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Evaluation of Genetic Yield Gain: A Case of Lowland Rice Growing in Madagascar

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Abstract

It was the first time in Sub-Saharan Africa, particularly in Madagascar, that a Genetic yield gain has been conducted among improved rice varieties during two successive cropping seasons (2014/2015 and 2015/2016) in the Middle West at the research station. It aims to analyze and to compare grain yields and their components for 12 varieties of rice distributed in Madagascar, by the Research Institutions since 1960 up to 2013. Given that water and nutrient management can be used to assess potential yields of rice, it is assumed that nutrient limitation and water stress are the main biophysical factor limiting the yield of irrigated rice grown outside of extreme temperatures. By a complete random block device with 3 repetitions, the 12 rice varieties are respectively subjected to the following three treatments such as T1: Optimal treatment in water and nutrients (target yield = potential yield), T2: Optimum nutrient treatment but sub-optimal in water, without additional irrigation, T3: Optimal treatment in water but sub-optimal in nutrients, closer to Malagasy farmers' practices. Thus, for these years, the research released genetic yield gain under water stress and a high level of fertilization, with average yields of 3.5t/ha; against 3, 9t/ha at low level of fertilization and good water conditions. Finally, under good rice growing conditions (rich soil and water control), it is yielding around 4.5t/ha. This result may resolve not only socio-economic constraints with low input fertilizer but also climate change effects (drought) on rice cultivation.

Keywords: Rice, fertilizer, water, yield, Tiller.

Introduction

Madagascar is part of a few countries in Sub-Saharan Africa that have undertaken "Genetic Yield Gain" trials during two successive rice crop seasons (2014/2015 and 2015/2016). Agricultural intensification can be achieved by improving agricultural practices through more appropriate crop management (FAO, 2009) and/or through improved and adapted varieties. There are the development and the introduction during several years (from 1960 until 2013) of improved and adapted varieties with higher yield potential and greater resistance to biotic and abiotic stresses (FAO, 2009).

Genetic yield gain can be defined as the yield gain obtained through varietal improvement (AfricaRice, 2014). On the one hand, the rice farmers are interested in the question of whether the genetic yield gain obtained by the varietal improvement is expressed both in optimal management conditions (Vandamne et al., 2015) and 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 varieties used by farmers to implement decision-making tools effectively, such as the Nutrient / Water Manager for Rice. Detailed knowledge of the phenological characteristics of the most important varieties introduced in various countries is required by crop modelers for more accurate prediction of potential rice yields in different environments/ agrosystems. They make it possible to better identify in situ the dynamics of rice varieties widely adopted in the farmers' environment according to the edaphic conditions and the climatic variability (decreased soil fertility, water stress linked to the drought and the flood) 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 and water use efficiency and economic returns?

Multilocal trials were conducted in selected countries in sub-Saharan Africa, including Madagascar:

- to assess, firstly, the genetic yield gain and the potential yield of the rice varieties disseminated by FOFIFA / WARDA / AfricaRice from 1960 to 2013;
- secondly, to identify the agronomic traits that contribute to the genetic yield gain (Nutrient uptake, Nutrient utilization, Crop duration, Harvest index, Percentage of grain filling, Number of spikelets per panicle, etc.).

As predicted hypothesis, there are to verify:

H1: The nutrient limitation is the main biophysical factor which reduces grain yield in irrigated or flooded lowland rice a part of extreme temperature.

H2: The water stress is the most important factor which reduces grain yield in rainfed lowland rice.

Method

Experimentation site

It was implemented on farm located in the regional research station of FOFIFA (National Agricultural Research Institute) in the Middle West of the Island in Kianjasoa, Rural municipality of Mahasolo, BONGOLAVA region. To be more accurate, it is at 19 ° 05' S and 46° 22' E. The rainfall is as follows:

