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ORIGINAL ARTICLE

Comparison of Soil Properties in Different Fertilizer Input Systems in Lowland Rice at the Third Year in Transition

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Abstract

Synthetic inorganic fertilizers (SIF) have the potential to impose detrimental environmental effects and are frequently utilized in Sri Lankan conventional rice farming. To maximize rice yield while maintaining soil health, soil nutrient management is vital. In this study, the soil properties of rice fields maintained using conventional (as recommended by the Department of Agriculture (DOA), 2013), reduced (50% DOA + 50% organic), and organic Input Management Systems (IMSs) were studied. The Rajarata University of Sri Lanka's Faculty of Agriculture established this experiment during the *Maha* season of 2020–2021 utilizing a Randomized Complete Block Design. At the initial, 50% flowering, and harvesting stages, soil samples were obtained from three distinct IMSs with three replicates at surface (0 - 15 cm) and subsurface (15 - 30 cm) soil depths. The data were analyzed using linear mixed effect models followed by Tukey's mean comparison. Three IMSs and three different stages of rice growth exhibited substantially varying soil pH, EC, available P, and exchangeable K values in this third transition year ($p<0.05$). Despite being highly varying across IMSs, soil CEC was not significantly different ($p>0.05$) among the stages of rice growth. Three IMSs' soil available N did not change significantly ($p>0.05$) yet differed across growth stages ($p<0.05$). In comparison to those obtained with conventional IMS, rice grain yield with organic IMS produced levels that were noticeably similar. The highest grain yield was produced with reduced IMS ($p<0.05$). This illustrates the possibility of boosting yields and sustaining soil fertility by substituting organic manure for 50% of SIF.

Keywords: *Grain yield, Input Management System (IMS), Rice, Soil Properties*

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1. Introduction

Rice (*Oryza sativa* L.) is the staple food crop of Sri Lanka, and it is one of the main crops grown in the country. Today's agriculture is under unprecedented pressure to meet the demand for food due to decreasing land available for agriculture and population growth. In the 1960s, the concept of the Green Revolution introduced enhanced chemical fertilizer application as an alternative for improving rice yields. Nitrogen (N), phosphorus (P), and potassium (K) are the three main essential nutrients for the optimum growth of the rice plant (Ekanayake 2009). At present, conventional rice farming in Sri Lanka is highly based on synthetic inorganic fertilizers to supply nutrients for the rice plant. Urea, TSP (Triple Super Phosphate), and MOP (Muriate of Potash) are the most used inorganic fertilizers in rice cultivation (Jayasumana et al. 2015). While inorganic fertilizers, due to their solubility in water, have simplified nutrient supply to plants, their repeated and excessive use can result in nutrient loss, soil health disruption, surface & groundwater contamination, reduced biological activity, and environmental pollution. Despite their contribution to high paddy production, inorganic fertilizers and agrochemicals come with these negative consequences (Kakar et al. 2020). Therefore, organic farming is identified as an environmentally friendly alternative. Organic manure increases soil fertility by increasing soil organic matter content and soil biological activity. Additionally, it increases the water holding capacity, improves both the soil structure and texture, and provide a reservoir for the plant nutrients available in the soil. Hence, organic inputs improve soil chemical, physical, and biological properties (Moe et al. 2019; Surekha et al. 2010). However, organic manure takes a long time to decompose and release nutrients. Additionally, their application is a labor-intensive practice and can be challenging due to the limited availability of materials (Moe et al. 2019). It is suggested that combining organic and inorganic inputs is a good solution to reduce the negative impacts of conventional farming while obtaining a higher yield than applying organic inputs alone (Saha et al. 2010). Hence, it is crucial to implement a sustainable input-use farming system that efficiently meets the plant nutrient requirements without reducing paddy yields. Comparison of different input use systems is imperative before proposing the sustainable paddy farming system to the dry zone of Sri Lanka. Therefore, this experiment was conducted to compare major soil chemical properties and final grain yield among three different input management systems of conventional (Department of Agriculture recommendation (DOA), 2013), reduced (50% DOA + 50% organic (compost)), and organic (compost) input management system to identify suitable input management system for the dry zone.

