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Long-term impact of a gliricidia-maize intercropping system on carbon sequestration in southern Malawi

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Abstract

Tree/crop systems under agroforestry practice are capable of sequestering carbon (C) in the standing biomass and soil. Although studies have been conducted to understand soil organic C increases in some agroforestry technologies, little is known about C sequestered in simultaneous tree/crop intercropping systems. The main objective of this study was to determine the effect of agroforestry practice on C sequestration and CO_2-C efflux in a gliricidia-maize intercropping system. The experiment was conducted at an experimental site located at the Makoka Agricultural Research Station, in Malawi. The studies involved two field plots, 7-year (MZ21) and 10-year (MZ12), two production systems (sole-maize and gliricidia-maize simultaneous intercropping systems). A 7-year-old grass fallow (Grass-F) was also included. Gliricidia prunings were incorporated at each time of tree pruning in the gliricidia-maize. The amount of organic C recycled varied from 0.8 to 4.8 Mg C ha^{-1} in gliricidia-maize and from 0.4 to 1.0 Mg C ha^{-1} in sole-maize. In sole-maize, net decreases of soil carbon of 6 Mg C ha^{-1} at MZ12 and 7 Mg C ha^{-1} at MZ21 in the topsoil (0–20 cm) relative to the initial soil C were observed. After 10 years of continuous application of tree prunings C was sequestered in the topsoil (0–20 cm) in gliricidia-maize was 1.6 times more than in sole-maize. A total of 123–149 Mg C ha^{-1} were sequestered in the soil (0–200 cm depth), through root turnover and pruning application in the gliricidia-maize system. Carbon dioxide evolution varied from 10 to 28 kg ha^{-1} day^{-1} in sole-maize and 23 to 83 kg ha^{-1} day^{-1} in gliricidia-maize. We concluded that gliricidia-maize intercropping system could sequester more C in the soil than sole-maize.

Keywords: Tree/crop; Agroforestry system; C sequestration; CO_2-C efflux; Soil

1. Introduction

In Sub-Saharan Africa the degraded soils are low in soil organic matter. The rate of soil organic carbon (C) loss has been exacerbated by continuous cultivation with little or no organic matter amendment and by soil erosion (Follet, 1998). Land preparation in Sub-Saharan Africa involves tillage and at times burning of biomass and crop residues. It has been reported that carbon stocks in agricultural soil under tillage decline compared to no-tillage (Duiker and Lal, 1999; Mrabet et al., 2001), and both tillage and burning have been shown to reduce organic matter levels (Chan et al., 1992; Slattery and Surapaneni, 2002). Tillage is known to decrease soil organic nitrogen (N) and C pools with negative consequences for soil fertility (Kristensen et al., 2003). The decline in soil organic C may have a negative long-term effect on the cation exchange capacity of the soil, and the ability to retain nutrients and to remain fertile. On the other hand, application of tree prunings may increase soil organic C (Jones et al., 1996; Kang et al., 1999) and exchangeable cations.

The long-term effects on soil nutrient stocks, which influence the sustainability of crop production, are major benefits of regular additions of legume tree prunings and of root turnover. The magnitude of changes of soil organic matter (SOM) depends on the quantity and quality of prunings, soil type, system management, climate and

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duration of practice of the system. According to Andèrn and Kätterer (2001), application of high quality organic materials has a small effect on soil C build-up because most of the substrate C is rapidly returned to the atmosphere through CO_2 evolution.

Most studies showing the improvements of soil organic C in agroforestry systems have concentrated on changes in the topsoil layer, 0–20 cm (e.g. Jones et al., 1996; Wendt et al., 1996; Kang et al., 1999). Information is lacking on stocks of organic C in the deeper soil layers where most of the tree roots occur that supply substantial amounts of C through root exudates and fine root turn over. The C sequestration potential of tropical agroforestry systems has been estimated to range between 12 and 228 Mg ha^{-1}, and a mean of 95 Mg ha^{-1} (Albrecht and Kandji, 2003). The authors also identified that there is still a paucity of quantitative data on specific systems and recommended that more work needs to be done to increase our understanding of C sequestration and greenhouse gas mitigation. Since the Gliricidia intercropping is becoming increasingly recognized as efficient fertilizer tree system for smallholder farmers in Southern Africa, it is fundamentally important to estimate its role in the sequestration of C below and aboveground.