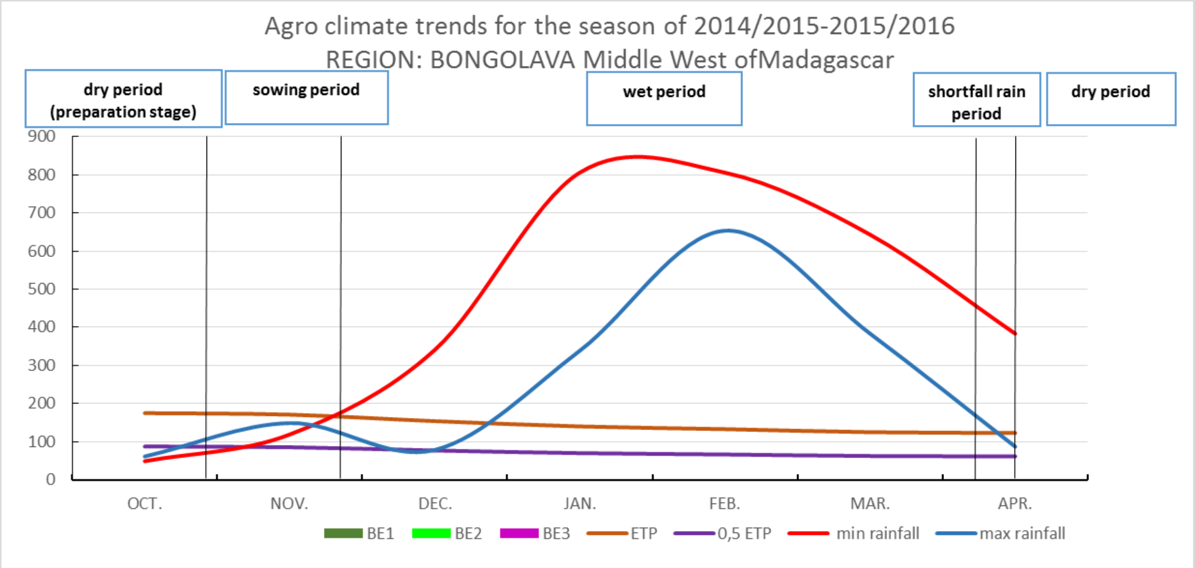

Figure 1: *Rainfall trends (Source: DGM)*

For rice cultivation, it may be implemented up to 100 mm of monthly rainfall knowing the ferralsoil characteristics in this region. The soil and the organic fertilizer analysis are as follows:

Table1: Soil properties and basic organic fertilizer brought by farmers

Parameters	pH (H_2O)	pH (KCl)	N (%)	C (%)	C/N	Ca (meq/ 100g)	Mg (meq/ 100g)	K (meq/ 100g)	Na (meq/ 100g)	P2O5 (ppm)	CEC (meq/ 100g)	Clay %	Limon %	Sand %	organic matter (%)	Moisture (%)
paddy soil	5,45		0,15	1,95		1,27	0,81	0,24	0,19	0,20	10,17	27,33	22,67	50,00		
Compost/farmyard manure	8,06	7,33	0,81	12,10	14,19	0,02	0,38	0,55	0,22	0,16					20,81	55,50

The soil is relatively poor in terms of nutrient, but the hydromorphisation decreases its acidity and influences nutrient uptake.

Design

The design is characterized by RCBD (Complete Randomized Block Design) with 3 replications for each variety in each treatment, around 2m*3m per plot.

The management of water and nutrients helps to evaluate potential yields. For sub-optimal management processing, a more "realistic" scenario will be tested. Therefore, treatment with nutrient suboptimal fertilizer rate (nutrient limitation) will be imposed in irrigated lowland rice cultivation, and other treatment without additional irrigation (water limitation). The severity of water stress imposed in lowland rice will depend on rainfall during the experimentation.

T1: Optimal water and nutrient treatment, permanently flooded + fertilization at a high rate (target yield = potential yield)

T2: optimal nutrient treatment but sub-optimal in water, without additional irrigation (except at the time of transplanting) + fertilization at a high rate

T3: Optimal treatment in water but sub-optimal in nutrients, flooded permanently + low input fertilizer, closer to the Malagasy Farmers' practice.

The layout is as follows:

