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Salinity Reducing Food Security and Financial Returns from Rice Production in Rwanda

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Abstract: Rice is a crucial food crop and source of income for smallholder farmers in Rwanda. Its annual consumption in 2012 was estimated at about 104,000 tons with about 48,000 tons of this covered from imports. In recognition of the great potential of rice in improving food security and household incomes, the government of Rwanda and donors have invested over US$ 10 Million to improve rice production. The average rice yield is estimated at 5 tons/ha but the government rice policy is targeting 7 tons/ha through improved seeds and better agronomy. Most of rice production is done in the marshland. Patches of some crucial marshlands have started exhibiting stunted rice growth, yellowing and low crop yields of less than 3 tons/ha irrespective of use of the right seeds and good agronomy, hence threatening the rice improvement targets. Recently, we evaluated one of the marshlands (Muvumba marshland) to understand the causes for such yield decline. The marshland was demarcated into affected and non-affected patches. The visual and lab analysis of soil and water from affected patches linked declining rice yields to salinity suggesting gradual development of salinity in Muvumba marshland. This paper uses Muvumba data to discuss salinity, the indicators, potential impact of salinity on returns to rice production. Salinity decreased rice yields by about 30% and financial returns by about US$ 1,500 per hectare of affected patches in Muvumba. We recommend remediation of salinity through improved drainage and better fertilizer management. In case these measures do not work, salt tolerant rice species should be adopted for these sites.

Keywords: Food security, Rice, Irrigation, Benefit, Cost.

Background

Since the 1980s, Rwanda has been unable to meet its domestic food needs from national agricultural production (MINECOFIN, 2002). Owing to high household demand and high market returns, rice is considered a priority food crop with a potential for bridging the gap between the domestic food production and demand and boosting the incomes of farming households in Rwanda (Jagwe et al, 2003). Although there has been a rapid rise in rice production in the past decade, the country has not yet achieved rice self-sufficiency as Rwanda annually imports over 30,000 tons of rice to cover for the demand deficits. For example, while the annual rice consumption in 2008 was estimated at about 61,000 tons, the annual consumption in 2012 was about 104,000 tons (Table 1). For the same period the annual cumulative rice production in Rwanda increased by less than 20,000 tons to about 56,000 tons (Table 1).

The government of Rwanda and a number of development partners are supporting rice production as a way of boosting household food security though rehabilitation, development of irrigation infrastructures and input supply. Within the agriculture transformation strategy the production of rice has been given high priority by Government, especially in the valley bottom marshlands, where the opportunity for expansion and yield improvement are high (MINAGRI, 2002). Marshlands are owned and managed by government but leased to farmer cooperatives after accepting the terms in the agreement. The terms include crops to be grown, methods of production, maintenance of the marshlands and the target yield. The government supports cooperatives through construction of hydraulic structures, dykes and dams and provision of agricultural inputs on credit at subsidized rates.

Muvumba marshland is a 1,750 ha rice production marshland equivalent to about 15% of total marshland area in Rwanda. Previously, the crop yield in this marshland averaged

5-6 t/ha per season which cumulatively translates to about 9,600 tons per season or 19,200 tons per year (rice is grown for two seasons in a year). However, in the recent past the crop yields have declined by over 50% in some parts of the marshland. This has become a major source of concern among the farmers, policy makers and researchers. Driven by observations of white crystals on the soil surface and stunting of crops, we hypothesized that salinity could be the cause for declining crop yields. This study was carried out to determine whether salinity is the main cause of declining rice yields in Muvumba marshland, so as to advice the policy makers, investors, extension workers and farmers.

Table 1: Rice production and consumption in Rwanda 2005-2012

Year	Allocated area (ha)	Yield tons/ha	Production Milled Rice (tons)	Imports (tons)	Annual total consumption (tons)
2005[a]	13,922	4.4	ND	11,527	ND
2006[a]	14,034	4.5	ND	16,639	ND
2007[a]	15,005	4.1	ND	18,605	ND
2008[b]	12,000	5.2	40,560	17,925	60,825
2009[b]	14,000	5.5	52,780	31,660	84,440
2010[b]	12,186	5.5	45,942	44,545	90,482
2011[b]	14,200	5.2	47,996	45,231	93,227
2012[b]	15,615	5.5	55,823	48,284	104,107

