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Original article

Integrated nitrogen management improves productivity and economic returns of wheat-maize cropping system

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A B S T R A C T

Objectives: Continuous cultivation of rice and wheat crops in rice–wheat cropping system has resulted in numerous edaphic, social and environmental problems. Nonetheless, increasing water scarcity is also threatening the sustainability of rice–wheat cropping system. Therefore, farmers are compelled to cultivate alternative crops, like maize for water saving and higher economic returns. However, limited is known for integrated management of nitrogen (N) in wheat and maize crops. This study investigated the impact of integrated N management on productivity and profitability of wheat-maize cropping system.
Methods: The study was conducted at Agriculture Research Farm of Bahauddin Zakariya University, Mulan, Pakistan. Wheat and maize crops were cultivated with recommended N dose using inorganic and organic sources, either alone or in combination with biofertilizer, while no N application was regarded as control. Data relating to root biomass yield and soil organic carbon (SOC) were collected.
Results: Organic fertilizer alone and in combination with inorganic fertilizer and biofertilizer significantly improved root biomass and SOC. Improved SOC and crop root system resulted in better productivity of wheat-maize cropping system. Sole inorganic fertilizer application improved crop yield; however, had almost no effect on SOC. Integrated N management strategy (50% organic and inorganic fertilizer in combination with biofertilizer), improved crop yield (7168, 6405 kg/ha), net benefit (US$ 779, 961) and SOC (2.75%, 1.59%) for maize and wheat crops, respectively.
Conclusion: Integrated N management strategy using different N sources seemed a viable and economically sound alternative of conventional N management, which would further strengthen the sustainability of wheat-maize cropping system.

1. Introduction

Rice-wheat is one of the largest production systems spread >26 M ha worldwide (Dhillon, 2000). It provides staple food for >20% population residing in south Asia and China (Khalofah et al., 2021). Continuous cultivation of rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) has resulted in various edaphic, social and environmental problems. Nonetheless, productivity rice–wheat cropping system is declining due to depleting ground water resource, increasing energy cost, declining soil organic matter, imbalanced soil fertility, evolution of herbicide resistance in weeds and poor management of crop residues (Hira, 2009; Humphreys et al., 2010; Ladha et al., 2000; Tiwari et al., 2009). This situation has forced the farmers to grow alternative crops requiring less water to meet food security issue (Jat et al., 2015).

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Maize (*Zea mays* L.) is among the important cereal crops adaptable to diverse climatic conditions (Khan et al., 2012; Kumar et al., 2015). Maize ranks fourth in Pakistan in terms of area under cultivation after wheat, rice and cotton (*Gossypium hirsutum* L.) with total production of 4.920 million tons (GOP, 2020). Maize demand has increased in recent years due to expansion of poultry and livestock industry in the country. Maize contributes 2.2% value added in agriculture and 0.4% to gross domestic production (GDP) of Pakistan (GOP, 2020). Irrigated maize–wheat cropping system (MWCS) is the 3rd most important (1.13 Mha) cropping system after rice–wheat and cotton–wheat systems in Indo-Gangetic plains (Yadav and Subba Rao, 2001). Wheat is also a very important cereal crop, grown as staple food in the country. Wheat cultivation is extended over 17% of the world arable land and feeds 35% of global population (CIMMYT, 2006; Dixon et al., 2009). Wheat contributes 9.6% value added in agriculture and 1.9% in GDP of Pakistan (GOP, 2020). Maize is a good alternative to rice, which would save water and improve agricultural system productivity. However, substituting rice with maize without effective resource management did not justify the crop diversification. Crop nutrients', particularly nitrogen (N) management strategies are crucial as maize consumes more nutrients than rice (Lu et al., 2021).