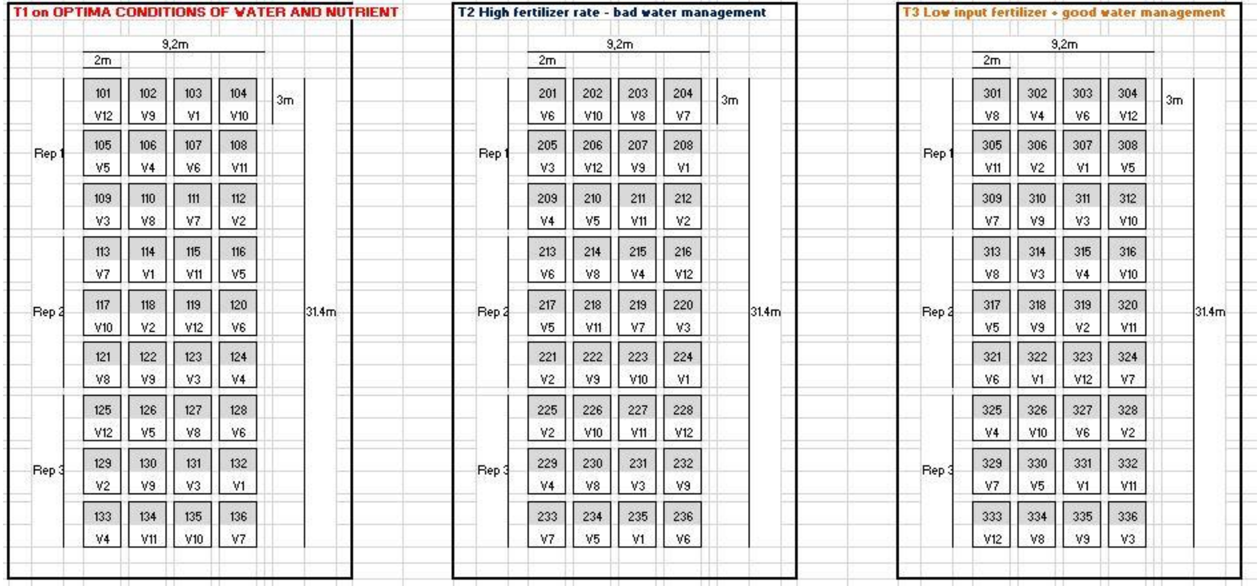

Figure 2: *Experimental design*

Materials

Twelve (12) 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 regarding to a specific resistance to abiotic and biotic stress (blast, so on). They are recorded in Table 2:

Table 2: List of varieties and year of release

N°	*Variety/cultivar*	*Year of release*
V1	ROJOFOTSY	1960
V2	2509	Recent
V3	KALILA	1980
V4	2787	1986
V5	X 265	1993
V6	SOAMEVA	recent
V7	FOFIFA 160	2002
V8	SEBOTA 70	2010
V9	X 1648	2013
V10	NERICA L 19	Check (witness or témoin N°3)
V11	IR 64	Check (witness or témoin N°2)
V12	ALI COMBO	Local Check (witness or témoin N°1)

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 (optimal condition in nutrient) et T2 (optimal condition in water)						
Nutrient:	N			P2O5	K2O	
Type of fertilizer used:	NPK (11:22:16)	Urea	Urea	NPK (11:22:16)	NPK (11 :22 :16)	Farmyard Manure*
Application period (JAT):	At transplanting time	14 JAT	45 JAT	At transplanting time	At transplanting time	At ploughing time
Rate (kg of NUTRIENT ha-1):	33	30	30	66	48	*
Rate (kg of fertilizer.ha-1):	300	65	65	300	300	10000
T3 (sub optimal condition in nutrient)						
Nutrient:	N			P2O5	K2O	
Type of fertilizer used:	NPK (11:22:16)	Urea	Urea	NPK (11:22:16)	NPK (11 :22 :16)	Farmyard Manure *
Application period (JAT):	At transplanting time	14 JAT	45 JAT	At transplanting time	At transplanting time	At ploughing time
Rate (kg of NUTRIENT ha-1):	3.3	3	3	6.6	4.8	*
Rate (kg of fertilizer.ha-1):	30	6.5	6.5	30	30	5000

JAT = days after transplanting;

* 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.

During 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 management and varieties responses. They are among the key factors for rice yield gain. To manage well water, this is as follows:

During vegetative period, rice needs at least 2 mm of water layer above the paddy soil, then its water needs increase progressively during reproductive stage till 4 mm and finally decrease till 0 mm for the maturation period. The fact of alternating irrigation and drainage daily is the ideal water management, beneficial for soil and plant. Most of farmers adopt transplanting method for upland rice at around 21 days after sowing, which is really more dependent on water availability at the plot level. It is around 4 leaves stages that farmers should transplant for a good tillering. That is why top-dressing fertilizer is very required around 14 JAT (days after transplanting).

