ricin, a poisonous protein from the seeds of castor, having been used for terrorism and suicide attacks [4]. Currently, castor is under investigation as a potential biofuel crop with records showing seed yield of 1.2 tons ha^{-1} yr^{-1} but can reach up to 1.8 tons ha^{-1} under irrigation [5,6]. The seed oil content has been documented to be between 36.6 - 53.85% with potentials of up to 3.0 tons oil ha^{-1} yr^{-1} under good management. The crop has been described as a high yielding biodiesel plant as compared to either croton (*Croton megalocarpus* L.) or jatropha (*Jatropha curcas* L.). For instance, reports show that croton yield's up to 3.6 tons seeds ha^{-1} yr^{-1} with seed oil content of 30 - 32% contributing to about 1.2 tons oil ha^{-1} yr^{-1} while jatropha has been documented to have seed oil content of between 35 - 40% giving about 0.404 ton oil ha^{-1} yr^{-1} .

In tackling the endeavor issue of food situation and energy crisis in several parts of the world, most research is currently focused on biofuel-based cropping system. It is worth noting that cereal-legume intercropping has been shown to play a significant role in the smallholder farmers subsistence food production in both developing and developed countries [7,8]; therefore by integrating non edible biofuel crops into these cropping systems it would be imperatively significant not to impact negatively on the productivity of these food crops whose yields have also been shown to be on the decline. For instance, in India, castor has been grown successfully and profitably with crops such as cluster bean, groundnuts, pigeon pea, Indian bean, cucumber, Calliandra, cassia, chick pea, finger millet with the objective of increasing the productivity of the land and provision of food and fodder [9]. In Kenya, however, castor had been grown commercially since 1910 but this production witnessed a major decline in 1980s due to poor marketing [10]. The country had also placed low priority on researching on castor a condition which contributed to the low and varied yield of this crop and other biofuel crops [11]. It is, however, noted that with the current campaigns, smallholder farmers are rapidly embracing on-farm biofuel production against limited information on the resultant crop yields. Therefore it was worth investigating the possible effect of castor-based intercropping system. The objective of this study was to determine the effect of intercropping castor with maize and beans on growth and yield. It was hypothesized that intercropping castor with maize and beans had no significant effect on growth and yield.

2. MATERIALS AND METHODS

2.1 Site Description

Egerton University farm is at an elevation of 2238 m above sea level and located on latitude $0^{o}23'$S and longitude $35^{o}56'$E. It receives an average rainfall of 1012 mm annually with 60% reliability of 908 mm. The site has a mean temperature of 14.7^{o}C with minimum and maximum temperatures of 8.5^{o}C of 21.0^{o}C respectively. The area is under the Agro-ecological zone of LH3 which is described as wheat and barley zone. The soils are well drained, silty clay to clay with humic top soil (Mollic Andosols) with pH of 5.5 - 6.5 [12].

2.2 Description of Materials

Materials were seeds for castor (*Ricinus communis* cv. Zanzi palm), maize (*Zea mays* cv. H513D) and beans (*Phaseolus vulgaris* cv. Rose Coco) respectively. Di-Ammonium Phosphate (DAP) (18:46) and Calcium Ammonium Nitrate (CAN) (26% N) fertilizers, SC-1 leaf porometer for stomatal conductance, leaf chlorophyll meter (CCM-200), Stanton weighing balance for weight determination and a tape measure for plant height determination.

2.3 Treatment Description

A 3 × 3 × 2 factorial experiment consisting of three levels of crops (castor, maize and beans), three levels cropping systems (sole cropping for all crops, intercrop combinations of castor-beans, castor-maize and maize-beans; and castor-maize-beans intercrop combination); and two levels of spacing for each crop i.e. high and low levels, for “low” level of spacing 1.5 m × 1.0 m, 0.5 m × 2.0 m and 0.75 m × 0.3 m while 1.8 m × 1.0 m, 0.6 m × 0.2 m and 0.9 m × 0.3 m were used as the “high” spacing for castor, beans and maize respectively. The experiment was laid in randomized complete block design (RCBD) replicated three times in plots of 9 m x 4 m for three seasons beginning May, 2010 to December 2012.

