Principles of Direct Seeding Mulch-Based Cropping Systems – A Holistic Research Approach Implemented in Laos

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Abstract

This paper gives an overview of the holistic research approach implemented by NAFRI and CIRAD and the principles of direct seeding mulch-based cropping (DMC) systems. Conventional agriculture and intensification of shifting cultivation are now being questioned, as they seem unable to face the main challenges of food safety, soil and water conservation, environmental protection and cost reduction. A holistic approach has been developed and managed by farmers, researchers and extension agents, whose aim is to propose agro-ecological systems that are compatible with farmers' strategies and conditions and which can be reproduced inexpensively on a large scale. Agro-ecology is the understanding of dynamics and functions of agro-ecosystems, including all physical, economical and human environments. Direct seeding mulch-based cropping (DMC) systems, replicating functions of forest ecosystem, are one of the components of agro-ecology strategy. The main principle of these systems is that the soil is no longer disturbed by mechanical action, and is always kept covered by former crop residues and dead or living mulch. These systems can be based on annual and perennial crops integrated with one or two cereal or forage crops per year, which may be associated with livestock production. Systems of no tillage and proper use of cover crop stop soil erosion and increase organic matter. Deep rooting cover crop systems improve physical soil structure, increase below-ground insects and microbial communities and recycle nutrients leached deep in the soil. If the quantity and quality of mulch are sufficient, weeds are controlled and water availability for crops increases. This leads to environmentally friendly and technologically and economically efficient agriculture.

Introduction

Poverty alleviation is strongly dependent on soil and natural resource access and preservation. Maintaining productive capacity of the soil is a crucial element for long-term improvement of smallholder conditions. Shifting cultivation is one of the best examples of farmer ecological strategy: with a mosaic of sites under fallow and some in cropping, soil potential is maintained and biodiversity (source of gathering and hunting, medicinal plants, firewood) is optimised by smallholders (Roder 1995; Altieri 2002). However, intensification of shifting cultivation, with longer periods of cropping and more frequent return to a given field, is now being questioned as it seems unable to face the main challenges of food safety, soil and water conservation and environmental protection (Hansen and Sodarak 1996; Roder 1997a). In many countries, including the Lao PDR, the rationale of slash-and-burn collapses under changes in social conditions (increasing population density) and modification of land access. During the past few decades, many approaches and alternatives, based on bench terracing, reforestation and alley-cropping, have been tested and scaled-up for the uplands without achieving the expected results (Fujisaka 1991; Roder, 1997b). This paper gives an overview of the holistic research approach implemented by NAFRI and CIRAD and the principles of direct seeding mulch-based cropping (DMC) systems.

Principles of agro-ecology and direct seeding mulch-based cropping systems

Many authors emphasise that in creating new technologies, deep knowledge of agro-ecological conditions should take precedence over permanent transfer of technologies (Fujisaka 1991; Roder 2001).

The technologies that should be promoted are those which focus on agro-ecosystem processes such as organic matter accumulation, water resource, soil biological activity, resource preservation and general enhancement of agro-biodiversity and synergisms between components (Altieri 2002). In many countries, and specifically in Latin America, smallholders and different stakeholders (researchers, extension workers and the private sector) develop alternative systems based on green manure, mulching and use of cover crops to preserve soil potential, stability of the plant-soil system, and farmer livelihoods (Flores 1989; da Silva 1999; Richter *et al.* 2002).

Altieri (2002) and Dalgaard *et al.* (2003) define agro-ecology as a holistic study that focuses on the form, dynamics and functions of agro-ecosystems, including all physical, economical and human environments. Direct seeding mulch-based cropping systems are considered as one component of agro-ecology strategy. To be efficient, DMC systems should mimic the functioning of ecosystem forestry (Séguy *et al.* 1998; Ewel 1999, cited by Altieri 2002): a natural ecosystem is sustainable as soil is continuously created and permanently protected. Stability and resilience of plant-soil systems create the conditions that allow the systems to persist (Gobat *et al.* 1998). Plants provide energy that fuels the biological processes and either directly or indirectly create the structure within soils. For example, a large amount of photosynthate is allocated to roots and much of that photosynthate is diverted to mycorrhizal symbionts or exuded into the surrounding rhizosphere. Eliminating energy inputs may significantly affect the physical as well as the biotic structure of soils (Perry *et al.* 1989). Corman *et al.* (1987) reported that populations of mycorrhizal fungi and *Rhizobium* sp. drop rapidly in the absence of living roots. Mycorrhizal fungi produce extracellular polysaccharides that glue mineral particles together into water-stable aggregates (Lynch and Bragg 1985; Gobat *el al.* 1998). The basis of DMC is to maintain an equilibrium system of plant and soil where the diversity in plants (crops and cover crops), insects and microbial communities stabilise the system during environmental fluctuations.

