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Contributions of Managed Fallows to Soil Fertility Recovery

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Fallow management and improvement is as old as agriculture itself. Fallows are currently still intrinsic parts of many tropical farming systems. The development of agricultural systems and the spatial dynamics of land use are strongly correlated with the evolution of fallows patterns. Indeed, some classifications of farming systems have been based on fallow characteristics, e.g., Boserup (1965) and Ruthenberg (1980). While fallow is commonly referred to a resting period for agricultural land between two cropping cycles during which soil fertility is restored, it has more roles than just fertility restoration.

Fallows functions include weed control and the interruption of pest and disease cycles. They provide cash income in times of immediate need and help to balance food supply (Styger et al., 1999). They produce wood, fibers, and medicinal plants for households and can serve as pastures for livestock. For resource-poor farmers with constraints on their labor, inputs, and access to new techniques, fallows are economically often a good option for optimizing agricultural production, especially when noncrop products can be harvested. Fallows can also be important reservoirs of above- and belowground biodiversity. A wealth of indigenous knowledge is associated with the diversity and richness of these fallow systems.

The oldest form of fallow management was shifting-cultivation systems where very long fallow periods (>20 years) alternated with short cropping periods (1 to 2 years). A multitude of fallow systems has developed across the tropics over many centuries, diverging from this primordial model as farmers have developed diverse strategies for intensified fallow use.

Two major pathways of fallow intensification were identified at the conference on indigenous strategies for intensification of shifting cultivation in Southeast Asia in 1997 (Cairns, 2004b). The first strategy has as its main objective, increasing fallows' economic productivity. Fallow lengths stay the same or even lengthen as farmers add value by introducing economic perennial species and take appropriate steps to enhance soil fertility. These systems include interstitial tree-based improved fallows, perennial–annual crop rotations, and what are called complex agroforests. These fallows can be characterized as more *productive* fallows. The second strategy aims to improve the biological efficiency of a particular fallow system, seeking to achieve greater benefits within the same or shorter time frame. These include shrub-based accelerated fallows and short-term herbaceous fallows. They can be referred to as more *effective* fallows. Biophysical and economic benefits can accrue from either strategy (Cairns, 2004a).

Given the wide range of fallow systems, dynamic and continually changing, the operational definition of managed fallows covers a spectrum of practices, from growing viney legumes husbanded as dry-season fallows for a few months, to long-term complex agroforests, which capitalize on multiple synergies, tapping opportunities at various heights and depths above- and belowground. For improvement and optimization of farming systems, the management of fallow and cropping cycles needs to address continually the dual aims of production and soil fertility enhancement. For this reason, Brookfield (2004) characterizes such systems as *farmer-guided ecological change* rather than as fallow improvement, since the objectives include biological diversity and quality and quantity of livelihoods, rather than just soil improvement or combating soil degradation.

29.1 Fallowing for Soil Fertility Improvement

Keeping in mind this broader concept of fallow and crop management, this chapter concentrates on the roles and functions of fallows for sustainable soil fertility improvement. Across all continents, poor farmers in the tropics face similar dynamics and constraints. As populations grow and pressure on land area increases, fallow periods are reduced, and traditional fallow management is often not sufficient to restore soil fertility, leading over time to soil and vegetation degradation and to noticeable declines in crop yields. Given the fact that future food production in the world will have to be achieved with less land and water per capita, and given the expectations that poverty will be reduced, efforts for sustainable intensified agriculture should give priority to developing knowledge and skills for optimizing ecological and agricultural environmental conditions. Associated priority should be attached to getting more efficient labor use, capital, and external inputs, addressed later.

The agronomic performance of agroecosystems can be enhanced by managing more efficiently the biological cycles and interactions among the components that determine crop productivity. Improved fallow management as an entry point has the potential to capture nutrients within the system and make them plant-available, to reduce weed pressure, to restore soil organic matter (SOM), litter layers, and biological activity in the surface soil, and to rehabilitate soil micro- and macroorganisms that were reduced during the cultivation phase. These concepts of improved fallow management can be extended to the rehabilitation of degraded and abandoned land. However, what is actually happening within a fallow cycle and how do fallows work?

