The role of legume fallows in intensified upland rice-based systems of West Africa

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Abstract

Traditional upland rice-based cropping systems in West Africa rely on periods of fallow to restore soil fertility and prevent the buildup of insect pests and weeds. Population growth and increased demand for land are forcing many farmers to intensify their rice-production systems. The farmers have shortened the fallow periods and increased the number of crops they grow before leaving the land to extended fallow. The result has been a significant yield reduction. Promising cropping-system alternatives include the use of site-specific, weed-suppressing, multipurpose cover legumes as short-duration fallows. In view of the poor rate of adoption of legume technology and the paucity of research on fallow management in the extremely diverse upland rice-based systems of West Africa, a multiscale approach to generating and extrapolating fallow technology is needed.

In this study, we determined the constraints to rice production and the yield gaps related to intensification in 190 farmers' fields in three agroecological zones (farm level). We evaluated N accumulation and weed suppression in 54 legume accessions grown for 6 months during the dry season under a range of hydrological and soil conditions (plot level). To increase the benefits of improved fallow technology, we also determined the timing of legume establishment in relation to that of rice and the effect on crop and weed growth of four treatments: removing, burning, mulching, and incorporating fallow residues before the rice crop is planted. Farmers' reactions to improved legume fallows were evaluated in group interviews. "Best-bet" technologies for given rice-based systems were being evaluated at the village level throughout the region in the framework of a regional research network (Rice Cropping Systems Task Force).

Legume fallows appeared to offer the potential to sustain rice yields under intensified cropping. Absolute effects varied as a function of site, legume species, and management practice. Weed control and multiple-use options were important determinants of legume-technology adoption. Farmers' preferences for various legume phenotypes and management practices depended on their resources and the production system.

Résumé

La croissance démographique et la pression foncière contraignent de nombreux paysans d'Afrique de l'Ouest à intensifier leur système de production de riz caractérisé traditionnellement par des jachères de courte durée pour améliorer la fertilité du sol et contrôler les ravageurs. La surexploitation des terres entraîne généralement une réduction importante du rendement. Les activités de recherches de l'Association pour le développement de la riziculture en Afrique de l'Ouest indiquent que la gestion de la jachère par l'introduction des légumineuses de couverture peut aider à stabiliser les systèmes de production à base de riz pluvial grâce à la réduction de la pression des mauvaises herbes et des ravageurs, et à améliorer des paramètres physiques du sol et la capacité d'amendement en N. Le criblage et l'évaluation de 54 espèces de légumineuses ont révélé que *Stylosanthes guianensis*, *Macroptilium* spp. et *Aeschynomene histrix* étaient les meilleures espèces sur des sols acides fixant le P (Ultisols) dans la zone de forêts humides. Dans la zone de savane, *Canavalia ensiformis* a montré la plus forte accumulation en N, *Crotalaria juncea*, *Aeschynomene afraspera* et *Sesbania rostrata* étaient plus efficace dans la lutte contre les mauvaises herbes, et *S. guianensis* était plus résistant à la sécheresse. Les légumineuses ligneuses telles que *C. juncea*, *A. afraspera* et *S. rostrata* ont fourni, outre le bois de chauffe, une capacité d'amélioration du sol en N. Une réduction considérable de la population de nématodes parasites des racines, *Hirschmaniella* spp. et *Tylencorynchus* spp., a été observée avec l'utilisation du *Dolichos*, de l'*Aeschynomene*, du *Mucuna* et du *Calopogonium*. Cette utilisation a démontré sa supériorité économique à la jachère naturelle par la réduction de la demande en main-d'uvre. La réflexion des paysans au sujet des légumineuses a prouvé que le profit économique direct des jachères de légumineuses pourrait largement améliorer leur adoption.

Introduction

In contrast to agricultural practices in Asia, in Africa rice is largely grown in the uplands. In West Africa, the uplands constitute the most important rice-growing environment, in terms of area (60%) and regional production (40%) (Terry et al. 1994). Most food crops, including rice, are produced in extensive production systems, in which farmers traditionally rely on extended periods of fallow to restore soil fertility and to control insect pests and weeds (Johnson and Adesina 1993; Roose 1994). However, population growth has forced farmers to intensify land use in an unprecedented way (Becker, Johnson et al. 1995). Surveys of rice-based systems in West Africa indicate a reduction from about 12–15 years of secondary forest fallow in the early 1980s to 3–7 years at present (Becker and Assigbe 1995). In fallow-rotation systems of the Guinea savanna zone, the number of crop cycles between the 12- to 15-year fallows has increased from 23 to 47 during the same period. Finally, in cash-crop rotations (mainly cotton and soybean based), sedentary production systems without extended fallow periods are emerging in some areas (Le Roy 1995).

