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Research paper

Assessing the diversity of smallholder rice farms production strategies in Sierra Leone

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SUMMARY

In Sierra Leone, several international organizations are trying to help the government improve the productivity of its rice farms, which currently have the lowest rice yields in West Africa. However, the various programmes attempting to increase rice production, and consequently rice self-sufficient food production, are handicapped by an absence of thorough studies explaining the way rice farmers take the available socio-economic, technical and natural production factors into account when making their decisions. The purpose of the current article is to assess rice production performance on smallholder rice farms in Sierra Leone. To achieve this goal, an agronomic and socio-economic survey was carried out among 180 rice farmers in the district of Bombali in Northern Sierra Leone. The survey, combined with a specific statistical analysis, made it possible to assess production strategies for rice farms according to various discriminant parameters (family size and composition, fallow duration, seeding density, labour availability, ecosystems, share of oil palm, distance from field to farm. . .).

This analysis revealed that the rice smallholder farms that perform best are those growing rice under two ecosystems together with oil palm. Those farms have more income to purchase rice seed in years when production is low or if they have large families to feed. However, subsistence rice farms with one exclusive ecosystem will probably not be sustainable and they will not be able to satisfy their households' future rice needs.

1. Introduction

Twelve years after the end of its civil war (1991-2001), Sierra Leone is still ranked as the third poorest country in the world [1].

Agriculture is an important aspect of its economy, providing 56% of its GDP and employing 2/3 of the rural population [2]. In this context, rice farmers mainly produce rice for their own consumption [3]. This means that smallholder rice farms are very vulnerable to fluctuations in the amounts of rice produced. Rice yields by small farmers in Sierra Leone are the lowest and most variable of all the countries in West Africa [4,5]. There even is considerable variability between rice farmers using similar growing practices [2].

In Sierra Leone, rice is generally grown without either fertilisers or irrigation [6]. Field-clearing, sowing, transplanting, weeding and harvesting are all carried out without mechanization [7]. This means that rice production is very vulnerable to the availability of labour and the initial fertility of the soil [8–11]. The question of soil fertility is of particular importance for the upland ecosystem which is highly dependent on the duration of the fallow period [12].

Other determining factors, such as the availability and quality of seed, could also explain low and variable yields [13]. It has often been noted that the proportions of rice grains stored as seed, sold, or consumed by the growers vary according to the structure of the farms and households (size of family, needs in terms of vegetables, storage capacity for seed, etc.) [2]

Traditionally, farms have often consisted of a single plot of upland rice [14]. Since the end of the war and the massive return of displaced populations, there is no longer enough uplands for all,

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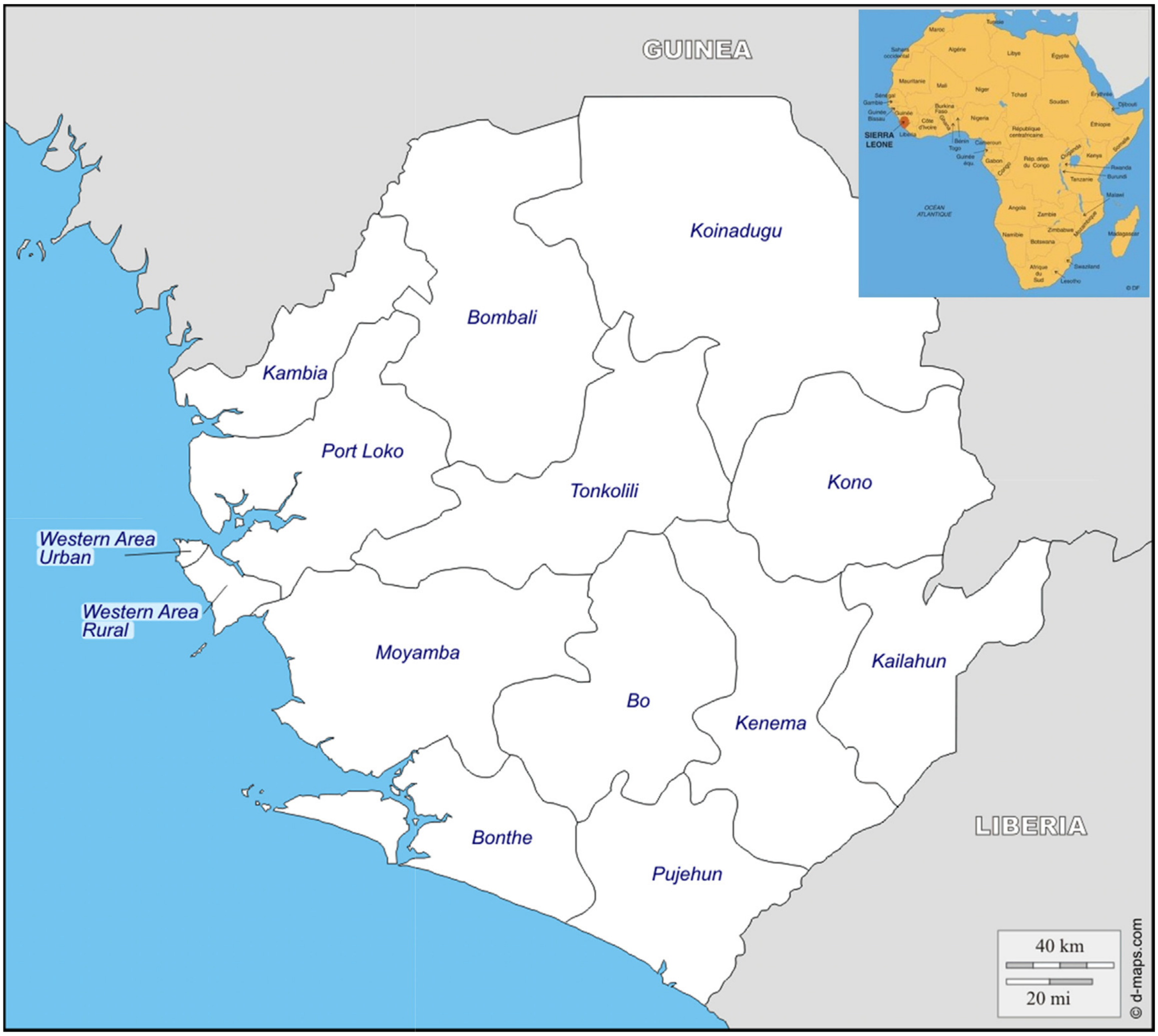

Fig. 1. Location of Sierra Leone and the Bombali district (www.d-maps.com).

and rice farmers find themselves compelled to grow in the lowlands to satisfy their family's rice needs [15]. Other rice farmers branch out into oil palm or Manioc, fairly profitable crops compared to rice [16]. This leads farmers today to think carefully about the importance of cash crops (oil palm, cassava) which compete with other food crops (legumes, sweet potatoes, beans, etc). The latter are certainly more resource-consuming (labour, land) and less productive, but play a significant part in the balanced diet of households.

Recently, several national and international projects have been launched to help Sierra Leone restructure its agriculture, and its rice production in particular (e.g. the European STABEX fund from 2007 to 2009). However, these projects are handicapped by the lack of any thorough characterization of current rice growing systems and their productivity by ecosystem (upland or lowland) and type of farm (with or without oil palm) [2]. Such characterization is necessary in order to identify main drivers of farmers' decisions making process depending on the main production factors, the different ecosystems (upland or lowland) and the surface area of each farm allocated to oil palms.

The purpose of the current article is to assess the performance of smallholder rice farms in northern Sierra-Leone. Its aim is to show how rice farmers make their choices depending on the ecosystems cultivated, the main production factors and the surface area allocated to oil palms. This study was carried out as part of the FSSIM-Africa (2009-2012) project aimed at developing a decision-support tool to help boost rice production in Sierra Leone [17].

