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INTERACTIVE EFFECT OF PLANTING METHODS AND NUTRITION ON SOIL FERTILITY UNDER SEMI-ARID INCEPTISOLS WITH COTTON-WHEAT CROPPING SYSTEM

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SUMMARY

Imbalance fertilization and high intensity farming reduced the soil nutrient status and also impaired the quality of soil. So, the present study explores the impact different planting system and implementation of nutrient management practices based on STCR approach of inductive-cum-targeted yield model on fertility of soil. The experiment was planned with five treatments viz. T_1-Control, T_2-FYM, T_3-FYM with bio-fertilizer and cow urine formulation, T4 and T_5-STCR with targeted yield of wheat/Bt. cotton (TY 5.5/2.8 and 6.0/3.2 tha^{-1}) under raised-bed and flatbed planting. Results showed that soil organic carbon (SOC) significantly increased by 26 & 35% and 24 & 31% in T_2 & T_3 treatments under raised and flat-bed planting, respectively over control at 0–15 cm soil. The application of FYM alone or with cow urine formulation and bio-fertilizer increased the available macronutrients (NPK) of surface and sub-surface soil. Application of FYM alone or with bio-fertilizer and cow urine formulation significantly and positively impacted Zn, Fe and Mn while negatively impacted the Cu concentration of soil. Raised-bed was superior to flat-bed planting in regard to the availability of nutrients in soil, thus leading to higher seed germination and uniform crop growth that ultimately increased the seed cotton and wheat grain yield.

Key words: STCR, FYM, Methods of planting, Bio fertilizer and cow urine formulation

The increased utilization of synthetic agrochemicals and adoption of nutrient-efficient high-yielding varieties during the green revolution period caused significant boost in agriculture production. However, over time this growth has slowed due to excessive removal of native nutrients resulting in soil degradation, and decreased environmental. The increase in yield from fertilizer application was due to improved growth and yield attributes resulting from enhanced nutrient supply and fertilizer efficiency in the soil (Apoorva *et al*., 2010; Debarati and Gautam *et al.,* 2013).

The primary constraint in cotton-wheat production is the availability of essential nutrients and most of soil in rainfed areas is not only thirsty but also hungry. Cotton-wheat is a well-established crop production system of the Indian subcontinent's northwestern plains and this rotation has a prominent role in agricultural growth of India. This cropping system is the second most important wheat-based system in the South Asia (4.5 M ha) & India (2.6 M ha) and contributes significantly to the food security in the region (Das *et al*., 2014). According to Monga *et al.* (2009), the cotton-wheat system covers an area of approximately 1.7 million hectares in Punjab, Haryana and Rajasthan. This crop system is a combination of grain and cash crops which benefits farmers by providing source of both food security and industrial commodities.

The traditional farming system has increased food and fiber production to meet human needs but it heavily relies on synthetic fertilizers, pesticides, herbicides and traditional plowing methods (Tu *et al*., 2006). Although the excessive use of pesticides has altered the physical, chemical and biological properties of soil leading to low production, poor quality and environmental issues (Rivera-Becerril *et al*., 2017). Therefore, ensuring soil quality and output through effective nutrient management is a significant research focus in modern agriculture. The STCR technique is a concept that supports judicious and balanced fertilizer recommendations. The targeted yield approach (Ramamoorthy *et al*., 1967) is based on crop nutrient requirements, contributions from soil, fertilizer and manure nutrients towards their uptake, and nutrient interactions in soils and plants (Saxena *et al*., 2008 and Chatterjee *et al*., 2010).

Organic manures play a crucial role in crop production (Usman *et al.*, 2013). They impact the physical properties of soil resulting in the formation of soil crumbs and making the soil more easily worked, allowing for better air and water flow as well as nutrient absorption (Kumar et al., 2021). Decomposition of organic matter also adds essential plant nutrients to the soil and making insoluble nutrients into biologically available form. As well as the method of sowing can also enhance the availability of soil nutrients. Bed planting has been found to improve seedling emergence and reduce soil crust formation (Ahmad *et al.*, 2009). Ridge sowing of cotton also improves soil physical properties such as increased soil moisture content, reduced root penetration resistance and improved seed cotton yields (Gursoy *et al*., 2011). The FIRB (furrow irrigated raised bed) system has been found to provide 5 to 10% higher yields over conventional sowing methods and offers significant savings in irrigation water and making manual weeding easier (Kumar *et al*., 2001).

