SLJoAS Sri Lankan Journal of Applied Sciences

Research Article

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Impacts of Different Fertilizer Application Approaches on the Selected Soil Properties and Rice Yield in the Dry Zone of Sri Lanka

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(Received 10th July 2024; Accepted 22nd February 2025)

Abstract

There is a growing concern to apply sustainable agricultural practices to optimize the crop productivity. Hence, this study examined the effects of various organic/inorganic fertilization strategies on soil fertility and rice yield. The study was consisted with three different treatments: T1-conventional fertilizer input management system (IMS); Department of Agriculture inorganic fertilizer recommendation (DOA), 2013, T2- reduced IMS; 50% DOA+ organic manure, and T3-organic IMS; organic manure alone. The study was conducted during the 2020/2021 *Maha* season, which marked the fifth season of the long-term cropping system research project at the farm premises of the Faculty of Agriculture, Rajarata University of Sri Lanka. A randomized complete block design was used with three replicates for the field experiment. Statistical analysis was carried out using the mixed procedure in SAS version 9.0. Mean comparisons were performed using Tukey's method, with a significance level at $p \leq 0.05$. Soil samples were obtained from the surface (0-15cm) and subsurface (15-30 cm) soil depths during three growth stages of paddy: at initial stage, at 50% flowering stage, and just after harvesting. Soil Total Nitrogen (STN), Soil Organic Matter content (SOM) and Soil Microbial Biomass Carbon (SMBC) were analyzed and paddy yield was measured. STN levels did not significantly differ among the three IMSs ($p \geq 0.05$). SOM content in the organic IMS showed stability across all growth stages. The three-way interaction of the IMS, plant growth stage, and soil depth showed a significant effect on SMBC content ($p \leq 0.05$). Rice grain yields under organic IMS were notably similar compared to yields obtained with conventional IMS. The highest grain yield was significantly higher with reduced IMS ($p < 0.05$). This indicates the potential to increase rice yields and sustain soil fertility by replacing 50% of synthetic inorganic fertilizers (SIF) with organic manure. Further investigation is required for definitive results.

Keywords: Input management systems, Rice Yield, Soil Carbon, Soil microbial biomass, Soil Nitrogen

1. Introduction

Rice (*Oryza sativa* L.) is one of the most vital staple crops, providing nourishment to a significant portion of the world's population [1]. As rice production plays a crucial role in food security in most countries, ensuring optimal yield is paramount. Soil fertility, which directly influences the growth and productivity of rice plants, is a key factor that must be addressed to achieve optimal yield [2, 3]. In this regard, the integrated approaches play a pivotal role in sustaining soil fertility and maximizing rice production. For thousands of years, organic amendments have been the primary nutrient source for rice production in Sri Lanka [4]. The Green Revolution has been a significant milestone in the transformation of global crop production in recent history [5]. Sri Lanka, like many other countries, embraced the principles of the Green Revolution to enhance its agricultural production by employing various strategies including the extensive use of synthetic fertilizers [6, 7]. Conventional agriculture, known as the prevailing approach in rice production in Sri Lanka, relies heavily on the use of synthetic fertilizers to enhance crop yields [8]. However, conventional agriculture in rice cultivation has raised concerns regarding its environmental impact, including soil degradation, water pollution, and potential health risks associated with the use of agrochemicals [9, 10]. However, maintaining soil and plant health sustaining grain yield and food security is of paramount importance in the present-day context. As a result, there is a transition in global agriculture towards organic, integrated, and low external input production methods [11].

Fertilizer applications can have a significant impact on soil fertility while soil organic components, such as soil organic carbon (SOC) and soil total nitrogen (STN), are crucial factors in determining soil fertility [12]. The dynamics of SOC and STN storage in agricultural soils play a vital role in driving microbial activity and nutrient cycles, as well as promoting favorable soil physical properties [13, 14]. The soil microbial biomass carbon (SMBC), representing the living component of the soil, is significant in the decomposition of organic matter and the turnover of nutrients. Changes in the SMBC content serve as an indicator of the fertility status of paddy soil, particularly in terms of soil carbon levels, as influenced by different fertilizer applications [15, 16]. Overall, understanding the dynamics of SOC, STN, and SMBC in response to different fertilizer applications is crucial for managing soil fertility in paddy soils.

