Weed Infestation and Soil Erosion Resulting from The Breakdown of The Slash and Burn Cultivation System

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INTRODUCTION

Slash and burn was the elementary and pioneering cropping system used by the early agricultural occupants of many forested areas all over the world. It still is one of the most widespread types of cropping system in the hilly areas of Asia. Upland rice is the major crop, but some other crops like maize, opium and cassava are also cultivated. In Thailand, slash and burn system is restricted to the North and covers approximately 5 million hectares where about 1 million people live (Bass and Morrison, 1994). The rate of deforestation in the 1980s to 1990s was estimated at an annual rate of 3.3 % (Rerkasem and Rerkasem, 1994). Upland rice is normally followed by maize and opium. In Vietnam, slash and burn is practised in about 3.5 million hectares with a rate of deforestation estimated over the same period at about 1.5 % per annum (Do Dinh Sam, 1994). Maize and cassava are the other crops in addition to upland rice. Schiller (1996) estimated that in Laos, 179,000 hectares under upland rice cultivation use slash and burn techniques. This corresponds to 31% of the total area under rice and does not include the area planted to maize, the second major crop. The rate of deforestation was 4.1% per annum (Bass and Morrison, 1994).

The importance of the slash and burn cultivation system lies less on the productivity of the system than in the total area it covers. Slash and burn can be a subsistence economy practised by those who have almost no opportunity to trade or sell their produce. But it is also a system followed by crop growers whose sole aim is to produce a crop for sale to a distant market. Slash and burn system is used by the seekers of quick profits, unmindful of destruction, waste or problems it creates for the future. It is also practised by careful occupants who think of the long-term good of the land.

It is recognized that when local populations possess adequate land areas for cultivation, their shift cycles are usually ecologically sound and not destructive. However, slash and burn may become destructive when local populations become too crowded, or when commercial aims strongly enter into practice. And the breakdown of the slash and burn cultivation system causes problems of weed infestation and soil erosion.

As a strategic research support to the MSEC programme in Laos, Thailand and Vietnam, the Institute of Research for Development (IRD) has started studies on erosion and land use change. It is argued that increasing weed infestation is one of the driving forces of the land use change and not much as a symptom of the breakdown of the slash and burn system. Thus, in relation to erosion, the breakdown of the system needs investigation under specific, yet widespread and often typical conditions of a colder climate, longer dry season, mixed cropping systems, and intensive use of herbicides.in the target countries.

This paper presents a short review of the slash and burn cultivation system, its advantages, the problems that occur when the system breaks down, and its relation with changes in land use. It also discusses a number of measures to control weeds. Discussion is limited to relevant results in tropical areas with more than 1500 mm of annual rainfall and practising low-input food cropping system.

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VARIANTS OF THE SLASH AND BURN SYSTEM

Extensive studies (Conklin, 1957; Geertz, 1963; Spencer, 1966; Kunstadter, 1978) have described main types and variants of the slash and burn cultivation system. In the traditional and simple system of slash and burn, farmers moved from one field to another annually. As a rule, they employ incomplete clearing and weeding operations such that they probably have not contributed markedly to soil erosion. However, when the farmers could no longer maintain these traditional practices at full scale, soil erosion results. When the rotational cycles of land use are shortened, forest-like vegetative re-growth becomes scanty, recurrent burning is used to control excessive weed growth, and soil erosion becomes serious. The situation gets worse if hand pulling becomes ineffective in clearing the ground and the topsoil has to be cultivated with some kind of implement. In addition to completely exposing the ground, the use of implements affects the soil aggregates, and both actions favour soil loss. Soil erosion thus becomes one of the several manifestations that the whole system is in serious danger of breaking down (Spencer, 1966; Roder *et al.*, 1997; Roder *et al.*, 1998).

