Evaluation of Yield Gain: A Case of Upland Rice Cultivation in Madagascar

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Abstract
Following the large dissemination of rainfed upland rice in Madagascar, this is to conduct yield gain among improved rice varieties through different fertilizer rates during the cropping season (2018/2019) in the Middle West at farmer's plot. It aims to analyze and to compare grain yields and their components for two popular varieties of rice such as Nerica 4 and B22. To assess potential yields of rice, it is assumed that nutrient and water stresses are the main biophysical factor limiting the yield of rainfed upland rice. By a random complete block device with three replications, the two rice varieties are respectively subjected to the following three fertilizer rate treatments such as T1: high quantity of crop nutrients, T2: low referring to Malagasy farmers' practices, T3: medium. Thus, for this year, the research released yield gain under a low-level of fertilization, with average yields of 1,55T/Ha; against respectively 1,13T/Ha at medium and 1,58T/Ha at a high-level of fertilization conditions. This result may resolve not only socio-economic constraints with low input fertilizer but also water stress on rice cultivation.

Keywords: Rice, fertilizer, yield, upland

Introduction

Madagascar is part of a few countries in Sub-Saharan Africa that rice cultivation provides people' staple food (FAO, 2000). For the last two decades, this upland cropping system represents 17% of the rice fields (FAO, 2000). Due to food insecurity compared to demographic boom, water stress, nutrient depletion in the paddy soil, research has been undertaken "Yield Gain" trials during the rice crop season (2018/2019). Agricultural intensification can be achieved by improving agricultural practices through better crop management (FAO, 2000) and/or through improved and adapted varieties.

Yield gain can be obtained through coupling crop nutrient management and varietal improvement (AfricaRice, 2014). On the one hand, the rice farmers are interested in that yield gain is due to the optimal management conditions, by the nutrient improvement (Vandamne et al., 2015). Or, yield gain may be obtained in the context of Malagasy farmers' practices characterized by under- optimal conditions in nutrients (nutritional stress) or water supply (water stress). On the other hand, agronomic researchers need information on the potential yield of rice varieties under a given fertilizer application used by farmers. It is to implement decision-making tools effectively, such as the Nutrient Manager for Rice. Detailed knowledge of the phenological characteristics of the most important varieties is required by crop modelers. It is to make a more accurate prediction of

potential yields in different agrosystems such as lowland or upland rice. That is to better identify in situ the dynamics of rice crop nutrient management widely adopted in the farmers' environment according to the soil conditions and the climatic variability (decreased soil fertility, water stress linked to the drought), and the socio-economic constraints (low purchasing power of farmers generating a low input of nutrients in their plot). So, this is the problem to be solved: What improved and profitable agricultural practices would we suggest for farmers in terms of grain yield, nutrient use efficiency, and economic returns at a strict rainfed upland ecology?

This trial was conducted in the Middle West of Madagascar:
- to assess, firstly, the yield gain and the potential yield of the rice varieties disseminated by FOFIFA / AfricaRice, widely adopted by Malagasy farmers;
- secondly, to determine the appropriate fertilization formula for upland rice in a given area.

As the predicted hypothesis, this is to verify:
H1: The good yield is provided by using improved varieties with a high fertilization rate for rainfed upland rice.
H2: Each variety has its specific nutrient needs for a target yield, in a given area with water limitations.

