Exploring Cropping

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Exploring the Impact of Cropping Intensity on Soil Nitrogen and Phosphorus for Sustainable Agricultural Management

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Abstract

Sustainable agriculture plays a key role in maintaining environmental health and also guarantees long-term food security and the preservation of natural resources. We therefore, examined the response of intensified cropping systems over four years across five diverse cropland ecosystems viz. Basmati rice-Wheat-Cowpea, Basmati Rice-Potato-Wheat-Mixed Fodder (Maize+ Cowpea + Charni), Basmati Rice-KnolKhol-Potato-Greengram, Basmati Rice-Radish-Green onion-French bean vegetable-Okra, and Rice-Fenugreek-KnolKhol-Green onion-Dry Onion-Black gram to assess the changes in substrate availability and fertilizer application on nitrogen and phosphorus pools. Soil samples were collected from three depths (0-5 cm, 5-15 cm, and 15-30 cm) during the *kharif* season. Significant results were observed in the mean values of mineralizable nitrogen, total nitrogen, ammonical nitrogen, nitrate nitrogen, and soil microbial biomass nitrogen at the 0-5 cm depth, with the highest values recorded under Rice-Fenugreek-KnolKhol-Green onion-Dry Onion-Black gram. At the 0-5 cm soil depth, available phosphorus and labile organic phosphorus exhibited significant differences, with the highest values observed in Basmati Rice-Potato-Wheat-Mixed Fodder.. Basmati Rice-Radish-Green onion-French bean vegetable-Okra resulted in ---- % higher non-labile organic phosphorus, compared with ------------- at the 0-5 cm soil depth. On a regional

scale, the results suggest that more diversified cropping systems hold promise as sustainable agricultural practices that support nitrogen and phosphorus retention, contributing to overall soil sustainability.

Keywords: Nitrogen, cropping intensity, ammonical nitrogen, phosphorus fractions, randomized, labile phosphorus

1. Introduction

The intensification of agriculture and increased cropping intensity are critical for boosting production. Cropping intensity, defined as the number of crops grown annually in a given area (Biradar and Xiao, 2011). It affects nutrient demand, cycling, and distribution in the soil, influencing nutrient needs and dynamics throughout the crop cycle. Intensification alters nutrient availability, including nitrogen and phosphorus that are essential for plant growth (Grant et al., 2002). Nitrogen is a fundamental component of all proteins and protoplasm and is crucial for soil fertility. Organic nitrogen constitutes 94.2% of total nitrogen, with the remainder as mineral nitrogen (Nayak et al., 2013). Plants primarily uptake NH_4^+ and NO_3^- ions, favouring the latter when the former is abundant. Moreover, the mineralization of the organic nitrogen fraction plays a substantial role in supplying nitrogen to plants. On the other hand, phosphorus in soil primarily exists as the orthophosphate anion, which is less mobile macronutrient. However, it is essential for genetic information and energy transfer in cells. Unfertilized soils have very low phosphorus levels, less than 0.1 parts per million (ppm) phosphorus. Soil phosphorus fractions vary in mobility, bioavailability, and can change under specific conditions (Sharpley and Moyer, 2000). In the current era, our emphasis is on ensuring global food security despite rapidly diminishing cultivated land. The goal is to intensify cropping while maintaining soil health and sustainability. However, excessive intensification may harm soil fertility. Incorporating legumes and organic amendments can enhance nutrient availability through plant mediated C input, intensity of cultivation and maintain long-term productivity under a diversified cropping system. Therefore, in present era farmers can move towards intensive cropping but only by practicing diversification of cropping systems. we hypothesized that increasing legume based cropping system diversity would help enhance soil nutrients, biological nitrogen fixation and their impact on long-term agricultural output requirements. To test this hypothesis, we aimed to identify the most productive, resource-efficient cropping systems with high levels of soil nitrogen pools and organic phosphorus fractions.

