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# Mechanized land preparation in forest-based fallow systems: The experience from Eastern Amazonia

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## Abstract

The slash-and-burn practice of land preparation that farmers use traditionally in forest-based fallow systems in the humid tropics causes land degradation and human health hazards. As an alternative to slash-and-burn, a mechanized, fire-free method of land preparation was evaluated on smallholdings in the eastern Amazon region. The use of machinery for harvesting fallow vegetation and chopping it for mulch eliminates the need for hard labor and fire for land clearing and increases labor productivity. Four different tractor-propelled choppers with power demand of 50 kW to 122 kW were tested. Their chopping capacity varied between 4.5 Mg and 20 Mg of fresh biomass per hour. The mechanized chop-and-mulch technology can be used in fallow vegetation that is up to 12 years old, which in the study region corresponded to 20 Mg to 150 Mg fresh biomass per hectare. Two additional choppers – a stationary silage chopper and a high-powered crawler tractor with a chopping device – were also tested but both were not suitable for smallholder fallow systems. In the context of the mulch technology, new low-input crop varieties were screened and their response to fertilizer was studied. The mulch technology facilitates extended cropping, to plant crops off-season, and modify crop rotation. Degraded fallow vegetation can be improved by enrichment planting using fast-growing leguminous tree species. Financial analysis of different scenarios revealed that farm income and labor productivity from chop-and-mulch systems can be up to two times greater than from the traditional slash-and-burn system.

## Introduction

Forest-based fallow systems involve temporal integration of woody components into the land-use cycle. Such agroforestry land-use systems consist of a cropping period and a fallow period. The fallow vegetation serves a number of beneficial functions in low-input agriculture in terms of: (i) nutrient accumulation (Nye and Greenland 1960), (ii) suppression of weeds (Rouw 1995; Gallagher et al. 1999), (iii) nutrient retrieval and recovery from deeper soil layers (Sommer 2000), (iv) erosion control (Hoang Fagerström et al. 2002; McDonald et al. 2002), (v) supply of fuel wood (Sanchez 1995), and (vi) maintenance of biodiversity in the agricultural landscape (Baar 1997).

Resource-poor, smallholder farmers have traditionally been practicing the forest-based fallow systems. In developing regions, however, where agro-industrial and traditional land-use systems lie side by side or close to urban centers, fallow systems are not popular as ‘modern’ land-use because of their high manual labor requirement, low productivity, and the use of the almost archaic slash-and-burn practice. The burning of fallow biomass has its advantages: it is a cheap and easy practice for land clearing, the ashes reduce soil acidity and supply nutrients to crops, and the heat of the fire eliminates pests and diseases in the field. But this method has also adverse effects on the agroecosystem in terms of nutrient losses during burning through volatilization, loss of organic matter as carbon dioxide, health problems to the local population due to smoke (causing an estimated $1 million to $11 million in health costs per year in Amazonia: Diaz et al. 2002), and accidental fires in the agricultural landscape.

Fallow systems require a minimum time- and space-frame. The sustainability of fallow systems is guaranteed only if fallow periods are maintained long enough for the system to recuperate its productivity. The length of the fallow period is a function of land availability. Although longer fallow periods might result in higher crop yields, the greater land area required for longer fallow periods is often not proportionately balanced by higher yields (Kato et al. 1999; Mertz 2002). Shortening the fallow periods cannot be explained only by the wish to achieve a higher land-use factor (fallow period in relation to duration of land-use cycle) or by demographic pressure. Labor considerations and location of a field within the farm property are also important: the younger the vegetation, the easier it is to clear manually, and the closer the fields to a farmhouse or access road, the more often they are cropped.

Continuation of the traditional slash-and-burn practice under shortened fallow cycles provokes a downward spiral of decreasing productivity. In the long run, the system degrades in terms of crop production, vigor of fallow vegetation, and soil properties. Farmers finally will have to abandon their land and occupy new, more productive land or adapt their agronomic activities to cope with the escalating degradation process by, for example, progressively increasing the inputs such as labor and fertilizer, and/or expanding the cropped area. In such cases, crop yields may largely remain stable, and the system degradation becomes visible in the form of lower fallow biomass and nutrient accumulation. The deterioration of soil properties in tropical agriculture is caused mainly by an accelerated loss of soil organic matter (Tiessen et al. 1994; Shang and Tiessen 2000; McDonald et al. 2002), which leads to a decline in nutrient availability and cation exchange capacity as well as biological activity, aggregate stability, and soil aeration. Hence, to maintain soil productivity, the organic matter that is lost during the cropping period has to be replenished during the subsequent fallow period.

Efforts to modernize traditional fallow systems concentrated on replenishing soil fertility, suppressing weeds, and improving biomass and nutrient accumulation in a relatively shorter fallow period as well as on increasing the economic value of the fallow vegetation. These objectives are achieved by management practices such as 'enriched fallows' and 'improved fallows' (Nair 1993; Sanchez 1999). In enriched fallows, selected tree species are planted into natural fallows to improve biomass and nutrient accumulation (Denich et al. in press) or/and to deliver economically valuable by-products such as timber or fruits during the fallow period. Improved fallows are mostly sole stands of fast-growing nitrogen-fixing leguminous trees planted with the primary purpose of replenishing soil fertility. Both these systems are rotational fallows, and the transition from fallow to cropping is usually through fire-free land preparation, where the best stems and branches are removed and the leaves and remaining woody parts spread as mulch over the field; mulching is sometimes also combined with burning (Kanmegne and Degrande 2002). Improved fallows may perform as well as natural fallows (Tian et al. 2001), they increase crop yields and returns to labor and land (Degrande 2001), and reduce weed pressure compared to natural fallows (Akobundu and Ekeleme 2002). Improved fallows under adverse environmental conditions such as in heavily degraded lands, however, might not always be profitable (David and Raussen 2003).

Numerous studies have shown that improved fallows are agronomically and ecologically beneficial. Nevertheless, adoption of improved fallows has been low, which is mainly attributed to the discrepancies between the biophysical information on the performance of improved fallows and the socioeconomic and political realities of the farmers (Kaya et al. 2000; Mercer 2004). The time-consuming and labor-intensive management (Kanmegne and Degrande 2002) or seasonal labor demands that do not fit into the cropping calendar of the farmers (Opio 2001) may also be restricting their adoption. These problems can be overcome only by thorough assessment of improved fallows taking the socioeconomic and biophysical conditions into account (Franzel and Scherr 2002).

