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Relative contribution of trees and crops to soil carbon content in a parkland system in Burkina Faso using variations in natural ^{13}C abundance

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Abstract

The origin of organic matter was studied in the soils of a parkland of karité (*Vitallaria paradoxa* C.F. Gaertn) and néré (*Parkia biglobosa* (Jacq.) Benth.), which is extensively cultivated without the use of fertilisers. In such systems, fertility (physical, chemical and biological) gradients around trees have been attributed by some authors to a priori differences in fertility, allowing for better tree establishment on richer sites. In reverse, other workers believed that these gradients are due to the contribution of trees to the formation of soil organic matter through litter and decay of roots. Measurements of the variations in the ^{13}C isotopic composition allowed for a distinction between tree (C_3) derived C and crop and grass (C_4) derived C in the total soil organic C content. The organic carbon contents of the soils were recorded under the two species at two soil depths and at five distances going from tree trunk to the open area and their C isotopic signatures were analysed. The results showed that soil carbon contents under karité (6.43 ± 0.45 g kg^{-1}) and néré (5.65 ± 0.27 g kg^{-1}) were significantly higher ($p < 0.01$) than in the open area (4.09 ± 0.26 g kg^{-1}). The δ^{13}C of soil C was significantly higher ($p < 0.001$) in the open area (-17.5 ± 0.3‰) compared with the values obtained on average with depth and distance from tree under karité (-20.2 ± 0.4‰) and néré (-20.1 ± 0.4‰). The C_4-derived soil C was approximately constant, and the differences in total soil C were fully explained by the C_3 (tree) contributions to soil carbon of 4.01 ± 0.71, 3.02 ± 0.53, 1.53 ± 0.10 g kg^{-1}, respectively under karité, néré and in the open area. These results show that trees in parklands have a directly positive contribution to soil carbon content, justifying the need to encourage the maintenance of trees in these systems in semi-arid environments where the carbon content of soil appears to be the first limiting factor for crop growth.

Introduction

The coexistence of woody plants and grasses in subtropical and tropical savanna ecosystems, called parklands, is currently of great interest due to the rate at which relative tree abundance declines by human influence, especially through manipulation of fire, grazing and bush clearing to create crop fields. In parkland systems, the woody plant component is comprised exclusively of C_3 species and the crops of C_4 species (including grass weeds). Therefore, δ^{13}C values of the soil organic matter can be used to document the relative contributions of these two components of parklands to the soil organic carbon (SOC) contents in savanna region (Balesdent and Mariotti 1996; Boutton 1996; Andriulo et al. 1999; Diels et al. 2001).

The soil carbon contents constitute one of the factors essential for assessing the sustainability of cropping systems and their effect on the environment particularly in region with kaolinite as the main type of clay in the soils (Andriulo et al. 1999; Bationo and Buerkert, 2001). For their contribution to soil carbon contents, trees have a different impact on soil properties than annual crops, because of their longer residence time, larger biomass accumulation, and longer-lasting, more extensive root systems. In natural forests nutrients are efficiently cycled with very small inputs and outputs from the system (Sanchez et al. 1997). In most agricultural systems the opposite happens. Agroforestry encompasses the continuum between these extremes, and emerging hard data is showing that successful agroforestry systems increase nutrient inputs, enhance internal flows, decrease nutrient losses and provide environmental benefits, when the competition for growth resources between tree and the crop component is well managed (Sanchez et al. 1997). Therefore, there is a strong need to develop research activities on soil C sequestration as this is truly a win-win situation (Lal 2002). Above- and below-ground carbon sequestration values, however, need to be generated locally, taking into account the duration of each agroforestry system, and extrapolated geographically in a realistic fashion, based on actual rates of agroforestry adoption (Sanchez et al. 1997).

Although fertility gradients around trees have been well studied (Breman and Kessler 1995; Belsky and Amundson 1998), the hypothesis that these differences reflect a priori differences in fertility, allowing for better tree establishment on richer sites, forms an alternative to the explanation based on soil improvement by the trees (Brouwer et al. 1993; Van Noordwijk and Ong 1999).

