Title

Effects of accession, spacing and pruning management on *in-situ* leaf litter decomposition of *Jatropha curcas* L. in Zambia

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Abstract

Jatropha curcas L. leaf litter decomposition and subsequent nutrient release was monitored in three experimental *J. curcas* plantations in Zambia, comparing accessions from six countries, pruned versus non-pruned and different plant spacings. Leaf litter production was low (267-536 kg ha^{-1} at the end of the growing season) and contained, on average, 1.23% N, 0.14% P and 2.61% K. Litter decomposed rapidly, losing 80% of total mass by 70 to 105 days after incubation in the field and followed a negative exponential pattern with an average decomposition constant, k, of 0.08 $week^{-1}$. No significant effects of plant accession, plant spacing or pruning on the decomposition rate were detected. K, P, Mg and Na had nutrient release rates exceeding mass loss, explained by their high mobility and solubility, together with high soil temperature and rainfall conditions. Others, such as Ca and Mn, were initially retained in the decaying leaf litter before later release. The rate of N release closely approached that of mass loss. *Jatropha curcas* litter can be a supplemental source of nutrients in areas known for nutrient deficiency and low organic matter, which represents an additional input in intercropping systems above biofuel production. Considering that the total primary nutrient input through *J. curcas* litterfall to the soil is limited (for example, for nitrogen between 9.7 and 14.2 g kg^{-1} and for phosphorus between 0.8 and 1.9 g kg^{-1}), organic or mineral fertilizer application remains crucial to satisfy fully the nutrient requirements of surrounding crops.

Key words: Africa; agroforestry; biofuel, litter bag experiment; nutrient cycling

1. Introduction

Jatropha curcas L. (family Euphorbiaceae) is a small tropical tree with a lifespan of about 50 years [1]. Due to its popularity as a feedstock for biodiesel production, its medicinal values [2] and its potential to rehabilitate and grow in dry degraded lands, there is increasing interest to intensify *J. curcas* cultivation in tropical and subtropical regions [3-6]. The species can be cultivated as a monoculture or intercropped with annual and perennial crops [7,8]. However, monocultural *J. curcas* systems have recently raised controversies, as they may increase food insecurity risk in areas where land shortage is prevalent [9]. In this case, the previously mentioned concerns are circumvented and some other additional benefits can be gained from

the *J. curcas* trees, like the addition of nutrients to the soil through litterfall. As the majority of soils in Africa are characterized by deficiencies of N, P, K, low soil organic matter [10-12] and the world's lowest mineral fertilizer application rates [11], this additional service could significantly improve soil fertility and hence crop an fodder yields. *J. curcas* has been shown to increase soil pH and maintain higher soil microbial biomass and activity [13]. In Senegal, under low rainfall conditions (400 – 600 mm year^{-1}), Dieng et al. [14] assessed topsoil under one-year old *J. curcas* plantations and found significantly higher total soil C, N and P than under adjacent paired fallow sites representing the previous land use system. A study from Burkina Faso also demonstrated that *J. curcas* associated with cereal crops is more profitable than monocropping cereals [13]. Although more experience and studies are needed on how to intercrop *J. curcas* with food crops on arable lands, integration into the local food production system as hedges and small woodlots might play a significant and less contentious role in sustainable food and energy production systems for smallholder farmers [9] and thus may directly benefit the rural economy [7].

Yet there is little information available on the production, quality and nutrient release dynamics of *J. curcas* leaf litter, even though such characteristics would partially determine its potential to rehabilitate land and to be integrated in intercropping systems. Litter quality refers to the characteristics of the litter (chemistry and physical attributes) that influence its susceptibility to decomposition [15]. This is species-dependent although such traits exhibit phenotypic plasticity according to the growing conditions and accessions [5,16]. Some studies (e.g., [17,18]) highlight the requirement for a detailed investigation of litter production, quality and nutrient release of different plant species to develop reliable information on their functions and management.

Different *J. curcas* accessions have been introduced to Africa long ago, which are a subset of the Central American genetic diversity [19-21]. Plants, of different accessions managed in different ways, can have different decomposition trends [22]. So far, only one study was found which assessed the impact of management factors on the decomposition rate of *J. curcas* litter in Ghana [7]. They concluded that *J. curcas* leaf litter has potential as a source of nutrients and highlighted the significant impact of canopy closure on the litter decomposition rate through its direct effect on soil temperature. The impact of plant accession on the decomposition of *J. curcas* litter remains however unknown.