2. Materials and Methods:

2.1 Geographical Location:

The experiment was conducted in the sub-tropical zone of Jammu and Kashmir at 32°40' N and 73°64' E, 293 m above sea level. The climate is hot and dry in summer, hot and humid in monsoon, and cold in winter. Average annual rainfall is 1115 mm, with 70-75 % falling in June-September and 25-30 % in winter due to Western disturbances (Jan-Mar). The soil texture is sandy loam with 71.70% sand, 16.80% silt, 11.50% clay, 7.61 pH, 5.54 g kg^{-1} OC, 290.62 kg ha^{-1} N, 13.45 kg ha^{-1} P, and 133.80 kg ha^{-1} K. Soil texture was determined by Bouyoucos-hydrometer method.

2.2 Treatment Details:

The experiment involved five rice-based sequences of varying cropping intensities (300-600%) with four replications each. The 20 plots, each 5.40m by 3.60m, were arranged in a randomised block design, separated by a 1.0m strip.

2.3 Crops and their recommended doses (kg/ha) in five different treatments:

T_1: Control: Rice (Basmati 370)-Wheat (HD-3086)-Cowpea (Lobia Super-60) with N:P:K doses of Rice (30:20:10), Wheat (100:50:25) and Cowpea (17.5:40:0):- Cropping intensity 300%.

T_2: Rice (Basmati- 564)-Potato (KufriPukhraj)-Wheat (Raj-3756)-Mixed Fodder (Maize+ Cowpea + Charni) with N:P:K doses of Rice (37.50:25:12.50), Potato (120:60:120 and 50 t ha^{-1} FYM), Wheat (80:40:25) and Mixed fodder (60:40:20):- Cropping intensity 400%.

T_3: Rice (SJR- 129) – KnolKhol (G-40) – Potato (KufriSindhuri) – Green gram with N:P:K doses of rice (60:25:15), Knolkhol (100:50:50 and 30 t ha^{-1} FYM), Potato (120:60:120 and 50 t ha^{-1}) and Greengram (16:40:0):- Cropping intensity 400%.

T_4: Rice (Pusa- 1121) – Radish (CR-45) – Green onion (Nasik red) – French bean (Anupama) – Okra (Seli special) with N:P:K doses of Rice (50:25:15), Radish (60:30:50 and 30 t ha^{-1} FYM), Green onion (100:50:50 and 20 t ha^{-1} FYM), French bean (50:100:50 and 50 t ha^{-1} FYM) and Okra (100:60:60 and 2.5 t ha^{-1} FYM):- Cropping intensity 500% in relay mode from French bean onwards.

T_5: Rice (IET- 1410) - Fenugreek (JF-07) - KnolKhol (G-40) - Green onion (Nasik Red) -Dry Onion (Selection-1)-Blackgram (Pant U-19) with N:P:K doses of Rice (50:30:20), Fenugreek (60:20:20 and 15 t ha^{-1} FYM), Knolkhol (100:50:50 and and 30 t ha^{-1} FYM), Green onion (50:25:25 and 10 t ha^{-1} FYM), Dry onion (50:25:25 and 50 t ha^{-1} FYM) and Blackgram (16:40:0):- 600% in relay mode from knolkhol onwards.

2.4 Initial properties of the experimental site:

Prior to initiating the study, a comprehensive assessment of the site's initial properties was conducted as described in Table 1.

2.5 Collection and analysis of soil samples:

Soil samples from varying crop intensities were collected at three depths (0-5, 5-15, 15-30 cm) from central rows of each plot during kharif to study nitrogen pools and organic phosphorus fractions. After removing roots, residues, and stones, samples were air-dried, sieved to 2 mm, and analyzed.