2. Materials and methods

2.1. Description of the study area

The Bombali district covers 7985 Km^2, or 40% of the total surface area of the northern part of Sierra Leone [1]. The area receives considerable rainfall with average precipitation of about 2500 mm/year [18]. The rainy season lasts from June to November. The district has an estimated population of 435,000, each household having an average of seven people, and an average of 2.5 men and 4.5 women. Agricultural land is made up mostly of uplands (60 to 80%) and lowlands (20 to 40%) [19].

Agricultural activity in the district mainly consists of rice production. Bombali produces more rice than any other district in Sierra Leone and actually supplies rice for the entire country (Fig. 1).

In the two main ecosystems found in the district, soils are relatively homogenous in terms of organic matter and texture, which is often clayey. Upland soils are fairly shallow (ultisols and oxisols) with an average organic matter content of about 1% [20]. Oil palm and rice are the main upland crops.

The lowlands have deeper soil that also contains more organic matter (1.3% on average) [21]. However, the lowlands have three major disadvantages: the difficulty in working the land (Kayombo et al., 1993); the toxicity, in places, caused by iron [22] and the inability to produce vegetables and rice in this type of ecosystem (Erenstein, 2006).

Table 1
Types and number of rice farms and number of rice fields per ecosystem (upland or lowland) and per farm for 126 rice fields on the 81 farms selected and surveyed within the study.

Types of surveyed farms	Total farms	number of rice plot/ecosystem	
		Upland	Lowland
Rice_U: Farms with only one rice field in an upland ecosystem.	14	14	**0**
Rice_U_palm: Farms growing both rice and oil palm in an upland ecosystem.	6	6	0
Rice_L: Farms producing only rice in a lowland ecosystem.	11	0	11
Rice_L_palm: Farms with two crops: rice in the lowland ecosystem and oil palm in the upland ecosystem.	5	0	5
Rice_U_rice_L: Farms producing rice only, but in both upland and lowland ecosystems.	21	21	21
Rice_U_L_palm Farms with three types of crop: rice and oil palm cultivated (separately) in an upland ecosystem and rice cultivated in a lowland ecosystem.	24	24	24
Total	**81**	**126**	

Unlike upland rice, which is cultivated with very variable fallow periods (from 3 to 20 years), lowland rice is often cultivated as a monoculture for several years running [18].

2.2. Database

The study was carried out as part of the FSSIM-Africa (2009-2012) project to develop a decision-support tool to propose and assess policies to support subsistence smallholder rice farms in Sierra Leone [17]. Subsistence smallholder rice farms account for the largest number of farms in Sierra Leone, the largest farming area and the largest contributor to national rice production [2].

The database used was compiled from surveys of Bombali rice farmers conducted between 2009 and 2010 by the Joint Research Centre of Seville (JRC) and the Institut Agronomique Méditerranéen de Montpellier (CIHEAM-IAMM) [2,17]. Two main related criteria were taken into consideration in defining the sample size. First, the sample needed to be sufficiently inclusive, so that most common types of farm households engaged in the different ecosystems could be integrated. This is particularly relevant, as in Sierra Leone, rice production practices are widespread. Second, the sample had to be large enough to lend itself to statistical inferences. Both purposive and stratified random sampling techniques were employed to select the farming households to interview. Thus, the total sample size of farm households is 81 farmers that will serve for the JRC centre as a basis, before expanding the study for other farms, to identify and test technical and socio-economic levers and options in order to promote rice production and consumption. The description of the 81 surveyed farms in terms of dominant crop and ecosystems is described in Table 1.

Face to face interviews were conducted using multiple choice questionnaires. Three questionnaires (A, B and C) were presented to the heads of the farming households. Questionnaire A investigated the socio-economic characteristics of the household (composition, age of its members, farming activities, sources of income, etc.). Questionnaire B considered the farms already surveyed by Questionnaire A and looked in more detail at each household's farming activities (Table 2). The aim was to describe the crop cycles of rice and oil palm by ecosystem. A second aim was to identify the main tasks involved in growing rice and oil palm as well as the breakdown of labour (for men and women) by type of task.

Questionnaire C sought structural data to describe the farms growing both rice and oil palm: usable agricultural area, land use (crops grown), amount of time per agricultural task, proportion of family labour, proportion of hired labour, proportion of each task performed by men and women, length of fallow period for each ecosystem, and yields per ecosystem (upland, lowland) and by farm (Table 2).

These questionnaires were pre-tested in one of the target communities in Kenema district. In order to conduct the survey, six

Table 2
Description of the variables used for this study, from Questionnaires A, B and C. The data were collected from farmers in Bombali between March and November 2009. They concern only the 81 farms chosen for the study. Yield is the only variable to have been calculated (total production per hectare) instead of being obtained directly from surveys in the field.

Variables	**Description**
Total rice production (t/farm).	The total production per farm is broken down for each farm into total production per type of crop and by ecosystem. It corresponds to the quantity harvested, before drying and winnowing.
Cultivated area and crop rotation per farm (ha)	This area is broken down by crop and by ecosystem.
Seeding density (t/ha)	This is the quantity of rice seed used per hectare and per ecosystem.
Total work carried out on farm (d/ha)	- This is the amount of male and female labour actually used on the farm. The amount of labour was calculated after discussions with several growers on the basis of 6h/d. The total amount of labour per farm is calculated on the basis of the total amount of male and female labour, whether family or hired, per task, per crop (rice or oil palm) and per ecosystem. - For the uplands, the amount of work for sowing includes land clearance, burning and actual sowing. - For the lowlands the amount of planting work includes field clearance and transplanting. - We decided not to take child bird-scaring labour into consideration as there was considerable uncertainty about the quality of the data.
Family size per farm	This variable concerns the total number of adults and young people per family.
Proportions consumed, sold or stored per farm	These proportions are percentages of the entire production per farm, of the quantities consumed by the family, sold at the local market or stored as seed for the following year.
Quality of plot and difficulty of working the soil	This qualitative item describes the quality of the field that has been left to lie fallow, after clearance and burning, and the difficulty of working the soil as a result of its texture. The possible answers were "Good" or "Bad" regarding its post-fallow condition and "Difficult" or "Not difficult" regarding the difficulty of working the soil.
Yield (t/ha)	Calculated by taking the production per crop and per ecosystem divided by the surface area of each crop per ecosystem.

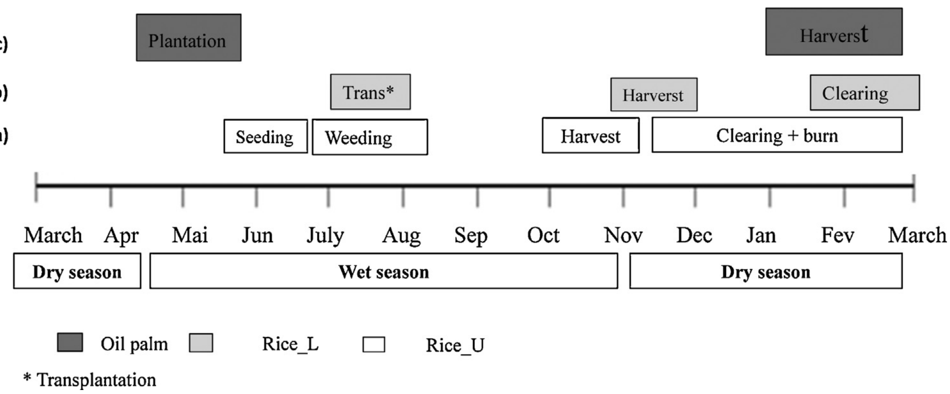

Fig. 2. Work schedules by type of crop system (rice and oil palm) and by ecosystem. (a) Upland rice; (b) Lowland rice and (c) Oil palms.

interviewers (enumerators) were selected among the students of Njala University and received three days of specific training by the project coordinators [2]. The preliminary field visit to test the questionnaires was organized on 20 farms with the duration of two weeks in March 2009, and it was followed by an expert meeting to validate the questionnaires. The number of households visited per day was on average 5 per enumerator. The number of households surveyed per village was on average of between 15-25 farm households. Questionnaire A was administered in March and April 2009. The duration of field visits for investigators was 3 weeks. The questionnaires B and C were achieved in November 2009 (since the main harvesting season is between August and October). The multiple visit interview schedule adopted in this study is expected to improve the reliability of the information provided by the respondents. Here, due to the high illiteracy rate and the culture of not keeping farm records, the assumption being made is that the shorter the memory recall period the higher the accuracy of the information provided. Interviews were held with household heads in their respective villages at times convenient to the respondents, usually in the morning or evening hours. The approximate duration of interviews per questionnaire was around 1 hour ([2].