This study aims to understand the impacts of different fertilization approaches on STN, SOC, SMBC, soil texture, and rice yield, to identify effective means to maintain soil fertility without compromising grain yield.

2. Materials and Methods

This study was conducted as part of a main project initiated in the 2018/19 *Maha* season. This research was conducted during the 2020/2021 *Maha* season in the research field situated at Puliyankulama, Anuradhapura district (8˚ 22' 14.41" N, 80˚ 25' 13.66" E), within the premises of the Faculty of Agriculture, Rajarata University of Sri Lanka. The experimental site belongs to DL_{1b} agro ecological region and exhibits an undulated catenary landscape [17]. The average annual rainfall in this region has been recorded to be less than 1750mm, while the average annual temperature ranges from 25°C to 30°C. The study area in the experiment is characterized by imperfectly drained Reddish-Brown Earth soils [18].

The field experiment was designed using a randomized complete block design (RCBD) with three replicates and the plot size was 15m×6m. Bg 300, a three-month duration rice variety, was sown at a seeding rate of 100 kg/ha. The treatments applied were as follows: T1 – Conventional IMS, utilizing 100% of the Department of Agriculture chemical fertilizer recommendation- 2013, alongside synthetic agrochemicals for pest, disease, and weed control. T2 – Reduced IMS, involving a 50% reduction in the Department of Agriculture-2013 chemical fertilizer recommendation, supplemented with organic manure (compost) by volume, and employing integrated approaches for pest, disease, and weed management. T3 – Organic Input Management System (IMS), where 100% compost was applied, and pests and diseases were managed using organic pesticides available in the market, along with other integrated approaches. Twelve plots were designated for the organic input system, receiving 10,000 kg/ha of compost, while another twelve plots were allocated to the reduced input system, receiving 5,000 kg/ha of compost. At the end of the rice growing season, plots were harvested, and the final grain yields for each treatment were recorded.

Soil sampling was done at three specific time points during the experiment: just after land preparation (initial stage), at the 50% flowering stage, and just after harvesting. Soil samples were collected from each experimental plot at two different depths, namely surface (0-15 cm) and subsurface (15-30 cm) using an Edelman clay auger. The sampling procedure followed a Zig-Zag pattern with four sampling points across each plot. These four samples were then combined to form a composite representative soil sample for each plot, which would be further analyzed for soil nutrient contents. Each soil sample was analyzed for the following soil physical, chemical, and biological properties. Soil total nitrogen (STN) was measured using the Kjeldahl procedure [19] and soil organic matter (SOM) content [20] was measured using Walkley and Black chromic acid wet digestion method. Soil Microbial Biomass Carbon (SMBC) was determined by the chloroform fumigation method [21]. The soil texture of each sample was determined by a simplified hydrometer method [22].

The collected data were subjected to statistical analysis using the mixed procedure in SAS version 9.0. Mean comparisons were performed using Tukey's method, with a significance level at $p \leq 0.05$.

3. Results and Discussion

3.1 Soil total nitrogen content

Soil total nitrogen (STN) content refers to the overall amount of nitrogen present in the soil, encompassing both organic and inorganic forms [23]. Based on the recorded data, the mean STN content of soil samples throughout the entire growing season ranged from 0.1% to 0.14%. This indicates that the STN levels for rice soil in all the soil samples analyzed were above the critical level of 0.1% [24]. The three-way interaction of IMS, growth stage, and soil depth did not significantly affect the STN content ($p \geq 0.05$). The results indicate that the two-way interactions between IMS and growth stage, IMS and depth, as well as growth stage and depth, did not have any significant impacts on the STN content ($p \geq 0.05$). The analysis of STN across three IMSs did not reveal any significant differences ($p \geq 0.05$) as indicated in Figure 1. This lack of significant difference may be attributed to the development of STN content in the organic and reduced IMSs, gradually reaching levels comparable to that of the conventional IMS over time. In this research, urea was used as an inorganic nitrogen fertilizer, providing readily available nitrogen that rice plants can easily absorb and utilize [25]. The integration of organic manures improves the efficiency of inorganic fertilizers, leading to an increase in soil total nitrogen content within the reduced IMS and therefore, there is no significant difference compared to conventional IMS [26]. The organic IMS involved the addition of organic inputs for four consecutive cropping seasons, resulting in a gradual enhancement of soil total nitrogen content over time and therefore promoting efficient nutrient uptake by plants [27]. Given the beneficial impact of organic fertilizers on STN content and their capability to counteract the negative consequences of inorganic fertilizers, incorporating organic inputs emerges as a superior approach to promote sustainable soil management [12, 28].