29.2 Soil Fertility Restoration during a Fallow Cycle

At the start of a fallow period, the fallow vegetation grows rapidly, from new seedlings and from the root systems already in place from previous crop and fallow periods. Nutrients are taken up from the surface soil and subsoil and are stored in the vegetation. They are in part returned to the soil through litter and rain wash from the aboveground vegetation. With intense biotic activity at the soil surface, litter decays rapidly and is transformed partly into SOM. At the same time, erosion is minimized, as is leaching, due to ground cover and rooting mass. Humus and litter layers increase until they reach an equilibrium between build-up and rate of oxidation (Nye and Greenland, 1960).

29.2.1 Soil Chemical Improvements

Buildup and maintenance of SOM is critical to soil productivity and generally corresponds to nutrient buildup. SOM increases the cation exchange capacity (CEC) of the surface soil which is especially important in kaolinitic soils. Of special importance, increasing SOM can reduce phosphorus fixation in soils with high iron and aluminum oxide content. In West African Alfisols, SOM accounts for 80% of CEC, and available P, K, Mg, Ca and CEC are highly correlated with SOM levels (Agboola, 1994). The big opportunity for management in such soil systems is that SOM is a renewable resource, whose level can be replenished by additions of organic inputs (Fernandes et al., 1997).

29.2.2 Soil Physical Improvements

Beneficial soil physical changes occur as well. The fine surface roots of the fallow vegetation mold the soil into soft and porous granules or crumbs, worms deposit their casts on the soil surface, and drainage channels are created. Such a soil surface permits rapid infiltration of water and resists erosion unless completely unprotected. SOM, especially in sandy soils, has a profound impact on soil structure. Physical properties such as hydraulic conductivity, bulk density, total porosity, and aggregate stability all decrease as SOM falls, as a result of the duration and intensity of cropping (Nye and Greenland, 1960; Agboola, 1994).

29.2.3 Soil Biological Improvements

Biomass production, litter fall, and SOM influence microclimates and the substrates for soil fauna. Litter fall under fallows has been shown to increase microarthropod and earthworm population in Southwestern Nigeria (Salako and Tian, 2001). A cover crop within an agroforestry system in Amazonia has been seen to exert a favorable effect on the soil fauna, presumably by keeping the soil moist and shaded and by providing litter as a substrate (Barros et al., 2003). In a comparison of a 15-year fallow and a 3-year potato field in the high tropical Andes, labile carbon and nitrogen soil pools under fallow increased significantly; microbial biomass nearly doubled; the microbial community was much more diverse; and the rate of plant material decomposition was much faster under fallow (Sarmiento and Bottner, 2002). Furthermore, belowground organic matter quality, SOM, fine and coarse roots, and heterotrophic biota have been shown to have a suppressive effect on phytoparasitic nematodes.

In the sudanian zone of Senegal, it has been shown that woody species can control harmful nematodes better then in herbaceous fallows, since coarse roots play a key role in maintaining nematode diversity, with nonparasitic species competing with those that are parasitic (Manley et al., 2000). SOM decline also exacerbates the problems with Striga infestation. In northern Ghana, in fields closer to the homestead, where organic matter inputs had increased SOM to 2.54% compared with 1.42% in the more distant fields, the close-by soils had 40% higher CEC and microbial biomass was four times greater. Striga infestation was found to be inversely correlated with the total nitrogen content and microbial biomass in the soil (Sauerborn et al., 2003).

