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Innovations within upland rice-based systems in northern Vietnam with *Tephrosia candida* as fallow species, hedgerow, or mulch: net returns and farmers' response

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Abstract

Land degradation and crop yield decreases in tropical uplands in general and in southeast Asia have been recognised as the main problems arising from intensification of upland cultivation. With the purpose to search for solutions to these problems, agroforestry systems with a leguminous shrub *Tephrosia candida* (Roxb.) D.C. were experimentally tested on-farm in an upland rice (*Oryza sativa* L.) system on sloping land in northern Vietnam during the period 1996–1999. The upland rice-based systems tested were: (1) fallow crop rotation, including natural fallow (NaFa) and *Tephrosia* fallow (TepFa); (2) continuous cropping, including monocropping (Mono), *Tephrosia* hedgerow intercropping (TepAl), and *Tephrosia* mulch transfer (TepMu). In this paper, findings concerning net returns per labour day and the response of farmers to the test systems are presented. The *Tephrosia* systems (TepFa, TepAl, and TepMu) and the existing systems (NaFa and Mono) were evaluated using both experimental measurements and participatory rural appraisal (PRA) techniques. In the different treatments over a 4-year rotation, 386–778 labour days ha^{-1} were used, while 2612–4924 kg ha^{-1} upland rice grain and 939–9601 kg ha^{-1} fuel wood were harvested. The upland rice grain harvested was enough to feed 8.7–16.4 persons ha^{-1}. During the same period, the economic net present values were positive for the NaFa and TepMu treatments, but negative for the TepFa, Mono and TepAl treatments. The returns per unit labour were 3.7–6.7 kg rice or US$ 0.8–1.44 labour per day. Farmer criteria concerning management, labour input and soil conservation were well in accordance with the findings on labour input, crop yields and net returns. The *Tephrosia* systems seemed not to be rational alternatives for situations where the natural fallow systems are still viable. However, the *Tephrosia* fallow and the *Tephrosia* mulch transfer systems could increase crop yield per hectare at acceptable rates of return to labour. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Tephrosia candida; Upland rice yield; Farmers assessment; Net return; Labour input; Mulch; Hedgerow; Vietnam

1. Introduction

Tephrosia candida (Roxb.) D.C. — a leguminous shrub indigenous to southeast Asia (Oyen, 1997) — has been tested experimentally as an improved fallow species, in hedgerows or via mulch transfer on sloping land in northern Vietnam since 1996. The

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experiments were established to search for solutions to the problems of land degradation and crop yield decrease due to intensification of upland cropping in the tropics in general, and in northern Vietnam in particular (Fagerström, 1998).

Upland rice grows on approximately 20 million hectares in the tropics (IRRI, 1998), which is about 13% of the total rice area of the world (Hanfei, 1992). In Vietnam, the area under upland rice in 1991 was 0.5 million hectares, comprising 8% of the total area planted to rice. Upland rice is a major subsistence crop for about 52 ethnic minority groups, who are poor and face food shortages of varying intensity (Pandey and van Minh, 1998; Fagerström, 1998). Most upland rice farmers practise shifting cultivation based on slash-and-burn with no or little use of organic or inorganic fertilisers. With the closure of the land frontier in recent years and a continuing increase in the population pressure, farmers are forced to intensify their land use by reducing the fallow period. As a result, crop yields have declined, which has provided incentives for further encroachment onto forested areas (Pandey and van Minh, 1998). When fallow periods are reduced and cropping intensity is increased, crop yields per area during the cropping cycle and return per unit labour decrease, but total yield per area (including fallow land) can increase until a critical point is reached. Thereafter, land degradation reduces the number of people that can be sustained without the use of external inputs (van Noordwijk, 1999).

Agronomic alternatives for such short fallow rotation can attempt to enhance the fallow functions of restoring soil fertility, attempt to replace them by mulch transfer systems, or replace the main staple crop by a less demanding one (e.g., cassava (*Manihot esculenta* Crantz) replacing rice) or by a crop on which fertiliser use is economically feasible. Alley cropping is a specific form of a mulch transfer system in which the mulch is produced close to the crop zone; in other systems, a “mulch bank” is used outside the plot. These two represent extremes in a wide range of choices of spacing hedgerows in a permanently cropped field.

Apart from *Tephrosia*, several other species such as *Leucaena leucocephala* (Lamk) de Wit, *Erythrina poeppingiana* (Walpers) O.F. Cook, *Gliricidia sepium* (Jacq.) Kunth ex Walp and *Peltophorum dasyrachis* (Miquel) Kurz are considered promising for use in agroforestry in humid and subhumid tropical regions in alley cropping systems (Fagerström, 1998). The enhancement of the natural fallow vegetation by the introduction of fast growing trees or shrubs is an attractive approach for increasing the yield of subsequent crops. This practice is recommended in cases where the duration of the cropping period accounts for at least half of one shifting cultivation rotation (Kang, 1997). *Sesbania sesban* (L.) Merrill or *Tephrosia vogelii* J.D. Hooker fallows of 2 or 3-year duration in Zambia gave increases in grain yield of maize (*Zea mays* L.) without additional nitrogen fertilisers (Kwesiga and Coe, 1994; Kwesiga et al., 1999).

A *Tephrosia* fallow improved the maize yield in acid soils in Nigeria by increasing the N availability in the soil (Gichuru, 1991). In Indonesia, *Tephrosia* was reported to be one of the most effective green manuring species for reclamation of shifting cultivation (lalang) fields on poor soils (de Wit, 1913; van Helten, 1913; Gerlach, 1938). Since 1991, *Tephrosia* has been planted as hedgerows in agroforestry systems at some experimental and demonstration sites in the highlands of northern Vietnam (at altitudes up to 300 m). The species was chosen for these experiments because of its potential value as a source of fuel, green manure and seeds, as well as for soil conservation purposes (Littooy, 1989; Gayfer et al., 1990; Tu Siem and Phien, 1993). The species has been used as green manure by farmers in the lowlands of Vietnam since the 1960s. In the highlands of northern Vietnam, it is usually planted on ridges to protect the soil structure and to produce biomass for fuel and green manure (Phien and Tu Siem, 1991). However, there is still no information concerning the effects of this species as a fallow species, hedgerow or mulch in systems based on upland rice (*Oryza sativa* L.).