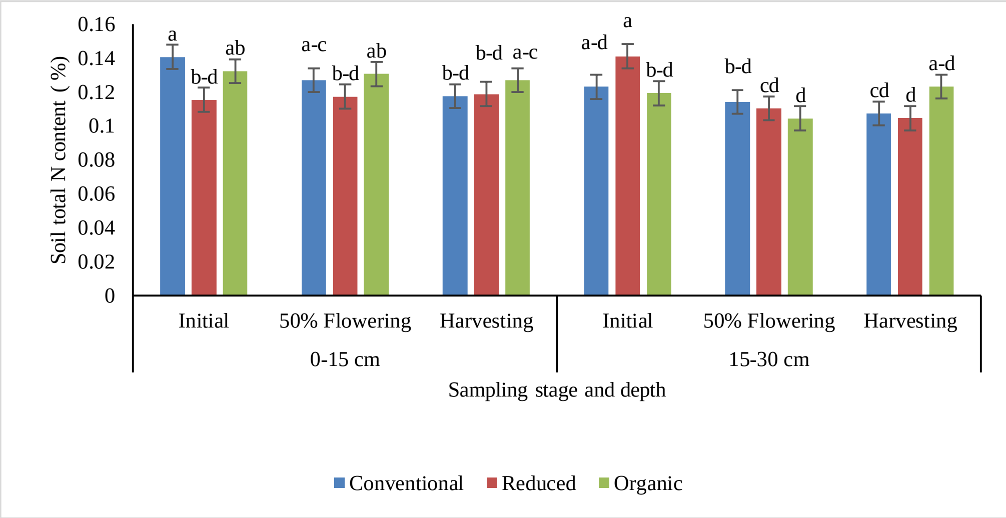

Fig. 1. Soil total nitrogen content (%) as affected by the input management system, growth stage and soil depth interaction. Vertical bars with different letters are significantly different at p≤ 0.05. Bars represent standard errors.

3.2 Soil organic matter content

Soil organic components, specifically soil organic carbon (SOC) and soil total nitrogen (STN), are crucial indicators of paddy soil fertility. Higher soil organic matter content (SOM) generally leads to higher levels of both SOC and STN, enhancing paddy soil fertility [12, 16]. The three-way interaction of IMS, growth stage, and soil depth did not significantly affect SOM content (p≥0.05). The two-way interaction of IMS and the growth stage had significant impacts on the SOM content (p≤0.05). There were no significant changes in IMS and depth (p≥0.05) (Figure 2). Initially, in surface soil, the organic IMS shows a significantly higher (p≤0.05) SOM content than reduced IMS while conventional IMS and reduced IMSs do not express any significant difference (p≥0.05). Continuous 100% organic manure application in previous seasons results in a significant increment of SOM content in the initial stage of an organic IMS compared to a reduced IMS. The analysis of SOM content in the surface soil did not indicate any significant differences between the organic and conventional IMSs (p≥0.05). The accumulation of SOM via organic manure application relies on the decomposition rate of the materials [29]. The application of inorganic fertilizers promotes the growth of above-ground and root biomass, primarily due to the rapid availability of essential plant nutrients in sufficient quantities. Consequently, the use of inorganic fertilizers indirectly leads to a significant increase in SOM content [14, 30]. However, previous research has indicated that the application of organic manure results in higher SOC content when compared to the equivalent amount of inorganic fertilizers [13]. The surface soil in both conventional and reduced IMSs exhibited a significant increase in SOM content from the initial stage to the 50% flowering stage. However, from the 50% flowering stage to the harvesting stage, there was a decrease in SOM content in both systems. However, SOM content in the organic IMS remained stable throughout all the growth stages in both soil depths. Manure application proved to be the most effective in preserving SOM [31]. This indicates that the application of organic manure helps to maintain a consistent level of SOM content throughout the entire growth stage. These findings highlight the benefits of organic IMS in sustaining SOM content, as compared to conventional and reduced IMSs. In all the IMSs, it was observed that the SOM content was below 3%, which was even lesser than the recommended optimum level of 3-5% for dry zone low-country rice cultivation [24] proving the fact that the development of SOM in a comparatively slow process due to relatively high temperature in this area.