Inorganic fertilizers improve soil productivity with good management practices. However, management practices deteriorate physical, biological and chemical soil properties (Rosenzweig et al., 2014). Long-term use of inorganic fertilizers reduces soil organic carbon (SOC), which in turn declines crop yields (Ladha et al., 2003; Pathak et al., 2003). The SOC is significantly affected by climate factors, cropping systems and soil types (Chabbi et al., 2009; Jagadamma and Lal, 2010; Miller et al., 2004; Saikia et al., 2015). Most of the farmers in Pakistan burn crop residue; thus, waste major source of organic matter. Mixing crop residues in soil can significantly improve soil organic matter (SOM) (Jarecki and Lal, 2003). Inorganic fertilizers increase soil fertility for a short-term and pose negative effect on soil health for a longer period (Yang et al., 2015). Sustainable crop production should rely on organic manures rather than chemical fertilizers. Several studies have revealed that manures improve crop yield, SOM and soil quality (Saikia et al., 2015). Organic manures supply essential nutrients for plant growth; however, they are not produced enough to meet the production requirements. Therefore, integrated nutrient management seems an attractive option to improve soil health and crop yields.

Organic and inorganic fertilizers are applied in combination to fulfill the crop nutrient requirements in integrated nutrient management (Bharti et al., 2016). The application of microbial-fortified compost in rice has improved crop growth, productivity and soil health (Ng et al., 2016). Integrated nutrient management exerts positive impact on biological, physical and chemical properties of soil. Combined application of N and farm yard manure (FYM) significantly improves soil fertility and crop yield (Sarma et al., 2015). Application of organic manure in combination with inorganic fertilizer increased crop yield (Kätterer et al., 2011). Unfortunately, intensive cultivation and non-judicious use of inorganic fertilizers are the main agricultural practices in Pakistan, which negatively affects soil health. Pakistani soils are deficient in organic matter due to high temperature, which needs much attention for sustainable crop production. Moreover, farmers supply macronutrients without any organic manure in the country. These practices have created nutrient imbalance. Therefore, integrated N management is essential for existing and prospect cropping system.

Nitrogen is a highly mobile element, required in large quantities by crop plants. The N is supplied through inorganic fertilizers in the country, which could affect soil health. Limited work has been done to evaluate the role of integrated N management in improving the productivity and economic returns of different crops. Nonetheless, limited is known about integrated N management in wheat-maize cropping system. This study was aimed at inferring the role of integrated N management in improving productivity and economic returns of wheat-maize cropping system.

2. Materials and Methods

This study was conducted at Agricultural Research Farm, Bahauddin Zakariya University, Multan, Pakistan during 2015 and 2016. Pre-sowing soil analysis indicated that soil was silty-clay, alkaline, having 0.56% soil organic carbon and 0.03, 4 and 86 mg/kg of N, available phosphorus (P) and potassium (K), respectively. The experimental area lies in semi-arid climate. Average temperature is 30–40 °C, atmospheric pressure ranged between 995 and 1030 mbar and relative humidity during the cropping seasons ranged between 50 and 90% (Fig. 1).

2.1. Experimental treatments and design

The treatments were biofertilizer (*Rhizobium pisi*), inorganic fertilizer (NPK) and organic fertilizer (FYM). The N application treatments included, N_0 = no N fertilizer, N_1 = inorganic N fertilizer, N_2 = organic N fertilizer, N_3 = 50% inorganic N fertilizer + 50% organic N fertilizer, N_4 = inorganic N fertilizer + biofertilizer, N_5 = organic N fertilizer + biofertilizer, N_6 = 50% inorganic N fertilizer + 50% organic N fertilizer + biofertilizer. Recommended rate of inorganic fertilizer and FYM (6 ton/ha) were applied before sowing. Experiment was laid out in a randomized complete block design (RCBD).