2.4 Cultural Practices

The experimental field received an initial disc plough followed by a disc harrow and manual raking and removal of the grass. Castor seedlings were transplanted from the nursery at a height of 0.15 m in May, 2010. Maize and beans were then sown into already established castor plants (in 2011 and 2012); at two seeds per hole which were later thinned to one seedling per hill at 14 DAS (days after sowing). DAP (18.46.0) (Di-ammonium phosphate) fertilizer was used at planting at the beginning of each season to supply nitrogen and phosphorus at the rate of 33 kg N ha^{-1} and 42.2 kg P_2O_5 ha^{-1} respectively. Calcium ammonium nitrate (26% N) fertilizer at the rate of 188 kg ha^{-1} for each season was used to top dress maize at knee high. Two manual weeding was done at 21 and 45 DAS. Data on plant height, stomatal conductance, leaf chlorophyll content and leaf area was determined at 21, 42, 63 and 84 DAS. Harvesting and threshing were done manually and hundred mean seed weight determined through an electronic weigh balance (Stanton).

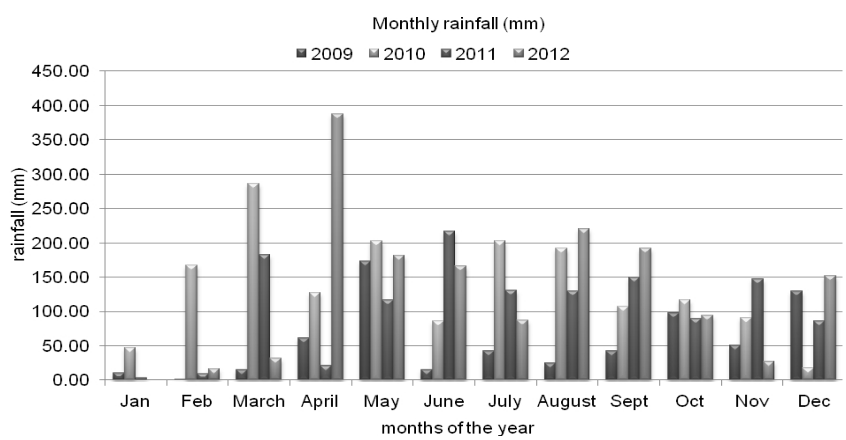
2.5 Data Analysis

The data was subjected to analysis of variance (ANOVA) by SAS/STAT in release 9.2 for windows and means separated through Duncan's Multiple Range Test (DMRT).

3. RESULTS AND DISCUSSION

3.1 Rainfall (mm)

During the three year period of the experiment the area received an average monthly rainfall of 107.13 mm $month^{-1}$ with much of the rains experienced in 2010 and 2012 as compared to 2009 and 2011. Furthermore, an average of 1599.2 mm rainfall was recorded for 2011 and 2012 combined compared to 972 mm for 2009 and 2010 while the year 2009 recorded the lowest total annual rainfall (663.7 mm). It was also evident that most of the rains were received between March and September with the wettest months showed as May to August (Fig. 1). Generally, it was observed that the region experienced a bimodal pattern of rainfall with March to September notably as the main cropping season.



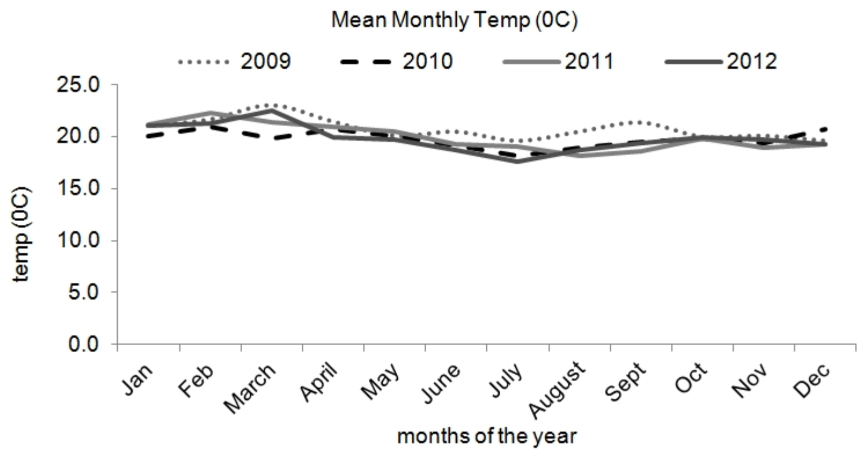
1

Fig. 1. Monthly mean rainfall figures for 2009 to 2012

[1] *Data collected from Egerton University weather station No. 9035092 Lat 00^0 23'S Long $35^°$ 55'E for 2009-2012*

3.2 Temperature (°C)

Mean monthly temperature ranged from 17.6 °C to 23.1 °C with reports indicating 2009 as the hottest year. Temperature means above 20 °C were recorded between January and May while June to September showed temperature below 20 °C (Fig. 2).



