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Carbon and nitrogen mineralization potential of biofuel crop (*Jatropha curcas* L.) residues in soil

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Abstract

Use and management of jatropha residue is currently an important global issue for attaining sustainability in biofuel production from *Jatropha curcas* on wastelands. Perhaps, knowledge about the decomposition characteristics and nutrient release pattern from jatropha residues amended soils are lacking. Thus, the objective of present research was to characterize the carbon (C) and nitrogen (N) mineralization of jatropha residues during decomposition in soil. The chemical composition of the residues, in terms of C, N, cellulose, hemicelluloses, lignin and phenolics contents were determined. Laboratory incubation studies were carried out with two soils (inside and outside-canopy soil of jatropha shrub) and four jatropha residues (1% w/w) amendments (cake, leaf, fruit shell or control soil only). The cumulative CO_2 evolution of the added residues was in the magnitude of fruit shell>leaf>cake>control soil. Net C mineralized in soils were in the range of 46-50, 66-67 and 75-77% of C added by cake, leaf and fruit shell, respectively at the end of incubation study. Soils amended with leaf immobilized N during the first 64 days but subsequently released inorganic N. The addition of cake and fruit shell resulted in net N mineralization and net N immobilization, respectively throughout the incubation period. Cumulative N released by the end of incubation was in the order of cake>leaf>control>fruit shell. Net N mineralization in soils during the study was 75-92 and 21-27% of N added by cake and leaf, respectively whereas there was net N immobilization in fruit shell amended soil. Cumulative CO_2 evolution as well as N mineralization during incubation were higher in inside-canopy soil compared with that of outside-canopy soil. Jatropha cake and leaf proved to be a potential source of mineral N, however leaf will take about 60-70 days as gestation period to mineralize the nitrogen. Similarly, leaf and fruit shell also exhibited a good potential of C mineralization.

Keywords: Jatropha- residue, C and N mineralization, mineralization potential, nitrogen release pattern

1. Introduction

Jatropha curcas (physic nut, purging nut, ratanjyot) is a multipurpose shrub that has gained popularity as a potential biofuel crop. It is member of the Euphorbiaceae family, is native to tropical America and is widely adapted to tropical and subtropical Asia and Africa. Its seeds contain up to 34% oil that is easily converted to biodiesel, which has stimulated a growing interest in its use as a renewable energy source (Openshaw, 2000). Jatropha can tolerate high temperatures and low fertility; adopted well under arid and semi-arid conditions. Establishment of jatropha plantations could help to put marginal land into productive utilization by way of biofuel production (Openshaw, 2000). Additionally, when marginal land planted with jatropha, it reclaims them by exploring the soil with an adequate deep root system that results in recycling of nutrients from deeper soil layers. Thus, marginal soil might be restored as the soil organic matter may increase, while having a positive effect on the soil quality (Ogunwole *el al.*, 2008) and at the same time could enhance the productivity of rural poor farmers for livelihood.

The seeds represents up ~70% of the total weight of fruits (30% fruit shell/ fruit coat). After oil extraction, the high nutritive valued seed cake results as a by-product. Like other jatropha species, *J. curcas* is a succulent that sheds its leaves during the dry season (Heller, 1996) to reduce water loss and adopt drought stress. These jatropha residues contain many toxic substances for animals feeding, all these molecules such as: phorbol esters, curcains, trypsin inhibitors and others make really complicated the whole detoxification process (Heller, 1996). Therefore, alternatively, cake together with other residues namely, fruit shell and leaves can be recycled to improve the quality of soil. Further, recycling of nutrient is necessary to maintain the soil fertility, decreasing input requirements and costs for sustainable jatropha cultivation, especially in marginal lands. However, the role of these residues in nutrient cycling and ecosystem function is not well understood. Non-thermal management of these residues holds potential to add organic matter to soils and thus can be a source of nutrients (Dossa *et al*., 2009).

Nutrient release from the plant residues regulated by their chemical composition as well as abiotic and biotic factors of soil (Mafongoya *et al*. 2000) which alter the C and N mineralization potentials and decomposition patterns. Although the C/N ratio or N related indices are major governing determinant (Dossa *et al*., 2009), other factors like, lignin, cellulose, polyphenolic content also control nutrient release dynamics during decomposition of residues (Iyamuremye *et al*., 2000; Dossa *et al*., 2009). Knowledge of litter quality may help conserve soil resources. The question remains, how the jatropha residue will affect dynamics of C and N in soil as residues contain toxic phorbol esters (Heller, 1996) that might affect soil processes.

Shrubs in arid and semi-arid environments can dramatically influence and alter spatial distribution of soil resources (Schlesinger *et al*., 1996), C and N cycling (Diack *et al*., 2000; Dossa *et al*., 2009), soil moisture (Whitford *et al*., 1997), and create microclimate for favoring conductive environment for microbial activities (Zheng *et al*., 2008) under canopy area of shrub compared to outside-canopy area which may influence mineralization and nutrient availability in soil. A number of physical and biological mechanisms cause these increases in resource availability, including the concentration or organic material due to leaf fall, pruning materials and root sequestrations. However, little is known about these processes in jatropha production system.

The most important aspect towards understanding the ecological processes and effective management of jatropha cultivation on wastelands/ marginal lands and understanding of C and N mineralization from its residues (cake, leaf and fruit shell) is fundamentally essential. We hypothesize that jatropha canopy will

increase the variability of soil properties distribution and C and N mineralization pattern of added jatropha residues with different chemical composition. Therefore, the objective of this study was to determine whether C and N release pattern change during decomposition of different jatropha residues amended in inside and outside-canopy soil of shrub.

