

Ecological aspects of site recovery under swidden-fallow management in the Peruvian Amazon

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Abstract. The ecological importance of fallowing to swidden (slash and burn) agriculture is well known. Cyclic agroforestry systems which emphasize utilization of the fallow cycle should, where appropriate, consider the ecologic processes of site recovery, so as not to impair the productivity of the subsequent swidden cycle. This article discusses the ecologic 'fit' of a cyclic swidden-fallow management scheme into swidden cultivation and fallow succession. Such a fit suggests a reciprocally reinforcing situation between this agroforestry design and processes involved in site recovery. Observed among some indigenous and colonist inhabitants of the Peruvian Amazon, this system produces fallow crops and products, while enhancing site nutrient recovery. The economic benefits of this scheme have recently been reported (Denevan and Padoch, n.d.) while the ecologic attributes involved in promoting site recovery have not; primarily these include:

- a) Less destruction of the nutrient cycling root-mat in the swidden cycle, and its quicker re-formation in the fallow cycle.
- b) Discouraging the establishment of exotic, pantropical weeds and grasses such as *imperata*, while encouraging the colonization of local, early successional species.
- c) Encouraging the earlier establishment of woody plants in abandoned swiddens.
- d) A natural litterfall higher in nutrients than in unmanaged fallows.
- e) Additions of 'slash' litterfall higher in nutrient content than natural litterfall in the proximity of valuable managed plants.
- f) The increased capacity of the managed stand to scavenge limiting nutrients such as N and P from, and leach unneeded quantities of non-limiting nutrients such as K, Ca and Mg to, throughfall.
- g) Increasing the alkalinity of throughfall, possibly resulting in less soil cation leaching in managed fallows.
- h) Staggering seed production, germination and maturation times of the rapid nutrient cycling softwood trees.
- i) Increasing the spontaneously occurring abundance of valuable fallow plants with management of successive fallow cycles, thereby possibly reducing the labor requirement, and increasing the value of this agroforestry scheme over time.

Introduction

The realization that mechanized farming does not necessarily provide permanently greater agricultural yields in energy-limited tropical countries has

re-focused scientific interest on traditional subsistence farming systems which are able to provide sustained yields [Horowitz, 1986; Rambo, 1980]. Recent research in fact attests to the ecological viability of swidden (cyclic, or slash and burn) agriculture at appropriate levels of population [Rambo, 1980; Pelzer, 1978; Dove, 1983; Rambo, 1980; Conklin, 1957; Geertz, 1963; Denevan, 1984; Raintree and Warner, 1986]. The suitability of swidden agriculture to the humid tropics appears to be borne out by the failure of a great deal of agricultural research to perfect alternative systems having comparable merits. In fact much attention is currently being placed on improving shifting cultivation – in order to cope with increasing population pressure – rather than trying to replace it (Rambo, 1980, and references cited therein).

The ecological significance of fallows and the fallow cycle to swidden agriculture is well documented, and investigations into the nature of fallow fields, the secondary succession occurring in these, and site recovery, has contributed much to swidden ecology. A problem with fallowing as a means to overcome agricultural difficulties in the cropping cycle, is that it requires a great deal of time; time that is traditionally spent in an unproductive state. And while economic utilization of the fallow cycle in the humid tropics does occur, and can exhibit significant agronomic potential [Barrera et al., 1977; Harris, 1971; Hart, 1980; Eden, 1980; Basso, 1973; Raintree and Warner, 1986; Manner, 1981; Hiraoka, 1985; Gliessman, 1981; Janzen, 1973; Posey, 1985; Weaver, 1979] the focus of the majority of the research on this topic has been to describe and/or experiment with assemblages of plants which are inserted into appropriate stages of succession. However utilization of the fallow cycle necessarily involves changes in site nutrient dynamics which affect the recovery of soil fertility and hence the agricultural productivity of the subsequent swidden cycle, an aspect of fallow exploitation which thus far has received little attention.

This paper discusses the ecological 'fit' of an existing fallow utilization scheme in the Peruvian Amazon in the context of the changes in plant succession and nutrient dynamics which result in a favorable site nutrient recovery. Evidence is presented which suggests that a reciprocally reinforcing ecological relationship exists between this particular design and certain processes which encourage rapid recovery of soil fertility. This relationship not only speeds site nutrient recovery but also promotes, via the local ecology, an increasing abundance of spontaneously occurring, economically valuable fallow plants in an iterative fashion, while discouraging the invasion of exotic weeds and grasses such as *imperata*.

Following a brief description of the fallow management scheme, information is drawn from the author's observations in the Iquitos region of Peru

[see Unruh, n.d.] and from the ecological literature to explain how management practices interact with specific aspects of swidden ecology – from the point at which the field is cleared, through the phases of burning, cultivation, harvesting, site abandonment, and distinct stages of succession – to allow a variety of economic fallow plants to thrive while setting the stage for continued favorable re-use of managed sites. For a detailed description of swidden-fallow management in the Peruvian Amazon the reader is referred to Denevan and Padoch (n.d.). The present discussion deals primarily with the ecological ramifications of this design.

This discussion, while review in nature, presents data and observations from several villages in the northeast Peruvian Amazon, all within a 250 km radius of Iquitos, in the general area of the confluence of the Ampiyacu, Napo, Marañon, Ucayali and Amazon rivers. This area lies between 3 and 5 degrees south latitude, and 71 and 74 degrees west longitude. Average annual precipitation in this region for a recent nine year period (1971–1979) was recorded at 2,550 millimetres, ranging from 1,800 to 4,100 millimetres. Temperatures for the same period varied between 21 and 32 degrees centigrade [Martinez, 1982]. Seasonally, the heaviest rains occur from December to May and subside from June through November. The soils are primarily deep ultisols (paledults, tropohumults and tropoudults) which include red and yellow clay soils, and red and brown sandy soils [ONERN, 1976]. The general terrain of the region is dissected fluvial terrace with numerous seasonal streams, and the climax vegetation is humid tropical forest [ONERN, 1976]. The vegetation considered in this discussion consists primarily of secondary regrowth on fallow sites involved in swidden agriculture.