Method
Experimentation site
It was implemented on -farm located in the Middle West of Madagascar. in Ankazomiriotra II, Rural municipality of Ankazomiriotra, Mandoto district, Vakinankaratra region. To be more accurate, it is at 19 ° 40' 6.6" S and 46° 32' 60" E. The rainfall by decade is as follows:
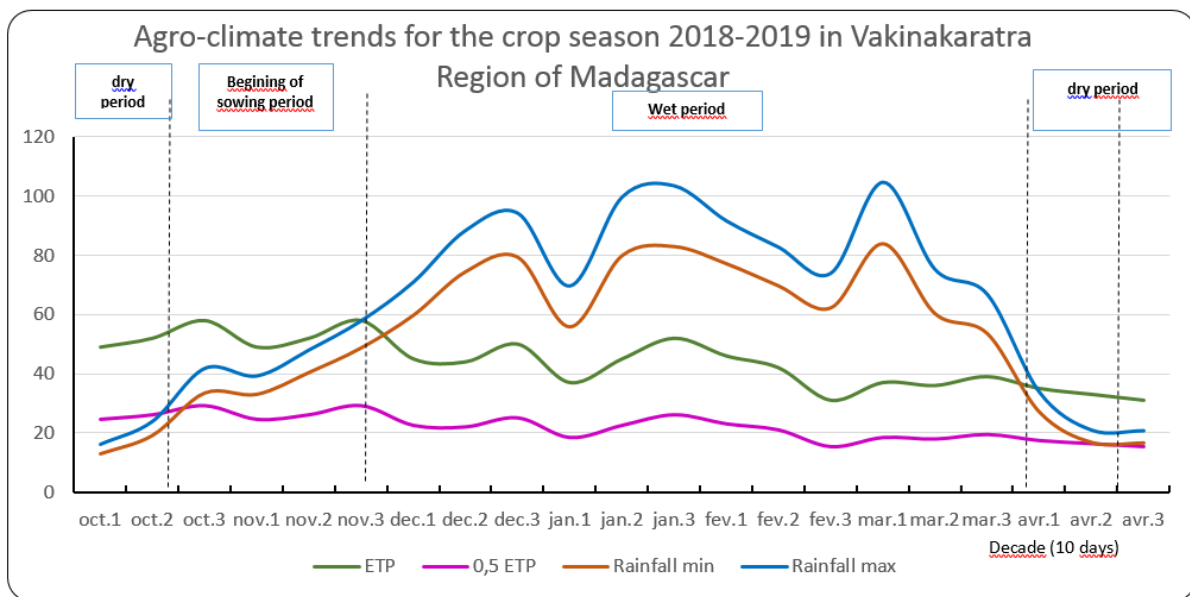

Figure 1: *Rainfall trends (Source: DGM)*

For upland rice cultivation, it may be implemented up to 60 mm of monthly rainfall, up to 0.5 ETP (evapotranspiration), for those that are under 900m of elevation, knowing the ferralsoil characteristics in this region. The soil and organic fertilizer analysis are as follows:

Table 1: Soil properties and basal organic fertilizer brought by farmers

Parameters	pH water	N%	Pppm	C%	MO%	C/N	K meq/100g
paddy soil with monocutivation of rice	5,42	0,056	0,1	0,534	0,92	9,535714	0,315
paddy soil after crop rotation legumes-rice	5,61	0,056	3,4	0,637	1,09	11,4	0,15
Compost/farmyard manure	8,06	0,81	0,16	12,1	20,81	14,19	0,55

Parameters	Na meq/100g	Ca meq/100g	Mg meq/100g	Moisture (%)	Clay %	Limon %	Sand %
paddy soil with monocutivation of rice	0,246	3,14	1,67		14	19	67
paddy soil after crop rotation legumes-rice	0,143	0,807	0,385				
Compost/farmyard manure	0,22	0,02	0,38	55,5			

The soil is relatively poor in terms of nutrients, but the crop rotation increases its fertility and influences nutrient uptake.

Design

The design is characterized by RCBD (Complete Randomized Block Design) with three replications for each variety in each treatment, around 3m*3m per plot.

The management of nutrients helps to evaluate potential yields. The previous crop for all treatments is legumes as it can be uniform, following crop rotation "legumes/rice/legumes/rice" during many successive seasons. The severity of water stress imposed in upland rice will depend on rainfall during the experimentation.