Without adaptation of management practices to the new production objectives, cropping intensification of upland ecosystems occurs at the expense of the quality of the resource base. Loss of soil nutrients is a major factor in the degradation of the African resource base, and 45.4 x 10^6 ha was estimated to have become moderately to severely degraded between 1945 and 1990 as a result of inappropriate management and nutrient depletion (Oldeman et al. 1991). Studies on shifting cultivation, mainly in maize-based systems, indicate that cropping intensification allows increased weed infestation (Nye and Greenland 1960; de Rouw 1994, 1995; Heinrichs et al. 1995) and reduces soil organic matter (Agboola 1994; Hien et al. 1994), which leads to a decrease in soil N (Gigou 1992). In cash-crop rotations, weed growth and nutrient deficiencies may be partially controlled by using herbicides and mineral fertilizers (Adesina et al. 1994). In this situation, the physical degradation (wind erosion, compaction) of the soils is rapidly emerging as the major production constraint (Wilson et al. 1982; Pieri 1992; Alegre and Cassel 1994).

Given the current intensity of land use and the fragility of upland soils in West Africa, production gains from subsistence food-crop agriculture are likely to be modest, despite the large area occupied by these systems. Efforts to generate technology should realistically aim at sustaining productivity gains and stabilizing intensified subsistence food-based systems. One of the most prominent cropping-systems alternatives is the use of leguminous cover crops to improve the quality of fallows (Balasubramanian and Sekayange 1992; Hoefsloot et al. 1993). Despite a large variability, the mean N accumulation in leguminous cover crops is reportedly high (about 100 kg N ha^{-1}). A major share of this N (about 70%) appears to be derived from biological N fixation (Peoples and Craswell 1992; Becker, Ladha et al. 1995; Peoples et al. 1995).

The encouraging results of three decades of research on leguminous cover crops in Africa (Hartmans 1981; Tarawali 1991), Asia (Yost and Evans 1988; Carangal et al. 1994), and Latin America (Lathwell 1990; Lobo Burle et al. 1992) have helped to promote and extend such technologies for improving soil fertility throughout the tropics (Bunch 1990; IITA 1993; Ladha and Garrity 1994). These efforts, however, stand in stark contrast to the poor rate of adoption of improved fallow technologies in tropical food-crop production systems (Becker, Ladha et al. 1995). Many of the studies have tended to focus on the benefits of such systems in terms of soil fertility and erosion control, ignoring system diversity, socioeconomic specifics, weeds, and farmers' perceptions and production objectives.

Rice is grown worldwide under a wider range of conditions than any other cereal crop, and rice in West Africa is no exception (Becker and Diallo 1992; Adesina 1993). However, very few studies on improved fallows in West Africa have been conducted on the rice-based cropping systems. To identify appropriate technologies and improve the likelihood that farmers will adopt new legume-fallow options, one needs to understand the diversity of regional, biophysical, and socioeconomic environments and target specific environments. Accordingly, our research involved the following activities:

- On-farm analysis of fallow-related rice-production constraints;
- Selection of legumes for a range of biophysical conditions;
- Adaptation of crop-management practices to maximize benefits from legume fallows;
- Determination of socioeconomic factors in farmers' adoption of improved fallows; and
- Participatory on-farm evaluation of "best-bet" technologies.

Materials and methods

The experiments in this study were conducted in four benchmark watersheds in three agroecological zones, as well as on the research farm of the West Africa Rice Development Association at Mbé, near Bouaké, in Côte d'Ivoire. A characterization of the five experimental sites is given in Table 1.

Table 1. Experimental sites.