Swidden-fallow management

The practice of managing a fallow in the Peruvian Amazon actually begins at the time the forest is cleared for cultivation, when valuable species such as palms, and those used later for timber, are spared during cutting. Then as the swidden is being cultivated, perennial species such as pineapple (*Ananas comosus*), banana (*Musa* sp.) and guineo (*Musa* sp.) and fruit and palm trees such as umari (*Poraqueiba sericea*), uvilla (*Pourouma cecropiaefolia*) and pijuayo (*Guilielma gasipaes*) among others (see Table 1 for a more complete list) are planted, interspersed among annual cultivars such as manioc (*Manihot esculenta*) or maize (*Zea mays*). These perennials mature more slowly than annual crop cultivars, and many will not be ready to harvest until the swidden is older and fading into fallow, or later in the

Table 1. Common cultivated and protected economic plants, Brillo Nuevo, Peru

Common name (English and/or Peruvian)	Bora name	Scientific name	Main Uses ¹
*Annatto; achiote	–	<i>Bixa orellana</i>	H, U
*Annona, anona	tacááhe	<i>Annona</i> sp.	F
*Assal, chonta; huasá	tóólliují	<i>Euterpe oleracea</i> <i>Euterpe precatoria</i>	F, C
*Avocado; palta	–	<i>Persea americana</i>	F
*Balsa; topa	hiínújuicyo	<i>Ochroma lagopus</i>	U
*Banana; guineo	ujúoh	<i>Musa paradisiaca</i>	F, U
*Barbasco	muujúrriwa	<i>Lonchocarpus nicou</i>	U
Basil; albahaca	–	<i>Ocimum micranthum</i>	F, U
*Breadfruit; pandillo, árbol de pan	nájahe	<i>Artocarpus incisa</i>	F
Caimito	mutsitsihe	<i>Pouteria caimito</i>	F
Calabash tree; pate	–	<i>Crescentia cujete</i>	U
*Cashapona	íiwajkyo	<i>Iriarte</i> sp.	C
*Cashew; cashu, marañón	anáájihe	<i>Anacardium occidentale</i>	F
Culantro; celantro	–	<i>Eryngium foetidum</i>	F
*Cedar (tropical); cedro	–	<i>Cedrela odorata</i>	C
*Chambira	níijihe	<i>Astrocaryum chambira</i>	C, H, F
Chili pepper, ají	–	<i>Capsicum</i> sp.	F
*Coca (Amazonian)	íipi	<i>Erythroxylon coca</i> var. <i>ipadu</i>	M
*Cacona	roolláhe	<i>Solanum sessiliflorum</i>	F
Coconut; coco	–	<i>Cocos nucifera</i>	F
Cocoyam; huitina	hóónawa	<i>Xanthosoma</i> sp.	F
*Copal, copalhuallo	íijillehe	<i>Dacryodes</i> sp.	F, C
Cotton (tree); algodón	–	<i>Gossypium barbadense</i>	M
Cowpea; chiclayo	–	<i>Vigna unguiculata</i>	F
*Cumala	allíuunéhe, cúúruco	<i>Virola surinamensis</i> <i>Virola</i> sp.	C
Dale-dale	cúúniycye	<i>Calathea allouia</i>	F
*Genipa; huito	–	<i>Genipa americana</i>	H, F, M
*Guaba	túútsihe,	<i>Inga edulis</i>	F
*Guayaba	–	<i>Psidium guajava</i>	F
Huaca	awáámihe	<i>Clibadium</i> sp.	U
*Huacra punta	aallaáhe.	<i>Iriarte</i> sp.	C
*Huamansamana	méneco	<i>Jacaranda copaia</i>	C
*Huicungo	dsúhsába	<i>Astrocaryum huicungo</i>	C, F
Lemon, limón	–	<i>Citrus aurantifolia</i>	F
Lemon grass; yerba luisa	–	<i>Cymbopogon</i> sp.	F, M
*Macambo	ááhe	<i>Theobroma bicolor</i>	F, U
Maize; maíz	–	<i>Zea mays</i>	F
Manioc; yuca	áánuwa (bitter) pácýóómuwa (sweet)	<i>Manihot esculenta</i>	F
*Moriche, aguaje	íñéjhe	<i>Mauritia flexuosa</i>	F, U

*Ojé	páácamico	<i>Ficus insipida</i> (F. <i>anthelmintica</i>)	H
Orange; naranja	–	<i>Citrus sinensis</i>	F
*Papaya	–	<i>Carica papaya</i>	F
*Peach palm, pejibaye; pifuayo	mééme	<i>Bactris gasipaes</i>	F, U
Peanut, maní	mátsájca	<i>Arachis hypogaea</i>	F
Pineapple, piña	cúdsiha (see Table 2-2)	<i>Ananas comosus</i>	F
*Plantain; plátano	–	<i>Musa paradisiaca</i>	F
Pomarosa	–	<i>Syzygium malaccensis</i>	F
Rice; arroz	–	<i>Oryza sativa</i>	F
Shapaja	–	<i>Scheelea</i> sp.	C, F
*Shimbillo	wacháábowa	<i>Inga</i> spp.	F
Soursop; guanábana	–	<i>Annona muricata</i>	F
Sugar cane; caña de azúcar	–	<i>Saccharum officinarum</i>	F
Sweet potato; camote	caátu	<i>Ipomoea batatas</i>	F
Tangarine; tangerina	–	<i>Citrus reticulata</i>	F
Tobacco; tobacco	–	<i>Nicotiana tabacum</i>	M
*Umari	nímuhe	<i>Poraqueiba sericea</i>	F
Ungurahui	–	<i>Jessenia bataua</i>	F
*Uvilla	baácohe	<i>Pourouma cecropiaefolia</i>	F
Yam; sachá papa	–	<i>Dioscorea trifida</i>	F
*Yarina	tókehíiba	<i>Phytelphas macrocarpa</i>	C, F

Source Denevan and Padoch (n.d.).

