Impact of Crop Residue and Green Manure Management in Rice Crop on Soil Nutrient Dynamics in Tarai Belt of Shivalik Himalaya

Abstract

The study explores the effects of different soil management practices on various soil properties within the Tarai Belt of the Shivalik Himalaya regionto assess the effects of different nutrient management strategies on various soil properties in the context of rice cultivation. Ten treatments were employed, including varying combinations of crop residues, organic and inorganic fertilizers, and green manure. Soil properties examined included soil organic carbon, available nitrogen, available phosphorus, available potassium, pH, and electrical conductivity (EC) at two different soil depths (0-15 cm and 15-30 cm. Organic sources enhanced soil organic carbon, while inorganic sources notably improved the availability of nitrogen, phosphorus, and potassium.The results showed that treatments incorporating both organic and inorganic nutrient sources demonstrated improved soil health and nutrient availability, with treatment T_9 (150% recommended dose of fertilizer, RDF) showing the best results, particularly in terms of available nitrogen, phosphorus, and potassium. However, the sustainability of this approach over the long term may be a concern. Treatment T_{10}, which combined 100% RDF with farmyard manure, zinc, and boron supplementation, emerged as a promising alternative for sustainable soil management. Treatment T_3, with the incorporation of crop residues and the application of Pusa decomposer, also showed potential for maintaining soil health. These findings emphasize the importance of a balanced approach to nutrient management that combines readily available nutrients from inorganic sources with the long-term benefits of organic matter.

In summary, this study emphasizes the importance of integrated nutrient management and sustainable agricultural practices for enhancing soil fertility and overall soil health, thereby contributing to sustainable crop production. These findings hold significance for addressing soil nutrient imbalances and ensuring the well-being of farmers and environmental sustainability.

Keywords: Keywords: crop residues, green manure, nutrient management, soil properties.

Introduction:

The rice-wheat cropping system holds the distinction of being the most extensively cultivated cropping system globally, as documented by **Kaur *et al.* in 2021.**According to data from the Food and Agriculture Organization (FAO) in 2020, the global aggregate acreage dedicated to rice cultivation amounted to approximately 164.19 million hectares, yielding a total production of around 508.7 million metric tons.In India, rice is cultivated on an extensive land area of approximately 43.8 million hectares, resulting in a total production output of 177.6 million metric tons, and boasting a productivity rate of 4,057 kilograms per hectare.

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Approximately 85% of the rice-wheat cropping system is predominantly practiced within the Indo-Gangetic plain in South Asia, as noted by Banjara et al. in 2021. Over the past five to six decades, this agricultural pattern, accompanied by assured irrigation, has been the primary agricultural mode in India's Indo-Gangetic plains. Uttar Pradesh, Punjab, and Haryana, as highlighted by **Kaur *et al.*(2021)**, stand as the three most pivotal states in India for the cultivation of the Rice-Wheat Cropping System (RWCS), encompassing an expanse exceeding 10 million hectares in the Indo-Gangetic plains region.

Rice cultivation in Uttarakhand, on the other hand, encompasses an approximate area of 2,43,666 hectares, yielding a total production of 5,74,963 metric tons, with a productivity rate of 23.60 quintals per hectare.

Typically, it has been calculated that the rice-wheat cropping system, with rice yielding approximately 7 metric tons per hectare and wheat yielding around 4 metric tons per hectare, extracts more than 300 kilograms of nitrogen (N), 30 kilograms of phosphorus (P), and 300 kilograms of potassium (K) per hectare from the soil, as outlined by Singh and Singh in 2001. Moreover, **Gupta *et al.*(2002)** estimated that the crop, producing 10 metric tons per hectare, removes about 730 kilograms of combined NPK (nitrogen, phosphorus, and potassium) from the soil, and this nutrient load is often not replenished back into the soil. Over time, this practice can lead to a detrimental net negative nutrient balance and a deficiency in multiple essential nutrients for crops. To mitigate this nutrient imbalance, one viable solution is the recycling of nutrients through the incorporation of crop residues.