2.5. 1. Mineralizable nitrogen

Mineralizable nitrogen was detected/analysed using the alkaline permanganate method (Subbiah and Asija, 1956): The conversion of organic nitrogen into ammonium ions, which can subsequently be quantified, is the basis of the Kjeldahl method. This involves digesting the sample in concentrated sulfuric acid, which releases nitrogen as ammonium sulphate and breaks down organic materials. Sodium hydroxide is then added to make the mixture alkaline, causing the ammonium ions to turn into ammonia gas. The trapped ammonia is added to a flask with boric acid, forming ammonium borate.

2.5.2 Total nitrogen

Total nitrogen was estimated using Kjeldhal's method (Page *et al*., 1982): The sample is digested with Con. H_2SO_4 while being exposed to $CuSO_4$ to digest the organic components. Conc. H_2SO_4 and $CuSO_4$ digest organic components, while K_2SO_4 and H_2O catalyse the digestion. Ammonia content is determined by distilling with NaOH and absorbing the NH_3 with HCl. Methyl Red is used to titrate the excess HCl against NaOH. Acid-base titration reduces acid multi-equivalence, which can be used to calculate nitrogen content.

2.5.3 Ammonical nitrogen

Ammonical nitrogen was analyzed in the presence of MgO, soil was shaken with 2 N KCl to obtain extract for ammonia estimation by Kjeldahl steam distillation with an alkaline reagent.

2.5.4 Nitrate nitrogen

The estimation of nitrate was done by distilling the extract following ammonium extraction using a reducing agent (Deverda's alloy).

2.5.5 Soil microbial biomass nitrogen

Soil microbial biomass nitrogen was analysed using the fumigation approach given by Brookes *et al.*, (1985 a): In a 100 ml beaker, two 10 g soil samples were weighed. One was treated with chloroform and vacuumed until it boiled rapidly, then kept in a sealed desiccator for 24 hours. The other sample was kept as a non-fumigated control. Both were later extracted with K_2SO_4.

2.5.6 Available phosphorus: Available phosphorus was analyzed using 0.5 N Sodium bicarbonate (pH 8.5) (Olsen *et al.*, 1954): The approach is based on the utilization of HCO^{3-}, CO_3^{3-} and OH^- in a pH 8.5, 0.5M $NaHCO_3$ solution to lower the solution concentrations of soluble Ca^{2+} by precipitation as $CaCO_3$ and soluble Al^{3+} and Fe^{3+} by the production of Al and Fe oxyhydroxides, hence enhancing P solubility.

2.5.7. Organic phosphorus fractions:

In general, this fractionation system is based on Bowman and Cole's (1978) procedures, which have been modified by Sharpley and Smith (1985). Organic P is fractionated into a labile pool, a moderately labile pool, and a non-labile pool in both calcareous and non-calcareous soils.

- **Labile Pool:** The labile pool was extracted using 0.5M $NaHCO_3$ at pH 8.5.
- **Moderately Labile Pool**: 1.0 M HCl was used to extract the moderately labile pool, which is then followed by 0.5 M NaOH.
- **Non-Labile Pool:** To separate the non-labile fraction (humic acid fraction) from the moderately labile fraction (fulvic acid fraction), the NaOH extract was acidified with concentrated HCl. Finally, the extremely resistant, non-labile fraction was obtained by ashing the NaOH extraction residue at 550°C for 1 hour, then dissolving it in 1.0 M H_2SO_4. The phospho-molybdate method of was used to determine P content in extracts in all cases. After an aliquot has been digested with 2.5 M H_2SO_4 and potassium persulfate ($K_2S_2O_8$), total P in the extracts was determined using Bowman's (1978) technique, as modified by Thien and Myers (1992).

2.6 Statistical analysis: The data was statistically analyzed using ANOVA as per the randomized block design. To assess the effects of different treatments, statistical significance was determined using the F-test at 0.05 level of probability, and critical differences were calculated for those parameters that became significant ($P<0.05$).

