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Study of agronomic activities at the Kalimbeza rice project Namibia and the implication for sustainable productivity of the rice soil

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Abstract

In order to design sustainable management of the Kalimbeza rice project soil, it is expedient to assess the sustainability implication of the current agronomic activities which has the potential to threaten long term productivity of the rice soils. First, structured questionnaires were used to collect data from 10 field workers based on their memory recall of the different agronomic activities carried out at the rice project. Furthermore, soil samples were collected from the Kalimbeza rice soil at two depths: 0-15cm and 15-30cm for analyses of the soil properties. A fallow land of more than 10 years was also sampled at the same soil depths and analysed as control. The results obtained from the questionnaires responses revealed that chemical fertilizers are frequently used to improve the rice soil fertility but the fertilizers were applied without prior soil analysis to ascertain the nutrients status. It was also revealed that rice mono-cropping system is solely practiced, coupled with maximum harvesting as rice residues were used to produce livestock feed and not left to decay into the soil. T-test (paired sample mean, $p < 0.05$) analysis of the soil properties revealed that the rice soil has significantly lower levels of: total nitrogen, phosphorus, organic carbon, and cation exchange capacity than the control soil. Rice mono-cropping and maximum harvesting practiced at the Kalimbeza rice project could affect recovery capacity of the rice soil and present adverse implications for its sustainable productivity over long period. Therefore, it is recommended that crop rotation, leaving rice residues to decay and improve the soil structure, and applying chemical fertilizers after pre-determined site-specific properties should form part of the agronomic activities.

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Introduction

In view of the continued declining productivities of most farm soils, sustainable agronomic activities have become expedient and a pre-condition for guaranteeing food security and poverty alleviation worldwide. Rigby and Caceres (2001) noted that there is a global concern on the ability of the agricultural production systems to sustain the current population food demands without compromising the environmental resources capabilities to meet the needs of future generation. Sustainable agriculture is the capability of maintaining agricultural natural resources, ecosystem productivity and its usefulness to society over a long run (Rigby and Caceres, 2001). As of the rice farming sustainability, it may be understood as the process by which farmers manage soil, water and other basic inputs to enhance productivity and maintain it to meet farm and family needs, without adversely affecting the production environment and future resources (Najim *et al.,* 2007). Opportunities for sustainable increase of rice production differ from one rice ecosystem to another due to differences in environmental and socio-economic conditions, degrees of intensification, and crop management operations (Chandima Ratnayake *et al.,* 2011). Thus, mitigation measures through sustainable agricultural practices are required to reduce ongoing or foreseen soil degradation in natural agricultural resources.

In recent decades, a paradigm shift has emerged from the traditional rain fed rice production to irrigation rice cultivation and this is associated with environmental degradation (Nwilene *et al.*, 2008). Under irrigation, poor management of rice soil could leads to several adverse physicochemical changes such as depletion of molecular oxygen, reduction of soil total nitrogen, soil pH alterations (Kabir, 1999; Zhang *et al.,* 2005; Yan *et al.,* 2007 and Nwilene *et al.*, 2008). These may eventually create a bigger problem of low rice production due to gradual decline of soil productivity, low microbial activities and loss of important nutrients.

Although, unsustainable intensive rice cultivation pose a serious threat to ecological sustainability of rice environment and soil productiveness (Nwilene *et al.*, 2008), the rice producers are less motivated to practice sustainable rice farming because of short-term goals and economic aspects which drive them into fast profit making farming practices. The farmers practice intensive rice mono-cropping which has been proven to account for the major decline in rice production over long run as a result of soil deterioration, low fertility, low organic matter and low nutrients availability (Yan *et al.*, 2007; Bi *et al.,* 2014). In a separate report, Neeson *et al.* (2005) noted that rice production mainly by mono-cropping increases nitrogen loses from the soil. Mono-cropping system heavily contributes to soil degradation and exhausting until it becomes un-productive (Rokonuzzaman, 2012). In India, rice productivity has declined due to depletion of soil fertility by rice mono-cropping system (Shukla *et al.*, 2005). According to Neeson *et al.* (2005) and Rokonuzzaman (2012), rice mono-cropping creates the spread of pest and diseases which requires more chemicals for treatment and this deepen the severity of rice mono-cropping effects on environment as these chemicals make their way into streams, surface water, underground water, as well as cause air and soil pollution.