¹ Use code

F: Food and Beverage

C: Construction or Thatching

H: Handicrafts and Dyes

U: Utilitarian

M: Medicinal and Drugs

* Plants appearing in fallows.

fallow cycle. Such an approach allows for a phased harvest of different crops. Under the fallow management scheme, new swiddens are dominated by annual and fast maturing crops, while older swiddens have a greater abundance of slower maturing perennials and semi-perennials which may be better adapted to conditions of declining soil fertility and increased weedi-ness [Manner, 1981]. And the fallow species (fruit and palm trees) will be ready for harvesting during the fallow cycle. Planting fallow species at the same time the annual cultivars are planted allows them to take advantage of the more fertile soil present at the beginning of the cropping cycle when they are young, and ensures that they will be of an adequate size when the cropping cycle is over and weed communities are invading. Manner [1981] notes a similar situation in ecological successions controlled partly by

human populations and partly by ecological processes among the Kauwatyi Maring of Papua New Guinea.

Additional practices which take place near the end of the cropping cycle further prepare the field for gradual abandonment to a managed fallow. Peanuts for example (for the Bora in Eastern Peru), are planted in second or third year swiddens by packing loose soil mixed with ashes into several dozen mounds, into which are planted the shelled seeds. Coca patches are also planted and remain intact and well tended well into the fallow cycle [Denevan, and Padoch, n.d.]. In contrast to traditional swidden abandonment, abandonment in the context of fallow management constitutes a non-distinct transition from swidden to fallow, resulting in a sequence from a cultivated field, to a managed fallow combining economic plants and natural forest regrowth, to a 'forest fallow' in which valuable plants are still greater in numbers than in the original forest. In other words, 'abandonment is not a moment in time but rather a process over time' [Denevan and Padoch, n.d.].

Later in the fallow cycle, management involves protection (cutting away or 'slashing' the surrounding competing regrowth) of useful plants, both planted and spontaneously occurring. The result is a fallow with a combination of perennial herbaceous and tree crops together with natural forest regrowth, which change in composition and proportion at various stages of succession (Fig. 1). Thus instead of dense secondary forest with a relatively tight canopy, and a predominantly single, distinct life form which occurs in natural rainforest successions [Richards, 1964; Kellman, 1969] there is a much more patchy stand of fruit trees and other valuable plants, interspersed with a subcanopy of woody shrubs, open areas, and natural forest regrowth [Unruh, n.d.].

Field abandonment and weed establishment in managed and unmanaged fallows

Studies of swidden ecology note that the reasons for the abandonment of fields involve a decline in productivity, which is due to nutrient impoverishment of the soil, weed invasion, and problems associated with insects and disease [Kellman 1969, 1980; Manner 1981; Blood 1980; Altieri et al., 1983; Harcomb, 1980; Ewel, 1971; Ewel et al., 1982; Denevan et al., 1984; Uhl et al., 1981]. Uhl et al. [1981] state that on soils of low fertility abandonment usually occurs with the disappearance of the surface root-mat which protects the soil from erosion, and acts – via decomposition – as a slow release pool of fertilizer.

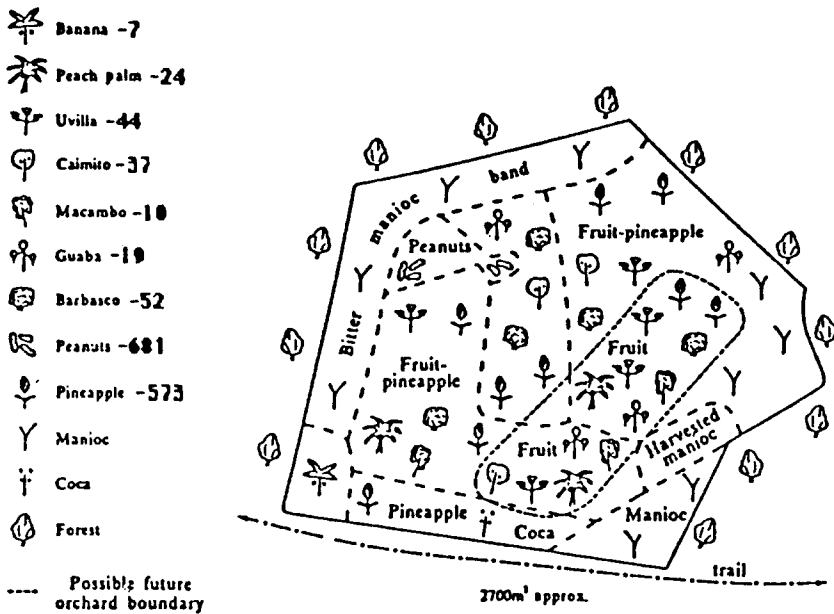


Fig. 1. Map of three year old transitional swidden. Numbers next to species common names refer to the number of plants observed in the fallow. For species latin names see Table 1. Source: Denevan and Padoch (n.d.).

The abandonment of agricultural land in the humid tropics is followed by a transformation to an environment that induces successional change. As the first occupants of the abandoned swidden, weeds play an important role in succession. Differential composition of the weed vegetation may result in distinct successions, as weed communities often comprise the floristic ingredients of later successional stages [Kellman, 1980]. In examining the ecological fit of swidden-fallow management, it is necessary to consider the differences in the practice of abandonment between traditional swidden agriculture and swidden fallow management, and the successional processes which result from each.