2. Materials and Methods

The experiment was conducted during the 2020/2021 *Maha* season in the research field at the Faculty of Agriculture, Rajarata University of Sri Lanka at Puliyankulama in Anuradhapura district (located in 8° 22’ 14.41” N and 80° 25’

13.66” E). This area belongs to the DL_{1b} agroecological region and consists of the undulated catenary landscape. The mean annual rainfall of the area is less than 1750 mm and the mean annual temperature is 25- 30°C. The common soil type distributed in the dry zone area is Reddish Brown Earth and while paddy fields are associated with Low Humic Gley (LHG) soil (Punyawardena et al. 2003; Vidyarathna et al. 2008).

Field Experiment Layout

The experimental design was a Randomized Complete Block Design (RCBD) with three replicates. The three months duration rice variety of Bg 300 was established at 120 kg/ha seeding rate. The treatments applied were: T1 – Conventional IMS (100% DOA, chemical fertilizer recommendation, 2013, and synthetic agrochemicals used for pest, disease, and weed control). T2 – Reduced IMS (50% reduction of Department of Agriculture (DOA), chemical fertilizer recommendation, 2013 + organic manure(compost) by volume and pest, disease, and weeds were controlled using integrated approaches without agro chemicals). T3 – Organic input management system (IMS) (100% compost and pests and diseases were controlled using organic pesticides available in the market as well as other integrated approaches). Twelve plots were designated for the organic input system, receiving 10,000 kg/ha of compost, and another twelve plots were allocated to the reduced input system, with 5,000 kg/ha of compost. At the end of the growing season, the plots were harvested, and the total yield of each treatment was recorded.

Soil Sampling

Soil sampling was conducted at three time points [just after land preparation (initial stage), 50% of the flowering stage, and the harvesting stage] from each experimental plot. Soil samples were collected from two depths (0-15 and 15-30cm) separately using an Edelman clay auger in a Zig-Zag pattern using 4 sampling points across each plot. Subsequently, these four samples were mixed to obtain composite representative soil samples for analyzing soil nutrient contents. Each soil sample was analyzed for the following soil chemical properties. Soil pH was determined in soil suspension (soil/water 1:2.5) using a pH meter (H1 98108, HANNA, Korea) (Rowell 1994). The electrical conductivity of the soil solution (soil/water 1:5) was determined using EC meter (H1 98311, HANNA, Korea) (Black 1965). Available N content in the soil was determined by the Kjeldahl method (Stanford and Smith 1972). Soil available P was extracted by 0.5 M sodium bicarbonate solution and determined by the molybdate blue colorimetric method (Olsen et al. 1954). Soil exchangeable potassium was determined by the ammonium acetate extraction method (Jackson 1958) followed by flame photometry. Soil cation exchange capacity (CEC) was measured by the NH_4OAc method (Chapman 1965).

Data Analysis

Data was statistically analyzed by mixed procedure in SAS 9.0 version and mean comparison was performed by the Tukey’s method ($p \leq 0.05$).

3. Results and Discussion

Soil pH

Soil pH is the measurement of the acidity and alkalinity of the soil solution (McCauley et al. 2009). Soil pH was significantly different among three IMSs and three different rice growth stages (*$p<0.05$*) (Fig.1). The mean values of soil pH at the initial stage of conventional, reduced, and organic input management systems were 7.66, 7.59 and 7.74, respectively. The soil in the experimental plots was slightly alkaline in all IMSs at the initial stage. Then soil pH decreased and become neutral in submerge conditions which could be due to the production of CO_2 by microbial decomposition of organic matter. Thus, occupy high nutrient availability for plant uptake and therefore most suitable for crop growth (Fageria et al. 2011). Soil pH values were significantly higher in organic IMS than the conventional IMS at the 50% flowering and harvesting stages. This result is in agreement with several other studies that report organic manure increases soil pH and inorganic fertilizers decrease soil pH (Han et al. 2016). This might be due to the continuous application of urea for the conventional and reduced IMSs which increased the $NH4^+$ ion concentration in the soil solution leading to soil acidification (Fageria et al. 2010).