Rice production primarily depends on good agronomic practices, and the most consistent and highest yields of the crop can be harvested in irrigated systems (Singha, 2013). Sustainable rice farming such as effective and efficient application of chemical fertilizer with organic fertilizer promotes balance soil nutrients and enhances soil fertility (IRRI, 2015). Among other sustainable practices, leguminous crop rotation in rice cultivation has significant benefits toward addition of soil nitrogen and increasing rice productivity (Neeson *et al.,* 2005). Good agronomic practices include the effective fertilization, water and weed management, lower plant densities and sustainability of the farmers (Hossain, 1998; FAO, 2006). Sustainable rice farming is very important in any developing countries/region, reason being not only the staple food of the majority of the people, but also the country's food security, poverty alleviation and rural employment depend largely on rice production (Hossain, 1998; Roy *et al.*,, 2014).

The Kalimbeza National Rice Project is an irrigated lowland rice production system which is cultivated on flood-plains. According to Kanyomeka (2007), the rice project has a high potential productivity of 5-8t/ha but currently, rice yields ranged from 1.5t/ha to 3t/ha. At the rice project, there is animal fodder production which might promote maximum harvesting of rice residues and promote soil nutrients loss. Furthermore, the rice cultivation approaches appear to focus on yearly land expansion and mono-cropping system. However, these practices may adversely affect the capability of the soil to naturally regain some of its nutrients and hence lead to loss of soil productivity value. Despite the potential threat of some of these agronomic activities to both long term and sustainable productivity of the rice soil, there is currently no documented study to track the effect of the activities on the health of the Kalimbeza rice project soil. Therefore, this study has the main objective of assessing the implication of the current agronomic activities at the Kalimbeza rice project to sustainable productivity of the rice soil and recommending appropriate approaches.

Materials and methods

Study area

The Kalimbeza rice project field is a floodplain ecosystem located in Kalimbeza village; 32 km east of Katima Mulilo, the administrative headquarter of Zambezi region in Namibia. On Google map, it is situated along the Zambezi river at latitude 17°32'54.53'S and longitude 24°31'0.96'E. The pproject field receives annual rainfall of 500mm to 600mm, summer temperature of 23°C to 30°C and winter temperature of 15°C to 18°C (CPP Namibia, 2005).

Soil sample collection

For the purpose of this study, 1 ha was marked within the Kalimbeza rice soil and divided into eight sampling grids (0.125 ha each). According to the International Plant Nutrition Institute (IPNI, 2013) sampling grid/segment minimises field selection bias and offers systematic and structured samples with proper field representation. Then, 2 soil samples (consisting of 1 sample within topsoil [0-15cm] and another 1 sample within subsoil [15-30cm]) were randomly collected from each sampling grid. Thus, a total of 16 soil samples were collected for laboratory analysis. Another 4 soil samples were similarly collected (within topsoil [0-15cm] and subsoil [15-30cm]) from a virgin soil (un-cultivated land for more than 10 years) and analysed as control.

Samples preparation and analysis

The soil samples were dried at room temperature. Then, each sample was crushed and sieved using a 2 mm sieve mesh and laboratory analyses of the soil parameters were carried out on the < 2.00mm fractions using standard laboratory procedures. Particle size was determined using the hydrometer method (Gee and Bauder, 1986), pH was measured in 1:2.5 suspensions in water, and organic carbon was determined by the potassium dichromate oxidation method (Gelman *et al.*, 2011). The soil exchangeable cations: calcium, (Ca), magnesium (Mg), potassium (K) and sodium (Na) were extracted using 1N ammonium acetate at pH 7.0 (USDA, 2004) and their levels were determined using Inductively Coupled Plasma-Optical Emission Spectrophotometer (ICP-OES) at the Ministry of Agriculture's Analytical Laboratory, Windhoek Namibia. The measured values in ppm were converted to meq/100 soil using the standard conversion factors in Table 1. Thereafter, the cation exchange capacity (CEC) of the soil was determined by summation method (IITA, 1979). Electrical conductivity (EC) of the soil was determined by measurement in supernatant of 1:2.5 soil:water suspension using conductivity meter. Available phosphorus was determined by the Olsen method while total nitrogen was determined following Kjeldahl digestion method (Bremner and Mulvaney, 1982).