Our aim was to investigate the contribution to soil carbon accumulation of tree and crop (and grass) components of agroforestry parklands using the natural ^{13}C tracer technique. We hypothesized that tree component would have a higher contribution to soil organic carbon than crops.

Materials and methods

Study site and tree species studied

The study was carried out in the parklands of the village of Saponé (12°03′ N and 1°43′ W and at an altitude of 200 m), the characteristics of which have been described in Bayala et al. (2002). Soil density and texture data are shown in Table 1 displaying a slight non-significant higher clay content under karité compared to néré as well as under both tree species compared to their open areas (Bayala, Unpublished data). The mean rainfall of the last 10 years was 728 mm. Annual evapotranspiration (ETP_{Penman}) is 1963 mm whereas annual maximum temperature is 34.9 °C and the minimum is 21.5 °C (Sivakumar and Gnoumou 1987). According to FAO (1988) classification the major soils types are Ferric/Luvisols.

The dominant tree species of agroforestry parkland systems in Saponé are *Vitellaria paradoxa* and *Parkia biglobosa*. *V. paradoxa* (known as karité in French and shea butter tree in English) gives a variety of useful products including kernel, medicine, and fuelwood. Karité is the source of vegetable fat which, in Africa, is second in importance only to palm oil (Hall et al. 1996) and its primary traditional role is derived from this oil present in the kernels. Karité belongs to Sapotaceae family. It can grow upto 15 m height and its leaves are as large as 12–25 cm. This species occurs within a belt ranging from 1°00′ N to 34°35′ E and 13°53′ N, 16°21′ W (Hall et al. 1996). *P. biglobosa* (known as néré in French and locust bean in English) is found in savannah zones with a natural range extending from 5° N to 15° N and 16° W to 32° E (Hopkins and White 1984). It is a large tree, up to 20 m high, with a wide-spreading crown. *P. biglobosa* belongs to family Mimosaceae, with small leaflets; 0.8–3.0 × 0.2–0.8 cm (Maydell 1983), but it doesn't fix atmospheric N_2 (Dommergues 1987; Tomlinson et al. 1998). The tree yields a condiment locally called '*soumbala*' (type of cheese

Table 1. Soil physical properties according to tree species, distance from the trunk and soil depth under karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in an agroforestry parkland system in Saponé, Burkina Faso.

Species	Zone	Depth (cm)	Density (mg m^{-3})	pH-water	pH-KCl	Texture (%)		
						Clay <2 μm	Silt 2–50 μm	Sand 50–2000 μm
Karité	A	0–10	1.60	6.59	6.23	21	8.9	70.1
Karité	A	10–30	1.72	6.61	6.29	22	13.6	64.4
Karité	B	0–10	1.58	7.27	6.64	9.5	18	72.5
Karité	B	10–30	1.70	6.46	6.12	17	18.4	64.6
Karité	C	0–10	1.59	6.74	6.50	9.5	19.5	71
Karité	C	10–30	1.71	6.03	5.46	20.8	17.5	61.7
Karité	D	0–10	1.61	6.39	6.14	8.3	19.7	72
Karité	D	10–30	1.73	5.87	5.23	20.5	17.5	62
Karité	Control	0–10	1.63	6.17	5.55	6.5	17.5	76
Karité	Control	10–30	1.75	5.60	5.02	17.7	15.5	66.8
Néré	A	0–10	1.57	7.18	6.72	9.3	23.6	67.1
Néré	A	10–30	1.68	7.29	6.81	18.5	24.7	56.8
Néré	B	0–10	1.53	6.55	6.43	8.8	27.4	63.8
Néré	B	10–30	1.64	6.46	6.30	19	23.7	57.3
Néré	C	0–10	1.60	6.91	6.29	7.2	22	70.8
Néré	C	10–30	1.71	6.14	5.70	19.2	21.5	59.3
Néré	D	0–10	1.63	6.29	6.08	6.8	24.2	69
Néré	D	10–30	1.74	5.86	5.25	17.2	21.2	61.6
Néré	Control	0–10	1.61	6.33	5.99	6.7	19.8	73.5
Néré	Control	10–30	1.72	5.87	5.11	22.3	19.8	57.9

made from seeds), food (pulp), medicine, and fuelwood (Hall et al. 1997).