Rulli et al. [26] recently compiled a list of large-scale *J. curcas* projects, each exceeding 200 hectares, in Zambia and three of its neighbouring countries, Democratic Republic of Congo, Tanzania and Mozambique. They calculated that the total area exceeded 50,000 Km^2, implying that the potential impact of *J. curcas* is huge. Considering such expansion in Africa, it is essential to understand its nutrient dynamics and impact in representative environments. In situ litter decomposition experiments of different accessions under different management regimes provide preliminary data on assessing nutrient dynamics. This would help to generate useful knowledge on methods of how to grow *J. curcas* with food crops to secure both energy and food production systems in the region with minimal external agricultural inputs. In addition, estimating litter inputs and decomposition may provide more insight into carbon fluxes and nutrient cycling [27]. The changes in litter turnover through decomposition may also help to understand vegetation–soil feedbacks, improving forecasts of the global carbon stock, climate warming and other global environmental changes, which is the current research priority of many countries.

In this study, we estimated the potential of *J. curcas* leaf litter as an additional source of nutrients to the soil and assess the effects of both plant accession and management (pruning regime and spacing) on this service, in three *J. curcas* trials. In particular, this study aimed to: (i) estimate the total nutrient input to the soil through *J. curcas* litterfall, (ii) determine leaf litter decay rates of different accessions of *J. curcas* under different management practices and (iii) assess the nutrient release trend and fibre content changes in the decomposing leaf litter of *J. curcas* over time.

2. Materials and methods

2.1. Study site and plant material

The study was conducted from April 2010 until July 2011 in three *J. curcas* plantation trials in Zambia, Southern Africa. All trials were located in Chongwe district, 24 km Northeast of central Lusaka (15°22’ 09” S; 28 º 27’ 33” E) at an elevation of 1160 m a.s.l. The mean annual maximum and minimum temperatures are 26 and 14 °C, respectively. The area is characterized by a long rainy season between late October and May and a mean annual rainfall of 802 mm. During the experimental period (between October 2010 and July 2011)

the monthly rainfall ranged from 35 to 244 mm with a total rainfall of 869 mm (Figure 1). The maximum and minimum temperatures within this period are given in Figure 1.

The first trial, i.e. the accession trial, comprised six accessions collected from three continents, Asia (India and Thailand), South America (Mexico) and Africa (Zambia, Mali, and Cape Verde). The accessions were planted in six unreplicated plots of 13.5 × 5 m, each containing 18 trees from the same accession, at 1.5 × 2.5 m spacing (2667 ha^{-1}). Seeds from foreign accessions were imported from their respective country of origin and directly used in the trial (i.e. first generation in Zambia). All trees were established from seed with seedlings raised in a nursery, close to the plantation site. The second trial was a pruning trial with a one-factorial design at two levels, each replicated four times. Plots contained nine trees that were either pruned before the beginning of the rainy season (October) or left unpruned. Plot sizes were 9 × 6 m and trees (Cape Verdean accession) were established from seed and spaced at 2 × 3 m (1667 ha^{-1}). The third trial was a spacing trial with a one-factorial design at three levels, i.e. plant spacing of 4 x 4 m (625 ha^{-1}), 2 × 3 m (1667 ha^{-1}) and 2 × 2 m (2500 ha^{-1}). Each treatment was applied in four plots, each containing nine trees of Cape Verdean accession and established from seed. All trials were rainfed and were planted at the end of 2008. In the first year, trials were fertilized with 42 g N, 12 g P, and 48 g elemental K per tree in the form of urea, single superphosphate and potassium chloride, respectively. The nutrients were applied twice per year (mid-February and early April). Trees from the accession and spacing trials were pruned at the first year of establishment in September 2008. The site has well-drained, moderately shallow sandy-clay-loam soils with an average depth of 1 m, classified as Ferric Luvisols based on the FAO classification system [28]. The soils of all trials were slightly acidic and were low in available phosphorus and soil organic matter. The physical and chemical soil properties at the different trials are displayed in Table 1.

(Insert figure 1)

(Insert table 1)

2.2. Litter production

To estimate litter production per tree, 11 leaf litter traps (one for each treatment) were stretched around one tree per treatment, selected randomly, between April and July 2010. Litter traps consisted of mosquito netting (2mm mesh) placed 50 cm above the soil surface, with a surface area of 6.25 m^2 aimed to cover the entire canopy. Litter was harvested from the traps every week and oven dried to estimate total dry matter weight.

2.3. Litter collection and initial quality assessment

Jatropha curcas litter was collected during the peak leaf fall period at the beginning of the dry season from May to July 2010. An additional nine litter traps were placed randomly in each trial during this period in a similar fashion as the first 11 traps. The traps were mounted between 4 trees and switch to other trees every 10 days within the same treatment. The surface areas of the traps were 6 m^2 and 16 m^2 respectively for pruning and spacing trials and 3.7 m^2 for the accession trial with smaller plant spacing. Litter was collected every ten days and air dried. Composite sub-samples of litter were collected for each treatment separately and oven dried at 65^oC for 72 hours. After oven drying, the samples were milled to analyse for macro- and micro-nutrients and fibre content. For the decomposition experiment, all air-dried litter samples were bulked together per treatment and homogenized before bagging.