The experiments in this study were set up in the sloping area of northern Vietnam, where upland farming seemed to be changing towards more intensive cropping than previously, but is still of low priority in terms of farmers inputs. As highlanders are often poor, any innovations for improving the farming situation in the uplands have to be low-cost financially. In an area where paddy land is available and farmers rely on this land type to augment their food supply, new farming activities due to these innovations should not coincide with peak periods of paddy cultivation (Simelton, 1999; Hansson and af Petersens, 1999).

New technologies are required that are not only able to replenish depleted soils and are appropriate for the sub-optimal production conditions of small-scale farmers, but also offer an attractive return per unit labour (Swinkels et al., 1997).

The experiments were installed in the upland fields belonging to a farm to obtain realistic environmental conditions and to stimulate farmers to participate in our research. New technologies are often most successful when built upon existing practice and knowledge and local participation can complement scientific manpower (Walker et al., 1995). Local people, as competent observers, can extend the range of data channelled to the scientific decision maker (Howes and Chambers, 1980; cited in Walker et al., 1995). The involvement of farmer evaluation in on-farm research is now known to lead to the design of more appropriate technical interventions. Rapid rural appraisal (RRA) and participatory rural appraisal (PRA) are essentially qualitative survey methodologies and are primarily aimed at better understanding the needs of farming communities and the constrains under which they operate (Walker et al., 1995). For this reason, the RRA/PRA methods were used in this study for gathering farmers' evaluations of the cropping systems tested.

The objective of this study was to evaluate the effects of *Tephrosia* as a fallow species, hedgerow species or mulch in the upland rice-based system in terms of net return per labour day and of responses of farmers. The innovations were compared to the existing fallow crop rotation system and the existing continuous monocropping system. Findings presented in this paper will, together with the findings from the same experiments about nutrient cycling, soil P availability, competition and mulching effects (Hoang Fagerström, 2000), contribute towards a complete evaluation of the use of *Tephrosia* in agroforestry in northern Vietnam.

2. Materials and methods

2.1. General description of the study site

A field experiment was installed close to the Rong Can village in Hoa Binh province (21°N, 105°E, elevation 100 m above sea level), approximately 45 km SW of Hanoi. The village is situated in an area consisting of high hill ranges intersected by narrow valleys, where paddy fields are common. The climate is characterised by monsoons, with a dry period from October to March and moderate to high rainfall from April to September. The mean annual rainfall was 1772 mm in 1986–1996. The mean air temperature throughout the year was 22.8°C in 1986–1996. Gneiss (ancient metamorphic rocks), sandstone of Paleozoic origin and limestone of Permian age are the dominant geological formations in the region (Young, 1985).

In 1997, the population in the Rong Can village was 236 people, belonging to 45 different households. The whole population belonged to the Muong ethnic group. The total area of the village was 300 ha, among which there was about 10 ha used for paddy rice with two crops per year and 112 ha of sloping land mainly covered by bamboo (*Bambusa bambos* Druce), secondary vegetation and upland crops. The farmers were poor and faced rice shortages for 1–2 months each year. Off-farm activities were not common in the village (Simelton, 1999).

The main upland crops were maize, upland rice and cassava. Paddy rice was cultivated in the valleys between the hills. There was no shortage of fuel wood, as plenty of bamboo and trees were available in the area. With two crops per year, paddy rice is the main food supply in the villages studied and provided farmers with enough food for about 10–12 months. The upland crops provided the farmers with food for about 1–2 months, fodder for animals and cash for buying fertilisers to be used in paddy land. There were two peak labour periods, once at the beginning of the year and the other in the summer months. During the first peak period, which was also the rice shortage period (February–April), a lot of work was allocated to the sowing of different crops and slash-and-burn on the sloping land. During the second peak time (April–October), paddy land and upland management coincided. Men and women participated equally in almost all upland farming, except for harvest of upland rice, which was mainly women's work (Simelton, 1999).

Upland rice was chosen to be one of the upland crops for several reasons. Upland rice is traditionally used for special occasions such as New Year and parties, as well as to supply the farmers with food during the rice shortage period. Furthermore, farming

Table 1
Two examples of the pattern of existing natural fallow crop rotation systems in Rong Can village

Fields	Cropping period (years)	Fallow period (years)	Crop/fallow ratio	Crop/fallow rotation pattern (years)
"Doi Trua"[a]	5	3	1.7	Upland rice (3)–cassava (2)–fallow (3)–maize (5)–fallow (3)–maize (2)
"Doi Danh Bai"[b]	4–5	1–2	4.3	Fallow (2)–upland rice (1–2)–maize (3–4)

[a] Cropping pattern since 1977 of one field in the hill named "Trua", belonging to one Muong family.
[b] General cropping pattern since 1981 of one hill named "Danh Bai", belonging to several Muong households.

in the upland was also explained as filling up the time between the farming activities in the lowland. Weeds and low yield were identified by the farmers in the area as the main problems of the upland cultivation (Hoang Fagerström, 2000). Examples of the pattern of existing natural fallow crop rotation systems in the village is given in Table 1.

2.2. The design of the experiment

The field experiment was established in 1996 on a hill with an average slope of 22–24°, which was a representative slope angle where farmers cultivated existing fallow crop rotation systems. The soil is silty clay to clay, reddish brown and moderately acidic, and classified as a Haplic Ferralsol (FAO, 1990). The experiment consisted of plots which were 5.0 m × 22.5 m. A randomised block design (three blocks) with one treatment replicate per block was used. For 2 years before the installation of the experiment in 1996, both maize and upland rice occupied the area of blocks 1 and 2. No fertilisers had been used for these crops. The area of block 3 was under natural fallow comprising of grasses and bushes for a long time. Since this piece of land belonged to the community land before and has recently been allocated to the present landowner, it was unclear for how many years it had been under fallow.

The experimental treatments during a 4-year rotation, 1996–1999, are described in Table 2. The NaFa and TepFa treatments represented the existing and the innovative fallow crop rotation systems with the crop/fallow ratio of a 4-year rotation equal to 1. The Mono, TepAl and TepMu treatments represented the existing and two innovative continuous cropping systems, respectively. Continuous cropping means permanent annual cropping for a whole 4-year rotation.