Results

The results of ANOVA are shown in Table 4. The figure 1 illustrates its variation according to treatment and cultivars. It appears that, statistically, there is no significant difference between the two years of experimentation. However, from a treatment point of view, there is a significant difference between T1 and T2 as well as between T1 and T3. But, the T2 and T3 treatments are statistically equivalent (by R program and XL STAT 2013 software) such as:

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 T1  T2  T3
"b" "a" "a"
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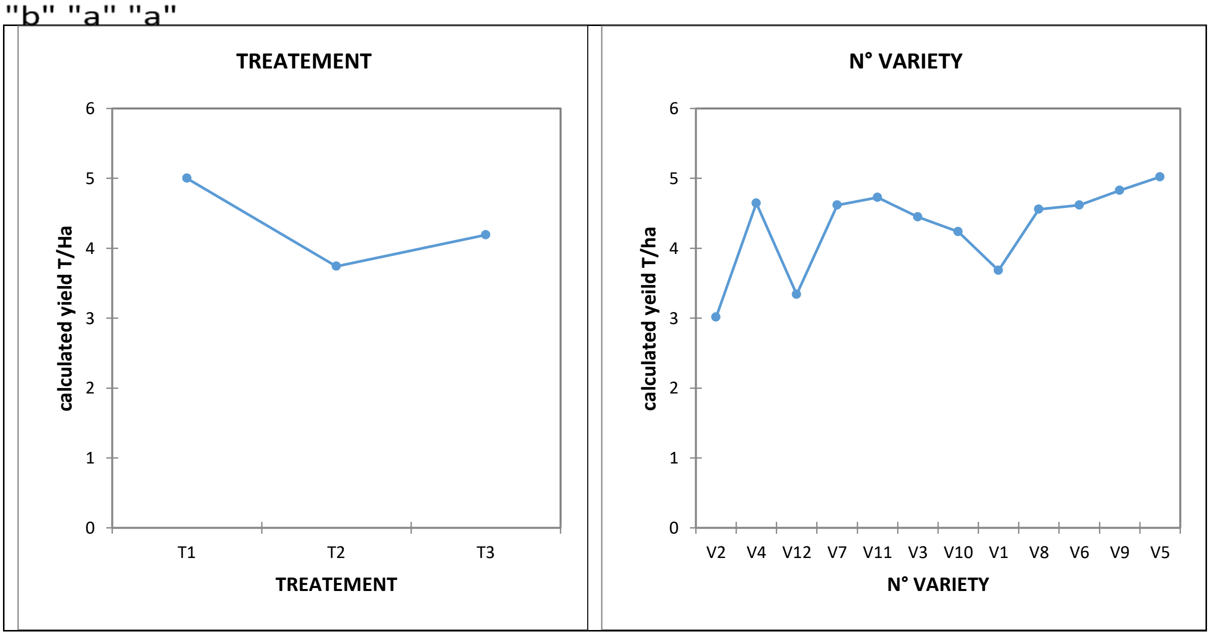

Figure 3: *Overview of calculated yield variation according to treatment and types of varieties*