2.4. Litter bag incubation, decomposition and nutrient analysis

The most frequently used method to determine litter decomposition rates is the litterbag technique [27,29]. In this method, a known amount of newly shed litter is enclosed in bags with appropriate mesh sizes and laid on the soil surface or buried in the soil to collect and measure the remaining mass in periodic intervals. In our case, *in situ* litter decomposition of six *J. curcas* accessions (Mexican, Indian, Thai, Zambian, Malian, and Cape Verdean) and litter harvested from trees with different canopy management (pruning and plant spacing) was determined over nine months (between October 2010 and June 2011). Four grams (4 g) of air dried *J. curcas* litter, weighed using a precision balance (± 0.001 g), was carefully put into 0.20 × 0.20 m nylon litter decomposition bags with a 1 mm mesh size. The litter was not

shredded before placing in the bags to maintain its natural form in field conditions. This mesh size avoids excessive particle loss in *in situ* experimental conditions, while allowing free access for all soil micro-fauna and most meso-fauna [30]. One hundred and ninety eight (198) litter bags were prepared (11 treatments × 3 replications × 6 recovery dates) and placed randomly under *J. curcas* trees of the respective treatments. The bags were placed on the soil surface and covered with surrounding leaf litter to mimic field conditions. All bags were numbered using trial and tree number and fixed to the soil surface with metal pegs. One bag was removed from each plot at 2, 4, 8, 14, 24, and 34 weeks after placement. After retrieval, each sample was put in a paper envelope. Adhering soil, soil fauna and other extraneous materials were carefully removed from the bag by brushing or swiftly rinsing with water. The remaining litter sample was oven dried for 72 h at 65°C and weighed using a precision balance (± 0.001 g). The three replications per treatment were bulked for nutrient analysis since the amount of remaining litter per bag was often too small to be analysed separately. C and N concentrations were determined using a CN analyser (Carlo Erba 1110 Elemental Analyser) and a ratio of carbon to nitrogen (C:N) on a weight basis was then derived based on the result. Concentrations of P, K, Mg, Mn, Na, and Ca were analysed using inductively coupled plasma emission spectroscopy (ICP) with EPA method after HNO_3 digestion. Crude fibre content (lignin, cellulose and hemi-cellulose) was analysed using the fractionation method Van Soest [31] and Van Soest et al. [32]. To analyse these different crude fibre constituents, dried litter samples were digested in a detergent solution, which separated non-polar extractives (NPE) from neutral detergent fibre (NDF), which includes fractions that are not immediately nutritionally available. A dilute acid detergent solution was then used to determine acid detergent fibre (ADF, lignocellulose) before lignin was separated from cellulose in 72% H_2SO_4.

2.5. Data analysis

Litter production was expressed in kg ha^{-1} by multiplying the amount of leaves trapped per tree to the total number of trees per ha. Before analysing the data obtained from the decomposition experiment, the remaining dry weight of litter and the remaining nutrient content (= mass of remaining litter × nutrient concentration) at each time step were expressed as a fraction of the initial litter weight and initial nutrient content respectively. The mass decomposition and nutrient release data were analysed after Wieder & Lang [33]: differences

between treatments were analysed using two-way ANOVA with time, treatment and the interaction term included in the model, combined with a Tukey post-hoc test. Both the assumption of normality and homogeneity of variance were verified using the Shapiro-Wilk and Levene's test, respectively. In case the assumption of homogeneity of variance was violated by the data, a significance level of $\alpha = 0.01$ rather than 0.05 was used to prevent the occurrence of Type I errors. A single negative exponential function was used to further describe the data and estimate a decomposition rate constant (k) for each treatment [34]. This function is well-supported by decomposition theory [33].

$$X_t = X_0 \times \exp^{-kt}$$

where X_t is the remaining litter weight or nutrient content at time t, X_0 is the initial litter weight or nutrient content, k is the decomposition rate constant, and t is the time in weeks. These k values were then related to the initial nutrient content of the litter, which is known to have a primary effect on litter decomposition (e.g. [35]), by calculating the Pearson correlation coefficients. All data were analysed using SPSS 17.0 software (IBM, Chicago, USA).

3. Results

3.1. Litter production

The average litter deposition per treatment during the dry season between May and July varied between 111 kg ha^{-1} and 581 kg ha^{-1} for the different experiments (Table 2). Litter production is primarily affected by plant spacing.