29.2.4 Time Dynamics of Nutrient Accumulation and Soil Fertility Restoration

In the early stages of a fallow when biomass is increasing and nutrient uptake is rapid, there may actually be a net loss of nutrients from the topsoil. It is only later in the fallow development, when litter fall greatly exceeds the increase of nutrient uptake into biomass, that the amount of nutrients in the topsoil may be increased and restored. Looking at nutrient stocks during the fallow cycle in an Ultisol in the Peruvian Amazon, total stocks of phosphorus and potassium under three types of fallow, *Inga edulis*, *Desmodium ovalifolium*, and natural fallow, were, respectively, about 40, 80, and 12% greater at 53 months than initial values; however, calcium and magnesium stocks were reduced by 25 to 40% in the three fallow types. While nitrogen was restored quickly, carbon restoration was estimated to take at least 8 to 10 years. Since calcium and magnesium were incompletely restored, there is a concern about the sustainability of short-term, fallow-based systems on such acidic, infertile soils. Either fallow species with deep root systems should be selected for more efficient uptake of these elements, or inorganic inputs have to be applied to provide the key limiting elements (Szott and Palm, 1996).

In natural fallows in eastern Madagascar, nutrients regenerated rapidly in the fallow vegetation, attaining already within one year 36 to 57% of the previous phytomass pools, whereas topsoil nutrient concentrations started to increase only after 3 to 5 years of fallow (Brand and Pfund, 1998). In a study looking at carbon and nutrient accumulation in secondary forests regenerating on pastures in Central Amazonia, Feldpausch et al. (2004) found that in a 14-year-old forest, most of the carbon and nitrogen had been stored within the soil, while the increased phosphorus, potassium, magnesium, and calcium resided more within the vegetation. These findings have important implications for management. When nutrients are accumulated in the vegetation rather than in the soil, there is a danger of nutrient stock depletion when biomass is exported or burned rather than being carefully recycled within the plot.

29.3 Fallow Systems

Two major fallow systems are generally distinguished: (1) fallows composed of natural vegetation and (2) fallows that consist of deliberately planted, introduced species.

29.3.1 Natural Vegetation Fallows

The most common approach to fallow management is the opportunistic use of the germplasm available *in situ*. In systems with long fallow periods and in early cycles after deforestation, natural fallow establishment is characterized by regenerating trees either coppiced from old plants or growing from seeds. If fallow periods shorten and cropping frequencies increase, tree seedlings do not survive disturbances from cultivation and fire use, tree stumps die, and tree seedbanks in the soil become progressively depleted. Thus, trees are replaced by shrubs that are either indigenous or exotic naturalized species. Then, with further intensity of cropping/fallowing (meaning reduction in the length of fallow period), shrubby fallows are replaced by herbaceous fallows that have lower soil-restoring abilities and are often difficult to control, which may result in abandonment of the land for agriculture.

Trees often depend upon bats or birds for seed dispersal whereas some shrubby species, grasses, and forbs have wind-dispersed seeds and are able to colonize new areas more rapidly. Also, when nutrients are released during burning and are liable to rapid loss through leaching or runoff, those species that can establish themselves quickly will steadily increase in density and cover (Uhl et al., 1981).

These transitions in vegetation composition can occur very rapidly. A fallow study in the rainforest region of eastern Madagascar documented what happens when fallow periods are significantly reduced. Within the past 30 years, the length of fallow periods declined from 8 to 15 years to currently 3 to 5 years. These current fallow periods are much too short to maintain soil and vegetation productivity, and the fertility of soil systems is being lost. A very rapid increase of upland degradation and transition from primary forest to abandoned grasslands is occurring within periods of 20 to 40 years, five to ten times faster than previously reported (Styger, 2004).

29.3.1.1 Natural Tree Fallows

Natural trees establish in young fallows only if the previous fallow periods were long enough to regenerate soil system fertility or if pioneer tree species can regenerate rapidly from existing seed pools after forest disturbance. If shrubs, forbs, or grasses come to dominate the early fallow phases, shade-tolerant trees establish only gradually under the canopy of other species, and shade-intolerant species lose out. This considerably slows the speed of successions into mixed forest vegetation and can mean that such mixture never materializes (Uhl et al., 1981).