Slashing and burning followed by fallow were once strategies for soil fertility maintenance and weed and disease control. Increasing weed infestation, however, was thought of being the primary factor leading to shifting cultivation (Nye and Greenland, 1960; Moody, 1975; Arnason *et al.*, 1982; Roder et al., 1997). The fallow period functions as a weed break when overhead shade is formed suppressing the arable weeds present, and preventing new ones to invade. A study of weeds in shifting cultivation must consider both the cropping phase when arable weeds grow and produce seeds on the site, and the fallow phase when weeds diminish or even disappear from the vegetation and from the seed bank.

Shifting cultivators use shade as a tool against the general build up of infestation because weeds are highly heliophyl. They create shade at the appropriate moment and maintain it as long as necessary. Still, overhead shade can only be employed at the end of the cropping cycle because almost all food crops are strongly light demanding. Though shade can be produced by cover crops that develop after the main crop, or by the growth of planted fallow trees in agroforestry systems, most often, it is the re-growth of the natural vegetation that checks the weeds (Spencer, 1966; Ahn, 1979; Alexandre, 1989). The shading out of weeds is cheap and effective, yet demands relatively much land. (Moody, 1975). Though the role of shade as a weed-break is at least as important as soil restoration, the conservation and restoration of soil under fallowed land have received much more attention. Yet the worldwide trend of shortening fallow periods and the degradation of forest-structured fallow vegetation into thickets and grassy shrub lands, usually under the pressure of land shortage, brings on explosive development of weeds. Where the weed-break no longer functions effectively, farmers are often forced to change the cropping system. Rainfed rice cultivation for example, being very sensitive to weeds, is abandoned in many parts of Africa, and maize and cassava became the staple crop instead (Sankaran and de Datta, 1985; Fresco, 1986; Garrity et al., 1992).

WEED INFESTATION AND LAND USE CHANGE

As mentioned earlier, the increasing weed infestation could be a driving force of the change in land use. This argument is based on the fact that: 1) each farming system produces its typical weed population being the result of cultivation practices, local climate and soil conditions, and 2) continuous or excessive use of the same management practise brings on a selection within the pool of weeds toward even more troublesome species.

Four stages in land use related to weed infestation are identified. In Stage 1, burning and hand pulling are sufficient to control weeds. This is shown in systems with long forested fallows and short cultivation periods. The tall and leafy traditional rice varieties, with their dense ground cover, prevent the invasion of more aggressive weeds. With frequent land clearing, the green cover is reduced and this enables the arable weeds to infest the field. Stage 2 is characterized by systems with short fallows and the forest cover is replaced by the bush fallow of *Chromolaena odorata*. As long as stumps of *C. odorata*, with their re-sprouting capacity left intact, are maintained in the system, excessive weed growth notably the grassy species is checked by the rapid vegetative cover formed after the harvest. Rice cropping remains possible as long as grasses are suppressed. With repeated burning and weeding, the *C. odorata* stumps are killed and grasses invade. A selection takes place toward very short cycle weeds which are able to complete their life cycle between weeding rounds. Weeds are now predominated by *Mimosa* species (Stage 3). Hand pulling and fire are no longer effective to suppress weeds. Tillage successfully eliminates seedlings but vegetative propagation is stimulated because buried stolons, rhizomes, and runners form new plants each time they are cut. Grassy herbs with morphology of *Imperata* become dominant (Stage 4).

Observations in the Huay Pano catchment in April 1999 shortly after burning, showed all four stages in a sequence that ran with the slope. Old forest had been cut and burned on the crest presenting a perfect seedbed and excellent soil structure (Stage 1). *C. odorata* stumps were present on the upper slope, already re-sprouting (Stage 2). At the lower slope, they have been replaced by *Mimosa seedlings* (Stage 3). At the flattest part of the lower slope, *Imperata* grasses sprouting from buried vegetative reserves were dominant (Stage 4).