A description of the principles of DMC systems is given in recent articles by Séguy *et al.* (2003) and Scopel *et al.* (2003):

- **Soil is no longer disturbed**, or as little as possible, **by mechanical action** and **is always kept covered by crop residues and the cover crop**. By stopping mechanical action, soil sensitivity to erosion decreases because of soil cohesion improvement. Recent works by de Rouw *et al.* (2004) showed that conventional weeding could contribute significantly to soil erosion in the uplands whereas a layer

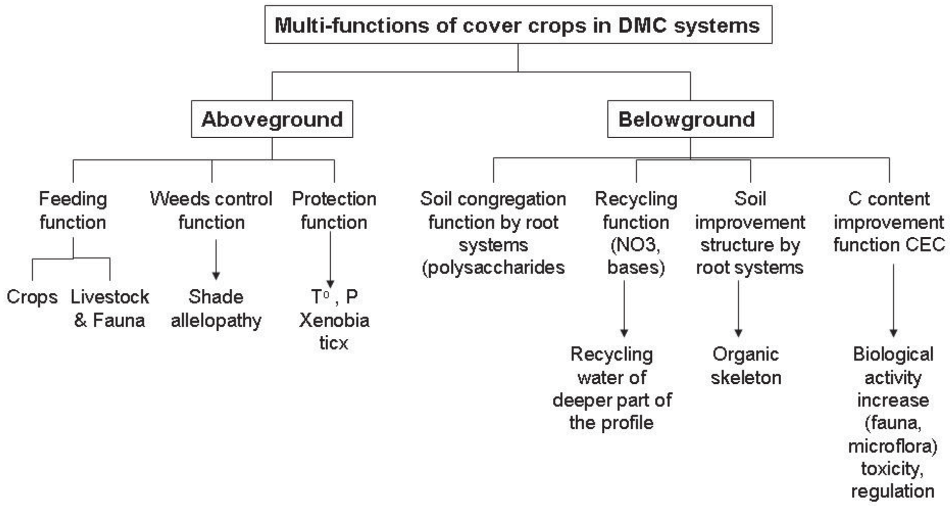

Figure 1 (from Scopel *et al.* 2003)

of mulch on the soil can control soil erosion caused by rainfall runoff, decrease soil temperature fluctuations and enhance macro- and micro-fauna activity (Boyer *et al.* 2001; Scopel and Findeling 2001).

- **Spatial and temporal diversified schemes** (rotations, association, annual crop sequence) are provided in order to increase farming incomes by reducing cost production and climatic risks (S�guy *et al.* 1998; Richter et al., 2002).
- In order to **maintain soil-plant stability and resilience**, cover crops are used to produce grains and dry matter (soil protection and rational use of fodder to feed cattle) when available resources are too limited for main crops (S�guy *et al.* 1998).
- **Cover crops enhance the efficiency of the whole system** fulfilling many agronomic and ecological functions. S�guy *et al.* (2003) emphasise the multi-functionality of cover crops, which are considered as nutrient-pumps.

Above-ground biophysical and chemical functions:

- Permanent protection against erosion by rainfall runoff.
- Increasing water availability (Abrecht and Bristow 1990; Scopel *et al.* 1999) and water use efficiency (Fischer *et al.* 2002).
- Decreasing soil temperature variations (Thiagalingma *et al.* 1996).
- Integrated management of pests (equilibrium between populations) and weeds through shade and/or allelopathic effects (Florentin *et al.* 1991; S�guy *et al.* 1999; Chiapusio *et al.* 2002).
- Nutritional function for the main crop via mulch mineralization.
- Trapping herbicide on mulch cover (Jansen 1999).

