Cover legumes increase productivity of upland rice under intensified land use in West Africa

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Abstract

Population pressure has forced upland rice farmers in West Africa to drastically reduce fallow periods or expand cultivation onto marginal soils. These processes have reduced production potential. Improved legume fallow technologies were hypothesized to contribute to the stabilization of upland rice-based systems. Diagnostic trials in >120 farmers' fields in the forest and the savanna zones of Côte d'Ivoire compared extensive with intensive fields regarding biophysical and socio-economic parameters. In the same environments, 7 legume species were compared with the traditional weedy fallow in replicated field experiments and gender-differentiated farmer-participatory on-farm evaluation studies. Declining fallow length was associated with a 30% yield reduction. Weeds were the dominant factor responsible for land use intensification-related yield loss in the forest, while the reduction in soil organic matter and N supplying capacity were the main culprits in the savanna. In both environments, increasing demand for hand weeding reduced labor productivity. A regression model presented indicates that farmers will adopt labor-saving legume technologies. Cover legume as an alternative to natural weedy fallow increased N input 3-5 fold, in some instances, reduced weed growth and increased grain yield of rice by about 0.4 t ha^{-1} over the "weedy" fallow. Farmers selected legumes largely on the basis of labor considerations such as ease of land clearing (male) and weed suppression (female), but also on the basis of yield effects (male and female). Frequently selected fallow legumes included *Indigofera hirsuta* in the savanna, and *Crotalaria micans* in the forest. Their adoption is likely to increase upland rice production and productivity.

Keywords: Cover crops, Crotalaria, Indigofera, N_2 fixation, Oryza sativa

Introduction

In contrast to Asia, rice in West Africa is largely grown in the uplands (about 2.5 million hectares) which are both in terms of area (60%) and regional production (40%) the most important rice-growing environment (Terry *et al.,* 1994). The majority of food crops, including upland rice, are produced in extensive production systems where farmers traditionally rely on extended periods of fallow to restore soil fertility and control insect pests and weeds (Nye and Greenland, 1960). Population pressure has forced upland rice farmers to drastically reduce fallow periods or expand cultivation onto marginal soils (Becker and Assigbe, 1995; Weber *et al.*, 1996). These processes have denuded large areas of natural vegetation, increased erosion (Juo and Lal, 1977), mined soil fertility (Oldeman *et al.*, 1991), provoked the build-up of weeds (de Rouw, 1995), and reduced production potential (Pieri, 1992), especially labor productivity (Dvorak, 1993). Improved fallow technologies were hypothesized to contribute to the stabilization of upland rice-based systems. Particularly legume-based technologies may provide opportunities to contribute to the conservation of the natural resource base while maintaining inter-annual yield and generating increased output (Carsky et al., 1998). Such alternative technologies to traditional fallow rotations need to be evaluated not only regarding their biophysical potential but increasingly regarding labor demands or labor savings. A summary of six years of interdisciplinary cover legume research conducted in collaboration with the West Africa Rice Research Association (WARDA) is presented.

Material and Methods

Diagnostic trials were conducted in >120 farmers' fields in representative rice-growing environments of two agroecological zones in Côte d'Ivoire between 1994 and 1996. They compared extensive systems (6-30 years of fallow in the forest and 2-3 crop cycles before leaving the land to fallow in the savanna) with intensive systems (1-5 years of fallow in the forest and 4-8 crop cycles before leaving the land to fallow in the savanna) regarding soil parameters, weed infestation and rice yield. Household economic data and crop and soil parameters were collected. An unrestricted transcendental logarithmic production function was estimated and the elasticity of substitution between land and labor were derived:

$$\ln Y = \alpha_0 + \sum_{i=1}^{3} \alpha_i \ln(x\ \ ) + \frac{1}{2}\sum_{i=1}^{3}\sum_{i=1}^{3} \beta_{ij} \ln(x_i)\ln(x_j) + \sum_{k-1}^{2} \delta_k F_k + \sum_{l-1}^{2} \phi_l A_l + \sum_{m-1}^{2} \gamma_m R_m + \varepsilon_i$$