Soil Electrical Conductivity

Soil electrical conductivity (EC) was significantly different among the three IMSs and three different rice growth stages (*$p<0.05$*) (Fig.2). In all three IMSs, lower soil EC values were observed at the harvesting stage in comparison to the initial and 50% flowering stages due to greater leaching of water-soluble ions with frequent irrigation and greater uptake of plant nutrients. Soil EC of conventional IMS at 50% flowering stage was significantly higher than organic and reduced IMSs (*$p<0.05$*). This might be due to the application of 100% inorganic fertilizers in conventional IMS which are readily soluble in soil solution.

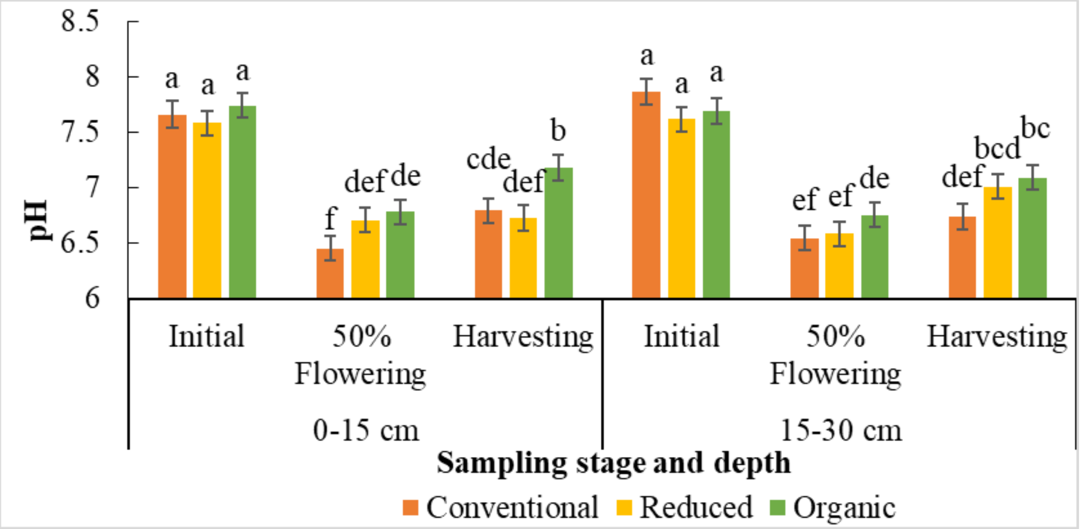

Figure 1: The fluctuation of soil pH among three input management systems and at two depths over the rice growing season. Vertical bars labeled with different letters indicate statistically significant differences at *$p \leq 0.05$.*

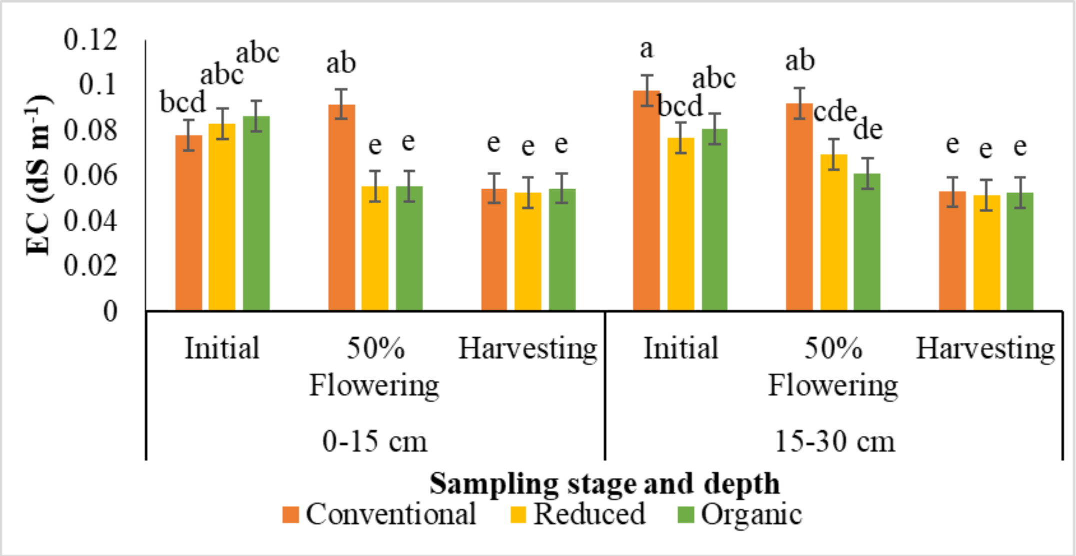

Figure 2: The fluctuation of soil EC among three input management systems and at two depths over the rice growing season. Vertical bars labeled with different letters indicate a statistically significant difference at *p≤ 0.05*.

