Biomass carbon: litter quality and implications for carbon sequestration by agroforestry in coastal Kenya

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Abstract
The potential impact of agroforestry systems on C sequestration is widely recognized. However limited data is available on its impact on C dynamics, as much of the previous research has been focused on agricultural productivity. This research was therefore conducted to determine biomass carbon and litter quality of commonly recommended improved fallow species, at the coastal region in Kenya. An on-farm experiment was established in 2006 at a coastal Kenya site, using a Randomized Complete Block Design with five agroforestry species replicated thrice. Biomass carbon and litter quality was assessed at 6 and 12 months after sowing (MAS). Data was analysed using R version 2.9.0. The effects of species, measurement time and their interaction on total carbon were highly significant ($P < 0.001$). Total carbon stocks at 6 MAS ranged from 0.04 (*S.sesban*) to 1.4 Mg C /ha (*M.pruriens*) compared to 1.7 (*S.sesban*) to 20.3 Mg C /ha (*T.candida*) at 12 MAS. Results indicate that substantial amounts of C were sequestered in the biomass. However, duration of the fallow is a key factor to be considered. Litter quality was high with average polyphenol contents of 2.6 % while lignin contents were highest in *T.candida* (16.3 %).

Key Words
Carbon sequestration, agroforestry, litter quality, lignin.

Introduction
The significance of agroforestry with regards to C sequestration has been widely recognized with an estimated global potential of between 12 and 228 Mg/ha (Albrecht *et al.* 2003). However, variability can be high within various agroforestry systems as biomass C stock depends on several factors including environmental conditions, soil type, magnitude of land degradation and the length of fallow period (Albrecht *et al.* 2003; Kaonga *et al.* 2009). Residue quality differences among agroforestry species further play a key role in regulating long term C build up, as the rate of soil organic matter decomposition is dependent on residue chemical quality which is mainly defined using various ratios of carbon, nitrogen, lignin and polyphenols (Vanlauwe *et al.* 1997).

Contrary to the argument that agroforestry systems can only contribute substantial C sinks if the rotation of trees is greater than 20 years, research has shown that short fallows of even less than 5 years represent a substantial C pool (Schroeder 1994; Albrecht and Kandji 2003). However, there is limited data available on impact of C dynamics by agroforestry species, as previous research has focused on agricultural productivity. Therefore, knowing the sizes of carbon pools in agroforestry systems is important to promoting the land use system as a C sink. The objective of this research was to determine the biomass carbon and litter quality of commonly recommended improved fallow species, in the coastal region of Kenya.

Methods
Site description and soil type
An on farm field experiment was established at Malindi Kenya (0^0 12'S 40^0 05E), at an altitude of 20 m ASL, with a mean annual temperature of 25^0C (Njarui *et al.* 2004). The site receives a mean annual rainfall of 1050 mm. The soils are weakly developed Arenosols characterized by a sandy texture with less than 15% clay (Walela *et al.* 2006; MOA 1982).

Field experiment and measurements
The experiment was arranged in a randomized complete block design with five treatments and three replicates during May/June 2006 long rains. The plot sizes were 5m by 5m and treatments comprised of: *Crotolaria grahamiana, Sesbania sesban, Tephrosia vogelii, Mucuna pruriens,* and *Tephrosia candida.*

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Above ground biomass production (foliage and woody parts) was assessed at two intervals; 6 and 12 months after sowing (MAS). Aboveground total carbon stocks in the improved fallow species were calculated by multiplying aboveground biomass by a factor of 0.48 (Kaonga 2005). Root biomass was estimated on the basis of a factor of 0.25 of aboveground vegetation biomass (Snowdon *et al.* 2000). Root carbon stocks were calculated by a default conversion factor of 0.26 of aboveground tree C stocks (IPCC 2003). Plant foliage was harvested, oven-dried at 70^o C for 48 hours and ground (20 mesh) for plant tissue analysis. Lignin content was determined following the acid detergent fiber (ADF) method while total extractable polyphenols were analysed calorimetrically using the Folin-Cio Calteu method (Anderson and Ingram 1993). Data was analysed using R version 2.9.0 (R Development Core Team 2009). Analysis of variance (ANOVA) was used to determine treatment differences in biomass carbon and substrate quality of improved fallow species.

Results and discussion

Carbon stocks in plant biomass

The effects of species, measurement time and their interaction on total carbon were highly significant ($P < 0.001$). Total carbon stocks at 6 MAS ranged from 0.04 (*S. sesban*) to 1.4 Mg C /ha (*M. pruriens*) compared from 1.7 (*S. sesban*) to 20.3 Mg C /ha (*T. candida*) at 12 MAS (Figure1). Within the individual fallow species, duration of the fallow period significantly ($P < 0.001$) affected the amount of total carbon stocks. The highest increase of 19.3Mg C /ha was observed in *T.candida* with C stocks of between 1.0 to 20.3 Mg C /ha at 6 and 12 MAS respectively. Similar results of *T.candida* accumulating the largest aboveground C stocks as compared to eight other species have been reported in eastern Zambia (Kaonga 2009).