2. Materials and Methods

2.1. Soils and plant materials

The soil samples were collected from Delol village, Godhra, Panchmahal District which is in the eastern part of Gujarat, India (22° 38´N; 73° 45´E). The average annual rainfall is approximately 728 mm and temperature ranges from 22 °C (minimum) to 44 °C (maximum). The soil has loamy texture and is classified as fine loamy mixed, hyperthermic Fluventic Ustochrepts as per USDA taxonomy. Jatropha is growing as hedges around the agricultural fields as live fence for protection from animals.

Three shrubs of jatropha with canopy circumference 5-8 m, height 2.5-3.5 m and 4-8 years old were randomly selected for soil sampling. In November 2010, soil samples were collected randomly with a shovel from 0-20 cm depth at five random locations beneath (middle of canopy) and outside of the shrub canopy (1.5 to 3 m away from canopy). These soil samples were composited homogenized then crushed to pass through 2 mm sieve and maintained at field moisture separately (inside and outside-canopy soil). Jatropha residue samples (leaf and fruit) were collected from Jatropha Experimental Farm of Central Salt and Marine Chemicals Research Institute (CSMCRI) at Chorvadla (21° 40´N, 71° 46´ E) in Gujarat State, India. Fruits were dehusked to separate the fruit shell (fruit cover) and seed. The seeds were deoiled in oil expeller and deoiled cake was used for further experiment. Composite samples of jatropha residues (cake, leaf, and fruit shell) were dried at 50 °C for 4 days and individually chopped to 2 mm and subsequent used for soil amendments. The experiment was laid out in a completely randomized design (CRD) having two soils (inside and outside the jatropha canopy) and four residue treatments (cake, leaf, fruit shell or control only).

2.2. Carbon and nitrogen mineralization incubation study

The carbon mineralization study was carried out according to method of Anderson (1982) with some modification. Triplicate fifteen grams (dry weight basis) of soil were homogenized with 0.15 g (1% w/w) of jatropha residues (cake, leaf and fruit shell) in 100 mL beaker and transferred into a 1L glass jar with alkali trap consisting of 10 mL of 0.3M KOH. Soil moisture adjusted to 20% (w/w) and jars were tightly closed and incubated 25 °C for 95 days. The alkali traps were replaced at 1, 2, 7, 12, 18, 25, 33, 39, 45, 53, 66, 84 and 95 days depending on the rate of CO_2 evolution. Unreacted alkali in the KOH trap was back titrated with 0.1M HCl to determine CO_2-C (Nelson and Sommers, 1982). Cumulative CO_2 was calculated for each sampling date as mg C-CO_2 per kg soil. After each sampling, jars were opened, aerated replaced with alkali trap and soil moisture was adjusted gravimetrically.

The nitrogen mineralization study was conducted on the same soil as C mineralization study following the methods of Standford and Smith (1972) with some modification (Dossa *et al*., 2009). Triplicate 40 g samples of soil mixed with 0.4 g of jatropha residue amendments were transferred into leaching tubes with the bottom packed with glass wool. A thin layer of glass wool was also placed over the soil to minimize the soil dispersion when leaching solution was poured into the tube. Initially N was removed by leaching with 30 mL of 0.01M $CaCl_2$ solution in three increments followed by 20 mL of a nutrient solution devoid of N (0.002*M* $CaSO_4.2H_2O$, 0.002*M* $MgSO_4$, 0.005*M* $Ca(H_2SO_4)_2.H_2O$ and 0.0025*M* K_2SO_4).

Excess solution was removed under vacuum (60 cm Hg). This leaching procedure was repeated at each sampling day. The tubes were covered with parafilm with small hole in the center for aeration and incubated at 25 °C. Samples were leached after 1, 9, 21, 33, 64 and 94 days. Mineral N in the leachates was analysed for NO_3^--N and NH_4^+-N by ion chromatography (DIONEX 500) equipped with CS12 and AS11 columns for cation and anion, respectively. Net mineralization of applied C and N was calculated by subtracting the control soil from residue treatment on respective sampling day.

2.3. Soil and plant analysis

The pH and EC were analysed with glass electrode and conductivity meter, respectively in 1:2.5 soil to water ratio. Soil organic C was determined by the Walkley- Black wet oxidation method (Nelson and Sommers, 1982). Total N in soil, and total N and C in jatropha residues were determined by combustion on Elmentar Vario MICRO cube (Elementar Analysensystene, GmbH, Germany). Lignin, cellulose and hemicelluloses were determined by the methods of Goering and Van Soest (1970). The phenolic content was extracted with 80% ethanol and determined by Folin-Ciocalteau reagent (Malick and Singh, 1980) using gallic acid as standard.

2.4. Kinetic models and statistical analysis

The mineralization potential and the rate constants were estimated using first order exponential function: $N_t = N_o(1\text{-}e^{-}kt)$, where N_o = potentially mineralizable C or N, N_t = cumulative amount of C or N mineralized, k = mineralization rate (day^{-1}), t = time of incubation (days).

Effect of jatropha residue amendment on C and N mineralization during incubation period was analyzed by one way ANOVA using SigmaPlot 12.0 (Systat Software, Inc., San Jose, CA, USA) separately for both soils. Two way ANOVA was carried out to find the interaction effects between residues and soils, considering soils as one fixed factor and the jatropha residue treatment as the other. Fisher's least square difference was used to differentiate treatments within each sampling data (p <0.05) using SigmaPlot 12.0 software. Pearson correlation was used to examine the relationship between jatropha residue quality and C, N mineralization rates.