It was in the above background that a research and developmental project was undertaken through a joint

*Table 1.* Aboveground biomass (dry matter) of fallow vegetation of different ages in the northeast of Pará state, Brazil.

| Component | 1-year fallow | 4- to 5-year fallow | 7-year fallow | 10-year fallow |
|---|---|---|---|---|
| Wood (Mg ha$^{-1}$) | 1–3 | 9–25 | 29–61 | 58–68 |
| Leaves (Mg ha$^{-1}$) | <1–2 | 3–5 | 4–6 | 6–9 |
| Litter, standing dead (Mg ha $^{-1}$) | 3–6 | 6–8 | 8–11 | 12–17 |
| Herbs, grasses (Mg ha$^{-1}$) | <1–4 | <1–1 | <1 | <1–1 |
| Total (Mg ha$^{-1}$) | 8–12 | 19–38 | 42–77 | 78–94 |

Source: Denich (1989); Nunez J.B.H. 1995 Fitomassa e estoque de bioelementos das diversas fases da vegetação secundária, provenientes de diferentes sistemas de uso da terra no nordeste paraense, Brasil. Master of Science thesis, Federal University of Pará, Belém, Brazil, 184 pp.

German–Brazilian project aimed at improving the use of natural fallow vegetation in the east of Belém (Pará state) in the eastern Amazon region. This chapter is based primarily on the results of that project and is presented in the expectation that the results will be applicable elsewhere in the tropical humid lowlands with comparable ecological, socioeconomic, and land-use conditions.

Climatically, the region belongs to the humid tropics. The land topography is mostly flat or gently sloping; the predominant soils are Ultisols with sandy topsoil. The region covers 23 000 km$^2$, which is about 2% of the state's area; however, it accounts for 20% of the value of total agricultural production in Pará state. Ninety-eight percent of the farms in the region are smallholdings (<100 ha) with an average area of 14 ha, of which a third is cropped and two thirds is under fallow or forest. Family members mainly provide the labor for agricultural operations. Most smallholders participate in the local and regional markets and many in the national market. Fertilizers and farm machinery are applied by 30% of the farmers (IBGE 1998). In this project, the fallow vegetation was transformed into mulch for *in situ* use through a mechanized cut-and-chop process. This way, the burning that causes nutrient losses during land preparation is avoided and organic matter preserved. As all field studies were conducted on farmers' land, the gap between on-station research and farm reality was bridged, which is an important aspect in successful technology transfer (Muschler and Bonnemann 1997). This chapter synthesizes the work done on chop-and-mulch technology and its implications for management of subsequent crops, including economic feasibility.

## Characterization of fallow vegetation in northeastern Pará

The smallholder land-use system in northeastern Pará involves a one- to two-year cropping period with maize (*Zea mays*), upland rice (*Oryza sativa*), cowpea (*Vigna unguiculata*), and cassava (*Manihot esculenta*) in rotation with a three- to seven-year fallow period. The fallow vegetation following annual crops attains a height of 1 m to 5 m and is relatively homogeneous. It differs structurally from vegetation that develops subsequent to semi-perennial crops such as passion fruit (*Passiflora edulis*) and black pepper (*Piper nigrum*) and on fields plowed before cropping which is heterogeneous and consists of a mosaic of shrub islands and grassy patches. Long cropping periods with repeated weeding as well as tillage deteriorate the regeneration potential of the fallow vegetation, as the vast majority of woody species regenerate by re-sprouting from their roots (Denich 1989; Clausing 1997; Jacobi 1997). Hence, on farmlands having rotational fallows, woody fallow vegetation develops only when the plant species that are competitive re-sprout vegetatively. Although species numbers are lower in fallow vegetation than in primary forests, vegetation surveys in 92 young- to medium-aged fallow areas (one- to 10-year-old) revealed a total of 673 plant species (Baar 1997), which included 316 species of trees and shrubs. Most of these species, however, are relatively rare: In four-year-old fallow vegetation, for example, only 20 species represent 80% of the tree and shrub individuals and biomass. Leguminous species provide 25% of the biomass (Denich 1989). Biomass accumulation plays a crucial role in fallows in which the vegetation is used as a source of mulch. Suitable mulch layers are achieved with the application of 20 Mg ha$^{-1}$ to 30 Mg ha$^{-1}$ of plant biomass. In first-cycle fallows of central Amazonia, these biomass quantities are pro-

*Table 2.* Average stem diameter, height and biomass of woody species, and number of stems per hectare in fallow vegetation of the northeast of Pará state, Brazil.

| Fallow age (years) | Stem diameter[a] (cm) | Height (m) | Biomass, dry wt. (g tree$^{-1}$) | Number of stems (stems ha$^{-1}$) |
|---|---|---|---|---|
| 3 | 0.7–1.0 | 1.5–1.9 | 97–163 | 107 000–140 000 |
| 4–5 | 0.9–1.4 | 1.8–2.4 | 135–366 | 67 000–97 000 |

Source: Denich (1989); B. Schuster (unpublished data);
[a]Measured at 0.3 m height.

duced within one year (Gehring 2003), in the degraded fallow vegetation of northeastern Pará, only within four to five years (Table 1). The latter contains 77% to 84% woody biomass and the remaining is leaf biomass (Denich 1989).

In the fire-free land-clearing practice, fallow vegetation is transformed into mulch through chopping. The efficiency of the chopping process depends on plant morphological parameters such as stem diameter, height, and biomass of the predominant trees and shrubs. The lower the values of diameter, height, and biomass, the lower are the energy demands for mulch production. In the study region, the respective values are in the lower ranges (Table 2), so that manual, semi-mechanized or fully mechanized mulch production was feasible even though individual plants with stem diameters up to 8 cm and height of more than 4 m occurred in three- to five-year-old fallow vegetation (Denich 1989; B. Schuster 2001)[1]. Another relevant property of woody plants is the wood density. Withelm (1993)[2] studied 125 woody species in fallow vegetation in northeastern Pará and found their density values to range from 0.24 to 0.99 (at 0% moisture content) with an average of 0.69 (SD = 0.18). The weighted average for young fallow vegetation was 0.68, considering the share of different individual species. Most of the density values were medium-ranked and did not seem to be a serious constraint for mulch production. On the whole, the woody fallow plants are morphologically suitable for chopping. However, the high number of stems per hectare (Table 2) might pose a problem for mulch production by fully mechanized chopping. Furthermore, the heterogeneous distribution of the plant biomass in the field at a very small-scale makes mechanized chopping a challenging operation, since very low biomass quantities alternate extreme biomass peaks irregularly (Figure 1). In our study, the fallow area was divided into strips of 2 m width and each further subdivided into 0.1 m sections lengthwise. The width is equivalent to the working width of a chopping device and the 0.1-m section is the distance moved by a chopping device in 0.1 s while chopping the vegetation. The observed biomass values ranged from 0 to 10.8 kg per 0.2 m$^2$, with an average of 0.33 kg per 0.2 m$^2$ (SD = 0.59 kg per 0.2 m$^2$; based on data of B. Schuster (2001)[1]. Another relevant property of woody plants is the wood density. Withelm (1993)[2] Fallows with planted trees are presumably much more homogeneous.

