Effect of P fertilizers use on rice (*Oryza sativa*) productivity in Southern Province of Rwanda, Rwasave marshland.

Hirwa Hubert

University of Lay Adventists of Kigali (UNILAK). Telephone: (+250)783207153, P.O. Box: 6392 Kigali/Rwanda, E-mail: huberty07@yahoo.fr.

Abstract: *The present study aimed at evaluating the effect of P fertilizers on rice productivity in Rwandan marshlands. It was conducted in Rwasave marshland. A Randomized Complete Block Design (RCBD) experiment comprised four P treatments [T1 as 0 kg (control), T2: 30kg, T3: 60kg, T4: 90kg of P_2O_5] replicated four times and Yunkeng was the test rice variety. The soil samples were randomly collected at 0-30cm depth and various chemical and physical analyses conducted. The results revealed the significant difference ($p<0.05$) among treatments for available P. The laboratory results were pH_{H2O} of 5.37, pH_{KCl} of 4.13 and available P (Bray I) of 4.03ppm. The P_2O_5 had significant ($p<0.05$) effect on grain yield and yield components and increased the plant height (109.0 cm), tillering, 241 filled grains/panicle, empty grains/panicle, 1000grains weight (50.6gm), and panicle numbers. Tillering activity was the growth parameter that affected most significantly the grain yield. P rich fertilizer (P_2O_5) applied at 90kg P ha^{-1} produced the highest grain yield (7.69t/ha) against the lowest grain yield (3.31t/ha) of control. This study revealed that the supply of P fertilizers for some farmers did not meet the rice requirements. The response of rice to P application depends on available soil P levels. It is necessary to apply P fertilizers with adequate doses and at the right time in order to maintain the stability of available P in the soil.*

Keywords: *Rwasave marshland, Phosphorus (P), fertilizer, Oryza sativa, yields*.

1. INTRODUCTION

Agriculture is the backbone of Rwandan economy, counting itself 39% of GDP, 80% of employment, and 63% of foreign exchange earnings and cover 90% of the country food needs (MINAGRI, 2009).

Rice has been selected as a strategic food crop in Rwanda by Ministry of Agriculture and Animal Resources (MINAGRI) (RADA, 2007). Rice is a staple food for almost half of the world's population and offers variety of uses to farming community. Rice is a cereal with growing importance in Rwanda; it is the second most important cereal crop in Rwanda with annual production of 61.797 tons. Subsequently, rice production in Rwanda has increased to about 55000 tons in 2007 (MINAGRI, 2007 and MINAGRI, 2009).

Soil P is the second major macronutrient after nitrogen and is followed by Potassium without which nothing crops can produce (Brady, 2002). The P involves in many plant processes, including: energy transfer reactions in ATP molecule, development of reproductive structures, crop maturity, root growth and protein synthesis (Smack, 1985). P deficiency is one of serious limiting factors for plant production in many Rwanda agricultural soils (Muhawenimana, 1987).

Most of Rwanda's marshlands soils fertility is highly variable and wetlands soils have high soil available P than upland soils (MINAGRI, 2011). The optimum rate of P in soil solution for plants growth is estimated to 0.2-0.32 mg/kg (Hakizimana, 2007). Today, major physical challenges in lowland rice ecosystem are the nutrient deficiencies (i.e. N, P, S and Zn), toxicities (Fe, Mn and Al), acidity and uncontrolled floodwaters that sometimes inundate the crop or produce flash floods, which may carry away the harvest (Oteng, 1997).

Yosef (2013) declared that judicious and proper use of fertilizers can markedly increase the yield and improve the quality of rice. Indeed, the low P sufficiency hinders the rice production in Rwanda marshlands including Rwasave marshland by decreasing plant growth, plant height, branch number and the grain yield (Vahed *et al.*, 2012).

The purpose of this paper was to evaluate the effect of P fertilizers on rice productivity in Rwasave marshland in order to improve the sustainability of yields and the profitability of rice.

