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Potential of improved fallows to increase household and regional fuelwood supply: evidence from western Kenya

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Abstract Fuelwood is the main energy source for households in rural Africa, but its supply is rapidly declining especially in the densely populated areas. Short duration planted tree fallows, an agroforestry technology widely promoted in sub-Sahara Africa for soil fertility improvement may offer some remedy. Our objective was to determine the fuelwood production potential of 6, 12 and 18 months (the common fallow rotation periods) old *Crotalaria grahamiana*, *Crotalaria paulina*, *Tephrosia vogelli* and *Tephrosia candida* fallows under farmer-managed conditions in western Kenya. Based on plot-level yields, we estimated the extent to which these tree fallows would meet household and sub-national fuelwood needs if farmers planted at least 0.25 hectares, the proportion of land that is typically left under natural fallows by farmers in the region. Fuelwood yield was affected significantly ($P < 0.05$) by the interaction between species and fallow duration. Among the 6-month-old fallows, *T. candida* produced the highest fuelwood (8.9 t ha^{-1}), compared with the rest that produced between 5.6 and 6.2 t ha^{-1}. Twelve months old *T. candida* and *C. paulina* also produced significantly higher fuelwood yield (average, 9.6 t ha^{-1}) than *T. vogelli* and *C. grahamiana* of the same age. Between the fallow durations, the 18-month fallows produced the most fuelwood among the species evaluated, averaging 14.7 t ha^{-1}. This was 2–3 times higher than the average yields of 6 and 12-month-old fallows whose yields were not significantly different. The actual fuelwood harvested from the plots that were planted to improved fallows (which ranged from 0.01 to 0.08 ha) would last a typical household between 11.8 and 124.8 days depending on the species and fallow duration. This would increase to 268.5 (0.7 years) and 1173.7 days (0.7–3.2 years) if farmers were to increase area planted to 0.25 ha. Farmers typically planted the fallows at high stand densities (over 100,000 plants ha^{-1} on average) in order to maximize their benefits of improving soil fertility and providing fuelwood at the same time. This potential could be increased if more land (which fortunately exists) was planted to the fallows within the farms in the region. The research and development needs for this to happen at the desired scale are highlighted in the paper.

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Introduction

Fuelwood energy accounts for about 80% of energy used in sub-Saharan Africa (World Bank 1992). It is by far the most important source of energy in this region, with an average annual per capita consumption of 1.0 m^3 (Agarwal 1986), and accounts for 58% of the total energy used in Africa (Bogach 1985). Trees in individual farmlands and forests are, however, progressively disappearing as a result of population pressure, associated decline in land holding per unit household and commercial demand for wood products, consequently making fuelwood scarce (Anderson and Fishwick 1984; O'Keefe and Raskin 1985). This problem is very evident in western Kenya, one of the most densely populated areas in Africa, where densities of over 1,000 persons per square kilometre are not unusual. Barnes et al. (1984) report weekly per capita wood consumption figures of 6.8 kg for this region. Women gather the wood and carry it home on their back or head. Paradoxically, tree density and diversity on farms is also high (Kindt et al. 2006)—a phenomena Bradley et al. (1988) described as '*more people, more trees*'. The trees, however, are typically planted for other purposes, including cash, and not for fuelwood. Poverty is also pervasive in the region, with 50% or more of the population estimated to be living in poverty in several of the districts (GoK 2000), and which is significantly higher than other regions of the country of similar high agricultural potential.

In order to meet their energy needs, farmers are increasingly using crop residues as their energy source. For instance, Mugo (1999) observed that due to fuelwood scarcity, about 40% of the farmers in western Kenya use crop residues and cow dung as a source of household energy. Consequently, farmers do not get enough organic matter to return to the soil, leading to low soil fertility, declining production and food insecurity (Sanchez 2002). The task of fuelwood collection often falls disproportionately on children and women, taking time away from education and other productive activities (Kituyi 2004). Mugo (1999), for instance, estimated that women who collect fuelwood for cooking from far off places spend, on average, 130 h per year, as compared to only 36 h spent by those who harvest firewood from their own farms. Increased labour allocation to wood collection affects the time women spend on food production, food processing, food preparation and income generating activities (Cecelski 1985; Kumar and Hotchkiss 1988).

Agroforestry technologies can generate fuelwood in addition to providing other tree products and services such as improving soil fertility. One such technology is the short duration planted fallows or improved fallows (IF) usually with N_2 fixing trees and shrubs. *Sesbania sesban*, *Tephrosia vogelii* and *Crotalaria grahamiana* are among the most widely used or promoted leguminous species in western Kenya (Niang et al. 2002). Several studies demonstrate the complementary value of IF to inorganic fertilizers in increasing crop yields (Niang et al. 2002; Jama et al. 1998; Gathumbi et al. 2004). They are more efficient than natural fallows and can, in certain soils, have the same effects as inorganic fertilizers on crop yields (Kwesiga and Coe 1994; Place et al. 2003). IFs, particularly *Sesbania sesban*, also control weeds, including striga (*S. hermontheca*) that parasitizes on maize and other cereal crops (Gacheru and Rao 2001). In addition, the proportion of poor households in western Kenya, which use improved fallows, exceeds the use rates of most other soil-fertility improvement options (Place et al. 2002).