T1: 7,7 Tonnes of compost/ha + 1112 kg of urea/ha **(high** fertilizer input, rate split in two times)

T2: 3,88 Tonnes of compost/ha + 278 kg of urea /ha (**low** fertilizer input)

T3: 7,7 Tonnes of compost/ha + 556 kg of urea /ha (**medium** fertilizer input)
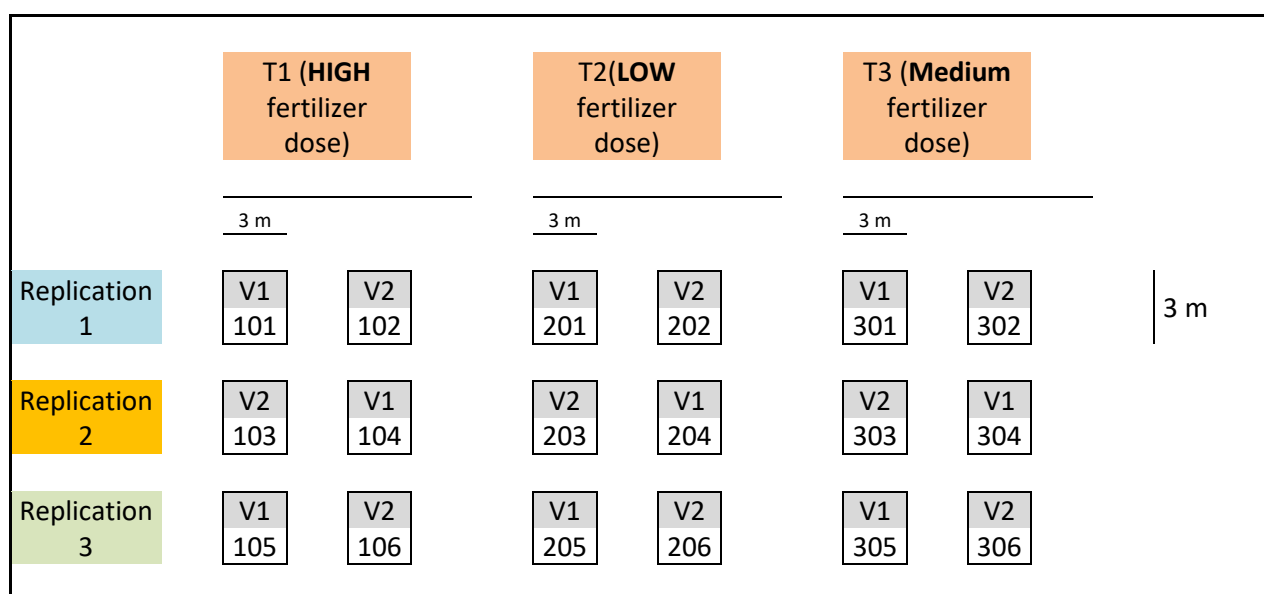
The layout is as follows:

Figure 2: *Experimental design*

Materials

Two (2) varieties were tested, representative of the varieties which were most widely adopted by Malagasy rice farmers for several years from 900m to 1200m of elevation. These varieties are selected mainly for their character of better yield and better plant growth with a cycle duration of 100 to 120 days, regarding a specific resistance to abiotic and biotic stress (*Striga* Asiatica, so on). They are recorded in Table 2:

Table 2: List of released varieties

N°	*Variety/cultivar*
V1	Nerica 4
V2	B22

Procedure

The types of fertilizer used, the period of application, and the quantity of fertilizer for each treatment are given in Table 3:

Table 3: Treatments, fertilizer types, time and Rate of intake

T1: HIGH fertilizer input			
Nutrient:	Basal	Topdressing (broadcasting method)	
Type of fertilizer used:	Compost	Urea	Urea
Application period (JAS):	At plowing time	14 JAS	30JAS
Rate (kg of NUTRIENT ha-1):		256 N	256 N
Rate (kg of fertilizer.ha-1):	7 700	556	556
T2: LOW fertilizer input			
Nutrient:	Basal	Topdressing (broadcasting method)	
Type of fertilizer used:	Compost	Urea	Urea
Application period (JAS):	At plowing time	14 JAS	30JAS
Rate (kg of NUTRIENT ha-1):		128N	0N
Rate (kg of fertilizer.ha-1):	3 880	278	0
T3: MEDIUM fertilizer input			
Nutrient:	Basal	Topdressing (broadcasting method)	
Type of fertilizer used:	Compost	Urea	Urea
Application period (JAS):	At plowing time	14 JAS	30JAS
Rate (kg of NUTRIENT ha-1):		256 N	0N
Rate (kg of fertilizer.ha-1):	7 700	556	0

JAS = days after sowing;
* A sample of the manure used is analyzed for determining N, P, and K grades. For each treatment, a complete randomized block device with 3 replications.

It has been sowing by 20cm * 20cm as an interval. During the rice-growing season, we did the best on managing and controlling other factors such as insects and weeds, we focus our study on fertilizer effects, water stress, and varieties responses. They are among the key factors for rice yield gain.

Results

The results of the ANOVA are shown in Table 4. Figure three illustrates yield variation according to treatment and cultivars. It appears that, statistically, from a treatment point of view, there is no significant difference between T1, T2, and T3 as well as between V1 and V2 (by XL STAT 2016 software); they are at the same category. However, only the interaction T1V1 differs significantly to others, such as:

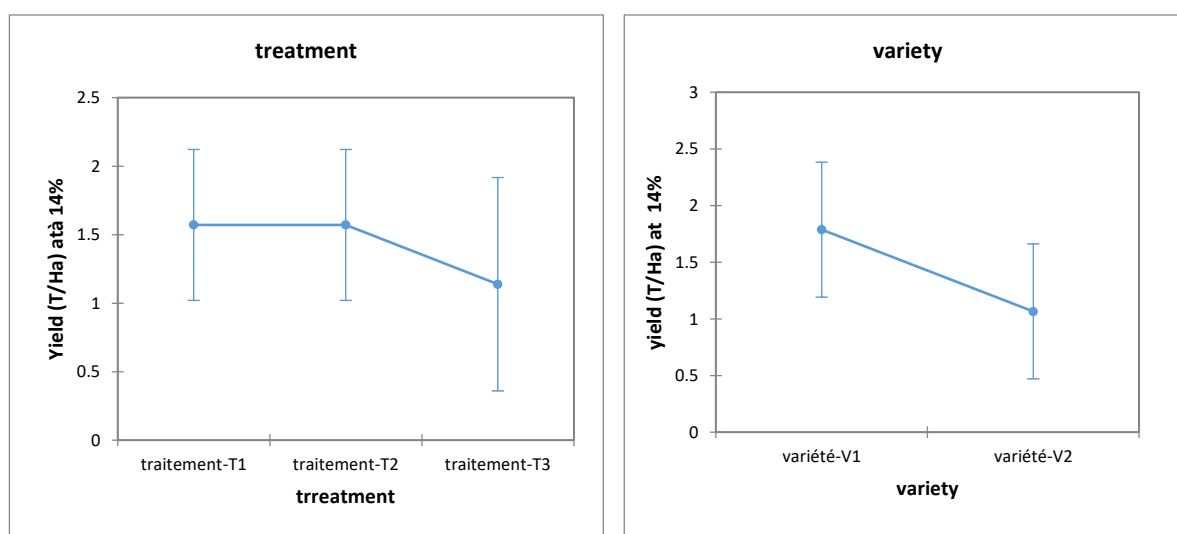| Category	LS means	Standard error	Lower bound (95%)	Upper bound (95%)	Groups
T1*V2	1,1916	0,1909	0,7870	1,5962	A
T2*V1	1,1916	0,1909	0,7870	1,5962	A
T2*V2	1,1916	0,1909	0,7870	1,5962	A
T3*V1	1,1916	0,1909	0,7870	1,5962	A
T3*V2	1,1916	0,1909	0,7870	1,5962	A
T1*V1	2,6014	0,4268	1,6967	3,5062	B

Figure 3: *Overview of calculated yield variation according to treatment and types of varieties*

T1 and T2 show almost similar yield (on average of 1,58T/Ha against respectively 1,55T/Ha), statistically no significant, even though the fertilizer rate is completely different. Generally, V1 is highly productive than V2 as their cycle duration are respectively 120 days against 100 days; it means particularly much more vegetative development with much more fertile tillers and plant height as below.