(Insert table 2)

3.2. Initial leaf litter chemical constituents

J. curcas leaf litter chemistry is in Table 3. The Mexican accession had the highest P concentration (up to 61% higher compared to the lowest value in the Indian accession). The

C:N ratio of the six accessions ranged between 31 and 36 with the highest value for the Indian accession, however there was no consistent effect of accession on *J. curcas* litter nutrient concentrations. Similarly, the lignin concentration of the Indian accession was higher (up to 127%) compared to the lowest value of the Zambian accession. A higher C:N ratio was observed for the accession and spacing trials compared to the pruning trial, however this can be attributed to the differences in soil fertility between the different fields (Table 1).

(Insert table 3)

3.3. Total leaf litter nutrient content

Annual leaf litter nutrients added to the soil were calculated based on litter production and its nutrient content and are displayed in Table 4. Plant spacing affected the total amount of nutrients that can be added to the soil through litterfall during this early plantation stage. Other treatments had no significant effect.

(Insert table 4)

3.4. Litter mass decomposition

The decomposition pattern of *J. curcas* leaves is similar between treatments (Figure 2). A low rate of mass loss during the first four weeks of incubation is followed by an exponential decomposition trend. The rate of mass loss is reduced after 10 to 15 weeks when approximately 80% of the initial mass has decomposed. The period of maximal rate of decomposition coincided with the rainfall peak period of December and January and higher soil temperature and soil moisture (Figure 1). All material was decomposed 34 weeks after incubation.

The analyses of variance conducted for each trial was revealed no significant effects of plant accession ($P = 0.118$), plant spacing ($P = 0.636$) or pruning ($P = 0.703$) on the decomposition rate of *J. curcas* leaves. The interaction term treatment × time was not significant ($P =$

0.057), meaning that any treatment effect was independent of time. These results are confirmed by the small and non-significant differences in estimated k-values between treatments within each trial (Table 5). The average decomposition rate in the pruning trial was found to be significantly higher than the average k-value in the accession trial.

(Insert figure 2)

(Insert table 5)

Significant ($P < 0.05$) correlations of k were found with the following initial leaf characteristics: % C (-0.802), % Mn (-0.778), % Mg (0.758), % P (0.701), C:P ratio (-0.679), N:P ratio (-0.667), % cellulose (0.617) and % ash (-0.617).

3.5. Nutrient release from decaying J. curcas litter

The nutrient release patterns of C, N, P, K, Mg, Ca, Na and Mn are represented for each treatment in Figure 3. Differences between treatments were small, but could not be assessed using statistical methods since only one replication per treatment was analysed for nutrient content. The nutrient release pattern was found to vary considerably between the different nutrients. The release of N, P, Mg and Na was initially rapid in the first 2 weeks followed by a short immobilization phase for 2 to 3 weeks, after which the release gradually continued. Potassium release occurred at a high constant rate and was completed 8 weeks after incubation. In contrast, Ca and Mn were initially retained in the decaying leaf litter for 4 weeks before they were released at approximately the same rate as mass loss.

Nutrient release constants (k; see Table 6) were similar between treatments, with the exception of the k values of the pruning trial being higher for C, N and P. K, P, Mg and Na had nutrient release rates exceeding mass loss rate, thus were leached from the material. The rates of C and N release were similar to the mass loss rate, while Mn and Ca were retained in the litter during decomposition. The evolution of nutrient and fibre contents in the decaying litter is presented in Table 7.

N and P release are known to be highly dependent on the chemical properties of litter (e.g. [36]), so correlations were calculated between their release constants and the initial litter nutrient content. Nitrogen release was significantly correlated with % P (0.894), C:N ratio (-0.847), % N (0.761), C:P ratio (-0.705), % Mg (0.655), % Mn (-0.652) and N:P ratio (-0.625). Likewise, phosphorus release was positively correlated with the initial phosphorus and nitrogen contents of the litter: % P (0.871), C:P ratio (-0.765), N:P ratio (-0.735) and C:N ratio (-0.643).