3. Results:

3.1 Mineralizable nitrogen:

The mean value of available nitrogen ranged from 249.26 kg ha^{-1} to 287.46 kg ha^{-1} in 0-5 cm depth. The highest values were recorded in T_5 while the lowest values were recorded in T_1 whereas, T_2, T_3 and T_4 were statistically at par with T_5.The available soil nitrogen values decreased with increasing depths (Fig 1a). The mean value of available soil nitrogen was highest (287.46 kg ha^{-1}) in 0-5 cm depth and lowest was recorded in 15-30 (195.97 kg ha^{-1}) cm depth. Under high intensity cropping, the available nitrogen content exhibited a significant increase in 0-5 cm soil depth. However, no significant difference was observed in other soil depths.

3.2 Total nitrogen:

The data shows that the mean value of total nitrogen content ranged from 872.78 mg kg^{-1} to 884.58 mg kg^{-1} in 0-5 cm soil depth.The highest values were recorded in T_5 while the lowest values were recorded in T_1. Also, T_4 was statistically at par with T_5 at 0-5 cm depth (Fig 1b). The total soil nitrogen values decreased with increasing depths. The mean value of total soil nitrogen was highest (884.58 mg kg^{-1}) in 0-5 cm depth and lowest values (821.75 mg kg^{-1}) were recorded in 15-30 cm depth. Under high intensity cropping, the total nitrogen content exhibited a significant increase in 0-5 cm soil depth. However, no significant difference was observed in 5-15 cm and 15-30 cm soil depth.

3.3 Nitrate nitrogen:

The data presented in Fig 2a. showed that the mean value of nitrate nitrogen ranged between 22.96 mg kg^{-1} to 29.58 mg kg^{-1}. The highest values were recorded in T_5 while the lowest values were recorded in T_1 whereas, T_2, T_3 and T_4 remained statistically at par with T_5 at 0-5 cm soil depth (Fig 2a). The similar trend was observed in 5-15 cm and 15-30 cm depths. The nitrate nitrogen values decreased with increasing depths. The mean value of nitrate nitrogen was highest (29.58 mg kg^{-1}) in 0-5 cm depth and lowest values (19.49 mg kg^{-1}) were recorded in 15-30 cm depth. Nitrate nitrogen exhibited a significant increase due to high intensity cropping in 0-5 cm depth.

3.4 Ammonical nitrogen:

Ammonical nitrogen content ranged from 41.82 to 45.58 mg kg^{-1}, with the highest values in T_5 and the lowest in T_1. Ammonical nitrogen decreased with depth, with the highest mean value in 0-5 cm depth where T_4 was statistically at par with T_5 and lowest values were recorded in 15-30 cm depth (Fig 2b). Ammonical nitrogen increased significantly due to high intensity cropping in 0-5 cm depth, but no significant difference was seen in 5-15 cm and 15-30 cm soil depths.

3.5 Soil microbial biomass nitrogen (SMBN)

A common biological indicator of changes in soil management is SMBN, which is extremely sensitive to changes in soil management. From the data given in fig. 3a, it was concluded that the mean value of SMBN ranged between 19.94 µg g^{-1} to 23.78 µg g^{-1} in 0-5 cm soil depth. The highest values were recorded in T_5 while the lowest values were recorded in T_1. T_2 and T_4 were statistically at par with T_5. The similar trend was observed in 5-15 cm and 15-30 cm depth. The results showed that SMBN decreased with increasing depths. The mean value of SMBN was highest (23.78 µg g^{-1}) in 0-5 cm depth and lowest values (16.38 µg g^{-1}) were recorded in 15-30 cm depth. SMBN exhibited a significant increase due to high intensity cropping at 0-5 cm and 5-15 cm soil depth. However, no significant difference was observed in 15-30 cm soil depth.