Farmers pursue various management techniques in natural tree fallows: selective weeding, protecting favored species during the cropping cycle, and enrichment planting with favored species. The selective retention of desirable species gradually alters the forest fallows with the production of desirable and economically valuable species to farmers. The ability of tree fallows to regenerate, referred to as their resilience, can vary considerably. In Thailand, for instance, farmers are able to maintain a productive system of upland rice production by depending on the regrowth of the pioneer species *Macaranga denticulata* (Euphorbiaceae) within 7-year fallow/cropping cycles (Yimyam et al., 2003). In eastern Madagascar, on the other hand, the pioneer tree *Trema orientalis* (Ulmaceae) is able to colonize and dominate only the first fallow cycle after deforestation. In the second fallow cycle, *Trema* is displaced from the agroecosystem, and shrubby fallows establish themselves instead (Styger, 2004).

29.3.1.2 Natural Shrubby Fallows

Progressive loss of forest cover and increased land-use intensity favors the expansion of pioneer shrubs at the expense of trees. In many locations in the tropics, exotic, naturalized, and invasive shrubs have replaced the indigenous vegetation. In many cases they have proved themselves successful in restoring soil fertility and in delaying further transition to herbaceous fallows. A prime example is *Chromolaeana odorata* (Asteraceae) which once introduced into Asia and Africa spread aggressively, altering the natural fallow vegetation so that in many parts of the world it is considered a noxious weed.

However, in Southeast Asia, farmers learned to appreciate the ability of *C. odorata* to colonize young fallows rapidly, developing dense, almost monospecific thickets that protect the soil. Very importantly, this plant can shade out *Imperata cylindrica* and other light-demanding gramineous weeds. *C. odorata*'s rapid biomass accumulation and copious leaf litter appears to accelerate nutrient cycling and increase SOM. Although not a nitrogen fixer, Chromolaena plays a critical role in nutrient conservation by aggressively scavenging labile nutrients from the soil nutrient pool. *C. odorata* plants have been shown to have higher nitrogen, phosphorus, and calcium contents compared with indigenous fallow (Roder et al., 2004).

Another species from the Asteracaeae family with similar properties is *Tithonia diversifolia*. Both species have nematocidal properties, reducing disease problems in the subsequent cropping phase. Indeed, farmers use *Tithonia* juice extracts as an ingredient in botanical pesticides. Exotic Asteraceae are seldom subject to insect herbivory. Most importantly, these fallows require little labor, establish spontaneously when seed is available, require no special management, and are easily cleared (Cairns, 2004a).

In eastern Madagascar, the second fallow cycle after initial deforestation is most often dominated by the indigenous shrub species *Psiadia altissima* (Asteraceae). However, this species is in turn quickly outcompeted in subsequent fallows by *Rubus moluccanus* (Rosaceae) and/or *Lantana camara* (Verbenaceae), two exotic invasive species. *Rubus* is the most aggressive among all the shrubby fallow species and quickly forms a thick stand. In eastern Madagascar, *Rubus* accumulates the highest nutrient stocks in short-term fallows up to 5 years, while *Trema* tree fallows accumulate higher nutrient stocks only beyond 5 years. *Rubus* also has very prolific litter production, and its root biomass constitutes 35% of total biomass compared with 15 to 20% for *Psiadia* and *Trema*. This enables the species to recover quickly and be competitive after the frequent disturbances by burning and cropping. However, *Rubus* is not robust enough to withstand repetitive slashing and burning, so after 3 to 4 fallow cycles, it gives way to ferns and to *I. cylindrica* (Poaceae) (Styger, 2004).

These exotic and naturalized fallows can be labeled "improved fallows" if they restore soil fertility more rapidly than would the indigenous vegetation and at minimum labor cost to farmers. These fallow plants, however, have some negative qualities as their rapid dispersal and colonization make it difficult to control their expansion. *Rubus* is a spiny plant, and this makes its plant residues difficult to manage. Farmers use fire as the most practical solution for field preparation. Chromolaena, despite its desirable qualities as a fallow species, has shown allopathic effects on tree growth, and because both species suppress the regeneration of desirable woody species, they represent a threat to native biodiversity. Also, because neither species is palatable to livestock, their expansion reduces grazing (Roder et al., 2004; Styger, 2004).