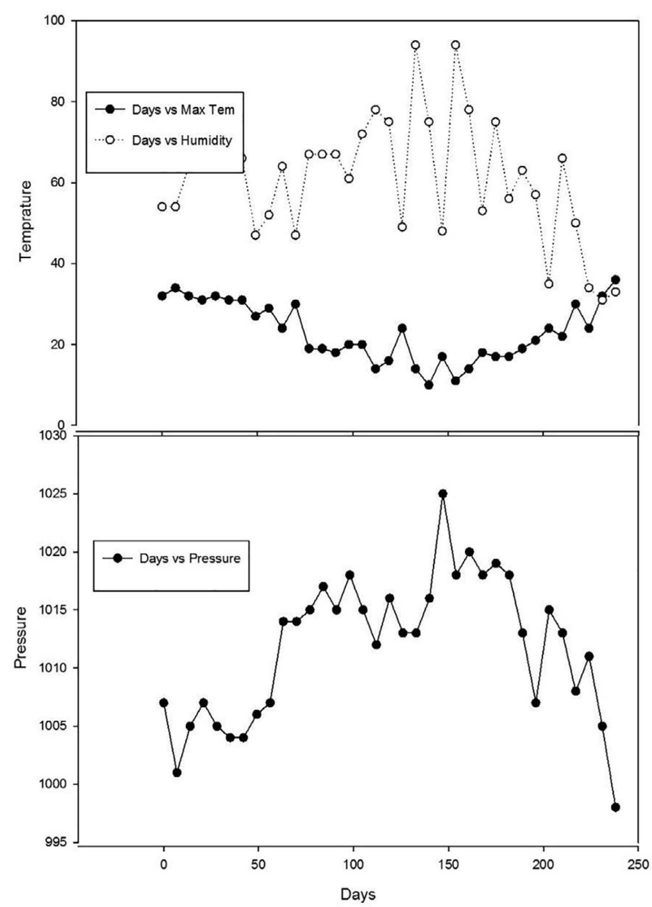

Fig 1. Climatic data during wheat crop growth season.

Experimental unit was 1.5 m × 6 m with three replications for both crops.

2.2. Wheat cultivation

Before sowing, field was laser-leveled for better management practices. Pre-sowing irrigation was applied to achieve the desired soil moisture for seed sowing. All sources of organic fertilizers, P and K were used at the time of sowing, while 33% N was used during crop sowing. Remaining N was applied in equal quantities during tillering and booting stages. Crop was manually sown by using hand drill on 27th November during both years. Interrow distance was 25 cm (Fig. 2) and seed rate was 150 kg ha^{-1}. Irrigation was applied at all critical growth stages or as per crop needed. Recommended plant protection practices were implemented for keeping crop free from weeds and insects. Crop was harvested at physiological maturity and various growth and yield-related parameters were recorded. Plant height (cm) was measured from the base of plant to the tip of the spike by a meter rod. Twenty plants were randomly selected from each experimental unit for the measurement of plant height and recorded heights of all plants were averaged. Similarly, 1 m^2 area was randomly selected from each plot and harvested for the calculation of number of productive tillers. Spike-bearing tillers (m^{-2}) were counted as productive tillers, while those without spikes were regarded as non-productive tillers. All experimental units were harvested at maturity and left in the field for drying under sunshine. After two days, plants were weighed for biological yield, which was converted to kg ha^{-1} by unitary method. All plants were threshed manually for recording grain yield and 1000-grain weight. Harvest index was calculated by dividing grain yield with biological yield and expressed in percentage.

2.3. Maize cultivation

After harvesting of wheat, same field was prepared for the cultivation of maize. Field was rotavated and all residues were mixed in soil, which was further cultivated to acquire fine tilth. Furrows were made by maintaining a distance of 70 cm (Fig. 2). Seeds of hybrid maize cultivar 'P-1574' were sown on the furrows by dibbling method. After sowing, field was irrigated to moisten the ridges to favor seed germination. The recommended dose of NPK (140 kg N ha^{-1}, 80 kg P ha^{-1} and 60 kg K ha^{-1}) were supplied. Full dose of P and K, while 1/3rd of N were applied at sowing. Remaining N was applied at six-leaf and silking stages in two equal splits. The seed rate was 25 kg ha^{-1}. Thinning was done 30 days after sowing (DAS) to maintain inter-row space of 25 cm.

At physiological maturity, all yield-related traits were recorded, including cob length, grains per cob, 1000-grain weight, grain yield and biological yield etc. Twenty plants were randomly selected for each experimental unit and tagged for data recording. The whole plot was harvested at maturity to record biological and grain yields.

2.4. Root biomass and soil organic carbon

Destructive sampling was opted to record root weight (g) at seedling and booting stages. Four plants from each plot were uprooted and roots were washed to remove the soil and debris. Roots were separated and air-dried. Air-dried root samples were placed in oven for 48 h at 105 °C until constant weight. Soil samples were taken after the crop harvest with soil augur (0–15 cm). All visible plant residues were removed from soil samples before sending for chemical analysis.

2.5. Cropping system productivity

Productivity of wheat-maize cropping system was calculated by adding total benefits of both crops.