FACTORS CONTRIBUTING TO WEED CONTROL

Weeds that grow on a piece of land are adapted to the local conditions. If these local conditions change, like another crop is cultivated, or the soil is flooded or tilled, or fertilisers are applied, then the weed population changes too. Normally, each crop – soil – climate combination has a typical weed species group. One widespread tactic in suppressing weeds is to quickly change the favourable growth conditions for weeds to develop and become a threat to production. Crop rotation, flooding, tillage, cover cropping, and fallowing are techniques against the build up of troublesome weed populations. In the past, typical weed populations have been described for most European cropping systems. However, these originally varied populations have evolved into often quasi monospecific stands under the treatment of advanced techniques, monoculture and high inputs. In modern agriculture, more effort goes into the control of weeds. In tropical regions, both the flora and cultivation practices are far more varied. This offers a variety of possibilities of control and a challenge to do more study on agroecology to get a clear view of the often complex situations.

Burning

The agricultural use of a forest soil requires the removal of the forest and substitution by crop plants. In most cases, burning is the only means of clearing away the vegetation, but it also helps improve certain soil properties. Burning liberates large quantities of mineral nutrients to the soil and leads to an accumulation of all kinds of minerals, but phosphorus and potash (Brinkmann and Nascimento, 1973; Andriesse and Schelhaas, 1987). These valuable phosphates are released at just the right time.

Burning produces a marked decrease in acidity which stimulates further release of cations, which is especially important in the very old lateritic soils. In the acid forest soils of southwestern Ivory Coast, rice can not be grown without increasing the pH through burning (de Rouw, 1994). Crops are then planted which grow while the decomposition of the forest residues continues. With most of the nutrients present in the ash accumulated over many years, it is not surprising that the first crop after burning is good. In Northern Thailand (Sabhasri, 1978), in Brazil (Sanchez et al., 1982; Salati and Vose, 1984) and in Côte d'Ivoire (De Rouw, 1991), the first harvest was almost entirely dependent on minerals derived from the ash. After the area has been cropped for some time, the release from the organic residues further slows down and crops suffer. Liberated nutrients are used up, removed with the harvest, fixed by colloids or are lost by leaching (Harcombe, 1980). The supplying capacity of most forest soils is not sufficiently large to continue cropping and fields are abandoned to revert to forest. Secondary forest species can apparently absorb nutrients at lower ranges of availability than crops (Ahn, 1979).

On the other hand, burning is disadvantageous because of the destruction of humus. Valuable micro-fauna and micro-flora are destroyed, and organic matter is oxidised. (Dommergues 1952; Nye and Greenland, 1960; Maggi et al., 1990). With burning, there is loss of nitrogen and sulphur due to volatilisation and instant mineralization of organic matter. Loss of soil organic matter affects aggregate stability and this increases erosion hazards.

Burning makes the soil surface soft and friable that is ideal for the planting of crops. It kills weed seeds, or prevents them from germination. De Rouw and van Oers, (1988) demonstrated experimentally on-farm that the stock of viable seeds in the soil dropped from about 2000 m^{-2} before burning to 1000 m^{-2} after one overall burn. A similar experiment in Costa Rica demonstrated the disappearance through burning of 52 per cent of the seed stock which was initially estimated at 8000 seeds m^{-2} (Ewel et al., 1981). Saxena and Ramakrishnan (1984) found equally significant weed seed reduction after burning of a 20 year old forest in India. Seeds to a depth of 5 cm could be killed by fire (Brinkmann and Vieira, 1971).