Depending on the species, IFs also produce fuelwood and fodder. A wide range of fuelwood yields have been reported under researcher-managed conditions. Examples include: 5–24 t ha^{-1} within a duration of 1–3 years in western Kenya (Swinkels et al. 1997; Jama et al. 1998; Gathumbi et al. 2004), 24–27 t ha^{-1} after 2 years in south western Uganda highlands (Siriri and Rausen 2003), 10 t ha^{-1} after 2 years in eastern Zambia (Sanchez 1995), and 13.7–21.2 t ha^{-1} after 2.7 years in coastal Kenya (Jama and Getahun 1991). These systems can also have high returns on investments, whether fertilizers, an expensive commodity in rural Africa, are used (Jama et al. 1998) or not (Siriri and Rausen 2003).

There is, however, limited information on the fuelwood production potential of IFs under farmer-managed conditions and the extent to which it can meet household energy needs. Knowledge of the fuelwood production potential of IFs would help in the selection of appropriate species for IFs and their management in association with crops. Besides species differences, age of the fallows and stand density are two management factors that would probably influence the amount of fuelwood that is produced by farmers as researcher-managed studies indicate (Jama et al. 1998; Gathumbi et al. 2004).

The objectives of this on-farm study in western Kenya were: (a) to determine the actual and potential fuelwood yield of four IF species under farmer-designed and managed conditions at farm level and on land in the entire region estimated to be suitable for IFs; (b) to estimate the potential of actual and potential fuelwood production to meet demands of households and communities in the region; and, (c) to identify management factors and attributes of the fallows that are of importance to the farmers.

Materials and methods

Study area

The study was carried out between 1998 and 2001 on farms in Yala and Luanda administrative divisions of the western Kenya region. The study area is part of Lake Victoria basin and highlands of East and Central Africa, with an elevation ranging from 1,200 to 1,800 m above sea level, and with tropical sub-humid climate. Although the rainfall amount and distribution differs within sites and districts of the study area, rainfall in the region ranges from 1,400 to 1,800 mm and occurs in two seasons: from mid-March to July (long rains) and from September to December (short rains). The long-term monthly average temperature is 19.5°C with a maximum of 29°C and a minimum of 14°C.

The soils are mainly Isohyperthemic Kandiudulfic Eutrudox, with the following soil properties in the top 15 cm: air-dried pH (1:2.5 soil water suspension) = 5.1, organic C = 15 g kg $^{-1}$, bicarbonate EDTA extractable P = 2 mg kg^{-1} (Yurimaguas Exp. Stn. Staff 1989), clay = 46% and sand = 26%. Both sites have a subsistence-level, mixed crop livestock farming system. The major crops of smallholder farmers are maize (mostly unimproved varieties) and beans (*Phaseolus vulgaris* L.), while the cattle are mostly unimproved breeds of Zebu (*Bos indicus*). Land pressure is high, with a population estimated at about 12 million, or about 35% of the total population of Kenya (GoK-CBS 2001). Population density is between 500 to 1,200 inhabitants km^{-2} (Hoekstra and Corbett 1995). Most farms are small-holders, ranging from 0.5 to 2.0 ha (Minae and Akyeampong 1988; David and Swinkels 1994).

Notwithstanding the small farms, leaving land fallow with natural fallows is a common practice among farmers in the study area, in order to improve soil fertility and crop yields (Bradley et al. 1988). Ohlsson and Swinkels (1993) study estimated that 52% of the farmers in Vihiga, Siaya, and Kisumu districts leave their land under natural fallow for at least one cropping season, mainly during the short rainy season. Such land can be between 10 and 50% of the total land holding. The reasons for leaving land fallow include improved soil fertility and lack of labour (Swinkels et al. 1997). About two-thirds of these fallows are kept for 2–4 seasons (Dewolf and Rommelse 2000).

The high percentage of land under fallow in such a densely populated area is unexpected and somewhat surprising. However, its short duration would be expected, when compared to areas where land is less limiting and fallow periods tend to be longer, i.e. over 2 years, as observed in eastern Zambia (Kwesiga and Coe 1994). Since the mid-1980s, these natural fallows have been the target of agricultural research and development institutions aiming to implement interventions that use improved fallows to enhance soil fertility and productivity (Sanchez 1995). Although there has yet to be a definitive count of improved fallow users in western Kenya, it is estimated that the figure is somewhere between 10,000 and 20,000 households in any given year (Place et al. 2004).