2. MATERIALS AND METHODS

2.1. Description of Study Area

Rwasave marshland is located at 02^0 36'09.5''S of latitude and 29^0 45'25.2''E of longitude. The highest hill has an altitude of 1200 m above sea level at Huye Mountain (Munyaneza, *et al.*, 2014). The average annual temperature varies between 19.1°C and 19.6°C. The annual precipitation varies on average between 1,170 and 1,270 mm year^{-1} (S.H.E.R, 2003). The actual evapotranspiration in the marshlands is between 974 mm and 1400 mm per year (Nahayo *et al.*, 2010). According to Mbonigaba (2002), Rwasave soils are classified as clay-loam soils. It derives from schisto-quartzites mica materials formed at the basin side. The clays on the site are the weathering product of the parent material which is dominated by kaolinite, hematite, and gibbsite (FAO, 2010). The red-brown subsoil is often thicker than 1.5 m and has a clay content (particles with a diameter < 2 μm) between 23% and 33% of its weight

(Moeyersons, 2003). The soils in the valleys are often ferrallitic, carrying a 50 cm thick humic A-horizon which are sometimes buried below actively colluviating deposits. The hydraulic conductivity is estimated between 1 and 10md^{-1} (Moeyersons, 1991).

2.2. Materials

Rice (*Oryza sativa)* var. Yunkeng was used as a planting material. The mean optimum temperature varies from 18 to 33^{0}C (Malabuyoc *et al.*, 1993). The growing period is between 130-150 days (Suresh, 2001). The spacing when grown in a nursery is usually transplanted at 20x15cm spacing in a well prepared main field (Haifa, 2008). Soil materials consisted of samples collected from rice field in Rwasave lowland. The P_2O_5 (18%) was used as the fertilizer material.

2.3. Methods

Experimental design and treatments

A factorial design in a Randomized Complete Block Design (RCBD) with three blocks comprising each four replications; 12 plots of equal size were used. Therefore, one factor was used which consisted of P fertilizers whereas the treatments were the combinations of 4 levels of P_2O_5 (18%) where T1: 0 kg (control), T2: 30kg, T3:60kg and T4:90kg). Each treatment in the experiments was laid out in a rectangle plot which has 35m of length and 20m of width.

Soil and agronomic data collection and analysis

The soil samples was taken in topsoil and subsoil at 0-30cm depth using auger. The samples were randomly collected from 5 different points of all experimental plots. The samples from those five points were mixed and treated as one composite sample. The Z sampling method in order to take soil sample for laboratory tests in each of 12 plots. The samples were transported in laboratory for analysis. The samples was kept in laboratory then the samples was dried for two weeks, crushed and then sieved at 0.5mm for Carbon analyses and at 2mm for other analysis.

Soil pH_{H2O} and pH_{KCl} was determined using potentiometer method by glass electrode in the suspension soil-H_2O or soil-KCl according to the 1/1.25 ratios (Cottenie *et al.,* 1982 In: Kumar, 2016). Available phosphorous was tested using Bray P1 (Bray and Kurtz, 1945) methodology which consists of combining HCl and NH_4F.

Rice response to P fertilizer application was tested and measured. The height of the plants was measured using a ribbon meter at the end of the experiment. The number of panicle per plant was determined, length of panicles, number of tiller per plant, the number of full grain and empty grain was determined using the numeric counts. The average of number of grains per plant was determined. The determination of the weight of 100 grains per was done using the balance of 0.001 precision.

Statistical analysis

Data were recorded from soil laboratory analysis at different period of observations. They were analyzed using ANOVA table calculated by GENSTAT discovery edition 4.10.3 for windows (VSN-International Ltd., UK.) and also to analyze the experimental data. The graph presentations were performed with the Microsoft Excel 2013 software.

3. RESULTS AND DISCUSSIONS

3.1. Soil and chemical parameters.

Soil reaction (pH_{H2O} and pH_{KCl}) and Available P.

The results (Fig.1) showed that the soil reaction of Rwasave marshland soils ranged (5.0-6.0) from acidic according to Mutwewingabo and Rutunga (1987), Pietrowiez (1985) and Boyer (1982) interpretation norms and the phosphorus availability is maximized when soil pH is between 5.5 and 7.5 (Uwanyirigira, 2013). The observed soil pH_{KCl} range is below the optimal (5 to 6.5) for rice reported by Hazelton and Murphy (2007) and may impair the crop. Values of relative pH suggest that the increase in pH were more attributable to the flooding of the soil due to irrigation (Synder, 2002) and less to applied treatments. It can be noted be that there is a dominance of acid soils which may impact the availability of nutrients especially P.