The two species are scattered forming an open permanent overstorey of associated annual crops consisting of rotation of millet and sorghum without the application of fertilisers.

Sampling approaches

The samples comprised 5 types of material: soil, tree leaves and roots, crop straws and crop roots. Soil sampling was made under randomly selected eight trees including 4 trees of néré (*P. biglobosa*) and 4 trees of karité (*V. paradoxa*). The area around each of the 8 trees was subdivided into 4 concentric zones:

Zone A – from the base of each tree up to 2 m away from the tree trunk;
Zone B – from 2 m to half of the diameter of the crown (on average 1.1 and 3.1 m width for karité and néré, respectively);
Zone C – from half of the diameter of the crown up to the edge of the crown (on average 3.1 and 5.1 m width for karité and néré, respectively);
Zone D – from the edge of the crown up to 2 m outside of the crown; and
A control plot – an area of 4×4 m situated at least 40 m away from the edge of the crown of the selected sample trees to insure that it is not under the influence of any surrounding tree.

Soil samples under trees were taken at 4 points (corresponding to the 4 compass directions east, west, north and south) in each concentric zone and at 2 points in the control plot. Each point was sampled according to two depths, 0–10 and 10–30 cm. The 4 samples from each concentric zone and the 2 samples from each control plot were bulked and mixed thoroughly per soil depth to make a total of 10 samples per tree and a total of 80 for the 8 trees for the 2 species.

Senescent yellow leaves, which were about to fall, were collected from each of the 8 trees. Trees roots extracted during fine root distribution study (Bayala et al. 2004) were bulked and used in the present study. Crop straws and crop roots were collected at harvest. All these samples were oven dried at 70 °C, ground, sieved at 200 μm and analysed for C and ^{13}C in the Laboratoire d'Ecologie Microbienne de la Rhizosphère, CNRS/CEA/Université de la Méditerranée, France.

Laboratory analyses

The carbon content and $\delta^{13}C$ values of plant and soil samples were determined by dry combustion in a CHN autoanalyser (Thermofinnigan flash EA series 1112). This apparatus was coupled to an isotope mass spectrometer (Thermofinnigan DeltaPlus). The ^{13}C natural abundance was expressed in δ units (Eq. 1) in relation to VPDB reference using international standards AIEA C6 and IAEA CH7:

$$\delta^{13}C = (R_{sample} - R_{standard})/R_{standard} \times 10^3 \quad (1)$$

where $R = {}^{13}C/{}^{12}C$.

Each sample was analysed 3 times. The analysis was repeated when the difference between replicates from a single sample was more than 0.3‰.

Calculations and statistical analysis

The total soil C content, C_t the mixed trees-crops of parklands can be expressed as:

$$C_t = C_C + C_T \quad (2)$$

$$C_t \times \delta^{13}C_t = C_C \times \delta^{13}C_C + C_T \times \delta^{13}C_T \quad (3)$$

Where $\delta^{13}C_t$ is the $\delta^{13}C$ of the soil organic matter at sampling time, $\delta^{13}C_C$ is the $\delta^{13}C$ value of C_4 plants, i.e. the crops and grasses (average of straws and roots values was −11.7 ± 0.1‰ over a population of 12 samples of sorghum, millet, and bulk grasses), $\delta^{13}C_T$ is the $\delta^{13}C$ values of C_3 plants, i.e. trees (averages of leaves and roots values were −26.2 ± 0.4‰ and −27.9 ± 0.5‰ for karité and néré, respectively).