Table 2
The experimental treatments during a 4-year rotation (1996–1999) with different designs in time and space

Treatment[a]	1996	1997	1998	1999
Fallow/crop rotation systems				
NaFa	Regrowth of natural vegetation	Regrowth of natural vegetation	Upland rice	Upland rice
TepFa	*Tephrosia* fallow	*Tephrosia* fallow	Upland rice	Upland rice
Continuous cropping systems				
Mono	Upland rice	Upland rice	Upland rice	Upland rice
TepAl	Upland rice with hedgerows[b] and mulching[c]	Upland rice with hedgerows[b] and mulching[c]	Upland rice with hedgerows[b] and mulching[c]	Upland rice with hedgerows[b] and mulching[c]
TepMu	Upland rice with mulching[d]	Upland rice with mulching[d]	Upland rice with mulching[d]	Upland rice with mulching[d]

[a] In 1995, both maize (*Z. mays* L.) and upland rice (*O. sativa* L.) occupied the area of all treatments in blocks 1 and 2. The whole of block 3 was under natural fallow vegetation consisting of various grasses and bushes.
[b] Hedgerows of 150 cm width, consisting of three rows of *Tephrosia.*
[c] Mulching of pruned biomass of *Tephrosia* from the hedgerows within the treatment plot.
[d] Mulching of pruned biomass of *Tephrosia* from the hedgerows growing outside the treatment plot.

2.3. Management of the experiment

The experiment was situated on the farmland called "forest garden". The "forest garden" term is used for hills situated close to the farm. Short fallow crop rotation is one of the most common land use systems in this type of land (Fagerström, 1998). The family who owned the land was contracted by a research partner in Vietnam (The National Institute of Soils and Fertilisers — NISF) to take care of all the farming activities at the site, following local techniques. Four persons in the family, including the husband, wife, and two daughters (aged 16 and 18 years), participated in the farming activities during 1996–1999. The timing for changing from fallow to crop in the two fallow crop rotation treatments at the beginning of 1998 was determined by this family. The new farming activities in the innovative systems such as planting of *Tephrosia*, pruning and mulching of the pruned biomass of *Tephrosia* were carried out by the family members with the technical assistance of an NISF's researcher. *Tephrosia* seeds were provided by NISF. The husband of the family assisted the researcher in measuring soil loss from each treatment. A further 5–6 farmers in the village, who were relatives of this family, participated in planting and harvesting at the site each year. They also worked with the slash-and-burn activities in the fallow crop rotation treatments at the beginning of 1998. By involving the farmers in the research, the farmers' evaluation reported in this paper could be obtained.

2.4. Treatment management and plant sampling

After installation of the plots in 1996, *Tephrosia* seeds (local variety named "Cot khi") were sown manually in the TepFa treatment and in the hedgerows of the alley treatment along the contour lines. The distance between rows was 50 cm and the seeds were placed at a soil depth of 5 cm. The plots of the NaFa treatment were left for the re-growth of natural vegetation. Before slash-and-burn of the NaFa treatment in April 1998 (24 months after fallow establishment), about 40 vascular species were found, of which about 25 species were woody shrubs and 15 were herbs or grasses (Hoang Xuan Ti, personal communication). The dominant bush was "Cho de" (*Chromolaena odorata* (L.) R.M. King and H. Robinson), while the dominant grass species were "Che ve" (*Miscanthus japonicus* (And.)) and "La tre" (*Panicum montanum* (Roxb.)). According to the farmers involved, the presence of *C. odorata* and the dense vegetation cover in the NaFa treatment plots in April 1998 indicated that at that time, the soil was good enough to shift from fallow to cropping.

Slash-and-burn in the fallow crop rotation treatments was carried out in April 1998 as follows. The 2-year-old fallow vegetation was clear cut, weighed in the field, divided into fuel wood (diameter $>$ 0.8 cm) and remaining parts (leaves and stems with a diameter $<$ 0.8 cm) left in the field. The parts left in the field were air-dried and burned 4 weeks later. The dry weights of the removed parts and of those left in the field were measured separately (oven-drying at 60°C for about 60 h of 300 g sub-samples). Two samples per plot, including one sample of the removed part and one sample of those left in the field, were collected randomly during the weighing in the field of the fallow biomass for determination of dry weight.

Pruning and mulching in the TepAl treatment and mulching in the TepMu treatment were carried out twice each year during 1997–1998, once before planting upland rice and once when the rice plants were flowering. However, only one pruning and mulching was carried out in 1996 and 1999. This was due to the fact that *Tephrosia* was sown only 1 month before planting upland rice in the first year (1996) and in the fourth year (1999), the *Tephrosia* became too woody and could therefore supply biomass for pruning only once, i.e., when the upland rice was flowering. The biomass of *Tephrosia* pruned from a nearby hedgerow treatment was transferred to the TepMu treatment to serve as a mulch. These hedgerows represented approximately 20% of additional area used for the TepMu treatment. The biomass of *Tephrosia* pruned in the hedgerows of the TepAl treatment was mulched in the same plots. The pruned biomass was weighed, chopped into pieces of about 2 cm length and mulched by spreading the biomass randomly between rice rows. One sample of the pruned biomass per plot was collected in the field, weighed and put into paper bags which were brought to the laboratory on the same day for dry weight determination.

Upland rice planting, weeding, application of pesticide and harvesting were carried out according to local practice. Rice was sown with the help of a dibble stick, at a density of 10–11 holes m^{-2}, and 5–7 seeds were put into each hole. Weeding was done manually 2–3 times per year, once about 1 month after rice planting, and once or twice during July–August. The weeds, including roots, were pulled up then left on the ground. To control harmful insects, "Monitor 24 EC" with dimethyl acetyl phosphoamidothioate 40% as active ingredient (AI) was applied 2 or 3 times per crop. The application rate was 1 l ha^{-1} of undiluted "Monitor 24 EC" or 400 ml ha^{-1} of AI each time. Harvesting was carried out on the entire plot. Tillers with grains and straw were cut and weighed before they were removed from the field. Dry matter (DM) content was measured separately for grains and straw on oven-dried samples of 200 g. The samples were collected randomly during the harvest and dried at 55°C for about 60 h. Crop yields were expressed on a total area basis (including the area under hedgerows for the TepAl treatment).

2.5. Labour inputs

Data on the use of labour and other inputs were collected for each experimental treatment by using two different methods: farmers' reports just after the task was completed (for crop management) and monitoring of work rates through observations (for planting, pruning and mulching). These activities were carried out regularly by the four family members involved, together with the researcher from NISF. The labour input per plot was later recalculated to a per hectare basis.

