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Abstract

Population pressure in the southern provinces of Benin has forced farmers to shorten or abandon the traditional bush fallow system. As a consequence, severe soil degradation and weed infestation constitute the most serious constraints to agricultural productivity. Mucuna *fallow is one of the most promising technologies for natural resource management to restore soil fertility in intensified cropping systems. It was introduced in 1987 to some 15 farmers through farmers' participatory research in the Mono province of Benin, and now more than 10 000 farmers are estimated to be using* Mucuna *nationwide. This paper examines the dynamics and determinants of* Mucuna *diffusion and adoption, and assesses its impact in southern Benin. Results showed that the rates of adoption of* Mucuna *fallow are promising, as more farmers are adopting the technology. The analysis conducted with a Probit model showed that the most important factors influencing farmers' adoption were weed infestation, land tenure rights, contact with extension services, and other farm-specific variables. The assessment of the economic impact showed that systems with* Mucuna *have a higher benefit:cost ratio than systems without* Mucuna. *Adoption resulted in a structural shift of the production function using the same pool of production factors. Advantages include yield increase, labor reduction, and soil fertility restoration. The majority of farmers expressed more satisfaction with* Mucuna *than with chemical fertilizer. Suppression of* Imperata cylindrica *and low capital requirement were perceived to be the major benefits of* Mucuna *fallow, and therefore provided a window for its rapid adoption and diffusion. Prospects for the use of* Mucuna *grain for human consumption and animal feed will certainly increase farm-level adoption and impact in small-scale farming systems. Other windows of opportunity for* Mucuna *fallow may exist and need to be identified to achieve greater adoption and impact in the intensified systems of West Africa.*

Key words: Adoption, diffusion, *Mucuna*, impact, *Imperata*, soil fertility, Benin

Introduction

Population pressures, intensive cultivation, and shortening fallow periods have resulted in declining soil fertility and an invasion of noxious weeds that pose a major threat to sustainable agricultural production in the densely populated areas of southern Benin. The bush fallows practiced by smallholders, which used to be long enough (10 years or more) to allow the replenishment of soil fertility, have been drastically shortened or simply abandoned. Decades of cropping without fallow have decreased soil fertility, reduced levels of soil organic matter, and acidified soils. Weeds have invaded the land, forcing small-scale farmers to abandon their plots. Thus, achieving food security for a rapidly growing population will require intensification of food production on existing crop land through improving soil fertility and agronomic practices. There is a wide range of technological options for improving soil conservation and land management that are economically viable, ecologically sound, and socially acceptable. These include inorganic fertilizers, crop residue management, green manure, composting, farmyard manure, agroforestry technologies, alley farming, planted fallow, cover crops, and cereal-legumes intercropping or rotation (Lal and Cummings 1979; Kang et al. 1991; Sanchez and Hailu 1996; Weber 1996; Franzluebbers et al. 1998; IITA 1998; Buckles et al. 1998). One of the most promising legume cover crops to improve soil fertility in intensified cropping systems is *Mucuna* fallow.

Mucuna is indeed a legume cover crop that is an efficient, low-cost source of nitrogen with considerable potential to improve soil fertility in intensified cropping systems (Buckles 1995; Sanginga et al. 1996; Carsky et al. 1998; Buckles et al. 1998; IITA 1998). It is also efficient in controlling noxious weeds such as *Imperata cylindrica* (Akobundu and Udensi 1995) and nut grass (*Cyperus rotundus*), two of the most difficult weeds to control in the tropics (Carsky et al. 1998). There are reports that *Mucuna* can be used for reducing nematode populations. *Mucuna* has also been used in cattle grazing, and can provide animal feed and human food (Carsky et al. 1998; Galiba et al. 1998; Versteeg et al. 1998; Yai 1998).

Two different management systems have been developed for the integration of *Mucuna* into cropping systems. One is a sole cover crop fallow for severely degraded fields. The other is a maize/*Mucuna* relay crop for fields requiring less rehabilitation. For severely degraded and *Imperata*-infested fields, *Mucuna* should be planted in a pure stand at the onset of the rainy season. Three or four weeks after *Mucuna* has been planted, a second slashing may be necessary to allow *Mucuna* seedlings to overcome *Imperata*, as it is a fast-growing weed. *Mucuna* usually produces substantial biomass which covers the soil and strangles all the weeds, or climbs as high as its supports (weeds, trees, associated crops) allow. Production of 7 to 9 t/ha of dry matter is commonly observed in the bimodal rainfall zone (Vissoh et al. 1998). In the dry season, *Mucuna* ends its life cycle, leaving a thick mulch free of weeds. This allows for a subsequent maize crop during the major rainy season with little or no land preparation or weeding. Maize can be seeded directly through the mulch using a stick, hoe, or cutlass.

Mucuna can also be intercropped with maize when the *Imperata* infestation is not severe. The technology is to plant *Mucuna* in a relay cropping system with food crops such as maize. Maize is planted first, and *Mucuna* seed are sown 40 to 45 days later (just after second weeding). After the maize harvest, the land is left to *Mucuna* fallow, which allows groundcover to develop fully for biomass accumulation and nitrogen fixation while weeds, such as *Imperata*, are smothered. During the following dry season, the *Mucuna* dies off and the farmer can farm the field in the next main cropping season (Versteeg and Koudokpon 1990).

Diffusion of **Mucuna** *fallow in Benin*

In 1987, the Recherche Appliquée en Milieu Réel (RAMR) project of the Institut national des recherche agricoles du Bénin (INRAB), with the technical support of the International Institute of Tropical Agriculture (IITA) and the Royal Tropical Institute (KIT), The Netherlands, initiated participatory experimentation with four alternative, low external input soil management technologies to improve soil fertility in maize cropping systems in Mono, a province in southern Benin. These technologies were alley farming with *Gliricidia sepium* and *Leucaena leucocephala*, improved planted tree fallow with *Acacia auriculiformis*, intercropping maize with *Cajanus cajan*, and a short season fallow with *Mucuna (Mucuna pruriens* var. *utilis*) (Versteeg et al. 1997).

