Fuelwood supply and soil carbon dynamics under rotational woodlot systems in semiarid eastern and western Tanzania

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Introduction

Conversion of forest to small-scale permanent agriculture is one the major causes of high deforestation rates in Africa, accounting for 87.3 % of greenhouse gas emissions in Tanzania (Makundi 2001). Tanzania, a pilot country in the UN program for reducing emissions from deforestation and forest degradation (REDD), is developing programs and policies to decrease deforestation rate estimated at 91,000 ha yr^{-1} (FAO, 2007). As a tree base-system, agroforestry can contribute significantly to these efforts through on-farm fuelwood supply and intensification of subsistent agriculture to minimize harvesting pressure and agricultural expansion into native forests. In contrast to humid and sub-humid zones (Palm et al., 2004), little is known on carbon sequestration potential of agroforestry systems in semiarid areas. We present here fuelwood yield and carbon accumulation under 5-year old rotational woodlot systems (Fig. 1) versus natural fallows and continuous cropping practices in semiarid Tanzania.

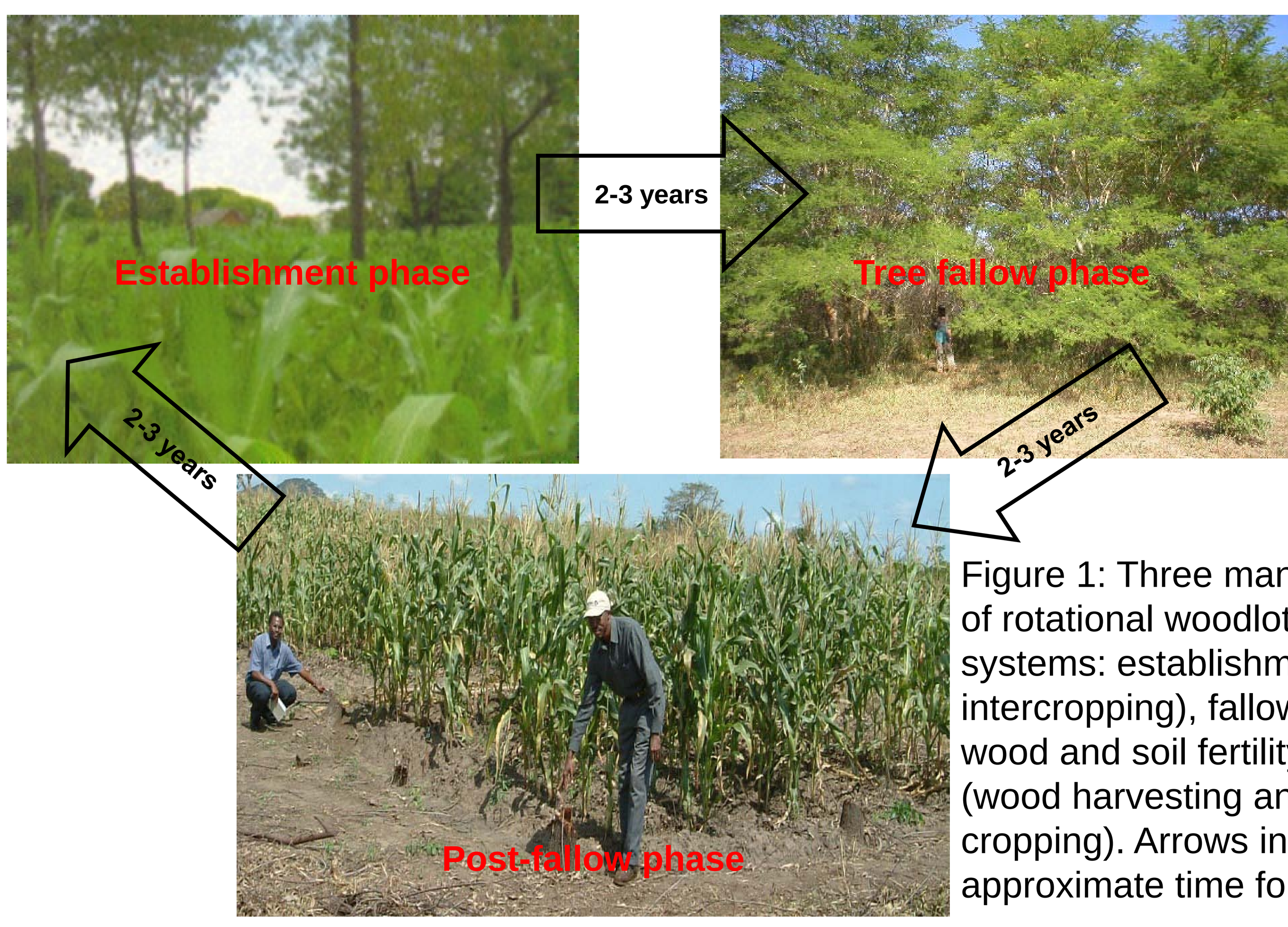

Figure 1: Three management phases of rotational woodlot agroforestry systems: establishment (tree-crop intercropping), fallow (build up of wood and soil fertility) and post-fallow (wood harvesting and sequential cropping). Arrows indicate approximate time for each phase.

Objectives

• Examine tree species effects on fuelwood supply and carbon stocks in soils and wood.

• Analyze results in the context of published data on wood yields and carbon stocks in wood and soils of the native Miombo forests (Fig. 2) to assess the efficacy of planted tree fallows to reduce deforestation and avoid carbon emissions. probably

Figure 2: Natural miombo woodland (a) and 5-year planted tree fallows of different species (b, c) in Morogoro, Tanzania.

Methodology