2.3. Levels of analysis and methods for assessing rice growing systems in Bombali

The study followed a procedure at two levels:

- **at crop per ecosystem level**, to describe cropping cycles and management for rice and oil palm, mainly based on Questionnaire B. It will also be a matter to compare for all rice smallholder farms, the rice crop performance per ecosystem (upland or lowland) (Table 2). This involves comparing the surface area, yield, amount of work for smallholder rice farms per ecosystem (upland or lowland), in order to be able highlight the diversity of rice systems in Bombali.
- **at farm level**, to help us understand and explain rice yields depending on farm type. As mentioned above, very few rice farms in Sierra Leone are mechanized or use artificial inputs. In this context, average rice yield per farm and per ecosystem is essentially analysed through 8 variables depending on three types of creteria as suggested by Norman (1995): 1- *the resource endowment* represented in our study by: i) the potential production of the location expressed by the variables ratio of lowland area to upland area and the duration of the fallow on the upland, and ii) the availability of financial resources represented, in the absence of non-farming income, by the the ratio of the cash oil palm land to total farming land, 2- *the production goal* expressed by the variables family size indicating the minimum rice requirement for consumption per household, and 3) the *farm production intensification level* represented by the types and quantities of inputs used to ensure rice production. Here, this means the seed density and the total quantity of labour used.

Concretely, the farm household typology was constructed by using two multivariate statistical techniques, respectively Principal Component Analysis (PCA) and the Hierarchical Ascendant Classification (HAC). The first step of this analysis (PCA) was applied to transform linearly the original set of variables, into a substantially smaller set of uncorrelated variables that represents most of the information in the original set (Bidogeza et al., 2009). Based on the first step, only the total amount of work invested in the farm, the length of the fallow period (which determines the level of soil fertility) and seeding density are considered for the HAC analysis to group the rice farms into homogeneous classes [23]. Those three criteria are selected because they present, accordantly to the Kaiser's criterion (Mokuwa et al., 2014), eigenvalues greater than 1.

In a second phase, a more detailed analysis of each type of farm was carried out so as to characterize their behaviour based on all the variables surveyed and listed in Table 1 (Section 2.3).

3. Results

3.1. Analysis at crop per ecosystem level

- Description of cropping cycles for rice and oil palm.**- Upland rice**: upland rice is cultivated mostly from June to November (Fig. 2). The field can be prepared for sowing from December to March, just before the arrival of the first rains. This includes tree-felling and field-clearing by slash-and-burn.

  Rice is sown in mid-June, the density of seed varying considerably depending on the labour available and the quantity of rice seed stored since the previous harvest. Rice is often sown in association with other crops such as beans.

  Weeding is usually done two weeks after sowing, during the second half of July. Harvesting may be staggered depending on the family's needs. Concerning the distribution of labour, women only play a marginal role in sowing but do a considerable part of the weeding. Men, meanwhile, do most of the tree-felling, field-clearing by slash-and-burn, and sowing. Men may occasionally participate in weeding and harvesting.

  - Lowland rice: preparing the field for lowland rice always begins with field-clearing. This operation (removing weeds) often begins in February but may continue into March (Fig. 2). This is done entirely manually.

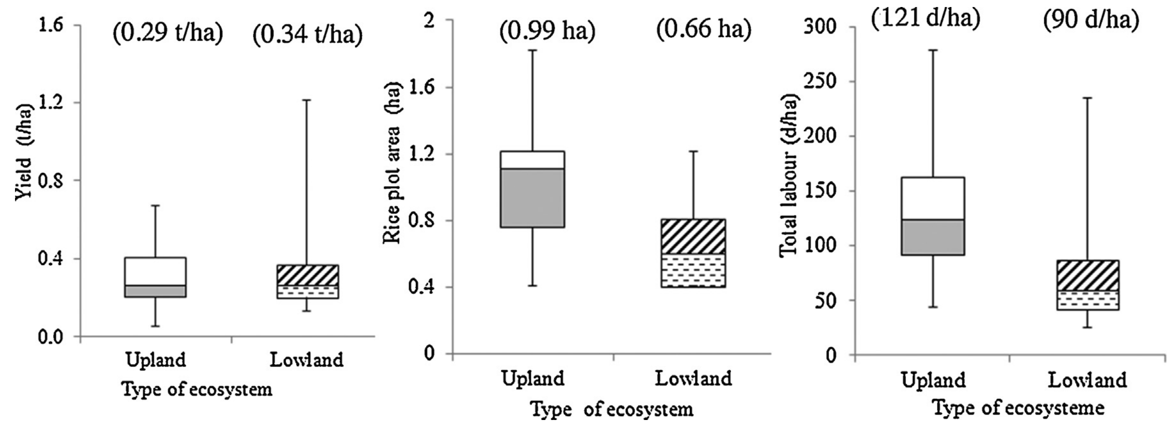

Fig. 3. Median, maximum and minimum values, first quartile, third quartile and mean (values in brackets) for upland and lowland ecosystems for the following variables: yield, surface area and total labour. These variables were calculated from surveys and concern 126 rice fields.

Plants, often obtained by barter, are prepared in nurseries from May onwards, and transplanted in July; the harvest follows at the end of November, sometimes extending into December.

- Oil palm

Oil palms are ideally planted in May and the first crop of fruit can be harvested from the third year after planting. The harvest begins in January and usually coincides with the sale of rice. The extraction of palm oil is an exclusively manual practice that starts in March and can extend over two months. This is often a crucial period for the preparation of rice fields (Fig. 2).

In Bombali, no maintenance tasks (such as weeding or pruning) are carried out on oil palms. They are only grown in the uplands. Before the war, oil palms were cultivated together with upland rice, but most farmers now allot separate fields to this crop. This choice is driven by the profitability of the crop, which tends to be planted at higher and higher densities, thus preventing any association with other crops.

- Comparative performance of rice per ecosystem

As shown in Fig. 3, rice growing practices in lowland ecosystems give higher average yields than in exclusively upland systems. Average yields are 0.29 t/ha (median yields 0.26 t/ha) and 0.34 t/ha (median 0.27 t/ha) for upland rice and lowland rice respectively. Conversely, the total amount of labour required per hectare is much higher for upland rice than for lowland rice. Rice farmers invest an average of 121 d/ha (median 110 d/ha) for upland rice and 90 d/ha (median 79 d/ha) for lowland rice. The distribution of labour between men and women differs for each ecosystem. Women provide approximately half of the total amount of labour for each type of ecosystem, specifically 45% and 41% for upland rice and lowland rice respectively (data not shown).

The average size of upland rice fields is larger (average 0.99 ha; median 1.11 ha) than that of lowland rice (average 0.66 ha; median 0.61 ha). A frequency analysis shows that more than 80% of lowland fields have a surface area of less than 1 ha (and 50% have less than 0.5 ha). By contrast, almost 70% of upland fields have a surface area of between 0.5 ha and 1.1 ha, and on average 10% of farms have a surface area greater than 1.1 ha (data not shown).

In fact, as shown in Fig. 3, irrespective of the variable analysed (yield, amount of work invested, etc.), there is considerable variability in both the average and the median values of these variables, demonstrating the wide diversity in the practices of these rice farmers. The same variability is found for upland rice as for lowland rice. For example, the standard deviations of yields for upland rice and lowland rice are 0.13t/ha and 0.2t/ha respectively for average yields of 0.29t/ha and 0.34t/ha.