Constraint analysis

Diagnostic field trials were conducted in three agroecological zones of Côte d'Ivoire in 1994 and 1995 (Gagnoa, bimodal forest; Touba, derived savanna; and Boundiali, Guinea savanna). Traditional, extensive upland rice-production systems (>6 years fallow; rice as first crop after fallow) were compared with intensified cropping (<5 years fallow, rice after more than three crop cycles) in 191 farmers' fields. Weed-species composition and dry-biomass and rice-grain yields were determined under farmers' management, as well as in three superimposed researcher-managed subplots (hand-weeding at 28, 56, and 84 d; 15 kg ha^{-1} mineral fertilizer-N application; and a combination of both). Soil samples (0–20 cm) taken at the start of the cropping season were anaerobically incubated in the laboratory (composite samples of five soils each in five replications) and extracted after 1 and 3 months for soil exchangeable ammonium (2 *N* KCl) to determine potential soil-N-supplying capacity in a 2-month period (NH_4^+-N at 3 months - NH_4^+-N at 1 month of incubation). Yield gaps were attributed to weeds and N, based on yield response to the researchers' management in the intensified systems.

Legume adaptation

Fifty-four legume accessions (39 species of 28 genera) were selected from germplasm collections at the International Centre for Tropical Agriculture, the International Rice Research Institute, and the International Institute of Tropical Agriculture, as well as from local markets and from wild plants in West Africa. Legumes were grown during the dry season for 6 months between two crops of upland rice. Four sites were used in Côte d'Ivoire: Gagnoa (bimodal forest, sandy loam, Alfisol), Man (monomodal forest, sandy clay, Ultisol), Bouaké (derived savanna, sandy clay loam, Alfisol), and Boundiali (Guinea savanna, loamy sand, Alfisol). At each site, the legumes were grown in three replications. In addition, to determine legumes' adaptation to hydrological conditions, we grew 15 accessions for 3 months (April to July) at the research farm at Mbé, each in 1-m-wide and 60-m-long strips along a toposequence ranging from drought-prone upland, over the hydromorphic valley fringe, to a flood-prone rainfed lowland. At this site, the legumes were also grown in three replications. Dry-biomass and N content of weeds and legumes were determined at bimonthly intervals (site-adaptation study) or at monthly intervals (hydrological-adaptation study). The percentage of N derived from biological N_2 fixation was determined by difference methods (Hauck and Weaver 1986); nonfixing *Cassia occidentalis* and *Cassia tora* were used as reference plants. Farmers' reactions to fallow legumes were recorded during individual and group interviews at the sites in the forest and savanna zones.

Fallow-management practices

Considerations related to improved management of legume fallows included the following:

- At what stage of the upland rice crop the legume should be sown to maximize establishment for dry-season survival and soil cover while minimizing competition with the associated rice;
- How the fallow vegetation should be cleared in preparation for the succeeding rice crop; and
- How to fit a range of technology packages into existing rice-based cropping systems.

The timing of fallow establishment in relation to that of rice was examined at the research farm at Bouaké for the legumes *Tephrosia, Stylosanthes,* and *Calopogonium*, sown at 1, 28, 56, and 112 d after planting (DAP) rice (WAB 56-50), in three replications. At the same study site, the effects of four treatments — of removing, burning, mulching, and incorporating fallow residues before the rice crop is sown — on crop and weed growth were compared. The fallows consisted of the legumes *Calopogonium, Canavalia, Centrosema, Mucuna, Pueraria,* and *Vigna* and the natural vegetation (weeds), in three replications. In each experiment, rice, weed, and legume growth were recorded at monthly intervals.

Best-bet legume species and management practices for the major rice-based systems are being evaluated in seven countries of West Africa in the framework of a regional research network, involving rice scientists from 12 national programs (Rice Cropping Systems Task Force).

Results

Analysis of biophysical constraint

Diagnostic field trials were conducted to determine whether long-term productivity of upland rice can be sustained at current levels of intensification. Land-use intensification increases total upland rice production in the short term but results in a substantial reduction in plot-level grain yield (Table 2). These intensification-induced yield losses were higher in the forest zone (41%, $P = 0.03$) than in the derived savanna (31%, $P = 0.05$) or the Guinea savanna (20%, not significant) and appeared to be related mainly to increased weed infestation and reduction in soil-N-supplying capacity. The relative importance of weeds and N varied by agroecological zone.

Table 2. Effect of intensification of upland rice-based cropping systems on grain yield, weed biomass, soil-N supply, and the relative contributions of weeds and soil-N supply to intensification-related yield gaps, on-farm trials, Côte d'Ivoire, 1994–96.