Above-ground systems integration:

- Nutritional function for livestock by rational use of fodder (S�guy *et al.* 1998).

Below-ground:

- Adding crop residues to the soil and root system of the cover crop, helping to avoid soil compaction.
- Replacing mechanical actions by biological improvement of the soil structure through the strong root systems of cover crops.
- Increasing organic skeleton to maintain and restructure the soil through the rooting systems and biological activity (Séguy *et al.* 2001). One of the main functions of cover crops is to enhance below-ground insect and microbial activity, which improve soil structure and plant nutrition (Boyer *et al.* 1998; Chabanne *et al.* 2001).
- Integrated management of macro-fauna and micro-flora communities (Michellon 1996; Boyer *et al.* 1998),
- Tapping deep ground water and recycling nutrients leached deep in the soil below soil layers used by cash crops or rice, through deep rooted cover crop systems (Séguy *et al.* 2001).
- Quicker recycling process, linked to biological activity increase and reduced pesticide pollution (Crovetto 1999).

It is estimated that 72 million hectares of DMC are cultivated throughout the world and that 47.5 % of this area is located in Latin America, 36.7% in the United States and Canada, 12.5 % in Australia, and only 3.3% in the rest of the world (Derpsch and Benites 2003). In the south of Brazil, smallholders have tested and adapted these systems since 1972. However, Latin America, and specifically southern Brazil, is an exception. Elsewhere in the world it is hard to find smallholders conducting DMC systems on a large scale. Soil conservation technologies in Brazil have received support from different agronomic institutes that have implemented many technologies (e.g. cover crops, mechanisation) and have obtained wide success in adapting DMC systems with smallholders. Involvement of different stakeholders (farmers, researchers, extension workers and the private sector) has been a crucial element in extending these systems (da Silva 1999; Richter *et al.* 2002). Organisation by group helps farmers to exchange experiences, to overcome technical constraints (technical skills requirement, calendar labour requirement, weeds and pests management) and to define adequate socio-economic conditions for adoption (access to credit; collective management on landscape unit of grazing areas, erosion and wild-fires).

Methodological framework

The Lao national agro-ecology programme follows a holistic research approach based on knowledge of local farming systems, including all agricultural aspects and socio-economic factors, and technology generation focused on soil conservation. This approach is composed of five interdependent components in order to create, adapt and validate technologies with and by smallholders (Séguy *et al.* 1998):

- Agro and socio-economic diagnosis of the region and farming systems, conducted during the first season (environmental and socio-economic analysis).

- Setting-up short (one season) and long-term (at least four seasons) experimental units on different topics (cultivars comparison, cropping systems, livestock, perennial crops, non timber products etc.).
- Adaptation and validation by smallholders:
  - on-farm experiments;
  - landscape and village levels.
- Permanent training for farmers and extension agents and information provision to policy makers.
- Follow-up and analysis of the conditions of extension and adoption by farmers. Evaluation of farming systems and the environmental, social and economic aspects of the sub-region and region.

The experiences of the national agro-ecology programme in southern Xayabury and Xiengkhuang provinces are related below.

Agro and socio-economic diagnosis

Knowledge of farming systems is key to rational generation of technologies (Fujisaka 1991). Our research priorities are based on agricultural aspects, socio-economic needs and the environmental conditions of farmers. Initial assessment of the situation has been carried out at different levels in order to integrate all aspects of smallholders' strategies and environmental conditions. The first and second steps are based on data collection (province, district, extension services, village) and environmental diversity observations: agricultural and demographic evolution, topography, landscape and nature of soils, meteorological data, land allocation maps, land use diversity and village accessibility. Headmen and village councils are interviewed in each village to assess community practices and recent changes related to land tenure and agricultural aspects. Information on market channels is obtained through interviews with agriculture officers, traders and village headmen. The third step records knowledge of farming systems in order to identify the advantages and constraints of present systems and to evaluate new technologies at farm level. Quantitative and qualitative household surveys are carried out on targeted farmer groups, as identified with project partners (agriculture officers, village council), in order to acquire information on household conditions and farming systems. These surveys were carried out in Kenethao, Parklai and Botene districts in Xayabury (four, two and two villages respectively) and in Nonghed, Pek and Kham districts in Xiengkhuang (seven, seven and eight villages respectively) during 2003. A total of thirty-one and seventy-four households were surveyed in Xayabury and Xiengkhuang respectively. The following agricultural aspects and socio-economic factors were recorded:

- Description of farming systems (cropping and livestock production, calendars, skills, labour requirements, division of labour, production cost, yield and labour productivity per crop or livestock unit, net income, self-sufficiency, fallow management practices).
- Use of natural resources (non-timber forest products).
- Non-farming activities and interactions with farming activities.
- Infrastructure and market access, credit.
- On-farm consumption.