2

Fig. 2. Mean monthly temperature for Egerton University weather station for 2009 - 2012

The information on rainfall and temperature is imperatively important considering timely planting and choice of adapted cultivars. Time of planting which generally corresponds to the onset of the rains especially for rainfed agriculture has been found to significantly influence crop yield [13]. Therefore, is it important that within this region planting be done around mid April, however, as a result of the prolonged rains that persisted until September, some losses were reported in beans. The reduction in ambient temperature recorded during the critical growth period accounted for the long growing season witnessed especially in the maize crop. However, castor remained unaffected by these factors. The crop shaded most of the leaves during the dry spells between January to March with resumption of an active growth and nut production the rainy season.

3.3 Plant Height (m)

Results on plant height (Table 1) indicated significant differences between seasons, treatments and crops at *P* = .0001 level of probability. It was observed that individual monocrops of castor, maize and beans recorded heights of 0.428 m, 0.126 m and 0.040 m respectively while castor with maize intercrop reported relatively tall castor plants (0.334 – 0.426 m) with significantly dwarfed maize crop (0.035 – 0.036 m) especially in the first season. This could be attributed to the influence of a strong castor canopy that prevented the maize crop from accessing the light. Furthermore, a general expectation would have been an increase in the plant height of beans as a result of crowding and competition of light but these results do not conform to such an expectation, probably because the bean population at which inter-specific competition for light becomes limiting may not have been

[2] *Data collected from Egerton University weather station No. 9035092 Lat 00° 23'S Long 35° 55'E for 2009-2012*

reached and also the growth habits for the three crop species were different. It was also showed that neither maize nor beans had any significant effect on the plant height of castor with results indicating that none of the spacing had any significant effect on the plant height. It was observed that the significantly tall castor plants could hamper harvesting of the nuts and as such an improvised home-made ladder was used in this process.

3.4 Stomatal Conductance (mmol m^{-2} s^{-1})

Leaf stomatal conductance was shown to be unique for the different planting patterns at P = .0001 level of significance (Table 1). Castor at 1.5 m × 1 m with beans at 0.6 m × 0.2 m intercrop recorded high values for the leaf stomatal conductance ranging from 102.4 – 115.8 and 69.8 – 119.9 mmol m^{-2} s^{-1} for castor and beans respectively. In contrast, maize grown under castor showed low levels of stomatal conductance of in the range of 42 – 67 mmol m^{-2} s^{-1} in the first season. It has been reported that high levels for leaf stomatal conductance especially under unlimited moisture supply correlates very well with high photosynthetic rate and the resultant high crop yield. These findings could support the resultant low performance in maize which had been exposed to stiff competition for light especially under castor-maize and castor-maize-beans intercropping systems. Miko [14] also noted that high stomatal conductance could be advantageous in allowing a faster induction and higher carbon gain during sun flecks or under strong canopies thereby maintaining a higher quantum yield because of the greater intercellular partial pressures of CO_2. This was observed on beans planted under castor that had no significant yield from the corresponding monocrops.

3.5 Chlorophyll Fluorescence

Results on chlorophyll fluorescence for the different crop species and planting patterns (Table 2) were in line with those recorded for carbon (4) oxide assimilation (Table 1). All crops reported significant (α =.05) high values for the mean leaf chlorophyll content in the first season (30.3) compared to the second season (27.8) with these results further indicating castor as recording high mean value (46.03) for the mean leaf chlorophyll content followed by beans (22.50) and maize (18.77). The first season maize grown under castor recorded generally low chlorophyll fluorescence which could have negatively influenced the crop's electron transfer capacity and carbon assimilations thereby exposing the crop to low photosynthetic capacity response leading to the poor performance of the crop. However, none of the crop spacing had any significant effect on the leaf chlorophyll fluorescence. Earlier experiments have linked leaf chlorophyll fluoresces to the expansion of the leaf mass area [15]. Marini and Sowers [16] also showed that shaded leaves usually have low net photosynthetic rate prompting that the two factors noted above may have had an effect on the general productivity maize.

