Analysis of Alternative Fallow Systems for Rice Production in the Savannah Soils of West Africa: a Risk-Efficiency Approach

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Abstract: In the savannah regions of West Africa, traditional natural fallow systems can no longer sustain cropping systems because of increasing human and livestock populations. These fallow systems have become short in duration and because farmers cannot afford chemical fertilizers, productivity has been declining over the years. An alternative short-duration, improved fallow system, which incorporates the cover crop, *Callopogonium mucunoides* was investigated in a rice production system in the northern savannah zone of Ghana, West Africa. The *C. mucunoides* improved fallow system was compared with a traditional natural bush fallow and a continuous rice cropping systems in terms of rice yields, incomes and risk efficiency. Mean yields and incomes from the improved fallow cropping sequence were significantly higher than those from the other cropping sequences. Results from stochastic dominance approach to ranking alternatives suggest that the improved fallow system involving *C. mucunoides* is more risk-efficient than the traditional natural follow system.
Keywords: rice yield, income, risk efficiency, stochastic dominance, fallow system, Ghana

1 Introduction

One of the key limiting factors to agricultural production in West Africa is declining soil fertility resulting from frequent use of land without adequate replenishing of lost nutrients (Tarawali *et al*., 1999). Natural bush fallowing and shifting cultivation primarily to restore soil fertility can no longer be sustained due to increasing human and livestock population pressures (Tarawali *et al*., 1999). Removal of subsidies on chemical fertilizers has resulted in a wide gap between current levels of chemical fertilizer use and the required level mainly because most farmers can no longer afford chemical fertilizers (Donhauser *et al.*, 1994). The use of animal manure as an alternative to chemical fertilizer is constrained by inadequacy, transport and labor costs (Langyintuo and Karbo, 1998). Cover cropping has the potential for minimizing the loss of nutrients and soil organic matter in the savannah regions of northern Ghana. For example, leguminous cover crop fallows can contribute to soil N (Tarawali *et al*., 1999), soil organic matter (Tian *et al*., 1999), soil physical properties (Wilson, 1982), and improve crop yield (Tian *et al*., 1999).

The Savanna Agricultural Research Institute (SARI) in Ghana in collaboration with the West African Rice Development Association (WARDA) in Cote d'Ivoire developed a short duration leguminous cover crop, *Callopogonium mucunoide*, fallow system for rice (*Oryza spp*.) production in northern Ghana, West Africa. This study compares the *C. mucunoides* improved fallow system with a traditional natural bush fallow and a continuous rice cropping systems in terms of rice yields, incomes and risk efficiency. Although the study is limited in scope, the results and study method is applicable to similar resource-limited farming systems in the tropics.

2 Study methods

2.1 Site description

The study area is the Tolon Kumbungu district of northern Ghana in West Africa, which lies between latitudes 8° 30′N and 0° 30′E. It is in an undulating plain with an altitude of 100 — 200 meters above sea level. It has a distinct rainy season from May to October with a mean annual rainfall of 1100 m and a dry season from November to April. Mean annual temperature range is 27°C to 28°C. It is situated in the voltaian sandstone basin, with savannah glycols and savannah ochrosols as parent materials. The main clay minerals are kaolinite and illite. Soils are usually well drained but because of prevailing clay minerals and low organic matter content, the water storage and cation exchange capacities are very low (Donhauser *et al.*, 1994).

In the Tolon Kumbungu district, farm sizes range from 3 to 20 ha with a mean of 9.2 ha. Lands are cropped for five to seven years before allowing them to lie fallow for an average of two years. Rice, sorghum (*Sorghum bicolor*), millet (*Pennisetum typhoideum*), maize (*Zea mays*), cowpea (*Vigna unguiculata*), groundnuts (*Arachis hypogaea*), cassava (*Manihot esculenta*) and yam (*Dioscorea spp*.) are planted in various mixtures. However, rice (which accounts for 30% of the cultivated area) is cultivated as a sole crop by most farmers (97%). Rice fields are ploughed by tractor and seeds broadcast (at the rate of 80 $kg{\cdot}ha^{-1}$) before harrowing. Weeding is by hand scouting and harvesting by combine harvesters. Farmers who can afford chemical fertilizer apply 30 $kg{\cdot}ha^{-1}$ each of NKP (15-15-15) and sulphate of ammonia (or urea) as basal and top-dressings fertilizers, respectively. On-farm yields range from 800 — 1200 $kg{\cdot}ha^{-1}$.