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

Table 4: Results of ANOVA

TREATMENT	N° VARIETY	VARIETY	Number of tiller		Plant Height		Calculated yield in T/ha at 14% of humidity		Real yield in T/ha		Percentage of grain by overground biomass	
T1	V2	2 509	9,19	a	85,34	a	3,72	a	3,15	abc	38,87	ab
T1	V4	2 787	11,97	a	97,78	a	5,12	a	4,65	abc	37,94	ab
T1	V12	Ali Combo	7,90	a	150,65	a	4,04	a	3,69	abc	27,54	ab
T1	V7	Fofifa 160	12,51	a	120,63	a	5,21	a	4,58	abc	38,74	Ab
T1	V11	IR 64	13,93	a	81,68	a	5,75	a	4,48	abc	43,87	Ab
T1	V3	Kalila	10,51	a	156,97	a	4,99	a	4,65	abc	40,41	Ab
T1	V10	Nerica L 19	9,06	a	109,98	a	4,84	a	4,93	bc	40,07	Ab
T1	V1	Rojofotsy	10,34	a	132,68	a	4,44	a	4,33	abc	34,62	Ab
T1	V8	Sebota 70	12,77	a	80,48	a	4,63	a	3,56	abc	44,27	Ab
T1	V6	Soameva	11,14	a	140,32	a	5,44	a	5,01	bc	41,08	Ab
T1	V9	X 1648	10,09	a	112,45	a	5,51	a	4,94	bc	44,59	Ab
T1	V5	X 265	13,38	a	122,45	a	6,29	a	5,21	c	42,25	Ab
T2	V2	2 509	8,52	a	71,16	a	2,46	a	1,93	a	34,53	Ab
T2	V4	2 787	11,81	a	89,34	a	4,43	a	3,54	abc	34,26	Ab
T2	V12	Ali Combo	5,50	a	126,90	a	2,06	a	2,05	ab	18,72	A
T2	V7	Fofifa 160	10,61	a	92,35	a	3,83	a	2,89	abc	35,30	Ab
T2	V11	IR 64	11,04	a	70,23	a	3,90	a	3,02	abc	40,53	Ab
T2	V3	Kalila	11,38	a	128,81	a	4,10	a	3,78	abc	32,64	Ab
T2	V10	Nerica L 19	8,96	a	103,97	a	4,43	a	4,77	abc	41,60	Ab
T2	V1	Rojofotsy	7,99	a	98,25	a	2,68	a	1,99	a	29,49	Ab
T2	V8	Sebota 70	15,03	a	71,13	a	4,59	a	3,64	abc	44,26	Ab
T2	V6	Soameva	9,05	a	125,35	a	4,28	a	4,11	abc	35,30	Ab
T2	V9	X 1648	8,78	a	102,44	a	4,37	a	3,95	abc	44,69	Ab
T2	V5	X 265	10,18	a	99,19	a	3,74	a	3,06	abc	37,29	Ab
T3	V2	2 509	7,10	a	76,87	a	2,86	a	2,10	abc	37,98	Ab
T3	V4	2 787	11,44	a	91,36	a	4,39	a	4,26	abc	38,21	Ab
T3	V12	Ali Combo	6,98	a	148,59	a	3,91	a	3,46	abc	30,15	Ab
T3	V7	Fofifa 160	10,45	a	112,87	a	4,82	a	4,54	abc	45,82	Ab
T3	V11	IR 64	12,28	a	74,84	a	4,52	a	3,79	abc	43,81	Ab
T3	V3	Kalila	8,52	a	124,67	a	4,24	a	3,50	abc	44,10	Ab
T3	V10	Nerica L 19	6,63	a	98,32	a	3,44	a	3,21	abc	41,85	Ab
T3	V1	Rojofotsy	8,20	a	122,00	a	3,93	a	3,33	abc	40,28	Ab
T3	V8	Sebota 70	11,54	a	78,57	a	4,45	a	3,49	abc	47,32	Ab
T3	V6	Soameva	9,33	a	122,43	a	4,12	a	3,69	abc	42,03	Ab
T3	V9	X 1648	9,29	a	104,11	a	4,60	a	3,74	abc	45,48	Ab
T3	V5	X 265	10,30	a	114,12	a	5,03	a	4,32	abc	46,80	Ab

There are the grain yields variations of the varieties following water and fertilization management during the two 2014-2015 and 2015-2016 rice seasons. Then, the evolution of the yield gain following the year of dissemination as a function of the water and nutrient management is shown in the graphs below:

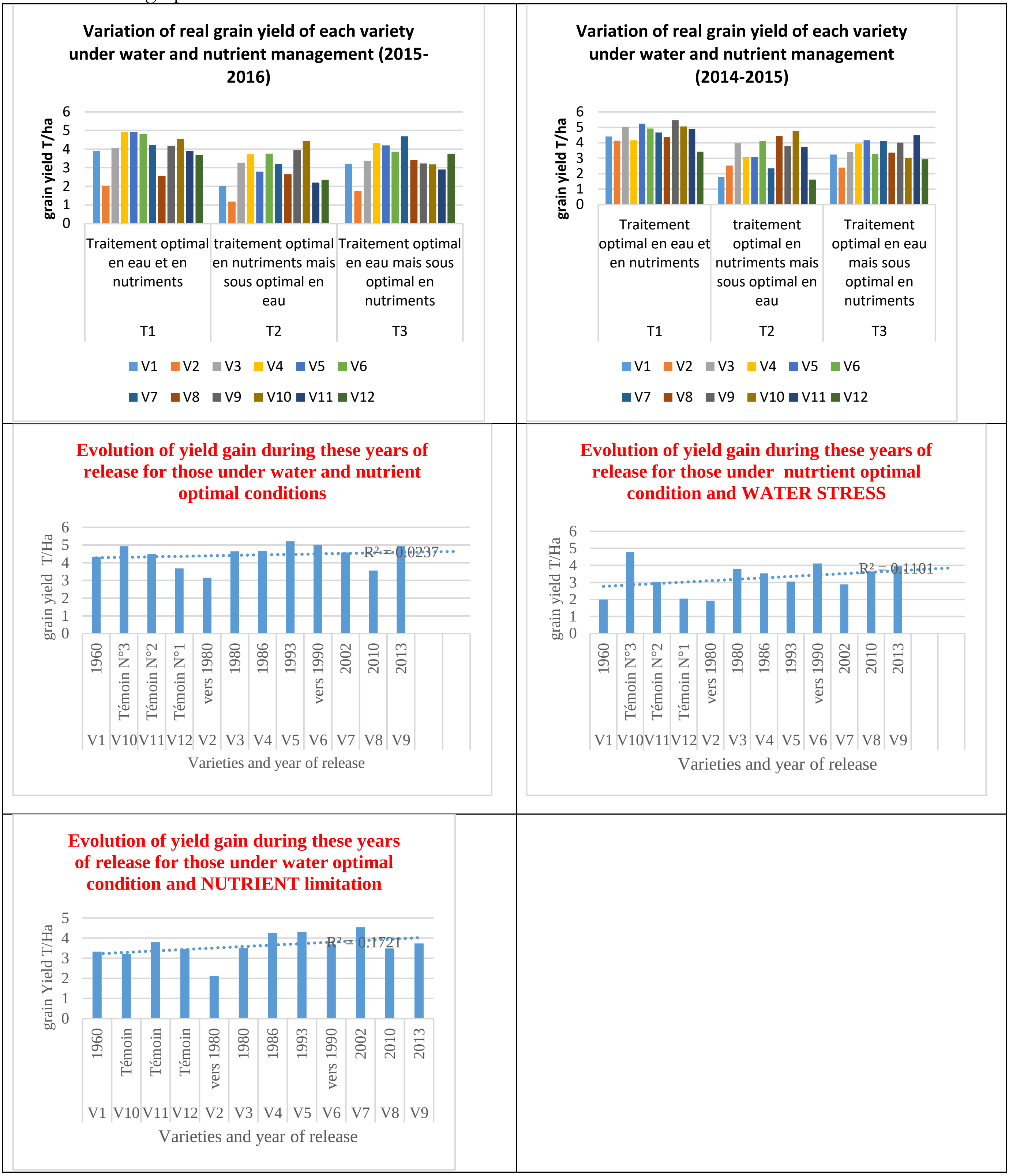

Figure 4: *Series of histograms showing the evolution of grain yields according to varieties, treatments and years of dissemination*

The fact of conducting field experiment for 2 successive years (main crop season) allows us to fix the results that we got. The two first histograms show the same flow (trends) whenever the year of experimentation.

- Firstly, for optimal water and nutrient treatment:
  All varieties respond positively to the optimum conditions. Peaks of yield higher than 5T/Ha were observed for V3 (Kalila), V5 (X 265), V9 (X1648), V10 (NERICA L 19), V11(IR 64). However, there is the poor performance of V12 (ALI COMBO).
- Secondly, concerning optimal treatment in nutrient and sub-optimal in water:
  Some varieties respond well to fertilization despite poor hydric conditions and give yields around 3.5T/ Ha V3 (KALILA), V6 (SOAMEVA), V8 (SEBOTA 70), V10 (NERICA L 19) and V11 (IR 64). They adapt much more to the drought. But, others are not able to express themselves and give yields less than 2.5T/ Ha such as V1 (ROJOFOTSY), V2 (2509), V7 (FOFIFA 160), V12 (ALI COMBO); they are testifying high sensitivity to water stress. However, it should be pointed out that the varieties V4 (2787) and V5 (X265) are able to give yields close to or above 3T/ Ha.
- Finally, as far as optimal treatment in water and sub optimal in nutrients are concerned, varieties are better expressed in good water conditions even if the fertilization level is low and give yields close to or above 3T/Ha such as V4 (2787), V5 (X265), V7 (FOFIFA 160), V9 (X1648) and V11 (IR64). Note the poor performance of V2 (2509), as yield is less than 2.5T /Ha, very sensitive to low fertilization).

Discussion

Table N ° 5 below gives a synthetic view of our study. It highlights the importance of water and nutrient management in the determinism of genetic yield gain.