Crop residues, the remnants of plants left behind after harvest, were once regarded as waste to be disposed of. However, there is now widespread recognition of their intrinsic value as natural sources of essential plant nutrients rather than mere waste **(Mandal *et al.*, 2004).** These residues play a pivotal role in promoting the sustainability of agricultural ecosystems due to their rich nutrient content and must be managed effectively. Notably, crop residues retain approximately 25% of the nitrogen (N) and phosphorus (P) absorbed, 50% of sulfur (S), and a substantial 75% of potassium (K) taken up by cereal crops, rendering them excellent nutrient resources when properly recycled. Both rice and wheat are known for their high nutrient demands, and the practice of double cropping significantly depletes soil nutrient levels **(Singh and Singh, 2001)**.

Rice residues are invaluable natural resources, and their incorporation into the soil enhances its physical, chemical, and biological characteristics. Various methods, such as burning, incorporation, surface retention, mulching, as well as baling and straw removal, are available for crop residue management. It is crucial to note that burning results in substantial losses of nitrogen (up to 80%), phosphorus (25%), potassium (21%), sulfur (40-60%), and contributes to air pollution, emitting around 13 tonnes of CO_2 per hectare, while also depleting organic matter in the soil (SOM). A primary concern for sustainability is the loss of soil organic matter. Incorporating crop residues into the soil leads to an increase in soil organic matter and nutrient levels, including soil N, P, and K. However, it's important to be aware that nitrogen immobilization is a notable drawback of residue incorporation compared to burning. Starting with a dose of approximately 15-20 kgha^{-1} of nitrogen when incorporating straw can significantly enhance wheat and rice yields **(Chauhan *et al.*, 2012)**.

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The integration of crop residue incorporation, combined with the practice of green manuring, has been consistently observed to exert a substantial influence on crop yields and the enhancement of various physico-chemical and biological properties of soil. This phenomenon has been documented by multiple researchers in different geographical locations, both in India and abroad, as exemplified by **Mandal *et al.* (2004)**, **Samra *et al. (*2003)**. The potential of recycling crop residues as a significant source of essential plant nutrients for crop cultivation and as a means to ameliorate soil characteristics to support sustainable crop production is of immense magnitude. However, realizing this potential necessitates the adoption of improved strategies for managing both soil and crop residues, as these factors play a pivotal role in the decomposition of residues and the subsequent release of nutrients, as elucidated by **Kumar and Goh (2000).**

Residue management within the rice and wheat cropping system holds significant importance, contributing not only to enhanced productivity but also addressing concerns pertaining to air pollution mitigation, soil fertility preservation, and the overall well-being of farmers. Recognizing the pivotal role of residue management during rice cultivation within the rice-wheat cropping sequence, the current study has been initiated. Its primary aim is to assess the effects of crop residue management and the application of green manure during the rice crop phase in the Rice-wheat cropping sequence on soil nutrient dynamics in the Tarai Belt of the Shivalik Himalaya region, specifically within Mollisol.

Materials and Methods:

Study Area:

The research, titled "**Impact of Crop Residue and Green Manure Management in Rice Crop on Soil Nutrient Dynamics in Tarai Belt of Shivalik Himalaya"**was conducted at the Norman E. Borlaug Crop Research Centre in Pantnagar. The experiment was specifically carried out in Block B1 of the Norman E. Borlaug Crop Research Centre, which is part of the Govind Ballabh Pant University of Agriculture and Technology, located in the Udham Singh Nagar District of Uttarakhand. Pantnagar is situated at the foothills of the Siwalik mountain range in the Himalayas, also known as the Tarai region. It has geographical coordinates of approximately 29 degrees North latitude and 79 degrees 29 minutes East longitude, with an elevation of 243.84 meters above mean sea level. The climate in Pantnagar is categorized as sub-humid and sub-tropical. It is characterized by hot and dry summers and cold winters. The dry season extends from early October to mid-June, while the wet season spans from mid-June to early October. The maximum temperatures typically range between 40 to 45 degrees Celsius in the months of May and June, and the minimum temperatures range between 2 to 5 degrees Celsius in December and January. The highest average relative humidity is observed in July, while the lowest occurs in April and May. The region experiences an annual average rainfall of 1400 millimeters, with the majority of precipitation being contributed by the southwest monsoon, accounting for 85-90% of the total annual rainfall, primarily occurring between June and September. The Tarai region is known for its fertile soils, characterized by clay-rich marshes and diverse vegetation. Common tree species in the area include Semal (Bombax ceiba), sal (Shorearobusta), and khair (Acacia catechu). The soils at the experimental site have an alluvial origin and are classified as Mollisol, as per the classification by **Deshpande *et al.*(1971)**. These soils vary in drainage characteristics from well-drained to poorly-drained and are typically dark in color. They have developed over calcareous alluvial deposits washed down from the Shivalik mountain range.The experiment involved ten distinct fertilizer treatments, namely: T$_1$ (100% recommended dose of NPK fertilizers), T$_2$ (50% crop residue + 50% recommended NPK dose), T$_3$ (50% crop residue + 50% recommended NPK dose with the addition of Pusa decomposer), T$_4$ (50% crop residue + 50% Green Manure (GM), T$_5$ (50% crop residue + 50% GM with Pusa decomposer), T$_6$ (Crop residue at 2.5 tons per hectare + Pusa decomposer), T$_7$ (Crop residue at 2.5 tons per hectare without Pusa decomposer), T$_8$ (Absolute control group with no fertilizer application), T$_9$ (150% recommended NPK dose), and T$_{10}$ (100% recommended NPK dose with the addition of Farm Yard Manure at a rate of 5 tons per hectare, along with Zinc and Boron supplementation).The rice variety used in this study was Pant Dhan-18, and the rice crop was transplanted on June 30, 2020 for first year and June 30, 2021 for two consecutive year in prepared plots with individual plot size of 30 square meters.