Compiled from: [a] European Cooperative for Rural Development (2012) and [b]Sendenge Norbert; www.rice for africa.org

Overview of the Rwanda National Rice Policy (NRP)

The main objective of Rwanda's agriculture policy is to intensify and transform subsistence agriculture into market-oriented agriculture, which requires modern inputs, notably improved seeds and fertilizers. The policy emphasizes marshland development for increased food production because the soils on hillsides are degraded. The policy promotes small-scale irrigation infrastructure development in selected marshlands while preventing environmental degradation. Rice cultivation is prioritized for import substitution. Under the National Rice Policy, Rwanda is seeking to attain self-sufficiency and competitiveness in rice production in 10 years from 2012. The NRP sets out interventions aimed at enhancing the productivity levels and raising the standards of post-harvest processing of rice in a bid to improve volume (quantity) and value (quality) of rice looking forward to create self-sufficiency in the domestic rice market. The government of Rwanda had earlier (in 2002) identified rice as a priority crop. However, due to the rapidly increasing population, its consumption continued to increase at a much higher rate than production which led to persistent rice shortage in the domestic markets. The NRP is streamlined with the Plan for Strategic Transformation of Agriculture (PSTA). Strategies are aligned in the PSTA to achieve the set objectives. These include: raising the total area under rice cultivation (to 16,442 hectares) by developing marshlands; subsidizing fertilizer, seed and water; offering training and access to finance; renting or selling mechanization services to farmers; developing an efficient private sector; assigning a greater role in policy implementation to markets; and increasing public investments in construction and rehabilitation of feeder roads (MINAGRI, 2009). PSTA-II aims at improving the production and productivity of rice crop. Under program 1of PSTA, the plan focuses on rice production intensification to improve the efficiency of use of inputs such as seeds, fertilizers, soil and water. Under sub-program 1.3, the plan intends to develop marshlands and raise the total area under rice cultivation.

Study area description

Muvumba marshland is located in Nyagatare district in Eastern province (between 020^{0} 35′ 56.8″ S and 29^{0} 43′ 46.6″ E at 1767 m of altitude) of Rwanda. The soils are derived from granitic or igneous parent materials. The intense rice cultivation that started from the upstream of the marshland in 2010 is progressively being extended to the lower parts of the marshland. The type of irrigation in place is the dam irrigation system with main and secondary channels to feed the rice cultivation plots. The rice cultivation is owned by farmer cooperative “Muvumba Rice growers” supported by the Ministry of Agriculture and extension services to implement the best rice management practices. These management practices include the improved seed varieties, clearing irrigation channels, timely weeding and fertilization as well as ensuring the proper operation of irrigation system.

Approach used for determination of salinity

Preliminary evaluation of occurrence of soil salinity in Muvumba marshland involved collection of in situ background information and visual characterization of the rice crop. This was complemented with collection of soil and water samples for laboratory analysis. The sampling was done in plots presenting signs of white crystals (affected plots) and plots without any salinity signs (unaffected plots considered as control). The analysis targeted key indicator parameters for soil salinity especially electric conductivity. The other parameters that were measured included soil pH, basic cations for both soil and water samples and CEC for soil samples. The electric conductivity was measured using Eijkelkamp 18.50.01 in a soil-water solution ratio of 1gram: 5ml. For water, these parameters were measured directly without dilution. The soil pH was measured using a pH-meter in soil-water solution of 1:2.5 after shaking for 2 hours. The exchangeable cations and CEC were analyzed using the Ammonium acetate method (Okalebo et al, 2002). The amount of exchangeable sodium, in the extract was determined by flame photometry and Ca and Mg by atomic absorption spectrophotometer (Anderson and Ingram, 1993).

Morphological and physiological indicators of salinity

Saline soils dominated by sodium cations with electrical conductivity (EC) more than 4 dSm^{-1}, but the dominant anions are usually soluble chloride and sulphate. For rice, soil salinity beyond ECe ~ 4 dS/m is considered moderate salinity while more than 8 dS/m becomes high. Extreme high salt stress conditions kills the plant but the moderate to low salt stress affect the plant growth rate and thereby manifest symptoms which could be associated with morphological, physiological or biochemical alterations. According to the International Rice Research Institute (IRRI) (http://www.knowledgebank.irri.org) the morphological symptoms of salinity includes: white leaf tip followed by tip burning, low harvest index, less florets per panicle, low grain yield, leaf rolling, white leaf blotches, patchy growth in field .The physiological and biochemical manifestation under higher salt stress conditions include: High Na+ transport to shoot, preferential accumulation of Na in older leaves, high Cl- uptake , Lower K+ uptake, lower fresh and dry weight of shoot and roots and low P and Zn uptake. The results confirmed occurrence of soil salinity in part of the Muvumba marshland.