Fertilizers application data collection

Quantitative data of fertilizers application rate (the number of kg applied per hectare per planting season [kg/ha/year]), for both chemical and organic fertilizers were collected through questionnaires administered to 16 field workers from both Research and Project departments, after which 10 of them were randomly selected and interviewed in order to probe for in-depth information on fertilizer utilization at the Kalimbeza rice project.

Data analysis

Data generated from eight replicate analyses of the soil parameters were computed as mean of each parameter. Furthermore, t-test (paired sample mean, $p < 0.05$) was calculated to determine the significance of mean data variations between the Kalimbeza rice project soil and control soil properties.

The questionnaires responses obtained on the cropping system used at the Kalimbeza rice project was calculated as percentages. All data analysis was performed using IBM SPSS 22 software on window 8.

Results and discussion

Soil fertilization at Kalimbeza rice project field

The results (Fig. 1) show that at the Kalimbeza rice project, chemical fertilizers are more frequently used (percent usage: 89%) to improve soil fertility while organic manure usage stood at only 11%. The questionnaires responses further revealed that the types of chemical fertilizers often used to improve soil fertility at the Kalimbeza rice project include Nitrogen-Phosphorus-Potassium (NPK) and urea. The result (Fig. 2) above showed that the average rate of application of NPK stood at350kg/ha while that of urea usage was 300 kg/ha per planting season.

Table 1. Standard coversion factors for soil exchangeable cations.

To convert each unit in column 1 to the corresponding unit in column 2, divide by	Column 1	Column 2	To convert each unit in column 2 to the corresponding unit in column 1, multiply by
390	ppm K	meq K/100g soil	390
200	ppm Ca	meq Ca/100g soil	200
121	ppm Mg	meq Mg/100g soil	121
230	ppm Na	meq Na/100g soil	230
1	meq/100g soil	cmol/kg soil	1
2*	Ib/acre (7 inch depth)	Ppm	2*
3.65*	Ib/acre (1 foot depth)	Ppm	3.65*
43.56	Ib/acre	Ib/1,000 sq ft	43.56
43,560	square feet	Acres	43,560
2.471	acres	hectares	2.471

Key: Values with * vary with soil bulk density.

Adapted from Marx *et al.* (1999).

The follow up interview further revealed that these fertilizers were frequently used for improving soil fertility on yearly basis and at 1 to 2 splits of application. It was also found that organic fertilizer (kraal manure) was applied to the field only once since large scale cultivation of rice started at the Kalimbeza rice project in 2007. One interviewee stated that the organic manure was applied in 2011, and only 1 trailer of kraal manure (equivalent to 1ton per 1.5ha) was used.

It was further revealed that there was no manure analysis or soil analysis carried out before the application. The finding here indicates that at the Kalimbeza rice field, soil fertility improvement is done mainly by the application of chemical fertilizers. Kabir (1999) reported that the sole dependence on chemical fertilizers for improving soil fertility has promoted soil nutrients imbalance in many rice fields worldwide. Sole application of chemical fertilizers promotes micronutrients deficiency and makes plant less resistance and susceptible to diseases (Primavesi, 1999).

In a similar study, Bi *et al*. (2014) observed that the sole application of chemical fertilizers lead to reduced rice productivity and reduced soil productivity on long-run.

At the Kalimbeza rice project, it was also found during the follow up interview that the usage of chemical fertilizers is not based on any research data of the soil available nutrients versus the cultivated rice (SUPA and CN 52) nutrients requirement.