Against the above background, we hypothesize that, compared to sole-maize systems, gliricidia-maize simultaneous intercropping systems sequester more C in the soil via continuous application of tree prunings and root turnover. The objective of the current study was to assess the amount of C sequestered in the soil and temporarily stored in the standing biomass of the tree in a gliricidia-maize simultaneous intercropping system.

2. Materials and methods

2.1. Site description

The study was conducted at Makoka Agricultural Research Station, in Zomba, Malawi (15°30′S, 35°15′E, altitude of 1029 m a.s.l.). The total rainfall ranges from 560 to 1600 mm, with a 10-year mean of 930 mm. The rainfall is unimodal with most of the rains falling between November and April. The temperature varied between 16 and 32 °C. Two long-term trials with gliricidia intercropping were used. The first trial was established in December 1992 and is coded MZ12. The top soil (0–20 cm layer) had 420 g kg^{-1} clay and 460 g kg^{-1} sand, a pH (H_2O) of 5.9 and 8.8 g kg^{-1} organic carbon (OC), 26 mg kg^{-1} available P (Olsen), 3.0 mmol kg^{-1} K, 44 mmol kg^{-1} Ca and 16 mmol kg^{-1} Mg. The second trial was established in December 1995 and is coded MZ21. The soil (0–20 cm) had 380 g kg^{-1} clay and 540 g kg^{-1} sand, a pH (H_2O) of 5.6, and 9.3 g kg^{-1} OC, 10.3 mg kg^{-1} available P (Olsen), 3.7 mmol kg^{-1} K, 17.3 mmol kg^{-1} Ca and 4.2 mmol kg^{-1} Mg (Ikerra et al., 1999, 2001). At both sites, the soils are described as Ferric Lixisols (FAO).

2.2. Treatments and management

The MZ12 field had the following treatments: (1) maize cultivation with or without intercropping with *Gliricidia sepium*, (2) three rates of inorganic N fertilizer (0, 24 and 48 kg N ha^{-1}), and three rates of P fertilizer (0, 20 and 40 kg P ha^{-1}). The treatments were arranged in a $2 \times 3 \times 3$ factorial. Calcium ammonium nitrate (CAN) fertilizer was used as a source of inorganic N fertilizer and was applied once at 4 weeks after planting. Triplesuper phosphate (TSP) was applied at the time of planting. MZ21 had the following treatments: (1) maize with and without intercropping with *Gliricidia sepium* and (2) two rates of inorganic N fertilizer (0 and 24 kg N ha^{-1}). The 24 kg N ha^{-1} fertilizer was applied once, at 4 weeks after planting.

At each site, only two treatments: sole-maize and gliricidia-maize intercropping without inorganic fertilizer were used in this study. Hereafter the treatment without intercropping with gliricidia and no inorganic fertilizer applied will be referred to as sole-maize and the treatment of maize intercropped with gliricidia without inorganic fertilizer will be referred to as gliricidia-maize (Gs-maize). At both sites, the treatments were replicated three times, hence the data presented are the means of the three replicates.

The plot size at MZ12 was 6.75 by 5.4 m, each tree plot had 4 tree rows and 6 trees per row. At MZ21 the plot size was 12 m × 11.7 m, each plot had 8 rows of gliricidia trees and 13 trees per row. The trees were planted in every other furrow at a spacing of 0.9 m within row and 1.5 m between rows.

2.3. Organic carbon additions

Amounts of organic carbon (OC) recycled annually through the application of organic materials were estimated from the yields of gliricidia prunings and maize stover incorporated annually in the soil. Total OC recycled was calculated as the product of C concentration in the samples and biomass yield per hectare. The gliricidia prunings and maize stover yields reported in this paper have been estimated annually for 1993–2002 at MZ12 and 1996–2002 at MZ21. In 2001 and 2002 at MZ21 an experiment was superimposed in this trial that necessitated the application rate of 3 Mg ha^{-1} of gliricidia prunings hence constant amounts of OC applied.