In addition to biomass, the nutrient stocks of the fallow vegetation are of interest. In contrast to the considerable nutrient losses through volatilization in slash-and-burn practice, all nutrients stored in the plant material (Table 3) are available to the crops in the mulch system. Nutrients in the latter system, however, are not released immediately, but after decomposition of the plant material in the course of the cropping period. How fast this takes place depends on the quality of the plant material with fresh leaf material being more readily decomposable than litter and wood. The leaf material contains one third of the aboveground N, P, K, Mg and S stocks, whereas its share in micronutrients and Ca is only one fifth of the aboveground stocks (Denich 1989; Sommer 2000).

The fallow vegetation is not only a source of organic material and nutrients, but also provides a variety of by-products to farmers. Withelm (1993)[2] reported 58% of the 144 species observed in fallows as useful for construction wood and Hohnwald (2002) reported 16% of the 192 species studied as useful as fodder plants for cattle. Furthermore, honeybees were reported to be visiting flowers of 59 species and collecting nectar and pollen in young fallow vegetation (G. Venturieri 1993. Annual Report of the project ‘Secondary forests and fallow vegetation in the agricultural landscape of the eastern Amazon region – Function and management’ submitted to the German Federal Ministry of Science and Technology). According to Hedden-Dunkhorst et al. (2003), two thirds of the small-scale farmers in northeastern Pará extract products from fallow vegetation, of which firewood (2 Mg ha$^{-1}$ to 8 Mg ha$^{-1}$ from five- to 10-year-old fal-

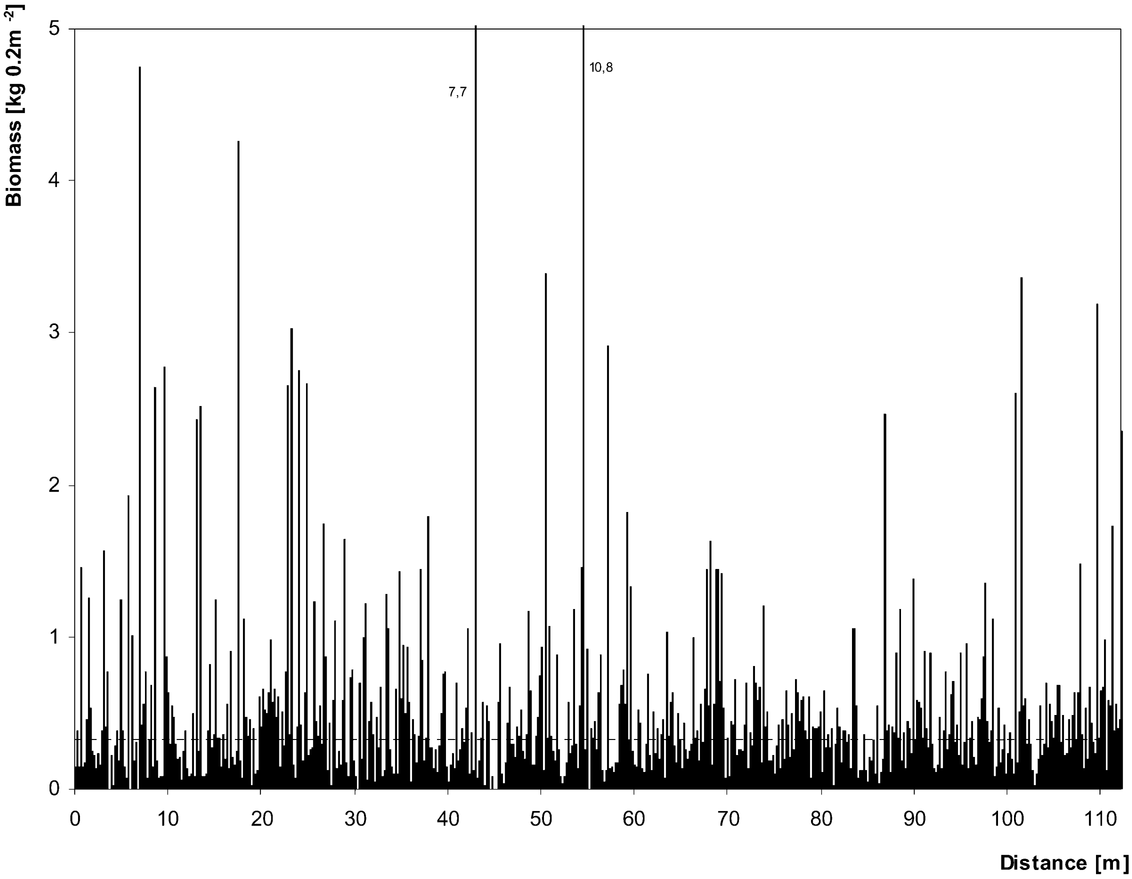


*Figure 1.* Spatial variability of biomass (kg 0.2 $m^{-2}$) in a 3-year-old fallow vegetation, in strips of 2 m width subdivided into sectors of 0.1 m (= 0.2 $m^2$). The horizontal line represents the mean. The strip length of 112 m was obtained by consecutively combining seven 16-m strips. See text for further explanation.

*Table 3.* Macro- and micro-nutrient stocks in 4- to 5-year-old fallow vegetation in the northeast of Pará state, Brazil.

| Component | N | P | K | Ca | Mg | S | Mn | Zn | Cu |
|---|---|---|---|---|---|---|---|---|---|
| | (kg $ha^{-1}$) | | | | | | | | |
| Leaves | 56–83 | 2.2–3.0 | 19–36 | 27–34 | 10–15 | 14 | 0.3–0.7 | 0.1 | 0.1 |
| Wood | 39–102 | 1.9–5.1 | 32–65 | 43–92 | 11–18 | 16 | 0.4–1.2 | 0.2–0.4 | 0.1–0.4 |
| Litter | 62–106 | 1.6–2.4 | 8–11 | 39–102 | 6–13 | 10 | 0.6–1.5 | 0.1–0.3 | 0.1–0.2 |

Source: Denich (1989); S stocks after Sommer (2000).

low) and wood for charcoal production are by far the most important in young fallow vegetation. Charcoal and firewood are mostly used for home consumption (65% and 93% respectively). Other products harvested from young fallows are materials for small implements or tools, and honey. The latter, however, as well as fruits, fencing material, construction material for houses, and wood for heavy construction are chiefly obtained from older fallows. The products derived from young fallow vegetation contribute, on average, only to a small or negligible extent to the livelihood income of the smallholders.