System productivity = maize crop income + wheat crop income

2.6. Statistical analysis

The collected data were tested for normality by Shapiro-Wilk normality test, which indicated that some of the parameters had non-normal distribution (Shapiro and Wilk, 1965). Therefore, non-normally distributed parameters were transformed by Arcsine transformation technique to meet the normality assumption of Analysis of Variance (ANOVA). One-way ANOVA was used to test the significance in the dataset (Steel et al., 1997). Tukey's test at 5% probability was used as post-hoc test to separate the means where ANOVA indicated significant differences. All analysis were performed on SPSS software version 21.

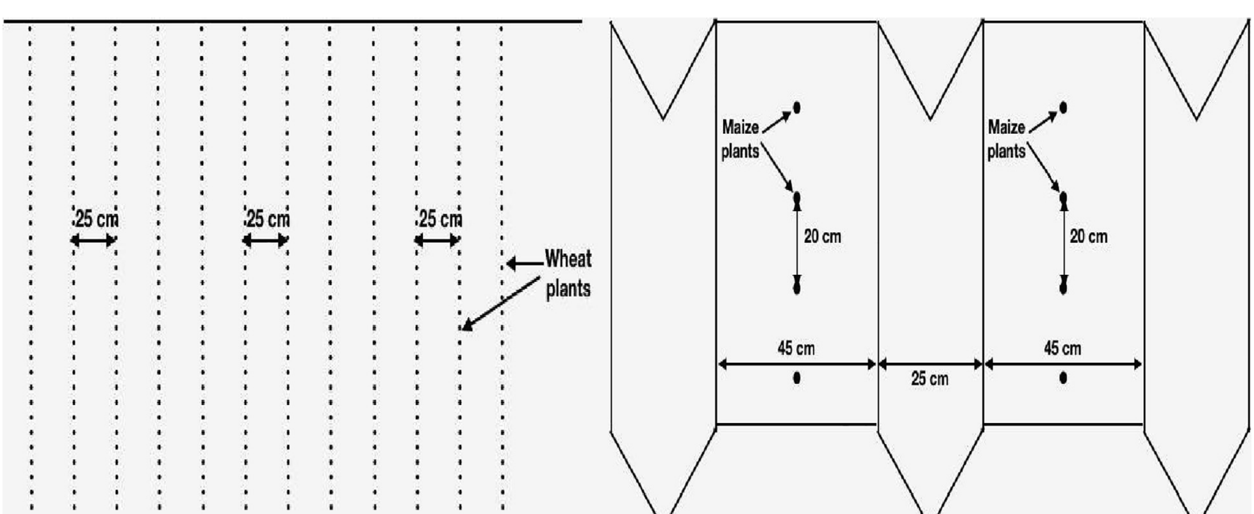

Fig 2. Sowing plan of wheat and maize crops.

2.7. Economic analysis

Economic analysis was carries out to assess the economics of different N management treatments (Shah et al., 2013). Expenses incurred during the production of both crops included costs for seed purchase, seedbed preparation, sowing, weed management, irrigation, fertilizer, harvest and land rent. The inputs were based on the prevailing prices in the local market. Gross income was estimated using the existing prices for wheat and maize grains, straw and hulls in the local market. Net income was calculated by subtracting the total expenses from gross income.

3. Results

3.1. Performance of wheat

All N fertilization treatments enhanced wheat performance in term of plant height, number of productive tillers, 1000-grain weight, grain yield, biological yield and harvest index as compared to no N application. Integrated N application (N_6) showed similar results with inorganic fertilizer (N_1) alone. The highest number of productive tillers were recorded in N_6, which were at par with N_1 and N_4. The lowest number of productive tillers were recorded in N_0. Similarly, the highest grain yield was recorded in N_1 and N_6. Similar trend was recorded for all other parameters like 1000-grain weight, biological yield and harvest index (Table 1).