Results and Discussions

Salinity is the measure of the concentration of dissolved (soluble) salts in water from all sources. The visual plant characteristics and measured soil/water characteristics indicated that salinity was the most probable cause of declining rice crop yield. This is illustrated by poor crop growth, patchiness and white ground crystals (Figure 1) coupled with soil and water based salinity indicators like the electrical conductivity (Tables 2).

Caption 1: White salt crystal within the paddy plots

Caption 2: Non affected plot versus affected plot and natural growth of invasive salt tolerant grasses (the invasive salt tolerant grasses are indicators of salinity)

Rice is rated as a salt sensitive crop (Shannon *et al.*, 1998). Current guidelines (Maas and Grattan 1999; Hanson et al., 1999) indicate that rice yields decrease by 12% for every unit (dS/m) increase in electrical conductivity (EC) above 3.0 dS/m. The units mS/cm and dS/m are equal and often used interchangeably. When exposed to salinity in excess of 6.65 mS/cm its crop yields could decrease by more than 50%. Salinity affects all stages of the growth and development of rice plant including young seedlings, vegetative growth and grain yield (Shereen et al., 2005). Salinity becomes a problem when enough salts accumulate in the root zone to negatively affect plant growth. Excess salts in the root zone hinder plant roots from drawing up water from the soil. This lowers availability of water to the plant, irrespective of the amount of water actually in the root zone.

Our present results show that the EC of Muvumba marshland sites under white crystal accumulation exceeded the threshold of 6.65 mS/cm by between 2 and 5 mS/cm for soil (Table 2) and by up to 2 mS/cm for water (Table 3). This indicates that Muvumba site is affected by salinity and in its current state only tolerant plants can yield satisfactorily. High values of EC in soil as compared to water as well as low sodicity (Sodium adsorption ratio-SAR) values (< 10) suggest that the identified salinity could have originated from rock or and other underground deposits. With SAR < 10 the irrigation water can be classified as low sodium water and hence can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. Considering values of electrical conductivity (EC), exchangeable sodium percentage (ESP), and pH, the affected soils can be classified as saline-sodic soils (USDA classification of salt affected soils). In such condition soils with sufficient exchangeable sodium contain appreciable quantities of soluble salt which limit with crop performance.

Table 2: Soil characteristics of salinity affected and non-affected parts of Muvumba marshland

Block ID	pH water	Ca (meq/100g)	Mg (meq/100g)	Na (meq/100g)	CEC	EC (mS/cm or dS/m)	ESP%	SAR
Block 9-affected	8.3	5.40	1.99	9.68	18.24	11.4	53.1	5.04
Block 9-Non-affected	6.5	4.82	1.00	0.76	32.00	0.6	2.4	0.45
Block 8- affected	7.8	4.97	1.60	4.00	12.96	8.8	30.9	2.21
Block 8- Non-affected	7.4	4.48	1.89	1.12	23.36	1.6	4.8	0.63
Block 20 -affected	7.5	3.70	1.40	5.05	14.96	0.4	33.8	3.16
Block 20-Non-affected	6.3	2.50	1.20	0.25	-------	0.1	-------	0.18
Block 24-affected	6.7	3.96	1.39	5.05	11.44	11.1	44.1	3.09
Block 24-Non-affected	5.7	3.40	1.32	0.92	37.04	1.6	2.5	0.60

Table 3: Water characteristics of salinity affected and non-affected parts of Muvumba marshland

Block ID	pH water	Ca (meq/100g)	Mg (meq/100g)	Na (meq/100g)	EC (mS/cm or dS/m)	SAR
Block 9 affected	7.5	1.50	0.20	4.44	6.4	4.82
Block 9 -Non affected	7.2	0.10	0.05	0.24	0.2	0.88
Block 20 affected	7.5	3.00	1.45	8.00	11.7	5.36
Block 20 -Non affected	7.0	0.45	0.31	1.18	1.6	1.91
Bloc 24 – affected	7.3	2.00	0.76	3.11	4.8	2.65
Bloc 24 - Non affected	6.9	1.40	0.28	2.06	4.9	2.25