Motto (1988) reported that pH for optimum P availability ranges from 5.5 to 6.5 when determined in water. While Bonnetto (1991); McCauley and Jacobsen (2009) stated that soil P most available for plant use at pH values of 6 to 7.

The greater, the pH increases the greater, available P increases also. It means that there is a positive correlation between pH and available P. The available phosphorus varied between 2.43ppm and 4.26ppm with an average of 3.43ppm. The coefficient of variation is equal to 67.16%. The data indicated the correlation coefficient (R^2) of 0.63.

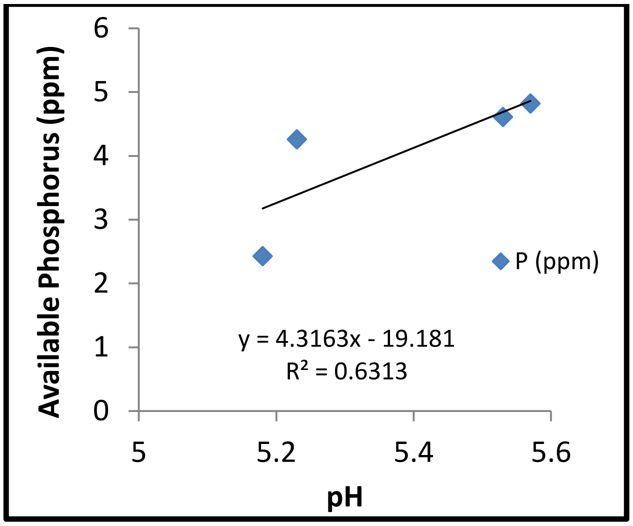

Figure 1: The influence of soil pH to available P in Rwasave marshland.

The results (Fig. 1) revealed that the available P is very low (<5ppm) in Rwasave rice paddy according to Landon (1991) interpretation norm, because soil available P is binded to organic carbon and high Iron oxides. Moreover, according to Marx (1999) interpretation norm, the P is not sufficient (0-5 ppm) in Rwasave marshland. These results were in agreement with Marc (2012), that the available P is very low (0-5 ppm) and not sufficient (25-50%) in most Rwanda paddy field.

This amount can be originated from the decomposition of organic matter and from mineral fertilizers applied. In the rice crop, P deficiency occurs when available P falls below 0.1% whereas the crop suffers toxicity where available P exceeds 1% (FAO, 2007). The increment of pH can improve availability of P for plant uptake.

According to MSU (2010), soil phosphorus is most available for plant use at pH values of 6 to 7. When pH is less than 6, plant available P becomes increasingly tied up in aluminum phosphates. As soils become more acidic (pH below 5), P is fixed in iron phosphates. According to Thompson (1993), P is very abundant in the soil where pH is less acidic and the problem of acid soils is the deficiency of plant available P. Correspondingly, the available P increases with the increasing of pH by the application of lime or organic matter; the efficiency of phosphate fertilizers is higher if lime is applied to fields prior to P fertilization (Mambani, 2004 and MSU, 2010).

Plant parameters

The values of rice response to P_2O_5 (18%) application are reported in table 1.

GY: Grain Yield (t/ha), **1000GW**: 1000grain weight (gr), **PHT**: Plant height (cm), **TwtP**: Tillers without Panicle, **TwP**: Tillers with Panicle, **GP**: Grain/panicle, **EGP**: Empty grain/panicle, **FGP**: Full grain panicle; **T$_1$:** Control, **T$_2$:** 30kg of P_2O_5, **T$_3$:** 60kg of P_2O_5, **T$_4$:** 90kg of P_2O_5.

Table 1. Rice response to P_2O_5 (18%) application.

Source: Author, 2017

Plant height

The results (table 1) showed that PHT of rice plant was significantly affected by the rate of P_2O_5 application and proved that difference observed between treatments was significant at $p<0.05$ with the C.V of 0.10%. In fertilized plots the PHT varied depending on the amount of fertilizer applied. The mean height was 63.0; 96.0; 102.5; 109.0 cm respectively under 0kg, 30kg, 60kg, 90kg of P_2O_5 revealed an increase in PHT respectively to the treatments. The PHT varied between 63 and 109cm.