## Slash-and-burn vs. chop-and-mulch technology

In traditional rotational fallow systems, slash-and-burn is the common practice applied by farmers world-

*Table 4.* Nutrient balances of fallow–crop rotation cycles with land preparation by slash-and-burn and chop-and-mulch practices.

| Land preparation (Nutrient cycling processes) | N | P | K | Ca | Mg | S |
|---|---|---|---|---|---|---|
| | - - - - - - (kg ha$^{-1}$) - - - - - - | | | | | |
| *Slash-and-burn* | | | | | | |
| Atmospheric deposition | 26[a] | 4 | 12 | 30 | 15 | 22 |
| Fertilization | 70 | 48 | 66 | 31 | – | – |
| Burning losses | −246 | −8 | −58 | −151 | −29 | −35 |
| Leaching losses | −16 | −1 | −11 | −48 | −9 | −5 |
| Harvest, firewood | −127 | −22 | −78 | −16 | −14 | −7 |
| Balance | −293 | 21 | −69 | −154 | −37 | −25 |
| *Chop-and-mulch* | | | | | | |
| Atmospheric deposition | 26[a] | 4 | 12 | 30 | 15 | 22 |
| Fertilization | 70 | 48 | 66 | 31 | – | – |
| Leaching losses | −10 | −1 | −3 | −25 | −6 | −13 |
| Harvest | −112 | −22 | −83 | −14 | −12 | −7 |
| Balance | −26 | 29 | −8 | 22 | −3 | 2 |
| Gains through chop-and-mulch | 267 | 8 | 61 | 176 | 34 | 27 |

Notes:
1. Length of fallow period was 3.5 years and cropping period 2 years.
2. Negative values indicate losses.
3. [a]biological nitrogen fixation included.

Source: Modified after Sommer (2000).

wide for land preparation for cropping but it is inefficient as it causes considerable nutrient losses. In the process of burning of seven-year-old slashed fallow vegetation in our study area, 96% of nitrogen, 76% of sulfur, 47% of the phosphorus, 48% of the potassium, 35% of the calcium, and 40% of the magnesium were released to the atmosphere (Mackensen et al. 1996). These losses, together with the removal of nutrients from the field with the harvested products, are responsible for the negative nutrient balance for the slash-and-burn system (Table 4). Current rates of fertilizer use cannot compensate for the losses except for phosphorus. Leaching losses are of minor importance, especially as leached nutrients are returned to the soil surface by the nutrient pump function of the deep-rooting trees and shrubs (Sommer 2000; Sommer et al. 2000). Based on these results, it can be concluded that continuous nutrient mining through burning and harvesting is taking place in the agricultural land of northeastern Pará leading to degradation of soils and putting the traditional land-use system as a whole under pressure. This pressure becomes obvious from a rapid decline in the vigor of the fallow vegetation (Denich et al. in press).

The negative nutrient balance of the slash-and-burn system can be improved by replacing the slash-and-burn with fire-free land preparation. The unburned fallow vegetation could be a source of biomass for the maintenance of soil organic matter and plant nutrients to improve the physical, chemical and biological soil properties, and thus counter soil degradation processes. Both fire-free land preparation and management of soil organic matter can be combined in chop-and-mulch approach. Additionally, the mulch layer protects the soil from erosion, conserves soil water during dry spells, and reduces germination of weeds (Thurston 1997).

In our studies, the favorable effects of mulch could be proven to some extent as follows: (i) in mulched fields, the fertilizing effect was observed only in a prolonged cropping period after the mulch had decomposed and the nutrients released (fertilization was essential during the earlier part of the cropping period; Kato et al. 1999), and (ii) farmers reported that in mulched fields weeding activities could be reduced. Yet, even after two land-use cycles, the soil carbon content was not significantly different in mulched fields compared to traditionally burnt or fallowed areas (Table 5).

After gaining experience with the mulch system, farmers pointed out that on mulched fields usually all plant biomass was converted into mulch and no stems

*Table 5.* Carbon content in the 0–10 cm soil horizon in slashed-and-burnt as well as mulched fields with different cropping patterns in 2001 in the northeast of Pará state, Brazil.

| Initial fallow age/ experiment established in | Land preparation | Cropping pattern | N | Carbon content (%) (±SD) | *P* value |
|---|---|---|---|---|---|
| 4 years/1994 | Fallow | | 8 | 1.29 (0.248) | |
| | Burned | R-C-M-F0.5-R-C-M-F3.5 | 16 | 1.31 (0.159) | 0.852 |
| | Mulch | R-C-M-F0.5-R-C-M-F3.5 | 16 | 1.26 (0.270) | |
| 10 years/1994 | Fallow | | 8 | 1.28 (0.338) | |
| | Burned | R-C-M-F0.5-R-C-M-F3.5 | 16 | 1.34 (0.315) | 0.663 |
| | Mulch | R-C-M-F0.5-R-C-M-F3.5 | 16 | 1.40 (0.274) | |
| 5 years/1995 | Fallow | | 8 | 1.29 (0.248) | |
| | Burned | R-C-M-F3.5 | 8 | 1.30 (0.145) | 0.179 |
| | Mulch | R-C-M-F3.5 | 8 | 1.46 (0.187) | |

R = rice, C = cowpea; M = manioc (cassava); F+ number = years of fallow; N = number of repetitions; SD = standard deviation; *P* = probability of 'F' test significance.

were available for use as firewood or for producing charcoal. It seems questionable whether suitable stems can be removed out of natural fallow vegetation before it is transformed into mulch. In the traditional system, unburned stems are collected for firewood or charcoal production.

In the study region, farmers plant maize, rice and cowpea in rows using a planting tool locally known as 'tico-tico' or 'matraca.' To plant in mulched fields, the mulch layer has to be penetrated by the tip of the 'tico-tico' so that the seeds can be released into the upper part of the mineral soil. This operation is more time-consuming in mulched fields than in burnt ones. Field tests revealed that planting maize in mulched fields with a 'tico-tico' takes two-times the time and planting cassava cuttings with a hoe takes even four times, as compared to those in non-mulched (recently burned) fields.

## Mechanized land preparation in fallow systems

The adoption of the mulch technology by farmers requires suitable techniques for the transformation of the woody fallow vegetation into mulch. In practice, the woody plant material in fallowed fields cannot be chopped manually, as it is a high labor-demanding and strenuous operation, which is not accepted by farmers. Mechanization of the chopping operation, therefore, is crucial for the introduction of the mulch technology.

As no adequate chopping device existed in the market, which *a priori* met the requirements for maintaining vigorous woody fallow vegetation, we set out to develop a bush chopper that fulfills the following four criteria. First, the fallow vegetation should be cut without damaging the root systems of the trees and shrubs as these were proved to be critically important for the regeneration of the woody species. Second, the fallow vegetation should be cut at ground level as this facilitates weeding unobstructed by stumps, while re-sprouting of the tree and shrub species is assured. Third, to make the whole operation more efficient, cutting the vegetation, chopping the plant material, and spreading the chips over the field should be carried out in a single operation. Fourth, the device has to be a simple and of robust construction to guarantee durability and to facilitate maintenance and repair in the already partly mechanized target region.