3.2. Analysis at farm level: farm typology

Smallholder rice farms were grouped into two clusters steps considering, as explained in section 2.3, the eight production factors represented by proxy indicators derived through PCA analysis. The analysis of the absolute value of the loadings (in %) of the production factor variables with respect to the two PC's shows that the seeding density has the greatest loading with PC1. PC2 is alternatively associated with total labour and fallow duration (data not shown). In the final analysis, the two axes (PC1 and PC2) explained 92% of the variance (data not shown). These PCs were used as classificatory variables in the Hierarchical Cluster Analysis (HCA) allowing the identification of 4 classes of farms as illustrated in Fig. 4a and b. In detail (Table 3):

- **Farms with high rice yields**: Class 1 contains the farms with the highest rice yields (average yields of 0.54 t/ha), high seeding density (0.32 t/ha), short fallow periods (6 years) and a fairly low total amount of work (97 d/ha). This class is mostly made up of farms growing rice in both ecosystems (upland and lowland) together with oil palm.
- **Farms with fairly high rice yields**: Class 2 mostly contains farms cultivating rice in one or both ecosystems but always associated with oil palm with the exception of a single farm with both ecosystems but no oil palm. This class has fairly high rice yields (0.43 t/ha), medium seeding density (0.22 t/ha), fallow periods similar to those of Class 1 (5 years) but the highest total amount of labour of all four classes (178 j/ha).
- **Farms with fairly low rice yields**: Class 3 contains farms with fairly low rice yields (0.30 t/ha), lower seeding density than the first two classes (0.11 t/ha), longer fallow periods than the first two classes (7 years) and the lowest total amount of labour of all the classes (74 d/ha). It contains 30 farms covering all types of ecosystems.
- **Farms with low rice yields**: Class 4 contains farms with the lowest average rice yields (0.23 t/ha) and sowing densities (0.08 t/ha) of all the classes. The farms in this class use very long fallow periods compared to the other classes (9 years) and a fairly large amount of labour (119 d/ha). This class contains 29 farms.

For a better comprehension of the behaviour of the four farm classes we also compared the:

- Surface area by class of farm and by ecosystem:

An analysis of Fig. 5 shows that the farms in all classes have almost the same average surface area (2.2 ha), with the exception of those in Class 3 (1.3 ha). As a proportion of our sample,

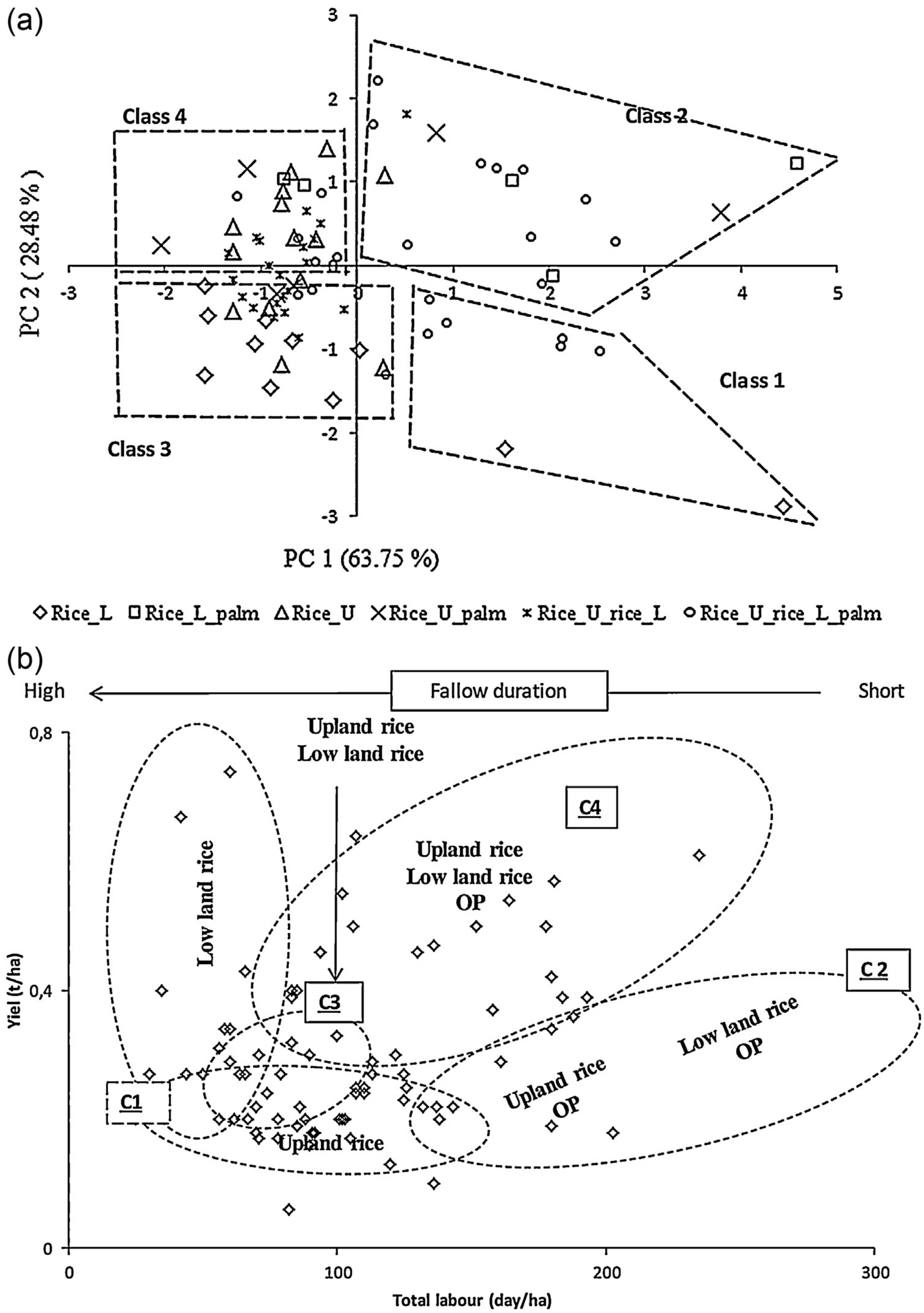

Fig. 4. a. Distribution of farms surveyed (n = 81) by classes of farms as a function of PC1 and PC2. b. variation of rice yield for the 4types of household rice farms (C1to C4) by taking into account the rice ecosystems (upland, low land and the oil palm (OP)) and fallow duration.

the farms in Classes 3 and 4 (rather low and low yields) are the most numerous, with 30 and 29 for the two classes respectively (Table 3, Section 3.3.2), compared to Classes 1 and 2 (fairly high and high yields) with 8 and 14 farms respectively.

The farms in Class 1 (high yields) have an average surface area presenting similar proportions of lowland rice and upland rice, respectively 28% and 32% of the farms' total surface area. The remainder (40%) is allocated to oil palm cultivated in the upland ecosystem. This distribution in terms of crops (rice and oil palm) and ecosystem (upland and lowland) is also found in the farms in Class 2.

For the farms in Classes 3 and 4 (fairly low and low yields), the proportion of oil palm is considerably higher (53% of the total farm area) than the proportion of upland rice or lowland rice, respectively 13% and 26% for Class 3 and 35% and 22% for Class 4.

- Distance from household to farm by class of farm and by ecosystem:

Farms in Classes 3 and 4 are located fairly close to the rice farmers' households, with average distances of 1.26 km and 0.83 km respectively (Fig. 6). The farms in Classes 1 and 2 (fairly high and high rice yields) are respectively 1.76 and 2 km from the rice farmers' households.

A more detailed analysis of these distances shows that irrespective of the type of class, farms with an exclusively upland or lowland ecosystem are closest to the rice farmers' households (average

Table 3
Average yield, seeding density, duration of fallow period, total labour and number of farms per class. Farms were classified on the basis of a PCA and HAC from a sample of 81 farms surveyed in Bombali. The total in the table gives the total number of farms and the weighted average and standard deviation corresponding to the weighted average and standard deviation by area of the following variables: average yield, seeding density, length of fallow period and total labour.