Then, the analysis of variance according to these factors will be:

Table 4: Results of ANOVA

TREATMENT	N° VARIETY	Number of the fertile tillers		Plant Height (cm)		*Calculated yield in T/ha at 14% of humidity		Real yield in T/ha	
T1	V1	16,11	a	88,56	a	2,60144169	b	2,70	b
T1	V2	13,22	a	82,89	a	0,57220397	a	1,94	a
T2	V1	12,67	a	71,33	a	1,31314002	a	1,89	a

T2	V2	14,11	a	69,22	a	1,80	a	2,00	a
T3	V1	15,22	a	76,00	a	1,44841178	a	2,30	a
T3	V2	13,89	a	85,89	a	0,82731794	a	2,26	a

*Calculated yield=Number of the fertile tillers (or panicles) per area*Number of grains per panicle*fertile and filled grains*grain weight

These results show us that: with a high rate of fertilizers, the yield of V1 and V2 are respectively 2,70T/Ha and 1,96T/Ha. Nevertheless, with low fertilizer input, V1 and V2 have 1,89T/Ha and 2T/Ha respectively. Finally, with a medium fertilizer application, V1 has 2,30T/Ha and V2 for 2,26T/Ha. Then, V2 responds relatively well to low input fertilizer as V1 to the high nutrient application.

Table 5: Yield components

Treatment	Variety	Replication	Number of spikelets per panicle	Grain fertility percentage	1000 grains weight (grams)
T1	V1	R1	80,00	77,50	7,313
T1	V1	R2	92,00	85,14	11,718
T1	V1	R3	87,33	70,61	8,914
T1	V2	R1	72,00	69,44	7,603
T1	V2	R2	73,00	53,42	3,337
T1	V2	R3	70,33	13,74	3,771
T2	V1	R1	83,33	78,00	6,483
T2	V1	R2	76,33	84,72	7,056
T2	V1	R3	80,67	83,06	5,608
T2	V2	R1	75,67	72,25	9,030
T2	V2	R2	88,00	78,79	8,944
T2	V2	R3	75,00	70,67	7,159
T3	V1	R1	78,33	89,79	8,336
T3	V1	R2	78,33	67,23	3,967
T3	V1	R3	67,00	70,65	7,740
T3	V2	R1	76,33	72,05	4,898
T3	V2	R2	65,00	67,18	4,362
T3	V2	R3	77,33	73,28	4,399

These components determine paddy yield as each panicle bears many spikelets, but they are partially filled, that's why their weight is too low compared to the target weight (FOFIFA, 2010).

Discussion
Regarding improved varieties, released by National Research, both Nerica 4 and B22 are resilient to water stress (drought) for middle elevation in Madagascar, according to varietal distribution (SNDR, 2016). Their responses to fertilization might be settled by many filed experiments, compared to local and traditional varieties. They are slightly higher yields not only under abiotic and biotic stress but also under optimal conditions (Raharimanana, 2018). As usual, yield response to fertilizer rate in the experiments with varying light intensity is illustrating by increased sensitivity