Economic implications of salinity

The costs of rice production at the farmer level include: cost of nursery preparation, labor costs, cost of fertilization, and cost of seeds, bagging cost, transport cost, pesticide costs and shelling cost. Our estimates show that in 2014 for Muvumba and most other parts of Rwanda, such costs were approximately US$ 1, 500 ha^{-1} (Table 4). The average seasonal rice grain yield in Muvumba is 4.8 tons/ha. The average yield from salinity affected plots was about 3.5 tons/ha (Table). This 27% decline decreased seasonal net benefits by over US$1,300 per hectare. As rice is grown for 2 seasons this implies an annual loss of about US$ 2,600 ha yr^{-1}. Benefit-cost ratio is an indicator of profitability. A benefit-cost ratio of 2 indicates return of 2 dollars per every dollar invested and is used as the threshold for identification of attractive enterprises. In plots with no salinity the benefit-cost ratio of rice production is 2 and therefore attractive. However, the average benefit-cost ratio of rice in saline soils was approximately 1.4. It implies that with salinity an investment of 1 dollar for rice production yields a dollar indicating a loss due to declining time value for money, labor and capital resources. Salinity therefore makes rice production un-attractive and un-profitable in Muvumba. Often salinization may lead to abandonment of irrigation project.

The potential risk of salinization may be viewed against the backdrop of the cost of irrigation projects. To put this into perspective we analyze the Rwanda irrigation plan 2012. The irrigation master plan for Rwanda 2012 (Malesu et al., 2010) estimates that the costs for establishment of a functional furrow irrigation on a per hectare basis would include at least US$ 55,000 for surveys, soil and water analysis, US$ 95,000 for designs and US$ 350,000 for implementation and activation of the project all this totaling to about US$ 500,000. As the area of irrigated land in Rwanda is more than 10,000 ha it implies a projected investment of more than US$ 5 billion. Rwanda could therefore be targeting to spend more than her total 2013 annual budget to implement irrigation projects. As the costs are high it calls for proper pre-feasibility studies, coupled with high level management of existing irrigation projects and rice producing marshlands to minimize losses and ensure the country gets the value for money.

Table 4: Effects of salinity on economic returns of rice in Muvumba

Parameter	Without Salinity	With Salinity	Effect/ha
Average Crop yield tons/ha	4.8	3.5	-1.3
Returns (USD/ha)	4835	3,525	-1,310
Cost of production USD/ha	1,500	1,490	+10
Net Benefits USD/ha	3,334	2,035	-1,299
Benefit-Cost Ratio	2.2	1.4	--

Average market price of rice in 2014; 1 kg = RWf 695, 1 dollar = 690 RWf; Negative sign (-) implies salinity associated decrease and vice versa

Recommendations

As highlighted earlier, rice production is very crucial for food security and economy of Rwanda and the number of marshlands that are favorable for rice production are limited. The best method for managing salt problem will depend on agronomic and socio-economic considerations. The first step in managing salt-affected soils is to determine the existence of problem and identify its cause. Generally, salt affected soils can be corrected through improvement of drainage, leaching out of salts and judicious fertilizer management. Based on the observed soil characteristics and plant behavior of Muvumba marshland we recommend the following interventions-:

Improve drainage: A pre-requisite to using leaching as a management tool is good internal and external drainage which can be done through tillage and soil amendment. Deep tillage can be used to break up the soil surface as well as crusts, clay pans and hardpans, which restricts the downward flow/infiltration of water. Further, addition of organic matter at the soil surface is crucial as it improves macro-fauna activities leads to better soil porosity and reduced capillarity thus improving the soil drainage.

Better management of fertilizers and other soil amendments: This practice consists of replacing excess of Na^+ from the exchangeable site with other cations like Ca^{2+} or Mg^{2+}. This is done by adding soil amendments that either directly or indirectly releases exchangeable Ca^{2+} or Mg^{2+}. In this regard some of available amendment that can be recommended include, lime ($CaCO_3$) and organic resources.

Adoption of salt tolerant rice varieties: There is a need to test and validate the efficacy of the proposed solutions for managing the salinity. If the proposed remediation fail to work there is a need to shift to more appropriate salt tolerant rice varieties.

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