Class of farm	Farm system(1)	Number of farm	Average yield (t/ha)	Seeding density (t/ha)	Lenght of fallow period (year)(2)	Total labour (d/ha)
Class 1: high rice yields	Rice_L	2	0.69	0.33		46
	Rice_U_rice_L_palm	6	0.51	0.32	6	106
Average		-	**0.54**	**0.32**	**6**	**97**
Class 2: fairly high rice yield	Rice_L_palm	3	0.52	0.3	-	182
	Rice_U_rice_L	1	0.39	0.04	10	193
	Rice_U_rice_L_palm	8	0.42	0.25	5	174
	Rice_U_palm	2	0.48	0.24	5	192
Average		-	**0.43**	**0.22**	**5**	**178**
Class 3: fairly low rice yield	Rice_L	9	0.29	0.07	-	57
	Rice_U_rice_L	11	0.29	0.07	8	79
	Rice_U_rice_L_palm	4	0.33	0.19	6	81
	Rice_ U	5	0.27	0.11	8	69
	Rice_ U _palm	1	0.2	0.13	5	78
Average		-	**0.3**	**0.11**	**7**	**74**
Class 4: low rice yield	Rice_L_palm	2	0.23	0.06	-	138
	Rice_ U_rice_L	9	0.23	0.08	9	106
	Rice_ U _rice_L_palm	6	0.21	0.12	13	129
	Rice_ U	9	0.25	0.05	9	131
	Rice_ U _palm	3	0.13	0.1	6	95
Average		-	**0.23**	**0.08**	**9**	**119**

(1) the abbreviation of the farm systems are given in Table 2.
(2) The minus sign (-) in the "length of the fallow period" column indicates lowland farms that do not use fallow periods.

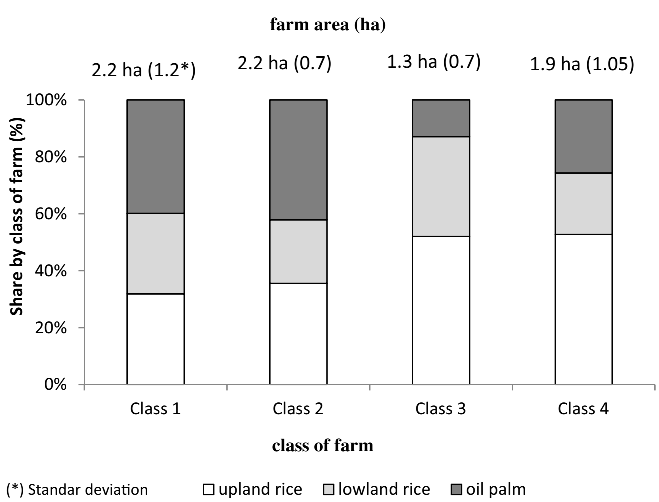

Fig. 5. Total surface area, standard deviation (value in brackets) and proportion of the surface area in upland rice, lowland rice and oil palm per class of farm. Class 1 (high rice yields), Class 2 (fairly high rice yields), Class 3 (fairly low rice yields) and Class 4 (low rice yields).

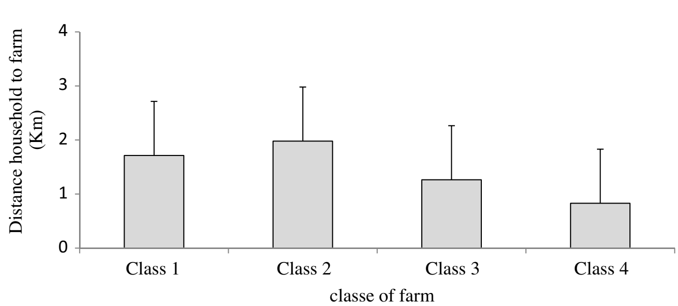

Fig. 6. Average distance and standard deviation from household to farm by class of farm. Class 1 (high rice yields), Class 2 (fairly high rice yields), Class 3 (fairly low rice yields) and Class 4 (low rice yields). Averages and mean deviations are calculated on the basis of the 81 farms surveyed.

distance of less than 0.1 km) (Fig. 7). Farms where oil palms are cultivated (Rice_U_rice_L_palm farms or Rice_U_palm farms) are the most distant. The latter (Rice_U_palm farms) have the lowest yields (Table 3, Section 3.3.2).

3.3. *Impacts of production factors on rice performance*

- Effect of labour use on yield

An analysis of the labour factor per class of farm shows, as previously explained in Section 3.2, a considerable difference in the total amount of labour invested per class of farm. This variability can also be observed in the proportions of total family and hired labour (Fig. 8). The proportion of total family labour in total labour is higher in farms belonging to Class 1 (40%) than in other farms (20% on average).

The same type of result is found in lowland ecosystems with a larger proportion of family labour (as a percentage of total labour) for Class 1 (52% of total labour) compared to the other classes, for which the average is approximately 45% (data not shown).

The distribution of the amount of labour between men and women per task and per class of farm shows that men do more of the sowing while women do more of the weeding and harvesting. Nevertheless, in the high yield class (Class 1), the proportion of female labour in weeding and harvesting is much higher than in

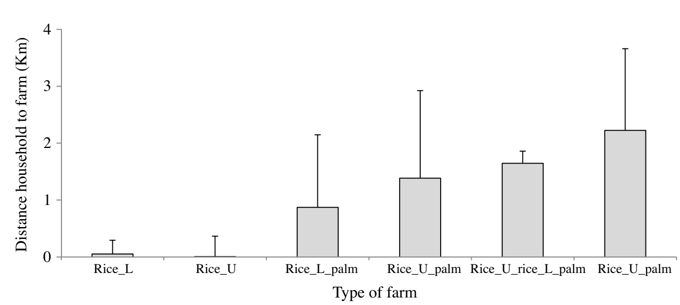

Fig. 7. Average distance and standard deviation from household to farm by type of farm. Class 1 (high rice yields), Class 2 (fairly high rice yields), Class 3 (fairly low rice yields) and Class 4 (low rice yields). Averages and mean deviations are calculated on the basis of the 81 farms surveyed.

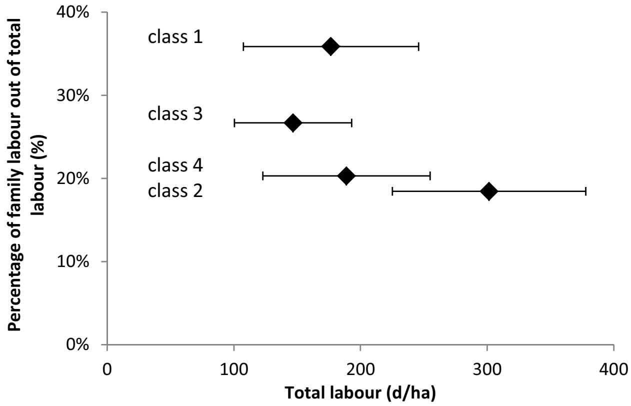

Fig. 8. Total labour, standard deviation relative to total labour and proportions (%) of family labour per class of farm relative to the total amount of labour. This analysis was made on the basis of the 81 farms surveyed. Class 1 (high rice yields), Class 2 (fairly high rice yields), Class 3 (fairly low rice yields) and Class 4 (low rice yields).

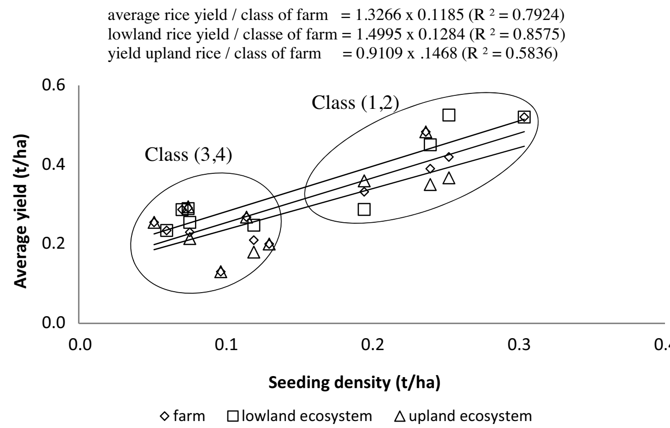

Fig. 10. Average rice yields per farm and per ecosystem (uplands and lowlands) and per farm as a function of seeding density. Average rice yield per farm is calculated as the weighted average for the surface area of rice grown for both ecosystems (upland and lowland).

the other classes (Fig. 9). The same type of result is found for farms in lowland ecosystems where female labour is more widespread during harvesting for Class 1 farms than for the other classes (data not shown). In both cases, female labour is mostly family labour (data not shown).