Methodology

The yield of fuelwood and stand density of four species (*Crotalaria grahamiana*, *Crotalaria paulina*, *Tephrosia vogelli and Tephrosia candida*) on 35 farms that have been randomly selected was assessed in 2001. The fallows were farmer-designed and farmer-managed, a practice commonly known as type 3 trials (Franzel et al. 1998). They were established primarily for soil fertility improvement and, therefore, fuelwood was a secondary product. Three age groups of fallows were harvested: 6, 12 and 18 months old. Several studies indicate these fallow durations are common among the smallholder farmers in western Kenya who practice natural fallows as a measure to improve soil fertility and productivity (Ohlsson and Swinkels 1993; Jama et al. 1998; Dewolf and Rommelse 2000). Some limited on-station research has also been done in the study area on the effects of fallow duration (6 vs. 12 months) on biomass production for some of the species used but not under on-farm conditions (Niang et al. 2002). Farmers consider long duration fallows important for improving soil fertility, rehabilitating degraded lands, and suppressing noxious weeds, including striga (Place et al. 2004).

The number of farmers who harvested fallows in each of the age groups was not equal, as the selection criteria included the presence of good stands and the percentage of canopy cover (at least 60%), based on visual estimation by both farmers and the research team. This drastically reduced the number of farms that could be evaluated but still provided a fair representation of the range of smallholder farm types found in the study area. Variations between stand densities of the fallows within and between farms occurred at planting times and at various times in their growth through periodic plant death and harvests for fuelwood.

From the selected farms, three quadrants were sampled for each fallow species. The size of each quadrant was either 3 m by 3 m or 2 m by 2 m, depending on the plot size designated for the fallows. The sampling grids were located carefully to avoid edge effects. The number of trees in each quadrant was counted and average stand density per quadrant determined. The trees were then harvested by cutting at the ground level and the biomass separated into wood (including twigs > 2 cm diameter) and foliage (leaves and wood < 2 cm diameter). Both the wood and leaf samples were oven dried at 60°C for 48 h to a constant weight, in order to facilitate comparison of the fuelwood production of the different fallow species and ages.

Estimating sub-national fuelwood supply

Based on the plot-level yields of the individual farms, estimate was made as to the amount of fuelwood that could be produced by a single household if 0.25 hectares of their land was allocated to the improved fallows for three seasons, using 6, 12, and 18 months old fallows. The 0.25 ha is based on the studies of Swinkels et al. (1997) that indicate that farmers in the study area typically leave between 10 and 50% of their total holdings under fallows. The fuelwood production level was then estimated from 0.25 ha of all the land in western Kenya, for which the improved fallow technology may be appropriate. This assessment was based on the total area of western Kenya that is about 85,000 km^2 (8,500,000 ha) (David and Swinkels 1994) and a proportion of it (1.8% or 153,000 ha) that is estimated to be suitable for improved fallows (Nanok 2003).

On fuelwood consumption, Barnes et al. (1984) report weekly per capita wood consumption figures of 6.8 kg for this region. This is consistent with the estimates of Mugo (1999) reporting fuelwood consumption of 1.23 kg per person per day for households in the same region (based on the average household size of 5–6 members). These consumption rates are also within the range of 0.8–2.7 kg per person per day reported by Kituyi et al. (2001) and similar to that reported by Nyang (1999) of 1.21 kg per person per day for households living in the rural highlands of Kenya. Using the 1.23 kg per person per day value, it was estimated that a typical household in western Kenya consumes about 8.61 kg of wood on daily basis. The period during which fuelwood could be utilized by a typical household was then estimated for each of the fallow species and ages evaluated.

Farmer's assessment

A formal questionnaire was used to assess farmers' perception of fuelwood supply and qualities of species that they would be likely to adopt in order to solve fuelwood supply and availability problems. Next, farmers' ranking of the four fallow species for fuelwood supply was assessed, based on the evaluation criteria they had identified.

Data analysis

Data analysis was conducted by use of Genstat version 8.0 statistical package (Genstat 2005). Since all the species and age classes were not equally represented across farms, data from all treatments were analysed using incomplete block design procedures with individual farms representing blocks. The standard deviation of the means was used to compare the mean wood yields of the four improved fallow species. Regression analysis was conducted to establish the relationship between wood yield and key variables hypothesized to influence wood production. Social variables such as farmers' evaluations were analysed by use of SPSS package and reported as percentages of the sample population evaluated. Mention of statistical significance refers to $\alpha = 0.05$ unless otherwise stated.