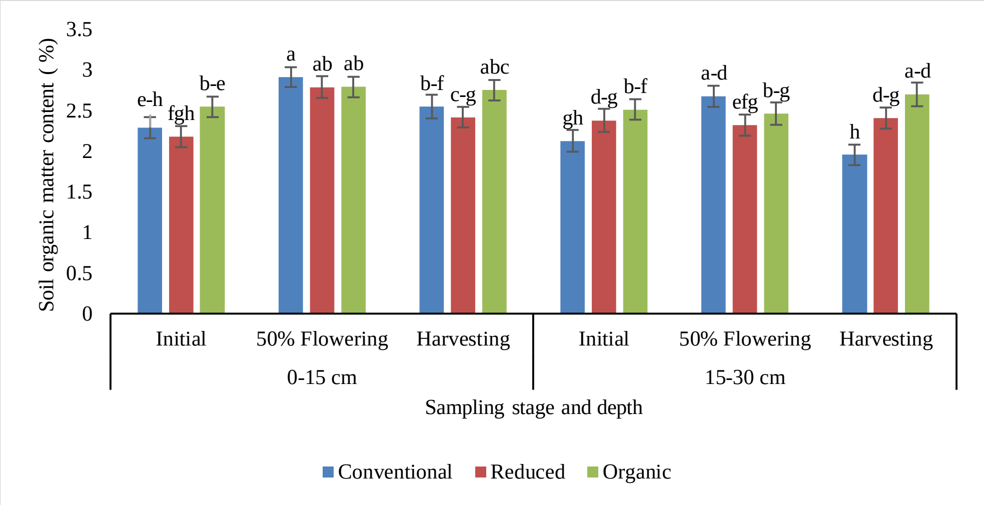

Fig.2. Soil organic matter content (%) as affected by the input management system, growth stage and soil depth interaction. Vertical bars with different letters are significantly different at p≤ 0.05. Bars represent standard errors.

3.3 Soil microbial biomass carbon

Soil Microbial Biomass Carbon (SMBC) is a measure of the carbon content present in the living microbial biomass within the soil [32]. It is considered as a key indicator of soil biological traits and can provide valuable information about soil health and functioning. Changes in SMBC can indicate shifts in microbial activity and the response of soil microbes to different input management practices or environmental conditions. Numerous studies have reported significant variations in SMBC levels among soils subjected to different fertilizer treatments, across different soil layers, and during different sampling seasons [33, 34]. In the initial stage, all IMSs exhibited significantly low SMBC content in both soil depths (p≤0.05) (Figure 3). SMBC content in the soil exhibited a substantial increase from the initial stage to the 50% flowering stage. All IMSs exhibited significantly high SMBC content at the 50% flowering stage in the surface soil (p≤0.05). The increased SMBC observed during the 50% flowering stage could be attributed to the enhanced nutrient availability in the soil resulting from fertilizer applications. Fertilizers stimulate nutrient absorption by microorganisms, leading to higher SMBC levels [35]. There was a significant decrement in SMBC content from the 50% flowering stage to the harvesting stage (p≤0.05). This decline in SMBC could be attributed to several factors, including nutrient depletion, plant uptake within the cropping period, variations in soil moisture, microbial turnover, fluctuations in root exudates, and changes in soil pH [33, 36]. The regular uptake of nutrients by plants can lead to deplete soil nutrients. Nutrient limitation can directly affect microbial growth and activity since microorganisms also depend on available nutrients for their metabolic processes [37].