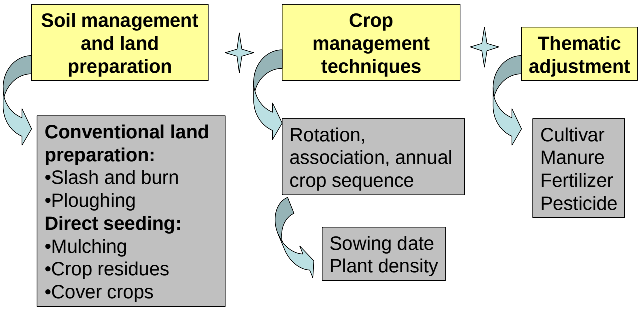

Figure 2: Components of cropping systems

Setting-up short- and long-term experimental units

Agro and socio-economic diagnosis provides a basis for modelling cropping systems and their components. In southern Xayabury, following the initial assessment, long-term experimental units representing the biophysical (integrating soil, slope and climate) and farming system diversities were set up in order to provide a large sample of cropping systems. Cropping systems comprise three major components (Figure 2):

- Soil management and land preparation through either conventional land preparation (slash-and-burn, ploughing) or through direct seeding (mulching, use of crop residues and cover crop).
- Crop management (rotation, association or crop sequence in the same season; sowing date and plant density). In DMC systems, efficient crop management can reduce weeds and pest pressure and maintain the main functions as close as possible to the natural ecosystem.
- Thematic adjustment (cultivar, fertiliser, pesticides).

Soil and crops management, cultivars and others inputs and natural conditions can be cross-linked to obtain a set of highly varied conditions (S□guy *et al.* 1998). The experiment in southern Xayabury involves the iterative generation of cropping systems. The first step is based on modification of soil management and land preparation. Weed and pest management and cultivar potentiality have strong relationships with soil characteristics. Soil with high biological activity and organic matter generally has good fertility and beneficial organisms that prevent diseases (Gobat *et al.* 1998). Moreover, S□guy *et al.* (2003) recommend that specific crop improvement programmes have to be established on DMC systems to radically modify the functioning of soil-plant systems.

Land preparation is first based on crop and weed residues management. In southern Xayabury, traditional cash crops like Job's tears (*Coix lacryma Jobi*) and rice-bean (*Vigna umbellata*) can be considered as key crops for providing DMC systems with crop residues. These species, with long cycle durations, produce a large amount of dry matter and degradation of these residues is relatively slow due to a high rate of lignin. This provides good soil protection, reducing evaporation and weed pressure. Moreover, the strong root system of Job's tears improves soil structure, making it a useful pre-crop for upland rice, rice-bean and sesame.

The second step integrates soil and crop management (association, rotation and/or annual crop sequence) in order to diversify production (grain production, rational use of forages by grazing and/or cut and carry), and so reduce economic and climatic risks while optimising the main functions of DMC systems through adequate use of main crops and cover crops. Main crops like Job's tears and rice-bean must return to a given field frequently to renew the beneficial characteristics they bring to the soil.

Many options are available when using additional crops (cover crops) but in the case of smallholders, who usually lack market access, an integrated cropping and livestock production system is more suitable. Two mains systems are being tested in southern Xayabury:

a. Rotations with direct-seeded grain crops (maize, Job's tears) followed by forage production for grazing (Séguy *et al.* 1998; Kluthcouski *et al.* 2000). Species like *Brachiaria ruziziensis* are sown at the first weeding stage by seed broadcasting in order to limit the additional working time. After two or three years, depending on the farmers' strategy, crops can be direct seeded on forage mulch. Due to their strong rooting systems, the most efficient species for recycling nutrients and using water deeper than 2 m are forages (*Brachiaria* sp. and *Stylosanthes guianensis*).

b. Grain production based on two crop sequences - a main crop of short cycle (peanut, sesame) followed by a crop for small animal feeding (sorghum, finger millet). The aim of this system is to use annual species which can produce grain and a high amount of dry matter, and which have a sufficiently strong rooting system to replace mechanical action.