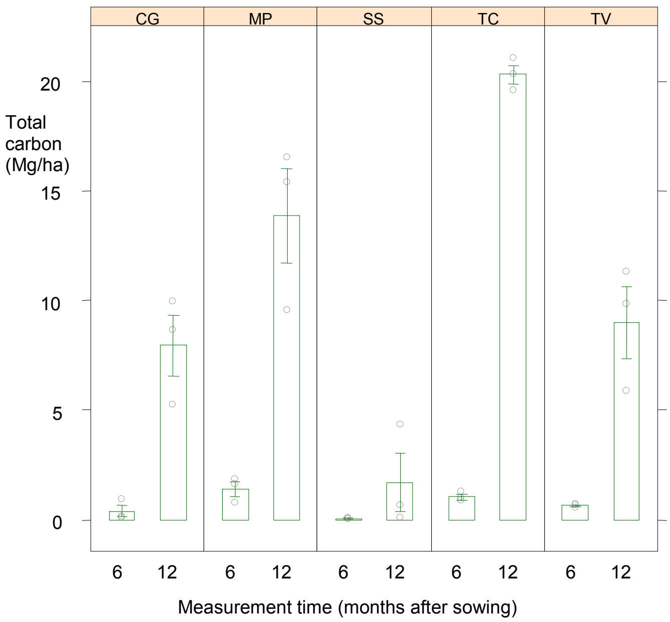

Figure 4. Effect of improved fallow species and time of measurement on total carbon stock accumulation (CG = *Crotolaria grahamiana*, MP = *Mucuna pruriens*, SS=*Sesbania sesban*, TC=*Tephrosia candida*, TV=*Tephrosia vogelii*).

By contrast, C stocks in this study compare similarly with those from other parts of the country particularly Western Kenya. Total C stocks were calculated from published biomass data (Boye 2000; Ndufa 2001; Nybert 2001; Impala 2001) in a 12-month old fallow. The results showed total carbon stocks in *C. grahamiana, S. sesban* and *T. vogelii* were 5.4, 10.3 and 7.1 Mg C /ha, respectively, while the C stocks for the same species in the current research were 7.9, 1.7 and 9.0 Mg C /ha, respectively. These results show similar C biomass build up except for *S. sesban* species. The disparity in performance of *S. sesban* between the two sites can be attributed to variability of climate and edaphic conditions.

Carbon build up in individual fallow species is clearly influenced by the duration of the fallow. A similar trend in C accumulation with a prolonged fallow duration has been calculated from biomass data of a 18-month fallow for *C. grahamiana* and *T.candida* (data from Boye 2000; Ndufa 2001; Nybert 2001; Impala 2001). Calculated C stocks show an accumulation of 17 and 30 Mg C /ha for the two above mentioned species, respectively. The results from the current and related research indicate the need to consider the duration of the fallow species, especially where C sequestration is a major objective. Results from this study would suggest that poorly degraded soils with carbon contents as low as 0.40 %, as those described in the current site (Walela *et al.* 2006), have the potential to sequester substantial amounts of C stocks.

Litter quality

The average polyphenol contents across the agroforestry species were 2.6 %. Lignin contents were highest in *T. candida* (16.3 %) and lowest in *S. sesban* (11.1 %). The lignin to N ratio ranged from 2.80 (*S. sesban*) to 4.52 (*T. candida*) (Table 1).

Table 1. Chemical indices of improved fallow foliage at 6 MAS.

Species	Polyphenols (%)	Lignins (%)	Nitrogen (%)	Ligin:Nitrogen ratio
Crotolaria grahamiana	2.76	11.4	4.03	2.82
Mucuna pruriens	2.37	15.7	5.20	3.02
Sesbania sesban	2.59	11.1	3.97	2.80
Tephrosia candida	2.87	16.3	3.60	4.52
Tephrosia vogelii	2.53	16.1	4.29	3.75

The quality of these species are similar to those reported from published data on agroforestry species; N > 2.5 %, lignin < 15% and polyphenols < 4% (Palm *et al.* 2001). However, *Tephrosia* provenances had a significantly slightly higher lignin content of > 15 % and the lignin to N ratio was also slightly higher in these species. In terms of building recalcitrant C pools in the soil, species with a slightly higher lignin to N ratio would be more effective. Lignin compounds exhibit a higher resistance to microbial degradation and hence are very important for potential of C sequestration.

Conclusions

Total biomass carbon in the improved fallow species tested at the coastal Kenya site increased in the order of *T.candida > M.pruriens > C.grahamiana > T.vogelii > S.sesban.* Further research on optimal duration for maximum biomass C sequestration for agroforestry species in specific climatic zones is needed. The litter quality of the species reported here is high; however, further detailed research is required to determine how litter quality affects the transformations of plant residues into stable soil organic matter. Additionally, the contribution of total biomass carbon of the species evaluated to total soil organic carbon and pool sizes will need to be determined.

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