The fractions of soil C derived from trees (C_T) and crops and grasses (C_C) were calculated with a simple mixing model (Balesdent et al. 1988; Nyberg and Hogberg 1995):

$$C_T = C_t * (\delta^{13}C_t - \delta^{13}C_C)/(\delta^{13}C_T - \delta^{13}C_C) \quad (4)$$

$$C_C = C_t * (\delta^{13}C_t - \delta^{13}C_T)/(\delta^{13}C_C - \delta^{13}C_T) \quad (5)$$

With the hypothesis that R value is not modified with the maturation of organic matter derived from leaves.

The C contents derived from C_4 and C_3 were calculated for each zone by multiplying the fraction of each component by the content of soil organic matter at sampling time for each zone.

The difference between species, zones, and soil depths in all the above parameters was analysed using ANOVA General Linear Model (GLM). Data were analysed as a multifactorial design with three factors (species, zone and depth) and including all possible two-way interactions between these factors and the three-way interaction. Where significant differences were observed Tukey's comparison test was used to separate all the means.

The karité or néré-derived C was obtained by deducting from the value of C_3-C in each zone the value of C_3-C obtained in the control (due to the uncertainty linked to possible old C_3). To establish the balance of karité or néré-derived C at the landscape scale, we have multiplied the concentrations of karité or néré-C by soil bulk density and sampling depth to convert it in kg C m^{-2}. Afterward we added the figures of the 2 depths to obtain the value for each zone. This value was multiplied by the surface areas of the zones and the data of zones integrated to give an amount per tree for each species. This amount was extrapolated to the landscape scale by multiplying the mean value of an average tree by the tree density for each species according to 2 modalities: balance up to the edge of the crown and balance up to 2 m outside tree crown influence.

Results

Crops (−11.7 ± 0.1‰) $\delta^{13}C$ mean value was more than 2 times higher than that of any of the 2 tree species. $\delta^{13}C$ of leaves of karité (−26.6 ± 0.4‰) was higher than that of néré leaves (−28.7 ± 0.5‰) by almost 2 units whereas the difference was 1 unit in favor of the roots of karité (−25.9‰) in comparison with the roots of néré (−27.1‰). The mean of leaves and roots carbon contents were 463, 430 and 407 mg g^{-1} for karité, néré and the crop, respectively. Interactions between zone and soil depth appeared in soil carbon and tree contribution to soil carbon (C_T) when analyses with three factors were done, suggesting that differences should be looked into separate soil layers for these 2 parameters. Only tree contribution to soil carbon showed significant difference ($p < 0.01$) between species (Figures 2 and 3). Soil carbon under karité (6.43 ± 0.45 mg g^{-1}) and néré (5.65 ± 0.27 mg g^{-1}) was significantly higher ($p < 0.01$) than in the control plot (4.09 ± 0.26 mg g^{-1}). The trend was similar for tree contribution to soil carbon with 4.01 ± 0.71, 3.02 ± 0.53, 1.53 ± 0.10 mg g^{-1}, respectively under karité, néré and in the control plot. As a consequence the δ^{13}C was significantly higher ($p < 0.001$) in the control plot (-17.5 ± 0.3‰) compared with the figures obtained under karité (-20.2 ± 0.4‰) and néré (-20.1 ± 0.4‰) (Figure 1). Nevertheless, it is necessary to indicate that a certain amount of C$_3$-derived-C corresponds to organic matter derived from trees of ancient savannas, i.e. old C. This old C can be expected to be spread homogeneously in all zones and thus would encompass the amount of tree-derived C in the control plot, i.e. 1.5 mg g^{-1}.