2.2 Agronomic data and analysis

Agronomic data for the analysis were generated from on-farm rice production trials conducted by SARI in collaboration with WARDA on 10 farms in Yipeligu, in the Tolon-Kunbungu district of northern Ghana. The cropping systems studied included: (i) a short-duration improved leguminous cover crop fallow system, involving *Callopogonium mucunoides*, and planting to rice after the second year; (ii) a traditional natural fallow system, also maintained for two seasons before planting to rice; and (iii) continuous rice cropping as a control treatment. The fallow systems were established in 1992, and the rice cropping initiated from 1994—1996.

The experiment was a Randomized Complete Block Design with split-plots and four replications; each farmer constituting a block. Land was prepared using a power tiller. Two nitrogen fertilization rates were managed in the main plots and fallow system treatments varied in the split-plots. A medium maturity (120 days) rice variety (GR 19) was dibbled in at 20 cm × 20 cm, at 80 $kg{\cdot}ha^{-1}$. Sulphate of ammonia fertilizer was broadcast at 0 $kg{\cdot}ha^{-1}$ N and at 30 $kg{\cdot}ha^{-1}$ N (in two equal splits, two weeks after planting and at maximum tillering). Weed control was by hand scouting.

2.3 Risk efficiency analysis

To rank the technologies according to their risk characteristics, first- and second-degree stochastic dominance approaches were used because they rely on simple, intuitive observations on farmer behavior (Hien *et al.*, 1997; Hardaker *et al.*, 1998). The first-degree stochastic dominance (FSD) compares the cumulative probabilities of two alternatives (e.g. cropping practices). The alternative with the lower probability dominates the one with the larger probability. The second-degree stochastic dominance (SSD) is useful when the cumulative distribution curves of two choices cross and the FSD rule cannot rank them. The tendency for a choice to have low value outcomes is reflected by the area under the cumulative distribution function (CDF). For a given level of outcome, the choice with the greatest area under the CDF has the highest probability of low value results.

The CDFs were estimated using the relationship: $(1/t)(1/f_t)$, where t is the number cropping seasons, and f is the number of farmers participating in farming in year t (Hien *et al*., 1997). To determine if two

CDFs are significantly different, Lowenberg-Deboer and Aghib (1999) proposed using the Kolmogorov-Smirnov (K-S) two-sample test (Steele *et al*., 1997). Two CDFs are different if the maximum vertical distance between them exceeds the critical level for a given level of significance (e.g., α = 5%).

3 Results and discussions

3.1 Mean yields comparison

Rainfall level and distribution affected rice production and yields during the on-farm trials. The best growing condition occurred in 1996, while the worse was observed in 1994 when planting was delayed by late onset of rains. In contrast, heavy rains in 1995 delayed land preparation and planting. Average yields were highest in 1996 (Table 1). As expected, N fertilization improved grain yields for all three cropping systems (Table 1). Across all three years, the percentage increase in yield was highest for continuous cropping (78%), followed by the improved short-duration cover crop fallow treatment. This result is consistent with the finding that improved cover crop fallow systems release plant-available N from inorganic sources more slowly compared to the continuous crop treatments, but has long-term benefits to soil fertility than the continuous cropping system (Hoffmann *et al*., 2001).

An important finding from this study relates to the effect of the improved fallow treatment on farmer's practice involving no fertilizer application. Average yields for the three years for continuous rice (1,185 kg·ha^{-1}) and the natural fallow system (1,175 kg·ha^{-1}) were not significantly different with no N fertilization, but were significantly higher for the improved fallow system (1,304 kg·ha^{-1}). This suggests that, relative to the natural fallow system, N contribution from the leguminous cover crop made up for crop N requirements in the improved fallow. This finding is significant because farmers who cannot afford chemical fertilizer can use the leguminous cover crop-fallow to meet some of the crop nutrient requirements.

As expected, N fertilizer application resulted in significantly higher yields across all years. The impact of incorporating the leguminous cover crop in the improved fallow system in terms of contribution to soil fertility was less dramatic with (than without) fertilization (Table 1).