29.3.1.3 Natural Herbaceous Fallows

Continuation of high frequency of land use, with shorter and shorter fallow times, means that natural fallows will eventually be dominated by herbaceous plants, forbs, and grasses. *I. cylindrica* is the most widespread and aggressive species in Asia and Africa, with some spread also in Latin America, although for unclear reasons, it has proved to be less aggressive there. In Madagascar, *Imperata* and the ferns *Pteridium aquilinum*

(Dennstaedtiaceae) and *Sticherus flagellaris* (Gleicheniaceae) replace *Rubus* as soil fertility levels decline through successive cycles of cropping and fallow. Once herbaceous fallows are established, farmers cease upland rice cultivation and may plant root crops for one or two more seasons before the land is completely abandoned. In Madagascar, unlike in Asia, *Imperata* is not the end stage of succession; it is eventually replaced by Aristida grasses (Poaceae). These grasses are nutrient-poor, lack good soil coverage, and thus favor soil erosion. They are burned periodically for low-productivity cattle grazing (Styger, 2004).

29.3.2 Planted Fallows

Under intensified rotations, natural fallows show considerable limitations characterized by soil and vegetation degradation and by species-replacement from woody to herbaceous species. The herbaceous species are seldom able to produce large amounts of good-quality biomass and to restore soil fertility quickly. A desirable step in agricultural intensification is, therefore, to plant fallow species that improve soil systems more efficiently than do the natural fallows.

Exotic, leguminous tree, shrub, or herbaceous species are often selected and planted in fallows and intercrops from a few months up to 3 to 5 years (Fernandes et al., 1994). Since the 1980s, research on improved planted fallows has increased, and adoption of new techniques is taking place in Latin America, Africa, and Southeast Asia. The main species used are legumes of the genus Sesbania, Tephrosia, Crotalaria, Cajanus, Leucaena, Indigofera, Mimosa, and herbaceous species Centrosema, Pueraria, and Mucuna (Sanchez, 1999). Results with several of these species used in fallow are discussed in Chapter 19.

Planted fallows are adopted where labor and technologies are available and where land has become a limiting factor. They are also favored when land tenure is secure and when markets exist for the variety of products that can be grown (or grown better) with improved soil quality. Technical issues that arise are selection of the best germplasm (species/varieties), cropping techniques such as optimal planting dates, plant densities, establishment methods, harvesting techniques, below- and above-ground residue management, and ease of seedbed preparation for the first crop after fallow. These new techniques demand access to germplasm, specific skills, and knowledge, and more labor than do natural fallows, and this is often a limitation for the adoption of these techniques. Furthermore, research and extension services need to support the process of innovation and adaptation in collaboration with the farmers since fallow systems need to be continually evaluated and often modified in light of local conditions that are often changing biophysically but also socioeconomically, e.g., affecting labor availability.

29.3.2.1 Planted Tree and Shrub Fallows

Planted tree fallows are often used when fallow periods are longer then 5 years and when additional products such as wood or fruits can be produced as an added benefit of the short-fallow restoration. Shrub species are often used in fallows from 6 months to 3 years. In general, the higher the biomass production, the higher are the nutrient stocks established and the better the soil fertility improvement, resulting in higher crops yields. This has been shown in various experiments, many reported in Chapter 19.

In one evaluation not reported in Chapter 19, the maize yields resulting after 2- and 3-year fallows with *Sesbania sesban* in eastern Zambia were 5.0 and 6.0 t ha^{-1}, respectively, compared with 4.9 and 4.3 t ha^{-1} from continuously cropped maize with fertilizer

(112 kg N ha^{-1}), and 1.2 and 1.9 t ha^{-1} without fertilizer. The total yield over four cropping seasons following a 2-year fallow was 12.8 t ha^{-1} compared with 7.6 t ha^{-1} for six seasons of continuous unfertilized maize. In addition, 15 and 21 t ha^{-1} of fuelwood were harvested after the 2 and 3-year fallows, respectively, a large benefit to households in the area (Kwesiga et al., 1999).