In addition, an *ex-ante* estimate of the field-level impact of labor-saving technologies was developped. In the same two environments, seven legume species were compared with the traditional weedy fallow in replicated field experiments between 1997 and 1999. Legumes were relay-established one month before the harvest of the first rice crop after an extended fallow period and were grown for 8 months during the “off-season”. At the onset of the rains (beginning of the cropping season), fallow vegetation was either slashed, let to dry and burnt (forest) or hand-pulled, let to dry and incorporated (savanna) before dibble seeding of the improved upland rice cultivar WAB 56-50. Comparative evaluations for two subsequent crop cycles concerned weed suppression, N accumulation, biological N-fixation ($\delta\ ^{15}N$), and yield effects on rice. In addition, labor data for fallow clearing, seeding, weeding and harvesting were recorded. Finally, the performance of the fallow systems was evaluated at fallow clearing, weeding and rice harvest by >20 male and >20 female farmers at each site.

Results and Discussion

Increased cropping intensity and reduced fallow duration were associated with significant yield reduction (Table 1) in both the savanna (1.48 vs. 1.15 Mg ha^{-1}) and the forest zones (1.55 vs. 1.02 Mg ha^{-1}). Intensification-induced yield loss was about 28% and appeared to be related mainly to increased weed infestation (77% more weed biomass) and declining soil quality (about 12% less soil organic C content and 28% less N supply).

Table 1. Effect of the intensification in upland rice-based systems on rice grain yield, weed biomass and selected soil parameters (on-farm surveys, Côte d'Ivoire, 1994-96).

PARAMETERS	Savanna Extensive n=25		Savanna Intensive n=27	Forest Extensive n=35		Forest Intensive n=39	Intensific.-induced changes [a]
RICE							
Yield (t ha^{-1})	1,48	(*)	1,15	1,55	*	1,02	- 28 %
WEEDS [b]							
Weed dry weight (g m^{-2})	0,27	*	0,44	0,16	*	0,30	+ 77 %
SOIL							
pH (H2O) [c]	5,7	ns	5,6	4,3	ns	4,4	ns
Organic C (%)	2,49	ns	2,08	1,65	*	1,54	- 12 %
Labile C (%) [c]	5,4	ns	5,7	8,0	ns	8,3	ns
CMI [d]	100	ns	98	100	ns	91	ns
C:N-ratio	13,1	ns	13,4	10,3	ns	10,2	ns
N supply (mg kg^{-1})[e]	24,9	*	16,6	14,9	*	11,3	- 28 %

[a] extensive: >5 years fallow (forest); <4 crop cycles (savanna); intensive: <5 years fallow (forest); >4 crop cycles (savanna)
[b] cumulative dry weed biomass at 28 and 56 DAS
[c] C in fraction oxidized by 333 mM $KMnO_4$
[d] CMI: Carbon Management Index (Blair et al., 1995)
[e] after 2 weeks of unaerobic incubation, modified after Stanford and Smith, 1972.
* significantly different at 5%; (*) p=0.053; ns not significantly different

Yield gap determinations based on super-imposed researcher-managed subplots indicate that weeds were the dominant factor responsible for rice yield loss in the forest area (explaining 65% of the intensification-related yield gap) while the reduction in soil organic matter and N supplying capacity were the main culprits for yield reduction in the savanna. In both environments, increasing demand for hand weeding reduced labor productivity. The elasticities (Table 2) highlight a dramatic difference on the ease of integrating labor-demanding or labor-saving technologies into the existing production practices of small scale farmers. Land and labor act as substitutes and can be adjusted to new input requirements. Labor saving technologies, and in particular technologies that require less weeding labor will allow farmers to grow larger areas of rice and resulting in output gains.

Table 2. Elasticities of Output and Substitution

	Area	Clearing Labor	Weeding Labor
Point Elasticities $\sigma_{yx} = \left(\frac{dy}{dx} \frac{x}{y} \right)$	0.95*	0.79**	0.70**
Morishima Elasticities of Substitution $\sigma_{ij}^{m} = \left(\frac{f_j}{x_i} \frac{F_{ij}}{F} - \frac{f_j}{x_j} \frac{F_{ij}}{F} \right)$			
Area	-	0.01	0.02*
Clearing Labor	1.632**	-	0.00
Weeding Labor	4.608**	-0.01*	-

Notes: f_i is the marginal physical product of factor *i*, F_{ij} is the cofactor corresponding to factors *i, j* and *F* the determinant of the bordered Hessian of the production function.
* Significant at 5% (standard error estimates generated by Taylor series expansion)

The parameter estimates of the production function (Table 3) further highlight that, besides soil fertility, rice production is significantly linked to clearing and weeding labor availability.