Table 1 Effect of cropping system on average yield of rice, 1994—1996

Treatment		Year				
Cropping system	Fertilizer rate	1994	1995	1996	Mean (1994—1996)	CV
	(kg·ha^{-1} N)	kg·ha^{-1}				(%)
Natural bush fallow	0	929a[1]	1,093a	1,502a	1,175	28.8
Improved fallow[2]	0	1,232b	1,269b	1,411a	1,304	13.1
Continuous rice	0	947a	1,122a	1,487a	1,185	29.5
Natural bush fallow	30	1,338b	1,602c	2,514b	1,818	30.9
Improved fallow	30	1,590c	2,230d	2,470b	2,096	20.1
Continuous rice	30	1,565c	2,246d	2,505b	2,105	22.7

[1] Means with the same letter (a,b,c,d) in a column do not differ significantly, $P < 0.05$

[2] Improved fallow treatment involved incorporating *Callopogonium mucunoides* into a natural bush fallow and managing the resulting agroecosystem for two years before planting to rice

3.2 Yield risk-efficiency comparison

Yield risk comparison for the three fallow cropping systems are presented for only the 0 kg·ha^{-1} N in Fig. 2 since that is the predominant practice in the area. In general, the cumulative distributions of the continuous cropping and bush fallow systems were to the left of the improved fallow system, implying that, the improved fallow system generated higher yields for most conditions than the other two systems.

The improved fallow treatment increased the probability of generating better yields under low to modest yield range; up to 1,360 kg ha^{-1} . This finding is important because it suggests that among the peasant farmers in the study region, the improved fallow system has the potential to improve rice yields, but beyond a certain limit, further yield increases may have to be generated from fertilization.

The improved fallow system also generated lower yield risk compared to the natural fallow and continuous cropping systems. The improved fallow system has a 60% chance of generating yields up to 1,342 kg ha^{-1} , compared to almost 90% chance with the natural bush fallow or 100% with continuous cropping treatment (Fig.1). In other words, the improved short-duration fallow system dominates continuous rice production according to the FSD criterion, and the natural bush fallow system according to the SSD. Furthermore, a K-S test indicates that the CDF of the improved fallow is statistically different from the CDFs of the other two cropping systems (at $\alpha = 5\%$). In contrast, the natural (bush) fallow and continuous rice cropping systems do not dominate each other. Thus, based on yield risk considerations alone, a risk-averse farmer would prefer the improved short-duration cover crop fallow system to the natural bush fallow and continuous rice cropping systems.

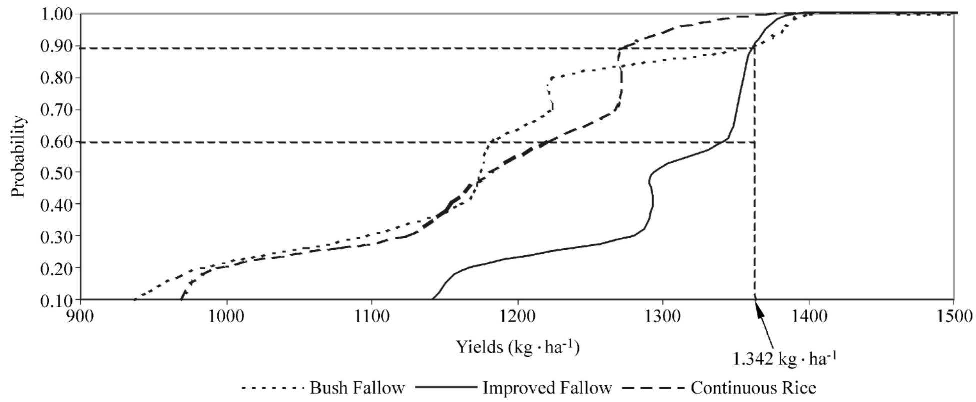

Fig. 1 Cumulative distributions of rice yield with 0 kg·ha^{-1} N, for alternative fallow cropping practices, 1994—1996

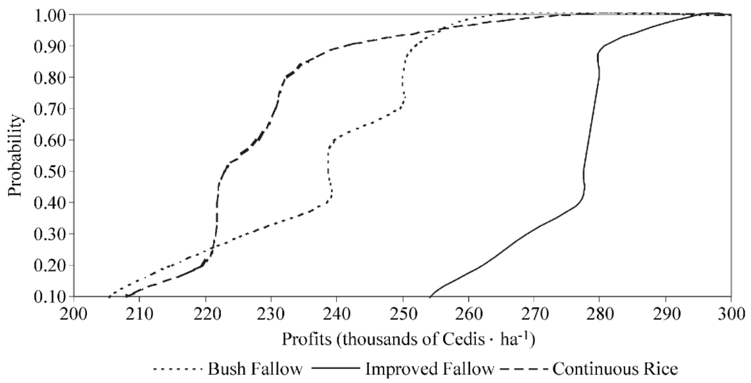

Fig. 2 Cumulative distributions of mono-cropped rice profits using 0 kg·ha^{-1} N, for alternative cropping practices, 1994—1996