Root biomass was recorded at different critical growth stages (seedling and booting) of wheat. The N management strategies significantly differed for root biomass. Organic N fertilizer alone and in combination with inorganic N fertilizer enhanced the root biomass at both growth stages, but the effect was obvious at booting stage. The highest root biomass (0.10 and 1.59 g/plant) was recorded in N_6, while the lowest (0.02 and 0.56 g/plant) was recorded in N_0. All other treatments which received organic N fertilizer enhanced root biomass (N_2, N_3, N_5) as compared with treatment which received sole inorganic N. Integrated N management strategy proved most efficient to enhance plant growth in terms of root biomass (Table 3). Furthermore, organic N fertilization significantly enhanced SOC. The highest SOC (1.59%) was recorded in N_6, which was further at par with N_2 and N_5, while N_0 and sole inorganic N fertilizer application reduced SOC (0.95% and 1.29%), respectively (Table 3). Linear correlation was recorded among root biomass and SOC (Fig. 3).

3.2. Performance of maize

The yield-related traits were improved by integrated N management strategy. The lowest cob length was recorded in N_0. Number of grains cob^{-1}, 1000-grain weight, grain yield, biological yield and harvest index were significantly improved under integrated N management strategies (T_5, T_6). The addition of biofertilizer improved soil fertility, which might be due to the accelerated mineralization process (Table 2).

Root biomass was observed at 30 DAS and at silking stage, which are critical growth stages. The root biomass was improved under organic fertilization (N_2, N_5 and N_6) as compared to control or sole inorganic N fertilizer application (N_0, N_1). Treatments' impact was more obvious at silking stage and N_6 performed better for root biomass (19.55 g/plant). Although inorganic N fertilizer increased crop yield, root biomass was less than organic N fertilization (Table 3). The highest SOC was noted in N_2, N_5 and N_6 (2.77, 2.77 and 2.75% respectively), while N_0 and sole inorganic N fertilizer reduced SOC (Table 3). Linear correlation was observed among root biomass and SOC, which explored the importance of organic matter for sustainable crop production (Fig. 3).

3.3. System productivity

The highest system productivity (1741 US$) was recorded for N_6, while it was near to sole inorganic N fertilizer treatment (1683.7 US$). All treatments having sole inorganic/organic or integrated N application improved system productivity as compared to no N application (Table 3).

3.4. Economic returns

Economics is a major factor determining the fate of any input. The lowest economic returns were noted for N_0 treatment in both crops. The N_6 proved the most economically sound treatment. The highest net benefits (US$ 779.4, 961.5) as well as BCR (1.24, 1.70) was recorded with this treatment in maize and wheat crop, respectively (Table 4).

4. Discussion

Integrated N management approach performed better than sole or no N application treatments in the current study. It can be attributed to the constant N availability to the crop as biofertilizer fix N and make it available to plants. This approach also reduces N losses as it may bind it. Decomposition of organic matter also releases nutrients slowly according to the crop need, while inorganic fertilizer become readily available after application resulting in leaching and volatilization losses. We applied organic matter in the form of crop residues, which enhanced organic carbon in the soil (Jarecki and Lal, 2003). Crop residues are the major source of SOC if mixed in the soil. Nitrogen losses are higher in the soils with low organic matter, while FYM application reduces these losses and improves the soil health or tilth (Chandra et al., 2004; Khalofah et al., 2021). Nonetheless, FYM increases water holding capacity and microbial activity, and improves soil quality (Chandra et al., 2004). Sole application of organic N fertilizer cannot fulfill the crop demands due to its slow mineralization, while integration with inorganic N fertilizer enhances N availability.

Table 1
The impact of different nitrogen management strategies on yield and yield components of wheat crop.

Treatments	Plant height (cm)	Spike length (cm)	Productive tillers(m^{-2})	Total tillers(m^{-2})
N_0	67.67 d	100.8	197.6 e	192.7 d
N_1	107.00 a	126.0	420.3 ab	412.0 bc
N_2	88.67c	157.8	302.3 cd	288.7b
N_3	100.33b	171.3	356.6 bc	352.0 ab
N_4	100.67b	172.8	385.3 ab	360.0 ab
N_5	104bc	180	390.0b	380.0b
N_6	110.00 a	183.8	431.5 a	450.0 a

N_0 = control, N_1 = inorganic N, N_2 = organic N, N_3 = 50% inorganic N + 50% organic N, N_4 = inorganic N + biofertilizer, N_5 = organic N + biofertilizer, N_6 = 50% inorganic N + 50% organic N + biofertilizer.