The first version of a tractor-propelled bush chopper that meets the above criteria and can be fixed to the front power lift of a conventional wheel tractor was Tritucap I (= prototype; Table 6). As the tractor moves forward, the vegetation, including trees and shrubs, is cut by two rotating circular saws, and subsequently chopped by two vertical steel helices (helical knives) sitting on the saw-blades. The two cut-and-chop units (rotors) are driven by the tractor's front power take-off (PTO) and rotate with a maximum of 1000 rpm. The chopped material is thrown out toward the back and under the tractor's front wheels. Chopping one hectare of degraded fallow vegetation containing an average fresh biomass of 13 Mg takes approximately one hour, whereas one hectare with a five-year-old fallow and an average of 45 Mg ha$^{-1}$ standing fresh biomass takes

*Table 6.* Overview of chopping equipment tested in different-aged fallow vegetation in the context of mulch technology in the northeast of Pará state, Brazil.

| Chopper type | Manufacturer | Tractor power (kW) | Working width (m) | Av. chopping capacity (Mg biomass $h^{-1}$) | Man power (Mh $Mg^{-1}$) | Average fuel consumption (l $Mg^{-1}$) | Maximum stem diameter[b] (cm) | Fallow age (years)/ Maximum biomass (Mg $ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| Silage chopper | Nogueira | 70[a] | n.a. | 0.25 | 10 | 6 | 3–4 | 1–4 / 50 |
| Rotary chopper | Super Tatu | 50 | 1.8 | 4.5 | 0.22 | 1.3 | 2 | 1–2 / 20 |
| Tritucap I | Inst. of Agric. Eng., Univ. of Göttingen | 70 | 2.0 | 10 | 0.10 | 1.6 | 10 | 1–4 / 50 |
| Tritucap II | | 122 | 2.4 | 15 | 0.07 | 1.3 | 10 | 1–4 / 50 |
| FM 600 | AHWI | 122 | 2.3 | 20 | 0.05 | 1.2 | 30 | 5–12 / 150 |
| RT 350 | AHWI | 220 | 2.3 | 20–25 | 0.05 | 2.0 | 100 | 25 / 300 |

*[a]During the tests a tractor with 70 kW was used. The silage chopper can also be driven by a lower-powered tractor (≈30 kW). Mh = man hours;
[b]Close to soil surface; n.a. = not applicable; biomass = fresh weight; AHWI = AHWI Maschinenbau GmbH, Herdwangen, Germany.

*Figure 2.* Newly developed bush chopper Tritucap II.

*Figure 3.* Tritucap II at work in 4-year-old fallow vegetation.

eight hours. As the speed of the operation is between 1 km $h^{-1}$ and 3 km $h^{-1}$, the tractor has to be equipped with an inching motion facility.

Tritucap II (Figure 2 and 3, Table 6) was an improvement over Tritucarp I. Two important modifications were necessary for solving the problems identified during the field tests: (i) the ordinary saw-blades quickly became blunt due to the sandy topsoil, so they were replaced by saw-blades with detachable teeth made of extra-tempered steel and (ii) the toothed-belt drive was replaced by a cardan shaft-drive, thus improving the power transmission from the PTO to the rotors. Some additional modifications were also made such that all together, durability and operational efficiency of the chopper was increased. The Tritucap II is mounted on the rear power lift of a tractor with a reverse drive facility. That way the driver sits closer to the chopper and gets a better view of the chopping process.

Testing different chopper types reduces the risk of failures and makes it possible to offer alternative chopper technology as the circumstances may require. Therefore, parallel to the two Tritucap choppers, a forest mulcher AHWI FM 600, which is already in the international market, was tested in-depth (Figure 4, Table 6). The FM 600 is a PTO-driven device mounted on the rear power lift of a conventional wheel tractor with a reverse drive facility because of its heavy weight (2790 kg). The horizontal rotor (diameter 600 mm) is tipped with fixed carbide hammers, which are individually replaceable. While the tractor is driving backwards, the vegetation is first roughly pre-chopped with 1000 or 1600 rpm. If desired, the pre-chopped plant material covering the soil surface

*Figure 4.* Forest mulcher AHWI FM 600.

may be more finely chopped in a second go. In this case, the tractor drives forward pulling the chopper. The rotor picks up the plant material from the ground and chops it again. Initially, we assumed that the chopping principle of the FM 600 would be unsuitable, as we expected heavy disturbance of the topsoil through the horizontally rotating rotor possibly destroying the upper root system thus impairing the regeneration of the fallow vegetation. This concern, however, turned out to be unfounded, if the tractor was operated by a well-trained and experienced driver.

On farmlands in northeastern Pará, degraded low-standing fallow vegetation is very common. For such stands, the Tritucap and FM 600 as well as high-powered tractors would be oversized and a rotary cutter widely used in the region is recommended instead. Rotary cutters (Table 6) are devices pulled by a wheel tractor and glide on vats over the soil surface. It is powered by the rear PTO. The power demand is considerably lower than that of the Tritucap and FM 600. A rotating blade enclosed in a metal housing cuts the vegetation much the same way a lawnmower operates, but it is designed for rougher applications. The chopped material is spread across the entire width of the machine. In the study region, rotary cutters are usually used to mow grass, cut weeds or clear brush on pastures. Occasionally, rotary choppers are used for fire-free land preparation before cropping, mostly combined with plowing.

Two additional chopping devices were tested. In the context of mulch systems, however, both were found to be applicable in exceptional cases only. First, we tested a stationary silage chopper, which also is coupled to the PTO of a tractor (Table 6). The fallow vegetation has to be cut manually and brought to the chopper, where the stems and branches are fed into an integrated hopper for chopping. Rotating cutter blades or hammers chop the material and the chips are blown out through a pipe on a heap beside the machine. From there, the mulch has to be spread manually over the field. As the silage chopper can only chop woody material up to a diameter of approximately 4 cm, thick stems have to be split lengthwise before chopping. This chopping operation requires high hard labor inputs and cannot be recommended for agricultural land preparation. It might be useful in horticulture and in cases where fine-chopped and homogeneous mulch is desired. During our field tests, the latter seemed to be attractive to the farmers but perhaps more for aesthetic reasons. The second machine tested was a forest mulcher AHWI RT 350, which is a crawler tractor with an integrated FM 600 rotor (Table 6). The RT 350 operates like a wheel tractor in combination with a FM 600, but its engine power makes it far oversized for most of the fallow stands on smallholdings. We tried it in a 15- to 25-year-old secondary forest and found that trees up to 40 cm diameter could be easily chopped. Such an application, however, is beyond the vision of our mulch approach. It is worth mentioning that we got excellent results in chopping of a 15-year-old oil palm stand, which needed only 1.5 minutes to two minutes per palm. Thus, the RT might be an option for the fire-free land preparation before replanting of oil palm and logged timber plantations.