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Soil site characterization

The soil under considerationoriginated from alluvial deposits and exhibited a silty clay texture, as determined by the **Bouyoucos hydrometer method (1936).** The initial pH of the soil was ascertained to be 7.51 at the surface and 7.66 in the subsurface, using a 1:2 soil-to-water ratio, according to **Jackson (1967).** The electrical conductivity (EC) of the soil was measured as 0.28 dS m^{-1} at the surface and 0.30 dS m^{-1} in the subsurface, following the **Bower and Wilcox method (1965).** Organic carbon content, determined through the **Walkley and Black method (1934),** was found to be 0.75% at the surface and 0.71% in the subsurface.The available nitrogen (N) content in the soil was quantified as 196.25 kg ha^{-1} at the surface and 188.35 kg ha^{-1} in the subsurface, using the Alkaline KMnO$_4$ method developed by **Subbiah and Asija (1956)**. The available phosphorus (P) content, extractable with NaHCO$_3$, was measured at 10.21 kg ha^{-1} at the surface and 9.58 kg ha-1 in the subsurface, following Olsen's method as described by **Olsen *et al.* (1954).**Lastly, the available potassium (K) content, extractable with NH$_4$OAc, was determined to be 160.35 kg ha^{-1} at the surface and 142.54 kg ha^{-1} in the subsurface using the Neutral 1 normal ammonium acetate method by **Hanway and Heidel (1952).**

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Soil sampling

Composite soil sampling for individual replication was conducted by amalgamating soil samples randomly obtained using a soil auger immediately following the harvest of each crop during the 2020-21and 2021-22 season. Soil samples were systematically collected from incremental depths of 0-15 cm and 15-30 cm. These samples were meticulously homogenized, subjected to air drying, passed through 2.0 mm sieves, and subsequently preserved within hermetically sealed plastic bags to facilitate the subsequent assessment of available soil nutrients.

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Statistical analysis

The evaluation of the effects of crop residue management and the application of green manure during the rice crop at various soil depths was carried out through an analysis of variance (ANOVA) technique, specifically suited for the randomized block design (RBD) as outlined by **Cochran and Cox (1959).**Statistical analysis of the collected data was conducted using Microsoft Excel, a product of Microsoft Corporation in the United States, as well as SPSS version 16 (SPSS Inc., Chicago, USA). Treatment mean comparisons were executed utilizing the least significant difference at a significance level of 5%.