Table 3. Parameter estimates for the translog unrestricted production function for upland rice production

	B-coefficient	Significance
Intercept	5,92	-
Savanna	0,25	-
Forest	0,33	-
Year	-0,07	0,123
Soil fertility	0,17	**0,015**
Area	1,08	0,034
Clearing Labor	0,92	**0,004**
Weeding Labor	-0,46	0,224
$(\text{Area})^2$	0,04	0,723
$(\text{Clearing Labor})^2$	-0,01	0,923
$(\text{Weeding Labor})^2$	0,22	**0,001**
Area*Clearing Labor	0,17	0,188
Area*Weeding Labor	-0,17	0,223
Clearing*Weeding Labor	-0,30	**0,004**

Adjusted R square 0.840; n=310

We conclude that long-term upland rice productivity can not be sustained at current intensification practices. Improved management strategies should aim primarily at reducing weed pressure and improving soil organic matter content and N supply. To be adopted by farmers, the proposed technical options must increase labor productivity.

Legume cover crops, grown for 8 months during the “off season”, were evaluated at the same two sites. Legume N accumulation varied between 32 and about 100 kg N ha^{-1}, with 59-88% of that derived from biological N_2 fixation. Highest N accumulation was observed by *Crotalaria micans* and *Cajanus cajan* in the forest and by *Indigofera hirsuta* and *Crotalaria juncea* in the savanna zone (Table 4). It exceeded N accumulation by natural fallow vegetation 3-5 fold. Grain yield of rice that had been preceeded by a legume fallow were on average 0.4 t ha^{-1} (30-90%) greater than that preceded by the “weedy” fallow. Biomass of the fallow was in most instances significantly greater with legumes than with natural vegetation and several legume species suppressed weed growth. Most striking was the weed growth reduction following *C. micans* at the forest site. Even in the third year of continuous cultivation, most legume treatments were able to maintain the initial yield level of 1996 (1.8 t ha^{-1} in the forest and 1.1 t ha^{-1} in the savanna), while rice yields declined to about one half in natural fallow treatments.

Table 4. Effect of short-season fallow vegetation on N accumulation, weed biomass and upland rice yield in Côte d'Ivoire (on-farm trials, mean values of 1997 and 1998)

Type of off-season fallow vegetation	Savanna			Forest		
	N accum. (kg N ha^{-1})	Weeds (t ha^{-1}) [a]	Rice yield (t ha^{-1})	N accum. (kg N ha^{-1})	Weeds (t ha^{-1}) [a]	Rice yield (t ha^{-1})
Natural fallow growth	28	0,23	0,51	32	0,58	1,48
Aeschynomene histrix	*59*	*0,29*	*1,00*	*55*	*0,42*	*1,92*
Cajanus cajan	*64*	*0,20*	*1,11*	*73*	*0,33*	*1,70*
Canavalia ensiformis	*59*	*0,20*	*0,95*	*32*	*0,52*	*1,89*
Crotalaria [b]	*98*	*0,12*	*1,23*	*99*	*0,29*	*2,17*
Mucuna pruriens	*35*	*0,20*	*0,97*	*34*	*0,41*	*1,78*
Stylosanthes guianensis	*38*	*0,27*	*0,85*	*41*	*0,51*	*1,95*
Tephrosia/Indigofera [c]	*72*	*0,16*	*1,20*	*25*	*0,30*	*1,89*
Fallow legumes mean	61	0,21	0,99	47	0,39	1,90
LSD (0.05)	*13*	0,05	*0,40*	*20*	0,24	*0,33*

[a] Cummulative dry weed biomass at 28 and 56 DAS
[b] *Crotalaria micans* at the forest site and *C. juncea* at the savanna site
[c] *Tephrosia villosa* at the forest and *Indigofera hirsuta* at the savanna site