Therefore, the present study aims to evaluate the effect of different nutrient management practices and bed planting methods on soil fertility under cotton-wheat cropping system.

MATERIALS AND METHODS

Study site and experimental treatments

The experiment was conducted at the research farm (Lat. 29° 162 N, Lon 75° 72 E, 215 m above mean sea level) of Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana. This area belongs to semi-arid area characterized by hot and dry summers and cold and arid winters. The average annual temperature at the site is 24.8°C with the highest temperature of 48°C in June and the lowest of 1.5°C in January. The region is mostly comprised of plains of fluvial alluvium, covering about 90% of the area and blanketing the sub-surface geology (Goyal *et al.*, 2008; Goyal *et al.*, 2009; Yadav *et al.*, 2023). The experiment was initiated in 2019 under cotton-wheat cropping system five treatments and three replications under both flat bed and raised bed planting systems (Table 1).

Preparation of cow urine formulation (Jeevamrut)

Cow dung (2.5 kg) and cow urine (1 litre) was mixed with 5 litre of water. Then, 500 g jaggery, 500 g chickpea flour and a handful of productive soil was added into it. This solution was stirred well and kept for 7-14 days to ferment under shade. Prepared cow urine based fertilizer was strained with the help of muslin cloth and kept in a clean container which was applied in the crop (T3) of wheat and cotton along with Ist and IInd irrigation after sowing the crop.

Fertilizer doses under treatment T4 and T5 were calculated based on fertilizer adjustment equations for specific yield targets (Ramamoorthy et al 1967) and initial soil test values.

Fertilizer prescription equation for wheat

$$FN = 5.22\ T - 1.04\ SN - 0.12\ FYM\ (N)$$
$$F(P_2O_{-5}) = 2.38\ T - 4.06\ SP - 0.14\ FYM\ (P_2O_{-5})$$

Fertilizer prescription equation for Bt. cotton

$$FN = 13.76\ T\text{-}- 1.95\ SN - 0.13\ FYM\ (N)$$
$$F\ (P_2O_5) = 4.47\ T - 4.78\ SP - 0.12\ FYM\ (P_2O_5)$$
$$F\ (K_2O) = 7.64\ T - 0.77SK - 0.10\ FYM\ (K_2O)$$

Where, FN, FP_2O_5 and FK_2O are fertilizer N, P_2O_5 and K_2O (kg/ha) rates, SN, SP and SK are the initial soil test values (kg/ha) for $KMNO_4$-N, Olsen's P and Ammonium acetate, FYM (N), FYM (P_2O_5) and FYM (K_2O) are the N, P_2O_5 and K_2O in FYM (kg/ha) and T is the targeted yield (Mg/ha).

Fertilizer adjustment equations of K_2O for wheat were not developed for the study area as local soils are very rich in potash due to presence of illitic clay minerals (Goyal and Jhorar, 2007). Hence, Potassic fertilizers were not applied in all the treatments in wheat as potassium response was not observed.

TABLE 1
Treatment details of experiment on *Bt*. cotton and wheat in cotton-wheat cropping system

Treatment	
T_1	Absolute control
T_2	FYM @ 15 t/ha both during *rabi* and *kharif* seasons (FYM)
T_3	FYM @ 15 t/ ha + seed treatment with Biofertilizer (Azotophosphotica) and Jeevamrut (cow urine formulation)
T_4	Fertilizer dose for 5.5/2.8 t/ha grain yield target of wheat/ *Bt*.cotton(STCR) (TY 5.5/2.8)
T_5	Fertilizer dose for 6.0/3.2 t/ha grain yield target of wheat/ *Bt*.cotton (STCR) (TY 6.0/3.2)

Crop Management

Wheat (var. WH 1105) and Bt. cotton (var. RCH 773) was grown in sequence during cropping seasons of *rabi* 2019-20 & 2020-21 and *kharif* 2020 & 2021 in a plot size of 100 m^2 (12.5 x 8.0 m). The experiment was managed using all of the recommended wheat and Bt. cotton production cultural practices consistently as required. The crop was manually harvested from each plot separately after attaining physical maturity of wheat and Bt. cotton in the month of April and November, respectively.