Table 1. Effect of different planting patterns on planting height and leaf stomatal conductance of castor, maize and beans

Planting patterns	Plant Height (m)						Stomatal Conductance (mmol m^{-2} s^{-1})					
	Castor		Beans		Maize		Castor		Beans		Maize	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Planting pattern 1 (sole cropping)												
CL	3.64a	4.17b	.	.	.	.	91.6a	129.7b	.	.	.	.
CH	3.40a	4.28b	.	.	.	.	102.4a	118.5b	.	.	.	.
ML	.	.	.	.	0.95c	1.01c	.	.	.	.	56.6de	74.3bc
MH	.	.	.	.	1.26c	1.06c	.	.	.	.	37.1de	63.7d
BL	.	.	0.22f	0.40e	.	.	.	.	52.6de	77.7bc	.	.
BH	.	.	0.23f	0.40e	.	.	.	.	53.5de	76.1bc	.	.
Planting pattern 2 (intercropping)												
BLML	.	.	0.26f	0.42e	1.37c	1.07c	.	.	44.8de	84.4bc	57.4de	81.1bc
BHMH	.	.	0.25f	0.40e	1.14c	1.03c	.	.	69.4d	87.5bc	86.1bc	81.8bc
BLMH	.	.	0.23f	0.37e	0.87c	1.00c	.	.	63.0d	78.5bc	64.7d	86.5bc
BHML	.	.	0.22f	0.41e	0.99c	1.06c	.	.	61.4d	82.2bc	55de	70.9bc
CLBL	3.37a	4.0b	0.28f	0.43e	.	.	102.4a	115.8b	69.8d	119.9b	.	.
CLBH	3.30a	4.06b	0.25f	0.39e	.	.	108.6a	129.3b	64.8d	146.0b	.	.
CHBL	3.44a	4.13b	0.26f	0.37e	.	.	91.1a	103.7b	76.8bc	95.6b	.	.
CHBH	3.31a	4.05b	0.26f	0.41e	.	.	97.8a	142.5b	69.6d	110.1b	.	.
CLML	3.63a	3.96b	.	.	0.38d	1.02c	87.0a	112.7b	.	.	42.1de	65.3d
CLMH	3.50a	3.97b	.	.	0.39d	95.6c	89.9a	119.7b	.	.	52.3de	94.8b
CHML	3.34a	4.24b	.	.	0.56d	0.99c	93.6a	108.1b	.	.	67.2d	77.4bc
CHMH	3.34a	4.21b	.	.	0.35d	1.05c	89.0a	121.1b	.	.	46.3de	71.3bc
Planting pattern 3 (intercropping)												
CLBLML	3.53a	3.97b	0.24f	0.37e	0.38d	0.98c	77.1a	97.2b	54.3de	90.9b	48.1de	62.2d
CLBHMH	3.29a	4.17b	0.21f	0.44e	0.39d	1.07c	94.4a	102b	54.5de	119.8b	51de	105.0b
CHBLML	3.37a	4.09b	0.22f	0.39e	0.29d	1.00c	84.4a	160.7b	55.7de	150.2b	45.1de	83.0bc
CHBHMH	3.41a	3.95b	0.23f	0.37e	0.35d	0.99c	107.0a	122.7b	52.1de	121.1b	45.4de	81.2bc
CLBLMH	3.50a	4.192b	0.24f	0.37e	0.40d	0.87c	82.1a	75.0a	54.6de	75.6bc	54de	65.3d
CLBHML	3.52a	4.207b	0.19f	0.43e	0.40d	1.06c	85.9a	79.0a	53.2de	98.5b	44.3de	69.9d

Means with the same letters are not significantly different at P = .0001

CL=1.5 m × 1.0 m; CH = 1.8 m × 1.0 m; BL=0.5 m × 0.2 m; BH = 0.6 m × 0.2 m; ML = 0.75 m × 0.3 m; MH = 0.9 m × 0.3 m