3.6 Available phosphorus:

The mean value of available phosphorus ranged between 13.74 kg ha^{-1} to 15.87 kg ha^{-1} in 0-5 cm soil depth. The highest values were recorded in T_2 (17.31 kg ha^{-1}) while the lowest values (11.50 kg ha^{-1}) were recorded in T_1. The results further showed that at 0-5 cm soil depth T_3, T_4, T_5 were statistically at par with T_2 (Fig. 3b). The available soil phosphorus values decreased with increasing depths. The mean value of available soil phosphorus was highest (17.31 kg ha^{-1}) in 0-5 cm depth and lowest values were recorded in 15-30 (11.50 kg ha^{-1}) cm depth. The same trend was observed in 5-15 cm and 15-30 cm soil depth i.e T_2 has highest values of available phosphorus while T_1 exhibited the lowest values. Under high intensity cropping, the available phosphorus content exhibited a significant increase in 0-5 cm soil depth.

3.7 Labile organic phosphorus (LOP):

It was revealed that under 0-5 cm depth the amount of labile organic phosphorus ranged between 50.46 mg kg^{-1} to 54.84 mg kg^{-1}(fig.4a). The highest values were recorded in T_2 while the lowest values were recorded in T_1. T_3, T_4 and T_5 were statistically at par with T_2 at 0-5 cm soil depth. The values of labile organic phosphorus showed a decrease with increasing depths. The mean value of labile organic phosphorus was highest in 0-5 cm depth and lowest values were recorded in 15-30 cm depth. At 5-15 cm and 15-30 cm soil depth, similar trend was observed i.e T_2 had highest values of available phosphorus while T_1 exhibited the lowest values. Labile organic phosphorus (LOP) exhibited a significant increase due to high intensity cropping in 0-5 cm depth. However, no significant difference was observed in 5-15 cm and 15-30 cm soil depth.

3.8 Moderately Labile Organic Phosphorus (MLOP):

The mean values of moderately labile organic phosphorus in soil ranged between 152.11 mg kg^{-1} to 157.65 mg kg^{-1} in 0-5 cm soil depth with T_2 displaying the highest value followed by T_3 (156.86 mg kg^{-1})and T_1 (152.11 mg kg^{-1})displayed the lowest value as given in fig 4b. The treatments, T_3, T_4 and T_5 are statistically at par with T_2. The similar trend was observed in 5-15 cm and 15- 30 cm soil depths. The highest values were obtained under 0-5 cm soil depth and the lowest values were obtained under 15-30 cm soil depth i.e decreasing trend with increasing depth. The effect of high cropping intensity on moderately labile organic phosphorus was found to be significant at 0-5 cm and 5-15 cm depth. However, the effect was non-significant at 15-30 cm soil depth.

3.9 Non-labile organic phosphorus (NLOP):

The non-labile organic phosphorus content among different treatments, ranged from 32.88 to 37.02 mg kg^{-1}. However, among different treatments, the maximum amount was observed in T_4 (37.02mg kg^{-1}) followed by T_5 and lowest value was observed in T_1 (32.88 mg kg^{-1}) (Fig 5). It was also concluded that T_3 and T_5 were statistically at par with T_4. At 5-15 cm and 15-30 cm depth, similar trend was observed with T_4 exhibiting the highest and T_1 exhibiting the least value. The results further revealed that non- labile organic phosphorus in soil decreased with increasing depth. The effect of different treatments on non-labile organic phosphorus were found to be significant in 0-5 cm soil depth and non-significant at 5-15 cm and 15-30 cm soil depth respectively.

4. Discussions:

Croplands ecosystems has significant effect on ecosystem functioning, sustainability and resilience due to noteworthy change in nitrogen pool The mean values of mineralizable nitrogen were found to be highest in T_5 followed by T_4 while the lowest values were observed in T_1. because of regular addition of organic mnaure , root biomass C and root exudates than other croplands (nitrogen (Sharma *et al*.,2009)). The introduction of legume crops into cropping systems, help in fixing atmospheric nitrogen in the soil, which might be responsible for the increased buildup of mineralizable nitrogen in the soil. Porpavai *et al*. (2011), also stated that adding legume crops to the cropping system increased the nitrogen status of the soil. Similar findings were reported by Ali *et al*. (2012) and Naresh *et al*. (2017). Additionally, the results showed that the mineralizable nitrogen content decreased with depth, which might be due to the reduced amount of soil organic carbon at lower depths.