Results per species showed a significant decreasing trend in soil carbon going from tree trunk to the open area both for the layer 0–10 cm ($p < 0.01$) and layer 10–30 cm ($p < 0.05$) under karité (Figure 2). Similarly, C$_3$ contribution to soil carbon decreased significantly in the same way for the upper and lower layer ($p < 0.01$ and $p < 0.001$, respectively). As a result δ^{13}C values decreased from the open area to tree trunk ($p < 0.001$) and from the lower layer to the upper layer ($p < 0.01$). Layer 10–30 cm (2.67 ± 0.11 mg g^{-1}) displayed significantly ($p < 0.01$) higher C$_4$ plants contribution to SOC compared to the upper layer (1.96 ± 0.26 mg g^{-1}). No significant difference was found in the contribution of C$_4$ plants to soil

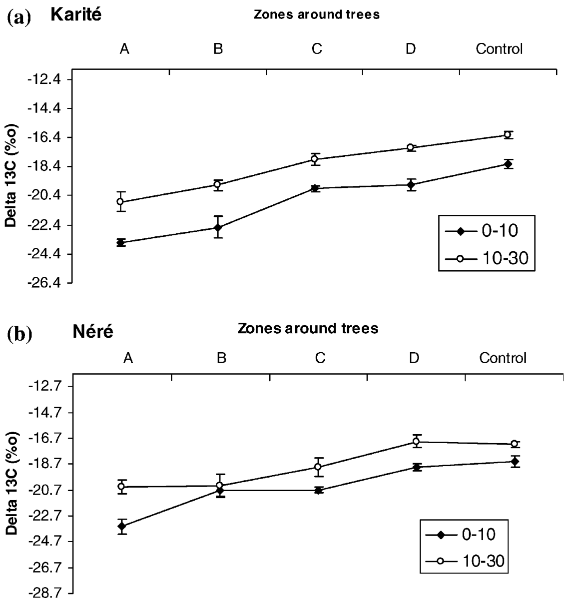

Figure 1. δ^{13}C in soil under karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland system in Saponé, Burkina Faso; Distance from tree trunk: Zone A = 0 to 2 m from the trunk, Zone B = from 2 m to half diameter of the crown, Zone C = from half diameter to the edge of the crown, Zone D = from the edge of the crown to 2 m outside of the crown, Control = open area; Soil depth: 0–10 = soil depth 0–10 cm, 10–30 = soil depth 10–30 cm.

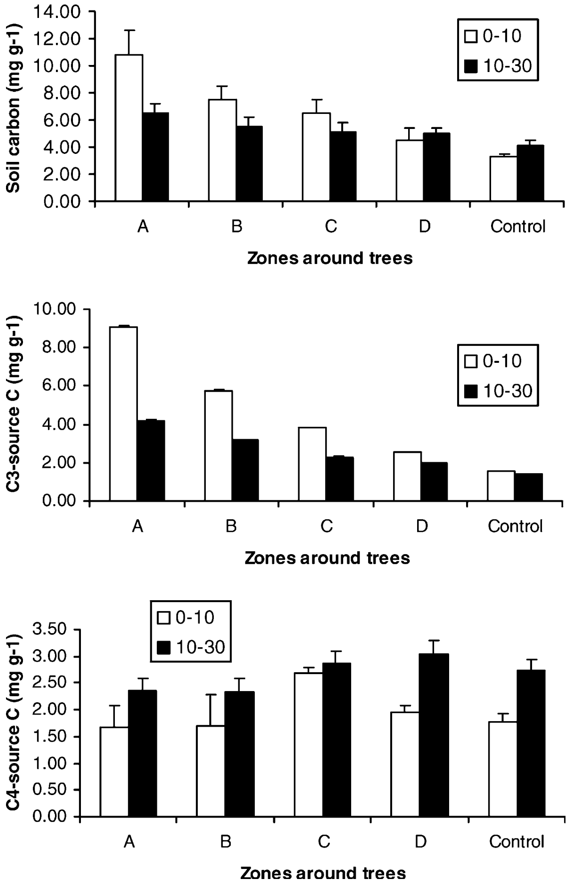

Figure 2. C3 and C4-derived C contributions to soil carbon building up under karité (*Vitellaria paradoxa*) in a parkland system in Saponé, Burkina Faso; Distance from tree trunk: Zone A = 0 to 2 m from the trunk, Zone B = from 2 m to half diameter of the crown, Zone C = from half diameter to the edge of the crown, Zone D = from the edge of the crown to 2 m outside of the crown, Control = open area; Soil depth: 0–10 = soil depth 0–10 cm, 10–30 = soil depth 10–30 cm.