Soil sampling and analysis

The initial soil sample before initiation of the experiment was collected and analyzed for electrochemical and chemical properties using standard methodology (Table 2). After the harvest of wheat 2020-21 and *Bt*. cotton 2021, soil samples were collected from 0-15 cm and 15-30 cm. The soil samples were air-dried and ground using a wooden pestle and mortar and pass through 0.5 mm (soil organic carbon) and 2 mm (rest of the chemical parameters) plastic sieve.

All the analysis was done using standard methods given in Table 2. Micronutrients (Zn, Cu, Fe &Mn) in the soil were determined through the DTPA-extractable method (Lindsay and Norvell, 1978) using an atomic absorption spectrophotometer.

Statistical analysis

The data of each treatment related to soil samples were analyzed in a randomized block design. Significance ($P<0.05$) of the treatment means were estimated by employing Duncan's multiple range test at 5 % level of significance. The graphing was done using Origin v.8.5 software (Origin lab Corporation, Northampton, United States).

RESULTS AND DISCUSSION

Soil pH and electrical conductivity (EC)

The soil pH significantly decreased in the treatments where FYM alone or with cow urine formulation and bio fertilizer (T2-T3) were applied in both the system of planting at 0-15cm soil depth as compared to control. It was due to the release of organic acids and carbon dioxide released during the decomposition of FYM which combine with water to form carbonic acids that might have increase the acidity of the soil, thus decreasing the soil pH (Swarup and Wanjari 2000 and Hati et al, 2008). The application of only fertilizers as per STCR model also decreased in pH of the soil, likely due to the nitrification of ammonium (NH_4^+) to nitrate (NO_3^-) and consequently releasing the H^+ ions. In the wheat crop, soil pH varied from 7.71 to 7.99 and 7.72 to 8.03 for the surface soil and 7.83 to 8.04 and 7.86 to 8.05 for the sub-surface soil in both raised and flat bed systems, respectively (Fig. 1). Among the planting systems, lower pH was found in the raised bed planting system compared to the flat bed system (Gaurav et al., 2018).

The electrical conductivity varied from 0.34 to 0.46 dS/m in the surface soil and 0.39 to 0.48 dS/

TABLE 2
Physico-chemical and biological properties (initial) of the experimental site

Parameters	Depth (cm)		Methodology
	0-15	15-30	
Mechanical Analysis			
Sand (%)	61.2	65.0	International Pipette Method (Day, R.P 1965)
Silt (%)	24.0	22.0	
Clay (%)	14.8	12.0	
Textural class	Sandy loam	Sandy loam	Soil textural triangle (ISSS)
Physical Properties			
Bulk Density (Mg/m)	1.53	1.58	Core sampler (Bodman 1942)
Chemical Properties			
pH	8.05	8.01	Potentiometric method (Jackson 1973)
Electrical Conductivity (EC) (dS/m)	0.43	0.37	Conductivity method (Jackson 1967)
Organic Carbon (%)	0.28	0.15	Wet digestion method (Walkley- black method 1934)
$KMNO_4$ available soil N (kg/ha)	112	85	Kjedahl distillation method (Subbiah and Asija 1956)
Olsen available soil P (kg/ha)	12	8	Olsen method (Olsen et al., 1954)
NH_4OAc available soil K (kg/ha)	220	200	NH_4Oac and flame photometry(Jackson 1973)