Initial burning of the cut vegetation destroys a percentage of weeds, surface seeds, and local insects [Manner, 1981; Kellman, 1980; Uhl et al., 1981; Ewel et al., 1981]. After cultivation, weed regrowth and patterning reflect the interplay of access to sites by species with different origins, and the selective environment prevailing in the abandoned field [Kellman, 1980]. Species involved in the establishment of weed communities in old swiddens can come from three sources: 1) vegetative residuum left at the site; 2) the buried viable seed component; and 3) interfield migration [Kellman, 1980]. A substantial proportion of the residual component is eliminated by burning

[Ewel, 1981; Uhl et al., in press], and over the long term the frequency of remnants decreases with increased frequency and efficiency of cultivation, resulting in a decreased role in total weed community establishment [Kellman, 1980]. The buried seed component in rainforest soils throughout the tropics tend to be dominated by herbaceous species [Chin, 1973; Guevara and Gomez-Pompa, 1972; Keay, 1960] and can provide a significant number of colonists depending upon the nature of the burn and frequency of weeding [Kellman, 1980; Uhl et al., in press]. The migratory seed component however has traditionally been considered a dominant source of weeds in swidden agriculture [Uhl et al., in press; Kellman, 1980]. The majority of migratory tropical weed species produce large numbers of seeds, and many possess efficient dispersal mechanisms. As the frequency and intensity of cultivation increases, so does the importance of the migratory seed component in weed community establishment in fallows [Kellman, 1980 with Havel, 1960; Snedaker, 1970; and Uhl et al., in press reporting similar trends]. Of significant importance then is just how the swidden prepared for fallow management interacts with these three sources of weed colonization in comparison to the non-prepared field, as the site is projected into succession.

Access to colonization sites from the above mentioned sources varies with in-field agricultural practices and frequency of cultivation. Although there are regional variations, the remnant component, in addition to being affected by burning, undergoes a transformation from woody to herbaceous species with prolonged use of a field [Kellman, 1980]. Site access by the buried viable seed component is selectively affected (reduced) by burning and weeding [Uhl et al., in press]. And while the local moisture content of the soil acts as a variable buffer against heat exchange (the greater the moisture the more heat is required to raise soil temperature) developed root systems, continuing to smolder during and after burning, serve as an important source of subsurface heat transport [Brinkman and Vieira, 1971]. The effect of such transport on seeds embedded in the soil is deadly at 2 cm and extremely serious at 5 cm. Burn effect on seeds buried at 10 to 20 cm is more selective, depending upon species' specific seed heat tolerance differences and the irregular heat exposure. On the whole, forest regeneration from the buried seed component on slash and burn fields, while variable, is, in many cases, poor [Brinkman and Vieira, 1971; Kellman, 1980]. The migratory seed component on the other hand can often take on considerable importance in the establishment of weed communities in traditional swidden fields. Unaffected by forest clearing and burning, and being able to take advantage of direct site access via bare fields, old swiddens are often quickly colonized by weed species which employ very efficient seed dispersal mechanisms [Kell-

man, 1980; Van Steenis, 1967; Uhl et al., in press], and which are adapted to germination in large openings in the forest [Denslow, 1980].

Site establishment of weed communities on a field prepared for fallow management however would be expected to occur in a manner different from that which occurs on traditionally abandoned swiddens. With respect to site access by the buried seed component constrained by burning, the presence of valuable trees purposely not cut while clearing the field creates a heterogeneous soil microclimate with regard to soil moisture and fertility. Standing trees in an otherwise bare field allow patches of moist soil to exist under the shade. Further, a living root biomass does not act as a transfer for heat during and after burning, resulting in moister soil in the active root zone. In addition, an intact root system would allow less deep leaching by soil nutrients throughout the life of the swidden, than would a decomposing root-mat under vegetation which had been completely cut and burned [Scott, 1978]. Such variable soil moisture and fertility within a field would allow for a greater proportion of the buried viable seed component to survive the burn than would be expected in a completely cleared field. This permits the buried seed component to play a greater role in secondary forest regeneration. In short, trees left standing during cutting, and the presence of valuable late swidden and early fallow perennial species and practices (peanut mounds, coca patches, etc.) means that a swidden much more heterogeneous in micro-environment enters into fallow succession.

The establishment of woody plants in old swiddens appears to be strongly influenced by microhabitats. Uhl et al. [1981; and Uhl, 1983; Uhl et al., in press] working in the Rio Negro region of the Venezuelan Amazon, found that after only one year, areas in the shade of fruit trees and fallen logs produced significantly more woody plants than did areas of bare soil. Such differences appear to be due to seed dispersal by birds and bats, which are attracted to these microhabitats and then excrete the seeds there. Live trees, and dead leaves and branches which fall from trees and other late swidden plants provide nutrients, and allow for less soil evaporation and lower soil temperatures [Uhl et al., 1981; Uhl, 1983], as would decomposing slash resulting from fallow management later in the fallow cycle. These localized patches of nutrients are the first sites of establishment for woody species in an abandoned swidden, and these islands of woody vegetation expand until the patches connect with each other and with the regeneration from the surrounding forest [Uhl, 1983; Uhl et al., 1981; Richards, 1964]. One of the more valuable ecological 'fits' of swidden-fallow management as an agroforestry system, is the much greater frequency of these microhabitats in the old swidden which, by means of such 'nutrient patches' provide more sites for the early establishment of woody species, conceivably speeding up

initial forest regeneration after crop abandonment. In addition, early successional species are often 'large-gap' adapted [Denslow, 1980], and breaking up the gap size, or open area, of the old swidden with a large number of such 'islands' would select for the establishment of later successional species more quickly.