Weeds seem to be the dominant factor responsible for yield loss in the forest (68% of the yield gap) but appeared to play a lesser role in the savanna. Short-fallow fields in the forest zone were dominated by broadleaf species (mainly *Chromolaena odorata*), whereas grasses (*Imperata, Digitaria, Hackelochloa,* and *Andropogon*) were dominant in the intensively cultivated fields in the savanna zones. Cropping intensification generally reduced soil-N-supplying capacity. This reduction was greatest in derived savanna soils, where N supply explained 39% of the yield gap. Changes in the soil's physical properties and increased pest pressure appear to have played a role in the observed yield decline (data not shown). This may be particularly true for the nearly continuously cultivated, mechanized rice–cash-crop rotations of the savanna zone, where more than 30% of the yield gap could not be explained by either weeds or N supply. These results clearly suggest that long-term upland rice productivity cannot be sustained at current levels of intensification. Improving the quality of the fallow vegetation by introducing leguminous cover crops may help to stabilize upland rice-based systems because legumes can reduce the buildup of weed infestations during short periods of natural fallow and improve the soil-N supply through biological N fixation.

Legume adaptation

The screening and evaluation of legume species for growth, weed suppression, and N accumulation in different agroecological zones, hydrological situations (as determined by toposequence position), soil types, and farmers' production systems indicated that no single species performs satisfactorily (>30 kg N ha^{-1} and >50% reduction in weed biomass) in all environments (Table 3; Figures 1 and 2). The forage-legume species *Stylosanthes guianensis*, *Canavalia ensiformis, Macroptilium latyroides,* and *Aeschynomene histrix* outperformed other legumes on acid P-fixing Ultisols in the humid forest zone in terms of biomass production ($P = 0.05$) and weed suppression ($P = 0.01$) (Table 3).

Table 3. Maximum dry-biomass accumulation by some selected short-season fallow legumes and associated weeds during 6-month off-season growth between two crops of upland rice, four West African Rice Development Association key sites in Côte d'Ivoire, dry season 1995/96.

Figure 1. Nitrogen accumulation by selected cover legumes grown as short-season fallow during the 1995/96 dry season at two sites (Bouaké and Gagnoa) with favourable soil (Inceptisol, Alfisol) and hydrological conditions (bimodal rainfall). Note: Ndfa, N derived from atmosphere; Ndfs, N derived from soil.

Figure 2. Nitrogen accumulation of selected cover legumes grown as short-season fallow during the 1995/96 dry season at two sites (Man and Boundiali) with unfavourable soil (Ultisol, Alfisol) and hydrological conditions (monomodal rainfall). Note: Ndfa, N derived from atmosphere; Ndfs, N derived from soil.

In the savanna zones, where N supply and soil cover are prime objectives of cover-legume use, *C. ensiformis* showed the highest biomass accumulation; *Crotalaria juncea* and *Mucuna* spp. showed good ground cover and suppression of weeds; and *Cajanus cajan* showed best dry-season survival. *Aeschynomene histrix, C. ensiformis,* and *S. guianensis* appeared to be well adapted across sites, producing good biomass and suppressing weeds. *Cajanus cajan, C. juncea,* and *Crotalaria retusa* (data not shown), which did well at three sites, failed at the forest–Ultisol site. The woody shrubs, *C. juncea, Aeschynomene afraspera*, and *Sesbania rostrata*, accumulated the largest amounts of N in rainfed lowland ecosystems (>60 kg N ha^{-1}) and effectively suppressed weed growth (Figure 3). The creeping annual legumes *Mucuna* and *Vigna* produced good growth relative to the natural weed growth in all studied hydrological situations (>1 000 kg ha^{-1}).

Figure 3. Dry-biomass accumulation by selected 3-month-old cover legumes and the associated weed flora along a hydrological gradient, inland valley toposequence, Bouaké, April–June 1995.

Farmers' reactions

The results of our survey of farmers' perceptions of legumes should be considered preliminary, as the sample size was small and interviews were limited to only two sites in Côte d'Ivoire. Farmers who rely on cutting and burning to clear land (as in the forest zone of Côte d'Ivoire) considered creeping-cover legumes, such as *Calopogonium, Centrosema, Mucuna,* and *Pueraria*, inappropriate for their farming system, as these legumes are difficult to cut. In addition, *Centrosema, Calopogonium,* and *Pueraria* were known to these farmers as weeds that are difficult to control in upland rice. However, large-seeded legumes, such as *Mucuna* and *Canavalia*, were appreciated for their ability to suppress weeds, although, once slashed, they were considered hard to dry and difficult to burn.