Table 2. Soil properties of the Kalimbeza rice project and control site.

Parameters	Soil sampling depth (cm)			
	Kalimbeza rice project		Control site	
	0 -15	15 – 30	0 -15	15 – 30
pH	5.73[a]	6.34	4.90[b]	6.59
OC (%)	0.30[a]	0.34	1.12[b]	1.22
N (%)	0.03[a]	0.05	0.16[b]	0.15
P (ppm)	2.50[a]	1.60	0.80[b]	15.50
K (meq/100g)	0.05[a]	0.04	0.14[a]	0.12
Na (meq/100g)	0.04[a]	0.01	0.30[b]	0.58
Ca (meq/100g)	1.41[a]	0.79	11.47[b]	13.66
Mg (meq/100g)	0.33[a]	0.21	1.89[b]	1.74
CEC (meq/100g)	1.83[a]	1.05	13.80[b]	16.10
Sand (%)	93.60[a]	95.60	32.00[b]	30.80
Silt (%)	3.10[a]	2.40	33.10[b]	33.00
Clay (%)	3.30[a]	2.00	34.90[b]	36.20
Textural class	Sand	Sand	Clay loam	Clay loam

Within rows, t-test (paired mean samples, $p < 0.05$) with different letters are statistically significant ($n = 8$).

This may be due to the fact that both the soil available nutrients and rice crop nutrients requirement ratio per growing season have never been scientifically determined at the Kalimbeza rice project because according to one interviewee, the project was established on a very fertile soil. However, this practice might promote nutrients imbalance and pose threat to sustainable productivity of the rice project soil. According to Isitekhale *et al*. (2014), in assessing the suitability of soils for rice production, both the soil and rice nutrients requirement should be known.

It was further noted from the interview conducted that some of the workers (50%) did not know the exact amount of fertilizer applied per planting season. This may be risky to the environment as it could lead to abuse of fertilizer application due to possible over or under soil fertilization. Fertilization of rice field is very critical for sustainability of both rice production and soil productivity (IRRI, 2015). Rice cultivation can easily deplete soil nutrients if rice field is not properly fertilized (Yan *et al*., 2007). However, rice soil fertilization should be based on specific site nutrients status and rice crop nutrients requirement for sustainable and long term productivity of the soil.

Usage of rice residues

The study found that at the Kalimbeza rice project, rice residues such as rice husks, rice leaves and rice straws are not left to decay into the rice soil in order to improve soil organic matter content. It was found that while the straws are used as livestock fodders (Fig. 3), other wastes such as the husks are dumped outside the rice field and are either burnt or left to decay. Figure 4 above shows an extract of the disposal of rice residues after harvesting at the Kalimbeza rice project. Lal (2009) indicated that rice residues are not waste but precious commodity which contains valuable organic matter that can improve soil quality and enhance soil fertility. Organic matter promotes sustainable soil management which lead to healthy agricultural productivity. Thus, the current practice of not allowing rice residues to decompose into the soil after harvest could affect the capacity of the rice soil to recover important nutrients naturally. According to Kabir (1999), the removal and burning of rice straws contribute to huge amount of nutrients loss.

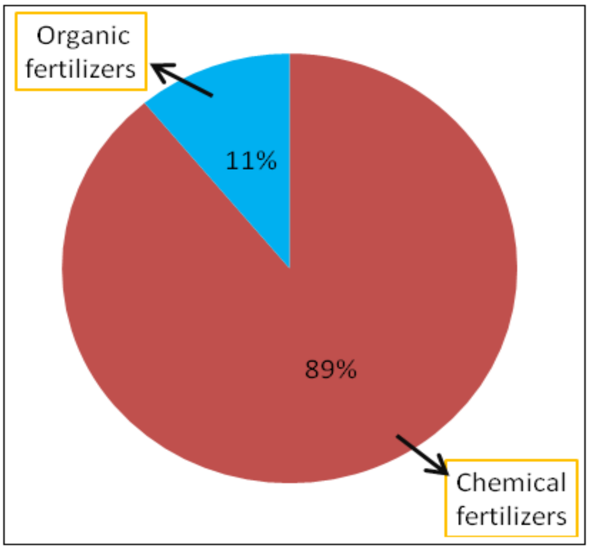

Fig. 1. Percentage usages of Chemical and organic fertilizers at Kalimbeza rice project.