Such in-field heterogeneity has an additional advantage. Reformation of the root-mat (essential to nutrient cycling and in reducing soil nutrient leaching) may occur much more quickly in young managed fallows. In contrast to the traditionally abandoned swidden with its depleted root-mat, the managed swidden-fallow would have many areas of intact root systems due to the presence of valuable trees and emerging late swidden perennials and woody plants.

The establishment of exotic weeds, and swidden-fallow management

The invasion of exotic weeds and grasses onto cultivated lands in the tropics – the most notable being *Imperata* – is a major agricultural problem, and can result in degraded areas of grasslands resistant to tree establishment [Kellman, 1980, 1969; Manner, 1981; Seavoy, 1973; Scott, 1978] and hence to site recovery and continued agricultural use [Kellman, 1969]. The ecological causes of this problem involve: 1) the enhanced importance of the migratory seed component in weed colonization due to a high frequency of agricultural activity [Kellman, 1980; Uhl et al., in press]; 2) poor soil fertility; 3) homogeneous soil conditions, which in conjunction with burning, makes immediate colonization by local weed varieties more difficult, thereby providing less competition to exotic arrivals [Kellman, 1980; Van Steenis, 1967]; 4) the presence of large, bare, open areas, which provide receptive site access – access playing the greatest role in weed patterning – for colonization via migration [Kellman, 1980]; and 5) uninhibited solar radiation, often a requisite condition for the germination of widespread exotics [Seavoy, 1973].

Heterogeneity of micro-site in swiddens at the time of abandonment can act as a deterrent to the establishment of aggressive, herbaceous, pantropical elements by inducing spatial variation in local weed communities. Indeed Kellman [1980] notes that 'major differentiation in weed communities usually exists at local scales in response to soil conditions and agricultural practices'. The techniques involved in swidden-fallow management select against the invasion of aggressive exotics and allow greater colonization of indigenous weed types. Once having gained access to a site by whatever means, a potential weed community is subject to intensive selection by the micro-sites available for germination. If a field comprises several soil types

or soil-moisture regimes, patterns of segregation will exist [Kellman, 1980]. And, as previously mentioned, site heterogeneity allows for variable heat penetration into the soil, leaving pockets of buried seed to participate in weed colonization where it otherwise would not, and for differences in soil moisture and soil fertility to exist.

Site access for migrant weeds is constrained by the existence of a large number of microhabitats within the field. Trees left uncut, along with valuable late swidden and fallow plants, all of which are protected well into secondary succession, serve to break up larger areas of bare ground, creating smaller gaps, which inhibit the site access of large gap adapted migrants [Denslow, 1980]. Further, the greater amount of shade provided by the larger managed plants at the end of the swidden cycle disrupts the establishment of the often shade intolerant exotics [Seavoy, 1973]. Brinkmann and Vieira [1971] note that many of the same processes which result in exotic weed establishment also favour the establishment of dense, single aged stands of *Cecropia* spp. in the forests of Brazil.

Fallow cycle management

Canopy structure

While swidden-fallow management during the cultivation cycle results in increased in-field heterogeneity at the end of the cropping period, which can speed initial site recovery, the single most important ecological impact of management in the fallow cycle is the alteration in the spatial location of foliage within the stand. Due to selective cutting (or slashing) of vegetation from early on in the fallow cycle in order to protect valuable plants, maturing managed fallows generally have a reduced, more open upper canopy than unmanaged fallows [Unruh, n.d.]. As a result, more light reaches the forest floor, allowing the germination and growth of understory plants which would have remained dormant under a fully developed canopy. Thus the net effect of management on canopy structure is two-fold: a patchy, open upper canopy, and a much more pronounced understory. In an investigation by the author into the nature of canopy structure in managed vs. unmanaged fallows in villages near Iquitos, it was determined that the two types did not differ significantly in total stand percent cover (using an index to percent cover) [Unruh, n.d.]. What did differ was the location of concentrated foliage. Understory vegetation (below 5 metres) in managed fallows expressed on average about twice the percent cover than in unmanaged fallows (Table 2). In a sense the spatial arrangement of foliage in managed

and unmanaged fallows might be viewed as inverses of each other; managed fallows having a greater relative concentration closer to the ground and lacking pronounced upper canopy development, while in unmanaged fallows the greatest concentration of foliage is toward the upper canopy, and comparatively less foliage is present at lower levels.

The spatial arrangement of foliage in managed fallows changes both stand nutrient cycling and plant succession for the remainder of the life of the fallow. The evidence which follows suggests that these changes encourage a quicker, more pronounced soil nutrient recovery while allowing the production of a variety of food and forest products.

Nutrient cycling in managed fallows

Managed fallow canopy structure effects stand nutrient cycling in two ways: 1) quality and location of decaying leaf material, and 2) canopy effects on throughfall. The nutrient content of slashed vegetation in managed fallows is significantly different from that of leaf litter which is naturally abscised. This is because during leaf senescence retranslocation of nutrients, especially limiting nutrients such as P, and N in the tropics, occurs from the leaf to the woody tissue, resulting in lower nutrient concentrations in senesced leaves than in green leaves still attached to the tree [Herrera et al., 1978; Stark, 1971; Chapin and Kedrowski, 1983]. Slashing secondary regrowth in the management of fallows would sidestep this mechanism of plant nutrient use efficiency, and result in slashed vegetation having greater concentrations of limiting nutrients than naturally abscised litterfall. This could be a particularly valuable nutrient input to the soil since such cutting takes place in the proximity of useful fallow plants. Such a concentration of recently cut leaves may actually serve to increase local forest productivity much in the same way that the leaf cutter ant (*atta colombica*) does by harvesting and bringing fresh cut leaves to a central point – effectively concentrating P [Lugo et al., 1973; Haines, 1975].