3.3 Mean income comparison

Income from rice production was estimated in terms of returns to the farmer's family resources (i.e. land, labour, capital and management). Costs associated with land and management, for example, depend on location of the individual farm and managerial expertise. Thus, each farmer can then determine the net returns for each particular enterprise. The analysis was necessarily partial enterprise budgets, since the typical farm family produced other outputs that were not the focus of this study. Total variable cost was highest for the continuous rice system due largely to additional labour cost associated with weed control.

Average returns to farm family resources was highest for the improved fallow system, followed by the natural fallow cropping system and then the continuous rice, under the no fertilizer treatment regime (Table 2). Across the three years, farm income with the improved fallow system (Cedis 275,168 ha^{-1}) was greater than the natural bush fallow treatment (Cedis 238,200 ha^{-1}) by approximately Cedis 37,000 ha^{-1}. As with the yield comparison, average returns were significantly higher for cropping systems with fertilizer than the corresponding systems without fertilizer application. Under the 30 kg· ha^{-1} N fertilizer treatment regime, returns to farm family resources were higher for the improved fallow system (Cedis 610,154 ha^{-1}) compared to the cropping system with a natural (bush) fallow (Cedis 530,584 ha^{-1}). As with the mean yield comparison, the effect of the improved fallow system on farm returns was more dramatic with no N fertilizer than when 30 kg ha^{-1} of N fertilizer was applied. When no N fertilizer was applied, returns for the improved cover crop fallow was 20% higher than the continuous rice system. In addition, average returns for the improved fallow system was 16% higher than the system which used a traditional natural fallow. In contrast, returns to farm family resources with N fertilizer application for the improved fallow system decreased by 0.8% relative to continuous rice because of faster nutrient mineralization effects of the added fertilizer on continuous rice.

Table 2 Effect of fallow system and N fertilization on average returns, 1994—1996

Cropping system	Fertilizer rate (kg· ha^{-1} N)	Gross returns (Cedis· ha^{-1}) [1]	Total Variable Cost (Cedis· ha^{-1})	Returns to farm family resources (Cedis· ha^{-1}) [1]
Natural bush fallow	0	416,201 (51)	178,333	238,200 (39)
Improved fallow	0	446,314 (34)	171,250	275,168 (26)
Continuous rice	0	411,404 (49)	181,250	230,214 (39)
Natural bush fallow	30	773,684 (55)	243,100	530,584 (45)
Improved fallow	30	843,504 (42)	233,350	610,154 (28)
Continuous rice	30	858,801 (43)	243,766	615,035 (29)

Note: [1] Fig. in parentheses are coefficient of variation (%)

3.4 Income-risk efficient comparison

Results of the income risk efficiency comparisons are reported in Fig.2 for only the 0 kg ha^{-1} N for similar reasons as for the yield risk comparison. The improved, short-duration fallow cropping systems dominated the remaining two cropping systems based on the FSD criterion. The stochastic dominance results were also consistent with results using the K-S two-sample test where the CDF of the improved leguminous cover-crop fallow was different from the CDFs of the other two cropping systems (at $\alpha = 5\%$). The cumulative distribution of the improved short duration fallow treatment was to the right of the other cropping systems (Fig. 2). This suggests that the improved fallow system provide higher returns to farm family resources than the alternative systems.

4 Conclusions

The results suggest that, relative to the natural fallow system, N contribution from the leguminous cover crop made up for crop N requirements in the improved fallow. Thus, farmers who cannot afford chemical fertilizer can use the leguminous cover crop fallow to meet some of the crop nutrient requirements. The effect of incorporating the leguminous cover crop in the improved fallow system, in terms of contribution to soil fertility, was less dramatic with than without N fertilizer application. The results also support the conventional wisdom that while the improved fallow system has the potential to improve rice yields, beyond a certain limit, further yield increases may have to be generated from fertilization. Stochastic dominance of yield distributions from the improved fallow system was dramatic with no fertilization.

The improved fallow completely dominated the natural fallow treatment in terms of average returns to farm family resources and risk efficiency. The additional benefits of the leguminous cover crop in the improved fallow such as improvements in soil organic matter, made that cropping system even more appealing to farmers during the on-farm trials.

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