Fire is a well-known means to control this source of weed infestation. After felling, many stumps and roots produce coppice shoots. Certain rain forest species may re-sprout after an initial burn, but successive fires eliminate most, if not all of them (Smitinand et al., 1978; Whitmore 1983; Uhl, 1987). The unburned or slightly burned areas serve a vital function in forest regrowth because here, re-sprouting stumps abound (De Rouw, 1993). The re-sprouting plants grow out rapidly, protect the soil against erosion and check weed growth (Vine, 1954; Delvaux, 1958; Rappaport, 1971; Zinke et al., 1978). Slash and burn farmers, who still practice long fallow periods, usually apply one quick overall burning. The intensity of the burning kills a sufficient number of weed seeds, but allows at the same time the survival of many re-sprouting forest stumps. With the shortening of fallow periods, the slashed material is also less and the fire less intense. To compensate the fact that less weed seeds have been killed after the first burn, farmers pile the unburned materials and burn a second or third time. This practice may reduce weeds but has a negative effect on the re-sprouting ability of stumps, thus compromising the regenerating ability of the vegetation. In all rain forest areas, re-sprouting plants are mostly woody (Stocker, 1981; Adedeji, 1984; Uhl, 1987). The danger of eliminating the re-sprouting plants by recurrent fires and enhancing the establishment of a thicket vegetation or a grass land instead of a forested fallow has been demonstrated in many regions (Hopkins, 1962; Richards, 1964; Ramakrishnan and Toky, 1981; Whitmore, 1982).

Not all biomass is burned, at least root systems stay unconsumed. Traditionally, a variable number of tall trees are left standing up to the equivalent of slashed material. (de Rouw, 1987). In short, the most detrimental effects accrue where burning is frequent. Here significant changes in the floristic composition of the weeds and the structure of the fallow vegetation occur. Recurrent burning results in slower growing species, that are more xerophytic and pyrophylous and more tolerant to high light conditions. If burning is excessive, a degenerate savannah flora will ultimately replace a forest fallow.

Tillage

Soils that have been under ground-covering forest are normally loose and permeable when first cleared and planting can be done without tillage or cultivation. Such soils have been protected from undue oxidation, from baking hard through drying out in full sun exposure, and from direct compaction by heavy rains. Working the ground or any form of tillage is not needed. Another very important consequence of not disturbing the soil other than making planting holes is that many weed seeds stay dormant. However, under normal conditions, shifting cultivators tend to disturb his soil even as little as possible (Nye and Greenland, 1960). Exposure to sun and rain rapidly tends to compact such soils making them hard and dense, and in a few years the soil surface becomes difficult to plant crops with simple hand tools (Nye and Greenland, 1960). Weeds can grow so numerously that burning and hand pulling are no longer effective. Working the ground with a hand hoe becomes necessary. This will disturb soil particles, bare completely the soil surface, and contribute to erosion.

Mixed cropping

Most fields are cultivated in mixed cropping, with a variety of crops, vegetables, herbs, spices, and medicinal plants grown in an often well defined pattern to maximize use of water, nutrients and light. The obvious reason for this is that farmers need a variety of products. Mixed cropping (including relay-cropping) maintains the soil cover more completely and for a longer period. The soil surface becomes better protected against the violent action of rains and under these shady conditions, less weeds get a chance to invade. However, agronomic research has neglected mixed cropping for various reasons. Firstly, the often complex growing patterns are difficult to study experimentally. Secondly, the cropping systems are well suited to the local conditions and are difficult to improve. Improvement would come from the introduction of high-yielding varieties and mechanisation; however, both innovations are often incompatible with mixed cropping. Besides, mechanisation on steep hill slopes is impracticable or undesirable. Mixed cropping on steep slopes could be most advantageous as a soil conservation technique.

Land races

Land races of rice varieties have the advantage of being well adapted to the local soil and climatic conditions. They will usually produce an economic yield under low input management, in contrast to the modern varieties. The land races of Africa and Asia are tall, often over 150 cm, and have broad droopy leaves, both characteristics allowing them to dominate weeds. These varieties also can tolerate fairly well the presence of other crops in mixed cropping systems and are capable of competing with a low level of weed infestation early in the season, by compensating the negative effects of competition later in the development cycle. Modern varieties, on the other hand, are shorter, less than 100 cm, and leaves grow upright thus allowing more light penetration. These traits makes modern or improved varieties less competitive to weeds (de Rouw, 1991). Any competition with weeds or secondary crops during the growing season results in yield loss.