Table 5: Productivity report

N° VARIETY	Real yield T/ha under OPTIMAL conditions of water and nutrient	Year of release	% of grain yield decreasing if nutrient is limiting	% of grain yield decreasing if water is not well controlled
V2	3,15	vers 1980	33,09	38,55
V4	4,65	1986	8,35	24,00
V12	3,69	Témoin N°1	6,25	44,32
V7	4,58	2002	0,99	37,02
V11	4,48	Témoin N°2	15,47	32,56
V3	4,65	1980	24,77	18,77
V10	4,93	Témoin N°3	34,92	3,33
V1	4,33	1960	23,00	53,99
V8	3,56	2010	1,93	-2,32
V6	5,01	vers 1990	26,36	18,08
V9	4,94	2013	24,27	20,00
V5	5,21	1993	17,18	41,39

Water stress may provide benefit for V8 or SEBOTA 70 and causes low loss if nutrient is limiting. Unfortunately, V1 or Rojofotsy and V9 or X 1648 are more sensitive to these nutrient and water factors. Many authors have already had the opportunity to address this issue of rice yield gap.

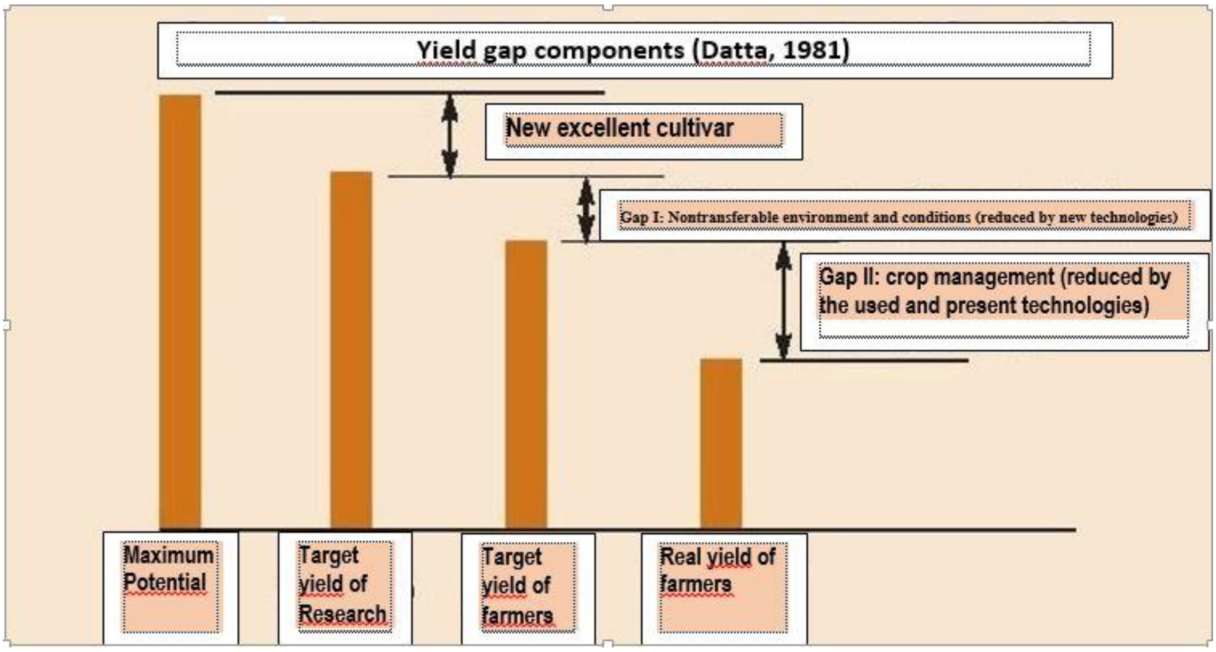

Figure 5: *Yield gap components* (Datta, 1981 recited by FAO, 2009)

Declining yields and productivity have been observed in several intensive rice production systems due to land degradation and poor water management according to Pulver and Nguyen, (1999) and FAO/IAEA. (2009). So from our study, we can draw that: "the control of water (water regime) is a key factor of increasing rice productivity when using improved varieties of research". Then, most varieties show slightly higher yields in a flooded/aquatic environment under low fertilization compared to the dry environment with high fertilization. But, most lowland rice varieties require an anaerobic environment (with permanent water) and an adaptation to their own ecology (the case of the Boeny – Extreme West in low elevation - variety IR 64) to develop. In lowland rice farming, water control is the most important management practice that determines the efficacy of other production inputs. Poor drainage that keeps soil saturated is detrimental to crops and degrades soil quality (Ceesay, 2004). Furthermore, grain yield attributes such as number of effective tillers per hill, panicle length and panicle weight of rice in both the varieties were significantly higher in integrated nutrient management (INM) as compared to chemical fertilizer alone (Singh, Singh, & Sharma, 2013). Notably, the research of Williams and Carrico (2017) identified farmers' use of hybrid seed varietals as the only local climate adaptation strategy to positively correlate with farmers' rice yields.