An additional problem was that dense stands, particularly of *Mucuna,* harboured snakes. Nevertheless, farmers who depended on slash-and-burn practices considered erect woody legumes, such as *Crotalaria* and *Cajanus*, manageable and appreciated their ability to provide firewood and sticks for fencing (for example, for agouti [bush rat] control). By contrast, farmers who incorporated residues into the soil, mainly manually (savanna upland rice-based systems and traditional or semi-improved lowlands), generally favoured creeping plants over erect ones, such as *Crotalaria* or flood-tolerant *Sesbania* spp., because labour requirements for incorporating creeping-legume residues were perceived to be less demanding.

Farmers were interested in other possible uses of the legumes. Weed suppression by the fallow vegetation was considered essential in both forest and savanna ecosystems, and most savanna rice farmers considered the availability of high-quality forage during the dry season as being desirable. A direct economic benefit of improved fallows would, reportedly, increase farmers' adoption of legume technology.

Fallow-management practices

Across species, sowing the legumes at the same time as rice provided the best ground cover and the highest N accumulation (39 kg ha^{-1}) in the fallow biomass at the onset of the dry season but led to very low rice yields (0.3 Mg ha^{-1}) because of the interspecific competition (data not shown). There were no significant differences in rice yields when legumes were sown at 28, 56, or 112 DAP rice (1.2 Mg ha^{-1}), but legume N accumulation at rice harvest increased with earlier fallow establishment (6, 19, and 36 kg N ha^{-1} when seeded 84, 56, and 28 DAP rice, respectively). The presence of legumes significantly reduced natural weed growth in rice at 56 and 84 DAP, compared with no-legume control plots. Modeling tools are being developed, as optimal legume-fallow establishment dates are likely to vary with rice cultivar, legume species, and ecosystem.

A summary of the results of the residue-management study is shown in Table 4. Across species, the legume-fallow vegetation accumulated more than three times as much N as the weedy fallow did and at the end of the fallow period contained only one-sixth as much weed biomass. Rice-grain yields after legume fallow were significantly higher than those following a weedy fallow ($P = 0.01$), and these tended to be highest when legume residues were incorporated. Across fallow-management treatments, weed growth at 28 DAP rice was lower when fallow vegetation had been removed than when it had been burnt, mulched, or incorporated (32, 67, 57, and 76 g m^{-2}, respectively, $LSD_{0.05}$ = 22).

Table 4. Effect of short-season fallow vegetation (October 1994 to May 1995) and residue management on weed infestation and grain yield of upland rice, field experiment, Bouaké, 1995.	Weedy fallow	Legume fallow [a]	$LSD_{0.05}$
N accumulation before seeding (kg N ha^{-1})	26	81	17
Mean weed biomass across residue treatments (g m^{-2})	126	21	26
Rice-grain yield (Mg ha^{-1})			
Residues removed	0.34	0.88	0.38
Residues burnt	0.40	0.93	NS
Residues mulched	0.29	1.05	0.55
Residues incorporated	0.26	1.15	0.34
Mean yield	0.32	1.01	0.33
$LSD_{0.05}$	NS	0.23	
Note: LSD, least significant difference; NS, not significant. [a] Mean of five legumes (*Calopogonium, Canavalia, Centrosema, Mucuna, Pueraria*).			

Based on a preliminary analysis of legume performance, site adaptation, and farmers' adoption criteria, we propose a number of best-bet legume scenarios for the major upland rice-based cropping systems in West Africa (Table 5). Major rice-growing environments, associated farming-system characteristics, relative importance in Côte d'Ivoire, some of the proposed fallow-legume species, and associated management practices are presented in this table.

Table 5. Major upland rice-based farming systems in West Africa, their relative importance in Côte d'Ivoire, and suggested fallow legume species and associated management practices, based on preliminary evaluation.