The choice of chopping device depends on the total biomass per hectare to be chopped as well as on the stem and branch diameters of the predominant woody plants. Studies showed that suitable chopping equipment is available for all kinds of smallholding mulch systems (Table 6). By far the most frequently applicable choppers are the Tritucap and FM 600 and our field tests revealed that these machines ideally complement one another. Tritucap works more efficiently and economically than FM 600 for fallow vegetation up to 4 years old, whereas for vegetation older than four years, the stronger FM 600 is the appropriate chopper. In contrast to Tritucap, which cuts and chops in one step, FM 600 cuts and chops in more time-consuming two steps, first it fells and roughly pre-chops and then finely chops the mulch – thereby making it possible to work in older fallow vegetation where the trees and shrubs are thicker and taller.

To obtain a suitable mulch layer, uniform distribution of the biomass in the field and the quality (chip size) of the mulch itself are important. As shown in Figure 1, the spatial biomass distribution is highly variable in natural fallow vegetation with frequent extreme values. The dense spots cause a considerable mechanical load (extreme torque peaks) for any kind of chopping device. In the case of 4- to 8-year-old fallow vegetation, the heterogeneous biomass distribution leads to mulch layers that cover 60% to 100% of the soil surface in 1- to 6-cm thickness (C.M.P. Bervald, pers. comm.). The size of the woody chips reflects the quality of the chopping operation and influences the quality and properties of the mulch and the subsequent decomposition. All the tested chopping devices delivered sufficiently splintered and frayed chips of a satisfactory size. The average chip size increased in the order Tritucap II < Tritucap I < FM 600. Depending on the fallow vegetation and the respective hardness and tenacity of the woody species, 50% to 90% of the chips were smaller than 4 $cm^3$. The share of only roughly chopped wood ranges from 10% to 30% of the chopped biomass (C.M.P. Bervald, pers. comm.). The FM 600 sometimes encountered problems in chopping of fibrous vine species and the very fibrous banana-like tree *Phenakospermum guyannense*, which were coiled up by the rotor and blocked it. These problems were not observed with the Tritucap.

## Implications of fire-free land preparation and mulching

The fire-free land preparation and mulch technology have some agronomic requirements and constraints, but they also offer different options to manage the system more flexibly and make it attractive to farmers. For example, fertilizer application is necessary for ensuring the success of the technology; similarly, extension of the cropping period, and choice of crop varieties suited for mulch conditions are important considerations. The chop-and-mulch technology allows, however, off-season planting and rearrangement of the crop rotation. These constraints, requirements, and opportunities were investigated in a series of experiments on farmers' fields in the eastern Amazonia region. While valuable lessons have been learned from these efforts, several trials are in progress and many results, especially of long-term nature, are inconclusive. The salient aspects of the major studies are summarized in the following section; detailed results of each will be published in international scientific media in due course.

### *Fertilization*

Fertilizer as a substitute for the ashes of the slash-and-burn system was proved to be indispensable to achieve economically acceptable yields in the proposed mulch system. A rice crop without fertilizer produces considerably lower yields in mulched fields than in burnt fields, whereas cassava produced satisfactory yields without fertilization; on the other hand, cowpea practically failed without fertilization in mulched and burnt fields (Kato et al. 1999).

### *Extending the cropping period*

The mulch technology allows extending the cropping period beyond the common one to two years, i.e., two cropping periods instead of one before the field enters into fallow, almost doubling the land-use factor from 0.27 to 0.43. In the second cropping period, the yields of the mulched fields were higher than in the first period (except cassava) and higher than those of the burned fields both with and without fertilizer application. The increased yields in the mulched fields could be explained as a consequence of the release of nutrients from the slowly decomposing mulch only in the second cropping period (Kato et al. 1999).

### *Selection of crop varieties suitable for mulch conditions*

Screening experiments conducted on farmers' fields with 11 maize, eight rice, 21 cowpea and five cassava varieties under mulch conditions without the use of fertilizer revealed scope for overcoming the limitations to plant growth in mulched fields through the use of selected rice and cassava varieties. Mulched fields cropped with modern rice varieties or with selected cassava varieties produced yields higher than the local average yields under slash-and-burn conditions (Kato et al. 1999).

### *Enrichment planting*

Enrichment planting – a fallow management technique in which tree or shrub species are introduced into the fallowed area to improve the ecological or/and economic value of fallow vegetation – was tested in two field experiments on smallholders' land using the leguminous tree species *Acacia angustissima*, *Acacia auriculiformis*, *Acacia mangium*, *Clitoria racemosa*, *Inga edulis*, and *Sclerolobium paniculatum.* The species differed in their origin (autochthonous, exotic), growth form, rooting depth, and leaf litter degradability (Brienza 1999). At the age of 21 months, the enriched fallows produced 13% to 132% higher aboveground biomass than natural fallow without enrichment planting. The planted trees significantly suppressed the natural vegetation depending on the density of the trees planted. Enrichment plantings seem to be feasible only with *A. auriculiformis* and *A. mangium.* Also, higher benefit-cost-ratio for biomass accumulation was found at the lower planting density that produced greater stem diameters. For a mulch system with cut-and-chop land preparation, higher planting densities that produce lower stem diameters might be preferable to facilitate mechanized chopping. This may play only a minor role, however, with the availability of suitable chopping devices. Enrichment plantings allow shortening of the fallow periods. The resulting increased land-use factor is highly desirable from the farmers' point of view. For example, an extended cropping period together with a shortened fallow period may increase the land-use factor to 0.6. There is concern, however, that very short fallow periods may restrict suppression of weeds, although this has not so far been confirmed by field observations.

The study also revealed that after 21 months of fallow, only 31 woody species were recorded in plots enriched with 10 000 trees $ha^{-1}$ compared with 38 species with an enrichment of 2500 trees $ha^{-1}$ and 39 species in plots without enrichment planting. Thus, the higher the planting density of the introduced leguminous trees, the greater is the reduction in the diversity of naturally occurring woody species. Moreover, enrichment planting reduced the growth of herbaceous weeds and grasses in the first year of fallow itself compared to two years required for natural fallow to have a similar effect so that even very short fallow periods seem to be possible without diminishing the weed suppression function of the fallow.