Fallowing

The forest fallow performs many functions. During this period, nutrients are stocked in the secondary forest vegetation and through litter fall in the topsoil. Thus, the leaching of nutrients is prevented or slowed down. Many trees and lianas are deeply rooted which enable them to bring up extra nutrients from the subsoil and return them to the topsoil through litter fall. Increase in above ground biomass also implies increase in soil organic matter. As the soil is permanently covered by leaves, the soil temperature drops and oxidation of soil organic matter is slowed down. Soil structure is improved both by the formation of stable aggregates and by the rich soil fauna that work the soil continuously. However, if one asks the farmers, they will respond that the chief function of the fallow concerns weeds. A rapid forest cover chokes the arable weeds present, prevents new weeds to invade, and interrupts the re-seeding of the field.

In a forest soil, dormant seeds of many plants have accumulated through time. The importance of this seed bank as a factor in weed infestation after clearing has been recognised by many authors. (Uhl et al., 1981; Putz and Appanam, 1987; Alexandre, 1989; Garwood, 1989). But farmers do not only care about the weeds after clearing, they are also concerned about the re-use of the land. In other words, they also want fewer weeds in the following cropping cycles. In order to continue the correct functioning of the slash and burn cultivation system on the same plot, farmers should also give attention to the seeds of the secondary forest plants. These sufficiently numerous seedlings will compete with the arable weeds that have developed with the rice crop. If forest plants grow up simultaneously with weeds, they will drive out the weeds. Without the seeds of tree species in the seed bank, arable weeds will continue to occupy the site and produce endless crop of seeds. This pollution of weed seeds in the soil, together with the rate at which forest plants invade an infested plot, will determine the re-use of the land for rice cropping.

Figure 1 shows the relation between the viable seed stock in the soil under fallow and the duration of the fallow. It also indicates the proportion of the weedy herbs to forest plants. Weedy herbs are much more difficult to eliminate from the cropped land. The seed bank of a one-year old fallow does not contain seeds of forest plants because in the fallow vegetation, the forest plants have not reached maturity yet and no seeds have been deposited in the soil. After about 2 years of fallow, the quantity of weed seeds in the soil no longer increases because weeds are eliminated from the fallow by its shade. During subsequent years of undisturbed growth of the fallow vegetation, weed seeds in the seed bank diminish while the seeds of forest plants accumulate in the soil. After clearing a 21-year old fallow, an average of 60 plants m^{-2} germinate in the field and the majority are secondary forest species. If a 6-year old fallow is cut and burned, a mean of 160 plants m^{-2} appear in the field, principally weedy herbs. After a 1-year fallow period, 900 plants, all of them weeds, germinate in the field.

The quantity of weedy herb seeds in the soil determines weed infestation for this cultivation period. The quantity of forest tree seeds determines the quality of the fallow vegetation and the weed infestation in future cycles. In fact, it determines the re-use of the land. If not enough trees are present at the end of the cultivation period, then weeds can continue occupying the land and subsequent cultivation will be exceedingly difficult (de Rouw, 1995)