carbon according to zones for both soil layers, nevertheless their contribution on average for the two soil layers increased from zone A (2.01 ± 0.22 mg g^{-1}) to zone C (2.78 ± 0.22 mg g^{-1}) and thereafter decreased going to the open area (2.26 ± 0.21 mg g^{-1}). Apart from zone C, the two other zones underneath tree crown showed lower values of C_4 plants contribution to SOC compared to the two zones outside the influence of tree crown (zones D, Control plot).

Under néré, a significant ($p < 0.01$) decreasing trend in SOC going from tree trunk to the open area was observed for zones whereas no significant difference was found between layers (Figure 3). In turn, $\delta^{13}C$ values revealed a significant increasing pattern going from tree trunk to the open area and from the upper layer to the lower layer (both $p < 0.001$). Consequently the values of both C_3 contribution to soil carbon in zones decreased significantly from tree trunk to the open area both for the upper 0–10 cm layer ($p < 0.001$) and for the lower 10–30 cm layer ($p < 0.01$). This parameter significantly also decreased with soil depth ($p < 0.01$). In reverse, layer 10–30 cm (2.82 ± 0.16 mg g^{-1}) displayed significantly higher C_4 plants contribution to SOC compared to the upper layer (2.33 ± 0.20 mg g^{-1}) ($p < 0.05$). Again as in karité, no significant difference was found in the contribution of C_4 plants to soil carbon under néré according to zones for both soil layers (Figure 3). However, the values of this variable on average for the two soil layers increased from tree trunk (2.44 ± 0.30 mg g^{-1}) to zone D (2.76 ± 0.22 mg g^{-1}) and thereafter slightly decreased in the control plot (2.70 ± 0.29 mg g^{-1}). Thus all zones underneath trees showed lower values of C_4 plants contribution to soil carbon compared to the two zones outside (zones D, Control plot).

In any case of the 2 modalities used to establish the balance of karité and néré-derived C, the relative contribution of karité was higher than that of néré because of the higher abundance of karité compared to néré (Table 2).

Discussion

In one hand, crop materials showed $\delta^{13}C$ values two times higher compared to those of the 2 tree species because of the natural isotopic difference between C_3 and C_4 vegetation in relation with their