Alongside other technologies such as alley farming and live mulch cropping, *Mucuna* was sown in village demonstration plots to monitor its effect on soil fertility. *Mucuna* rapidly gained popularity as more and more farmers began to join the ranks of participating farmers. In 1990, the extension services selected *Mucuna* technology for dissemination to hundreds of farmers nationwide in collaboration with Sasakawa Global 2000, an international nongovernmental organization (NGO) involved in rural development projects in several African countries. The dissemination of *Mucuna* progressed exponentially during the succeeding year, reaching over 10 000 farmers in many parts of Benin in 1996 (Versteeg et al. 1998; Carsky et al. 1998; Galiba et al. 1998), and about 14 000 farmers in 1997 (Honlonkou and Manyong 1999).

The purpose of this paper is to analyze the dynamics of *Mucuna* fallow diffusion, the factors determining its adoption by farmers, and the benefits arising from farmers' adoption and use of *Mucuna* in the heavily populated southern provinces of Benin. Understanding of the biophysical and socioeconomic factors driving *Mucuna* adoption, and the assessment of the economic impacts of *Mucuna* fallow would allow for extrapolation to similar situations, and consequently help to address the problem of land degradation and sustainable food production in West Africa.

The next section describes the study area and the methodologies for data collection, data analysis, and impact assessment. The following section presents and discusses the results of the study, focusing on the dynamics of *Mucuna* diffusion and adoption, the determinants of farmers' adoption of *Mucuna*, the constraints to the adoption of *Mucuna*, the economic benefits of *Mucuna* adoption, farmers' assessment of the benefits of *Mucuna*, and prospects of *Mucuna* for human consumption. The paper ends with a summary of findings and implications for research, policy, and extension.

Methodology

The paper is based on a series of studies conducted in the densely populated areas of southern Benin. The area represents about 10% of the country, but contains about 54% of the total population and about 60% of the rural population (Manyong and Houndékon 1997). It is one of the most densely populated zones of sub-Saharan Africa with about 220 inhabitants/km^2. The dominant soil type is sandy to sandy loam, locally called *terres de barre* and classified as *sol ferralitique appauvri* (Versteeg et al. 1998) or a degraded Ultisol following the USDA classification. The soils are physically stable (not prone to erosion) but chemically very poor. The traditional farming system consisted of a fallow system based on 12–15 years of oil palm in dense stands (Kang et al. 1991). However, demographic pressure has shortened the traditional fallow periods to such an extent that the decline in soil fertility is a major concern.

The first series of surveys was conducted in four villages where *Mucuna* technology had been introduced to the farmers since 1987 through on-farm experimentation (Houndékon et al. 1996; Manyong et al. 1996; Manyong and Houndékon 1997). In each village, farmers were selected from the lists of farmers who had used *Mucuna* at least once, and those who had never used *Mucuna*. A total of 446 fields belonging to 277 farmers (143 *Mucuna* farmers and 134 nonusers) were selected. The surveys collected data on the socioeconomic characteristics of farmers, their resource endowments, perception of the technology, farm characteristics, and land tenure systems.

The second series of studies was conducted in new areas where *Mucuna* had been introduced by the extension services. Galiba et al. (1998) carried out a survey of 127 farmers who had been reached by their extension services, while Honlonkou and Manyong (1999) administered a structured questionnaire to a total of 580 farmers in four provinces of southern Benin to collect information on their characteristics, land-use systems, type of resource management technologies, and biophysical and institutional environment. Farmers' technology preferences were assessed using a 5-point scale with 10 items, while the determinants of adoption were analyzed using contingency tables and chi-square statistics (Honlonkou and Manyong 1999). To examine the structural change and technology bias induced by *Mucuna* adoption, data were collected from 400 farmers using a structured questionnaire (Manyong and Honlonkou 1999).

Data analysis involved the use of appropriate descriptive statistics to estimate the rates and dynamics of adoption. Probit and Logit models were used to investigate the determinants of farmers' adoption of *Mucuna* fallow, while the assessment of the economic benefits was made using the conventional benefit:cost analysis, Cobb-Douglas production function, and ranking of farmers' preferences.

Results and discussion

Dynamics of Mucuna *fallow diffusion*

Mucuna was introduced in 1987 in a village field to demonstrate its effect on soil fertility alongside other improved technologies, such as alley farming and live mulching. A small number of demonstration plots of *Mucuna* fallow were established (often on local school grounds) and visits by farmers were encouraged (Versteeg and Koudokpon 1990). The next year, 15 farmers asked for seed to test the technology in their own *Imperata*-infested fields. The advantage of using *Mucuna* to suppress weeds, reducing the need for either manual weeding or herbicide, was an unexpected benefit identified by the farmer collaborators and resulted in some spontaneous adoption. In 1989, the research team observed that 103 farmers in the neighborhood had planted *Mucuna* (Versteeg and Koudokpon 1990). This spontaneous adoption was based on what farmers had seen through project demonstrations in 1986 and 1987 and on other farmers' fields in 1988.

The government extension services, Centre d'Action Régional pour le Développement Rural (CARDER), became interested in this success and started testing the system with farmers. In 1990, the CARDER for Mono province tested the system in 12 more villages with 180 farmers. They expanded the process to other southern provinces in 1991 and the number of farmers testing *Mucuna* grew to approximately 500 (IITA 1991). In addition, large NGOs such as Sasakawa Global 2000, Centre Régional pour le Développement et la Santé (CREDESA), and Project de Développement de l'Elevage dans le Borgou Est (PDEBE) became involved in the diffusion of *Mucuna*. Sasakawa Global 2000's effort started in 1992 when it purchased about 4 tonnes of *Mucuna* seed from farmers who were already exposed to the technology through the RAMR project in Mono province. This *Mucuna* seed was distributed free of charge to 128 targeted farmers in all provinces confronted with *Imperata* invasion and/or soil fertility depletion. Thus, many farmers throughout the country were given the opportunity to try the technology, evaluate it, and decide whether to adopt it. A spontaneous diffusion ratio of seven new farmers for every single farmer reached by Sasakawa Global 2000 was observed in Benin (Galiba et al. 1998), indicating that farmer-to-farmer diffusion played an important role in the diffusion process. Sasakawa Global 2000 has repeatedly purchased *Mucuna* seed from collaborating producers to expand the diffusion of the technology. Fifteen tonnes of *Mucuna* seed were distributed free of charge to farmers who were supposed to give back the same quantity for further distribution. The estimated number of farmers testing *Mucuna* increased to 3000 in 1993 (IITA 1993) and nearly 10 000 in 1996 (and 100 000 were exposed to the technology in 1996) throughout Benin (Versteeg et al. 1998; Galiba et al. 1998; Vissoh et al. 1998). Recent estimates (Honlonkou and Manyong 1999) indicate that more than 14 000 farmers were using *Mucuna* in 1997 in southern Benin (Fig. 1).