2.6. Economic analysis

On the basis of the annual cash flow of costs and returns, a net present value (NPV) of the experiment was calculated, using a discount rate of 20% per year:

$$\mathrm{NPV} = \sum_{t=1}^{n} \frac{\text{return} - \text{cost}}{(1+0.2)^t} \tag{1}$$

where Σ is the sum of the NPVs of 4 years (1996–1999), n the number of years for one rotation ($n = 4$), t the time (years), 0.2 the discount rate. In the NPV calculations, daily labour cost was calculated as the equivalent of US$ 1 per day.

Net returns per labour day were calculated for one rotation extending over a 4-year period (1996–1999), using a method developed from Swinkels et al. (1997) and could be described as follows:

$$\text{Return on labour 1} = \frac{\text{total return} - \text{cost of upland rice seed} - \text{cost of } \textit{Tephrosia} \text{ seeds}}{\text{total labour days}} \tag{2}$$

In these calculations, total return: value of upland rice yield, accumulated during one rotation, plus value of the fuel wood collected at the end of the fallow period in 1998; cost of upland rice seeds: cost of upland rice seed used per hectare for one rotation; cost of *Tephrosia* seeds: cost of *Tephrosia* seeds used per hectare for one rotation; total labour days: total labour days per hectare for one rotation; return on labour 2: as return on labour 1, but using a discount rate of 20% year^{-1} on annual cash flow and seeking the labour costs that lead to an NPV of 0.

The costs used for calculation, such as the cost of *Tephrosia* seeds and rice seeds, including both harvested rice and planted rice, were the current prices which the farmers had to pay. This was calculated first in Vietnamese dong, later in US$ using the exchange rate of 1999. Land value was not used in the calculation on the assumption that the land value was equal for the different cropping systems tested. No statistical analyses were carried for the economic calculations due to the fact that farmers recalled their activities for each treatment, not for each plot.

2.7. Farmers' evaluation

The farmers' evaluations of the systems were gathered through discussions with the participating farmers in October 1999 during 1-day group meetings. The group meetings were organised following some of the criteria given by Pretty (1995) for establishing trustworthiness of findings such as (1) parallel investigations and team communication, (2) triangulation by multiple sources, methods and investigators, and (3) participant checking. Nine farmers, who participated in the farming activities at the site during 1996–1999 (see Management of the experiment) took part in the group meetings. In order to avoid domination of either the husband or the wife of the family involved, the farmers to be interviewed were divided into two groups with the wife and husband of the family in

Table 3
Farmers' assessments methods — steps and PRA tools

Step	Outputs	PRA tools[a]
1	Getting farmers' description of the systems	Brainstorming on design/history of each treatment, using pictures
2	Getting farmers' qualitative evaluation and farmers' criteria	Brainstorming, using three main questions: Which system is the best? Which is the worst? Why they are best or worst?
3	Ranking the tested cropping systems using the farmers' criteria	Matrix scoring (10-scale) for each criterion for each system
4	Ranking farmers' priority in choosing different systems	Pairwise ranking

[a] Pretty (1995); PRA: participatory rural appraisal.

different groups. The discussions in the two groups went on in parallel, and were led by one researcher in each group. The RRA/PRA tools (Pretty, 1995) used were brainstorms and rankings. Cross checking of the information obtained was done by comparing the information gathered from the two groups and from the two different ranking exercises (Table 3). The findings were summarised by the two researchers involved and reported to the group of farmers for participant checking during the same day.

2.8. Statistical analyses

Treatment effects on upland rice yield were statistically evaluated by the following four orthogonal contrasts, using Genstat 5 Release 3.2 (the parameters 1.5 and 0.5 were introduced to facilitate comparisons between treatment combinations which contained different numbers of individual treatments):

$$\text{Fallow vs. crop} = 1.5 \times (\text{NaFa} + \text{TepFa}) - (\text{Mono} + \text{TepAl} + \text{TepMu})$$

$$\text{NaFa vs. TepFa} = \text{NaFa} - \text{TepFa}$$

$$\text{TepAl and TepMu vs. Mono} = 0.5 \times (\text{TepAl} + \text{TepMu}) - \text{Mono}$$

$$\text{TepAl vs. TepMu} = \text{TepAl} - \text{TepMu}$$

3. Results

3.1. Total labour input per hectare

The labour inputs over a rotation of 4 years (1996–1999) were lower in the fallow crop rotation systems than in the continuous cropping systems (Table 4). The main labour inputs were allocated to clearing (TepFa treatment), land preparation, rice weeding and harvesting (all treatments). Furthermore, the TepFa treatment required 214 labour days (55%) more than the NaFa treatment. This was due to the fact that more labour inputs were needed at the beginning of the fallow period, when the land was prepared for the planting of *Tephrosia*, as well as when *Tephrosia* was planted and thinned.

Compared to the non-mulched system (Mono), the mulched systems (TepAl and TepMu) required "extra" labour inputs for pruning and mulching activities. However, these "extra" labour inputs in the hedgerow intercropping (TepAl) were compensated for by decreasing the amount of labour inputs given to other farming activities due to less upland rice being cultivated in this treatment. As a result, the TepAl treatment even required 7 labour days less than the Mono treatments (Table 4).

3.2. Upland rice and fuel wood yield

The yield of upland rice ranged between 700 and 1700 kg ha^{-1} year^{-1} for the land under continuous cropping, and up to 1900 kg ha^{-1} year^{-1} for the post-fallow years (Table 5). The yield of the second post-fallow year tended to decrease more in the TepFa treatment than in the NaFa treatment (42% in comparison to 25%). The yield of the Mono treatment decreased about 5% per year during the first 3 years, but the decrease was 15% in the fourth year. The yield of the TepMu transfer treatment increased by about 24% per year during the first 3 years, but dropped by 50% in the fourth year. The TepAl did not show any clear temporal trend (Table 5).