Soils are considered saline soils when their EC is 4 dS m^{-1} at 25°C (Eynard et al. 2005). The mean recorded electrical conductivity of soil samples during the entire growing season ranged between 0.05 and 0.10 dS m^{-1}. Therefore, the soil electrical conductivity values in all three input management systems remained at a lower level indicating no potential to develop soil salinity.

Soil Available Phosphorus

Phosphorus is a crucial macronutrient essential for maintaining the root growth and nurturing early flowering and maturation stages (Shrestha et al. 2020). P acquisition and requirement for rice is greatest during the early phases of growth. The mean recorded soil available P content ranged between 2.56±2.0784 - 14.89±2.0784 mg/kg in conventional IMS, 6.15 - 21.28 mg/kg in reduced IMS and 12.14 - 28.23 mg/kg in organic IMS. However, the soil available P content in the conventional IMS at both the initial and harvesting stages, as well as in the reduced IMS at the harvesting stage, was found to be below the lower critical level of 10 mg/kg, as reported by Bandara et al. (2005). The soil available P content was significantly different among IMSs and three different rice growth stages ($p<0.05$) (Fig.3). The Triple Super Phosphate (TSP), an inorganic fertilizer added at the beginning of the season (basal application) was used as a P source to supply the total P requirement in the conventional input management system and half of the P requirement in the reduced IMS. It is possible that most of the added P is converted to unavailable forms due to fixation by Al^{3+}, Fe^{2+}, and Ca^{2+} ions in soil (Jimenez et al. 1993). However, organic IMS showed gradual releasing of P, most likely via microbial decomposition and compost has a high affinity

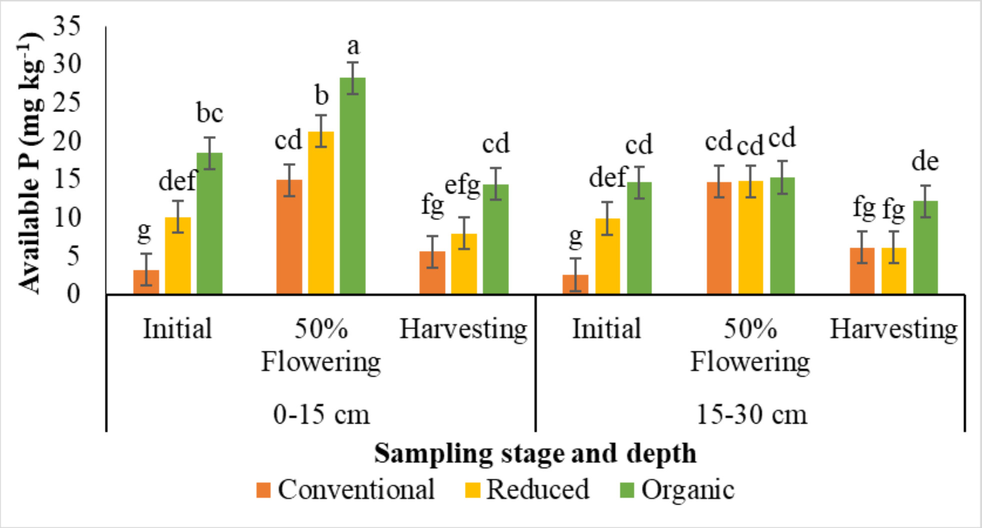

Figure 3: The fluctuation of soil available P among three input management systems and two depths over the rice growing season. Vertical bars labeled with different letters indicate statistically significant differences at *p≤ 0.05*.