The results showed that as the quantity of fertilizer (P_2O_5) increases, there is an increase in PHT; this is why the highest PHT was observed at 90kg and gave the highest plant height (109.0cm). The strong R^2= 0.9 between the phosphorus rich fertilizer (P_2O_5) and PHT (Fig.2); this means that fertilizers influence positively the growth parameters especially PHT.

Effect of P fertilizer to plant height

Plant Parameters	Treatments			
	T_1	T_2	T_3	T_4
GY (t/ha)	3.31	3.75	5.387	7.69
1000GW (gm)	18.00	20.70	41.85	50.66
PHT (cm)	63	96.0	102.5	109.0
GP	149	153	172	241
FGP	106	135	168.25	216
EGP	43	18	4	25
TwP	26	28	30	32

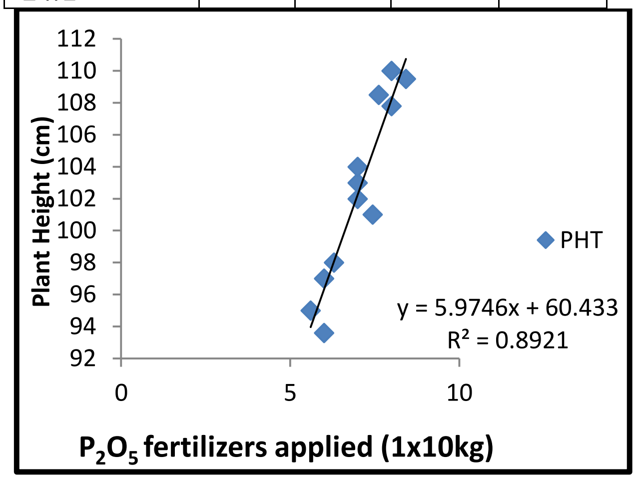

Figure 2: Correlation between fertilizer (P_2O_5 applied) and plant height

Correspondingly, the same results were obtained by Alam *et al.*, (2009) reported that it is necessary to apply much P fertilizer to accelerate the phosphate absorption for increased plant elongation and tillering. Tabar (2013) reported the significant differences in tiller numbers due to phosphorus application.

Grain per panicle (GP) and Empty/unfilled grain per panicle (EGP)

The ANOVA (table 2) of GP confirmed that the treatments were statistically significant at a level of probability 5% (<0.05). The C.V is of 1.81%.

Table 2. ANOVA for grain per panicle

SV	d.f.	S.S.	M.S.	v.r.	F
REP	3	2894.92	964.97	78.77	
NPK	7	17421.08	2488.73	203.16	0.05*
Residual	1	12.25	12.25		
Total	11	20328.25	1848.02		

* * Significative at a level of 5% of probability (p<0.05).

The results (table 1) illustrated that the number of GP changed with the rate of P application, as the average value of 149, 153, 172 and 241 were observed respectively under 0kg, 30kg, 60kg, and 90kg of P_2O_5. It implies that the application of rich P fertilizer rate correspond to the GP. However, the results (table 1) confirmed that in this experiment the highest number of EGP was produced with control (0kg) without P_2O_5 fertilizer. Due to lack of P, the EGP was highest with lower doses of P. The application of 60kg and 30kg reduced the EGP. The number of filled grains/panicle was significantly affected by different rate of P application. The means separation showed that these differences was statistically significant at level of 5% (p<0.05). The C.V is of 1.44%.

Table 3. ANOVA for full grain per panicle.

SV	d.f.	S.S.	M.S.	v.r.	F
REP	3	2790.917	930.306	148.85	
NPK	7	14935.75	2133.679	341.39	0.042*
Error	1	6.25	6.25		
Total	11	17732.92	1612.083		

* Significative at a level of 5% of probability (p<0.05).

The results (table 1) showed that P_2O_5 at 90kg produced the highest number of filled grains per panicle (216 grains) compared to control (106 grains). The figure 3 showed that there is a positive correlation (R^2=0.7) between P rich fertilizer (P_2O_5) applied and the number of filled grains produced/panicle. This implies that the application of P rich fertilizer (P_2O_5) influence positively the production of grains.