*Change of cropping calendar*

Traditionally, land preparation in the fallow system depends on a sufficiently long dry season to allow the slashed vegetation to dry before it can be burnt satisfactorily. The chop-and-mulch system, however, makes planting possible even in the rainy season (January to May). The mulch conserves water and permits with low risk to extend cropping into the drier part of the year, thus enabling the farmer to change the cropping calendar and plant off-season. Fire-free land preparation and off-season planting would allow farmers to organize their agronomic activities in a way that the work load is spread out evenly over the whole year. Moreover, farmers can avoid the peak produce supply period when prices are usually low and capture rising off-season market prices of annual crops.

*Rearrangement of crop rotation*

In mulch systems, nutrient release from the decomposing mulch material occurs relatively slowly. Furthermore, microorganisms decomposing the organic materials may even temporarily immobilize nutrients. Slow nutrient release and immobilization result in nutrient shortage at the very beginning and an increased supply during the later stages of the cropping period. Thus, we hypothesized that inversion of crop rotation by planting a less nutrient-demanding crop such as cassava as a pioneer crop and more nutrient demanding crops such as maize or rice later might adequately mitigate temporary nutrient constraints in the mulch system. This way, we attempted to synchronize the nutrient demand of the crops with the nutrient release from the mulch, making best use of the nutrient pool in the mulch layer. On-farm (farmer-managed) studies to compare the traditional cropping sequence of maize – cassava with the inverted cassava – maize sequence have been carried out. On the basis of maize and cassava yields, we tentatively conclude that the traditional sequence slightly outperforms the inverted. To come to a final conclusion, further studies on the rearrangement of the crop rotation are necessary, particularly on the inclusion of modern low-input crop varieties combined with fertilizer.

## Financial analysis of chop-and-mulch approach

Farmers adopt new land-use systems and agricultural practices only if they are economically attractive. Financial analysis was conducted to assess returns to land and labor of selected chop-and-mulch scenarios compared with the traditional slash-and-burn system. The four scenarios compared were: (i) slash-and-burn with low fertilizer input (S+B, land-use factor R = 0.27), (ii) chop-and-mulch with high fertilizer input (C+M, R = 0.27), (iii) chop-and-mulch with high fertilizer input and extended cropping period (C+Mi, R = 0.43), and (iv) chop-and-mulch with high fertilizer input, extended cropping period and half fallow period (C+Me, R = 0.60). Although additional scenarios were evaluated, only those that were considered sustainable and

*Table 7.* Receipts and expenditures of four cropping scenarios in the northeast of Pará state, Brazil.

| | S+B | C+M | C+Mi | C+Me |
|---|---|---|---|---|
| Cycle length (years) | 5.5 | 5.5 | 7 | 5 |
| Cropping period, *fallow period* [years] | 1.5 + *4* | 1.5 + *4* | 1.5 + 1.5 + *4* | 1.5 + 1.5 + *2* |
| *Receipts* | (R$ ha$^{-1}$) | | | |
| Rice grains | 897 | 1446 | 3317 | 3317 |
| Cowpea grains | 1570 | 1540 | 3520 | 3520 |
| Cassava meal | 3260 | 5760 | 10960 | 10960 |
| *Total receipts* | 5727 | 8746 | 17797 | 17797 |
| *Expenditures* | | | | |
| Tractor and chopper rent | | −760 | −760 | −760 |
| Fertilizers | −423 | −803 | −1606 | −1606 |
| Other inputs (seeds, plant protection, transport) | −300 | −300 | −600 | −600 |
| Tree seedlings (2500 trees ha$^{-1}$) | | | | −417 |
| Hired labor at 10 R$ per man day | | −730 | −3358 | −3391 |
| Financing of costs additional to S+B | | −393 | −1176 | −1271 |
| *Total expenditures* | −723 | −2986 | −7500 | −8045 |
| *Balance of receipts and expenditures* | 5004 | 5760 | 10297 | 9752 |

S+B = slash-and-burn; C+M = chop-and-mulch with fertilization; C+Mi = chop-and-mulch with fertilization and extended cropping period; C+Me = chop-and-mulch with fertilization, extended cropping period and shortened fallow period due to enrichment planting.
1 R$ = 0.31 US$.

feasible for the farmers are reported here. All the tested scenarios included rice, cowpea, cassava and a fallow period. Low fertilizer input means that only cowpea was fertilized, and high fertilizer input means additional fertilizer to rice. Halving the fallow period was possible by fallow enrichment with fast-growing leguminous trees.

The spatial reference for the analysis was one hectare and, where necessary, cross-system comparability was obtained by standardizing the temporal reference to one year by dividing all systems by the respective length of the land-use cycle. All prices used for inputs, labor and products are farm-gate prices in August 2002 obtained through inquiries in northeastern Pará. Product prices were derived from the statistics of DIEESE (2002). The chopping unit used for the calculations was a 120 kW wheel tractor with driver and the forest mulcher FM 600. To obtain expenditures for the chopping unit, a renting price of 760 R$ ha$^{-1}$ (236 US$ ha$^{-1}$) was calculated based on a profitability calculation for a private contractor of farm services, which is not shown here. Being a mere cash-flow analysis, noncash elements such as environmental services of the mulch system, e.g., the plant nutrients preserved in the system, are not included. This also holds for the unpaid family labor, the remuneration of which is represented by the net benefit that each system offers. Expenditures of variable costs and receipts are balanced, resulting in the monetary return of each cropping system (Table 7), which is then applied to calculate land and labor productivity. Land productivity increased in the order S+B < C+M < C+Mi < C+Me whilst labor productivity was highest for C+Mi (Table 8), the latter being the greater incentive to the farmer. C+M alone was still clearly above S+B, which makes the chop-and-mulch a viable system even when applied with very little additional input.

Since experimental yields are not 100% transferable to farmers' practice, a sensitivity analysis was done to know how far yields could drop in all systems before chop-and-mulch became less viable than slash-and-burn (Figure 5). C+Mi and C+Me became less profitable in terms of both land and labor productivity than the traditional S+B system only if the yields drop to 30% of the experimental yields, whilst C+M less profitable at 50% of the yields. The average yields obtained in northeastern Pará are around 60% to 70% of the experimental yields. We conclude that (i) chop-and-mulch with fertilization of rice and cowpea and an extended cropping period (C+Mi) and (ii) chop-and-mulch with fertilization of rice and cowpea, an

*Table 8.* Contribution margins to land (land productivity) and labor (labor productivity) of four cropping scenarios in the northeast of Pará state, Brazil.

| | S+B | C+M | C+Mi | C+Me |
|---|---|---|---|---|
| Land (ha) | 1 | 1 | 1 | 1 |
| *Land productivity* (R$ ha$^{-1}$) | 910 | 1047 | 1471 | 1951 |
| NBI [R$ ha$^{-1}$] of land productivity relative to S+B | | +138 | +561 | +1041 |
| NBI [%] of land productivity relative to S+B | 100 | 115 | 162 | 214 |
| Family labor in man days (MD) | 203.6 | 203.6 | 203.6 | 203.6 |
| *Family labor productivity* (R$ per MD) | 24.6 | 28.3 | 50.6 | 47.9 |
| NBI (R$ per MD) of family labor productivity relative to S+B | | +4 | +26 | +23 |
| NBI (%) of family labor productivity relative to S+B | 100 | 115 | 206 | 195 |