Results and Discussion

Organic carbon

In the topsoil layer (0-15 cm), the concentration of soil organic carbon exhibited a range from 0.65% to 1.09%. The highest observed soil organic carbon content was recorded in treatment T_5 (1.09%). This notable increase in soil organic carbon within T_5 can be attributed to the utilization of a green manure crop, specifically dhaincha, characterized by a narrow carbon-to-nitrogen (C: N) ratio. This resulted in improved nutrient availability compared to other residue treatments. Additionally, the application of Pusa decomposer in T_5 accelerated the decomposition rate of crop residues and green manure, further contributing to enhanced organic carbon levels in the soil. Conversely, the lowest organic carbon content was observed in treatment T_8 (0.65%). In the second trial, a consistent pattern was evident across both soil layers. Within the 0-15 cm depth range, the soil organic carbon content exhibited a range of 0.63% to 1.16%, while in the 15-30 cm depth range, it ranged from 0.48% to 1.10%.This outcome is attributable to the absence of both organic and inorganic sources of fertilizer in T_8. The lack of these fertilizers hindered the enrichment of soil organic carbon in this treatment. Moreover, it is worth noting that organic carbon content decreased in the subsurface layer (15-30 cm) in comparison to the surface layer. This phenomenon can be attributed to the addition of organic matter and increased microbial activity primarily concentrated in the surface layer. In the 15-30 cm layer, the organic carbon content ranged from 0.51% to 1.04%, with the highest value observed in treatment T_5 (1.04%) and the lowest in treatment T_8 (0.51%). The significant increase in organic carbon in T_5 can be linked to the practice of incorporating crop residues into the soil. This incorporation facilitated the decomposition of these materials, ultimately enriching the soil with organic carbon. These findings are consistent with prior studies conducted by **Regar *et al.* (2005)** and **Singh *et al.* (2009),** highlighting the beneficial impact of crop residue incorporation on soil organic carbon levels and overall soil health.

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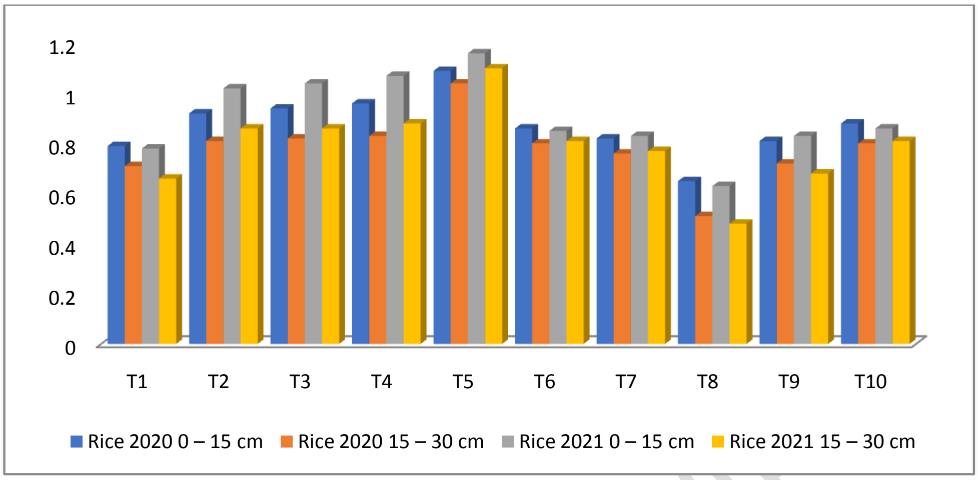

Fig. 1. Organic carbon (%)

Available Nitrogen:

In the topsoil layer (0-15 cm), the concentration of available nitrogen in the soil ranged from 189.90 kg ha^{-1} to 291.74 kg ha^{-1}. The highest level of available nitrogen was recorded in treatment T9 (291.74 kg ha^{-1}), which can be attributed to the application of higher doses of fertilizer, providing a greater abundance of inorganic nitrogen forms. Conversely, the lowest available nitrogen content was observed in the control treatment, T8 (189.90 kg ha^{-1}).In the subsoil layer (15-30 cm), the available nitrogen content ranged from 167.25 kg ha^{-1} to 261.33 kg ha^{-1}. Treatment T9 once again exhibited the highest available nitrogen content (261.33 kg ha^{-1}), while the lowest was found in T_8 (167.25 kg ha^{-1}).The data implies that treatments incorporating crop residues (T_2, T_3, T_4, T_5, T_6, and T_7) yielded lower available nitrogen levels compared to treatments utilizing inorganic sources (T_1 and T_9). A congruent pattern was noted during the second trial (2021-22) across both soil depths.This discrepancy can be attributed to the fact that inorganic nitrogen sources provide nitrogen in readily available forms that can be rapidly assimilated by plants. In contrast, organic nitrogen contained in crop residues undergoes a slower process of mineralization. Additionally, crop residues often possess a high carbon-to-nitrogen (C:N) ratio, signifying a greater proportion of carbon relative to nitrogen. This elevated C:N ratio may temporarily immobilize nitrogen as soil microorganisms consume the carbon, rendering nitrogen less readily available to plants initially.In comparison to the control treatment (T_8), all the other treatments exhibited superior levels of available nitrogen. These findings align with the research of **Huang *et al.* (2016), Ladha *et al.* (2011), and Singh *et al.* (2015),**which underscore the impact of organic and inorganic nitrogen sources on soil nitrogen availability and support the advantages of supplementing soil with nitrogen from inorganic sources in agricultural practices.