(Insert figure 3)

(Insert table 6 & 7)

4. Discussion

4.1. Litter production

Litterfall from the two-year old *J. curcas* trees in this study was low compared to other *J. curcas* studies conducted in other regions. Wani et al. [37] found an annual litter production of 0.92 and 2.42 Mg ha^{-1} for a 1- and 3-year old plantation (2 × 3 m plant spacing), respectively, in a region of India in a comparable agro-ecozone with similar rainfall characteristics. Our study resulted in an annual production of only 0.271 Mg ha^{-1} for the same 2 × 3 m plant spacing. Also, compared with more humid regions, our average observed litter production (0.45 Mg ha^{-1}) is low. Firdaus & Husni [38] reported 1.29 Mg ha^{-1} yr^{-1} for a 1-year old plantation (2 × 3 m spacing) in Malaysia at a site with an annual rainfall of 2200 mm, while Abugre et al. [7] reported 2.27 Mg ha^{-1}, 1.10 Mg ha^{-1} and 0.79 Mg ha^{-1} for 1 × 1 m, 2 × 1 m and 3 × 1 m spacing, respectively, in Ghana with annual rainfall of 1300 mm . In the current study, litter production was only measured during 3 months (May – July 2010), representing the peak leaf fall period, and therefore annual litterfall may be underestimated. The results obtained by Abugre et al. [7] and Firdaus & Husni [38] suggest that in constantly humid regions *J. curcas* sheds its leaves continuously throughout the year, unlike in drier areas where leaf fall is seasonal. During the course of the experiment, part of the plantation suffered from infections caused by mealy bugs (*Homoptera: Pseudococcidae*), broad mites (*Acari: Tarsonemidae*) and powdery mildew (personal observation). In addition, in most of

the pruned treatments, a high mortality of branches was observed after the first pruning in October 2009. These factors caused a decline in plant productivity, which in turn can partly explain the low litter production.

4.2. Litter constituents

Jatropha curcas litter is relatively poor in N and P, but rich in Ca and Mg compared to other frequently used leguminous tree species in agroforestry projects in Africa (e.g., *Leucaena leucocephala* and *Gliricidia sepium*) [36,39]. In contrast litter of *Ricinus communis* (castor oil), from the same family as Jatropha, , contains more N (5.1%), less P (0.38%) and has a far lower C:N ratio (8.0) than *J. curcas* litter [40]. The average N content of *J. curcas* litter measured in this study is lower and the C:N ratio is higher than those reported by Abugre et al. [7] for green *J. curcas* leaves from Ghana (i.e. 2.53% and 16.7), whereas P and lignin concentrations are more similar between the two studies. These differences can be explained by nutrient resorption prior to abscission [24, 25]. The other reason could be the accumulation of specific nutrients mainly in the reproductive organs of the plant. High accumulation of N and P in the seed organ of *J. curcas* (N = 49.5 g kg^{-1}, P = 4.4 g kg^{-1}) was observed by Wani et al. [37] compared to leaves (N =9.5 g kg^{-1} and P= 0.7 g kg^{-1}) at plant age of 4 years. Leaf lignin contents found here are similar to those reported by Yamamura et al. [41] (9.1%) and Ruíz-Valdiviezo et al. [23] (11.1%).

Litter in our trial had very high K concentrations, exceeding all those presented by Drechsel and Zech [42] in a review of fresh leaves of tropical tree species and also higher than most studies presenting data on fresh or dry leaf litter of *J. curcas*. However, Camergo et al. [43] working in Brazil did report similarly high values of K in fresh leaves of *J. curcas,* exceeding their N concentrations, under unfertilized conditions. Here high amounts of K fertilizer had been applied and thus the foliar chemistry may reflect this. Potassium is highly mobile in plants [44]. In laboratory studies simulating severe drought conditions, it has been demonstrated that leaf K concentrations of *J. curcas* fresh leaves can increase to 2.44% (recalculated from Díaz-López et al. [45]). Given that in the current trial, the soil conditions were sandy, soil water retention is low and rainfall was low, these conditions might explain the high K concentrations found.

4.3. Total nutrient input through J. curcas litterfall

From the comparison between the nutrient input through *J. curcas* litterfall (Table 4) and a typical dose of mineral fertilizer applied in *J. curcas* plantations in Zambia, it becomes apparent that only 6.5, 0.9 and 9.1% of the estimated requirements for N, P and K are covered by the litterfall nutrient flux (assuming a planting distance of 1.5 × 2.5 m as was the case in this study). However, as the soil in this study area is characterised by deficiencies of N, P and K (Table 1), even this small contribution can be relevant for crop production. *J. curcas* yields a marketable product thus any soil fertility benefit is an additional benefit rather than the main reason for incorporating *J. curcas* in any intercropping system and highlight a significant advantage over typical hedgerow intercropping species. Indeed, Snapp et al. [46], working in southern Africa, and Nederlof and Dangbégnon [47] working in West Africa, concurred that technologies, such as integrating leguminous trees that only contribute to soil fertility are unlikely to be adopted by farmers unless they significantly lower labour requirements.