3.6 Leaf Area (m^2)

Results on the different seasons, crops and planting patterns showed significant (P =.0001) effect on the leaf area (Table 2). However, there was no significant different between the different spacing used. The second season showed high values for the mean leaf area (94.98) compared to the first season (36.67) at LSD $_{0.05}$ 6.56. These results further indicated significant leaf area reduction in the first season-maize; with castor-maize or castor-maize-beans intercrops recording mean leaf area ranging from 28.5 – 59.9 compared to sole maize or maize-beans intercrop (83.5 – 112.5). In contrast, no planting pattern had any significant effect on the leaf area expansion of beans with the mean values reported lower than those of maize at all planting patterns and seasons. In an earlier experimental report, Rwamugira [17] indicated that intercropping and plant density reduced the leaf area of both pigeon peas and maize, results which might confirm the limited performance of maize under castor intercrop. However, in other results, Njoku and Muoneke [18] showed that cowpea planting density increased the leaf area index of cowpea (a legume), sentiments which might contrast with these findings especially on the beans in which none of the spacing had an effect on the leaf area expansion.

3.7 Mean seed weight (gm) and yield (tons ha^{-1})

A hundred seed mean weight analyzed indicated unique differences (P = .0001) in the productivity of the different planting patterns (Table 3). The different planting patterns recorded significant effect on the seed mean weight of maize (in the first season) with no seeds weight (0 gm) reported for the maize crop under castor-maize-beans intercrop while castor-maize recorded 12.6 – 18.6 gm compared to 28 – 32 gm and 26 – 28 gm for maize-beans and maize sole crop respectively. In general, maize had high performance under maize-bean intercrop and worst in either castor-maize or castor-maize-beans intercrop. In contrast, the different planting patterns had no significant effect on the mean seed weight of castor and beans which recorded figures ranging from 37.0 – 56.6 gm and 51.6 – 60.9 gm for castor and beans respectively.

An intercrop of castor at 1.5 m × 1 m with beans at (0.5 m × 0.2 m) showed the best cropping system recording seed yields ranging from 2.15 - 2.43 tons seeds ha^{-1} yr^{-1} and 0.616 - 0.760 tons seeds ha^{-1} yr^{-1} for castor and beans respectively (Table 4). Relatively high land equivalent ratio of 2.34 was reported for this system compared to 0.98 for castor-maize intercrop. This concurs with earlier research assertions that castor and legumes provide best intercrop combination. Sharath [19] also reported higher castor seed yield when intercropped with legumes compared to non leguminous crops. He noted that the high yield of castor could have resulted from the translocation of biologically fixed nitrogen by the legumes towards the roots of castor; sentiments which had been noted earlier by Mavarkar [20] and Leelarani [21].

Table 2. Effect of the different planting patterns on the leaf florescence and area of castor, maize and beans

Planting patterns	Chlorophyll Fluorescence						Leaf area (m^2)			
	Castor		Beans		Maize		Maize		Beans	
	2011	2012	2011	2011	2012	2011	2011	2012	2011	2012
Planting pattern 1 (sole cropping)										
CL	51.1a	42.5b	.	.	.	.	-	-	-	-
CH	55.7a	43.3b	.	.	.	.	-	-	-	-
ML	.	.	.	.	15.7h	21.5g	-	-	88.9a	14.2c
MH	.	.	.	.	21.1j	20.7g	-	-	108.4a	17.3c
BL	.	.	25.8e	25.3c	.	.	10.7d	8.5de	-	-
BH	.	.	24.0e	23.1c	.	.	11.2d	8.4de	-	-
Planting pattern 2 (Intercropping)										
BLML	.	.	22.4e	25.3c	18.8h	20.3g	12.3d	8.5de	102.4a	14.0c
BHMH	.	.	22.5e	25.7c	18.6h	20g	11.6d	8.7de	89.3a	17.5c
BLMH	.	.	24.2e	22.9c	18.6h	22.4g	10.0d	9.0d	112.5a	14.6c
BHML	.	.	22.6e	23.5c	15.9h	21.2g	10.8d	10.2d	83.4a	17.6c
CLBL	49.5a	44.6b	21.6f	24.6d	.	.	9.72d	9.9d	-	-
CLBH	54.4a	37.0b	19.9f	25.4d	.	.	10.9d	11.1d	-	-
CHBL	48.1a	42.3b	21.7f	20.8d	.	.	11.5d	10.1d	-	-
CHBH	52.2a	35.6b	19.6f	24.0d	.	.	11.7d	10.2d	-	-
CLML	53.7a	38.7b	.	.	14.9h	20.3g	-	-	38.2b	14.2c
CLMH	54.2a	36.7b	.	.	17.2h	20.5g	-	-	24.1b	13.8c
CHML	53.5a	37.8b	.	.	14.2h	19.1g	-	-	50.3b	13.3c
CHMH	56.2a	38.7b	.	.	15.0h	19.7g	-	-	57.7b	15.5c
Planting pattern 3 (Intercropping)										
CLBLML	54.4a	41.1b	19.1f	24d	18.2h	18.3g	9.3d	10.6d	59.8b	13.3c
CLBHMH	50.8a	41.7b	19.4f	23.6d	19.6h	20.4g	8.7d	9.5d	43.0b	16.6c
CHBLML	50.2a	40.8b	19.8f	20.6d	19.9h	21.6g	10.9d	10.0d	28.5b	16.1c
CHBHMH	52.4a	38.6b	16.7f	22d	18.6h	21.0g	9.5d	10.1d	47.7b	13.7c
CLBLMH	52a	39.4b	21.9f	20.3d	16.8h	17.7g	9.7d	12.0d	32.4b	12.1c
CLBHML	46.4a	38.3b	19.6f	24.36d	14.0h	17.2g	10.1d	10.7d	37.2b	15.5c