3. Results

3.1. Chemical analysis of soil and jatropha residues

Organic C and mineral N concentration of soil used in incubation study showed higher levels in inside compared to outside-canopy soil. Whereas, total N (0.72 kg^{-1} soil) was similar in both soils. Similarly, pH and EC values were higher in inside-canopy soil than to outside-canopy soil of jatropha shrub (Table 1). The jatropha residue showed a wide variation in chemical composition (Table 2). Nitrogen (3.3%), carbon (46%) and cellulose (14.4%) contents of cake were higher than those of leaf and fruit shell. Hemicellulose (17.7%), lignin (5.5%) and phenolic (3.3%) contents were higher in leaf compared to their contents in other jatropha residues. Among all the jatropha residues, the lowest hemicelluloses (12.5%) and lignin (1.3%) contents were found in cake (Table 2). However, phenolic content (0.46 mg g^{-1}) was lowest in fruit shell and highest in leaf (3.3 mg g^{-1}). These jatropha residue amendments had a wide range of C:N ratios, i.e. from 13.9 to 42.9.

3.2. Carbon mineralization

Results of cumulative CO_2 evolution with time of incubation are shown in Figure 1. These data revealed that, at any given time, cumulative CO_2 evolved was significantly greater in jatropha residue amended soils (inside as well outside-canopy soil) compared to that in the control soil. Jatropha cake decomposed more quickly and produced significantly higher CO_2 from day 1 to 25 and 1 to 18 days, respectively in inside and outside-canopy soil, whereas cake and fruit shell amended soils evolved similar rate of CO_2 on day

33 and 25 to 33 days in inside and outside-canopy soils, respectively. Thereafter, fruit shell amended soils evolved significantly higher amount of CO_2 compared with other treatment till end of incubation study. Cumulative CO_2 evolution from control soil was significantly lower compared to jatropha residue amended soils throughout incubation study. Leaf amended soils had significantly higher CO_2 evolution compared to cake amended from day 84 and 66 till end of incubation in inside and outside-canopy soil, respectively but it was significantly lower than fruit amended soil.

Table 1. Characteristics of soil used for incubation study

Soil location	pH	EC (dS m^{-1})	$CaCO_3$ (%)	O.C. (%)	C/N	Total N (g kg^{-1})	Available N (mg kg^{-1})	Texture
Inside-canopy soil	7.41	0.14	0.92	0.67	9.57	0.72	47.6	Loam
Outside-canopy soil	7.31	0.11	0.92	0.60	8.57	0.72	41.3	Loam

Table 2. Chemical characteristics of jatropha residues

Jatropha residues	C (%)	N (%)	C/N	Cellulose (%)	Hemi-cellulose (%)	Lignin (%)	Phenolics (mg/g)
Cake	46	3.30	13.94	14.44	12.46	1.25	1.91
leaf	43	1.22	35.25	8.96	17.71	5.48	3.32
Fruit shell	42	0.98	42.86	6.85	15.78	1.82	0.46

Irrespective of residue amendment, cumulative CO_2 evolution was significantly higher in inside-canopy soil compared to outside-canopy soil (except day 1, 18, 25 and 39) during the incubation period. Two way ANOVA revealed that inside-canopy soil amended with fruit shell and leaf have evolved significantly higher CO_2 at early stage (day 2 and 7) and later stage (day 66, 84 and 95) of incubation, respectively compared to outside soil.

By end of the incubation study, the order of cumulative CO_2 evolved was as follows: fruit shell > leaf > cake > control soil. Net C mineralization from jatropha cake amended soil had significantly higher from day 1 to 25 and 1 to 18 days, respectively in inside and outside-canopy soil, whereas fruit shell amended soils had significantly higher net C mineralization compared with other treatment from day 39 to till end of incubation study in both soils (Figure 2). Net C mineralized in soils at day 95 as a result of organic amendments varied from 46-50, 66-67 and 75-77% of C added by cake, leaf and fruit shell, respectively. At the end of incubation study, Net C mineralization was higher in all treatments for inside-canopy soil than outside-canopy soil.