Results and discussion

Fuelwood and foliage yield

Fuelwood yield was affected significantly by the interaction between species and fallow duration (Table 1). Among the 6-month-old fallows, *T. candida* produced the highest fuelwood (8.9 t ha^{-1}), compared to *C. paulina*, *C. grahamiana* and *T. vogelli*, which produced between 5.6 and 6.2 t ha^{-1} of wood. Twelve months old *T. candida* and *C. paulina* produced significantly higher fuelwood yield (average, 9.6 t ha^{-1}) than *T. vogelli* and *C. grahamiana* of the same age. Fuelwood yield from 12 months old C. *paulina* and *T. candida* (average, 5.5 t ha^{-1}) were statistically similar. Similarly we did not observe any significant yield difference between 12 months old *T. vogelli* and *C. grahamiana*. Apart from *C. paulina*, there was no significant species specific differences between 6 and 12 months old fallows for other fallow species.

Within the same species, 18 months old fallow species always produced significantly higher quantity of fuelwood relative to 12 and 6 months old fallows. Aggregate average yields increased by 10.5 and 9.6 t ha^{-1}, respectively, over the average yields of the 6 and 12 months old fallows. In terms of species, when averaged over the three fallow durations, fuelwood yield (t ha^{-1}) was the highest for *T. candida* (12.5), intermediate for *C. paulina* (10.8), and the lowest but comparable for *C. grahamiana* (8.0) and *T. vogelii* (7.3). These discrepancies between the performance of the fallow species suggests their management needs for purposes of fuelwood production are different.

This observation of high fuelwood or biomass yield by *T. candida* fallows relative to the other species is consistent with the results of other studies (see, Mafongoya et al. 2003; Albrecht and Kandji 2003). In these studies Mafongoya et al (2003) observed a yield of 13.4 t ha^{-1} from 18 months old *T. candida* fallows compared to 6.2 t ha^{-1} from *T. vogelli* fallows under the same management conditions in eastern Zambia. In western Kenya, Albrecht and Kandji (2003) observed higher total aboveground biomass yield of 31 t ha^{-1} from 18 months old *T. candida* compared to 24.7 t ha^{-1} for *C. grahamiana* and 19.8 t ha^{-1} for *C. paulina* fallows. The consistent superior performance of *T. candida* across these two regions that contrast sufficiently well in their agro-ecologial conditions indicates its robustness and potential to meet expected fuelwood production levels. The fuelwood yield from 12 month-old *T. vogelli* and *C. grahamiana* fallow observed in our study were, somewhat surprisingly, higher than those reported by Girma et al. (2006) in the same study area but under researcher management. In part, these differences could be explained by the higher stand densities used by the farmers (see section on 'stand density').

The large discrepancies observed in fuelwood yields between and within species at the same

Table 1 Fuelwood production by four improved fallow species as determined from 6, 12 and 18 months old fallows under farmer-managed conditions in western Kenya

Species	Fallow duration (months)			Average
	6	12	18	
	t ha^{-1}			
C. grahamiana	5.8 (3.5; 8)	4.9 (2.3; 11)	13.4 (0.7; 4)	8.0
C. paulina	6.2 (1.2; 4)	10.8 (2.2; 5)	14.8 (7.8; 4)	10.6
T. vogelli	5.6 (3.8; 5)	6.0 (3.0; 8)	10.2 (7.6; 6)	7.3
T. candida	8.9 (1.8; 6)	8.4 (3.4; 5)	20.2 (9.4; 5)	12.5

Figures in parenthesis are standard deviation and sample size location could be attributed to site and species differences. It could also be due discrepancies in the management of the fallows by farmers such as the existence of different stand densities. Such differences between farms would be expected in farmer's-managed trials and is, indeed, one of the objectives of conducting Type 3 trials (Franzel et al. 1998). It is, however, encouraging to note that fuelwood production under farmer-managed conditions can be as high as those under researcher-managed. Higher yields (at least 1–2 t ha^{-1}) have been reported by Gathumbi et al. (2004), from the same study area under researcher-managed conditions, which also included the application of phosphorus. In phosphorus-deficient soils, such as those in western Kenya, response of fast growing trees to the application of phosphorus can be significant (Ndufa et al. 1999).

The absence of significant fuelwood yield differences between 6 and 12-month-old fallows for some species is noteworthy (Table 1). Under these conditions, some of the justification for retaining the fallows beyond 6 months would include increased benefits in firewood quality, such as higher calorific value, improved soil fertility, and better weed control. Older fallows also produce more foliage, drop more litter and may have more profound effects on soil fertility and crop yields, which is usually the primary reason for fallowing (Buresh and Cooper 1999; Kwesiga et al. 1999). Farmers do, indeed, leave land under natural fallows for 2–3 seasons as a way to regenerate lost soil fertility (Swinkels et al. 1997). The opportunity cost of fallowing these lands is also low (Franzel et al. 1998). Among the species evaluated, *T. candida* fallow stands out as the one that yields the most biomass (both foliage and fuelwood), and probably the one with the highest payoff in improved soil fertility and crop yields from investments beyond 6 months.