2.4. Determination of soil carbon and bulk density

The carbon concentrations of the surface soil (0–20 cm), assessed at the establishment of the trials were used as baseline data for the soil C change in sole-maize and gliricidia-maize cropping systems. Three plots (one from each replicate) that had been left to grass fallow since 1995 were used as a reference for changes of OC, and will be referred to as grass fallows (Grass-F). Grass-F was used as a reference instead of the initial soil data, because at the establishment of the trial soil OC was determined only in the top 0–20 cm soil layer and no soil information was available for the 20–200 cm soil layer.

Soil samples were taken from 0 to 200 cm at 20 cm intervals in three replicates in April 2002. Five soil samples were collected from each depth from different points in each plot and the five samples from the same depth were bulked to make a composite sample. Edelman's auger was used to collect soil samples. Soil OC was determined by ''wet'' oxidation by acidified dichromate (Anderson and Ingram, 1993). A soil profile was dug from 0 to 200 cm depth in each plot, and a core sampler was used to collect soil samples at 20 cm soil depth intervals on the soil profile wall. These core samples were used to determine the soil bulk density.

2.5. Carbon dioxide evolution

Carbon dioxide evolution (soil and root respiration) from the soils in sole-maize and gliricidia-maize intercropping systems was assessed at MZ21 on a weekly basis between October 2001 and April 2002 using the method described by Bundy and Bremner (1972) with a slight modification on the tube length. A week after incorporating gliricidia prunings, aluminum pipes, 5 cm in diameter and 30 cm long were inserted on a ridge one pipe per plot per treatment in each of the three replicates. The aluminum pipes were inserted to 25 cm depth leaving 5 cm protruding in the soil surface. Carbon dioxide evolved was trapped in 20 ml of 1 M NaOH in a 25 ml glass vial that was placed in the aluminum pipe and the open end of the pipe was capped with an iron cap. A rubber band was tied round the brim of the cap to minimize gas leakage from the pipe. After 24 h of *in situ* incubation the glass vials were removed and immediately capped to prevent exposure to CO_2 from the atmosphere. The amount of CO_2 trapped in the solution was determined by a titrimetric method. First, the excess of 1 M NaOH in the CO_2 trap was titrated with 0.5 M HCl to a phenolphthalein endpoint (about pH 8.3). At this pH value, carbonate is converted to bicarbonate, and the remaining bicarbonate as a product of the reaction of CO_2 with NaOH is then titrated to a bromocresol green end-point (about pH 3.8) with standardized 0.1 M HCl.

2.6. Determination of amounts of carbon in the trees

Five trees were selected at random in the net plots in each of the tree replicates of Gs-maize intercropping system at MZ21. The experiment at MZ12 is still continuing for long-term observations, therefore destructive sampling was not possible. Since the trees in the simultaneous intercropping system were pruned to a height of 30 cm, the above ground part of the tree consisted of a stump only. The selected trees were carefully dug excavating all roots (>5 mm diameter) growing down to 200 cm depth. Stumps and roots, including the taproot, were separated at the root collar and after the recording the fresh weights, they were then chopped into smaller pieces (about 2 cm long) from which sub-samples were taken. The sub-samples were dried in an oven at 75 °C until constant weight and the dry weights were recorded. Fine roots (<5 mm diameter) were not included in this study, since it was difficult to retrieve them, using this method, and considering that a high proportion of these roots dies annually during the dry seasons.

2.7. Data analysis

The data was subjected to two way ANOVA using GENSTAT Discovery Edition 1. Standard error of difference (SED) at 5% was used to compare the means for the treatments. Differences of soil OC concentrations between replicates of the same treatments are shown by standard errors (S.E.).