In western Kenya, a species screening of 22 shrubby and herbaceous legumes in a 2-year fallow showed 30 to 100% increases in maize yield compared with the natural fallow (Niang et al., 2002). In Uganda, with a one-season fallow of *Crotalaria ochroleuca*, which was intercropped and then mulched with maize or beans, yields decreased during the intercropping season by an average of 30%; but then the yields in the first season after mulching increased by an average of 40%, with a best response being 68%. In the second season, there was still an increase of greater than 20%. In fields where Crotalaria was planted, it was also seen that water infiltration increased and bulk density of the soil decreased (Fischler et al., 1999).

29.3.2.2 Planted Herbaceous Legumes

Herbaceous legumes or cover crops are often relay-planted during the cropping cycle, and once the crop is harvested, the soil surface is covered quickly and nutrient losses are minimized. Cover crops and green manures are discussed in more detail in the next chapter. An ideal cover crop is:

- Easy to establish
- With few external inputs and costs
- Fast-growing
- Adapted to a broad range of soil conditions
- Has few pests and diseases
- Provides good soil cover and erosion control
- Improves soil fertility
- Fixes nitrogen (Hairiah, 2004)

In addition to soil fertility restoration, some cover crops also produce grains for human consumption or fodder for livestock. Although such benefits are appealing, there is a trade-off as the grain production and harvest will affect the amount of nutrient accumulation in the soil. If the harvest index increases, a species intended for fallow enrichment may become really a legume crop and part of a permanent crop rotation.

29.3.2.3 Natural vs. Planted Fallows

It is not always the case that planted fallows outperform natural fallows. An evaluation of 2-year leguminous shrub fallows, comparing this with Chromolaena as a natural fallow in northern Laos, showed that leguminous shrubs produced 4 to 6 times higher aboveground biomass (20 t to 30 t ha^{-1}) than did Chromolaena (5 t ha^{-1}). However, the superior biomass did not have any significant impacts on rice production or soil parameters (Roder and Maniphone, 1998). A planted Tithonia fallow in western Kenya did not differ in the quantity of aboveground biomass produced compared with a natural weed fallow, although soils were improved more efficiently, indicating that some important rhizosphere processes were taking place (George et al., 2002).

Species difference can be remarkable. In the Peruvian Amazon, a comparison between single species fallows showed that *I. edulis* and *D. ovalifolium* produced the highest nutrient stocks after 53 months, followed by the natural fallow, which outperformed the other planted species, Centrosema, Stylosanthes, Cajanus, and Pueraria (Szott and Palm, 1996). Fallow improvement is thus not only a function of the amounts of inputs invested, but depends on a host of interacting factors, including the quality, timing, and location of inputs (above- or belowground), soil biological dynamics, and the effect of these differences on SOM and nutrient availability patterns (Fernandes et al., 1997). The interactions among these factors remain in many instances not well-known.

29.3.2.4 Supplementary Inorganic Inputs

Fallowing alone may not be sufficient to achieve a productive and sustainable system. This can be the case where soil systems have experienced serious depletion due to overexploitation and erosion or in soils with low pH, low CEC, high aluminum content, or specific nutrient deficiencies. In addition to organic inputs, raising pH through liming and targeted use of inorganic fertilizers can often jump-start the system, stimulating soil microbial activities and increasing the efficiency for soil restoration. A combination of organic and targeted inorganic inputs has often been reported to have synergistic effects that exceed the effect of applying a single kind of amendment with the same level of nutrients. Combinations can provide a solid basis for sustained system improvements.