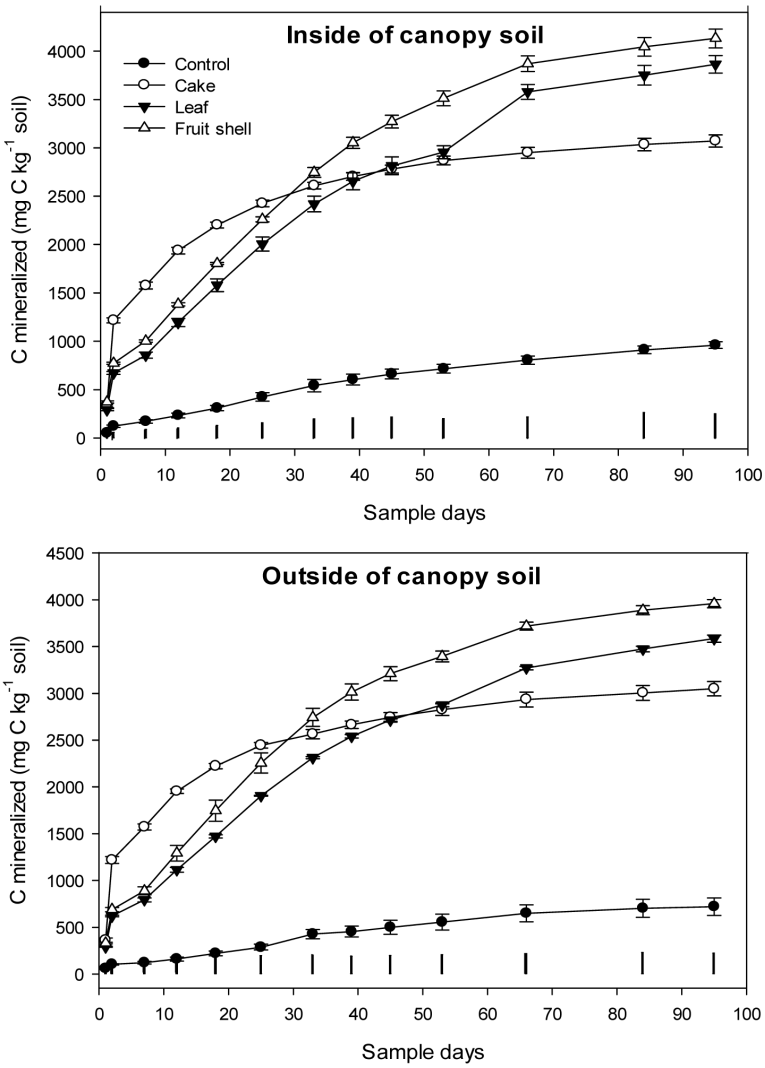

Figure 1. Cumulative CO_2 evolved from inside and outside-canopy soils of *Jatropha curcas* amended with jatropha residues. Bars represent Fisher's least difference ($p < 0.05$). Error bars indicate standard error.

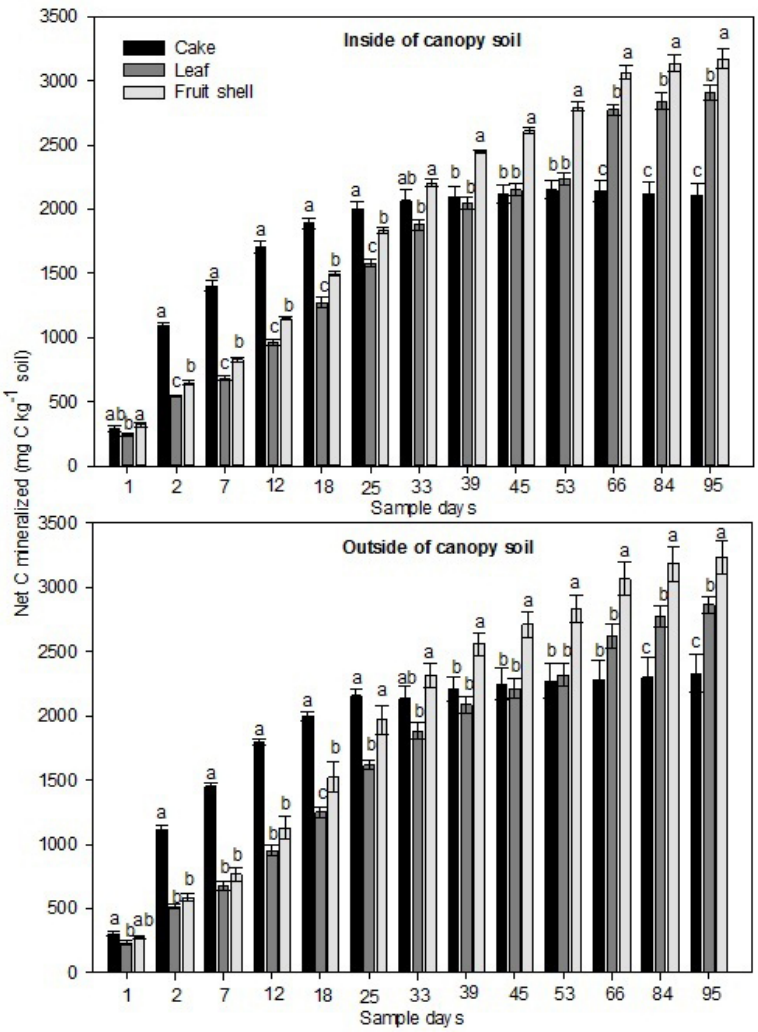

Figure 2. Net carbon mineralized in comparison to control from inside and outside-canopy soils of *Jatropha curcas* amended with jatrpha residues. Error bars indicate standard error. Different letters denote statistically significant differences ($p < 0.05$) within each sampling day.

The relationship between rate of CO_2 release at different stage of mineralization and quality of jatropha residues are presented in Table 3. The initial CO_2 evolution rate was significantly and positively correlated with C, N and cellulose contents whereas, it correlated negatively with hemicelluloses, lignin contents and C/N ratio. Nevertheless, this relationship was reversed at advanced stage of incubation. Phenolic content were negatively correlated to rate of CO_2 evolution at intermediate stage of incubation.

3.3. Nitrogen mineralization

The cumulative concentrations of mineral N (NO_3-+NH_4^+) released with time of incubation of soil with jatropha residue is presented in Figure 3. Mineral N detected in soil released from added organic matter was highest for cake amended soils throughout the incubation period (day 1 to day 94) in both inside and outside canopy soil compared to other residue and the control, showing there was net N mineralization. Mineral N release in leaf amended soil on day 64 and 94 was statically identical to control soil. The net N mineralized in cake amended soil ranged from 18.7 to 302.4 mg N kg^{-1} soil and 36.1 to 249.1 mg N kg^{-1} in inside-canopy and outside-canopy soil, respectively during in incubation period (Figure 4). Leaf residue amended soils immobilized N up to day 64 and 33, respectively in inside-canopy and outside canopy soil respectively, whereas, fruit shell amended soil net N immobilized throughout the incubation study in both soils (Figure 4). On day 1, there was no significant change in mineral N released from leaf and fruit shell amended soils compared with control soil but thereafter, release of mineral N was significantly decreased from day 9 to 33 and day 9 to 94 in leaf and fruit shell amended soil, respectively over control soil resulted in net N immobilization. The net N immobilization in leaf amended soil ranged from 2.4 to 27.72 mg N kg^{-1} soil and 7.7 to 20.0 mg N kg^{-1} in inside-canopy and outside-canopy soil, respectively whereas these respective values were 11.4 to 33.6 mg N kg^{-1} soil and 7.4 to 27.52 mg N kg^{-1} in fruit amended soils (Figure 4).