3. Results

3.1. Additions of aboveground organic carbon to soil

Table 1 shows the amounts of recycled C calculated from the OC content of the biomass incorporated. At MZ12, the

Table 1
Amount of aboveground organic C recycled (Mg ha^{-1}) via the organic materials applied since 1993 at MZ12 and 1996 at MZ21

Treatment	Material	1993	1994	1995	1996	1997	1998	1999	2000[1]	2001	2002
MZ12 trial											
Sole-maize	Stover	1.0	0.7	0.7	0.6	0.3	0.5	0.5	0.4	0.4	0.4
Gs-maize	Stover	0.7	1.7	1.3	2.4	1.5	1.9	2.0	1.1	2.3	1.9
	Gs-prunings	1.2	1.8	1.7	2.2	2.4	2.5	2.8	1.5	2.1	2.3
	Total (Gs-maize)	1.9	3.5	3.0	4.6	3.9	4.4	4.8	2.6	4.4	4.2
MZ21 trial											
Sole-maize	Stover	–	–	–	0.7	0.7	0.6	0.4	–	0.7	0.7
Gs-maize	Stover	–	–	–	0.5	1.0	1.2	1.4	–	1.3	1.3
	Gs-prunings[2]	–	–	–	0.3	0.8	1.1	2.4	–	1.4	1.4
	Total (Gs-maize)	–	–	–	0.8	1.7	2.3	3.8	–	2.7	2.7

[1] Organic materials were not incorporated in the 1999–2000 season at MZ21.
[2] Gs-prunings: Gliricidia prunings. The amounts of gliricidia prunings applied at MZ21 were fixed at 3 Mg ha^{-1} in 2001 and 2002 according to the treatment requirements of the experiment that was superimposed in this trial (Makumba, 2003).

amount of carbon added declined in sole-maize from 1.0 Mg C ha^{-1} in 1993 to 0.4 Mg C ha^{-1} after 2000, and increased in Gs-maize from 1.9 to 4.8 Mg C ha^{-1}. Yields at MZ12 were higher than those at MZ 21, and this was likely to have been caused by the higher initial soil fertility in MZ12 than in MZ21; P especially was higher (P-Olsen was 26 in MZ12 compared to 10 mg kg^{-1} in MZ21). The overall decline of added OC in sole-maize with time was caused by the maize yield decline due to nutrient depletion. At MZ21, OC applied in sole-maize via the organic materials decreased between 1996 (0.7 Mg C ha^{-1}) and 1999 (0.4 Mg C ha^{-1}). In 2001 and 2002, the amount of maize stover incorporated was fixed at 1.5 Mg ha^{-1}, corresponding to 0.7 Mg C ha^{-1}. Because of increased maize stover and the combination with gliricidia prunings, the amount of OC applied was, as in the MZ21 trial, much higher in Gs-maize than in sole-maize. During the 7 years of organic material incorporation, OC additions in MZ21 varied between 0.8 and 3.8 Mg C ha^{-1}.

3.2. Soil organic C and bulk density along the soil profile

At both sites soil OC decreased with depth (Table 2) with significant ($P < 0.001$) accumulation in the top 0–40 cm soil layer compared to the deeper soil (below 140 cm depth). In the sole-maize only a trace of OC was detected in the sub-soil below 140 cm. The amounts of OC were higher in gliricidia-maize plots than in sole-maize and grass fallow, especially at the top 0–60 cm soil depth. The pH of the soil was higher in Gliricidia than in sole-maize and grass fallow.

3.3. Carbon sequestered in soil and temporarily stored in trees

In the surface soil layer (0–20 cm), amounts of OC sequestered were larger in Gs-maize at MZ12 (by 11 Mg ha^{-1}) and at MZ21 (8 Mg C ha^{-1}) than in sole-maize (Table 3). Compared to the initial soil carbonic content, topsoil (0–20 cm) C at both sites had decreased in sole-maize and increased in Gs-maize and Grass-F. Analysis of variance shows that there were significant ($P < 0.001$) differences with treatment and also with depth. Grass-F had higher OC in the top 0–40 cm than Gs-maize at MZ21 but much lower in the sub-soil below 40 cm. Gs-maize had 26 Mg C ha^{-1} per 200 cm more than Grass-F. The tree stumps stored 7 and 10 Mg C ha^{-1} was stored in the structural roots. Thus, a total of 17 Mg ha^{-1} of C was temporarily stored in the trees (stumps and roots) in the field after 7 years of practice at MZ21.