Table 4
Labour inputs (labour day ha^{-1}) for different cropping systems during 1996–1999 (figures within brackets are % of total labour days)

Activities	Fallow/crop rotation (labour day ha^{-1})		Continuous cropping (labour day ha^{-1})			
	NaFa	TepFa	Mono	TepAl	TepMu 1[a]	TepMu 2[a]
Clearing[b]	56 (15)	142 (24)	82 (12)	82 (12)	82 (11)	82 (12)
Land preparation[c]	66 (17)	100 (16)	133 (19)	110 (16)	133 (17)	110 (16)
Rice sowing	52 (13)	52 (9)	115 (17)	93 (13)	115 (15)	93 (13)
Tephrosia sowing	0	50 (8)	0	10 (1.5)	0	10 (1.5)
Tephrosia thinning	0	19 (3)	0	4 (0.6)	0	4 (0.6)
Tephrosia mulching	0	25 (4)	0	82 (12)	82 (10)	82 (12)
Rice weeding	76 (20)	76 (13)	136 (19)	114 (17)	136 (17)	114 (17)
Pesticide spraying	5 (1)	5 (1)	22 (3)	19 (3)	22 (3)	19 (3)
Rice harvesting	131 (34)	131 (22)	208 (30)	175 (25)	208 (27)	175 (25)
Total labour input	386 (100)	600 (100)	696 (100)	689 (100)	778 (100)	689 (100)
Distribution of the total labour input						
1996	0	210	226	230	239	230
1997	0	0	140	140	166	140
1998	187	191	131	122	146	122
1999	199	199	199	197	227	197

[a] TepMu 1: mulching treatment with the yield estimated for only the cultivated area of upland rice; TepMu 2: mulching treatment with the yield estimated for the same area plus the area planted with *Tephrosia* used for collecting the mulching biomass (as in the TepAl treatment).

[b] Clearing means the slashing of fallow biomass and weeds and collection of some fallow biomass for fuel wood purpose. Labour input for the initial clearing carried out in the NaFa treatment was not used in this table. This activity was carried out for experimental purposes and therefore is not fair to include into the estimation of the labour input of this treatment.

[c] Land preparation includes the assembling of dried biomass in piles which are burnt on the site. It also includes the removal of stones from the plots.

Table 5
Upland rice yield during 1996–1999 and fuel wood harvested at the end of the fallow period, April 1998 (figures within brackets are the number of people that can be fed by the rice grain produced)[a]

Parameter	Treatment (kg DM ha^{-1})						*P*-values of ANOVA[b]				
	NaFa, A	TepFa, B	Mono, C	TepAl[c], D	TepMu 1[d], E	TepMu 2[d], G	A,B vs. C,D,E	A vs. B	D,E vs. C	E vs. D	G vs. D
Grain yield											
1996	(0)	(0)	877 (2.9)	701 (2.3)	1049 (3.5)	874 (2.9)			0.976	0.023	0.089
1997	(0)	(0)	814 (2.7)	1045 (3.5)	1318 (4.4)	1098 (3.6)			0.150	0.315	0.828
1998	1498 (5)	1895 (6.3)	795 (2.6)	804 (2.7)	1697 (5.6)	1414 (4.7)	0.009	0.172	0.083	0.011	0.046
1999	1114 (3.7)	1095 (3.6)	683 (2.3)	547 (1.8)	860 (2.8)	717 (2.4)	0.001	0.884	0.856	0.038	0.215
Sum 1	2612 (8.7)	2990 (9.9)	3169 (10.5)	3097 (10.3)	4924 (16.4)		0.025	0.510	0.084	0.007	
Sum 2	2612 (8.7)	2990 (9.9)	3169 (10.5)	3097 (10.3)		4103 (13.6)	0.077	0.508	0.289		0.059
Fuel wood											
April 1998	939	9601						0.004			

[a] Requirement of food per capita per year is 300 kg rice (Statistical Publishing House, 1999).

[b] Five contrasts were tested: fallow crop rotation vs. continuous cropping = 1.5 × (NaFa + TepFa) − (Mono + TepAl + TepMu); NaFa vs. TepFa = NaFa − TepFa; TepAl and TepMu vs. Mono = 0.5 × (TepAl + TepMu) − Mono; TepAl vs. TepMu 1 = TepAl − TepMu 1; TepAl vs. TepMu 2 = TepAl − TepMu 2.

[c] The yield of TepAl was estimated for the entire plots, including the area under the hedgerows.

[d] TepMu 1: mulch transfer treatment with the yield estimated for only the cultivated area of upland rice; TepMu 2: mulch transfer treatment with the yield estimated for the same area plus the area under hedgerows of *Tephrosia* used for collecting the mulching biomass.

For the post-fallow years (1998 and 1999), the fallow crop rotation systems (NaFa and TepFa treatments) gave significantly ($P < 0.01$) higher yields than the continuous cropping systems (Mono, TepAl and TepMu treatments). However, for the entire 4-year period, the fallow crop rotation systems gave significantly ($P < 0.1$) less than the continuous cropping systems. Consequently, the number of people that could be fed by rice produced in the continuous cropping systems was higher than that in the fallow crop rotation systems (10–16 persons compared to 9–10 persons, respectively, Table 5).

The TepMu treatment gave the highest yield among the treatments tested (Table 5). TepMu 1 (excluding the area for growing mulching material) was significantly ($P < 0.05$) higher than TepAl for all years, except in 1997, as well as for the whole 4-year period. When the yield of the TepMu treatment was calculated for the total area, including the area for growing mulch material, which was 20% of the cultivated area (TepMu 2), no significant yield differences were found for both 1997 and 1999 between the TepMu 2 and TepAl treatments. The amount of fuel wood harvested at the end of the 2-year fallow period was significantly ($P < 0.01$) larger in the TepFa treatment than in the NaFa treatment (Table 5). The amount of fuel wood, that would be harvested in the TepAl and TepMu later, was not included into the yield estimation of these two treatments.

3.3. NPV and net returns per labour day

The total return of the tested systems ranged from US\$ 577 to 1063 ha^{-1} and NPV ranged from US\$ −75 to 123 ha^{-1} for a 4-year period, 1996–1999 (Table 6). Net returns of the same period ranged from 3.7 to 6.7 kg rice labour per day or US\$ 0.8 to 1.44 ha^{-1} labour per day. The ranking of the treatments:

1. In terms of NPV (with 20% discount rate): TepMu transfer 1 (when the area for planting mulching materials excluded) > NaFa > TepMu transfer 2 when

Table 6
Returns and costs of the cropping systems during 1996–1999, 1 US$ = 13 900 VN dong (exchange rate in October 1999)

Cost and return	Fallow/crop rotation (US\$ ha^{-1})		Continuous cropping (US\$ ha^{-1})			
	NaFa	TepFa	Mono	TepAl	TepMu 1[a]	TepMu 2[a]
Returns						
Upland rice yield[b]	564	645	684	668	1063	886
Fuel wood[c]	14	138	0	0	0	0
Total	577	783	684	668	1063	886
Costs (excluding labour)						
Tephrosia seed[d]	0	135	0	30	30	30
Upland rice seed[e]	22	22.4	40	33	40	40
Total	22	157	40	63	70	70
NPV at 20% discount[f]	95	−75	−33	−59	123	74
Return per unit labour 1[g]	1.44	1.04	0.93	0.88	1.28	1.19
Return per unit labour 2[h]	1.47	0.80	0.93	0.87	1.26	1.16

[a] TepMu 1: mulching treatment with the yield estimated for only the cultivated area of upland rice; TepMu 2: mulching treatment with the yield estimated for the upland rice cultivated area plus the area under hedgerows of *Tephrosia* for collecting the mulching materials.