to an added fertilizer (Bockel et al., 2001). However, in this study, it is not the case. It seems very important to underline that up to a convenient fertilizer rate, varieties do not respond significantly in terms of yield. It suggests that although under dry ferralitic soil, as nutrients may be a limiting factor, yield reduction may have resulted in an overdose of fertilizer application. The average yield does not exceed 1,58T/Ha whatever the fertilization rate, except the top of 2,04T/Ha for T1V1, by combining high fertilization (562N) with adapted variety (Nerica 4) which is impossible for most of the Malagasy farmers. Simultaneously, other agricultural constraints such as drought should be one of the factors. It implicates a significant loss in terms of investment, considering the cost and accessibility of these mineral fertilizers by farmers. Yet, for degraded soil of the Middle West of Madagascar, with a high attack of *Striga* Asiatica, upland rice yield is around 0 to 1T/Ha without fertilizer application (Rakotondramanana, 2013). Hence, the appropriate fertilizer rate is one of the requirements of the improved varieties, which has not been well -respected at the farmer level (Bockel et al., 2001). Moreover, advanced agricultural technologies can increase yield in eight times (Rakotoson, 2013). That's why this study provides information for implementing accurate agriculture in Madagascar to help farmers in their decision making in terms of fertilization. Consequently, in this study area, these varieties B22 and Nerica 4 are highly yielded at the appropriate fertilizer input not only its quantity (rate) but also its quality (other elements such as P, K, and so on).

Apart from that, as far as nutrient mobilization is concerned, soil moisture is very required for its better management (Raharimanana, 2018). Rainfall is one of the critical factors for upland rice as it may suffer from drought at the booting stage. Other research confirmed that the water deficit reduced rice plant growth duration, its height, and its tillering, its root biomass, and especially its grain fertility (Hassane, 2017). Therefore, concerning this affirmation, Huguet (1996) said that raising leaf nitrogen from N to 4N increases grains sterility at 30%. It is a symptom of Nitrogen overtop in rice and then causes maturity delay. Besides, high fertilizer rate is making plants to produce more tillers per hill, but coupling with water deficit, while grains per panicle per tiller are decreasing its filling ability. It is shown by a low 1000 grains weight (Lalanirina, 2014). Nevertheless, during this crop season, according to the rainfall data, it does not seem strictly severe. In this study, the more we increase the fertilizer rate (for T3 comparatively to T2), the more we have a yield slightly decreased 1.55T/Ha to 1,13T/ha. Yield losses go around 0.99 to 34.92% if the nutrient is inadequate as -2.32 to 53.99% if the water is not well controlled (Raharimanana, 2018). It suggests that yield potential for these varieties is not well expressed in these conditions. It can reach till 4 to 5T/Ha for the other upland rice cropping system (such as SCV or the use of plant cover without plowing), as an average of 2,3T of grains per hectare (Rakotondramanana, 2013).

Furthermore, in this cropping system point of view, in this study, the previous crop "legumes" is providing nutrients for the rice, especially the massive returns of organic carbon to soil (Bechini et al., 2009) and then nitrogen to plant nutrition. There are more additional Nitrogen inputs by a significant quantity of farmyard manure or compost per plot. Despite the fact that Nitrogen is one of the limiting factors in Malagasy paddy soil, the high number of tillers and the plant height comparatively to grains weight shows nutritional unbalance. In other words, rice plant seems to lose time for tiller and leaf fabrication instead of accumulating grain glucose reserve (Gros, 1962). Hence, soil content may be dominated by nitrogen than the other major elements such as phosphorus. According to Matsuo et al., (2016), it is better to assess soil chemistry and nutrient status of soil in an attempt to improve the productivity of rainfed uplands. The result is as flows at the end of the vegetation period.

Table 6: Soil analysis at the end of tillering stage

Soil simple under treatment	pH water	N%	Pppm	C%	MO%	C/N	K meq/ 100g	Na meq/ 100g	Ca meq/ 100g	Mg meq/ 100g
check	5,61	0,056	3,4	0,637	1,09	11,4	0,15	0,143	0,807	0,385
T1	5,51	0,091	4,1	0,996	1,71	10,9	0,135	0,149	1,87	0,875
T2	5,7	0,115	4,9	1,2	2,06	10,4	0,154	0,133	2,15	0,912
T3	5,42	0,112	4,5	1,18	2,03	10,5	0,115	0,196	1,68	0,743

This result shows us the nutrient perdition during the growth cycle, which is not uptake by rice. It is a waste of urea application by nitrogen volatility and hydric erosion if it is not immediately absorbed by the plant. Indeed, nitrogen absorption is different for variety with short cycle duration (B22) than those with medium/long cycle (Nerica 4) as its pick is a little bit shifted [Tanaka et al., (1966), recited by De Datta (1981)]. Moreover, the fact of splitting nitrogen fertilizer two times during the vegetative period is more beneficial (Rakotoarisoa, 2011) as it reduces nitrogen perdition.