3.4. Carbon dioxide evolution

Carbon dioxide evolution was low for about a period of a month after organic material application showing a time lag for decomposition in both sole-maize and Gs-maize treatments (Fig. 1). A peak CO_2 evolution was observed between December and February, with a maximum of 83 kg

Table 2
Soil pH, C concentration (mg g^{-1}) and bulk density (g cm^{-3}) along the soil profile between 0 and 200 cm soil depth in three production systems (sole-maize, gliricidia and grass fallow) at two sites (MZ12 and MZ21)

Soil depth (cm)	Sole-maize			Gliricidia			Grass fallow		
	pH	OC	Bd[1]	pH	OC	Bd	pH	OC	Bd
MZ21 field									
0–20	5.3 (0.04)	7.7 (0.45)	1.47 (0.04)	6.1 (0.15)	12.0 (0.70)	1.23 (0.01)	5.7 (0.06)	11.9 (0.30)	1.35 (0.02)
20–40	5.3 (0.11)	6.7 (0.10)	1.40 (0.01)	5.9 (0.10)	10.2 (0.35)	1.29 (0.03)	5.7 (0.11)	11.0 (0.09)	127 (0.01)
40–60	5.1 (0.03)	5.0 (0.39)	1.38 (0.06)	5.6 (0.04)	7.4 (0.45)	1.28 (0.02)	5.5 (0.05)	5.6 (0.38)	1.42 (0.02)
60–80	5.1 (0.07)	2.8 (0.40)	1.31 (0.02)	5.7 (0.12)	5.9 (0.25)	1.31 (0.04)	5.4 (0.21)	4.5 (0.26)	1.45 (0.04)
80–100	5.1 (0.10)	2.0 (0.05)	1.37 (0.01)	5.4 (0.01)	5.1 (0.12)	1.34 (0.04)	5.6 (0.23)	3.9 (0.30)	1.41 (0.03)
100–120	5.3 (0.05)	1.7 (0.25)	1.49 (0.12)	5.2 (0.06)	4.3 (0.15)	1.39 (0.01)	5.5 (0.03)	3.4 (0.22)	1.34 (0.01)
120–140	5.2 (0.08)	1.4 (0.15)	1.49 (0.04)	5.3 (0.05)	3.4 (0.09)	1.45 (0.03)	5.5 (0.05)	2.0 (0.25)	1.47 (0.04)
140–160	5.1 (0.12)	Trace	1.41 (0.06)	5.1 (0.09)	3.3 (0.18)	1.42 (0.04)	5.4 (0.06)	1.8 (0.06)	1.41 (0.05)
160–180	5.3 (0.09)	Trace	1.37 (0.09)	5.1 (0.10)	2.7 (0.16)	1.34 (0.01)	5.6 (0.02)	0.7 (0.24)	1.48 (0.07)
180–200	5.2 (0.05)	Trace	1.36 (0.03)	5.1 (0.02)	2.7 (0.11)	1.33 (0.05)	5.6 (0.09)	0.3 (0.09)	1.45 (0.03)
MZ12 field									
0–20	5.7 (0.25)	6.6 (0.23)	1.44 (0.01)	6.0 (0.10)	10.9 (0.26)	1.38 (0.03)			
20–40	5.6 (0.10)	6.3 (0.11)	1.45 (0.05)	5.9 (0.12)	8.2 (0.54)	1.33 (0.02)			
40–60	5.8 (0.11)	4.0 (0.54)	1.47 (0.03)	5.6 (0.15)	6.9 (0.14)	1.29 (0.01)			
60–80	5.9 (0.15)	2.3 (0.19)	1.31 (0.01)	5.9 (0.20)	5.1 (0.23)	1.28 (0.01)			
80–100	6.1 (0.17)	2.2 (0.18)	1.42 (0.02)	5.8 (0.24)	4.4 (0.13)	1.27 (0.02)			
100–120	6.3 (0.09)	1.1 (0.22)	1.38 (0.04)	5.7 (0.05)	3.6 (0.10)	1.26 (0.03)			
120–140	6.2 (0.12)	Trace	1.32 (0.01)	6.0 (0.01)	3.7 (0.21)	1.25 (0.05)			
140–160	6.4 (0.20)	Trace	1.30 (0.01)	6.3 (0.06)	1.9 (026)	1.27 (0.04)			
160–180	6.3 (0.25)	Trace	1.31 (0.01)	6.2 (0.15)	2.4 (0.09)	1.28 (0.03)			
180–200	5.9 (0.11)	Trace	1.31 (0.01)	6.4 (0.20)	1.2 (0.32)	1.24 (0.04)			

The figures in parentheses are S.E.s.
[1] Bd: bulk density.