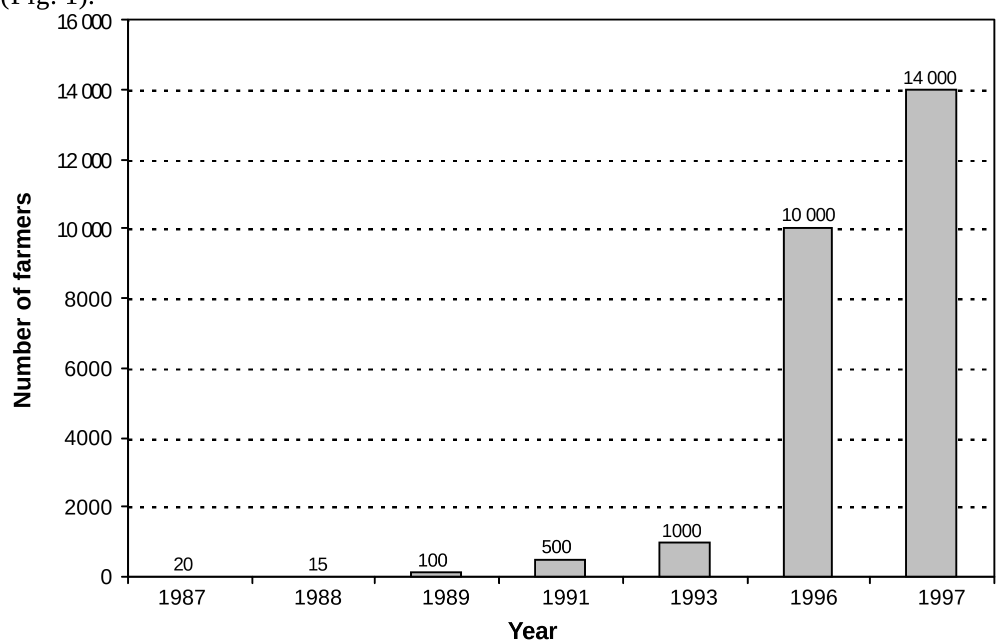

Figure 1. Evolution of use of *Mucuna* by farmers in Benin (1987–1997).

Rates of adoption of Mucuna *fallow*

Various rates of adoption have been reported by various authors in different villages and periods, attesting to the dynamics in the adoption process. Manyong et al. (1996) found that the rates of adoption of *Mucuna* in the initial research villages were as high as 52% of farmers. However, a rate of only 21.1% was recorded when adoption was defined by the number of fields that were planted with *Mucuna*, and whether the farmer was satisfied with using the technology in the survey field and was willing to continue using it, either in the same field or another field that could require the same intervention (Manyong and Houndékon 1997; Houndékon et al. 1998). In this definition, it is the field, not the farmer, that is considered as the unit of adoption.

In their survey of 128 farmers who received *Mucuna* seed from 1992 to 1994, Galiba et al. (1998) found that 74% of these farmers had used *Mucuna* fallow for at least 3 years consecutively while 83% had used it for 2 consecutive years. The remaining participating farmers had either used *Mucuna* from time to time or had abandoned it. The occasional use of *Mucuna* suggests that some farmers have recourse to the technology only when their plots are exhausted and/or invaded by *Imperata*.

Figure 2 shows the rates of adoption of *Mucuna* technology by provinces. Regional differences in the adoption rate were noticed between the south (71%) and the north (41%). The rates of rejection were more important, approximating to 50% in the northern provinces. The low adoption rate in the northern provinces could be explained by the fact that abundant cropping land still exists due to the low population density (< 25 people/km^2). In addition, *Imperata* is not often a problem in the drier zones. Farmers located in the north specialize in cotton production, and have relatively easy access to chemical fertilizers from the cotton companies. Late relay planting does not allow *Mucuna* to accumulate much dry matter or to produce seed.

A survey of 142 farmers who had been exposed to the technology over a period of 5 years indicated that 63% of the participating farmers used the technology for at least 3 consecutive years (Galiba et al. 1998). Floquet et al. (1996) also estimated that 50% of farmers had adopted *Mucuna* in their six research villages in southern Benin.

Another study of 580 farmers was conducted in 1998 to examine the dynamics in the diffusion and adoption of *Mucuna* (Honlonkou et al., in preparation) in new areas where *Mucuna* had been introduced recently. The results showed (1) that the rate of adoption of *Mucuna* in the new areas was about 7%, and (2) that the rates had increased steadily from 1991 to 1996 (Fig. 3). In 1996, the rate of adoption was three times higher than in 1994, due to the intensified effort of extension services such as Sasakawa Global 2000 in technology dissemination. Although the