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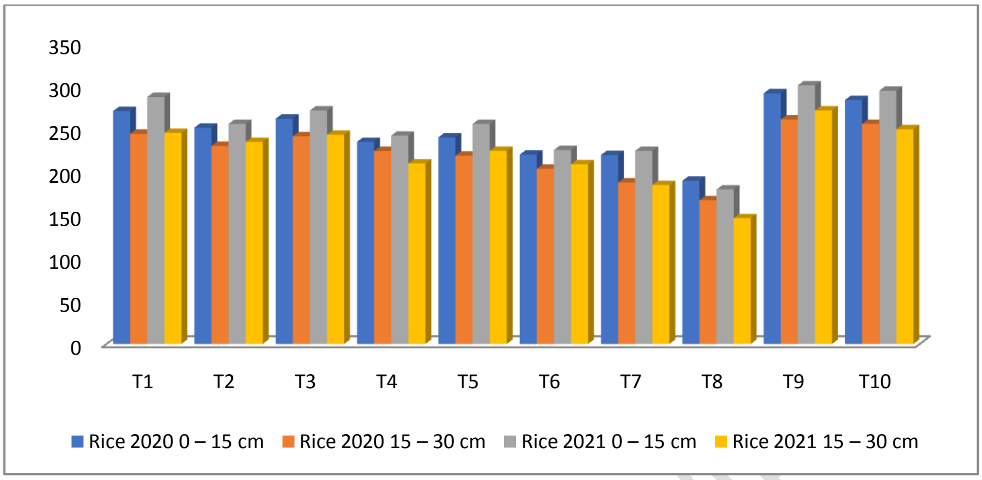

Fig. 2.Available Nitrogen (Kg ha-1)

Available Phosphorus:

In the 0-15 cm soil layer, the available phosphorus (P) content exhibited a range between 9.66 kg ha^{-1} and 23.58 kg ha^{-1}. The highest concentration of available P, reaching 23.58 kg ha^{-1}, was observed in treatment T_9. This notable increase is likely attributed to the enhanced solubility of phosphorus, primarily facilitated by the application of inorganic fertilizers. Inorganic fertilizers serve as a readily accessible source of nutrients, as evidenced by the substantial rise in soil P availability. Conversely, the lowest available P content was recorded in treatment T8, registering only 9.66 kg ha^{-1}. This variation underscores the significance of sustainable agricultural practices that emphasize nutrient cycling and overall soil health. By optimizing the delicate balance between nitrogen application and organic matter decomposition, farmers can effectively enhance nutrient dynamics. This, in turn, contributes to more productive and environmentally sustainable agricultural practices. In the 15-30 cm soil layer, the available P content ranged from 8.84 kg ha^{-1} to 20.63 kg ha^{-1}. Treatment T_9 once again displayed the highest soil available phosphorus concentration at 20.63 kg ha^{-1}, while the lowest value of 8.84 kg ha-1 was associated with treatment T_8. In the second trial, the available phosphorus (P) content spanned a range of 8.35 kg ha^{-1} to 26.69 kg ha^{-1} within the 0-15 cm soil depth, and within the 15-30 cm depth, it exhibited a variation from 7.70 kg ha^{-1} to 21.78 kg ha^{-1}. A congruous trend was observed in the second trial. This observation underscores the importance of implementing holistic agricultural methods that promote both nutrient cycling and the overall health of the soil. The observed increase in phosphorus availability within the soil plots when both fertilizers and organic sources are applied concurrently, as opposed to their individual application, underscores the synergistic effects of combining these nutrient sources. This combined application synergistically enhances phosphorus levels in the soil by facilitating the release of organic acids during the decomposition of organic materials. These organic acids play a pivotal role in solubilizing phosphorus, thereby aiding in the release of native phosphorus compounds within the soil matrix. These findings align with previous research by **Kumar*et al.* *(*2017), Ghosh *et al.* (2012), and Pooniya*et al.* (2016),**providing robust scientific support for the observed effects of nutrient management strategies on soil phosphorus dynamics.