Irrespective of residue amendment, inside-canopy soil had mineralized significantly higher amount of N at day 64 and 95. Two way ANOVA revealed that inside-canopy soil mineralized significantly high N on day 9, 21 and 64 compared to outside control soil. Further, N mineralized from cake amended soil behave differently, it was significantly increased inside-canopy soil on day 1 and 9 whereas, significantly decreased on day 64 and 94 compared to inside-canopy soil.

Cumulative N released by the end of the incubation was as follows: cake > leaf > control > fruit shell in both soils inside and outside-canopy (Figure 3). Net N mineralized in soils at day 94 as a result of jatropha residue amendments varied from 75-92 and 21-27% of N added by cake and leaf, respectively whereas there was net N immobilization in fruit shell amended soil. At the end of the experiment, soils inside the canopy amended with jatropha cake had significantly higher cumulative mineral N than soils outside the canopy although in other treatments of inside-canopy soil had higher cumulative N than outside-canopy soil.

There was a significant relationship between rate of N mineralization and chemical characteristics of jatropha residues (Table 3). The rate of N mineralization was positively and significantly correlated with C, N and cellulose contents but negatively with hemicellulose, lignin content and C/N ratio, however, there was no effect of phenolic content.

3.4. Mineralization models

The first order kinetic model provided a good fit to C mineralization data with R^2 ranged between 90 to 99% (Table 4). The first order rate constants for jatropha cake amended soil (0.104 and 0.110 day^{-1}, respectively for inside and outside-canopy soil) were significantly higher than those of all other treatments followed by that in fruit shell amended soils which was statistically similar to leaf amended soil. Further, lowest rate constant (0.019 and 0.018 day^{-1}, respectively for inside and outside-canopy soil) was observed in control soil.

Table 3. Correlation coefficient of jatropha residue characteristics with daily mineralization rate for C and N during incubation study. * and ** denotes level of significant at $p < 0.05$ and $p < 0.01$, respectively.

Rate at day	C	N	Cellulose	Hemicellose	Lignin	Phenolic	C/N ratio
Carbon mineralization							
1	0.18	0.28	0.16	-0.56*	-0.72**	-0.64**	-0.17
2	0.92**	0.96**	0.90**	-0.96**	-0.70**	-0.13	-0.91**
7	0.91**	0.96**	0.90**	-0.96**	-0.71**	-0.14	-0.90**
12	0.87**	0.93**	0.86**	-0.97**	-0.75**	-0.21	-0.87**
18	0.78**	0.86**	0.77**	-0.96**	-0.81**	-0.34	-0.78**
25	0.56*	0.66**	0.54*	-0.88**	-0.89**	-0.57*	-0.55*
33	-0.13	0.12	-0.15	-0.39	-0.73**	-0.86**	0.14
39	-0.49*	-0.37	-0.51*	-0.03	-0.50*	-0.85**	0.50*
45	-0.64**	-0.54*	-0.66**	0.14	-0.36	-0.80**	0.65**
53	-0.72**	-0.62**	-0.74**	0.24	-0.28	-0.77**	0.73**
66	-0.91**	-0.88**	-0.92**	0.64**	0.19	-0.41	0.92**
84	-0.93**	-0.90**	-0.94**	0.69**	0.25	-0.36	0.93**
95	-0.94**	-0.92**	-0.95**	0.73**	0.30	-0.31	0.94**
Nitrogen mineralization							
1	0.95**	0.97**	0.94**	-0.91**	-0.59*	0.01	-0.94**
9	0.95**	0.97**	0.94**	-0.92**	-0.61**	-0.02	-0.94**
21	0.96**	0.99**	0.95**	-0.93**	-0.61**	-0.01	-0.96**
33	0.97**	0.99**	0.96**	-0.93**	-0.61**	0.01	-0.96**
64	0.98**	0.99**	0.98**	-0.88**	-0.52*	0.11	-0.98**
94	0.99**	0.99**	0.98**	-0.85**	-0.48*	0.17	-0.98**

Regardless of soil, significantly higher C mineralization potential was observed in fruit and leaf amended soil compared to cake amended and control soil.

The cumulative N mineralization data could not be fitted to first order kinetic model (low R^2 and lack of convergence). The mineralization of N by cake and leaf followed roughly two patterns. In case of cake, slow release of N was observed upto day 9 which was followed by sharply increase, whereas, in case of leaf amended soil N immobilization was observed upto day 64 following which mineralization occurred. Immobilization of N without net release during the entire 94-day incubation period was observed in fruit shell amended soil.