4.4. Decomposition of J. curcas litter

The average decomposition constant found in this study (0.08 $week^{-1}$ or 0.035 day^{-1}) is much higher than the value of 0.018 day^{-1} reported by Abugre et al. [7] for *J. curcas* leaf litter decomposition under similar conditions in Ghana, despite the lower C:N ratio in the latter case (i.e. 17 versus 33). Low C:N ratio may not always be a reliable indicator of high decomposition rate. In Zambia for instance, litter of *Senna siamea* (C:N = 30, N = 2.31, lignin = 28%) was found to decompose as fast as *L. leucocephala* (C:N = 18, N = 3.5, lignin = 30%) [50]. *Jatropha curcas* litter mass loss during decomposition was rapid, with a decrease of about 80% of the mass between 70 and 105 days, but is slow compared with *R. communis* in the same family (90% within 35 days) [40]. This can be explained by the significantly higher N concentration (Muoghalu et al. [48]; Vanlauwe et al. [49]) of the latter.

No significant effects of accession, planting distance or pruning were found on the decomposition rate of *J. curcas* litter in this study. In case of the accession trial, this can be explained by the limited differences in litter quality observed between the accessions, which in turn, is known to be the most important determinant of litter decomposition within the same climate region [50,51]. Based on the results of Abugre et al. [7], who found a significantly higher decomposition rate of *J. curcas* litter under open canopy compared to closed canopy, an impact of canopy management on litter decay was expected in this study.

This effect, however, appeared to be negligible. Instead, this study demonstrated that soil fertility might be an important factor to consider, as it can explain the higher rate of decomposition observed in the pruning trial compared to the other trials (Table 1).

4.5. Nutrient release pattern from decaying J. curcas litter

The main cations were released in the order K > Mg > Ca, as was also observed by Palm & Sanchez [35]. An initial immobilization of Ca and Na has been frequently observed in the tropics (e.g., [7,40,52]). An early immobilization of Ca has been attributed to an accumulation of calcium oxalate in decomposing fungi [53]. The accumulation of Na at the early stage of decomposition could be attributed to sodium input from rain or dust [48]. In general K, P, Mg and Na showed a nutrient release constant which was larger than the mass decomposition constant. This can be explained by the high mobility and solubility of these nutrients, combined with high temperature and rain [54,55].

Conclusion

Jatropha curcas leaf litter decomposes rapidly but has a lower nutrient concentration than legume trees commonly grown in Africa. No effects of accession, spacing or pruning on litter decomposition of *J. curcas* were observed. The plant shows rapid release of nutrients. From an ecosystem service perspective, *J. curcas* has the potential to positively affect nutrient cycling and soil fertility in tropical intercropping systems, creating an extra added value besides biofuel production. However, as the total nutrient input through *J. curcas* litterfall to the soil is limited, organic or mineral fertilizers remain crucial to fully satisfy the nutrient requirements of surrounding crops.

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Table 1[1]

	Experimental trials and soil sampling depth (cm)					
	Accession trial		Plant spacing trial		Pruning trial	
Properties	0-30	30-90	0-30	30-90	0-30	30-90
Available P (mg kg^{-1})	1.86	1.51	2.14	0.81	3.33	1.02
K (mmol kg^{-1})	6.30	5.60	7.70	8.30	5.90	5.60
Ca (mmol kg^{-1})	13.85	11.10	23.75	21.50	15.45	13.30
Mg (mmol kg^{-1})	3.15	4.65	8.70	12.85	2.85	3.25
Na (mmol kg^{-1})	2.20	2.10	2.30	2.50	2.20	2.10
Cu (mg kg^{-1})	0.24	0.20	0.52	0.46	0.24	0.24
Mn (mg kg^{-1})	16.96	11.22	29.64	10.48	10.26	15.38
Fe (mg kg^{-1})	7.18	4.36	9.10	3.16	5.08	5.58
AL^{3+} (mmol kg^{-1})	0.07	0.13	0.10	0.17	0.10	0.03
H^{+} (mmol kg^{-1})	0.40	1.60	0.80	0.70	1.10	0.90
S (mg kg^{-1})	0.67	1.17	1.50	0.33	1.00	Trace
Zn (mg kg^{-1})	0.58	0.22	0.90	0.24	0.66	0.30
B (mg kg^{-1})	Trace	Trace	0.09	Trace	0.11	0.01
EC ($mscm^{-1}$)	0.23	0.13	0.22	0.14	0.18	0.17
pH ($CaCl_2$)	5.34	5.32	5.65	5.62	5.92	6.44
Soil Organic matter (g kg^{-1})	15.20	6.40	20.80	8.00	12.00	5.60
Soil Organic Carbon (g kg^{-1})	8.80	3.70	12.10	4.60	7.00	3.20
Sand (%)	82.8	76.8	76.8	64.8	84.8	78.8
Clay (%)	10.0	18.0	16.0	32.0	8.0	18.0
Silt (%)	7.2	5.2	7.2	3.2	7.2	3.2
Texture class	LS	SL	SL	SCL	LS	SL

Note: LS (Loam Sand), SL (Sandy Loam), SCL (Sandy Clay Loam)

[1] **Table 1** Chemical and physical properties of the top 90 cm of soil at the experimental sites, Chongwe, Zambia (source: QUINVITA NV 2011, unpublished, extraction methods not specified).