Foliage production

Foliage yield was always lower than wood production for each species and ranged between 3.7 and 5.7 t ha^{-1} for 6-month-old fallows; 3.5 and 7.3 t ha^{-1} for 12-month-old fallows; and, 3.3 and 10.5 t ha^{-1} for 18-month-old fallows. The relationship between wood and foliage yield for each season separately and across seasons for each species was linear, positive and significant ($P < 0.01$). The percentage of wood to total aboveground biomass for each season and for each species was always greater than 50%. Generally, the percentage ranged between 50 and 65% for both the first and the second seasons and between 70 and 80% for the third season (Fig. 1).

When averaged across seasons, the percentage wood to total aboveground biomass was 62% for *C. grahamiana*, 66% for *C. paulina*, 68% for *T. vogelli* and 71% for *T. candida*. High wood- to-foliage ratio for

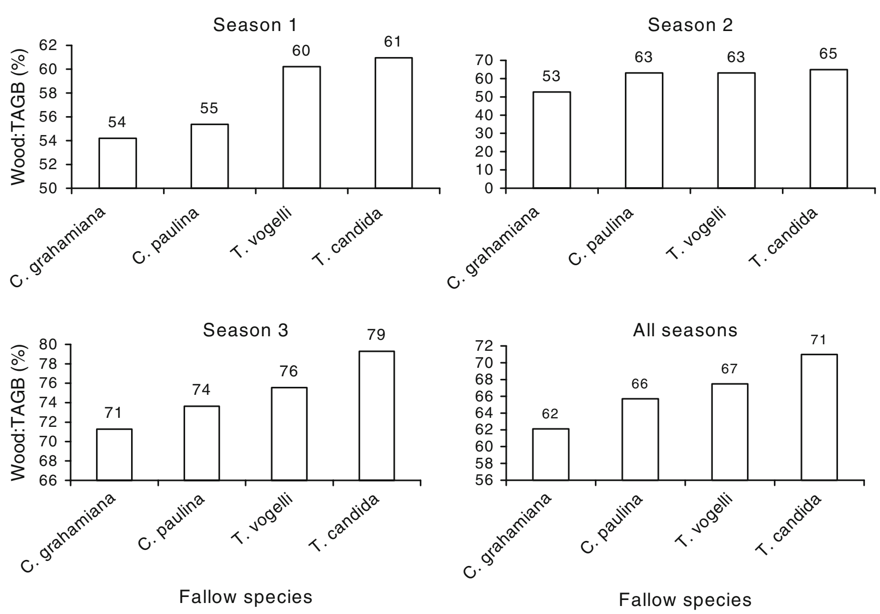

Fig. 1 Percentage of wood to total aboveground biomass (TAGB) of four improved fallow species in western Kenya

these species have also been reported by a number of workers (Jama et al.1998; Gathumbi et al. 2004; Mafongoya et al. 2003) and, basically, indicates the fitness of a provenance to produce more wood due to higher biomass allocation to woody components. Compared with the wide range observed in the fuelwood yield of the four species evaluated, the range in the % of foliage produced is relatively narrow (29–38%). This would suggest that, at this aggregate level, any of the species would qualify for use in IFs. This would, however, need to be tested empirically under different sites and farmer management conditions.

Effects of stand density on fuelwood yield

Stand density was higher than 100,000 plants ha^{-1} for most fallow species across the three seasons (Table 2). The exception was *T. vogelli* which was evidently sparse during the second season (stand density = 87,000 plants ha^{-1}). Average stand density across the three seasons was highest for the C. *paulina* fallows, intermediate for the *T. candida* fallows, intermediate for the *C. grahamiana* fallows and low for the *T. vogelli* fallows. It is interesting to note that these stand densities are several folds higher than those reported from researcher-managed trials (Gathumbi et al. 2004). One reason for this discrepancy is that farmers usually thin the high stand density over time and use the thinning for firewood or staking materials on the farm.

The relationship between stand density and fuelwood production for every species during the 6 and 12-month-duration was always positive ($R^2 > 0.5$) and significant ($P < 0.05$). Although this relationship was positive for the 18-month-fallow duration, it was low ($R^2 = 0.04$–0.26). This suggests that as fallow age advances, a very high stand density may negatively affect wood production. These observations are consistent with those of Reshid et al. (1987) who reported lower diameter and wood yield from 3.8 years old *C. equisetifolia* species established at a high density relative to those established at a lower density.