Table 4 shows that for the four classes of smallholder farms, the yield is only slightly correlated, except for class 1 which has an R^2 of 0.49, with the total amount of work done on the farm. Nevertheless, a closer analysis of this variable (total work) shows that the levels of correlation with the yield vary greatly according to the cropping tasks per ecosystem and per type of manual labour (family, hired, male, female).

For the classes with high yields (classes 1 and 2), the rice yield for the upland ecosystem appears to be more sensitive to the amount of work per task than that of lowland rice. Indeed, classes 1 and 2 respectively show correlations of 0.89 and 0.48 for the upland areas and 0.1 and 0.31 for the lowland areas. The result is entirely the opposite for class 3 smallholder farms, with correlations of 0.52 and 0.03 respectively for the lowland and upland ecosystems.

For class 4 farms, the correlation between the yield variable and the total amount of work is practically the same for both ecosystems (0.48 and 0.45).

In upland areas, the correlations between yield and total amount of work per task (seeding, weeding, harvesting) varied according to the class of smallholder farm. The highest correlations were found for class 1 with an R^2 of 0.84, 0.67 and 0.6 respectively for seeding, weeding and harvesting. On the other hand, the lowest correlations were recorded for class 4 with an R^2 of 0.38, 0.31 and 0.30 respectively for seeding, weeding and harvesting. The table also shows that, depending on the tasks and type of labour (hired, family, male, female), the correlation between the amount of work and the yield vary greatly. For example, for class 1, the correlations between the amount of hired work and the yield are 0.84, 0.64 and 0.54 respectively for seeding, weeding and harvesting. These correlations are lower for class 4, namely 0.39, 0.35 and 0.58 respectively for seeding, weeding and harvesting. We also observed that the strong correlation between family labour and yield was only recorded for class 1 and class 3 and in particular for the seeding task (0.76 and 0.52 respectively for class 1 and class 3).

Fig. 9. Proportions of male and female labour relative to total labour by task and class of farm. This analysis was made on the basis of the 81 farms surveyed. Class 1 (high rice yields), Class 2 (fairly high rice yields), Class 3 (fairly low rice yields) and Class 4 (low rice yields).

In lowland areas, the correlations between the total amount of work per task and per type of labour and the yield are fairly low when compared to those of the upland areas. In this context the most significant correlations were observed for the amount of hired labour and the amount of work done by men, particularly for transplanting and harvesting.

- Effect of seeding density on yield

Fig. 10 shows that the average rice yield per farm is strongly correlated with seeding density ($R^2 = 0.8$). This correlation is closely linked to the strong correlation between seeding density and rice yields for upland ecosystems ($R^2 = 0.86$) and lowland ecosystems ($R^2 = 0.6$).

From this figure we can also conclude that the high yields in Classes 1 and 2 are due to a simultaneous increase in rice yields in both upland and lowland ecosystems. We find the same type of result for yields in farms belonging to Classes 3 and 4 (fairly low and low rice yields) where the low yield is explained by a simultaneous drop in yields in both ecosystems at the same time.

Seeding density itself depends heavily on:

- the quantity of rice stored by each farm (Fig. 11). This only concerns farms with low rice yields in Classes 3 and 4 (fairly low and low rice yields). The larger the quantity stored, the higher the density sown. For farms with high yields (Classes 1 and 2) this correlation is very low. Fig. 12 shows that the proportion of the harvest stored as seed is much higher in Class 1 than in Classes 2, 3 and 4. This seems to correlate with family size, which is lower in Class 1 than in the other classes (Fig. 12). Fig. 12 also shows how the proportion consumed increases from Class 1 to Class 4. In quantitative terms, this corresponds to an annual consumption per person of 0.03, 0.016, 0.015 and 0.014 tonnes for Classes

Table 4
Correlation values (R^2) between yield and the amount of labour by ecosystem, task and type (family, hired, women, men). These values are expressed by class of yield: high rice yields (class 1), Fairly high rice yield (class 2), Fairly low rice yield (class 3) et Low rice yield (class 4).

		Coefficient of correlation (R^2)					
		Upland			Lowland		Farm
		Seeding	Weeding	Harvesting	Transplanting	Harvesting	
Classe 1	Family labour	0.76	0.07	0.12	0.02	0.15	0.71
	Hired labour	0.84	0.64	0.54	0.48	0.03	0.11
	Man labour	0.79	0.16	0.52	0.59	0.46	0.51
	Female labour	0.39	0.83	0.52	0.02	0.15	0.42
	Labour/task	**0.84**	**0.67**	**0.6**	**0.47**	**0.28**	-
	Total labour		**0.89**		**0.1**	**0.49**	
Classe 2	Family labour	0.37	0.25	0.08	0.20	0.05	0.2
	Hired labour	0.21	0.05	0.34	0.20	0.43	0.2
	Man labour	0.24	0.00	0.28	0.25	0.42	0.1
	Female labour	0.40	0.16	0.33	0.20	0.05	0.02
	Labour/task	**0.4**	**0.16**	**0.53**	**0.23**	**0.37**	-
	Total labour		**0.48**		**0.31**	**0.04**	
Classe 3	Family labour	**0.52**	0.25	0.24	0.34	0.15	0.09
	Hired labour	0.33	0.29	**0.52**	0.17	0.32	0
	Man labour	0.49	0.30	**0.58**	0.24	0.39	0
	Female labour	0.21	0.30	0.34	0.34	0.15	0.03
	Labour/task	**0.51**	**0.49**	**0.89**	**0.36**	**0.4**	-
	Total labour		**0.03**		**0.52**	**0.01**	
Classe4	Family labour	0.01	0.00	0.06	0.17	0.04	0.06
	Hired labour	0.39	0.35	**0.58**	0.38	0.44	0.21
	Man labour	0.36	0.02	0.44	0.45	**0.54**	0.12
	Female labour	0.00	0.26	0.00	0.17	0.04	0
	Labour/task	**0.38**	**0.31**	**0.30**	**0.40**	**0.40**	-
	Total labour		**0.48**		**0.45**	**0.05**	

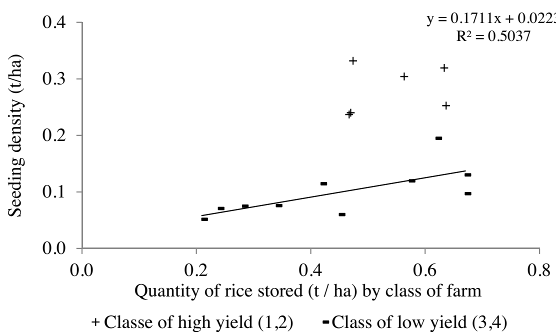

Fig. 11. Seeding density as a function of the quantity of seed stored per class.

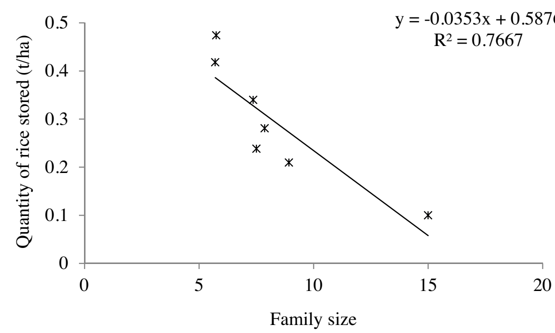

Fig. 13. Quantity of rice stored as seed as a function of family size for farms not cultivating oil palms.