In addition, simply the presence of a greater understory component in managed fallows may enhance soil nutrient recovery. Recent research suggests that understory vegetation may contribute significantly to total litterfall nutrients because of a higher leaf nutrient content than in the leaves of overstory trees [Yarie, 1980; Chapin and Kedrowski, 1983]. The much more prominent understory observed in managed fallows may actually benefit site recovery by the participation of a greater quantity of this vegetation in natural litterfall and stand nutrient cycling.

Another management induced alteration in fallow nutrient cycling involves differential nutrient concentration in leaves of different age. Nitrogen

Table 2. Index to percent cover (IPC)¹ for whole stands and the proportion in understories² of managed and unmanaged fallows

Age (yrs)	Managed fallows		Unmanaged fallows		Average stand IPC ³		Average percent IPC ³ in understory	
	Stand IPC	% IPC in understory	Stand IPC	% IPC in understory	Managed	Unmanaged	Managed	Unmanaged
1.5	6.28	96.6						
2			4.88	87.9				
2			5.78	37.5				
2.5	4.63	73.2						
3			3.30	29.4	5.5	4.7	84.9	51.6
4			5.88	34.2				
5			3.97	8.8				
6	4.32	67.3			4.0	4.9	67.0	21.5
6	3.63	66.6						
8			4.27	22.0				
8	5.06	90.7						
9	5.10	56.0						
10			5.39	38.7				
10	6.72	61.2			5.6	4.8	69.3	30.4
14	5.04	67.1						
15			5.28	27.5	5.0	5.3	67.1	27.5
20			5.69	24.3				
25	4.57	26.5			4.6	5.7	26.5	24.3
			Average for all stands ⁴ :		5.0	4.9	67.2	34.5

¹ Vertical foliage measurements were converted to IPC and percent distribution of cover by height using log transform equations developed by MacArthur and Horn (1969).

² Understory is defined as the cover present below 5 metres.

³ Values represent averages of similar aged (within 3 years) groups of fallows.

⁴ Averages for all stands were obtained from individual stand values and not from group averages. (Source: Unruh, n.d.)

and P fractions tend to be highest in young leaves and decline in concentration with age [Stark, 1971; Chapin and Kedrowski, 1983]. Slashing regrowth vegetation at three to four month intervals in the course of management (as practiced in the Peruvian Amazon) would mean that many young leaves – growing only since the last slashing – would be cut; leaves which would be much higher in both N and P than older senesced leaves which comprise natural litterfall elsewhere.

Viewing litterfall via management, or slash, strictly in terms of nutrient input into the soil, timing may be an important consideration. Large inputs of slash before root-mat reformation is well underway may result in high rates of nutrient leaching. In fact when any nutrient is applied to the soil in large quantities rather than in frequent small amounts, greater leaching loss can be expected [Glover and Beer, 1986]. In managed fallows however this is not the case, inputs of slash occur only when the regrowth surrounding the valuable plants becomes a threat and must be cut back; again, once every three to four months. And while Uhl et al. [1981; and Uhl, 1983] observe that full redevelopment of the root-mat is usually not complete until later in the fallow cycle, there is evidence that the root system of early successional species provides enough absorptive surface to exploit the natural short-term increase in nutrient availability associated with disturbed sites [Shukla and Ramkrishnan, 1984; Ewel, 1971]. Such evidence would be in addition to that previously mentioned, in which management practices in the swidden cycle encourage a much earlier reformation of the root-mat as the site fades into a fallow. An additional factor affecting leaching are the slower rates of leaf litter decay due to a higher lignin content observed in some secondary forest species in comparison to primary species [La Caro and Rudd, 1985; Singh, 1969]. Such a mechanism would bind nutrients for longer periods of time, perhaps avoiding additional marked losses of nutrients from secondary forest leaf litter [La Caro and Rudd, 1985].

Understory effects on throughfall can be substantial. Yarie [1980] reports that understory vegetation plays a much greater role than the overstory in reducing the amount of both P and N, and increasing the amount of K, Ca, and Mg reaching the ground in throughfall. In general the greater the total understory cover, the smaller the quantities of P and N and the larger the quantities of K, Ca, and Mg will be reaching the ground in throughfall. The absorption of scarce nutrients for plant use from precipitation and the leaching of others is a general phenomenon and has been widely reported [Herrera et al., 1978; Likens et al., 1977; Scott, 1978; Chapin and Kedrowski, 1983].

A reduced overstory may also increase the pH of throughfall, possibly resulting in less cation leaching in the soils of managed fallows. Johnson et

al. [1975] have shown that carbonic acid increases with CO₂ evolution as leaf litter decomposes, and that carbonic acid can be responsible for cation leaching in soils [also van Schaik and Miramoto, 1985]. The normally significant amount of leaf litter which is trapped and decomposes in the upper canopy [Stark, 1971] would be greatly decreased in the reduced overstory of managed fallows. This could result in less carbonic acid being picked up by precipitation, and a more alkaline throughfall and therefore less cation leaching in soils of managed fallows, soil pH generally being very similar to that of throughfall [Johnson et al., 1975].