An experiment in eastern Madagascar compared the productivity and effect on soil fertility of traditional slash-and-burn techniques with a crop and soil management system that mulched the slashed fallow biomass and recycled crop residues. The trials included plots with no added phosphorus (M0) and others with either 40 kg P ha^{-1} (M40) or 80 kg P ha^{-1} (M80), applied through a locally available guano-phosphate on a rotation of upland rice, beans, ginger, and *C. grahamiana* fallow. The aboveground nutrient stocks of the Crotalaria fallows in M0, M40 and M80 were, after 1 year, 2–3, 3.5–4, and 5–6 times higher, respectively, compared with natural fallow. Given the nutrient stock accumulation curve for natural fallows, it would take a natural fallow 5 to 30 years, depending on the fallow species and elements, to achieve the same nutrient stocks that the Crotalaria M80 treatment achieved in 1 year.

Yield comparisons showed that M80 yields were 200, 340, 155, and 180% higher for rice, beans, ginger, and *Crotalaria*, respectively, than for M0. Net monetary returns per hectare, subtracting the guano cost, were about 50% higher for M80 compared with M0 (U.S.$2760 vs. 1860) (Styger, 2004).

29.4 Limitations on Fallow Management

Fallow systems face a fairly inexorable limitation. With increased cropping frequency, i.e., shorter fallow periods, natural vegetation will change in its species composition from woody to herbaceous species, and it will, over time, become degraded as the loss in biodiversity aboveground parallels that associated with soil degradation belowground. In overexploited systems, more nutrients will be exported than are replenished, SOM is likely to decrease, and the environment for soil biota will become less favorable.

Fallowing faces some serious limitations if one wants to build up nutrient pools within short time-periods. The time needed for nutrient restoration varies greatly across elements; nitrogen, for instance, can be restored in less than 2 years, whereas in the same soil, calcium needs 15 to 20 years (Szott et al., 1999). In young fallows, soil nutrient pools may decrease temporarily and may accumulate in fallow biomass until returned through litter back to the soil. Management interventions at that stage need to manage fallow biomass carefully, minimizing its export and avoiding burning it.

Planted leguminous fallows often have higher biomass production and nutrient stocks compared with natural fallow, and this often translates into higher crop yields as seen above. However, this is not always the case. Careful testing of new fallow species and fine-tuning of management techniques needs to be carried out to optimize fallow functions. Exotic species have to be carefully chosen or else avoided, since some have the potential to become weeds outside their native locations. Yield increases for subsequent crops will be highest in the first crop season, but then will decline, sometimes rapidly, in the second and third crop. Additional inputs that correct soil pH, build up SOM and CEC, increase nutrient availability, and complement the limiting elements are welcome so that yield increases can be maintained longer. The change to planted fallows occurs when agricultural systems intensify, which demands more labor. Research and extension support are important for making best use of the available resources. Often the lack of well-suited germplasm can be a limiting factor for the adoption of new fallow species.

29.5 Discussion

The sustainable intensification of fallow and cropping systems should aim to provide continuous soil cover, maintain SOM, preserve nutrients within the systems, and keep nutrient cycling as efficient as possible, building on species diversity in fallows and in crops, with each contributing according to its specific comparative advantages to the overall increase of the system's productivity.

The selection of fallow species is critical for optimizing fallow functions. The species selected should be able to take up nutrients from poor soils, should rapidly accumulate biomass, produce high quality litter, and have balanced nutrient profiles in their biomass. Species with deeper rooting depth are better able to capture nutrients from subsoil. Those that suppress weeds efficiently and break cycles of pest and diseases make different but important contributions. Mixing species can increase fallow efficiency as the integration of deep-rooting woody plants is complemented by association with shallow but densely rooted, rapidly colonizing cover crops. It is important also to include species that form symbioses with mycorrhizal fungi and favor other beneficial soil microbes or macrofauna.