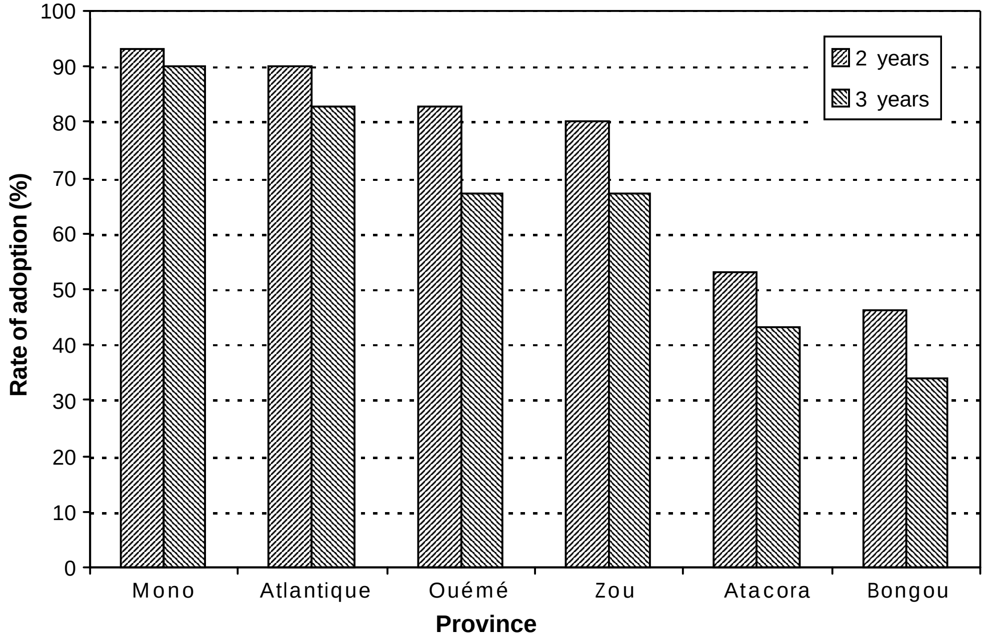

Figure 2. Rate of adoption of *Mucuna* fallow in Benin by province and consecutive years of use. Adapted from Galiba et al. (1998).

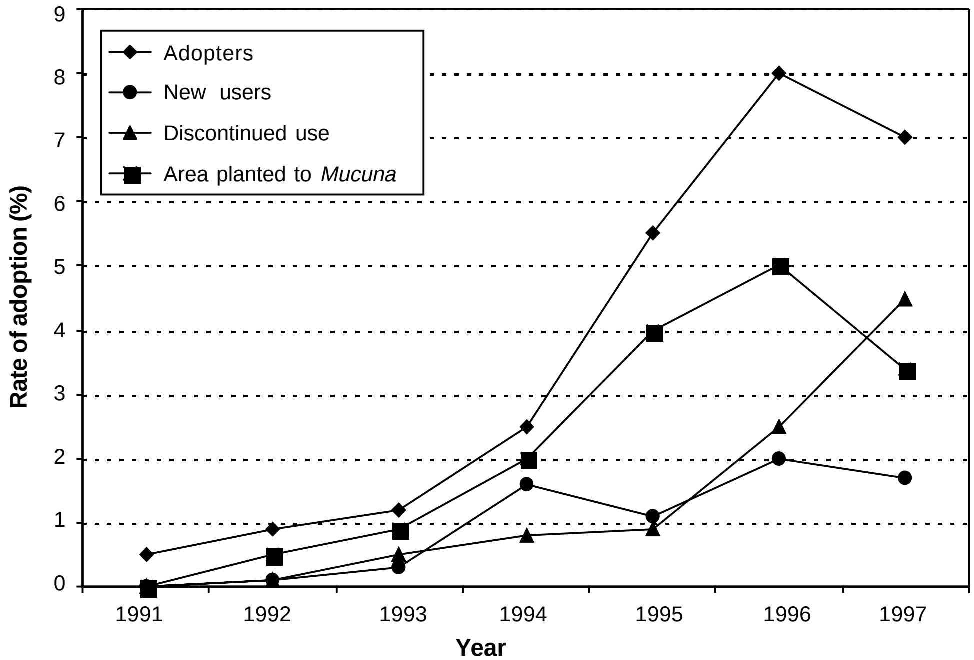

Figure 3. Dynamics of *Mucuna* fallow adoption in southern Benin (1991–1997).

present adoption rate seems to be low compared to that in the initial villages, it is important to note that this rate still indicates a promising technology when compared to other forms of technology previously introduced in the area. For instance, a new improved maize variety was adopted by only 7% of farmers in the same sample. Furthermore, extrapolating the adoption rate of 7% from the survey sample in 1997 to the total number of potential adopters in the three southern provinces covered by the study, it can be estimated that about 14 000 farmers would be considered as users of *Mucuna* in 1997 (Honlonkou and Manyong 1999).

It can be concluded, therefore, that the current rate of adoption of *Mucuna* is promising, especially in the south where there is a strong need to eradicate *Imperata* and enhance soil fertility.

Determinants of adoption of Mucuna *fallow in southern Benin*

The analysis of the determinants of farmers' adoption of *Mucuna* was conducted on a sample of 277 farmers and 446 fields in Mono province, using Probit and Logit models (Houndékon et al. 1996; Manyong et al. 1996; Manyong and Houndékon 1997; Houndékon et al. 1998). Both models yielded similar results. The dependent variable was defined as a field that had been planted with *Mucuna* at least once, or never; and whether the farmers were satisfied with the use of *Mucuna* and willing to continue its use in the same field or in any of their fields. Three sets of explanatory variables were included in the model: farm specific characteristics, technology specific attributes, and farmers' socioeconomic characteristics.

Estimates of the results of the Probit model are presented in Table 1. The model predicted correctly 89.5% of adopters and nonadopters. Variables found to have a significant and positive effect on the probability of adoption of *Mucuna* fallow are number of weedings during the cropping season, land tenure security, type of soil, farmers' perception of poor soil fertility status of the land, farmers' age, age of palm trees in the field, farmer contact with extension services, market opportunity for *Mucuna* grain, and other attributes specific to *Mucuna* (itching, palatability). Variables that have a significant and negative impact on adoption are the amount of land under fallow and the loss of the second season.