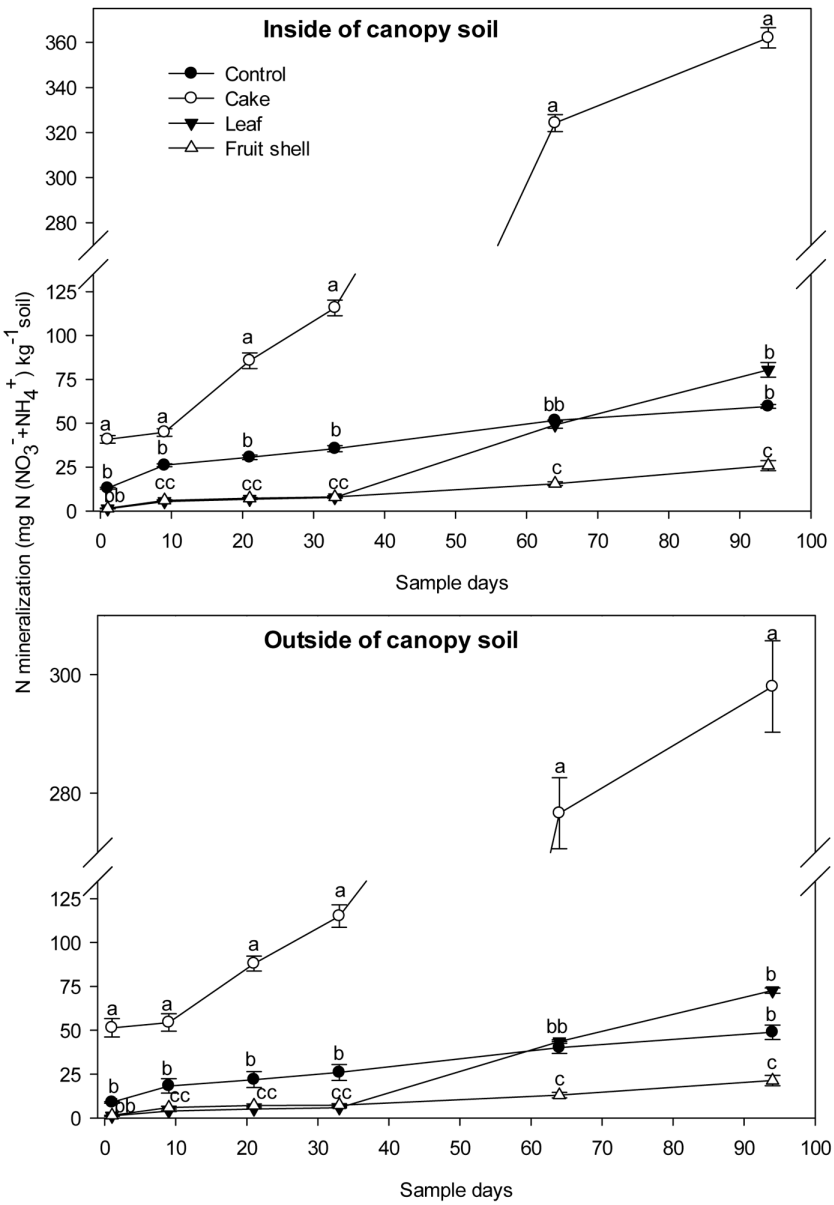

Figure 3. Cumulative mineral N released from inside and outside-canopy soils of *Jatropha curcas* amended with jatrpha residues. Error bars indicate standard error. Different letters denote statistically significant differences ($p < 0.05$) within each sampling day.