Table 2[2]

Trial and treatment	Leaf litter production (kg ha^{-1})
Accession (2667 ha^{-1})	
Cape Verdean	581
Indian	419
Malian	573
Mexican	557
Thai	517
Zambian	568
Plant density (Cape Verdean accession)	
2500 ha^{-1}	418
1667 ha^{-1}	271
625 ha^{-1}	111
Pruning (Cape Verdean accession, 1667 ha^{-1})	
Non-Pruned	418
Pruned	517

[2] **Table 2** Dry matter litter production of different *J. curcas* accessions and canopy management practices (plant age = 2 years) during May – July 2010 in Chongwe, Zambia.

Table 3[3]

Trial and treatment	Leaf litter constituents												
	C g kg^{-1})	**N (g kg^{-1})**	**C:N ratio**	**P (g kg^{-1})**	**K (g kg^{-1})**	**Ca (g kg^{-1})**	**Mg (g kg^{-1})**	**Na (g kg^{-1})**	**Mn (g kg^{-1})**	**Hemi-cellulose (g kg^{-1})**	**Cellulose (mg kg^{-1})**	**Lignin (g kg^{-1})**	**Ash (g kg^{-1})**
Accession													
Cape Verdean	430.8	12.08	35.7	0.82	18.75	28.30	8.53	0.59	1.00	48.0	53.8	207.3	6.0
Indian	425.2	11.82	36.0	0.79	20.24	21.05	6.66	0.60	1.12	44.1	44.7	237.9	6.0
Malian	412.7	12.38	33.3	0.89	18.15	24.94	5.69	0.50	1.43	54.0	77.8	140.3	5.9
Mexican	429.3	12.25	35.1	1.27	18.93	24.37	4.74	0.38	1.43	48.6	39.8	138.9	6.0
Thai	405.1	11.78	34.4	0.88	21.05	33.39	8.43	0.62	1.16	59.2	89.4	125.3	6.0
Zambian	397.6	12.57	31.6	0.96	24.58	31.49	9.83	0.79	1.48	58.4	111.0	104.8	6.0
Plant spacing													
2500 ha^{-1}	392.6	13.42	29.3	1.55	29.52	28.45	9.79	0.49	1.02	80.0	138.0	80.2	5.9
1667 ha^{-1}	369.6	9.98	37.0	1.37	36.90	37.87	10.53	0.41	0.63	59.8	162.4	70.9	6.0
625 ha^{-1}	378.2	9.72	38.9	1.06	41.19	30.93	8.76	0.43	0.86	71.0	168.4	73.7	5.9
Pruning													
Non-pruned	384.1	14.16	27.1	1.94	30.43	37.61	10.26	0.44	0.65	68.1	127.3	75.0	5.9
Pruned	373.5	15.32	24.4	1.41	27.88	25.17	11.81	0.31	0.45	54.0	119.4	82.0	5.9

[3] **Table 3** Dry leaf litter chemical constituents of different *J. curcas* accessions and canopy managements after 2 years in Chongwe, Zambia.

Table 4[4]

Trial and treatment	Nutrients							
	C (kg ha^{-1})	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Ca (kg ha^{-1})	Mg (kg ha^{-1})	Na (kg ha^{-1})	Mn (kg ha^{-1})
Accession								
Cape Verdean	250.5	7.02	0.48	10.90	16.45	4.96	0.34	0.58
Indian	178.0	4.95	0.33	8.47	8.81	2.79	0.25	0.47
Malian	236.6	7.10	0.51	10.41	14.30	3.26	0.29	0.82
Mexican	239.3	6.83	0.71	10.55	13.58	2.64	0.21	0.80
Thai	209.6	6.10	0.46	10.89	17.28	4.36	0.32	0.60
Zambian	225.9	7.14	0.55	13.96	17.89	5.58	0.45	0.84
Plant spacing								
2500 ha^{-1}	163.9	5.60	0.65	12.32	11.88	4.09	0.20	0.43
1667 ha^{-1}	161.8	2.71	0.60	16.16	16.58	4.61	0.18	0.28
625 ha^{-1}	42.1	1.08	0.12	4.59	3.44	0.98	0.05	0.10
Pruning								
Non-pruned	160.5	5.92	0.81	12.71	15.71	4.29	0.18	0.27
Pruned	193.0	7.92	0.73	14.40	13.00	6.10	0.16	0.23

[4] **Table 4** Total annual leaf nutrient release to the soil from different *J. curcas* accessions and under different canopy management.