for Fe^{2+} and Al^{3+} ions resulting low fixation rates compared to the other two IMSs (Baggie et al. 2004). As a result of this, organic IMS showed significantly the highest ($p<0.05$) soil available P content at all growing stages in surface soil. As organic inputs were added during previous seasons, initial stage of both organic and reduced IMS showed significantly higher ($p<0.05$) soil available P content compared to conventional IMS. There was a significant improvement in soil available P content from the initial to 50% flowering stage in all IMSs in surface soil due to the addition of external inputs (as TSP or organic manure) at the beginning of this rice growing season ($p<0.05$). Soil available P content at the harvesting stage of all IMSs were significantly low ($p<0.05$) compared to 50% flowering stage as plant uptake more P from the soil. These results corresponds with report that rice crop with a yield of 6000 kg ha^{-1} removes 20 kg ha^{-1} of P per season (Amarawansha and Indrarathne 2010).

Soil Available Nitrogen

Soil available N is defined as N that can be readily absorbed by plant roots and NH_4^+ is the main available N form in lowland rice soils (Fageria et al. 2011; Scarsbrook 1965). Nitrogen is an important macronutrient for the growth and development of the rice plant. It is typically the primary limiting nutrient in lowland rice production, and the application of N fertilizer is crucial for sustaining rice production to meet the demand. The mean recorded available N content in soil samples throughout the entire growing season in this study ranged from 1.99 to 8.29 mg/kg. Urea is readily soluble in water and provides plant available N form for the rice plants. The organic form of N is not readily available for plant uptake. But, soil microorganisms gradually mineralize the organic N over time, converting

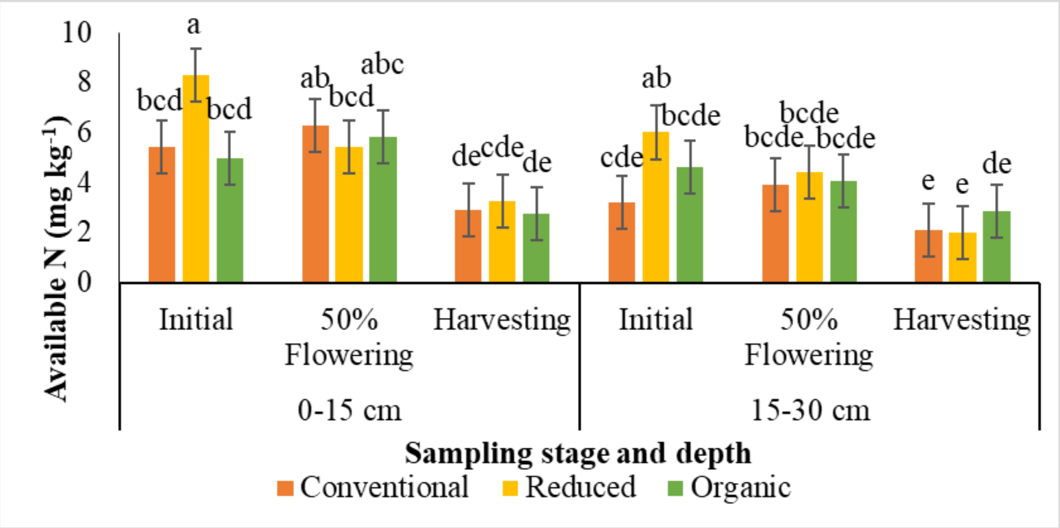

Figure 4: The fluctuation of soil available N among three input management systems and at two depths over rice growing season is represented. Vertical bars labeled with different letters indicate statistically significant differences at $p \leq 0.05$.

it into ammonium and nitrate forms.

In the third transition year, the amount of soil available N in the organic and reduced IMSs have developed to the same extent as the available N content in the conventional IMS due to addition of organic inputs (compost). As a result, soil available N denied showing significant different ($p>0.05$) across three IMSs (Fig.4). Soil available N was also significantly different ($p<0.05$) among different rice growth stages. The all IMSs showed significantly low ($p<0.05$) soil available N content at the harvesting stage. It might be due to the removal of available N through plant uptake and other forms of N loss. (Angus and Peoples 2012). A major part of N in the submerged rice soils is lost through leaching and denitrification (Fageria et al. 2011). Surface soil showed significantly higher ($p<0.05$) soil available N compared to subsurface soil as N was incorporated as urea or organic manure (compost) into the surface soil during fertilizer application.