Overall, Organic matter and root/plant carbon biomass may be responsible for the increase in total soil N over initial value was ascribed to increased C input and high net primary production mainly from root systems(Fu *et al*. (2019). The same happened in T_5 because of incorporation of two legumes which further increased the amount of soil total nitrogen. The rise in various organic and inorganic N fractions may be responsible for the increase in total-N content with continuous fertilizer application alone or in combination with organics over the years. Huang *et al*. (2021) and Kumar *et al*. (2022) all reported similar increases in total nitrogen content as a result of the application of N from inorganic or organic sources in other parts of the nation

The mean value of ammonical nitrogen was found to be highest in T_5 followed by T_4 while the lowest value was obtained in T_1 at 0-5 cm soil depth. Similar trend was followed at 5-15 cm and 15-30 cm soil depth. This might be due to the contribution of N from legume residues and N fertilizer which further enhanced NH_4^+-N concentration through mineralization of soil organic nitrogen. Fu *et al*. (2019) reported that the continuous application of manure and fertilizer over the period of time may be the cause of the rise in NH_4^+-N in the various treatments. This may be because cultivation accelerates the breakdown of organic matter and the organic-N that has been mineralized and have contributed to NH_4^+-N pool in the soil. From the data, it was observed that maximum nitrate content was found in T_5 while the minimum content was found in T_1. This might be due to the increased microbial growth and activity and also due to higher soil organic matter content which further leads to hastening of mineralization and increase NO_3 content in T_5. The findings are in concurrence with Li *et al*. (2019) and Arunrat *et al*. (2022).

The maximum content of soil microbial biomass nitrogen was observed in T_5 while the minimum values were observed in T_1. The lowest values in T_1 was attributed because no FYM application and legumes in T_1. This may be because crop residues of legumes have been found to promote higher microbial growth and activity. Chirinda *et al*. (2008) also reported that cropping systems utilizing legumes had greater MBN and nitrification rates than systems that only used inputs from manure and mineral fertilizer. The stronger root development and more plant residues in fertilised plots might have added more carbon to the soil, resulting in higher microbial biomass carbon and nitrogen. Muhammad *et al*. (2021) also discovered higher MBN value in crop rotations with legumes. The values of SMBN decreased with increasing depth. The lowest values were obtained at 15-30 cm soil depth. It was observed that the effect of cropping intensity was significant at 0-5 cm and 5-15 cm soil depth. The results are in conformity with Li *et al*. (2019), Muhammad *et al*. (2021) and Potter *et al*. (2022)

The values of available phosphorus ranged from 11.50 to 15.07 kg ha^{-1} at all the three depths. This might be explained by the fact that crops in cropping systems absorb less phosphorus than the applied amount. The findings suggest that large applications of P fertiliser may not be necessary to increase the available P fractions in the soil if organic and inorganic fertilisers are applied together. In order to prevent some of the additional P from being irreversibly adsorbed, a high organic matter content can mask enough Al and Fe sorption sites, or it can change the surface charge of minerals to reduce the number of sorption sites and increase the concentration of P in soil solution. In order to prevent Fe, Al, Mg, and Ca from reacting with phosphate, the organic anions and hydroxyl acids released during the breakdown of organic materials may complex or chelate them (Sharma *et al*.,2001). Deka and Singh (1984) reported that incorporating potatoes and radish to cropping systems reduced the amount of phosphorus that was easily available because of excessive phosphorus consumption and utilization. Also, it was found that available P decreased gradually from surface to subsurface layer and its content was higher at surface layer because mobility of phosphorus was low in soils. Similar results were reported by Arya *et al*. (2016), Nunes *et al*. (2020) and Qaswar *et al*. (2022).