Plant succession in managed fallows

As succession proceeds, micro-site heterogeneity brought about by management practices, continues to play an important role in the economic functioning of managed fallows. A managed fallow provides, through its patchy nature, an association of successional states which over time constitute a temporally and spatially changing mosaic of microhabitats. Such a mosaic would be suitable, at any given time, for occupation by a variety of valuable plants from distinct successional states – both planted and spontaneously occurring – to exist in managed fallows. Patches – open, closed and intermediate – are sites for micro-environmental variations in such parameters as: light, soil moisture, fertility, temperature [Posey, 1985], humidity [Denslow, 1980], and pH [Scott, 1978]. The effects of such variation on germination, seedling establishment, plant growth and succession is well documented [Brokaw, 1980; Lebron, 1979, 1980; Garwood, 1982; Augspurger, 1983, 1984; Vazquez-Yanes and Smith, 1982; Cheke et al., 1979; Guevera and Gomez-Pompa, 1972; Bell, 1970; Richards, 1952; Poore, 1968; Whitmore, 1975, 1978; Hartshorn, 1978; Bazzaz and Pickett, 1980; Kerr and Posey, 1984]. It is such heterogeneity which allows for the occurrence of the low shrub-like pineapple (*Ananas comosus*) in very close proximity to large umari (*Poraqueiba sericea*) and pijuayo (*Guilielma gasipaes*) trees as late as 30 years after the swidden cycle [Unruh, n.d.].

Variations in micro-environment within the managed fallow continue as valuable plants are maintained by slashing away the surrounding vegetation for as long as the plant produces a useful item. Many valuable species are planted together in the swidden stage, and this can result in whole zones of useful plants within the fallow, i.e., fruit and palm tree zones, and patches of peanut, pineapple and coca [Denevan and Padoch, n.d.]. The length of time that such a zone continues to produce can determine the length of time that the regrowth is held back (through cutting) and consequently the successional “distance” between the managed zone or patch, and the de-

veloping secondary vegetation. For example, in the Bora community of Brillo Nuevo in the Peruvian Amazon, a nine year old managed fallow was observed with a well tended, unshaded coca patch, while the regrowth in the same fallow was 10 to 15 meters high [Denevan and Padoch, n.d.]. When the coca patch no longer produces, it will no longer be weeded, and secondary plants from the more developed surrounding vegetation will invade and succession will begin to take place. But succession in the old coca patch may be quite different from that which occurred in other parts of the fallow, particularly with respect to species composition. In older managed fallows, clearings or gaps of variable size may be cut as valuable timber species – spared when cutting the forest – are removed, or when the old fruit trees are cut to make charcoal [Padoch et al., 1985]. Posey [1985] recognizes such microclimate variation as the principle mechanism for the economic productivity of forest ecotones created by the Kayapó in the Brazilian Amazon.

The multiformity of microhabitats in managed fallows may also have beneficial effects on soil nutrient recovery. Kellman [1969] notes for the Philippines that fallow stands of early and intermediate age (3–20 years) tend to be composed of quick growing softwood trees (*Omalanthus* spp, *Trema orientalis* and *Mallotus paniculatus*, but *Cecropia* spp. and *Vismia* spp. are the most conspicuous in many areas of the neotropics) which demonstrate a high leaf litter production (Table 3) [also Hart, 1980; Jordan, 1971; Gomez-Pompa and Vazquez-Yanes, 1974]. Analysis of this litter reveals that softwood tree stands cycle large amounts of nutrients, suggesting that the soil is enriched most rapidly during this phase of succession (Table 4). This is not to say that all nutrients recover to primary forest concentrations; in Kellman's study, recovery of soil nutrients under the softwood stand was variable. Soil C increased to levels approaching that of a primary forest, while N remained at consistently low levels even under old hardwood stands. Nevertheless if established in sufficient numbers these trees quickly bring about favorable soil conditions which improve little thereafter and may even deteriorate under succeeding stages unless the fallow period is extended for a very long time (well over 30 years) [Kellman, 1969]. Ewel [1971] and Bartholomew et al. [1953] mention similar situations in Panama and the Congo, respectively, as does Harcombe [1980] for several areas of the humid tropics. In most cases the time necessary for maximum soil improvement to be reached under softwood stands corresponded to the time when the trees mature, i.e., 5–10 years for the shorter lived species and approximately 15 years for the longer lived species [Kellman, 1969]. Kellman goes on to state that an optimum recovery time in a fallow would involve abundant establishment of softwoods at the time of abandonment, but because of repeated weedings which occur during the swidden cycle such

Table 3. Annual Litter Fall in Sampled Stands; Mindanao, Philippines. (Source: Kellman, 1969)

Stand*	Litter fall (leaves & twigs) (gm/m ² per year)
1	203
2	716
3	697
4	936
5	1253
6	1280
7	948
18	492
11	997
12	704
13	527

Table 4. Annual Nutrient Additions to the Soil Surface in Dead Above-Ground Plant Material (gm/m² per year); Mindanao, Philippines. (Source: Kellman, 1969)

Stand*	N	P	Ca	Mg	K	Na
1	2.83	0.24	1.19	0.62	0.39	0.14
2	8.88	0.63	7.95	1.95	3.72	0.37
3	13.94	1.00	9.62	2.31	2.86	0.39
4	13.66	1.09	21.15	2.55	4.77	0.48
5	17.29	0.90	13.78	2.34	3.13	0.54
6	22.97	2.02	16.77	2.15	3.33	0.94
7	16.66	1.08	9.38	1.98	3.03	0.58
18	11.81	0.74	9.00	2.07	3.20	0.16
11	17.05	1.08	12.76	3.24	3.29	0.53
12 [‡]	9.88	0.51	6.06	1.53	1.96	0.32
13 [‡]	10.54	0.67	8.49	1.08	1.77	0.11

[‡] Nutrient content of timber fall added to litter fall figures.

*Stands:

Herbaceous stand

1. Mixture of *Imperata cylindrica*, *Pteridium aquilinum*, *Paspalum conjugatum*, composites, etc., plus softwood seedling and tree fern sporelings.

Softwood tree stands:

3. *Omalanthus* cf. *surigaoense* predominant

4. Softwood tree canopy (*Omalanthus* cf. *surigaoense*) degenerating. Weedy herbs and *Hornstedtia* re-emerging.

5. *Mallotus paniculatus* predominant. Many forest saplings established.