Soil Exchangeable Potassium

Potassium is essential macronutrient for rice plant and that is needed for facilitate osmotic and ionic control (Shrestha et al. 2020). Soil exchangeable K content was significantly different among three IMSs and three different rice growth stages ($p<0.05$) (Fig.5). As organic inputs were added during previous seasons, initial stage of organic IMS showed significantly the highest ($p<0.05$) soil exchangeable K content compared to conventional IMS. Rice straw that is in compost contains about 1.0-3.7% K in highly available forms (Ponnamperuma 1972). The compost helps to bind the soil aggregates which provide good soil structure. Such soils have a higher ability to retain nutrients and it can hold nutrients tight enough to prevent them from washing out and leaching. Compost introduces diverse life forms into the soil, such as bacteria, insects, and worms, which are essential for soil fertility. Due to these factors, organic manure increases the availability of cations, including K+, in the soil (Ali et al. 2009; Bhardwaj and Omanwar 1994).

When the surface soil of different IMSs was compared, organic IMS showed the significantly highest value and conventional IMS showed the lowest value (*p<0.05*) and it was in between in reduced IMS. The reduced IMS incorporated with both organic manure and inorganic fertilizer and gained one half in inaccessible form of K and the half in a form of readily available. When comparing the rice growth stages, initial stage of conventional and reduced input management systems contained low levels of exchangeable K compared to organic and it was significantly increased from the initial to 50% flowering stage, with the application of inorganic fertilizer which is readily soluble in water (*p<0.05*). Due to plant uptake and leaching losses, all IMSs showed lower exchangeable K content at the harvesting stage than 50% flowering stage. Soil exchangeable K during the study period ranged between 37-70 mg/kg. However, these values were below the lower soil critical level of 80 mg/kg as reported by Bandara et al. (2005). This deficiency may be attributed to the higher sand percentage, lower organic matter content, and lower cation exchange capacity in the soil across all input management systems (IMSs) (Barber et al. 1981; Huang 2005).

Soil Cation Exchange Capacity

Soil cation exchange capacity (CEC) is a measurement of how well soil retains nutrients and availability of its nutrients to the plants (Aprile et al. 2012). Soil cation exchange capacity denied showing significant difference (*p>0.05*) with rice growth stages (Fig.6). It might be due to the long time taken for the increment of CEC in soil. According to past literature, a significant increase in soil CEC was not observed for 3 years of application of organic amendments (Zebarth et al. 1999).

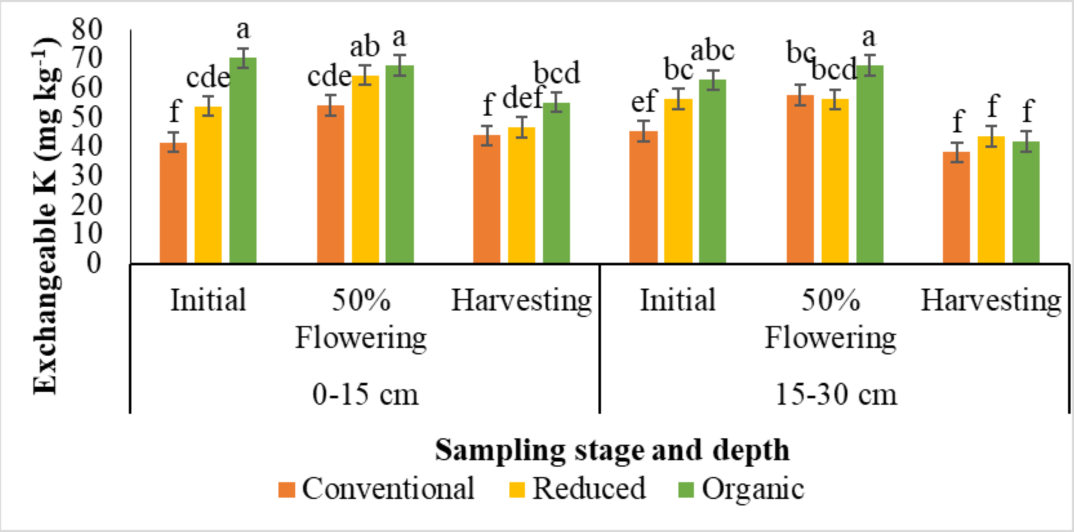

Figure 5: The fluctuation of soil exchangeable K among three input management systems and at two depths over the rice growing season is represented. Vertical bars labeled with different letters indicate statistically significant differences at *p ≤0.05.*