Effect of fertilizer to filled grains and empty grains production/panicle

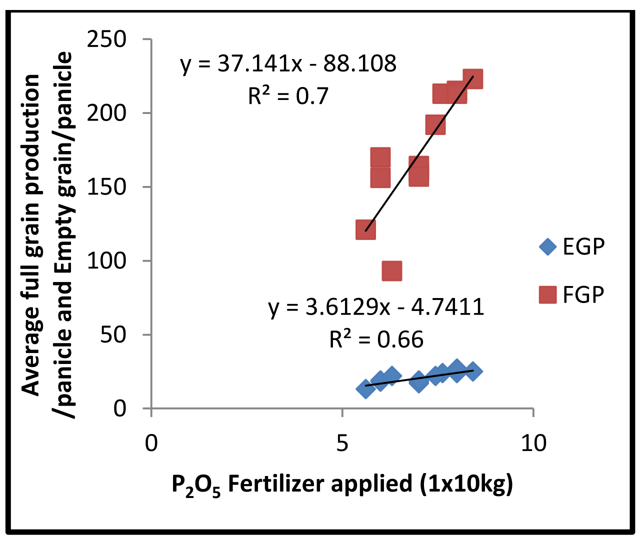

Figure 3: Influence of fertilizer on filled grains and empty grains per panicle

The results indicated that the increase in grain per panicle varies according to the P application. The number of spikelets was the second important yield-forming attribute of rice; it was associated positively and highly significantly with grain yield and panicle length (Gebrekidan and Seyoum, 2006). Irshad *et al.*, 2000 reported that nitrogen and phosphorus application over control did not influence the number of spikelets per panicle, number of grain per panicle maybe due to the genetic makeup of the specimen.

These results were in agreement with those of Frageria *et al.* (1982) who reported that increasing the rate of the P fertilizer positively affect the grains number/panicle. Uwanyirigira (2013) reported the similar results that the means separation showed that the differences was statistically significant at level of 5% ($p<0.05$) for most Rwanda marshland. According to Frageria *et al.*,(1982) P significantly improve yield of rice by improving yield components like panicle number, grain weight, and reduced grain sterility. In addition, P also improved grain harvest index, and plant height which are positively associated with grain yield. This result was in agreement with the findings of Gebrekidan and Seyoum, 2006.

1000 grain weight

The results reported (table 1) showed that the 1000GW varied with the rate of P_2O_5 application. It appears that under application of 90kg the weight of 1000 grains amounted to 50.66gm, 41.85gm, 20.70gm and 18.00gm under 60kg, 30kg and control (0kg) respectively.

Table 4. ANOVA for 1000grain weight

SV	d.f.	S.S.	M.S	v.r.	F
Plot stratum					
NPK	7	1884.07	269.15	15.76	0.009**
Error	4	68.31	17.08		
Total	11	1952.39			

** highly significative at a level of 1% of probability ($p<0.01$).

The ANOVA (table 4) revealed highly significant differences among these value at 1% ($p<0.01$) with the C.V is of 11.4%.

The results indicated that the 1000WG varied with the rate of P_2O_5 application. Unlike with P, N application significantly affected all yield components (Tabar, 2013). This is evident, the kernel (grain) weight differs among varieties, and it was reported to be the least variable yield component (Ahmad *et al*, 2015).

Grain yield (GY)

The GY per ha varied with the rate of P_2O_5 application of 90kg, 60kg and 30kg of P_2O_5 produced the highest grain yield of 7.695t/ha, 5.387t/ha and 3.75t/ha respectively whereas plants grown in condition without P_2O_5 fertilizer produced the lowest yield of 3.31t/ha (table 1).

The ANOVA (table 5) showed that the differences observed among treatments were globally significant at $p<0.05$. The C.V% is of 2.20.

Table 5. ANOVA for grain yield.

SV	df	S.S.	M.S.	v.r.	F
REP	3	1.09403	0.36468	25.32	
NPK	7	38.77327	5.53904	384.66	0.039*
Error	1	0.0144	0.0144		
Total	11	39.88169	3.62561		

* Significative at a level of 5% of probability ($p<0.05$).

Moreover, the superior effect of 90kg may be due to more filled grains/panicle. The straight line regression analysis shows a highly positive relation of phosphorus rich fertilizers (P_2O_5) with yield (R^2=0.9). Extensive field experiments research has shown that plants have a limit to their response to increasing supply of nutrients. This is a reflected in the final crop yield (Figure 4).