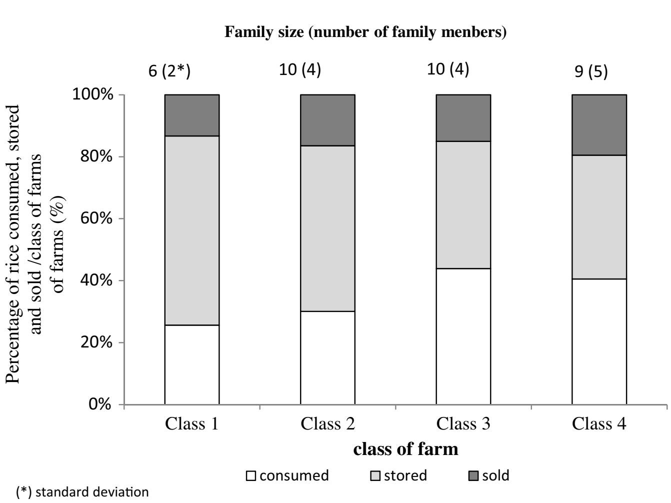

Fig. 12. Average family size (number of family members) and standard deviation per class of farm as a function of the proportion (as a percentage of total production) of the quantities consumed, sold and stored.

1, 2, 3 and 4 respectively. For all classes, the proportion of the crop sold is almost the same, irrespective of the class of farm.

- The correlation between the quantity stored and the family size expressed as the number of family members is particularly evident in farms that do not cultivate oil palm, i.e. mainly farms in the low yield classes (Classes 3 and 4). As expected, there is

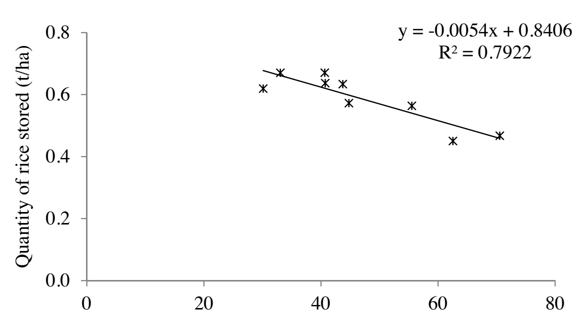

Fig. 14. Quantity of rice stored per farm as a function of the proportion of surface area allocated to oil palms per farm.

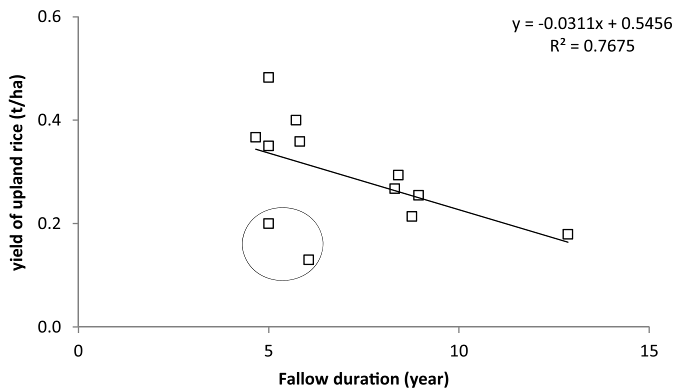

Fig. 15. Performance rice tray depending on the length of fallow. Farms are surrounded farms rice and palm oil pan (Rice_U_palm) in low yield (class 3.4).

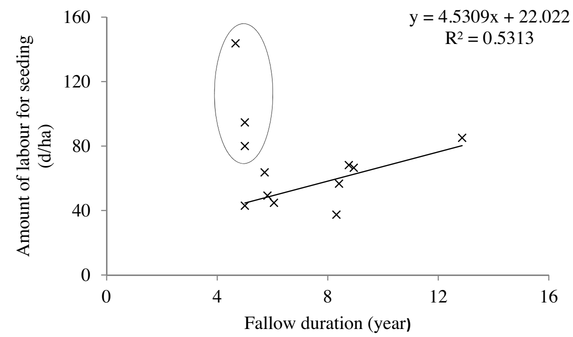

Fig. 17. Seeding based on the length of fallow. Farms are surrounded farms rice and palm oil (Rice_U_palm) in low yield (class 3.4).

a negative correlation between the quantity of rice stored (and consequently seeding density) and family size (Fig. 13).

- For farms where oil palm is cultivated, the quantity of rice stored as seed for the following year is negatively correlated with the proportion of oil palm on the farms (Fig. 14).

- Effect of the length of fallow periods on yield

An analysis of Fig. 15 showing the variations in yield as a function of the average duration of fallow periods for upland ecosystems per farm shows fairly heterogeneous behaviour for the different classes of farms. In general, yield declines in a linear fashion as the length of fallow period increases. Overall the correlation is 0.2 but this becomes 0.8 when the two outliers (the farms circled in Fig. 15) are excluded. These two farms grow upland rice in association with oil palm and have short fallow periods (5 to 6 years) and low yields, mainly caused by low seeding densities (Fig. 16). The lowest yields are associated with the longest fallow periods, mainly for farms in Classes 3 and 4.

As has been mentioned by several authors (e.g. Gleave, 1996), the length of the fallow period, and consequently its impact on soil fertility and the degree of invasion by bushes and weeds, may influence the choices of rice farmers in terms of seeding density and labour investment during the sowing period. Figs. 16 and 17 illustrate the way these two parameters (seeding density and amount of work invested during sowing) vary as a function of the length of the preceding fallow period. With the exception of the two exclusively upland farms that also cultivate oil palm (Figs. 16 and 17), there is a negative correlation between seeding density and the length of fallow periods.

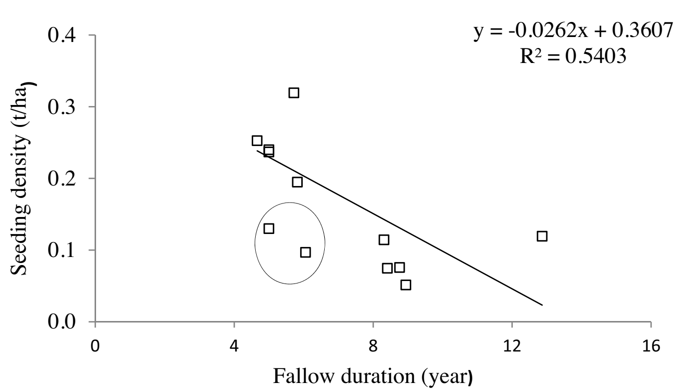

Fig. 16. Quantity of Labour depending on the sowing fallow periods. Farms are surrounded farms rice tray and oil palm (Rice_U_palm) in low yield (class 3.4).

However, the amount of work needed for sowing ("sowing" here involves tree-felling, slash-and-burn operations and the sowing itself, as explained in Table 1, Section 2.4) correlates positively with the length of fallow periods, except for farms in Class 2. Regarding the farms in Class 2, the considerable amount of work needed for sowing can be explained by the length of the fallow period and the condition of the rice field prior to sowing, as well as soil quality and the difficulty in working with that soil (DATA not shown).

4. Discussion

In Sierra Leone, rice farms are almost entirely non-mechanized and with low input, which largely explains the low average rice yields and their variability from farm to farm. Yield variability can often be accounted for by the types of overall decisions made by farmers.

The results of the current study suggest that the principal decisions concern seeding density, surface areas for rice per ecosystem and the surface area allotted to oil palms (Fig. 18). Nevertheless, before making these decisions, rice farmers must take into consideration a number of production factors such as the availability of land per ecosystem, the length of fallow periods in the uplands, and family size (number of family members). This last factor (family size) determines the family's rice needs and the availability of family labour. In practical terms, average rice yield by farm, and consequently total farm production, will be affected by:

- Labour availability: for several authors [8,24] the proportion of family labour to total labour primarily depends on family size (number of family members). The results of the current study contradict these findings. It was found that large families are often less involved in the activities of their own farms. According to Maclean et al. [25] large families are often either poor or new arrivals in Sierra Leone (returning after the war, or immigrants from neighbouring regions) who may well have to change their place of residence and occupy new land every year (which would explain the short distances from the homes of this type of grower to their farms). They are often sharecroppers, forced to hand over a small proportion of their production. Indeed, it seems that growers from this group work for other farmers more than on their own land, in order to bring in as much income as possible. This income often takes the form of sacks of rice or meals for the whole family [2].