The computed elasticities of the probability of adoption indicate the effects on adoption of changes in the independent variables, measured at the means of the variables (Table 1). Results show that the elasticity of adoption is highest for the number of weedings (1.37), followed by land security rights (0.83), contact with extension services (0.59), farmer's age (0.59), and type of soil (0.58). This result on the highest elasticity of the number of weedings required during the cropping season

Table 1. A Probit model of the estimates of the determinants of farmers' adoption of *Mucuna* fallow in southern Benin

Variable	Coefficient estimate	Standard error	T value	Elasticity at means	Weighted aggregate elasticity
Farm size	0.0033	0.0092	0.3633	0.1171	0.04064
Farmer's age	0.02185***	0.0083	2.6206	2.0235	0.58606
Education	–0.1298	0.3557	–0.0365	–0.0027	–0.0010
Membership of association	–0.3873	0.2795	–1.3856	–0.5632	–0.17730
Dependency ratio	0.021255	0.5861	0.3626	0.144484	0.03975
Gender	0.20675	0.2763	0.7483	0.299754	0.0911902
Extension contact	1.1321***	0.3698	3.3596	1.7031	0.5883
Land tenure security	1.3543***	0.4682	2.9264	2.2954	0.83928
Soil fertility	0.5732**	0.2239	2.5599	0.58922	0.19288
Soil type	0.99151**	0.4909	2.0020	2.0633	0.57884
Fallow land size	–0.017746	0.0079	–2.2302	–0.36110	–0.10178
Mucuna cash income	0.0001**	0.0000	2.4743	0.27091	0.10380
Seed availability	0.18597	0.3086	0.6026	0.10258	0.0333
Nonconsumption of *Mucuna*	0.0347	0.2410	0.1439	0.0482	0.0134
Second season	–0.4439**	0.2159	–2.0564	–0.5142	–0.1247
Age of palm trees	0.14139**	0.0623	2.2693	0.3176	0.10602
Number of weedings	0.6304***	0.0754	8.3617	2.5383	1.3673
Lack of market	0.43308	0.3035	1.4428	0.7993	0.2279
Snakes	–0.3504	0.2507	–0.1398	–0.1564	–0.0057
Itching	0.4411*	0.2386	1.8486	0.4490	0.1668
Palatability	0.4766*	0.2861	1.6657	0.2055	0.0683
Population density	–0.1137	0.3593	–0.3165	–0.15627	–0.0319
Constant	–7.3680***	0.9944	–7.4091	–16.478	–4.7591
Likelihood ratio test	246.8				
McFadden R^2	0.53				
Percent of right predictions	89.46				

***Significant at 0.01; **significant at 0.05; *significant at 0.10.
Source: Houndékon et al. (1996).

is consistent with other survey results that showed that the majority of farmers (76%) adopted *Mucuna* primarily to control *Imperata* (Houndékon et al. 1998). An increase of 10% in *Imperata* infestation would increase the probability of adoption to 25.3%. Similarly, increasing the number of farmers having contact with extension services would result in a 17% adoption rate. In the same vein, improving land tenure security for an additional 10% of farmers would lead to an adoption rate of about 22%.

The predicted probabilities of adoption of *Mucuna* fallow were also computed to assess the changes in the rate of adoption of *Mucuna* fallow with changes in some key explanatory factors such as soil degradation, opportunity for selling *Mucuna* seed, contact with extension, security over land rights, number of weedings, or their combination (Table 2). The results showed that increasing farmers' tenurial rights over land would increase the probabilities of adoption from 21.1% to 22.4%. Improving market opportunities for *Mucuna* seed would lead to a 41% adoption rate. In areas where farmers are forced to practice more than four weedings due to severe *Imperata* infestation, the probabilities of adoption would increase by 85% to reach 39% of all farmers. A combined change in the field characteristics and other factors would substantially increase the adoption rates. In areas where soil is degraded and needs more than four weedings for weed control, better access to extension services, and greater tenurial security would boost the adoption rate of *Mucuna* fallow to 72% or an increase of 241% from the current rate of 21.1%. In addition to this, creating market opportunities for *Mucuna* seed would increase the rate of adoption to about 85%.

Table 2. Predicted probabilities of adoption by selected farm characteristics and institutional factors

No.	Farm characteristic and institutional factor	Rate of adoption (%)
1	All fields are degraded	25.1
2	Fields requiring four weedings before maize harvest	39.1
3	Access to extension services	24.2
4	Land tenure security	22.4
5	*Mucuna* cash income	40.5
6	Combination of 1 to 4	71.6
7	Combination of 2 to 5	84.8

Source: Houndékon et al. (1998).

Table 3. Constraints to farmers' adoption of *Mucuna* fallow

Reason	No. of farmers	%
Loss of a second season	57	42
Insecure land property rights	25	19
Unavailabilty of seed	21	16
Lack of information	16	12
Others	15	11

Source: Houndékon et al. (1998).

Constraints to farmers' adoption of Mucuna *fallow*

While the current rate of adoption of *Mucuna* by smallholders in Benin is promising, its acceptance as a profitable agricultural practice faces many constraints. Table 3 shows the main constraints limiting farmers' adoption of *Mucuna* fallow. Survey results showed that the loss of a second season crop was the most important constraint limiting adoption of *Mucuna* for 42% of farmers. Other constraints included land scarcity, land tenure insecurity, lack of availability of *Mucuna* seed, lack of information, bush burning, a limited range of associated crops, and toxicity of *Mucuna* seed for human consumption and animal feed.

Although intensive use of the land is the cause of its degradation, farmers with very little land are reluctant to plant *Mucuna* because of the cost of land dedicated to a crop with no direct economic use. They are forced to cultivate their exhausted plots in the hope of harvesting something. Similarly, farmers with insecure land property rights have little or no incentive for the adoption of *Mucuna* and other sustainable land-use practices. Another constraint mentioned is related to the limited range of crops suitable for intercropping with *Mucuna*. Intercropping of *Mucuna* is confined to maize, sorghum, and millet. This limits its adoption in other cropping systems since *Mucuna*, an aggressive cover crop, cannot be intercropped with short stature crops such as tomato, cowpea, and groundnut, or with long duration crops such as cassava and plantain. Also, bush burning, especially during the dry season, a very common practice in the West Africa savannas, has been observed to destroy the accumulated *Mucuna* mulch in the dry season. Burning of *Mucuna* fallow biomass can be prevented by forming fire-breaks around plots. However, this is labor demanding and farmers might not find it worthwhile.