The decline in fuelwood production noted with increase in stand density (Table 2), especially as fallow duration increased, could be attributed to species death resulting from competition for growth resources. The data also suggests different responses between the species on the effects of thinning the stand density (through death or cutting by the farmers) on fuelwood yield. While increasing stand density improved the fuelwood yield of *C. grahamiana* fuelwood over time, it did not do so for the other species whose stand densities dropped considerably between 12 and 18 months (see Tables 1, 2). This suggests that, for these species, thinning could be instituted as an appropriate management practice for meeting the dual objectives of improving soil fertility which requires establishing high stand density and fuelwood production which needs less. The resulting thinning can then be used as fuelwood. Thinning the stand density would allow the remaining plants to expand in size due to reduced competition and produce wood of higher mass. More research, however, is needed to establish and better predict the most appropriate fallow stand density for different species and ages. In addition, there is a need to further explore the potential of mixing species, since this may reduce the risk of loss of a single species stand due to pests and diseases (Girma et al. 2006) or the risk of a single species failing to establish well (Gathumbi et al. 2004).

Table 2 Average stand density of the four fallow species in the farmers' fields at various harvesting age in western Kenya

Fallow species	Fallow duration (months)			
	6	12	18	Average
	Stand density (ha)			
C. grahamiana	118,000 (31,000)	102,000 (62,000)	153,000 (163,000)	125,667
C. paulina	245,000 (75,000)	349,000 (121,000)	190,000 (128,000)	261,333
T. vogelli	144,000 (46,000)	87,000 (51,000)	109,000 (82,000)	113,333
T. candida	136,000 (14,000)	180,000 (68,000)	136,000 (182,000)	150,667

Figures in parenthesis are standard deviation

Sub-national fuelwood supply potential

The area used for improved fallows in this study ranged from 0.01 to 0.08 ha (Table 3) and represents a small fraction—between 0.8 and 6.4% of the average land holdings in the study area. Place et al. (2003) have also made a similar observation in this densely populated region. Besides the small land holdings, other factors that could limit farmers' willingness to allocate more acreage to improved fallows include labour for planting and harvesting them (Place et al. 2004). While the area planted to fallows does not sound much, it should be recognized that the average farm size for many is about 0.6 hectares. The fallows are in rotations with maize field, after 6–18 months duration. Viewed in this way, the area planted to improved fallows can be effectively tripled in the study area.

When averaged over fallow species and duration, fuelwood harvested from fallow plots ranged between 0.1 and 0.6 tons. Household-projected fuelwood yield from a standard 0.25 ha for 6-month-old fallows was the highest for *T. candida* fallows (4.7 tons), intermediate for *C. paulina* fallows (3.4 tons) and low for *C. grahamiana* fallows (2.9 tons) and *T. vogelli* fallows (2.3 tons). Projected fuelwood yield for 12-month-old fallows was higher by 26% for *C. paulina*, 42% for *T. candida* and 109% for *T. vogelli*, but lower by 12% for *C. grahamiana* relative to 6-month-old fallow yield. For 18-month-old fallows, projected fuelwood yield was higher by 5.4 for *T. candida*, 4.2 tons for *C. grahamiana*, 1.5 tons for *C. paulina* and 1 ton for *T. vogelli* fallows relative to 12 months old fallow yields.

If 15, 000 households, the median number of households estimated to be using improved fallows in western Kenya (Place et al. 2004), were to allocate 0.25 ha to fallows, then the potential regional production would be between 67,159 and 87,952 tons yr^{-1} from *C. grahamiana*; 74,020 and 100,516 tons yr^{-1} from *C. paulina*; 69,344 to 151,500 tons yr^{-1} from *T. candida;* and, 58, 511 to 72,850 tons yr^{-1} of fuelwood from *T. vogelli.* The range in the yield estimates takes into consideration the length of fallow period. If all the land suitable for IFs in the region (153,000 ha) was put into this practice, the fuelwood yield of *T. candida* fallows would be between 4.1 and 6.2 million tons yr^{-1}; *C. paulina* fallows between 3.0 and 4.1 million tons yr^{-1}; *C. grahamiana* fallows between 1.6 and 3.6 million tons yr^{-1}; and, *T. vogelli* fallows between 2.4 and 3.0 million tons yr^{-1}.