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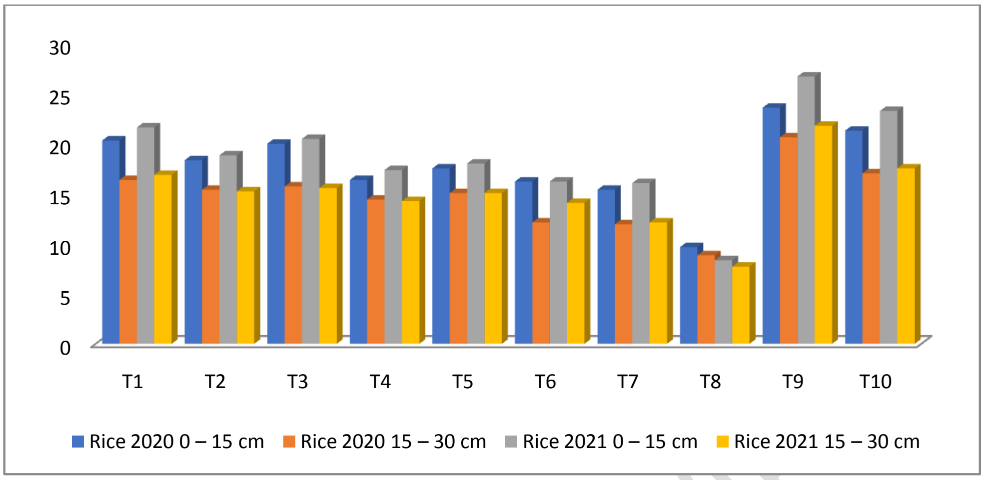

Fig. 3.Available Phosphorus (Kg ha-1)

Available Potassium:

Soil available K was higher in surface soil (0-15 cm) than the sub surface soil layer (15-30 cm). In the first year, at 0-15 cm the available potassium varied from 153.17 kg ha^{-1} to 235.04 kg ha^{-1}. The highest soil available potassium was reported under the treatment T_9 (235.04 kg ha^{-1}), while the lowest was under T8 (153.17 kg ha^{-1}). The data indicate that all the treatments having crop residue (T_2, T_3, T_4, T_5, T_6 and T_7) were inferior to T_1 and T_9. In comparison to the control T_8 all the treatments are superior. In comparison to the control (T_8), all the treatments were superior. From the data, T_9 and T10 were significantly superior to T_3, while T_4 and T_5 were at par with T_3 treatment. At 15-30 cm, available potassium varied from 148.84 kg ha^{-1} to 203.53 kg ha^{-1}. The highest soil available potassium was reported under the treatment T9 (203.53 kg ha^{-1}) while the lowest in T_8 (148.84 kg ha^{-1}). Similar trend was observed in the second year. At 0-15 cm available soil K ranged from 142.29 kg ha^{-1} to 243.28 kg ha-1 and at 15-30 cm, soil available soil K ranged from 148.29 kg ha^{-1} to 243.28 kg ha^{-1}. A comparable trend was noted during the second year. In the 0-15 cm soil depth, available potassium (K) ranged from 142.29 kg ha^{-1} to 243.28 kg ha^{-1}, while in the 15-30 cm depth, available potassium spanned a range from 148.29 kg ha^{-1} to 243.28 kg ha^{-1}. Finding shows significant differences in available potassium levels in both surface (0-15 cm) and sub-surface (15-30 cm) soil layers due to the incorporation of crop residue with organic and inorganic nutrient sources. These findings highlight the substantial impact of these treatments on soil potassium availability, a critical factor for plant growth and crop productivity. Among all the treatments where Pusa decomposer was applied the maximum available nitrogen was observed in T_3. This might be due to the reason that application of crop residue secreted organic acid during process of decomposition which led to mineralization of the fixed potassium and increased the availability of potassium **(Yaduvanshi and Sharma, 2007).**