The mean value of labile organic phosphorus was found to be significantly higher in T_2 followed by T_3 whereas the lowest values were found in T_1. The LOP fraction of OM is small but essential to P cycling, sustaining microbial and enzymatic processes. $NaHCO_3$-Po levels in T_1 might have decreased as a result of continuous cropping without external input.

Similar results were reported by Ahmed *et al*. (2020), Qaswar *et al*. (2022) and Sharma *et al*. (2022). Moderately labile organic phosphorus was found to be significantly affected by the treatments of different cropping intensities at 0-5 cm and 5-15 cm soil depth. The maximum amount of MLOP was recorded in T_2 followed by T_3. The moderately labile P pool was thought to consist of the NaOH-Po portions. This proportion was greater than the labile P fractions that could be extracted using $NaHCO_3$. The native soil P can change from moderately labile and non-labile P fractions to labile forms as a result of significant P extraction by plants. The results exhibited that the values of non-labile organic phosphorus was found to be significantly affected by different treatments. The highest values were found in T_4 followed by T_5. As chemical fertilizers were used more often, the amount of NLOP in the soil rose, suggesting that certain active soil P fractions were immobilised during long-term cropping and more P was chemically fixed. T_4 had the highest fertilizer application and NLOP values. The emission of significant amounts of carbon dioxide (CO_2) during organic matter might be the cause of the increase in P levels caused by the decomposition of organic inputs which is responsible for phosphorus fixation in alkaline, especially in calcareous soils. These results further get support from the findings of Ahmed *et al*. (2020) and Sharma *et al*. (2022)

Conclusion:

The results of the present study inferred that the high intensity cropping has significant effect on soil nitrogen pools and phosphorus fractions. Further, the study indicated that intensification of all the cropping systems through leguminous crops is responsible for higher nitrogen fixation and it enhanced the availability of various nitrogen pools with average increase of 2.02% for mineralizable nitrogen, 1.72% for total nitrogen, 14.76% for ammonical nitrogen, 30.07% for nitrate nitrogen and 41.84% for soil microbial biomass nitrogen at 0-5 cm soil depth. The application of organic manures along with fertilizers and their decomposition released organic acids and boost various phosphorus fractions. Long-term application of various organic inorganic amendments along with increased cropping intensity not only enhances the status of nitrogen pools and phosphorus accumulation but also hastens the process of mineralization in soils. In addressing the challenges of population growth and rising food demand in the developing world, a strategic reevaluation of agricultural practices is imperative. With a projected surge of 9.8 billion individuals by 2050 and limited agricultural land per capita (0.29 hectares), conventional methods fall short. To meet this demand sustainably, we must intensify cropping systems while preserving environmental integrity. Incorporating legumes into crop rotations and balancing organic and inorganic amendments enhances productivity while maintaining soil and ecosystem health. This synergistic approach not only enhance productivity but also fosters the overall health and resilience of soil and ecosystems. Therefore, farmers are advised to apply optimum P-fertilization in accordance with the needs of the crop to enhance the availability of organic phosphorus fractions under the high cropping intensities of the Chenab-Ravi basin.

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Figure legend:

Fig. 1 Fig depicting effect of high intensity cropping on (a) Mineralizable Nitrogen and (b) Total Nitrogen (TN) at different depths

Fig 2. Fig depicting effect of high intensity cropping on (a) Nitrate Nitrogen (NN) and (b) Ammonical Nitrogen (AMN) at different depths

Fig. 3 Fig showing effect of high intensity cropping on (a) soil microbial biomass nitrogen (SMBN) and (b) available phosphorus at different depths

Fig. 4 Fig showing effect of high intensity cropping on (a) labile organic phosphorus (LOP) (mg kg^{-1}) and (b) moderately labile organic phosphorus (MLOP) (mg kg^{-1}) fractions of soil at different depths:

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