Until recently, *Mucuna* beans were not consumed by humans and animals in Benin. *Mucuna* contains substantial quantities of the toxin 3-(3,4-dihydroxyphenyl)-L-alanine, known as L-DOPA, which makes it unsuitable for human consumption if not detoxified. Nevertheless, effforts are underway (Versteeg et al. 1997; 1998) to process *Mucuna* seed and to promote recipes including mixed *Mucuna* flour and maize or cassava flour for human consumption. Popularizing consumption of *Mucuna* grain would increase the market for *Mucuna* seed and stimulate adoption of the cover crop. This is therefore a useful avenue of research. Consumption of *Mucuna* hay by animals will also increase farmers' incentives to adopt *Mucuna*.

Economic impact of Mucuna *diffusion*

Galiba et al. (1998) reported that more than 50% of farmers derived an average of FCFA 10 000 from the sale of *Mucuna* grain, and about 20% obtained more than

FCFA 25 000. Some farmers have specialized in the production of *Mucuna* seed and obtained more than FCFA 100 000 from the sale. An assessment of the economic impact of *Mucuna* (Vissoh et al. 1998) indicated that high returns are achieved 3 years after *Mucuna* is adopted at both farmer and regional levels. If *Mucuna* seed can be sold, then the system is economically beneficial from the first year of introduction of the technology. An *ex ante* benefit:cost analysis over a period of 8 years indicated a ratio of 1.24 when *Mucuna* was included in the system, and 0.62 for the system without *Mucuna*. The ratio was as high as 3.56 if *Mucuna* seed were sold (Table 4). However, yearly analysis of the benefit:cost ratio indicated a declining trend over

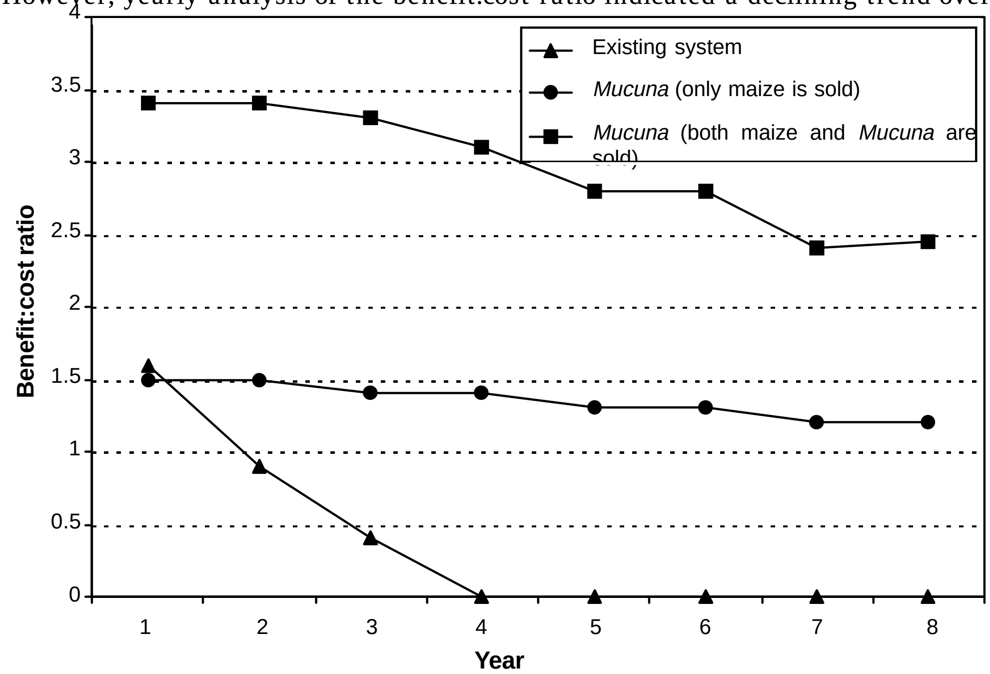

Figure 4. Trend of benefit:cost ratio for systems without and with *Mucuna* in Benin.

Table 4. Average future cost and returns over 8 years of systems with and without *Mucuna* planted fallow in Mono province, Benin

	With *Mucuna*		Without *Mucuna*
	Scenario 1[a]	Scenario 2[b]	
Gross returns (US$/ha)	354	836	110
Variable costs (US$/ha)			
Seed (US$/ha)	9	9	4
Labor (US$/ha)	276	276	172
Net revenue (US$/ha)	69	620	–66
Benefit:cost ratio	1.24	3.56	0.62
Marginal rate of returns (%)	124	629	

[a]Only maize seeds are sold. [b]Both maize and *Mucuna* seeds are sold.
Source: Vissoh et al. (1998).

time for all systems, suggesting that the addition of external inputs (probably P and K fertilizer) is required in order to achieve full sustainability (Fig. 4). Adoption of *Mucuna* throughout Mono province would result in savings of about 6.5 million kg of nitrogen or about US$1.85 million per year.

Changes in factor productivity and distribution as a result of the adoption of *Mucuna* fallow were also estimated (Table 5). Cobb-Douglas production functions were used to examine structural changes caused by the adoption of *Mucuna* technology; i.e., whether the coefficients of maize production function on *Mucuna* plots are different from those of maize production on plots without a previous *Mucuna* fallow. The factors considered in the analysis are land, labor, fertilizers, and seed.

The results showed that the adoption of *Mucuna* led to the reduction of labor use by 2%. This is intuitive since *Mucuna* adoption reduces the number and frequency of weedings. *Mucuna* adoption increased maize yield in farmers' conditions by 30% only. Although these results are significantly lower than the figures of 200–400% yield increases found in experimental trials, they nevertheless indicate a comparative advantage of *Mucuna* in increasing maize yield, reducing labor, and restoring soil fertility on degraded soils. The results also showed that the revenue to land increased by 14% and to labor by 20%, suggesting that *Mucuna* improved the competitiveness of agricultural systems in southern Benin. The results of homogeneity tests between systems with and without *Mucuna* show that systems with *Mucuna* experienced a structural shift in the production function (F_i = 10.93 significant at 5% confidence level) caused mainly by the difference in the intercept or difference in the productivity (F_g = 3.24, significant at 5% confidence level) rather than in difference of the slope (F_p = 1.69, not significant at 10% confidence level).