The actual fuelwood produced by the fallow plots represents a supply of between 11.8 and 46.7 days of households' energy needs from 6-month-old fallows; 13.7 and 35.4 days from 12-month-old fallows, and, 17.2 and 124.8 days from 18-month-old fallows (Table 4). Production could be increased considerably if plot sizes were increased to 0.25 ha, and the land for this purpose is apparently available (Swinkels et al. 1997). If this happened, 6-month-old fallows would provide adequate fuelwood to last

Table 3 Actual and projected household and regional wood yield in western Kenya

Species	Fallow age (months)	Average actual harvested area (ha)	Average actual wood yield (tons)	Household wood yield from 0.25 ha (tons)	Regional wood production potential (million tons yr^{-1})
C. grahamiana	6	0.05	0.3	2.9	3.6
	12	0.06	0.2	2.6	1.6
	18	0.08	1.1	6.7	2.7
C. paulina	6	0.06	0.4	3.4	4.1
	12	0.01	0.1	5.9	3.6
	18	0.01	0.1	7.4	3.0
T. candida	6	0.02	0.2	4.7	5.8
	12	0.02	0.3	6.7	4.1
	18	0.02	0.4	10.1	6.2
T. vogelli	6	0.02	0.1	2.3	2.8
	12	0.04	0.3	4.9	3.0
	18	0.04	0.5	5.9	2.4

between 0.7 and 1.5 years (Table 4), with the first figure representing fuelwood yield by *T. vogelli* fallows and the second figure the fuelwood yield by *T. candida* fallows.

The estimates of how long projected fuelwood yields could last households (Table 4) suggests a wide variation depending on the species and the duration. From 12-month-old *T. candida* fallows on 0.25 ha, fuelwood harvested could last households 1.3 years longer than *C. grahamiana*, 7 months longer than *T. vogelli* and 3 months longer than *C. paulina* fallows. Similarly, fallow durations of 18 months would generate enough fuelwood to last households for between 697 and 1,173 days (1.9–3.2 years) if any of the four fallows species was used on 0.25 ha. The differences between fallow yield at 12 months and 18 months implies that prolonging fallow duration to 18 months would generate more wood for an additional 1.3 years for *C. grahamiana* fallows, 0.5 years for *C. paulina* fallows and 0.3 years for *T. vogelli* fallows. Since wood markets are not well developed in western Kenya (Swinkels et al. 1997; Jama et al. 1998), farmers in the region would probably use the produced fuelwood for domestic energy. This could save considerable time (Mugo 1999) and energy for women, and increasingly children, who carry the burden of fuelwood collection. The importance of on-farm fuelwood production becomes even more compelling when one takes into considering the weekly per capita fuelwood consumption that is estimated at 6.8 kg (Barnes et al. 1984) and households that on average have 5–6 members.

The regional fuelwood supply estimates indicate the existence of a large potential that is yet untapped. It also indicates that improved fallows have not been widely adopted even for purposes of soil fertility improvement. This is in spite of the observation that unlike other soil fertility options, improved fallows are being used by large number of women farmers (Place et al. 2002). This is very important in places like western Kenya, where the number of female-headed households is large. This calls for major investments in the research and development efforts needed to scale up the use of the technology. The technology is knowledge-intensive and, where farmers have received seeds and technical support, adoption rates have been high (Place et al. 2003).

In order to scale up impacts of improved fallows, particular attention needs to go into increasing access to seeds and extension services, two key constraints that are recognized as limiting the wide scale adoption of the technology in the eastern and southern Africa region (Franzel 1999). Towards this end, one promising approach is the development and strengthening networks of research and development

Table 4 Comparison of lengths of period harvested and predicted improved fallow firewood would last a typical household in western Kenya

Fallow species	Fallow period (months)	Actual duration/planted plots Days	Predicted if 0.25 ha was planted
C. grahamiana	6	31.5	340.6 (0.9)*
	12	27.5	299.3 (0.8)
	18	124.8	780.0 (2.1)
C. Paulina	6	46.7	389.1 (1.1)
	12	13.7	682.8 (1.9)
	18	17.2	859.7 (2.4)
T. candida	6	21.9	548.8 (1.5)
	12	31.1	777.7 (2.1)
	18	47.0	1173.1 (3.2)
T. vogelli	6	11.8	268.5 (0.7)
	12	35.4	564.1 (1.5)
	18	54.4	697.1 (1.9)

* Values in brackets in the last column represent the number of years fuelwood from 6, 12 and 18 months old fallows would last a typical western Kenya household

institutions that promote agroforestry technologies as part of integrated soil fertility management options (Noordin et al. 2001; Place et al. 2002).

Among the species evaluated, *T. candida* stood out unmistakably as the best species for fuelwood production. For short duration fallows followed by 2–3 cropping seasons, *T. candida* had the highest fuelwood production potential at 6 and 12 months harvest. Its fuelwood yield from 12-month-old fallows would also last a typical household for about the same time or longer than the yield of other species harvested at 18 months. In addition to *T. candida*, *C. paulina* also yielded high from 6-month-old fallows, and continued to increase its wood yield up to 18 months.