To be profitable, this may help agronomists to review the appropriate dose of nitrogen for a target yield, considering specifically plant needs for their growth and reproduction. For many years, FOFIFA recommended, for upland rice in the Middle West of Madagascar, to adopt crop rotation and to apply up to 5Tonnes of organic fertilizer per Hectare, 60 to 90N, 30P$_2$O$_5$, and 20 to 30K$_2$O for a target grain yield of 4T/ha. Consequently, the appropriate rate of fertilization goes under T2 (low fertilizer rate in this trial). On the other side, Zhao et al., (2016) suggests that increasing soil organic matter enhances inherent soil productivity while offsetting the fertilization effect under a rice cropping system. Therefore, it is better to focus on fertilization investment by increasing significantly organic matter application as its content is showed in table1. By its decomposition and mineralization, it improves soil properties, then plant nutrition. It may be helpful and profitable for farmers regarding the cost of chemical fertilizers comparatively to farmyard manure, and particularly the low input fertilizer ability of rice farmers (SNDR, 2016). Research should contribute by improving nutrient use efficiency and economic returns, with existing farmers' fertilizer practices (Singh et al., 2014). Increasing the productivity and resilience of smallholder farming systems is a huge challenge. It will require significant and sustained technical, financial, and political support and action at both the national and local levels (Harvey, Rakotobe, Rao, Radhika, Razafimahatratra, Rabarijohn, Rajaofara & MacKinnon, 2014). These technical capacities for several years allow Malagasy farmers to adapt to some risks (Penot, Dabat, Rakotoarimanana, Grandjean, 2014). Therefore, reducing fertilizer rate and better making value the low chemical fertilizer input is among mitigation strategies to water stress, especially for upland rice, considering the cost of fertilizer unit (Galabi et al., 2011). It joined the ambition of FAO in 2016 that cereals farmers adopt the components and the essential practices of « Produce more with less » model. Crop rotation based successively by legumes such as bean and rice is more productive; yield increases by 25.5% through the incorporation of residual farmyard manure, crop residues, and biofertilizers (Davari et al., 2012).

Conclusion

Through this study, the first hypothesis is partially confirmed. Using a convenient rate of fertilizer input (chemical and organic) combined with an adapted variety, is highly productive at a given area to avoid nutrient perdition. It is harmful to the environment and economics knowing farmers' constraints. It may suggest that it is better to increase organic matter quantity instead of chemical fertilizer. The first one improves soil properties and provides plant nutrition by progressive decomposition and mineralization at convenient climatic conditions. This result joins what FOFIFA has been doing for many years. Farmers should bring compost up to 5T/Ha, and nitrogen

fertilizers at the right rate.It is variable according to soil organic matter content and its ratio carbon by nitrogen C/N. it requires the next research to determine this dose accurately. In this sense, each variety has his own needs as far as nutrient management is concerned, in a given area. It depends on its cycle duration. Finally, this study helps each category of farmers not to apply under or overdose of chemical fertilizers considering its agronomic, environmental, and economic impacts. The average grain yield does not exceed 1,58T/Ha even though combined with a great potential variety. According to FAO, the downward trend in productivity must be reversed. It focuses not only on the balanced nutrient that will reduce the problems associated with overexploitation of the land; but also on good control of water. It may suggest the other upland rice cropping system which conserves soil moisture at the right rate and enriches soil organic carbon.

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