Table 5[5]

Trial and treatment	k	k - CI	k + CI
Accession			
Cape Verdean	0.069	0.055	0.083
Indian	0.082	0.066	0.098
Malian	0.072	0.060	0.084
Mexican	0.068	0.050	0.086
Thai	0.085	0.069	0.101
Zambian	0.081	0.063	0.099
Average	0.076	0.069	0.081
Plant spacing			
2500 ha^{-1}	0.079	0.061	0.097
1667 ha^{-1}	0.087	0.069	0.105
625 ha^{-1}	0.088	0.068	0.108
Average	0.085	0.075	0.095
Pruning			
Non-pruned	0.098	0.076	0.120
Pruned	0.101	0.081	0.121
Average	0.100	0.086	0.114

[5] **Table 5** The decomposition rate constant (k; in $weeks^{-1}$), together with its confidence intervals (CI), obtained by fitting a single exponential function on the mass decomposition data for each treatment.

1 Table 6[6]

Trial and treatment	C	N	P	K	Mg	Ca	Na	Mn
Accession								
Cape Verdean	0.081	0.069	0.126	0.252	0.127	0.061	0.125	0.054
Indian	0.092	0.083	0.152	0.248	0.141	0.065	0.179	0.078
Malian	0.080	0.072	0.121	0.223	0.119	0.055	0.099	0.056
Mexican	0.076	0.075	0.192	0.228	0.121	0.062	0.129	0.079
Thai	0.096	0.083	0.150	0.251	0.168	0.078	0.167	0.072
Zambian	0.083	0.081	0.175	0.313	0.131	0.085	0.201	0.090
Average	0.085	0.077	0.153	0.253	0.135	0.068	0.150	0.072
Plant spacing								
2500 ha^{-1}	0.083	0.090	0.203	0.223	0.127	0.078	0.125	0.079
1667 ha^{-1}	0.090	0.071	0.178	0.284	0.115	0.073	0.113	0.085
625 ha^{-1}	0.093	0.079	0.148	0.317	0.101	0.063	0.106	0.071
Average	0.088	0.079	0.174	0.268	0.115	0.071	0.115	0.079
Pruning								
Non-pruned	0.102	0.105	0.152	0.215	0.118	0.068	0.111	0.086
Pruned	0.110	0.135	0.272	0.176	0.168	0.055	0.079	0.066
Average	0.106	0.118	0.197	0.193	0.140	0.059	0.090	0.073

2

[6] **Table 6** The nutrient release constant (k, in weeks $^{-1}$) for each treatment and nutrient obtained by fitting a single exponential function to the nutrient release data.

Table 7[7]

Time (week)	C (g kg^{-1})	N (g kg^{-1})	C:N (-)	P (g kg^{-1})	K (g kg^{-1})	Mg (g kg^{-1})	Ca (g kg^{-1})	Na (g kg^{-1})	Mn (g kg^{-1})	C:P (-)	N:P (-)	Cellulose (g kg^{-1})	Hemi-cellulose (g kg^{-1})	Lignin (g kg^{-1})	Lignin:N (-)
0	399.9	12.3	33.0	1.4	26.1	8.6	29.4	0.5	1.0	357.7	10.6	102.9	58.7	121.5	100.2
2	394.3	10.1	39.5	0.8	19.0	7.3	32.6	0.4	1.0	571.8	14.1	148.7	81.1	108.5	109
4	386.3	11.2	34.7	0.8	11.7	7.2	36.9	0.4	1.1	616.4	17.4	172	54.7	144.8	130.2
8	371.8	13.5	27.7	0.7	1.7	4.6	35.4	0.3	1.1	575.4	20.7	103.2	27.5	210.4	158.1
14	331.9	13.1	25.9	0.8	1.8	3.4	30.5	0.3	1.0	448.2	17.7	97	46	265.6	207.1
24	350.3	14.8	24.0	1.0	2.0	3.3	26.8	0.4	1.1	384.3	16.5	70.6	56.5	198.7	118.5
34	374.7	12.7	30.3	1.1	2.8	3.3	26.3	0.5	0.9	379.6	13.0	-	-	-	-

[7] **Table 7** Nutrient concentrations in remaining *J. curcas* litter at each time step, averaged for all treatments. C:N, C:P. N:P are mass ratios and are therefore unitless.