Discussion

Weeds, N, and labour are important biophysical and socioeconomic production constraints in upland rice rotations under shortened-fallow management. Future problems in forest fallow and savanna cash-crop rotations may include P deficiency (Sanchez and Salinas 1981) and soil degradation, including erosion (Pieri 1992). Legumes can sustain productivity gains in intensified systems (Lathwell 1990; Becker, Ladha et al. 1995; Peoples et al. 1995). However, new fallow-management options must take account of the diversity of cropping systems, management practices, and farmers' production objectives. Our studies have shown that no single legume is adapted to the wide range of biophysical and socioeconomic rice-production environments of West Africa. One clearly needs to exploit the existing genetic diversity and to select appropriate legumes for given environments and farmers' production objectives. Creeping legumes, such as *Calopogonium, Centrosema, Mucuna*, and *Pueraria*, have attracted much research attention (Agboola and Fayemi 1971; Akobundu 1993; Tarawali and Ogunbile 1995). However, farmers who rely on burning to clear land in the forest zone have not adopted such legumes, as they do not suit their farming system.

The use of creeping legumes that are fit for human consumption, such as, *Mucuna* and *Canavalia* (Osei-Bonsu et al. 1995), may partially overcome this problem. In mechanized systems in the savanna zone, where soil erosion and physical degradation pose a serious threat to systems sustainability (Pieri 1992) and where cattle have to be fed during the dry season (Hoefsloot et al. 1993), forage legumes may provide an acceptable alternative to weedy fallows. Crop survival and good soil cover during the dry season (Lobo Burle et al. 1992), however, may necessitate relay establishment of the legume crop (Balasubramanian and Blaise 1993). Such practices may not be acceptable in mixed cropping systems, where the cover legume would compete for land with associated noncereal crops (Milton 1989). Similarly, benefits arising from modified residue-management practices (mulching and incorporation, instead of burning) have to be evaluated in relation to practicability (establishment, farm equipment, termites, etc.). Further, the effects of legume fallows on populations of nematodes and insects and their natural enemies are likely to become more important as rice-based systems intensify (Becker, Johnson et al. 1995).

Improvements in traditional systems must aim at increasing returns per unit of labour, because labour is commonly the greatest constraint to production in smallholder systems. In the traditional rice-production systems, for example, returns per unit of labour are about half those of the improved systems that use purchased inputs (Adesina 1994). Ouattara (1994) reported that farmers in the savanna zone of Côte d'Ivoire spend 408–506 h ha^{-1} hand-weeding their upland rice crop, which represents 40% of the total labour invested in rice. Early attempts to introduce *Mucuna* to farmers in Nigeria were rejected by farmers because the legume involved extra labour (land preparation, sowing, and fallow management) and did not fit into the traditional mixed-cropping system (Faulkner 1934). Similarly, Rwandan farmers considered short-season fallows less attractive, partially because of the additional labour needed for planting and managing the fallow vegetation (Balasubramanian and Blaise 1993).

Weed suppression is an essential factor in the success of improved fallow management. In several Task Force trials throughout the region, researchers reported that labour requirements (for example, for hand-weeding of upland rice) were substantially lower with legumes than with a weedy-fallow control, which may justify farmers' investing in an improved legume fallow. The ability of *Mucuna* to suppress the perennial grass *Imperata cylindrica* in maize-based cropping systems (Versteeg and Koudopon 1990; Akobundu 1993) prompted farmers to adopt cover-legume technology in areas of Benin where agriculture was plagued by this weed. Widespread adoption of *Mucuna* in maize-based cropping systems of northern Honduras appears to be partially related to the reduced labour requirements for field preparation and weed control (Triomphe 1996).

Conclusions

Legume fallows and associated management practices must be considered in the context of the cropping systems in which they are used (including farmers' resource base and aspirations). Because farmers are looking for direct returns on their investments, legumes in most situations have to perform functions in addition to providing N; in particular, they also have to reduce labour requirements or increase returns per unit of labour. They may achieve this by suppressing weeds or by providing additional harvestable products, such as food, fodder, or fuel. Improved productivity through reduced requirements for labour and for maintenance of soil fertility, without additional cash investment, is likely to achieve progress in this direction. As discussed in this paper, particular solutions must take account of the biophysical and socioeconomic specifics of prevailing systems if these solutions are to be successful. Researchers working within the framework of the Task Force are investigating the effects of legume fallows on rice pests and their natural enemies, as well as conducting *ex ante* and *ex post* economic analyses and participatory on-farm evaluations of best-bet options throughout the region.

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