Table 3
Carbon sequestered (Mg ha^{-1}) in soil layers 0–20, 20–200 and 0–200 cm, and soil OC increase in gliricidia-maize simultaneous intercropping over sole-maize

Soil layer (cm)	MZ12			MZ21			
	Sole-maize	Gs-maize	$SED_{0.05}$	Sole-maize	Gs-maize	Grass-F	$SED_{0.05}$
0–20	19	30	1.71	22	30	32	4.29
20–200	45	93	0.90	51	119	91	5.76
0–200	64	123	1.31	73	149	123	8.57
Relative soil organic carbon increase (%) over sole-maize							
0–20		58			36	45	
20–200		107			133	78	
0–200		92			104	68	

The SEDs are for the differences between the treatments means for each soil layer.

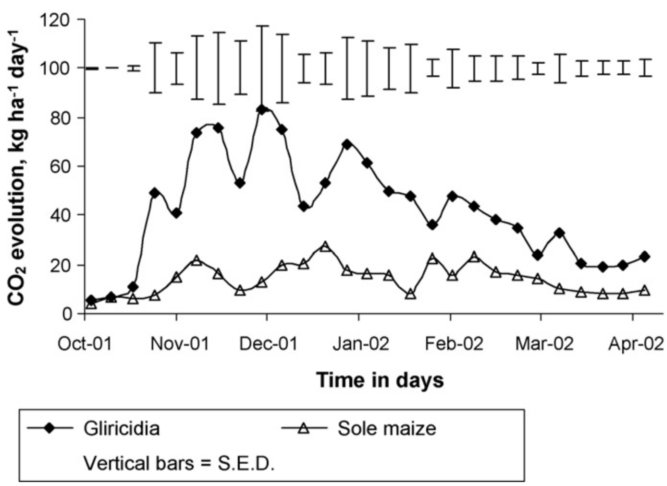

Fig. 1. Carbon dioxide evolution in sole-maize and Gs-maize between October 2001 and March 2002 at MZ 21. Vertical bars are $SED_{(0.05)}$.

CO_2-C ha^{-1} day^{-1} for Gs-maize, and of 28 kg ha^{-1} day^{-1} for sole-maize in January. After the rainy season, the release was reduced to 23 kg CO_2-C ha^{-1} day^{-1} for Gs-maize and 10 kg CO_2-C ha^{-1} day^{-1} for sole-maize.

4. Discussion

4.1. Carbon sequestration

At both sites, OC decreased in the topsoil of sole-maize during the course of the trials, despite annual additions of maize stover. A similar observation was made in an 18-year-old experiment in Kenya where 16% of soil OC was lost compared to initial soil OC, despite continuous application of a combination of inorganic fertilizer, animal manure and maize stover (Kapkiyai et al., 1999). Incorporation of slow-decomposing, low quality maize stover apparently was not enough to balance the release of soil OC due to tillage. Many studies have shown that soil OC declines in tillage systems (Hullugalle and Ndi, 1993; Salinas-Gracia et al., 2001; Matsumoto et al., 2002). In sole-maize, the preparation of land every season involved tillage with hand hoes whereby the old ridges were shifted into the old furrows to construct a new ridge.

Martin et al. (1974) reported that recalcitrant lignin-type structures in various straws might lose as much as 65–84% of the total C as CO_2 within the first 6 months of decomposition. On the other hand, many researchers have reported increases of soil OC, compared to the control, after continued application of crop residues and tree prunings in the topsoil (Wendt et al., 1996; Kang et al., 1999; Aulakh and Doran, 2002). In the current study, an overall increase of soil OC in the topsoil 0–20 cm in Gs-maize, at both sites, was obtained compared to the initial soil OC. In addition to the applied organic materials the net increase might be ascribed to belowground biomass, i.e. the roots partly sloughed off in the ridge during incorporation of prunings. The roots might add large amounts of C because they are more lignified (woodier) than the foliage prunings and have C in more stable compounds. Hence, roots may supply more stable C to the soil. Moreover, tillage management may be an important factor. Since the organic materials were incorporated within 0–20 cm on the ridge, C sequestered in the soil below 20 cm could be thought of as having been largely contributed by root turnover.