NBI = net benefit increase; S+B = slash-and-burn; C+M = chop-and-mulch with fertilization; C+Mi = chop-and-mulch with fertilization and extended cropping period; C+Me = chop-and-mulch with fertilization, extended cropping period and shortened fallow period due to enrichment planting.
1 R$ = 0.31 US$.

extended cropping period and a halved fallow period (C+Me) are the most appropriate intensified and sustainable land use systems to increase income to farmers. So far, economy of scale that greater numbers of chopping units would reduce costs of chopping below 760 R$ ha$^{-1}$ was not considered. A cost estimate by the chopper manufacturer for rental turned out to be 480 R$ ha$^{-1}$ (149 US$ ha$^{-1}$), when a minimum of 30 chopping units in a given region (AHWI do Brazil, pers comm) were introduced. But even in the unlikely case of increased chopper costs, these could rise up to factor of five before land and labor productivity of the two recommended systems would drop below the ones of slash-and-burn.

## Concluding remarks

- Mechanized land clearing of fallow vegetation with tractor-driven bush choppers in connection with the application of mulch technology appears to be agronomically and environmentally superior to the traditional slash-and burn practice of land preparation in forest-based land use systems in the northeastern Amazon region. This technology may be relevant to similar other humid tropical conditions where slash-and-burn is practiced.
- As the chop-and-mulch land preparation is not a completely new land-use system, but merely a replacement of the burn practice, this approach is not likely to lead to adoption problems, because farmers are not confronted with many changes. We observed that the farmers in the study region were keen to apply mechanized chopping. Indeed, it seems that the introduction of machinery is seen as a modernization of the traditional land-use, which makes it attractive, especially as it avoids the backbreaking labor and increases labor productivity.
- Environmental benefits such as soil conservation, reduction in the losses of nutrients and organic matter as well as the absence of accidental fires in the agricultural landscape are advantages of the mulch system that are important not only to individual farmers but to the society as a whole.
- The chop-and-mulch technology is versatile in the sense that the farmer can go back to the traditional fallow system any time he chooses. This option makes it easier for the farmer to overcome the psychological barriers or to encourage the farmer to take a calculated risk, which enhances the readiness for adoption.
- Before moving to technology diffusion, large-scale testing has to be carried out. Currently, the political circumstances in Brazil are most favorable for the introduction of environmentally friendly technologies in agriculture, especially those supporting smallholders. Chop-and-mulch would certainly be among those practices with a strong and direct impact, since burning can be stopped immediately.
- Avoiding fire in the land-use system allows farmers to establish perennial crops and plantations without the risk of loosing the crops through accidental fires. The latter represent an incalculable risk to farmers with respect to the establishment of permanent crops, woodlots for timber production or agroforestry systems combining crops and woody components.

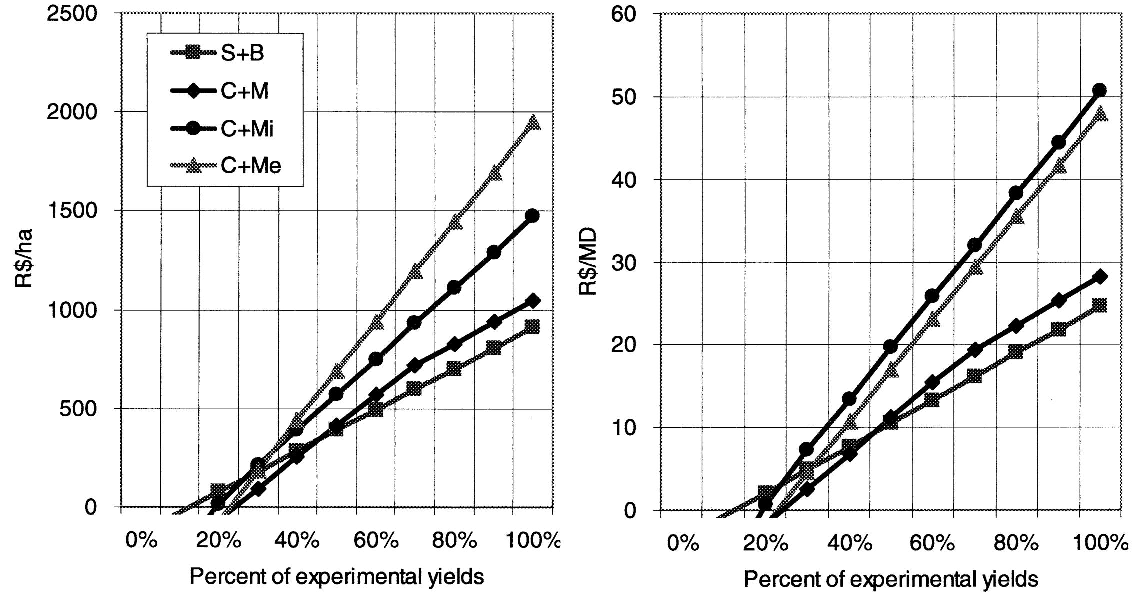


*Figure 5.* Sensitivity of land productivity (left) and labor productivity (right) at the experimental yields (100%) and at fractions of the experimentally achieved yields (<100%). S+B = slash-and-burn; C+M = chop-and-mulch with fertilizer; C+Mi = chop-and-mulch with fertilizer and extended cropping period; C+Me = chop-and-mulch with fertilizer, extended cropping period and shortened fallow period due to enrichment planting.

- Agroecologically, zero-tillage is mandatory in fallow systems for achieving one of the primary goals, which is to maintain the re-sprouting capacity of the root system of the fallow vegetation. However, in mulch systems, this requires further development of planting technologies suitable for woody mulch layers, especially when considering animal or tractor-driven planting machines.
- Biomass transfer (ex-situ mulch) may become increasingly important with respect to perennial crops and permanent cropping. Tritucap after a slight modification can readily serve such a system. A pipe has to be added at the outlet of the chopper that directs the chopped material onto a trailer to transport it. Mulch material could be obtained from areas that are specially kept for that purpose or from material from firebreaks that can be cut using the chopper.
- The Tritucap can be applied in alley cropping systems to cut and chop the hedgerows and spread the mulch over the alley.
- Researchers and farmers are increasingly under pressure to search for fire-free land preparation techniques as legal and political initiatives, national and international bodies are aiming at prohibiting the use of fire in land management. Chopping and mulching might play a crucial role in facilitating environmental compliance.

## End Notes

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