The legumes affected differentially the amount of time required to for land clearing and weeding (Table 5). In the forest zone, Stylosanthes guianensis,and Aeschynomene histrix increased clearing labor requirements by 30 and 50%. Cajanus cajan and Crotolaria micans decreased labor requirements by 35 %, saving about 65 hours. While cumulative weed biomass was generally less after a legume fallow (Table 4), few statistically significant reductions in weeding labor requirements were observed. Overall labor productivity in the legume-based rice production systems improved over the traditional fallow, mostly due to increased yields. Those legumes however that increased labor demand for clearing or weeding are likely to result in a decrease in the area planted to rice in order to compensate for the additional labor requirement.

Table 5. Labor requirements and induced production impact from legume adoption under labor-limited situations at the forest site.

Fallow vegetation	Rice yield ($t\ ha^{-1}$)	Total labor required ($hours\ ha^{-1}$)	Clearing labor ($hours\ ha^{-1}$)	Weeding labor ($hours\ ha^{-1}$)	Output effects (grain produced): if clearing labor is limiting	Output effects (grain produced): if weeding labor is limiting
Weeds	1,48 -	1280 -	240 -	300 -	-	-
Aeschynomene	1,92 *	1375 *	312 **	323 *	-8% ns	+7% ns
Cajanus	1,70 ns	1209 ns	166 ***	303 ns	+38% **	+1% ns
Canavalia	1,89 *	1259 ns	219 ns	300 ns	+26% *	+26% *
Crotalaria	2,17 **	1155 *	202 *	213 **	+65% ***	+43% ***
Mucuna	1,78 ns	1259 ns	242 ns	277 ns	+8% ns	+8% ns
Stylosanthes	1,85 ns	1365 ns	328 **	297 ns	-19% *	+12% ns
Tephrosia	1,89 *	1322 ns	269 ns	313 ns	+7% ns	+7% ns

The impact on rice production of farmers' adopting legumes can be disaggregated into direct and indirect effects. The direct effect relates to increased yield levels following legume fallows. The indirect effect is induced by saved labor which would permit the household to increase the area under rice cultivation.

Based on current cropping practices and labor requirements, the potential impact of adopting one hectare of legume was simulated, taking into account both the direct and indirect effects under the two labor scarcity scenarios (Table 4, last two columns). The first scenario assumed that land clearing operations are limited while the second scenario assumes that hand weeding is limited by labor availability. In situations where the use of legume fallow did not affect either the clearing or weeding activity, the net impact was wholly composed of the yield effect. In a situation where labor availability is limited, the use of *Crotolaria micans* could increase rice output by up to 65%. This occurs primarily because of the yield effect (43%) and secondly due to an expansion of the rice area (22%). *Cajanus cajan* also generated both direct and indirect positive effects on productivity, while *Aeschyomene histrix* and *Stylosanthes guianensis* decreased rice output. From these data and the regression model we conclude that farmers are likely to adopt legume fallow technologies that increase labor productivity. This conclusion is further substantiated by the results of gender-differentiated participatory legume evaluation studies. Over 60% of 89 farmers involved expressed interest in using fallow legumes in their own upland rice-based systems. Farmers selected legumes largely on the basis of labor considerations such as ease of land clearing (male) and weed control (female), and on the basis of yield effects (male and female). Most frequently selected fallow legumes included *Indigofera hirsuta* in the savanna, and *C. micans* and *C. cajan* in the forest. At the forest site, use of farmer-selected *C. micans* increased productivity in farmer-managed plots in 1999 and its use is being recommended by national extension services in Côte d'Ivoire.Since 1999, several legumes are grown by farmers. For the promising legumes, agro-ecological and farming systems niches have been determined and extrapolation domains visualized (GIS maps) as a basis for systems development research and technology transfer strategy. Improved legume fallows enable farmers to intensify cultivation of a given piece of land rather than practice shifting cultivation. This could allow natural fallow to reestablish, while individual plots would be permanently cultivated. The net effect of a legume fallow-driven rice area expansion, combined with a reduced demand for annual land replacement, could potentially increase fallow periods with obvious benefits for the environment and the conservation of biodiversity.

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