The author also added that approximately 66kg of N, 6kg of P and 160kg of K are lost if rice straws are removed from a hectare of land. Rokonuzzaman (2012) similarly stated that harvested rice crop always take away nutrients from the soil. This could lead to low rice production due to decline in soil fertility (Shukla *et al.*, 2005; Zhang and Wang, 2005; Rigby and Caceres 2001).

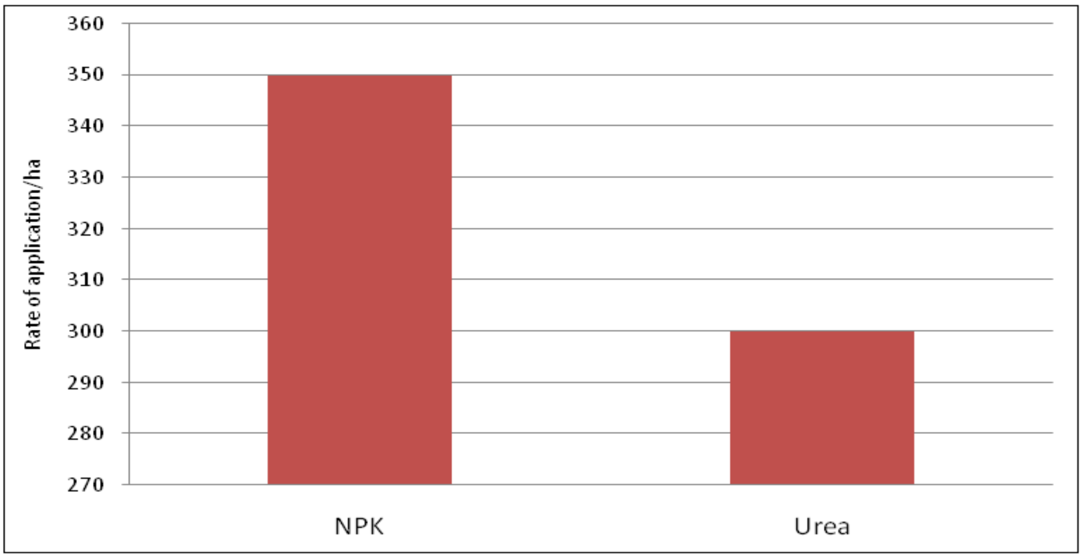

Fig. 2. Average rate of chemical fertilizer applications (Kg/ha) at the Kalimbeza rice project.

Thus, leaving rice straws, leaves, and husk to decay into the rice soil will not only maintain moisture but improve soil productivity in long-run for sustainable rice cultivation (Primavesi, 1999).

Cropping system at Kalimbeza rice project

Fig. 5 presents the results of the participants' memory recall on the cropping system used since Kalimbeza rice project commenced large scale rice production in 2007.

The results revealed that rice mono-cropping system is strictly used and rice crop is grown over and over on the same piece of land. Research report indicated that mono-cropping has negative impact on soil fertility and soil productivity (Shukla *et al.*, 2005).

Moreover, rice cultivation is known for depleting soil nutrients particularly nitrogen. However, increase in available nitrogen, phosphorus, potassium and sulphur content in cropping sequences involving vegetable, pea, and green gram were reported by Gangwar and Ram (2005).

Fig. 3. Livestock fodder (Rice hay) produced from rice straws at the Kalimbeza rice project.

Thus, cropping sequence involving legumes could be introduced at the Kalimbeza rice project and the crops grown in rotation after rice harvest to facilitate soil recovery from nutrients utilized by the rice crop.