Impact of Mucuna *on farmers' fields*

Mucuna was introduced to farmers to restore soil fertility. However, farmers were most impressed by the ability of *Mucuna* to smother the rampant weed *Imperata cylindrica*. *Mucuna* was thus most valued as a weapon against *Imperata*, reducing the number of *Imperata* plants from 270 to 32/m^2. Fields that needed an estimated 60–80 person days/ha to extirpate the weed, were now freed with a fraction of the labor effort (Versteeg et al. 1997).

Mucuna's ability to restore soil fertility was also important, resulting in 70% higher maize yields than on continuously cropped fields. Even some very depleted fields, where maize had given almost no yield, seemed to perform much better after *Mucuna*. This observation prompted researchers to propose *Mucuna* to farmers as one option to recover completely depleted soils (locally indicated as the

Table 5. Estimates of the production function of maize (kg/ha) for systems with and without *Mucuna* in southern Benin, 1997

Production factor	Maize production system		Pooled data (n = 469)	Pooled data with dummy (n = 469)
	Without *Mucuna* (n = 390)	With *Mucuna* (n = 79)		
Intercept	2.61**	3.08**	2.63**	2.64**
	(14.66)	(8.21)	(16.23)	(16.45)
Land	1.01**	–0.39	0.87**	0.84**
	(5.26)	(–0.90)	(4.94)	(4.79)
Fertilizer	0.05**	–0.04	0.05	0.05**
	(2.21)	(–0.79)	(2.27)	(2.08)
Seed	0.02	0.88**	0.11	0.12
	(0.11)	(2.40)	(0.79)	(0.87)
Labor	0.17	0.67**	0.22**	0.23
	(1.62)	(2.45)	(2.19)	(2.27)
Capital	–0.01	–0.03	–0.01	–0.02
	(–1.13)	(–1.32)	(–1.12)	(–1.51)
Mucuna	–	–	–	0.32**
				(3.31)
R^2	0.57	0.60	0.56	0.57
F	100.30**	21.46**	119.39**	103.45**
Homogeneity tests				
Sum of squared regression residuals	234.44	33.17	279.00	272.55
Degrees of freedom	384	73	463	462
Computed F		F_g = 3.24**	F_p = 1.69	F_i = 10.93**

**Significant at 0.05.
F_i = test for production system effects, F_p = test for homogeneity of slopes, F_g = test for difference of intercept.
Figures in parentheses are t statistics, n = number of plots.
Source: Manyong and Honlonkou (1999).

"*Mucuna* shock treatment for comatose soils"). Farmers who adopted *Mucuna* increased their maize yields from 480 to 1140 kg/ha. Galiba et al. (1998) also reported that *Mucuna* fallow increased yield from 600 to 2200 kg/ha compared to the system without *Mucuna*. These results were so satisfactory that *Mucuna* was taken as the general extension message for depleted soils wherever there was an *Imperata* problem. In Mono province, Versteeg and Koudokpon (1990) indicated that *Mucuna* reduced *Imperata* density to less than 10% of its initial density on farmers' fields. However, farmers working with Sasakawa Global 2000 reported a complete elimination of *Imperata* after only two to three consecutive *Mucuna* crops (Galiba et al. 1998).

Farmers' assessment of the benefits of Mucuna *technology*

Table 6 presents the results of pair-wise comparison between *Mucuna* and inorganic fertilizer using a 5-scale point with 10 items. The results show that 79% of farmers were satisfied with *Mucuna* fallow because of the following major at-

Table 6. Farmers' preference ranking (satisfaction score in % of farmers) of *Mucuna* fallow and inorganic fertilizers in Benin, 1998

Technology	Criteria										
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
Mucuna fallow (1)	91	83	88	49	88	80	92	31	89	95	79
Chemical fertilizer (2)	84	45	49	36	74	24	7	63	27	80	49
Difference (1) – (2)	7	38	39	13	14	56	85	-32	62	15	30

Criteria codes: C1 = short-term effects on soil fertility; C2 = long-term effect on soil fertility; C3 = availability of the technology; C4 = weed suppression; C5 = auto-diffusion; C6 = does not degrade soil fertility in the long run; C7 = weed control; C8 = appropriate for rented land; C9 = cheap; C10 = willingness to use the technology again; C11 = global appreciation.
Source: Honlonkou and Manyong (1999).

tributes cited in decreasing order of importance: weed control, soil fertility improvement in both the long and short term, low cost, availability, and auto-diffusion. The results further reveal that the majority of farmers (60%) were not satisfied with chemical fertilizer in 6 out of the 10 criteria, but were dissatisfied with *Mucuna* in only 2 out of the 10 criteria (Honlonkou and Manyong 1999).

In general, the study found that farmers derived more satisfaction in adopting *Mucuna* than in applying fertilizers, except on rented lands. The results showed that farmers are satisfied with *Mucuna* technology and are willing to continue using it in other fields.

Prospects for human consumption of Mucuna

Mucuna protein content is high (26%), and its quality is comparable to that of soybean. However, farmers in Benin were not aware of *Mucuna* consumption. Through interregional contacts, it was revealed that farmers in Ghana regularly used small quantities of *Mucuna* seed in the daily preparation of common sauces and stews (Osei-Bonsu et al. 1995). However, information and tests revealed that *Mucuna* seed contains substantial quantities of toxin (L-DOPA) which make it unsuitable for human consumption. This information led to the investigation of ways to promote the utilization of *Mucuna* in flour preparations that are acceptably free of toxic substances, and easily incorporated into staple dishes, as a complement to or a substitute for maize flour. Significant progress has been achieved in reducing the toxicity of *Mucuna* seed and in developing simple recipes for incorporating *Mucuna* flour in daily dishes (Versteeg et al. 1998). Prospects are favorable that properly treated *Mucuna* seed can be consumed in significant quantities. Field testing of food-processing techniques and acceptability among smallholder households in Benin should be continued, and promotional strategies for specific food products should be developed (Lorenzetti et al. 1998). There is no doubt that the human consumption of *Mucuna* seed and feed for animals will increase farmers' incentives to adopt *Mucuna*. Moreover, it will have a substantial impact on household food security, nutrition, and the alleviation of poverty.