Table 2
The impact of different nitrogen management strategies on yield and yield components of maize crop.

Treatments	Cob Length (cm)	Number of grains per cob	1000-grain Weight (g)	Grain yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index(%)
N_0	11.3 d	380c	232 d	4023c	11,230c	36c
N_1	17ab	432 ab	240b	7125 ab	13,427 ab	53 ab
N_2	16b	407b	238c	6813b	12,627b	54b
N_3	16.5 ab	409b	240 bc	7005b	13,211 ab	53b
N_4	15.5b	439b	241c	6917b	12,721b	54b
N_5	16.5 ab	440 ab	247b	6941 ab	13,100 a	53 ab
N_6	17.5 a	460 a	259 a	7168 a	13,110 a	55 a

N_0 = control, N_1 = inorganic N, N_2 = organic N, N_3 = 50% inorganic N + 50% organic N, N_4 = inorganic N + biofertilizer, N_5 = organic N + biofertilizer, N_6 = 50% inorganic N + 50% organic N + biofertilizer.

Table 3
Effect of integrated nitrogen management in comparison with inorganic and organic fertilizer on root biomass (g/plant) and soil organic carbon (%) in wheat and maize crop.

Treatments	Wheat (root biomass/SOC)			Maize (root biomass/SOC)			System productivity (US $/ha)
	Seedling stage (g/plant)	Booting stage (g/plant)	SOC %	30 DAS (g/plant)	Silking stage (g/plant)	SOC (%)	
N_0	0.02c	0.56c	0.95 d	3.33f	11.58 e	0.98 e	558.8
N_1	0.04b c	0.82b c	1.29c	5.45 e	15.49 d	1.29 d	1683.7
N_2	0.05b	0.88b	1.53 ab	6.07c	16.86 bc	2.77 a	1221.3
N_3	0.05b	0.95b	1.42 abc	5.88 cd	16.05 bcd	2.57b	1419.4
N_4	0.047b	0.84 bc	1.35 bc	5.54d e	15.80 cd	1.91c	1583.7
N_5	0.06b	1.02b	1.53 ab	6.50b	17.00b	2.77 a	1498.4
N_6	0.10 a	1.59 a	1.59 a	8.79 a	19.55 a	2.75 a	1741.0

N_0 = control, N_1 = inorganic N, N_2 = organic N, N_3 = 50% inorganic N + 50% organic N, N_4 = inorganic N + biofertilizer, N_5 = organic N + biofertilizer, N_6 = 50% inorganic N + 50% organic N + biofertilizer.

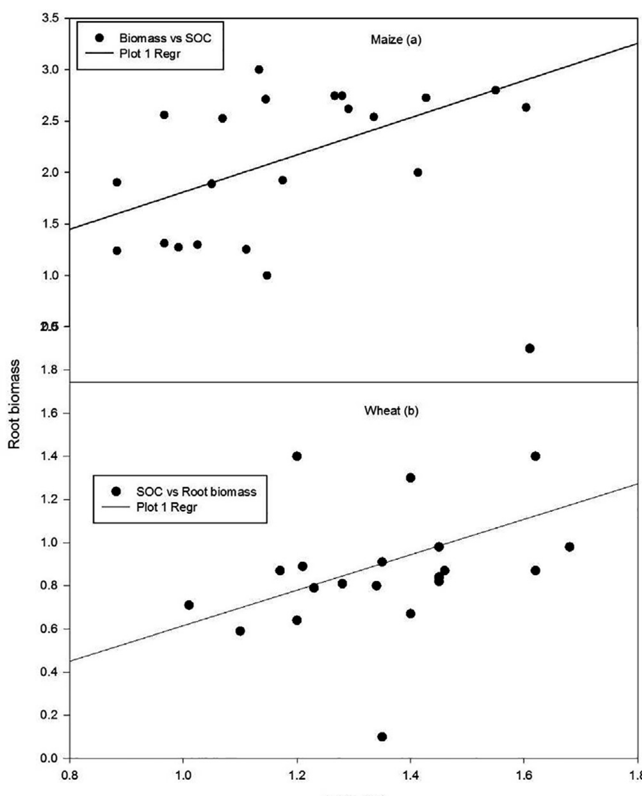

Fig 3. Correlation between root biomass and soil organic carbon.