Our results suggest that tree roots sequestered about 48 Mg C ha^{-1} in 20–200 cm depth of soil at MZ12 and 68 Mg C ha^{-1} in 20–200 cm depth of soil at MZ21, more than in the sole-maize. The increase of OC in the sub-soil is attributed to root contribution since the tree prunings are applied within the top 0–20 cm soil layer. Small roots die during the dry season (Akinnifesi et al., 1999; Rowland, 1998) which when decomposing increase OC. In the whole Gs-maize intercropping system, the apparent increase in soil C sequestered relative to sole-maize (in Table 3) amounted to 59 Mg C ha^{-1} at 0–200 cm soil depth at MZ12 and 72 Mg C ha^{-1} at 0–200 cm soil depth at MZ21.

Although the trees contained up to 17 Mg C ha^{-1} in the standing biomass (roots and stumps), the sequestering of this C ends at wood harvest or when the tree dies. As gliricidia stumps can only be used as fuel wood, a large part of the biomass C returns rapidly to the atmosphere as CO_2.

4.2. Carbon dioxide evolution

Carbon dioxide efflux from the soil amended with maize was within the range reported by other researchers

Table 4
Simple analysis of CO_2-C emissions (Mg ha^{-1} year^{-1}) from treatments sole-maize and gliricidia-maize, at MZ21 in 2002

		Sole-maize	Gs-maize	$SED_{0.005}$
1[1]	CO_2-C emission	2.58	7.80	0.40
2	C from added organic materials[2]	0.70	2.70	0.13
1–2	C from SOM and root respiration and decomposition	1.88	5.10	0.30
3	C from SOM (0–40 cm depth) decomposition	1.60	2.24	0.09
1–2–3	Apparent CO_2-C from root respiration and decomposition	0.28	2.86	0.30

The SEDs are for the difference between sole-maize and Gs-maize treatments.

[1] The numbers 1, 2 and 3 in the first column are serial numbers used to label the rows. These numbers help to guide the reader how the calculations in rows 4 and 6 have been derived, i.e. in the 4th row: 1–2 = results in row labeled 2 subtract from results in row labeled 1.

[2] C from SOM is the C converted from soil organic matter estimated at conversion rates of 4 and 2% (Janssen, 1995) for the 0–20 and 20–40 cm soil layer, respectively.

(Franzluebbers et al., 1995; Dao, 1998; Jacinthe et al., 2002). During the peak period, CO_2 evolution in Gs-maize was three times as much as in sole-maize. The low CO_2 evolution during the first month after the incorporation of tree prunings into the soil is in agreement with the time lag for decomposition that is found in most experiments (Yang, 1996). The peak CO_2 evolution period coincided with the peak N release in December (Ikerra et al., 1999, Makumba, 2003). At the end of the period (173 days) 2.6 and 7.8 Mg CO_2-C ha^{-1} had been evolved from sole-maize and Gs-maize, respectively (Table 4). This C may have originated from the applied organic materials, from old soil organic matter and from root respiration. The simple analysis of CO_2-C in Table 4 shows that 0.28 and 2.86 Mg CO_2-C ha^{-1} year^{-1} was to be ascribed to root respiration and decomposing tree and crop roots. In the root studies conducted at the MZ21 trial, Makumba (2003) reported total amounts of roots (2 mm or less) of 9510 and 13860 cm dm^{-3} in sole-maize and Gs-maize, respectively. These differences in roots cannot fully explain the differences in CO_2-C emission between sole-maize and Gs-maize, but at least they make a substantial contribution.

5. Conclusion

Our data suggest that Gs-maize sequestered between 123 and 149 Mg C ha^{-1} in the soil (0–200 cm depth), via root turnover and pruning application. In addition, 17 Mg C ha^{-1} was temporarily stored in the tree stump and structural roots (>5 mm) in gliricidia-maize intercropping. These data clearly show the importance of agroforestry systems in mitigating CO_2 evolution. In a simultaneous intercropping system, the soil is the main sink of C sequestered in the system because the aboveground part of the trees is not allowed to grow.

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