Study sites*:* Eastern (Morogoro region) and western (Tabora and Shinyanga regions) of Tanzania with annual rainfall of about 700 to 928mm.

Experimental design*:* Randomized complete block designs with three replications testing effects of tree fallows on fuelwood supply, stem carbon and soil carbon. Natural fallow and continuous cropping systems were used as controls.

Lab analysis: Trees were destructively sampled for dry weight determination. Carbon in wood was determined as 50% of oven dry weight of stem and branches and the value extrapolated to one hectare. Soil carbon in the top soil (0-15 cm) was analyzed using the Black and Wiley method and the values converted to one hectare based on bulk density.

Results and discussion

Wood biomass and carbon accumulation

After a 5-year fallow period, tree species produced fuelwood (Table 1) that was sufficient to satisfy household demands for 7–16 years (Nyadzi et al., 2003; Kimaro et al., 2007). Carbon in wood of *A. crassicarpa* and *A. leptocarpa* (20.5-25.5 Mg C ha^{-1}), and *A. mangium* and *A. polyacantha* (18.0 and 18.9 Mg C ha^{-1}) were respectively higher and similar to wood carbon (19 Mg C ha^{-1}) in the protected Miombo forests (Williams et al 2008). These results demonstrate the high capacity of planted tree fallows to sequester atmospheric carbon compared to native forests presumably due to faster growth, larger tree size, and more intensive management.

Based on our results, it would take about 4-10 years for the tree fallows to recover wood carbon lost by converting native forest reserves containing 19 Mg C ha^{-1} to agriculture. This period is considerably shorter compared to 2-3 decades for re-growing Miombo woodland after cultivation (Williams et al 2008). Potentially, about 2088 ha and 8,675 ha of local forests cleared annually in the Morogoro and Tabora regions can be protected from wood extraction (Luoga et al., 2000, Ramadhani et al. 2002) by putting a portion of the household's farm (0.09 to 0.91 ha, Table 2) under rotational woodlot culture.