Mono-cropping encourages pest population increase as the pest life cycle is always fulfilled by the host's presence season after season, unlike in crop rotation whereby, the pest life cycle is interrupted by rotating host plant with another crop (Primavesi, 1999). Thus, the practicing of mono-cropping at the Kalimbeza rice project might result in increased pest population which might lead to intensified pesticides usage with implication for ecosystem sustainability.

Soil properties of the Kalimbeza rice project field

The results in Table 2 show the soil properties of the sampled Kalimbeza rice project soil and virgin soil (control soil). The analyses results revealed that the Kalimbeza rice project soil recorded pH levels of 5.73 and 4.90 within the 0-15cm and 15-30cm soil depth while the control soil recorded pH of 6.34 and 6.59 with the respective soil depths.

According to Wanyama *et al.* (2015), the optimum soil pH required for rice productivity ranges from 5.0 - 8.0. Thus, the Kalimbeza rice project soil has suitable pH within the topsoil zone which can supports rice growth since rice is a shallow rooted crop. According to Clark and Baligar (2000), soil pH has a dominant effect on the solubility and therefore, availability and potential phytotoxicity of ions (nutrients as well as toxic elements). Hence, pH is an important measurement to assess potential availability of soil nutrients for rice growth.

The soil particle size analysis result shows that the Kalimbeza rice project soil is dominated by sandy textural class with 93.60% and 95.60% sand contents and as little as 3.3% and 2.0% clay contents within topsoil and subsoil respectively. On the other hand, the control soil is dominated by clay contents of 34.9% and 36.2% within 0-15cm and 15-30cm respectively; 32.00% and 30.80% sand content were recorded within the same soil depths.

The sandy textural class of the Kalimbeza rice project soil has implication for optimum rice productivity as rice crop requires soil with high water retention capacity and sandy soil generally has low moisture holding capacity, low organic matter content and low Cation Exchange Capacity (Aondoaka and Agbakuru, 2012).

The rice project soil also recorded low total nitrogen content of 0.03% and 0.05% within the topsoil (0-15cm) and subsoil (15-30cm) respectively compared to the virgin soil which recorded 0.16% and 0.15% within the same soil depths.

Fig. 4. Disposal of rice residues (left: rice straws; right: rice husks) at the Kalimbeza rice project.

The Kalimbeza rice soil recorded higher available phosphorus of 2.5ppm within the topsoil but lower level of 1.6ppm within the subsoil. However, the control soil recorded 0.8ppm and 15.5ppm within the same soil depths. Levels of exchangeable potassium in the Kalimbeza rice soil were 0.05 meq/100g soil within 0-15cm and 0.04 meq/100g soil within 15-30cm while in the control soil, 0.14 meq/100g soil and 0.12 meq/100g soil of exchangeable potassium were recorded within the respective soil depths.