In the other words, tolerance to poor water control is one of the major concerns of breeders and farmers in adopting a variety. Over the years, since the quality of the soils is progressively deteriorating, it is necessary to produce varieties that are not very demanding in terms of nutrients; that is to say they can be expressed even in low input conditions. This is how the variety V8 or SEBOTA 70 is more efficient in poor water control conditions and better tolerates low fertilization. In fact, it is one of the promising and resilient varieties to climate change. Estimated productivity gains are greatest for the poorest with respect to adoption of climatic shock mitigation measures and chemical fertilizer (Minten, Randrianarisoa, & Barrett, 2006). Both the reduction of the fertilizer input and the best uptake of these low input fertilizer are the appropriate method to adapt to water stress and climate change (Jérémie, Maméri, Albert, & Jules, 2011). It is combined with low water requirement and short duration crop varieties that may increase yields and save water (Sembiring, Makarim, Abdulrachman, & Widiarta, 2012). Increasing the productivity and resilience of smallholder farming systems is a huge challenge that 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 during many years allow Malagasy farmers to adapt to some risks (Penot, Dabat, Rakotoarimanana, Grandjean, 2014). It joined the ambition of FAO in 2016 that cereals farmers adopt the components and the essential practices of « Produce more with less » model.

Ultimately, good water management may be sufficient to mobilize nutrient stock in the soil using deep-rooted varieties. By focusing on the yield components, it turns out that it is the weight of a grain that has been most affected by water and nutrient stress for certain susceptible varieties. On the other hand, this stress allows other resistant varieties to accumulate reserves, then, explaining the high weight of 1000 grains. According to Lalanirina (2014), the results also indicate that in the presence of water deficit, cereal tends to decrease the yield and increase leaf area index. 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).

The research carried out by AfricaRice confirmed the crucial role a good water control at plot level, in rice yield (Wopereis, 2008). The effect treatments on the grain yield of these varieties demonstrates the importance of Water Control in Rice Intensification (Kambou, 2008). However, rice lowland cultivars showed severe growth and yield reductions under aerobic soil conditions. This might result from poor root systems and poor root function, which limits water absorption and thus decreases Low Water Potential (Matsuo & Mochizuki, 2009). Drought stress further increases this nutrient deficiency (particularly P). The qualitative root traits are more affected by water treatment than by P dose. However, better water management as the alternate wetting and drying allows a good yield (Ramarolahy, 2016). Similar results were also published by Victoriano and Wang (2016) that root dry biomass was highest under intermittent irrigation of three-day interval, which could indicate a strong water and nutrient absorption capacity translating into high grain production. However, Increases in grain yield for water use efficiency (WUE) treatment under moderate alternate wetting and drying (AWD) are due mainly to reduced redundant vegetative growth; improved canopy structure and root growth (Yang, Zhou, & Zhang, 2017)

Then, early onset results in a more persistent and severe course (Souleymane, Maméri, Zouzou, Zagbahi, Messoum, Sekou, 2010) also found that such variety with a good production potential is Nerica L19 which is less demanding in mineral elements (nitrogen and phosphorus).

Conclusion

We can conclude that over the years (1960 -2013), Research has revealed genetic yield gains face to water stress and low level of fertilizer inputs of Malagasy farmers (NERICA L19, X 1648, IR 64, X265 and FOFIFA 160) despite the high sensitivity to low fertilization for 2509. However, 2787, X265, SOAMEVA and FOFIFA 160 tolerate better the low level of fertilization in case of good hydric conditions. Thus, varieties 2787, X265, FOFIFA 160, SOAMEVA and X1648 have a high yield potential under good rice growing conditions (rich soils or high fertilization and good water control). According to FAO, the downward trend in productivity must be reversed by focusing not only on balanced nutrient that will help to reduce the problems associated with overexploitation of the land; but also on good control of water. These results need to be considered and valued by the Breeder Task Force in partnership with the *AfricaRice* to optimize rice yields throughout Madagascar and different types of rice ecology. For agronomic side, a comprehensive study which aimed at predicting or estimating the harvest/yield depending on the soil moisture regime and their level of fertility should be considered.

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