Means with the same letters are not significantly different at P = .0001

CL=1.5 m × 1.0 m; CH = 1.8 m × 1.0 m; BL=0.5 m × 0.2 m; BH = 0.6 m × 0.2 m; ML = 0.75 m × 0.3 m; MH = 0.9 m × 0.3 m

Furthermore, higher castor equivalent yield has been reported under paired row intercropping system with cluster bean; which had increased productivity and net profit, results which supported earlier findings [22]. Castor had, however, showed similar performance across all the treatments; with castor monocrops at 1.5 m × 1.0 m and 1.8 m × 1.0 m giving seed yields in the range of 1.85 – 3.5 tons ha^{-1} yr^{-1}. Moreover, these results showed that individual crop yields were significantly different, with castor recording higher seed yield compared to either maize or beans. However, an intercrop of castor with maize showed significantly low seed yields in maize ranging from 0 – 0.25 tons seeds ha^{-1} yr^{-1} especially in the first season. This could have been as a result of the stiff competition for sunlight experienced by the maize crop sown under a strong castor canopy. In contrast, the second season recorded up to 3.48 tons seeds ha^{-1} yr^{-1} for maize due to the significantly reduced shading from castor. These findings correspond to those made earlier with reports indicating higher seed yield of castor under intercropping with legumes as compared to non legumes [23].

Table 3. Effect of different planting patterns on leaf chlorophyll content and the hundred seed mean weight (gm) of castor, maize and beans

Planting Patterns	Hundred Seed Mean Weight (gm)					
	Castor		Beans		Maize	
	2011	2012	2011	2012	2011	2012
Planting pattern 1 (sole cropping)						
CL	57.3a	56.5a	.	.	.	.
CH	52.5a	51.6a	.	.	.	.
ML	.	.	.	.	26.0e	36.8d
MH	.	.	.	.	28.2e	36.7d
BL	.	.	43.4c	52.1b	.	.
BH	.	.	41.4c	53.8b	.	.
Planting pattern 2 (intercropping)						
BLML	.	.	42.1c	55.7b	28.3e	38.7d
BHMH	.	.	39.3c	56.0b	30.6e	38.2d
BLMH	.	.	39.0c	56.1b	30.7e	36.2d
BHML	.	.	41.7c	56.2b	32.5e	37.5d
CLBL	53.1a	57.6a	42.2c	54.9b	.	.
CLBH	56.7a	60.9a	44.5c	54.3b	.	.
CHBL	57.3a	55.3a	35.6c	56.8b	.	.
CHBH	53.7a	53.9a	36.5c	54.2b	.	.
CLML	55.0a	56.7a	.	.	0g	38.7d
CLMH	54.5a	56.7a	.	.	18.6f	39.0d
CHML	53.9a	53.1a	.	.	14.9f	36.9d
CHMH	56.7a	56.7a	.	.	12.6f	37.5d
Planting pattern 3 (intercropping)						
CLBLML	58.0a	57.3a	43.6c	60.4b	0g	40.7d
CLBHMH	53.1a	52.5a	47.2c	56.2b	0g	36.0d
CHBLML	56.7a	56.3a	41.7c	53.9b	0g	35.6d
CHBHMH	57.3a	53.7a	41.0c	58.7b	0g	37.4d
CLBLMH	52.5a	54.9a	48.2c	57.5b	0g	38.3d
CLBHML	56.3a	54.5a	43.6c	58.6b	0g	37.9d