Besides fuelwood, *T. candida* also produced the most foliage, suggesting that it had the most potential for improving soil fertility and crop yields. This is, indeed, consistent with the observations from the southern Africa region where the *T. candida* species is promoted by both research and development organizations (Mafongoya et al. 2003). It is also evident that extending the fallow duration results in more fuelwood for *T. candida* and for the rest of the species evaluated with the exception of *C. grahamiana*. Long duration fallows may, however, not be an option for those farmers who face constraints of either land or labour for harvesting the fallows. For these farmers, shorter duration fallows (6 or 12 months) may be the option. The extent to which short duration fallows can improve soil fertility and productivity relative to the longer duration fallows needs further assessment. Furthermore, continuous removal of wood from fallows may constitute nutrient exportation (Niang et al. 2002) and could limit the potential of the fallows to improve soil fertility.

Farmers' assessment

Nearly all the farmers noted the problem of scarce fuelwood in the area (Table 5). The shortages manifest in the large amount of hours that are spent gathering fuelwood, especially by women and children. In retrospect, this has often limited the person hours available for allocation to other development activities, such as weeding and planting, which, in turn, has led to low food production and high poverty levels in the region. Considering that the given region is rated as one of the highest in HIV prevalence, it is important to consider interventions that would minimize the time and energy required to collect and carry fuelwood, as consequent health implications may further limit households' scarce capacities.

Table 5 Farmers perception of fuelwood problem in western Kenya ($n = 53$)

Criteria	Frequency	Percent
Adequate	2	4
Scarce	41	77
Somewhat scarce	10	19

From farmers perspective, the key attributes of fuelwood species was the volume of wood produced, stem diameter and pod maturity (Table 6). While 74% of interviewed farmers preferred species that produce more wood, 62% preferred species that have bigger trunk diameter, and 55% preferred species that mature fast as exhibited by early pod maturity. Besides being an indicator of species maturity, pod maturity was also used by farmers for wood sturdiness. Sturdiness, or what farmers commonly referred to as 'wood strength', is related to the calorific value of wood. According to the farmers, sturdiness was associated with a stronger, brighter and longer lasting fire and hence faster and better lighting, warming, water heating and cooking quality. Bigger stems are mainly associated with higher fuelwood density and ability to preserve fire for a longer time, as compared to smaller stems that burn and finish fast.

As a result of farmers' fuelwood evaluation criteria, farmers' species preferences for fuelwood purposes did not necessarily follow the order of species actual and potential yields. Rather, it was a mix of productivity and perceived wood quality. In this respect, species preferences were high for *C. grahamiana* (39%) and *T. candida* (36%) but low for

Table 6 Farmers fuelwood species preference criteria in western Kenya ($n = 53$)

Criteria	Frequency	Percent responses[a]
More wood	39	74
Bigger stem diameter	33	62
Early pod maturity	29	55

[a] Percentages do not sum to 100 because farmers voted for more than one criteria

T. vogelli (14%) and *C. paulina* (9%). This particular order of species preferences for fuelwood production corroborates with the order of preferences reported by Place et al. (2003) for soil fertility amelioration. Place et al. reported that western Kenya farmers particularly liked *C. grahamiana*, *T. candida and S. sesban* for their proven impacts on soil fertility amelioration. Promoting improved fallows of these species, could help address simultaneously the needs of farmers to produce fuelwood and improve soil fertility. Based on the farmers' assessment, *T. vogelli* and *C. paulina* are the least preferred species for purposes of fuelwood production.

Farmers perceived that the fallow species that had less than 100,000 plants ha^{-1} were sparse and not dense enough. Farmers typically establish fallows at a high density to increase survival rates and ensure high biomass production for purposes of improving soil fertility. While high stand density may result in high fuelwood harvest, this is likely to be at the expense of stem diameter. A compromise can be achieved through thinning to the desired stand density.

Conclusions

This study suggests that there is a high potential of meeting both household and regional fuelwood demand simultaneously from improved fallows managed primarily for soil fertility improvement. However, this potential would only be realized if IFs were adopted by more farmers, and if more land within the farms was allocated to cultivating IFs. Allocation of 0.25 ha, an increase from less than 0.1 ha observed in this study, would generate enough fuelwood to be used by the households for 0.7 and 3.2 years. Increasing fallow duration from 6 to 18 months, increased fuelwood yield for nearly all the species evaluated, with *T. candida* being the most productive. This implies that women and children could save considerable time, which is currently spent in search of firewood. The saved person-days could be transferred to other development activities. Availability of adequate fuelwood could also release livestock and crop residues that are currently utilized as fuel energy for use as organic fertilizers. This is essential for improving soil fertility and crop yields, as well as mitigating land degradation.

Given that improved fallows may be viable even in this densely populated region, their potential recommendation domain may therefore be quite large in sub-Saharan Africa. What is needed next are greater research and development efforts to scale up the use of this promising technology. This should be done in combination with fertilizers so that removal of fuelwood from the fallows may not undermine their soil fertility functions in the long run.

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