[b] Price (mean of the prices during 1996–1999) for rice = 3000 VN dong kg^{-1}.

[c] Price (mean of the prices during 1996–1999) for fuel wood = 200 VN dong kg^{-1}.

[d] Price (mean of the prices during 1996–1999) for *Tephrosia* seeds = 15 000 VN dong kg^{-1}.

[e] Price (mean of the prices during 1996–1999) for rice planting seeds = 4500 VN dong kg^{-1}.

[f] NPV was calculated on the basis of the annual cash flow of costs, including labour costs, and returns, using the form: NPV = $\sum_{t=1}^{n}(\text{return} - \text{cost})/(1 + 0.2)^t$, where n is the number of years for one rotation ($n = 4$), t the time (years), 0.2 the discount rate with daily labour cost of US\$ 1 per day.

[g] Return per unit labour 1 = (total return − cost of upland rice seed − cost of *Tephrosia* seeds)/total labour days. Total labour days of each treatment, see Table 7.

[h] Return per unit labour 2 = as return per unit labour 1, but using a discount rate of 20% year^{-1} on annual cash flow and seeking the labour costs that lead to an NPV of 0.

(the area for planting mulching material included) > Mono > TepAl > TepFa.
2. In terms of return on labour 1 (without 20% discount rate): NaFa > TepMu transfer 1 > TepMu transfer 2 > TepFa > Mono > TepAl.
3. In terms of return on labour 2 (with 20% discount rate): NaFa > TepMu transfer 1 > TepMu transfer 2 > Mono > TepAl > TepFa (Table 6).

3.4. Farmer criteria and ranking results

Of the eight criteria/factors used by farmers when they evaluated the tested systems, four concerned management (insect/pests, light competition, disturbance by seed-eating birds and weed control), two concerned labour inputs (ease of slash-and-burn and labour required) and two concerned soil conservation (erosion control and maintenance of soil fertility).

Findings from the ranking exercise of both groups of farmers were similar. The treatments were ranked in the order from high to low scores as follows: TepFa > NaFa > TepMu > Mono > TepAl (Table 7).

Two reasons for the high marks in the two fallow crop rotation systems were mentioned by the farmers interviewed, namely maintenance of soil fertility and good weed control. The TepFa system was evaluated as better than the NaFa treatment due to its high amount of litter, which was considered as green manure contributed to the soil. However, the higher amount of fuel wood was not mentioned as an advantage of this treatment, as there was no fuel wood shortage in the village. The mulch transfer system was considered to be a good system, as the soil in this treatment was regarded to be improved due to the mulch input. However, the system was less good compared to the two fallow crop rotation systems for two reasons: (1) labour input for mulching would be a problem if the cultivated area were larger; (2) weed problems were also mentioned. Both the Mono and the TepAl systems were ranked the lowest due to several factors, e.g., many insects and low soil fertility due to planting of upland rice for more than 3 years, and lots of weeds due to the bad growth of upland rice.

Besides the above-mentioned factors, some more disadvantages of the TepAl system were mentioned, such as competition as three rows of rice close to the hedgerows could not grow; the hedgerows became a resting place for rice seed-eating birds; it was difficult to practise slash-and-burn due to the hedgerows; *Tephrosia* in the hedgerows became woody and could not give enough mulch after 3 years. In 1999, the hedgerows could provide mulching materials only once, not twice as during the previous 3 years. Again, the amount of fuel wood that could be collected from the hedgerows was not mentioned as there was no fuel wood shortage in the village. However, the advantage of the TepAl treatment in erosion control was clearly emphasised by the farmer involved with the erosion measurement during 1996–1999. This farmer also recommended that the number of hedgerows

Table 7
Farmers' systems evaluation through the ranking exercise: the higher the score, the better the treatment was rated by farmers

N	Factors	Fallow/crop rotation				Continuous cropping					
		NaFa		TepFa		Mono		TepAl		TepMu	
		I[a]	II[b]	I[a]	Ii[b]	I[a]	Ii[b]	I[a]	Ii[b]	I[a]	II[b]
1	Less insects	10	7	10	8	5	2	3	4	5	7
2	Easy to slash-and-burn	10	9	10	9	10	9	1	4	10	9
3	Less labour	8	5	10	5	4	3	1	3	5	4
4	Less light competition	10	8	10	8	10	8	2	4	10	8
5	Erosion control	10	1	10	3	1	1	8	4	1	3
6	Maintenance of soil fertility	10	7	10	7	3	1	1	5	5	2
7	Less disturbance by seed-eating birds	8	10	8	10	8	10	1	4	8	10
8	Weed control	10	4	10	4	2	2	2	2	2	3
Total		76	51	78	54	43	36	19	30	46	46

[a] Interview group 1, consisting of four farmers including the husband in the family, responsible for the farming activities at the site.
[b] Interview group 2, consisting of five farmers including the wife in the family, responsible for the farming activities at the site.

should be reduced from three to one, as this would help to reduce competition and there would be less seed-eating birds but still good erosion control.

The farmers' favourite system was evaluated by the number of times each system was preferred when all pair combinations were compared (pairwise ranking). Ranked in the order from high to low, the treatments rated as follows:

1. Group 1: TepFa (4) > TepMu (3) > TepAl (2) > NaFa (1) with the condition that the number of hedgerows in the TepAl treatment will be reduced to only one hedgerow.
2. Group 2: NaFa (4) > TepFa (3) > TepMu (2) > TepAl (1).

Besides comparing the test treatments, farmers also reported that the upland rice yield and growth were better in block 3 compared to blocks 1 and 2. This was explained by the fact that for 2 years before the installation of the experiment in 1996, blocks 1 and 2 were under cropping, while the area of block 3 was under natural fallow.