Means with the same letters are not significantly different at P = .0001
CL=1.5 m × 1.0 m; CH = 1.8 m × 1.0 m; BL=0.5 m × 0.2 m; BH = 0.6 m × 0.2 m;
ML = 0.75 m × 0.3 m; MH = 0.9 m × 0.3 m

Table 4. Effect of the different planting patterns on seed yield (ton ha^{-1}) of castor, maize and beans

	Seed Yield (tons ha^{-1})							
	2011				2012			
Planting Patterns	**Castor**	**Beans**	**Maize**	**Total**	**Castor**	**Beans**	**Maize**	**Total**
Planting pattern 1 (sole cropping)								
CL	2.00	-	-	2.00	3.052	-	-	3.05
CH	1.85	-	-	1.85	1.383	-	-	1.38
ML	-	-	3.315	3.32	-	-	6.333	6.33
MH	-	-	3.479	3.48	-	-	5.789	5.79
BL	-	0.583	-	0.58	-	0.405	-	0.41
BH	-	0.589	-	0.59	-	0.868	-	0.87
Planting pattern 2 (Intercropping)								
BLML	-	0.59	3.189	3.78	-	0.738	3.987	4.73
BHMH	-	0.83	3.088	3.92	-	0.782	3.619	4.4
BLMH	-	0.615	3.371	3.99	-	0.766	3.253	4.02
BHML	-	0.868	5.289	6.16	-	1.147	3.522	4.67
CLBL	2.43	0.616	-	3.04	1.35	0.768	-	2.12
CLBH	2.15	0.467	-	2.61	1.353	0.59	-	1.94
CHBL	1.72	0.316	-	2.03	0.973	0.507	-	1.48
CHBH	1.99	0.538	-	2.53	1.183	0.83	-	2.01
CLML	2.42	-	0	2.42	1.362	-	3.045	4.41
CLMH	2.34	-	0.145	2.49	1.096	-	3.594	4.69
CHML	2.08	-	0.25	2.33	0.786	-	3.172	3.96
CHMH	1.91	-	0.221	2.13	0.817	-	3.387	4.2
Planting patter 3 (Intercropping)								
CLBLML	2.71	0.462	0	3.17	1.132	1.091	3.675	5.9
CLBHMH	2.08	0.361	0	2.44	0.711	0.602	3.272	4.59
CHBLML	2.50	0.466	0	2.97	0.826	0.615	4.502	5.94
CHBHMH	2.19	0.505	0	2.70	0.728	0.57	4.549	5.85
CLBLMH	3.02	0.766	0	3.78	3.315	0.691	3.542	7.55
CLBHML	2.59	0.554	0	3.14	3.479	0.554	3.708	7.74
Mean	2.25	0.57	1.397	2.81	1.472	0.72	3.934	4.08
LSD (0.05)	0.000	0.000	0.008	0.999	0.000	0.000	0.543	0.991

4. CONCLUSION

This study finds out that castor could be intercropped productively with beans therefore smallholder farmers could successfully embrace castor-based intercropping system with beans without negatively interfering with food crop production. In addition intercropping castor with maize and beans may not have significant effect on the seed yield of castor. However, an intercrop of castor with maize would aggravate the already worsening food situation to smallholder farmers. This study recommends further trials with dwarf castor varieties and/or at wider spacing.