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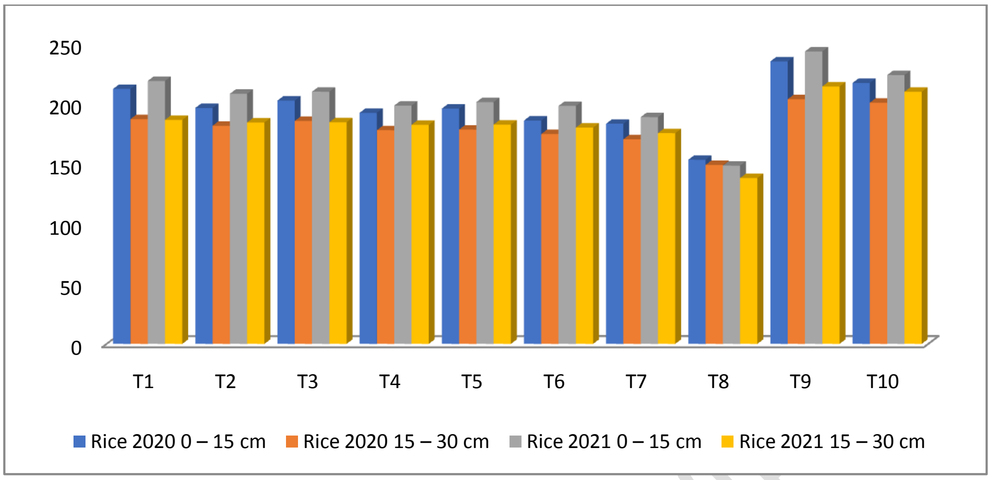

Fig. 4.Available Potassium (Kg ha-1)

pH:

Following the rice harvest and a two-year experimental period, the initial trial revealed notable variations in soil pH levels within the 0-15 cm depth range. The pH values ranged from 7.38 to 7.58. The lowest recorded pH occurred in T_5 (7.38), attributed to the incorporation of organic sources such as crop residues and green manure. These organic materials undergo decomposition, a process notably accelerated by the application of Pusa decomposer. This decomposition yields organic acids that have the capacity to lower the soil's pH. Organic acids, including humic and fulvic acids commonly found in organic materials, are contributors to soil acidification. Conversely, the highest pH value, 7.58, was observed in T_8, which involved the exclusion of organic sources. The treatments incorporating organic sources (T_2, T_3, T_4, T_5, T_6, and T_7) demonstrated superior soil pH levels compared to treatments reliant solely on inorganic sources (T_1 and T_9). This superiority can be attributed to the presence of organic acids within the organic sources. During the decomposition of these materials, they release organic acids into the soil, consequently generating hydrogen ions (H^+), leading to increased soil acidity and a corresponding reduction in soil pH. In the 15-30 cm depth range, soil pH ranged from 7.66 to 7.71, with T_5 exhibiting the lowest pH (7.66) and T_8 displaying the highest pH (7.71). A parallel trend in soil pH variations was observed in the second trial for both soil depths.

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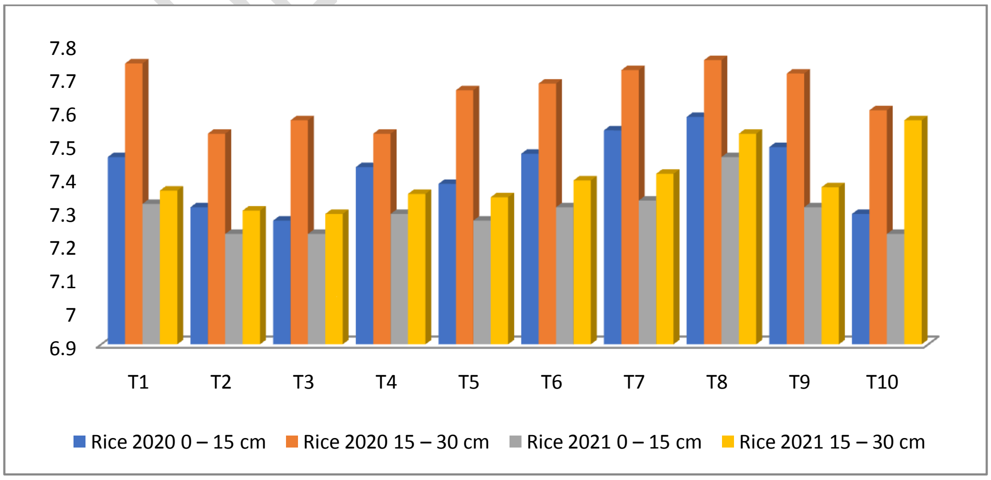

Fig. 5.pH

EC:

The data reveals that the inclusion of crop residues in conjunction with both organic and inorganic nutrient sources yielded no statistically significant disparities in soil electrical conductivity (EC) across treatments, observed at both the surface (0-15 cm) and sub-surface (15-30 cm) soil layers. Over the course of a two-year experimental phase following the rice harvest, in the initial trial, EC values at the 0-15 cm depth ranged from 0.15 dS m^{-1} to 0.45 dSm^{-1}, while at the 15-30 cm depth, EC varied from 0.17 dSm^{-1}to 0.42 dSm^{-1}.At the 0-15 cm depth, the highest EC value of 0.45 dSm^{-1} was recorded in T5, while the lowest EC value of 0.15 dSm^{-1}was observed in T8. Similarly, at the 15-30 cm depth, the maximum EC was noted in T_5 (0.42 dSm^{-1}), and the minimum EC was found in T8 (0.17 dSm^{-1}). In the second trial, EC values at the 0-15 cm depth ranged from 0.18 dSm^{-1}to 0.45 dSm^{-1}, and at the 15-30 cm depth, EC varied from 0.19 dSm^{-1}to 0.40 dSm^{-1}, exhibiting a similar pattern to the first trial. **Gogoi *et al.* (2015)and Harikesh *et al.* (2017)** have also documented comparable trends, whereby the application of both organic and inorganic sources resulted in an elevation of electrical conductivity (EC). This increase can be attributed to the heightened availability of soluble forms of essential elements such as potassium (K), calcium (Ca), sodium (Na), and magnesium (Mg). These available forms can combine with organic materials, leading to the formation of salts and consequent augmentation of soil EC.

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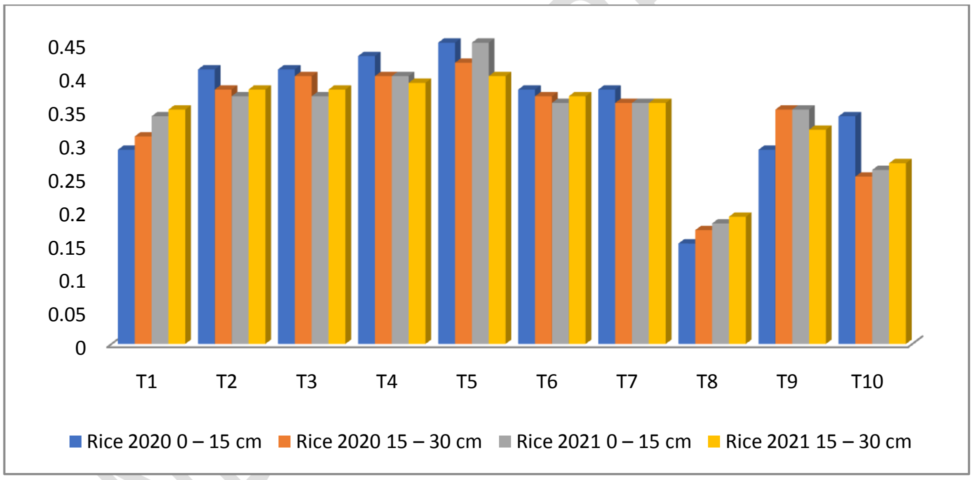

Fig. 6.EC (dSm-1)

Conclusion:

The integration of rice-wheat residue had a discernible impact on various soil properties, including pH, electrical conductivity (EC), and the levels of available nitrogen, phosphorous, potassium, and soil organic carbon, both within the surface (0-15 cm) and sub-surface (15-30 cm) soil layers. Notably, treatment T_9, characterized by 150 percent recommended dose of fertilizer (RDF) comprising solely inorganic nutrient sources, exhibited superior results compared to the other treatments. However, it's worth noting that this approach may not prove economically sustainable in the long run. Consequently, treatment T_{10}, involving 100 percent RDF along with farmyard manure (FYM) at a rate of 5 tonnes per hectare, zinc (Zn) at 25 kg per hectare, and boron (B) at 5 kg per hectare, emerged as a promising alternative. Similarly, treatment T_3, combining 50 percent residue, 50 percent RDF, and the application of Pusa decomposer, also demonstrated potential for maintaining soil health. These treatments present a balance between immediate and readily available nutrients from inorganic fertilizer sources and the enduring nutrient provision and soil quality enhancement afforded by organic sources. Consequently, they appear to be sound choices for sustainable soil management practices.

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