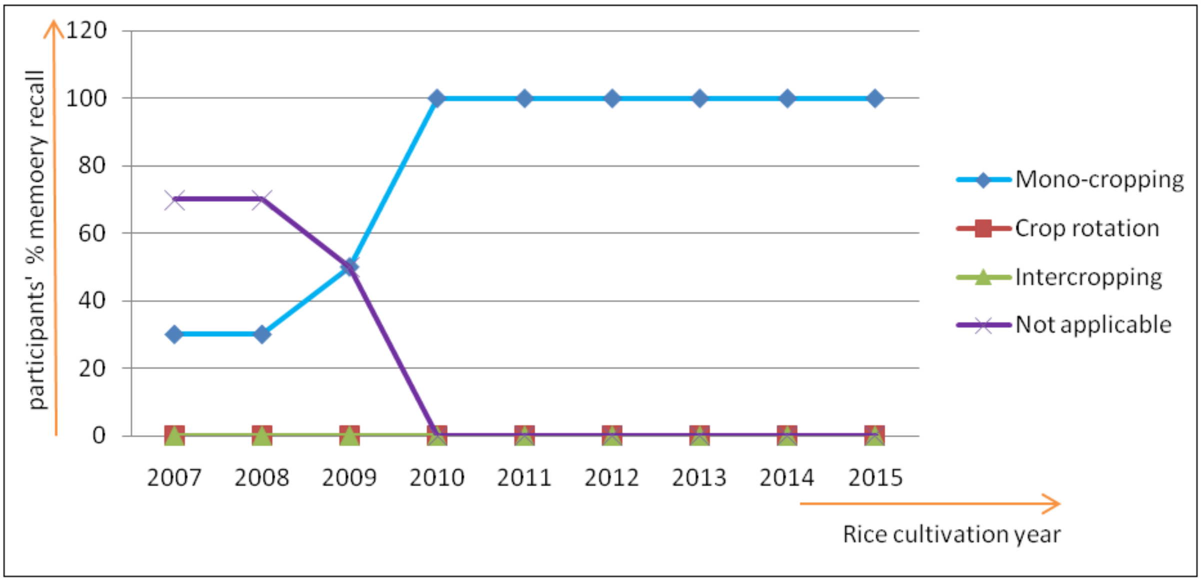

Fig. 5. Participants' memory recall on the cropping system practicedat Kalimbeza rice project (2007 - 2015).

The Kalimbeza rice soil also recorded very low organic matter in both topsoil (0.30%) and subsoil (0.34%) compared to the control soil's organic matter content of 1.12% and 1.22% within the respective soil depth. The results also showed that the Cation Exchange Capacity (CEC) of the Kalimbeza rice project soil is very low with 1.83 meq/100g (topsoil) and 1.05 meq/100g (subsoil), compared to the control soil which recorded 13.80 meq/100g (topsoil) and 16.10 meq/100g (subsoil). The low CEC recorded suggests that the Kalimbeza rice project is very prone to leaching of nutrient elements.

The results of t-test analysis (paired sample mean; $p < 0.05$) between the means levels of pH, OC, CEC, N, P, K, and EC recorded in the Kalimbeza rice project soil and virgin soil (control) was statistically significant. These variations between the two soils' properties may be due to the effect of on-farm activities carried out at the rice field. Intensive agriculture involving exhaustive high yielding varieties of rice and other crops, has led to heavy withdrawal of nutrients from the soil and resulted in deterioration of soil health (John *et al.,* 2001).

According to the United Nations University Institute of Advanced Studies (UNU-IAS, 2008), degradation of natural resources reduces the productivity, and this is a serious concern in rice soils. Furthermore, the protection of soil quality under intensive land use and fast economic development is a major challenge for sustainable resource use in the developing world (Doran *et al.,* 1996). However, Sanchez (2010) suggested that crop yields in Africa could be tripled through proper management of the soil environment. Thus, it has become a necessity for continued research to ascertain the implication of certain on-farm activities for sustainable soil productivity in order to sustain crop production and meet the food demands of the world's teaming population.

Conclusion

The results of this study revealed that chemical fertilizers are frequently used to improve soil fertility at the Kalimbeza rice project but the fertilizers were applied without prior soil analysis to ascertain the nutrients status.

The applications of chemical fertilizer without reference to soil tests data might result in nutrients imbalance (due to under fertilization or over fertilization), and this could affect sustainable management of the soil fertility with implication for sustainable rice production.

It was also revealed that rice mono-cropping system is solely practiced, coupled with maximum harvesting in which rice residues were used to produce livestock feed and not left to decay into the soil. T-test (paired sample mean, $p < 0.05$) analysis of the soil properties revealed that the rice soil has significantly lower levels of: total nitrogen, phosphorus, organic carbon, and cation exchange capacity than the control soil. These findings suggest that the rice soil is currently a low nutrient status soil. Thus, the practice of applying chemical fertilizers without prior soil analysis, rice mono-cropping and maximum harvesting at the Kalimbeza rice project could affect sustainable management of the rice soil and present adverse implications for its long term productivity.

Therefore, it is advisable to incorporate practices such composting/allowing crop residues to decay, increasing use of organic fertilizer, carrying out site-specific soil analysis prior to application of chemical fertilizers, and cultivating legume crops in rotation with rice after harvest in order to aid sustainable management and long term productivity of the rice soil.

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