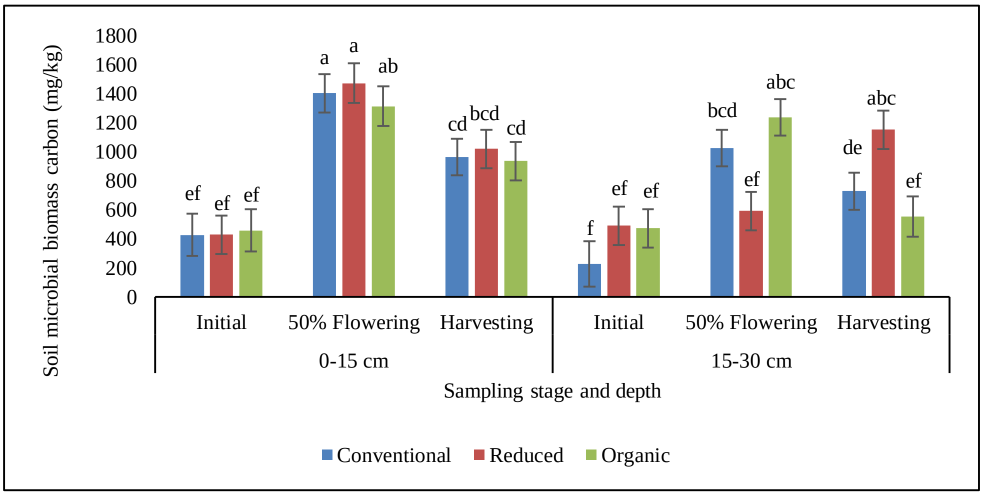

Fig. 3. Soil microbial biomass carbon content (mg/kg) as affected by the input management system, growth stage and soil depth interaction. Vertical bars with different letters are significantly different at p≤ 0.05. Bars represent standard errors.

3.4 Soil texture

Soil texture is the term used to describe the relative proportion of sand, silt, and clay [38]. It influences the soil pH, cation exchange capacity organic matter content, and structure of microbial communities in soil [39]. The texture of the soil in all IMSs was classified as loamy sand. The soil contained sand percentage around 83-89%, while silt and clay percentages varied between 2-4% and 8-13% respectively (Figure 4). Soil texture plays a significant role in nutrient management because it influences nutrient retention in soil [40]. Finer textured soils tend to have a better ability to retain soil nutrients. Since all three IMSs exhibited a high sand percentage (83-89%) in the surface soil, their nutrient retention capacity is likely lower, as sandy soils have reduced cation exchange capacity and water-holding ability [41].

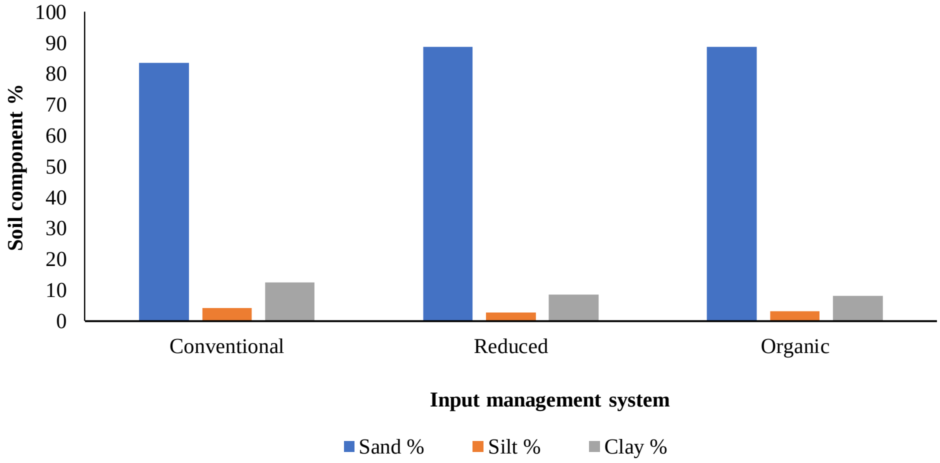

Fig.4. Average sand, silt, and clay percentages in different input management systems at after harvesting in surface soil