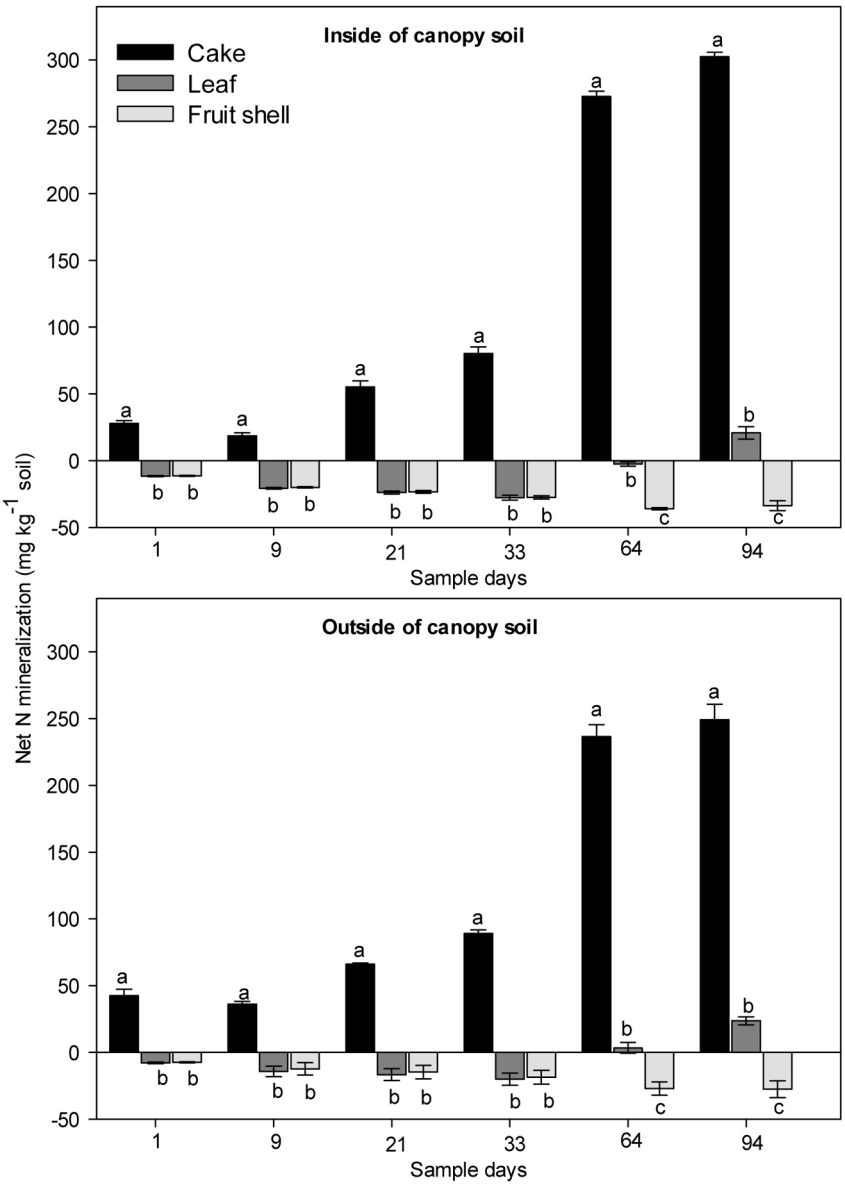

Figure 4. Net mineral N released in comparison to control from inside and outside-canopy soils of *Jatropha curcas* amended with jatrpha residues. Error bars indicate standard error. Different letters denote statistically significant differences ($p < 0.05$) within each sampling day.

Table 4. Parameter values for first order exponential model to describe the C mineralization in jatropha residues amended soil. Values in parentheses denote the standard error; different letters in column denote statistically significant differences within soil ($p < 0.05$).

	First order exponential function		
Treatments	**C potential (mg kg^{-1})**	**k (day^{-1})**	**R^2**
	Inside-canopy soil		
Control	1158.80 (41.12)c	0.019 (0.003)c	0.99
Cake	2851.63 (48.06)b	0.104 (0.000)a	0.90
Leaf	4166.70 (80.69)a	0.026 (0.001)b	0.98
Fruit shell	4345.39 (122.55)a	0.031 (0.001)b	0.98
	Outside-canopy soil		
Control	905.38 (139.45)d	0.018 (0.001)c	0.98
Cake	2813.79 (67.14)c	0.110 (0.006)a	0.90
Leaf	3814.27 (65.67)b	0.028 (0.001)bc	0.98
Fruit shell	4181.77 (75.84)a	0.032 (0.003)b	0.99

4. Discussion

4.1. Residue source and carbon mineralization

Carbon mineralization pattern studied using CO_2 evolution from laboratory incubated soil amended with different jatropha residues. Mineralization rates observed in laboratory may not depict the true rates taking place under field condition (Diack *et al*., 2000; Dossa *et al.*, 2009) however, this mineralization study will provide meaningful informations on potential of these residues intended to be used for amendment in jatropha production system for supply of nutrient and carbon sequestration. The pattern of C mineralization differed for jatropha residues and location of soil (inside and outside-canopy soil). In all jatropha residues amended soil showed an initially fast mineralization followed slow and later nearly constant rate (Figure 1) which reflect the mineralization of C with varying quality composition of residues (Table 2). The CO_2 evolution during initial (7 days) exceeded more than 50% of total cumulative CO_2 in cake amended soil but during the same period, 22 and 24% CO_2 of total cumulative CO_2 were evolved in case of leaf and fruit amended soil, respectively (Figure 1). Initial mineralization of C is associated with easily degradable compounds such as sugars, starch and utilization of readily available energy sources by microbes and loss of water-soluble components and non-structural carbohydrates from the residues (Bloomfield *et al*., 1993). Later phase of C mineralization represents the relatively higher percentage of difficult to decay (recalcitrant) fractions like cellulose, lignin and tannin which are known to control decomposition rate owing resistance to enzymatic attack and physical protection to chemical fractions of the cell wall (Alexander, 1977). In the beginning of incubation (up to day 25), cake amended soil evolved significantly higher CO_2 than other treatments but later (after day 33 till end of incubation) cumulative CO_2 evolution in fruit shell amended soil was significantly higher.

Similarly, net C mineralization from jatropha cake amended soil significantly higher at initial days of incubation period whereas, fruit shell amended soils had significantly higher net C mineralization at later stage of incubation of incubation in both soils (Figure 2). In our previous study, soil amended with cake had significantly higher total FAME (fatty acid methyl ester, indicator of microbial biomass) concentration and greater enzyme activities than did soils amended with leaves or fruit shell at beginning of incubation but at advanced stage of incubation, similar concentration was observed in leaf and fruit amended soil (Chaudhary *et al*., 2011). Additionally, our observation also confirmed the previously reported pattern that residues with higher N concentration and low C/N ratio can accelerate the initial C mineralization in comparison to residues with low N concentration and higher C/N ratio (Li *et al*., 2011). Higher CO_2 evolution in fruit shell amended soil compared to leaf amended soil might be due to low lignin and low phenolic contents in fruit compared to leaf (Table 2).

Rate of CO_2 evolution at end of incubation significantly correlated with different residue chemical characteristics. The CO_2 evolution rate on 95 days was correlated positively with hemicelluloses ($r=0.73$, $p < 0.001$) and C/N ratio ($r=0.94$, $p < 0.94$) but negatively with N ($r=-0.92$, $p < 0.001$) and cellulose ($r=-0.95$, $p < 0.001$) as presented in table 3. However, phenolics and lignin were not correlated significantly. Early mineralization rate was highly correlated with C, N, cellulose but correlation coefficient decreased and became negative at later stage of decomposition as also confirmed by Mafongoya *et al*. (2000), Trinsoutrot *et al*. (2000), Jensen *et al*. (2005) and Peters and Jensen (2011). Residue decomposition increases with increasing N concentration and decrease with increasing concentrations of cellulose and lignin as reported by Kazakou *et al*. (2009). The rate of carbon mineralization in initial period was positively related to C content which gets mineralized and the present results confirm the work of several authors (Trinsoutrot *et al*., 2000; Jensen *et al.*, 2005). As decomposition proceeded, the proportion of soluble C had less influence on rate of C mineralization; more resistant C compounds will come in existence. Initially, soluble /inorganic N control the kinetics of C mineralization (Trinsoutrot *et al*., 2000) and in longer term N could a negative effect on decomposition, as we also observed in present study (Table 3). A high N availability is also known to inhibit the synthesis of ligninolytic enzyme (Keyser *et al*., 1978) and have a negative effect of high soil N availability on decomposition (Berg and Matzner, 1997). The rate of C mineralization was negatively correlated with lignin content might be due to less C being available for mineralization in presence of higher amount of lignin (Peters and Jensen, 2011). Furthermore, contradictory results were also observed for cellulose and hemicelluloses contents with C mineralization (Jensen *et al*., 2005).