Throughout the experiment, DMC systems are continuously compared with traditional cropping systems, which remain the reference. The systems are modified gradually in order to evaluate each component's influence on system performance. In different experimental units, soil and crop management sets are conducted under three levels of fertiliser (conventional system without use of mineral fertiliser; a medium level which compensates nutrient exportation by grains; and an optimal level which compensates nutrient exportation by grains and straw) in order to assess the evolution of the different systems under time.

Short-term experiments, based on thematic adjustments (germplasm evaluation, introduction of new species and/or cultivar, use of inputs already available on site), have been conducted during the first year in order to build a strong and confident relationship with smallholders. This step provides better knowledge of farm practices and traditional cultivars used by smallholders.

Adaptation and adoption by smallholders – collective land management

Adaptation and validation at farm level

The third component of this holistic approach is based on on-farm adaptation and validation of the simple technologies from the experimental units. The validation and adaptation component is a demand-driven process, meaning that priorities are defined by smallholders in light of the constraints of their farming systems, the overall environmental conditions and the economic situation (market demand, inputs, credit etc.).

This step focuses on adaptation of DMC systems with and by farmers, and advises them on adequate crop management (rotation and/or annual crop sequence). In southern Xayabury, land preparation has for the last fifteen years been based on burning residues and ploughing on steep slopes. This 'mining' development is copied from Thailand and generates land erosion, fertility losses, yield decrease, chemical pollution, and road and paddy field destruction. Because of the environmental and financial costs of conventional land preparation (ploughing), farmers are shifting to herbicides, which are sprayed before and/or after crop emergence. However, crop residues and weed mulch are usually burned, increasing mineral losses and erosion on bare soil. Many farmers have requested technical support to modify land preparation. Experience has shown that organisation of farmers through groups is crucial for the adaptation and adoption of DMC systems which modify mostly conventional agriculture. Farmer groups were organised for a total of 53 families in Kenethao, Parklai and Botene districts (four, two and two villages respectively) to validate technical options aimed at decreasing production cost and labour, and limiting rainfed area erosion.

DMC systems for crop residues are carried out for upland crops such as maize, Job's tears and rice-bean. A few modifications to cropping systems are proposed to smallholders in order to set-up, adapt and validate each step using current crops and cultivars. DMC systems for crop residues can exhibit very good results in terms of net income, yield and labour productivity (Tivet *et al.* 2004). In the southern Xayabury tests, adoption of simple DMC systems by smallholders can be related to five main effects: labour and drudgery both decrease, while net income, access to credit, and calendar flexibility all increase.

Adaptation and validation at landscape and village levels

Interaction between farmer groups and other farmers who request technical support is essential to analysing the process of generating and adapting technologies at the village level. These interactions can be based on:

- Mutual training.
- Tool and cultivar exchange.
- Field day participation and evaluation with farmer groups.
- Access to technical support.

Follow-up should identify the constraints and the synergies of this dynamic. At present, the objective is to implement and generate environmentally sound alternatives with technologies which have been validated by farmers. For example, experimental trials have to be implemented in order to assess the modifications of land use and the integration of livestock, cropping and trees associated with DMC systems. Managing the interface between animal and crop components is crucial to the success of these systems. Over-grazing of cover crop or crop residues during the dry season may leave too little mulch for sowing the following wet season crop, thereby affecting the main functions of the DMC systems. Specific forage use and control of wild-fires on the landscape unit must be defined by farmers during the dry season.

In order to implement these activities at village level, formalising a research-development programme with the community appears to be necessary. The methodological framework of this programme is inspired by the work of Chaz□e (1994) and comprises the following topics:

- Analysing short- and medium-term strategy in the village.
- Analysing needs.
- Formal contracting of the research and development programme with the community.

- Definition of the activities which will be implemented with the community,
- Planning, from the beginning, for the continuation of this research-development process with farmers, headmen, and district and provincial agricultural services after the end of the programme.