Effect of P_2O_5 to GY

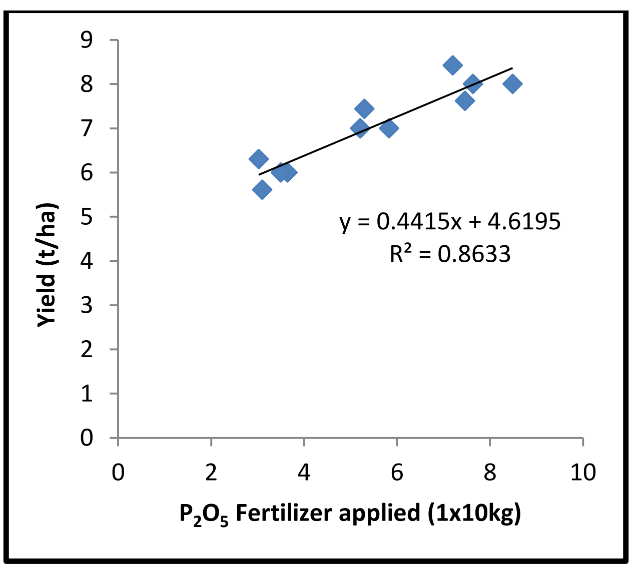

Figure 4: Influence of P_2O_5 to rice GY.

The results (Fig. 4) showed that the yield depends upon the P fertilizer application and it is positively correlated to P application (P_2O_5). According to IRRI (1996) interpretation norms, the grain yield is low (<4t/ha) Rwasave marshland in general even if farmers use the P rich fertilizers (P_2O_5). Shah *et al* (2011) declared similar effect of P on grain yield, Zaman *et al.*, (1995) also found significant increase in grain yield with P application over control treatment. Kumar and Rao (1992) and Thankur (1993) also reported improvements in grain yields and they attributed this to increments in yield components.

It is in agreement that the grain yield varied with P application rates (Uwanyirigira, 2013). The effect of P fertilizer on spikelet number and yield was significant in 1% probability level (Tabar, 2013).

In the field crop each increment of fertilizer gives a progressively smaller increase in yield until a maximum yield is reached (Simpson, 1986). The absence of maximum as shown by highly significant linear correlation in this study suggests that the fertilizers applied by farmers are not sufficient to meet the requirement of rice in Rwasave paddy field as far as P is concerned because of high Aluminium and Iron toxicity observed in Rwasave paddy field.

CONCLUSIONS AND RECOMMENDATIONS

The present study was conducted to evaluate the effect of P fertilizer use on rice (*Oryza sativa* var. Yunkeng) productivity at Rwasave paddy field in Huye District, Southern Province of Rwanda. It was found that the variability of rice growth and yield is caused by more P rich fertilizer (P_2O_5) application which affects the growth parameter and yield of rice positively. Although, the rice has been cultivated for some seasons in Rwasave paddy field, this study revealed that the supply of fertilizers for some farmers did not meet the rice requirements as far as phosphorus is concerned. The pH varied from strongly acidic to acidic. All parameters of rice (tillers/panicle, grain/panicle, 1000 grains weight, plant height, grain yield) the results disclosed that were positively correlated for plant height, grain yield and are affected by P rich fertilizers application. Low supply of P is one the factors that limits rice yield in Rwasave paddy field.

As conclusion, the response of rice to P application depends on available soil P levels for instance the high amount of P fertilizer (90kg) applied revealed the highest yield (7.695t/ha) in the Rwasave paddy field.

These recommendations were made in order to target the higher yield per unit area and to close the variability of rice yield in the study area. It is necessary to apply both organic and inorganic fertilizers with adequate doses and at the right time and to return crop residues in form of compost to the soil in order to maintain the stability of available P in the soil. In some cases, the low natural fertility is compounded by the problem of toxicity related to the high level of acidity in the soil which tends to reduce. It can be recommended that the same study can be conducted on P sufficiency level with other variety grown in Rwasave lowland.

Due to time and financial constraints, the study was conducted in one season and one place. Therefore, one may recommend that the same research can be repeated at the same for two seasons using more level of P to assess its effects. It is also suggested that the similar research can be conducted in different paddy fields in Rwanda to confirm the results of the present study and find out the effect of the site.

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