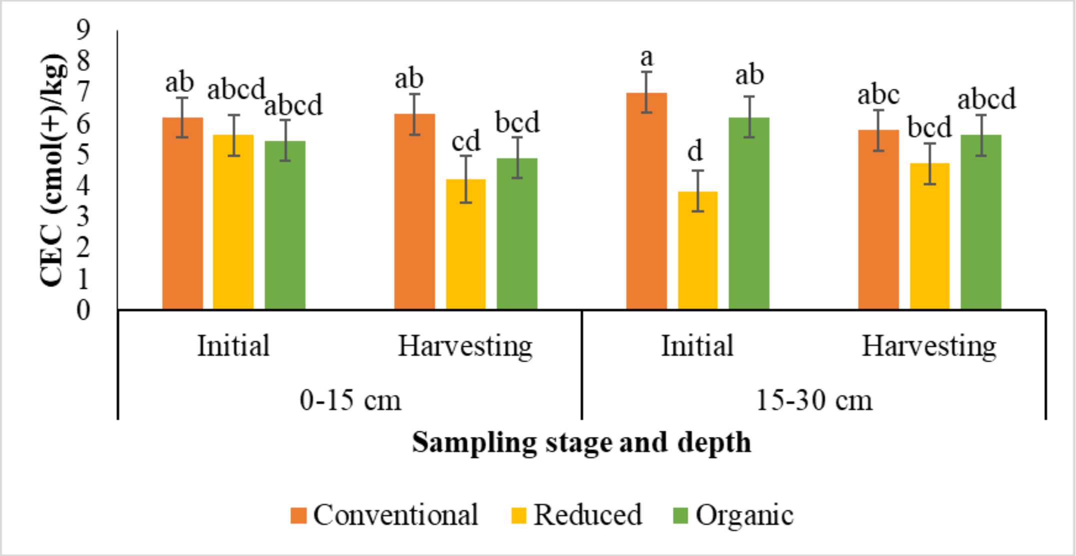

Figure 6: The fluctuation of CEC among three input management systems and at two depths over the rice growing season is represented. Vertical bars labeled with different letters indicate statistically significant differences at $p \leq 0.05$.

Soil CEC of all IMSs during the study period ranged between 3.8-7 cmol$_{(+)}$/kg. However, these values were below the optimum range of 15-20 cmol$_{(+)}$/kg as reported by Bandara et al. (2005). A low CEC indicates that the ability of soil to retain nutrients is limited. Many soil parameters are influenced for the enhancement of soil cation exchangeable capacity especially soil pH, soil texture, soil minerology and organic matter content up to a certain extent. Soil texture is one of the parameters that has a greater influence on CEC values. According to Oorts et al. (2003), clay and fine silt fractions are responsible for 76 to 90% of the soil CEC at pH 5.8. The soil textural group in the research area was the loamy sand textural group which has a higher sand percentage and very low clay and silt percentage. Clay has a great capacity to hold cations because it has higher negative charges on its surface and sand has comparatively much lesser capacity to exchange cations. Smectite, vermiculite, illite, and kaolinite are the clay minerals present in Alfisols. The CEC is the lowest in heavily weathered kaolinite in Sri Lanka (Mapa et al. 2020). Humid and hot climatic conditions in Sri Lanka resulted highly weathered soils including Alfisols, therefore this might be a reason for comparatively low CEC in this soil. Organic matter decomposes into humus, which has higher negative surface charges and thus raises the CEC. Since all three input management systems (IMSs) have comparatively lower soil organic matter content, this leads to a lower CEC in this soil (Aprile et al. 2012).