3.5. Relative comparison between the cropping systems

The relations between the systems tested were compared using both measured and farmers' parameters through two ways of comparisons (sum 1 or 2; Table 8). The sums differed by different economic terms used: return on labour 1, when no discount was included (sum 1) and return on labour 2, when 20% discount was included (sum 2). The order of the systems was fallow crop rotation systems > continuous cropping systems in both ways of comparisons.

4. Discussion

4.1. Evaluation criteria and farmers' response

The systems clearly differed in land use intensity, requiring different amounts of labour, feeding a different number of people and giving slightly different returns on labour. Preferences for a particular system

Table 8
Relative comparison between the cropping systems for a 4-year period, 1996–1999

Parameter	Treatments (relative value[a])					
	Fallow/crop rotation		Continuous cropping			
	NaFa	TepFa	Mono	TepAl	TepMu 1	TepMu 2
Labour input[b]	1	1.6	1.8	1.8	2.0	1.1
Crop yield[c]	1	1.1	1.2	1.2	1.9	1.4
Return on labour 1[d]	1.6	1.2	1.1	1.0	1.5	1.4
Return on labour 2[e]	1.8	1	1.2	1.1	1.6	1.5
Ranking[f]	2.6	2.7	1.6	1.0	1.9	1.0
Pairwise ranking[g]	2.5	3.5	0.0	1.5	2.5	1.5
Sum 1[h]	6.7	7.0	2.1	2.9	5.7	4.1
Sum 2[i]	6.9	6.8	2.2	3.0	5.8	4.2

[a] Relative value was calculated by dividing each absolute value by the lowest absolute value in each parameter.

[b] The lowest value of labour input (labour days ha^{-1}) was for the NaFa treatment (Table 4).

[c] The lowest value of crop yield ($kg\,ha^{-1}$) was for the NaFa treatment (Table 5).

[d] The lowest value return on labour 1 (US$ labour per day) was the TepAl treatment (Table 6). Return on labour 1 = (total return − upland rice seed − *Tephrosia* seeds)/total labour days.

[e] The lowest value return on labour 2 (US$ labour per day) was the TepFa treatment (Table 6). Return on labour 2 = as return to labour 1, but using a discount rate of 20% $year^{-1}$ on annual cash flow and with the labour costs that leads to an NPV of 0.

[f] The lowest value of ranking (scores) was for the TepAl treatment. Score of each treatment = mean of the scores given by the two groups of farmers (I and II; Table 7).

[g] The lowest value of pairwise ranking (repeating times) was for the Mono treatment, i.e., equal to nil. Farmers did not choose the Mono treatment when all pair combinations of the treatments were evaluated. The repeating times of each treatment = mean of those given by the two groups of farmers.

[h] Sum 1 = (−labour input + crop yield + return on labour 1 + ranking + pairwise ranking).

[i] Sum 2 = (−labour input + crop yield + return on labour 2 + ranking + pairwise ranking).

are thus likely to depend on the local (perceived) pressure on land. Farmers primarily thought of management, labour input and soil conservation when they evaluated the systems, rather than the crop yield. This could be due to the fact that they participated in documenting the crop yield together with us each year. Therefore, they might think that crop yield was self-evidently an important factor and differences in crop yield between the treatments were already known to us. The great difference in the scores given by the two groups of farmers when they evaluated soil erosion control of the two fallow crop rotation systems (Table 7) could be explained by the fact that different farmers looked upon the systems for different periods of the rotation. Findings from the same experiment showed that soil erosion during the fallow period was five times lower than during the cropping period (Hoang Fagerström, 2000). The other differences in the scores given by the two groups of farmers, e.g., the pairwise ranking result of the NaFa treatment (see Section 3.4) or the score given for the labour and weed control factors of the NaFa and TepFa treatments (Table 7), can be explained by different perspectives among the participating farmers. This could be due to differences in experience and interest, as well as gender. The gender effect could be one of the reasons for the differences in the scores due to the fact that the group 1 was led by the husband while group 2 was led by the wife in the participating family (Table 7). This showed the importance of having different farmers groups when assessing the systems tested. Howes and Chambers (1980) are certainly right when they say that local participation can complement scientific manpower and that local people, as competent observers, can extend the range of data channelled to the scientific decision maker.

4.2. Fallow crop rotation vs. continuous cropping

The fallow crop rotation systems had higher sums of the relative values than the continuous cropping systems (sums 1 and 2; Table 8). This was mainly due to the lower labour input required by the systems. According to Swinkels et al. (1997) the higher the cost of labour, the more profitable the fallow crop rotation systems in comparison to the continuous cropping systems. This is not the case for Rong Can village, where off-farm work was not common (Simelton, 1999). However, farmers still voted for the fallow crop rotation systems. This may show that farmers are aware of the importance of the fallow period for soil fertility maintenance and/or the lowland cultivation competed for labour.

The continuous cropping systems gave higher upland rice yield than the fallow crop rotation. Accordingly, the number of people that could be fed by the continuous cropping systems was also higher. This was due to the fact that the higher upland rice yield after the fallow period in the rotation systems (TepFa and NaFa) could not compensate for the lost production during the fallow period. Similar results were obtained in western Kenya by Swinkels et al. (1997). Both labour input and rice harvested in the continuous cropping systems were spread over the whole 4-year period of rotation, while they were concentrated only during the two post-fallow years in the fallow crop rotation systems. Such a “distribution” of rice and labour seemed to fit well with the farming system pattern in the village, where farming in the upland is for filling up the time between the farming activities in the lowland and upland rice is traditionally used for special occasions such as New Year and parties, as well as to supply the farmers with food during the rice shortage period every year (Hoang Fagerström, unpublished).

4.3. Tephrosia fallow crop rotation vs. natural fallow crop rotation

The *Tephrosia* fallow crop rotation system had a higher sum of relative values than the natural fallow crop rotation system when the return per unit labour was calculated without the 20% discount. The higher labour input required in the TepFa treatment was compensated for by the higher crop yield. In follow-up research, simpler ways of establishing the *Tephrosia* fallow may be tried, e.g., by relay planting into the last crop, as demonstrated in the work on *Sesbania* fallow in Zambia (Kwesiga et al., 1999). Furthermore, farmers preferred the TepFa treatment to the NaFa treatment (see ranking and pairwise ranking results; Table 8). The farmers explained that this was because the TepFa treatment had a higher amount of litter, which functioned as green manure, than the NaFa treatment.