3.5 Rice grain yield

In the study, the mean rice grain yield for conventional, reduced, and organic IMS were recorded as 4.2 ton/ha, 4.84 ton/ha, and 4.07 ton/ha, respectively (Figure 5). In the third year of the transition, the reduced IMS achieved significantly the highest grain yield among the three IMSs ($p \leq 0.05$). Furthermore, there was no statistically significant difference ($p \geq 0.05$) in grain yield between the conventional and organic IMSs in the third transition year. Soil nitrogen content in organic and reduced IMSs has developed similar to that of the conventional IMS in the same year which is one of the key factors governing the grain yield of rice [42]. [43] Surekha et al. found that continuous application of organic manures increased nutrient availability, while inorganic fertilizers enhanced the mineralization efficiency of organic manure. The reduced IMS demonstrated a higher grain yield due to the combined effect of organic manure and inorganic fertilizers, which optimized nutrient availability and uptake more efficiently than the conventional or organic IMSs alone. Kumara et al. [44] suggested that the main reason for higher grain yields under integrated nutrient application is the increased uptake of nutrients facilitated with the improvement of soil physical properties through organic/inorganic fertilizers combination. This synergistic effect enhances nutrient availability, uptake, and utilization by crops, leading to increased yields. It was observed that rice grain yield in organic farming has reached an optimum level after five years [43]. In this study, even in the 3rd transition year from conventional to organic IMS, the organic IMS produced more or less the same crop yield compared to conventional IMS. Initially, there can be a mismatch between nutrient release from organic sources and crop demand which may lead to decreased productivity. However, soil fertility can be built up gradually in long-term application of organic sources, allowing the organic IMS to potentially produce similar yields as the conventional IMS [45].

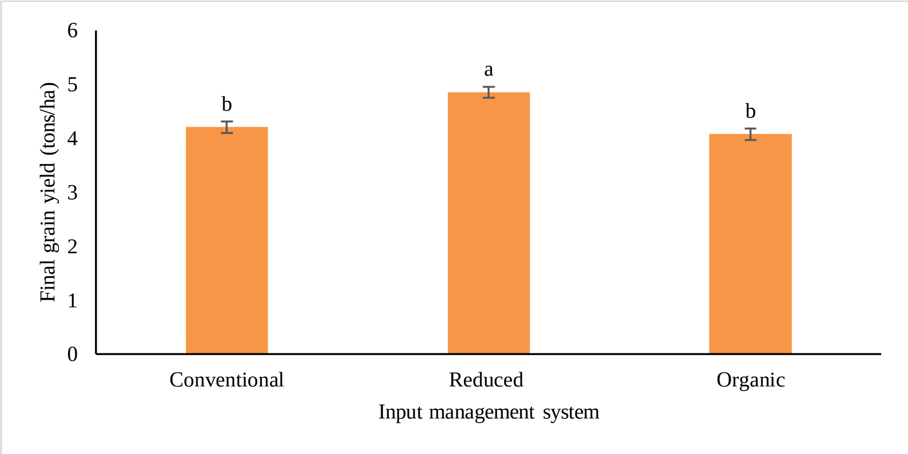

Fig. 5. Final rice grain yield among three input management systems. Vertical bars with different letters are significantly different at $p \leq 0.05$.

4. Conclusion

Only the SMBC content was affected by the combined effect of IMS, the growth stage of paddy, and soil depth. Whereas, STN content, SOM content, and soil C/N ratio were not affected by the combined effect of IMS, the growth stage of paddy, and soil depth. SOM content in the organic IMS remained stable across the growth stage and two soil depths and as a result soil C/N ratio was also subjected to increase at the initial stages at surface soil. Rice grain yield in the organic IMS was comparable to the conventional IMS, while the reduced IMS showed the highest grain yield. These findings confirm that the combination of organic/ inorganic fertilizer programs is found to be more promising and sustainable where an optimum and ecologically sound soil nutrient management system is restored. Further investigation is needed to determine the optimal ratio of organic/inorganic fertilizers depending on the site/soil before making any specific recommendation.

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

The authors extend their sincere appreciation to the laboratory staff of the Department of Agricultural Engineering & Soil Science, Faculty of Agriculture, Rajarata University of Sri Lanka, for their invaluable support and assistance in conducting laboratory analyses.

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