Optimizing organic matter recycling is important for successful fallow regeneration. Organic matter produced within the system, fallow biomass, weeds, and crop residues should be recycled as efficiently as possible and should not be exported or burned. As much as possible, other inputs such as homestead residues, livestock manure, and biomass transfer should be used if available to augment the buildup of organic matter. The maintenance of SOM, especially in tropical ecosystems, is dependent on the continual input of organic materials. SOM losses and gains depend on soil type, climate, and crop and fallow management practices, on length of fallowing and cropping, tillage, residue management, etc. The proportion of fresh material converted to soil humus will probably be between 10 and 20%. For tropical forests, these numbers can be closer to 10 than 20%. Root material that is amenable to mineralization contributes to soil humus between 20 and 50% of annual root growth (Nye and Greenland, 1960).

Combining organic matter recycling with inorganic nutrient amendments opens up some new possibilities. On infertile acid soils, phosphorus and calcium are often needed to prime biological processes such as nutrient cycling and nitrogen fixation. Mulches and the addition of organic matter to the soil can keep phosphorus fertilizer from becoming bound to aluminum and other ions in acid soils, thus making it more available for plants (Schlather, 1998).

The maintenance of biodiversity within soil systems and in the vegetative biomass helps to make intensification of farming systems more sustainable. This is important for ecological balance and to address product diversification better within the fallow and cropping cycles. Landscape management should strive for mosaics of different land-use forms where a range and variety of cropping and fallow systems are operated with short- to long-term fallows fulfilling various economic and ecological functions. If a broad range of farming systems is available, farmers can choose, adapt, and use various niches within the landscape that are as yet not used optimally.

More attention should be paid when developing these systems to the management and enhancement of environments for soil micro- and macrofauna. At this moment, it is obvious that many landscapes are degrading. Low yields are easily attributed to measurable deficiencies in available soil chemicals, and physical degradation is easy to see. What is not so easily evident is the loss of soil biota and of their contributions to a productive soil system. The current problem for agriculture is not so much that land *per se* is not available, but that fertile land for agricultural use is becoming scarce. Intensification is an almost unavoidable response. If improved management strategies with short-term fallows can be implemented, this can buy time for marginal land, which is degraded or not currently suitable for agriculture, to be rehabilitated for future production through longer-term restorative measures.

Published reports indicate that farmers in some locations have been quick to take up managed fallow technologies. For example, in Central America and West Africa, farmers have rapidly adopted the herbaceous legume Mucuna in rotation with maize (Buckles and Triomphe, 1999; Tarawali et al., 1999). In southern Africa, widespread adoption of *S. sesban* fallows has been reported by Kwesiga et al. (1999). While the large-scale adoption of single-species fallows is having positive results, this gives some cause for concern. If thousands of farmers convert landscapes to monospecific fallows, it is possible that pests or pathogens could emerge that decimate their fallow and/or cropping systems. The example of the widespread promotion and subsequent collapse of *Leucaena leucocephala*-based systems in Southeast Asia because of the psyllid pest in the 1980s underscores the need to maintain both crop and fallow species diversity at the landscape scale.

The regeneration of woody species supplemented by enrichment plantings can lead to stable agroforestry systems that fulfill ecological functions, such as watershed protection or the establishment of biodiversity corridors, while being economically productive. We expect that the emerging science and practice of *payments for environmental services* will eventually result in many farmers using fallows not for soil fertility restoration and low-value staple crops but for higher-value ecosystem services and associated payments.

For example, the World Bank's BioCarbon Fund is already funding the retention on or reforestation of degraded lands with native trees and shrubs to sequester carbon (U.S.$ 2–5 t^{-1} CO_2 equivalent). The private sector is also paying land-users to improve the hydrological cycle with tree-based systems rather than continue pasture and annual crops (Fernandes, 2005). Fallow management is always location-specific, needing to suit and be adapted to soil, slope, and socioeconomic factors. Natural and managed fallows, which protect landscape integrity and farmland productivity as well as watershed service functions, will be increasingly important to both rural and urban communities as they adapt to climate change and the increasing frequency and severity of extreme weather events.

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