Cumulative CO_2 evolution from soil amended with different jatropha residues was well described by the first order exponential model with R^2 from ranging 90 to 99% (Table 4). Many researchers have fitted C mineralization data with first order exponential model (Dossa *et al*., 2009; Aulen *et al*., 2012).

Irrespective of soils, C mineralization rate constant was highest in cake amended soil followed by fruit and leaf amended soil (Table 4). The values obtained in present investigation in different residues were similar to those found by Kumar and Goh (2003) with incorporated peas and white clover residues (0.095-0.148) but were somewhat higher than reported by Thonnissen *et al*. (2000) with incorporated soybean (0.01). The above differences might drive from the slightly different methodologies in the respective studies and/or differences in biochemical properties of residues.

4.2. Residue source and nitrogen mineralization

The N mineralization pattern of the residues closely reflected the differences in their chemical composition. Immobilization of N took place in leaves and fruit shell amended soil which occurred until 64 and entire period of incubation, respectively, although, there was a net mineralization of N in cake amended soil (Figure

3 and Figure 4). Mineralization and immobilization occur simultaneously when organic residues are incorporated to soil (Palm and Sanchez, 2000). Highest cumulative N release was observed in cake amended soil followed by leaf, control and fruit shell amended soil which could be attributed to the fact that cake had higher N (3.30%), low C/N ratio (13.94), hemicelluloses and lignin which caused a net N mineralization compared to leaf and fruit shell (Table 2). Reduced N mineralization by leaf and fruit shell addition may be due to the reason that N added by both might not be enough for microbes. Nitrogen inputs from residue decomposition contribute to meet the N requirements of the decomposers, and they produce a stimulating effect on C mineralization. The activity of soil microorganisms depends mainly on the quantity of mineralizable substrate and N availability (Li *et al*., 2011). It was reported that net N mineralization occurs only when N concentration of plant residue is above 2% (Palm and Sanchez, 2000). Jatropha leaves and fruit shell have low N content coupled with higher C/N ratio that resulted in net immobilization of N (Figure 4) thus N limitation for the decomposition these residue. Soil amended with residues containing high C/N ratio, lignin and hemicellulose showed N immobilization (Palm and Sanchez, 2000; Jensen *et al*., 2005).

Daily rate of N mineralization by jatropha residues was found to be positively correlated with C, N and cellulose, whereas negatively with hemicelluloses, lignin and C/N ratio of residues (Table 3). It has been hypothesized that the total N concentration or ratio C/N ratio determine whether N mineralization or immobilization will dominate during the decomposition of plant residues (Jensen *et al*., 2005; Peters and Jensen, 2011). The negative correlation of lignin and hemicelluloses with N mineralization rate has also been previous reported (Palm and Sanchez, 2000; Dossa *et al*., 2009). Lignin is resistant to rapid microbial decomposition and it can promote the formation of a complex phenyl-propanol structure, which often encrusts the cellulose-hemicellulose matrix (Sanger *et al*., 1996).

The N mineralization data could not be fitted to decomposition curves. The N mineralization of decaying jatropha residues followed three different patterns. One type of residue (leaf) immobilized N upto 64 days, which was followed by a net mineralization. Second type of residue (fruit shell) immobilized N throughout incubation. Third type of residue (cake) mineralized N throughout incubation. As in other studies (Iyamuremye *et al*., 2000; Dossa *et al*. 2009), N mineralization was not successfully fitted in the N release models because the results did not obey the mineralization model proposed by Stanford and Smith (1972).

5. Conclusions

Our observations showed that the jatropha cake amended soil evolved more cumulative CO_2 than other treatments up to day 25 of incubation but cumulative CO_2 evolution at the end of the incubation was as follows: fruit shell > leaf > cake > control. Inside-canopy soil had higher CO_2 evolution and N release suggesting there was more C and N mineralization potential, greater microbial or active biomass than outside the canopy soil. Net C mineralized in soils were in the range of 46-50, 66-67 and 75-77% of C added by cake, leaf and fruit shell, respectively at the end of incubation study. Net N immobilization occurred during the first 64 days but later had net N mineralization in leaf amended soils. Cumulative N released by the end of the incubation was as follows: cake > leaf > control > fruit. Net N mineralization in soils during the study was 75-92 and 21-27% of N added by cake and leaf, respectively whereas there was net N immobilization in fruit shell amended soil. Findings of present study suggests that cake could be a potential source of mineral N but for other residues supplemental addition of mineral or other nutrient rich organic fertilizers would be needed for sustained release of mineral N; however, these residue have potential for soil carbon sequestration for deteriorated ecosystem. It is further inferred that the jatropha shells has the great potential for N immobilization, hence it should be further studied on long- term basis.

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