For several authors the low rice yield in Sierra Leone is mainly related to the amount of labour used at the weeding stage [26,27]. In the current study it was shown that depending on the farm types the yield is differently correlated with the amount of labour

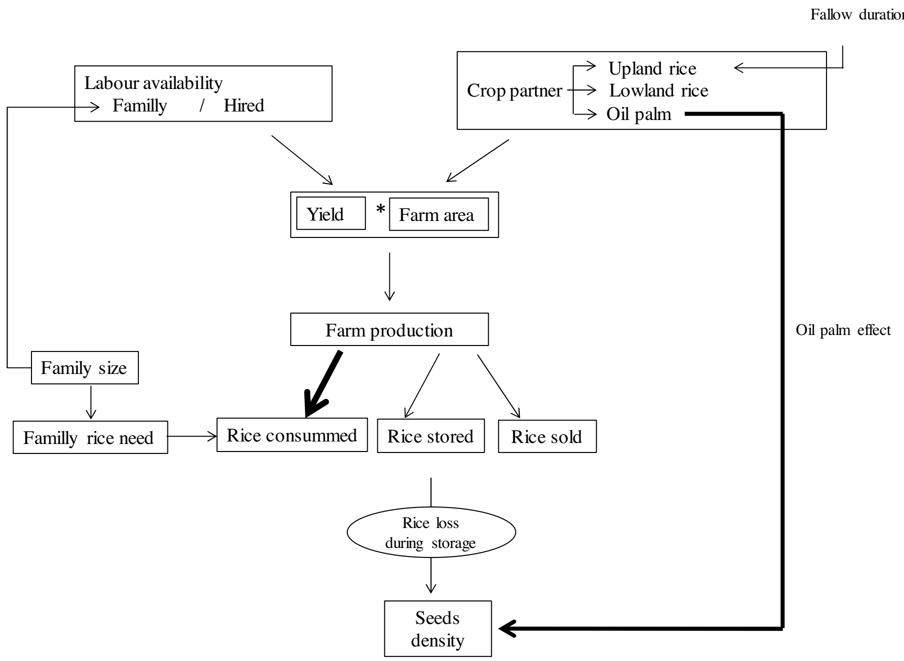

Fig. 18. Criteria influencing the decisions of smallholder rice farms in Bombali.

engaged in each work schedule. In addition, the highest correlation between rice yield and the amount of labour employed is observed for farms with high rice yields (class 1). For the other classes this result is less evident, thus proving that other limiting factors affect yield more negatively than the labour engaged.

- the quantity of seed stored: for CORAF/WECARD et al. [28] the quantity of rice seed stored from the previous season is a predominant factor affecting seeding density, and consequently production, for the following year. This situation reflects the real difficulty for rice farmers in deciding, each year, how much to keep for the year's consumption and how much to store as seed for the following year.

To summarize, the quantity stored as seed heavily depends on family size (the larger the family the larger the quantities consumed compared to the quantities stored), on the year's production (the larger and more fertile the fields cultivated, the higher the production) and on the area allotted to oil palms. On this subject, it seems that the more oil palms are cultivated per farm, the less seeding density depends on the year's production or on the family's rice needs. According to Ricardo [29] the income from the sale of palm oil is an important resource to break the interdependence of quantities stored and quantities consumed. This is because rice farmers can use the income from the sale of palm oil to buy rice seed or rice for consumption and can therefore decide what quantities of rice to store as seed irrespective of the year's production and their needs for household consumption.

Two more significant criteria (which are not dealt with in this article) can also affect the decision regarding the quantities of rice seeds to be stocked: i) rice seeds received as gifts from relatives or international organizations [2], which in some situations this may even represent half the seeds sown, and ii) rice seed varieties found on the farm, which can dependent on the existing ecosystems by farm (e.g. the Rok 10 variety is more suited for lowland ecosystems than upland ecosystems), and the quantities of inputs available (e.g. in the presence of inputs, rice farmers prefer to stock the RICA variety rather than less productive local varieties) [30]. However, regardless of the origin of seeds, wars, famines as well as epidemics such as Ebola have favoured the selection and spread of spontaneous interspecific rice hybrids (O. glaberrima parent and in some cases even pure glaberrimas), because – in the absence of inputs – of their adaptability to poor soils [31].

- length of the fallow period: this factor has a significant effect on soil fertility, especially in upland ecosystems. Several authors found that the longer the fallow period was, the more fertile the soil and the higher the yield were [32,33]. On the farms in the current study, however, yields after long fallow periods (more than 10 years) were rather low, compared to medium-length fallow periods (5 to 7 years). Because of the lack of any mechanization, the biomass produced during long fallow periods is not always burnt off correctly. As a result, larger items (trunks) remain on the ground and rot, causing several diseases [34]. In this context, rice-growers consider it important for a farm to combine upland and lowland ecosystems to ensure a minimum production, independently of the length of the fallow period in upland fields.

5. Outlook for rice farmers in sierra leone

In the light of the current results, subsistence rice farms with exclusively upland ecosystems will probably not be able to satisfy their households' future rice needs, especially those with large families. This result concurs with the findings of [35], who explain that this type of farm is tending to disappear because of low rice yields.

Combining lowland with upland rice can increase average yield compared to that of exclusively upland farms. This type of farm, which is very common in northern Sierra Leone, and given the lack of efficient rice storage facilities [36], reflects the real desire of growers to extend their rice production over as long a period as possible (from November to March). According to Toulmin and Guèye [24], this combination of ecosystems enables growers to reduce both climate-related and socioeconomic risks (access to seed, availability of labour, etc.), which can significantly affect one or other of the two ecosystems in a given year.

In view of the results obtained, the best-performing farms (high average yield and low total amount of labour invested per farm) all combine two ecosystems and cultivate both rice and oil palm. Many leading agricultural authorities believe that it is vital to promote this type of farming in the years to come. Combining the two ecosystems makes it possible to spread production over several months, thus reducing climate-related and socioeconomic production risks in each ecosystem, and disassociating the proportion to be stored as seed from the proportion to be stored for household consumption. However, it will be difficult to achieve this balance between the two types of ecosystems and between rice and oil palm, because of increasing population pressure in the uplands concomitant with political stability and the arrival of immigrants from neighbouring regions [37]. In addition, some politicians would like to lease the uplands to multinational developers for the intensive production of palm oil [38].

6. Conclusion

The purpose of the current article was to identify and characterize the main factors affecting average rice yield per farm in Bombali. The study found that two types of farms could be distinguished depending on the ecosystems cultivated, the area allotted to oil palm, the length of fallow periods, and seeding density.

In rice farms with one or both ecosystems but no oil palm **(classes 3 and 4 in our study)**, farmers cultivate rice primarily for their household consumption. These are mainly farms with low or very low yields, cultivating rice after long fallow periods and with low seeding density. In this group, there often is a positive correlation between the average farm yield and an increase in lowland rice area.

The second group of farms is made up of those cultivating land in one or both ecosystems and including oil palm **(classes 1 and 2 in our study)**. The yields in this group vary greatly (from very low to very high). Growers in this group cultivated rice after medium to long fallow periods. In these cases, a positive correlation was found between the average rice yield per farm and an increased seeding density, shorter fallow periods and greater areas allocated to oil palm per farm.

In this context of low and variable rice yields, several international organizations are currently working with the government of Sierra Leone to help rice farmers boost production (WASNET, 2005). In an agricultural context that is likely to remain largely unmechanized and low-input for several years, the current findings suggest that these initiatives should consider the problems of low seeding density and soil fertility (associated with the duration of fallow periods) as priorities for any action aiming to improve rice yields.

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