This framework seem essential to understanding the effects and impacts of our activities and particularly for understanding the whole *problematique* at the village level and the strategies followed by the community, which themselves indicate other forms of approach and other topics of research and development.

Permanent training of farmers and extension agents and keeping policy makers informed

The different components of this holistic approach generate a strong training environment for smallholders, research and extension officers and all of the stakeholders involved in development:

- Medium- and long-term training of smallholders is carried out throughout the different steps of the cropping system (soil and crop management, thematic adjustment). Training is conducted by research and extension officers on evaluation of fodder species, mechanisation, and use of pesticides,
- Organisation of farmers into groups for collective decisions and validation of soil conservation technologies and pasture land management,
- Organisation of village community,
- Decision-making for development programme priorities,
- Practical training for master's degree students.

Technical and socio-economic viability of DMC systems

Progressive changes in conventional cropping systems are better than drastic modifications, which are highly risky and often rejected by smallholders. Aggregation of cropping system components is a medium- and long-term process which implies defining a close link between the experimental unit and on-farm adaptation and validation. Feedback from smallholders is essential in order to integrate any constraints of new agricultural systems and modifications of socio-economic aspects into the experimental unit. In order to promote DMC systems for smallholders, the technical and socio-economic viability of different types of DMC systems (residues and/or cover crops) must be evaluated continuously. The circumstances of generation and adoption by smallholders must be analysed in order to identify priorities and key factors for extension: access to credit and inputs; mechanisation improvement, through specific tools like the hand-jab seeder; iterative modification of land preparation. Recent work by Erenstein (2003) gives a guide for understanding technical and socio-economic complexities related to the adoption of different DMC systems.

Conclusion

Few realistic alternatives presently exist to cropping under slash-and-burn shifting cultivation systems. Increasing population density and modifications in land access have drastically altered agricultural production in the uplands. During the past few decades, with the modification of land tenure, cultivated area per household has decreased and long fallow periods have disappeared (Fujisaka 1991). These recent changes do not allow for sustainable agricultural production or the preservation of soil and natural resources.

Soil conservation is the cornerstone of sustainable agriculture in the uplands. The main objective is to stay as close as possible to the natural ecosystem while improving soil-plant stability. Agro-ecosystem processes have to be emphasised: in order to convert the incomplete shifting cultivation system (i.e. rapid return of crop to a given field and reduction of fallow period) to a stable system, it is necessary to integrate DMC systems, livestock, trees and forestry products.

However, it is unrealistic to think that these approaches, based on soil conservation (DMC systems) and integration of systems, can be efficient in the uplands unless the land tenure of each household is defined. Land allocation must be flexible, taking into account the diversity of livelihoods and conditions in the uplands. Protection and conservation of natural resources is not possible without the involvement of local communities: including smallholders in the process of defining natural resource use is essential. Maintaining and protecting biodiversity will be effective if land tenure is modified so that a large area is allocated to smallholders for the integration of forestry area and resource uses. New farming systems based on the integration of forestry products, livestock and DMC systems could be stable and sustainable if, at the same time, economic incentives (access to market, inputs, credit, agriculture and forestry product processing) are promoted to allow this development. Through these methods, self-sufficient agriculture based on upland rice production can develop into soil conservation systems with diversified schemes that generate cash income and preserve natural resources.

In Mekong corridor conditions, promising results were obtained in southern Xayabury using simple DMC systems based on residue management for cash crop production (Tivet *et al.* 2004). This first step can be further improved by using cover crops and integrating livestock and tree production (like paper mulberry) as suggested by Fahrney *et al.* (1997). It seems to be possible to convert the present 'mining' production, based on cash crops and ploughing on steep slopes, to a system that conserves soil and nutrients, and is productive and economically viable for at least some smallholders. In the future, given the limited cultivated area available to each household, innovations that will generate added value and new non-farming activities must be considered. Possibilities include product processing (of crops and non-timber forest products) and short-term small animal production using locally produced cash crops. In addition, cattle production must be developed so that breeders can attain added value.

DMC systems are promising and could allow smallholders to preserve soil potential, which represents their major asset. Nevertheless, these systems depend largely on land tenure, the amount of cultivated area per household and local economic incentives.

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