Conclusions

This paper examined the impact of *Mucuna* fallow diffusion in the densely populated provinces of southern Benin where it was introduced to restore soil fertility and prevent soil degradation due to high population pressure and land-use intensification practices. Although *Mucuna* was primarily introduced to restore soil fertility, its ability to suppress *Imperata cylindrica*, a particularly noxious weed in southern Benin, provided a window of opportunity for farmer adoption. The positive impact of *Mucuna* in smothering *Imperata* led to its impressive diffusion and uptake by more than 14 000 farmers. The rates of adoption of *Mucuna* ranged from 7% in new areas where the technology was recently introduced to 84% among the farmers who had been exposed to the technology previously through on-farm trials in their area.

The analysis conducted with the Probit model showed that the most important factors influencing farmer adoption of *Mucuna* were land tenure security, weed infestation, contact with extension services, and other farm-specific variables. These important factors can be used in conjunction with agroecological factors to target *Mucuna* fallow to farmers in other environments. Results from the analysis showed that policies aimed at improving farmers' access to extension services and to secure land tenure, as well as creating market opportunities for *Mucuna* grain, will result in higher adoption rates in areas where weed infestation and soil degradation pose major problems to agricultural production.

The economic analysis showed that systems with *Mucuna* have a higher benefit:cost ratio than systems without *Mucuna*. These benefits increased substantially in the scenario where both *Mucuna* and maize grain are sold. A considerable proportion of farmers could derive cash income from the sale of *Mucuna* seed. The adoption of *Mucuna* led to changes in factors' productivity, increasing yields, improving soil fertility, and reducing labor for weeding. These results corroborate recent findings that revealed that maize production under *Mucuna* technology was financially competitive and socially profitable to farmers (Adesina and Coulibaly 1998).

Farmers' assessment of *Mucuna* revealed that farmers preferred *Mucuna* to inorganic fertilizers. Suppression of *Imperata cylindrica*, low capital requirement, and easy availability at the village level were perceived to be the major benefits of *Mucuna* fallow, and therefore provided a window for rapid adoption and diffusion.

An important factor in the diffusion of *Mucuna* in Benin was the collaboration between researchers and farmers in technology development and experimentation, and the involvement of governmental and nongovernmental extension services in technology dissemination.

Mucuna fallows have thus great potential to improve soil productivity and reclaim weed-infested lands. Therefore, their use as an alternative to shifting cultivation has to be encouraged and promoted. A short fallow of *Mucuna* may reduce by half the amount of nitrogen fertilizer required to grow a subsequent cereal crop, thus having a large economic and environmental impact for the region.

The suppression of *Imperata cylindrica* acted as a “window” or an “entry point” for the acceptance of the *Mucuna* technology by farmers in the humid savannas. The processing of *Mucuna* seed to eliminate the L-DOPA toxin, and the promotion of *Mucuna* for human consumption will certainly lead to a breakthrough in the adoption and impact of the technology. If this major constraint is solved, *Mucuna* is likely to be widely adopted as a staple legume. Other windows of opportunity for *Mucuna* may exist and should be identified with active farmer participation to provide incentives for its adoption. These might include control of *Striga hermonthica* parasitic weeds, or nematode infestation, or to provide dry season livestock feed in the dry savanna.

The dynamics of rapid diffusion and adoption of *Mucuna* fallow in Benin suggest that there are great prospects for adoption and impact in West Africa. However, *Mucuna* may not be the sole alternative sustainable soil conservation technology to be adapted in all farming systems. Whenever other choices are available, information becomes important. A legume expert system (LEXSYS), developed at IITA for integrating herbaceous legumes into farming systems, is a good start in that direction (Weber et al. 1997). Better communication is needed in order to allow researchers, extension services, and farmers in various parts of West Africa to benefit from each other’s experiences. The recent establishment of the Centre d’Information et d’Echanges sur les Plantes de Couverture en Afrique (CIEPCA) will surely speed up the exchange of both information and germplasm of cover crops, all of which would contribute to a wide dissemination and adoption of cover crops such as *Mucuna* for sustainable agriculture in Africa.

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About IITA

The International Institute of Tropical Agriculture (IITA) was founded in 1967 as an international agricultural research institute with a mandate for improving food production in the humid tropics and to develop sustainable production systems. It became the first African link in the worldwide network of agricultural research centers known as the Consultative Group on International Agricultural Research (CGIAR), formed in 1971.

IITA is governed by an international board of trustees and is staffed by approximately 80 scientists and other professionals from over 30 countries, and approximately 1300 support staff. Staff are located at the Ibadan campus, and also at stations in other parts of Nigeria, and in Benin, Cameroon, Côte d'Ivoire, and Uganda. Others are located at work sites in several countries throughout sub-Saharan Africa. Funding for IITA comes from the CGIAR and bilaterally from national and private donor agencies.

IITA's mission is to enhance the food security, income, and well-being of resource-poor people, primarily in the humid and subhumid zones of sub-Saharan Africa, by conducting research and related activities to increase agricultural production, improve food systems, and sustainably manage natural resources, in partnership with national and international stakeholders. To this end, IITA conducts research, germplasm conservation, training, and information exchange activities in partnership with regional bodies and national programs including universities, nongovernmental organizations (NGOs), and the private sector. The research agenda addresses crop improvement, plant health, and resource and crop management within a food systems framework and targeted at the identified needs of three major agroecological zones: the savannas, the humid forests, and the midaltitudes. Research focuses on smallholder cropping and postharvest systems and on the following food crops: cassava, cowpea, maize, plantain and banana, soybean, and yam.

Cosponsored by the World Bank, the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), and the United Nations Environment Programme (UNEP), the CGIAR is an informal association of over 40 governments and about 15 international organizations and private foundations. The CGIAR provides the main financial support for IITA and 15 other international centers around the world, whose collective goal is to improve food security, eradicate poverty, and protect the environment in developing countries.

This is one of a series of publications about the impact of IITA's work. The publications describe impact studies, conducted by multidisciplinary teams, which aim ultimately to confirm that IITA's research fulfils its mission to enhance the food security, income, and well-being of resource-poor people in sub-Saharan Africa.

IMPACT
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