6. Mixture of *Trema orientalis* and *Omalanthus* cf. *surigaoense*. Young *Cyathea* well established.

Hardwood tree stands:

12. Hardwood trees predominant. Indistinguishable from primary forest except for absence of large emergents.

13. Primary Forest.

Other stands:

2. Mixed weedy herbs being overtopped by softwood saplings.

7. *Hornstedtia* thicket; scattered *Cyathea* and softwood trees.

11. Mixture of softwood trees (*Mallotus paniculatus*, *Trema orientalis*) and hardwood forest trees.

18. Young *Musa* being overtopped by softwood saplings.

an ideal fallow most likely is not obtainable. However, the early establishment of woody plants in the diverse microhabitats of a 'prepared' old swidden about to become a managed fallow, might approach Kellman's notion of an ideal fallow.

In addition, the maturation time of softwood trees as a stand, may be less abrupt and more staggered in managed fallows; due to the presence of open

areas, and the continuous and copious production of seeds in many secondary species [Gomez-Pompa and Vazquez-Yanes, 1974, Young et al., n.d.]. In an investigation into the seed dynamics of unmanipulated tropical successions, Young et al. (n.d.) observe that although there is high production of seeds in early successional vegetation, abundant regeneration of such species did not occur – germination being low under the dense secondary regrowth. Instead, the seeds were dispersed, died or were incorporated into the soil seed bank; from which they might stand some chance of germination later. The same study noted that after a soil-seed density peak of four to seven years after a burn, the size of the seed bank declines due to the loss of viability of some seeds and domination by species which produce fewer seeds. However in managed fallows the changing patchwork of open areas might allow for a more continual germination of these early successional tree species by taking advantage of high soil-seed densities before they are lost. Even in older fallows where trees which produce fewer seeds predominate, patchiness due to management would still allow regeneration of fast growing early successional species, the seed rain in such gaps being significantly higher than in intact tropical forests [Young et al., n.d.]. This would be similar to Richards' (1964) 'telescoped' secondary succession in 'depleted forest', where selective felling in primary forests produces many gaps which are temporarily colonized by the same fast growing, easily dispersed species which dominate early secondary forest. Such a situation could actually lengthen the time in which the high nutrient cycling early successional species are still maturing in the managed fallow. This might result in a more pronounced soil recovery than observed in unmanaged fallows, but experimentation is needed.

Cyclic increasing abundance of valuable plants in managed fallows

One of the more interesting hypothetical aspects of long-term fallow management is the increase in abundance of valuable species in successive fallow cycles. By protecting both the spontaneously appearing and planted economic species during fallow succession, growth of these plants is spurred and a greater economic production realized [Denevan and Padoch, n.d.; Posey, 1985]. Seed production from such plants may become enhanced both through greater seasonal seed production (due to lack of competition for light and nutrients from other secondary plants) and the number of times the protected plant goes to seed due to its longer life in the managed fallow. The seedbank of the managed fallow then would comprise a greater

number of seeds from protected plants than what would occur naturally. When the site goes to fallow after the next swidden cycle, the total number of spontaneously appearing valuable species might also be greater than what would occur naturally, especially considering the nature of the ecological consequences resulting from management practices in the swidden cycle. Management of this greater number of valuable plants in the subsequent fallow cycle may then further the process.

On a regional scale, additional ecologic processes may contribute to the long-term increase of valuable plants in managed fallows. Seed from managed fallows surrounding an aging swidden may be a significant post-burn input, as are the seeds of more distant valuable trees which are dispersed by the wind, birds, and bats [Uhl, 1983]. In fact animal dispersal of seeds is a primary factor in the reproduction and establishment of plant species through succession in the tropics [Vazquez-Yanes et al., 1975]; the diversity of secondary forests in part being dependent on animals [Young et al., n.d.]. Frugivorous bats alone play a significant role in dispersing a wide variety of fruit species [Vazquez-Yanes et al., 1975; Palmeirim and Etheridge, 1985]. Uhl, et al. [1981; and Uhl, 1983; Uhl et al., in press] in noting the clumped nature of seeds in some successional woody species suggest that bats and birds transporting such seeds do not roost indiscriminately but have roosting preferences. And Palmeirim and Etheridge [1985] observe (for bats) that such preferences are often in the vicinity of existing fruit trees, which attract many species of frugivores [Denslow, 1980]. In addition, bats have been observed using man-made trails – especially common in areas of swidden agriculture – in their nightly movements. This use exposes nearby fruit trees to a larger number of bats than fruit trees far away from trails. Such observations, along with mist netting and studies of fruit removal by bats, suggest that bat generated ‘seed shadows’ of fruit trees exist along trails used as flyways [Palmeirim and Etheridge, 1985; Janzen et al., 1976]. Thus one might imagine that with a greater than natural abundance of fruit trees in an area due to fallow management, further enrichment of local secondary forests with fruit trees may occur via the foraging and seed dispersal activities of bats and other frugivores. The incorporation of this aspect of fallow management into local ecological process, may increase the value of this form of agroforestry over time, and decrease the labor requirement.

Summary

Development of the techniques of swidden-fallow management into a workable agroforestry system necessitates consideration of the ecologic relation-

ships between the productive managed fallow and the productive swidden. The fallow period serves to reduce problems of soil impoverishment, diseases and weeds. Utilization of the fallow cycle ideally should either enhance or maintain the natural ability of the fallow to overcome these agricultural problems.

Not only does fallow management appear to fit exceptionally well into the fallow cycle of swidden agriculture, but may actually serve to speed soil nutrient recovery and inhibit the spread of exotic weeds and grasses, in addition to providing a cyclically increasing abundance of valuable fallow plants. Heterogeneity of field micro-environment, beginning when a site is initially cleared and lasting throughout the fallow period, appears to be of utmost importance in realizing these aspects of swidden-fallow management.

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