However, the sharp decrease of upland rice yield during the second year after the fallow period in the

TepFa treatment showed that the high yield obtained in this system was not sustainable. The NPV and the return on labour (with 20% discount) of the TepFa treatment were lower than those of the NaFa. This was due to both higher labour input required and the costs for buying *Tephrosia* seeds in the TepFa treatment. Furthermore, the yield of the subsequent upland crop was slightly higher in the TepFa treatment than in the NaFa treatment for only 1 year (see Table 5). The good effects of the NaFa treatment for post-fallow crop yield can be explained by the relative dominance of the bush "Cho de" (*C. odorata* (L.) R.M. King and H. Robinson) in this treatment. This species has been judged by farmers in the Taï region, southwest Côte d'Ivoire (Slaats, 1993) and in the hills of northern Laos (Roder et al., 1997) to be a good fallow species as it gives positive yield effects on a succeeding rice crop. With *C. odorata* as a dominating species in the fallow vegetation, crop yields became higher and competition from weeds was reduced after a fallow period of 3 years.

4.4. Hedgerow intercropping system and mulch transfer system vs. existing monocropping system

The mulched systems (TepAl and TepMu 1,2) had higher sums of relative values than the existing monocropping system (sums 1 and 2; Table 8). However, the NPV of the Mono treatment was higher than that of the TepAl treatment. This was due to the costs of buying *Tephrosia* seeds in this treatment (Table 6).

According to the farmers, the main reasons for not voting for the Mono treatment were that there were many insects, that the soil fertility was depleted and that there were lots of weeds. Low crop yield and high labour input, resulting in a low return on labour in the Mono treatment, could also be the reason. The crop yield of the existing continuous cropping system (Mono) decreased with time. However, the accumulated yield for the 4-year period was slightly higher than that of the fallow crop rotation systems (Table 5). This could be an explanation why farmers in the villages studied still practised monocropping for more than 4 years despite the yield declining and the low net return per unit labour. Farmers in the Rong Can village solved the problem of the marked decrease in upland rice yield after the third cropping year by changing crops from upland rice to maize or cassava (Table 1). The intensified upland cropping systems in the study area could be explained by the lack of off-farm activities (Simelton, 1999).

The hedgerow intercropping system (TepAl) had the same crop yield and labour input requirement as the existing monocropping system (Mono). According to the farmers, there were many disadvantages of the TepAl treatment, such as competition, disturbance by rice seed-eating birds, difficulty of carrying out slash-and-burn, lack of pruned biomass in the fourth year, which was the reason why the farmers gave the lowest score for the system (Table 7). However, farmers still voted for the TepAl treatment but not for the Mono treatment (see pairwise ranking in Table 8). This was explained by the farmer who was involved in erosion measurements that the TepAl treatment could control erosion well. Farmers voted for the TepAl system under the condition that the number of hedges should be reduced. The fact that the hedgerow of *Tephrosia* could provide sufficient amounts of mulch for the first 3 years showed that the treatment should be introduced only for a crop period of 3 years. There is a need to investigate the design of hedgerows as well as the pruning scheme that should be used in order to minimise the disadvantages of the system.

The mulch transfer system had the highest sum of relative values among the continuous cropping systems both when the area for growing mulching material was excluded (TepMu 1) or included (TepMu 2) when crop yield was estimated (Table 8). The high crop yield could compensate for the "extra" labour input required in this system. As a consequence, the net returns of this system were higher than in the other two systems (TepAl and Mono).

The problem with the mulch transfer system was labour availability for pruning and mulching as the hedgerows were pruned at crop planting time in order to reduce shading, and then again after 2–3 months, during weeding. Farmers were very busy during these two periods with many other farming activities both in the lowland and in the upland (Simelton, 1999). Furthermore, pruning the hedges on the hills under the hot summer sun was considered to be very hard work. Therefore, the farmers did not like to do it. It was not surprising that farmers ranked the system behind the fallow crop rotation systems despite the high net return per unit labour. The marked decreasing upland rice yield in the fourth year of this system resembled the phenomenon in the *Tephrosia* fallow system. The alternatives could be to use some inorganic P fertiliser or shift the system into fallow after three cropping years. This would fit with the local technique as the local farmers did not plant upland rice for more than 3 years.

The mulch transfer system (TepMu), on one hand, can be seen as an alley cropping system with such a wide spacing between the hedgerows that the competition zone is minimized; on the other hand, it may be seen as a *Tephrosia* fallow-rice rotation where some of the biomass is transferred to sustain production on currently cropped fields. Findings from the same experiment showed that pruning stimulated *Tephrosia* species in giving more biomass instead for fuel wood. Furthermore, with the pruning scheme used during a 2-year period in the present study, soil N and P could still be maintained. However, due to the limited time (2 years) of this investigation, and long-term effects of the cut-and-carry system on soil fertility could not be demonstrated (Hoang Fagerström et al., unpublished). This type of mulch transfer from fallow plots would allow for a range of intermediate land use intensities, depending on the amount of labour available and the number of people to be fed.

5. Conclusions

Farmers criteria concerning management, labour input and soil conservation were well in accordance with the findings on labour input, crop yields and net returns measured at the experimental site. A combination of the farmers' evaluation and the field measurements could give a clear picture of advantages and disadvantages of the tested systems.

The fallow crop rotation systems were preferred to the continuous cropping systems due to less labour input required, a high net return and soil fertility maintenance. The "improved" fallow of *Tephrosia* gave higher return per unit labour of the subsequent upland crop, than the natural fallow, only when farmers could have access to low price or free of charge *Tephrosia* seeds and having more labour available. The external mulch system using *Tephrosia* pruned materials could significantly increase upland rice yield for the first 3 years. Consequently, the number of people that could be fed by rice produced per hectare in the external mulch systems was up to four persons higher than that in the existing systems. Furthermore, the increase in net return per unit labour was higher than the increase in labour input needed for this practice. No more labour input was required for the hedgerow intercropping system.

For both mulch systems, however, the problem was the timing of the "extra" activities coinciding with the farming activities in paddy fields. Furthermore, due to several disadvantages of the hedgerow intercropping system, it was recommended that the system should be used only after some changes in the design and pruning regime. So, the various *Tephrosia* system tested in this study seemed not to be alternatives for situations where the natural fallow systems are still viable. However, the *Tephrosia* fallow crop rotation and the *Tephrosia* mulch transfer systems could increase crop yield per hectare at acceptable rates of return to labour.

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