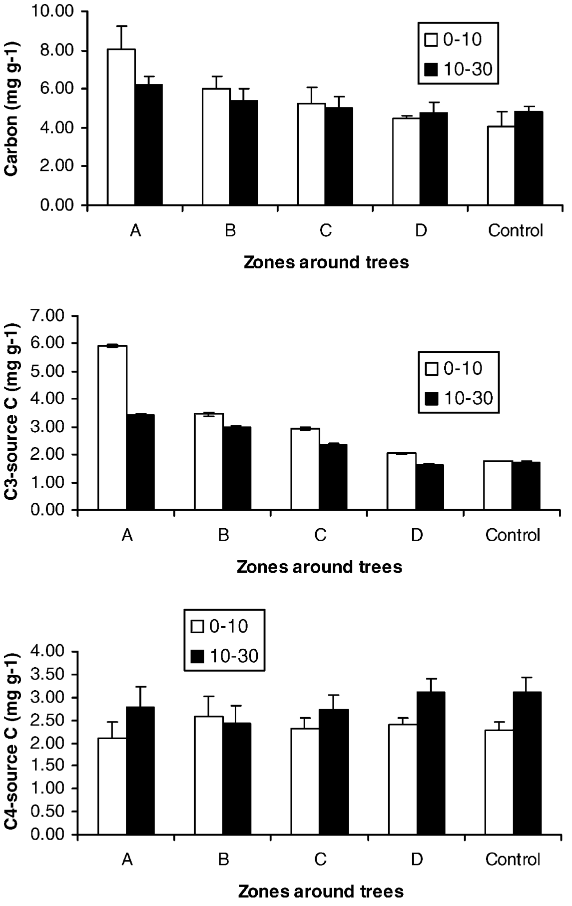

Figure 3. C3 and C4-derived C contributions to soil carbon building up under néré (*Parkia biglobosa*) in a parkland system in Saponé, Burkina Faso; Distance from tree trunk: Zone A = 0 to 2 m from the trunk, Zone B = from 2 m to half diameter of the crown, Zone C = from half diameter to the edge of the crown, Zone D = from the edge of the crown to 2 m outside of the crown, Control = open area; Soil depth: 0–10 = soil depth 0–10 cm, 10–30 = soil depth 10–30 cm.

Table 2. Balance of karité and néré-derived C in upper 0–30 cm layer at the landscape scale in an agroforestry parkland system in Saponé, Burkina Faso.

Modalities	Karité-source C (kg ha^{-1})	Néré-source C (kg ha^{-1})	Total karité and néré-source C (kg ha^{-1})
1	546	226	772
2	787	247	1034

Modality 1, tree-derive C under tree crown in zones A, B, and C; modality 2, tree-derive C upto 2 m outside tree crown in zones A, B, C and D.

different photosynthetic pathways (Andriulo et al. 1999). In another hand, leaves and roots of karité displayed $\delta^{13}C$ values higher than those of the leaves and roots of néré. The difference in $\delta^{13}C$ in the materials of the 2 species may be due to different metabolisms for water linked to the stomatal closure or a genetically difference in fractionation associated with stomatal closure. Eventhough no data are available for karité with this respect, Osonubi and Fusehun (1987), and Teklehaimanot et al. (1998) found that transpiration of *P. biglobosa* is under a high degree of stomatal control associated with a high tissue capacitance and internally stored water, which can be used during periods of rapid transpiration. The difference may stem from different reallocations of carbon just before leaf abscission as the leaves used in the present study are senescent ones. This hypothesis may stand true because Bayala et al. (2003) found higher carbon content in néré 'young' leaves of pruned materials (503.9 ± 2.1 mg g^{-1}) compared with karité leaves (484.4 ± 5.0 mg g^{-1}) whereas in the present study with abscised leaves the opposite was found. Finally the difference in lipid content (which are currently depleted by as much as 10‰) is another candidate for the explanation of this difference, which was not investigated here.

Despite the difference in $\delta^{13}C$ between the materials of the two species, soil carbon contents were not significantly different in the influence zones of the two species. Nevertheless higher soil carbon content under karité is consistent with the fact that its material showed higher values in $\delta^{13}C$ and has higher carbon content than that of néré. These findings are slightly different from those of Bayala et al. (2002) who found 5.64 ± 0.48 and 5.96 ± 0.49 mg g^{-1} of carbon for the 0–10 cm soil depth under karité and néré, respectively. Such differences may be due to sampling method, core sampling in discrete points having been used in the two studies.

Soil carbon contents were higher under trees compared with the open area showing the important contribution of trees to soil carbon contents and that may partly explain the lower soil bulk density under trees compared to the open area (Table 1). For the same reason soil bulk density was lower in the upper layer compared to the lower layer (Table 1). This higher SOC under tree and in the upper layer may also explain their higher pH values compared to the open area and the lower layer, respectively (Table 1).