Organic fertilizer in the form of FYM and biofertilizer seems a fruitful strategy to improve SOC as well as plant growth and yield. Our findings are in line with the previous researchers who agreed that organic fertilizer application improves SOC (Shrestha et al., 2008). Organic N fertilizer mixed with inorganic N fertilizer or biofertilizer reduced SOC as compared with sole organic N fertilizer. Although, sole organic fertilizer enhanced organic carbon, but crop performance was not better as compared with integrated N management. It might be due to the fast mineralization in integrated N management as compared with sole organic fertilization.

Inorganic nutrients may multiply the microbes to boost up the decomposition process and make nutrients available to crop plants. Due to this fact, SOC was minimized in integrated N management as compared to sole organic fertilizer. Treatment N_6 significantly enhanced the crop growth and yield. It might be due to fast mineralization of organic fertilizer. Root growth is basic need for the healthy plant growth. Root biomass was higher in organic as well as integrated N management systems. It might be due to the good aeration, higher microbial activities and improved soil fertility (Hoosbeek et al., 2007). Similar findings were recorded in our experiment for root system development. Moreover, Saikia et al. (2015) found combined use of inorganic and organic fertilizer as a good alternative for wheat crop yield as well as soil carbon status. It was also explored that SOC and root biomass are linearly correlated with each other. It might be due to the decay of old roots in the soil, which improved the SOC status. Plant roots play a dominant role in SOC as senescence of older roots improved soil carbon pool (Puget and Drinkwater, 2001; Tan et al., 2014).

Furthermore, economic analysis is a major factor, which decides about the input used which is most crucial in developing countries like Pakistan where most of the farmers are hand to mouth (Shah et al., 2013). Integrated soil fertility not only ameliorated the plant or soil health but also exhibited in improved benefit, which might be the most attractive factor for the farmers (Naeem et al., 2021). These results also directed that farmers can improve the productivity of wheat-maize cropping system with integrated N fertilizers and can save the precious inputs (Khalofah et al., 2021). This practice is environment-friendly as the plant or animal waste can also be used in useful manner, which squeeze carbon. With inorganic fertilization, farmer may get good yield as cleared by economic analysis, but it is not sustainable way of crop production and can't be followed for long time.

Table 4
Economic analysis of integrated nutrient fertilization in maize-wheat cropping system.

Maize					
Treatments	Yield (kg ha^{-1})	Net Benefit (US \$ ha^{-1})	Expenses (US \$ ha^{-1})	Benefit (US \$ ha^{-1})	B:C
N_0	4023	790.2	529.3	260.9	0.5
N_1	7125	1399.6	650.0	749.6	1.2
N_2	6813	1338.3	621.4	716.8	1.2
N_3	7005	1376.0	642.9	733.1	1.1
N_4	6917	1358.7	614.3	744.4	1.2
N5	6941	1363.4	664.3	699.1	1.1
N_6	7168	1408.0	628.6	779.4	1.2
Wheat					
N_0	3165	762.9	465.0	297.9	0.6
N_1	6304	1519.8	585.7	934.1	1.6
N_2	4404	1061.6	557.1	504.5	0.9
N_3	5247	1264.8	578.6	686.3	1.2
N_4	5763	1389.3	550.0	839.3	1.5
N5	5805	1399.3	600.0	799.3	1.3
N_6	6329	1525.8	564.3	961.5	1.7

N_0 = control, N_1 = inorganic N, N_2 = organic N, N_3 = 50% inorganic N + 50% organic N, N_4 = inorganic N + biofertilizer, N_5 = organic N + biofertilizer, N_6 = 50% inorganic N + 50% organic N + biofertilizer.
Wheat price: US $ 9.64/ 40 kg.
Maize price: US $ 7.86/ 40 kg.

5. Conclusion

Integrated nitrogen management improved crop root system and soil organic carbon, which leads to improved crop growth and increased yield. Mineralization of organic fertilizer can also be enhanced with the integration of inorganic N fertilizer or biofertilizer for constant N availability to the crop. Study also encourages the use of farmyard manure along with inorganic fertilizer and biofertilizer for sustainable wheat-maize cropping system.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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