ACKNOWLEDGMENT

The authors wish to thank Egerton University, BOKU University, Vienna, Szeged University, Hungary; ERAARD and KARI – Njoro Kenya for funding this work through the PROBIOFUEL Project with grant number 7933007352.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Nderitu SWK. Castor In. Smith, Chamberlain PD, AG Tyler RA. and Young EM. (eds) Review in Kenyan Agricultural Research, Oil Crops and Nuts 1997; (17).
2. Weiss EA. Oilseed crops, 2nd ed. Blackwell Science, Oxford. 2000.
3. Pant K, Vijay SK, Kumar D, Sumeet G. Seed Oil Content Variation in *Jatropha curcas* Linn in Different Altitude Ranges and Site Conditions in H. P. India, Journal of Ecology and Application, and 2006:11(2).
4. Coopman V, Leeuw M, Cordonnier J, Werner J. Suicidal death after injection of a castor bean extract. 2009.
5. Labalette F, Estragnat A, Messéan A. Development of castor bean production in France", In: Janick, J. (ed.) Progress in new crops. ASHS Press, Alexandria, VA. 1996:340-342
6. Prine GM, Rockwood DL, Stricker JA. Many short rotation trees and herbaceous plants available as energy crops in humid lower South, In Proceedings of Bioenergy, Northeast Regional Bioenergy Program. Buffalo. NY. 2000.
7. Tsubo M, Walker S, Mukhala E. Comparison of radiation use efficiency of mono-intercropping systems with different row orientations. 2001.
8. Dahmarden M, Ghanbari A, Syahsar BA, Ramrodi M. The role of intercropping maize (*Zea mays*) and cowpea (*Vigna unguiculata*) on yield and soil chemical properties, African Journal of Agric. Research. 2010:5(8):631-636.
9. Sharath HC, Mudalagiri Y, Nanjapa HV, Ramachandrappa, BK. Productive performance of castor (*Ricinus communis* L.) based intercropping systems under rain fed conditions of central dry zones of Karnataka, Mysore Journal of Agric, Sci. 2010:44(3):481-484.
10. Wegoro NC. EAC Regional Strategy for Scaling up Access to Modern Energy Services and Biofuel on East Africa. 2008.
11. Obiero C, Birech R, Maling'a J, Freyer B, Ng'etich K, Langat J. Performance and challenges of biofuel cropping systems in Kenyan smallholders farming systems: A case study on castor (*Ricinus communis* L.), jatropha (*Jatropha curcas* L.) and croton (*Croton megalocarpus* L.), Australian Journal of Crop Science. 2013:7(7):917–922.
12. Jaetzold R, Schmidt H. Farm Management Handbook of Kenya; Natural Conditions and Farm Management Information Central Kenya (Rift Valley and Central Provinces). 1983:II/B:381-382 and 625.
13. Nasser K, El-Gizawy B. Effect of planting date and fertilizer application on yield of Wheat under no till system, World Journal of Agric. Sc. 2009:5(6):777–783.
14. Miko U, Kirschbaum F, Robert WP. Gas exchange analsysis of the relative importance of stomatal and biochemical factors in photosynthetic induction in Alocasia macrorhiza. 1988.

15. Marini RP, Barden JA. Seasonal correlation of specific leaf weight to net photosynthesis and chlorophyll content of peach leaves, Photosynth. Res. 1981:2:251–258
16. Marini RP, Sowers DJ. Net photosynthesis, specific leaf weight and flowering of peach as influenced by shade, HortScience. 1990:25.331–334.
17. Rwamugira WK. Effects of Intercropping and plant density on growth, development and yield of pigeon peas (*Cajanus cajun* Cl.) Millsp.) and Maize (*Zea mays* L.) under Semiarid Conditions of Kenya. *Thesis,* University of Nairobi, 1988.
18. Njoku DN and Muoneke CO. Effect of cowpea planting density on growth, yield and productivity of component crops in cowpea/cassava intercropping system. Journal of tropical Agriculture, Food, Environment and Extension, 2008:7(2):106–113.
19. Sharath HC, Mudalagiri Y, Nanjapa HV, Ramachandrappa, BK. Productive performance of castor (*Ricinus communis* L.) based intercropping systems under rain fed conditions of central dry zones of Karnataka, Mysore Journal of Agric, Sci. 2010:44(3):481-484.
20. Mavarkar S. Production potentials of castor based cropping system in alfisols of Kamataka. PhD Thesis Univ. Agric. Sci., Bengaluru, Kamataka. 2006.
21. Leelarani P. Study on castor (*Ricinus communis* L.) based intercropping system under rainfed conditions. J. Oilseeds Res., 2008:25:92–93.
22. Rajput RL, Mishra MK. Studies on Intercropping in Castor (*Ricinus communis*) under Rainfed Conditions, Haryana Journal of Agron. 1995:1:141-144.
23. Makkar HPS, Becker K, Sporer T, Wink M. Studies on nutritive potential and toxic constituents of different provenances of *Jatropha curcas*, J. Agric. Food Chem. 1997:45:3152–3157.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=272&id=2&aid=2361