C_4 derived carbon was less variable (2–3 mg g^{-1}) along the transect going from tree trunk to the open area. To this amount was superposed the C_3-derived carbon with an increasing trend going from the open area to tree trunk. This impact of trees on soil carbon content is in line with the lower values in $\delta^{13}C$ of soil under trees compared to the $\delta^{13}C$ values of soil in the open area. These results corroborate those of Nyberg and Hogberg (1995) who recommended ^{13}C natural abundance as a particularly sensitive indicator of the influence of trees in soil organic matter. The higher soil carbon content in 10–30 cm depth compared to 0–10 cm depth in zone D and control may stem from the fact that either the priming effect on ancient C_4-derived carbon is high and equivalent for all zones in the upper 0–10 cm or the priming effect is lower in 10–30 cm layer of zones D and control because of lower organic restitutions at that depth.

Karité-derived carbon was higher than that of néré at landscape scale because this species was more abundant in tree samples used with 4 trees ha^{-1} for karité against 1 tree ha^{-1} for néré (Bayala 2002). Moreover, Karité and néré-derived C were underestimated in the present study because mature trees, which were ≥ 30 cm in diameter, were used thus excluding trees with lower stem diameters. In fact, the actual densities of trees were 9.1 trees ha^{-1} for karité and 1.2 trees ha^{-1} for néré (Bayala 2002). Tree-derived carbon was higher in the upper layer and this is consistent with the fact soil carbon in zones under tree influence (A, B, C) was higher in the upper soil layer compared with the lower layer (Figures 1 and 2). These findings corroborate those of Manjaiah et al. (2000) who found that irrespective of the cropping system, approximately 58.4, 25.7, and 15.9% of the carbon was distributed in 0–15, 15–30, and 30–60 cm depths, respectively. In another hand, C_4-derived carbon was higher in the lower layer in line with the higher soil carbon content found in the lower layer in zones outside tree crown (D and Control). This trend suggests that C_4 materials may be easily decomposable with a migration of soluble carbon down soil profile because the maximum root density of crops was found in 0–10 cm layer in these systems (Bayala et al. 2004). Besides, feeding activity of soil invertebrates and microbial respiration were shown to change natural abundance of ^{13}C of the organic matter in a range of 1–3‰ with soil depth (Boutton 1996; Santruckova et al. 2000). Furthermore, the older organic carbon deeper in the profile has been exposed to decomposer activity for a longer period of time than the younger organic carbon near the soil surface, and therefore, should have larger $\delta^{13}C$ values that reflect the cumulative effects of this activity (Boutton 1996; Balesdent and Mariotti 1996). According to the latter hypothesis, the little higher amount of C_4-derived C in the deeper layer would be partly apparent, due to the uncertainty of the isotopic composition of the C_4-derived source.

Higher soil fertility has been seen as controversial issue because trees may have simply grown in spots of higher fertility. The present study has proven that trees contribute to the increase and maintenance of soil carbon content showing their importance in carbon sequestration in semi-arid zones where soil carbon is also a major factor controlling soil fertility both for nutrients release and soil organic matter formation.

Conclusions

In summary, we found that soil carbon content was higher under both karité and néré species compared to the open area. The results also showed that the higher carbon under trees is due to the direct positive impact of trees in parkland systems on soil organic matter formation. Such results are very important for semi-arid zones where bush clearing and transformation into farmed fields is expanding with the increase in population pressure. Eventhough it can be argued that these trees are simply concentrating elements in their surroundings their role in avoiding losses of elements from the system is not negligible and should be considered. However, because in the parkland systems the level of organic matter restitutions is low (removal of crop residues and burning of tree litter), balanced fertilisation, residue management and cultivation practices that conserve soil organic matter need to be developed to maintain soil fertility. To develop such techniques, there is a need for continued monitoring of long term effects of trees to soil organic matter formation as well as the effects of this SOM in soil fertility in relation to different cropping systems for sustainable production. Moreover, the challenge of maintaining the quality of the soil resource in agriculture of semi-arid zones is as great as the problem of increasing atmospheric concentration of CO_2 due to total removal of trees in some cropping systems or mismanagement of tree litter in systems where they are preserved.

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