Table 1: Biomass and carbon accumulation (Mg ha^{-1}) in wood of tree species under 5-year-old rotational woodlot systems in Morogoro and Tabora regions, Tanzania

Tree species	Morogoro[1]		Tabora[2]	
	Biomass	Carbon	Biomass	Carbon
Acacia polyacantha	36.0cb[3]	18.0cb		
Acacia nilotica	23.2e	11.6e		
Acacia mangium	37.7b	18.9b		
Acacia crassicarpa	51.0a	25.5a	35.0ab	12.5ab
Acacia leptocarpa	38.3b	18.1b	40.9a	20.5a
Acacia julifera	30.8cd	15.4cd	20.5bc	10.3bc
Acacia auriculiformis	23.2e	11.6e		
Gliricidia sepium	29.1ed	14.5ed		
Leucaena diversifolia	33.7cbd	16.8cbd		
Leucaena pallida			9.6c	4.3c
Senna siamea			22.1bc	11.5bc
Probability	<0.0001	<0.0001	<0.01	<0.01

[1]Kimaro et al (2007 a, b), [2]Nyadzi et al. (2003), [3] Means within a column followed by the same letter are not significantly different according to least significant difference (n = 3).

Table 2: Estimated household farm size (ha) by tree species required to produce wood for firewood and charcoal supply in Morogoro and for tobacco curing in Tabora, Tanzania

Fallow type	Tobacco[1]	Fuelwood[1]	Charcoal[1]
Acacia crassicarpa	0.34	0.09	0.34
Acacia mangium	ND[2]	0.11	0.45
Acacia polyacantha	ND[2]	0.15	0.59
Acacia leptocarpa	0.29	0.14	0.54
Acacia julifera	0.57	0.15	0.61
Acacia nilotica	ND	0.23	0.91

[1]Area estimated based on wood yield (Nyadzi et al. 2003; Kimaro et al. 2007a,b) and wood basic density (Nyadzi, 2004; Luhende et al. 2006) of tree species, annual volume or biomass of wood extracted from native forests and the population size (Luoga et al. 2000; Ramadhani et al. 2002). [2]ND = Not determined because these species were not tested in Tabora.

Soil organic carbon

Higher soil organic carbon (15.8 to 25.6 Mg C ha^{-1}) after tree fallows than in the continuously cropped soils (13 Mg C ha^{-1}) reflects inputs from litter and root turnover during the fallow period (Table 3). Tree fallowing raised top soil carbon above levels obtained within 0-30 cm depth of the fallowed Miombo soils (9-15 Mg C ha^{-1}), but close to levels (14-27 Mg C ha^{-1}) obtained in soils under the forest reserves (Walker and Desanker 2004). Although labile fractions of soil carbon in agroforestry systems may be lost through cultivation, it has been shown that stable fractions of soil organic matter are unaffected during the first three years (Solomon et al. 2000). Hence rotational woodlot systems may not adversely affect soil carbon pools because the recommended length of the post-fallow cropping phase is shorter than three years.

Table 3: Soil carbon (Mg ha) under planted tree fallows in semi-arid Morogoro, Tanzania

Fallow type	Soil organic carbon
Acacia crassicarpa	15.8c[1]
Acacia mangium	25.6a
Acacia polyacantha	21.6ba
Gliricidia Sepium	18.8bc
Acacia nilotica	22.7ba
Natural grass fallow	17.8bc
Continuous cropping	13.0d

[1] Means marked by the same letter are not significantly different according to least significant difference (n = 3).

Conclusions

Rotational woodlot systems utilizing fast growing tree species can satisfy household and regional fuelwood demand while reducing harvesting pressure on local forests and the associated carbon emissions. Although wood carbon can be released after fuelwood harvesting, it represents amounts that counter increased carbon dioxide emissions from clearing local forests for wood fuel supply or from using fossil fuels. The rotational woodlot system holds promise to sustain soil organic carbon because stable fractions of soil organic matter are generally unaffected by the short (3-year) post-fallow cropping period under hand hoe cultivation. Of the tested tree species, *A. crassicarpa A. mangium*, *A. leptocarpa*, and *A. polyacantha* showed the highest capacity to sequester carbon. Besides increasing post-fallow crop yield (Fig. 1), these species can mitigate carbon dioxide emission through on-farm wood supply and soil organic matter build up.

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