Rice Grain Yield

The mean values of rice grain yield of conventional, reduced, and organic input management systems were 4.2±0.1043 ton/ha, 4.84±0.1043 ton/ha, and 4.07±0.1043 ton/ha (Fig.7). Reduced IMS has given the significantly highest grain yield ($p<0.05$).

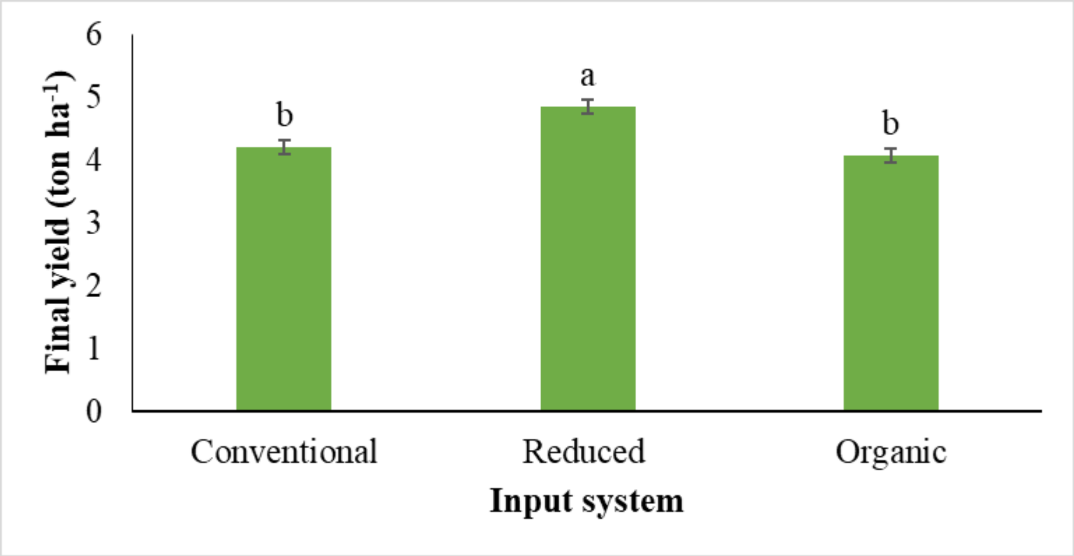

Figure 6: The fluctuation of final rice grain yield among three input management systems is represented. Vertical bars labeled with different letters indicate statistically significant differences at $p \leq 0.05$.

Therefore, rice grain yield favorably influenced by the combined application of chemical fertilizers and organic manure than the sole application of organic manure or chemical fertilizers in agreement with the finding of Sirisena et al. (2016). Khan et al. (2007) observe that combined fertilizer application gave a significant maximum ($p<0.05$) grain yield of rice when compared to the sole application of inorganic fertilizers. Previous transition years (1st and 2nd) showed significantly lower grain yield in organic IMS than the other two IMSs. However, in this third transition year, there was no any significant difference ($p>0.05$) in grain yield between the conventional and organic IMSs. Soil available N content in organic and reduced IMSs has developed as same as the conventional IMS in this third transition year which is one key factor governing the rice grain yield. The significantly highest ($p<0.05$) level of available P and exchangeable K content were recorded in organic IMS in this season. In the first few years conventional IMS was superior to organic IMS due to a mismatch of nutrient release from organic sources. However, once the soil fertility was built up sufficiently, organic IMS also produced significantly similar grain yields as conventional IMS.

4. Conclusions

In this study, organic IMS showed significantly higher available P and exchangeable K content in surface soil ($p<0.05$). The combined application of organic manure with inorganic fertilizer resulted in significantly higher soil available P and exchangeable K content compared to the sole application of synthetic inorganic fertilizers ($p<0.05$). Additionally, soil available N content in organic and reduced IMSs reached similar levels as the conventional IMS in this third transition year. Rice grain yield in organic IMS produced significantly similar levels with conventional IMS. Reduced IMS has given significantly highest grain yield ($p<0.05$). Therefore, these results highlight the potential of replacing 50% of synthetic inorganic fertilizer with organic manure to achieve higher yields while maintaining soil fertility in rice cultivation in the dry zone of Sri Lanka. However, further research is needed to refine the integrated nutrient management system with new ratios of inorganic fertilizers and organic manure before making concrete recommendations.

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