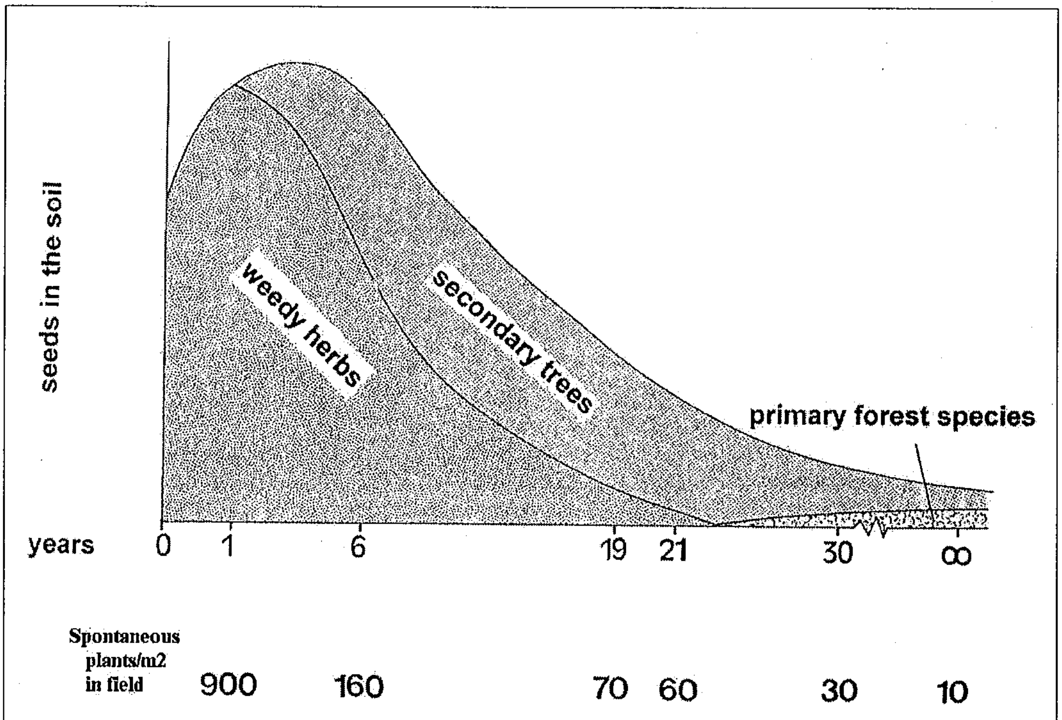

Figure 1. Relationship between the stock of viable seeds in the soil and the duration of the fallow period and the proportion of weedy herbs and of forest plants in the seed bank. Also indicated is the number of spontaneous plants m^{-2} germinating from the seed bank after slashing and burning a fallow vegetation of a particular duration. Numbers indicated are averages of all non-crop plants appearing in a field during the six months of upland rice cultivation (wet forest zone, Ivory Coast).

Presence of *Chromolaena odorata*

In many humid regions in the tropics, traditional shifting cultivation with forest fallows can no longer provide enough food for the increasing population. Moreover, further extension threatens the remaining tropical forests. Farmers extend cropping periods and shorten fallow periods but they keep relying on the natural fallow to maintain the chemical and physical soil properties and to reduce weed growth at the start of the subsequent cropping. In some parts of Africa and Asia, farmers no longer allow the forest vegetation to re-establish. They already clear the field after a few years of fallow, when the vegetation mainly consists of the shrub, *C. odorata* (Dove, 1986; de Foresta and Schwartz, 1991; Roder *et al.*, 1995; Slaats *et al.*, 1996). Because of its enormous seed production and rapid growth, *C. odorata* is a predominant coloniser of open spaces (Gautier, 1993). *C. odorata* is a suitable fallow species because of its rapid establishment of soil cover, its ability to suppress herbaceous species and to accumulate as much nutrients as other fallow species during the initial period (de Rouw, 1991; Slaats et al, 1996).

The dominant position of *C. odorata* leads to the suppression of the undergrowth of herbs and grasses during the first two years of the fallow period. Extending this period reduces the development of herbs in the regrowth after clearing, indicating the exhaustion of the seed bank. Probably, seeds in the soil gradually loose viability because of the shade of the dense and leafy *C. odorata* canopy. Hence, a fallow period of at least three years is desired to facilitate weed control in crop production on land cleared from *C. odorata* (Slaats et al., 1996). Another property of *C. odorata* which makes it a good fallow plant is the ease of its elimination by hand weeding (Roder and Maniphone, 1998). As more and more *C. odorata* dominated fallow is used for food production, various aspects of a semi-permanent cropping system for the humid tropics need to be examined with regard to productivity and sustainability.

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