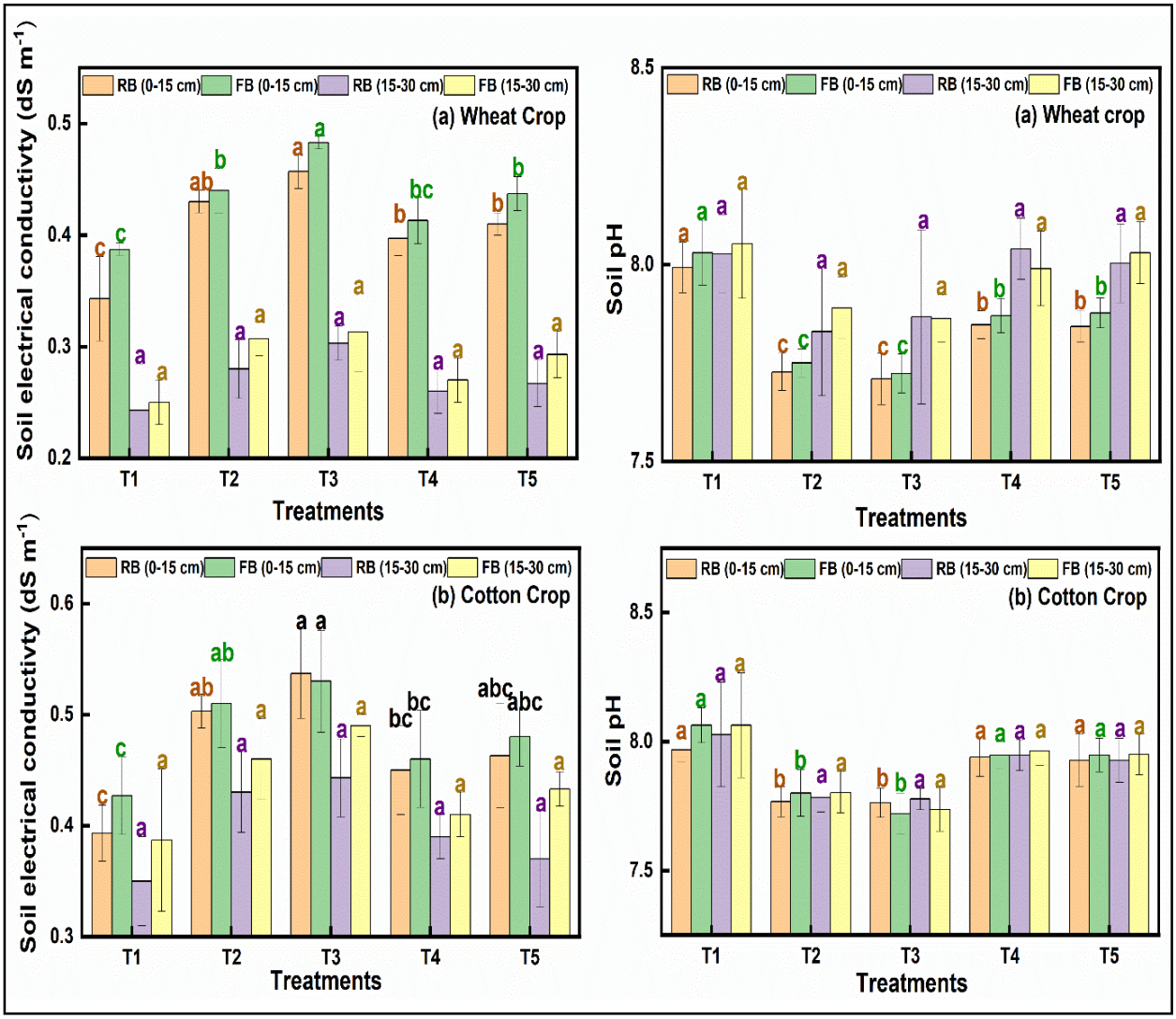


Fig. 1. Effect of nutrient management and planting system on soil electrical conductivity (dS/m) and pH at varying depth under cotton-wheat cropping system.

RB-Raised bed; FB- Flat Bed; (Error bars denote±1SD) (Treatments with same letters are not different significantly at p≤0.05).

m in the sub-surface soil for raised bed systems, and 0.24 to 0.30 dS/m in the surface soil and 0.25 to 0.31 dS/m in the sub-surface soil for flat bed systems under wheat crop (Fig. 2). The addition of organic sources of nutrients resulted in a notable rise in the electrical conductivity (EC) in the top 0-15 cm of soil compared to the control treatment. This is due to the addition of soluble salts through FYM (Antil and Singh, 2007, Goyal et al., 2008b). The water logging condition and high salt content in the study area caused due to canal irrigation water supply, may also contribute to the high levels of dissolved salts in the manures (Goyal et al., 2008a and Roy and Kashem, 2014). The electrical conductivity did not show significant differences in the fertilizer treatments (T4-T5) & FYM treatments (T2-T3) at 15-30 cm soil.

Soil organic carbon (SOC)

The increase in soil organic carbon significantly FYM alone and in combination with cow urine and biofertilizer, is likely due to improved crop growth and addition of more above and below-ground organic residue. Fertilizer alone treatments also showed higher organic carbon levels compared to control, due to increased crop yield and which enhance the addition of stubbles and root residues to the soil but was found lower than FYM (Mohrana et al., 2012; Urkurkar *et al.*, 2010; Kumar *et al.*, 2020). However, application FYM alone or combining with bio-fertilizer and cow urine formulation significantly increased soil organic matter content compared to fertilizer alone and control plots. Similar buildup of SOC due to application of

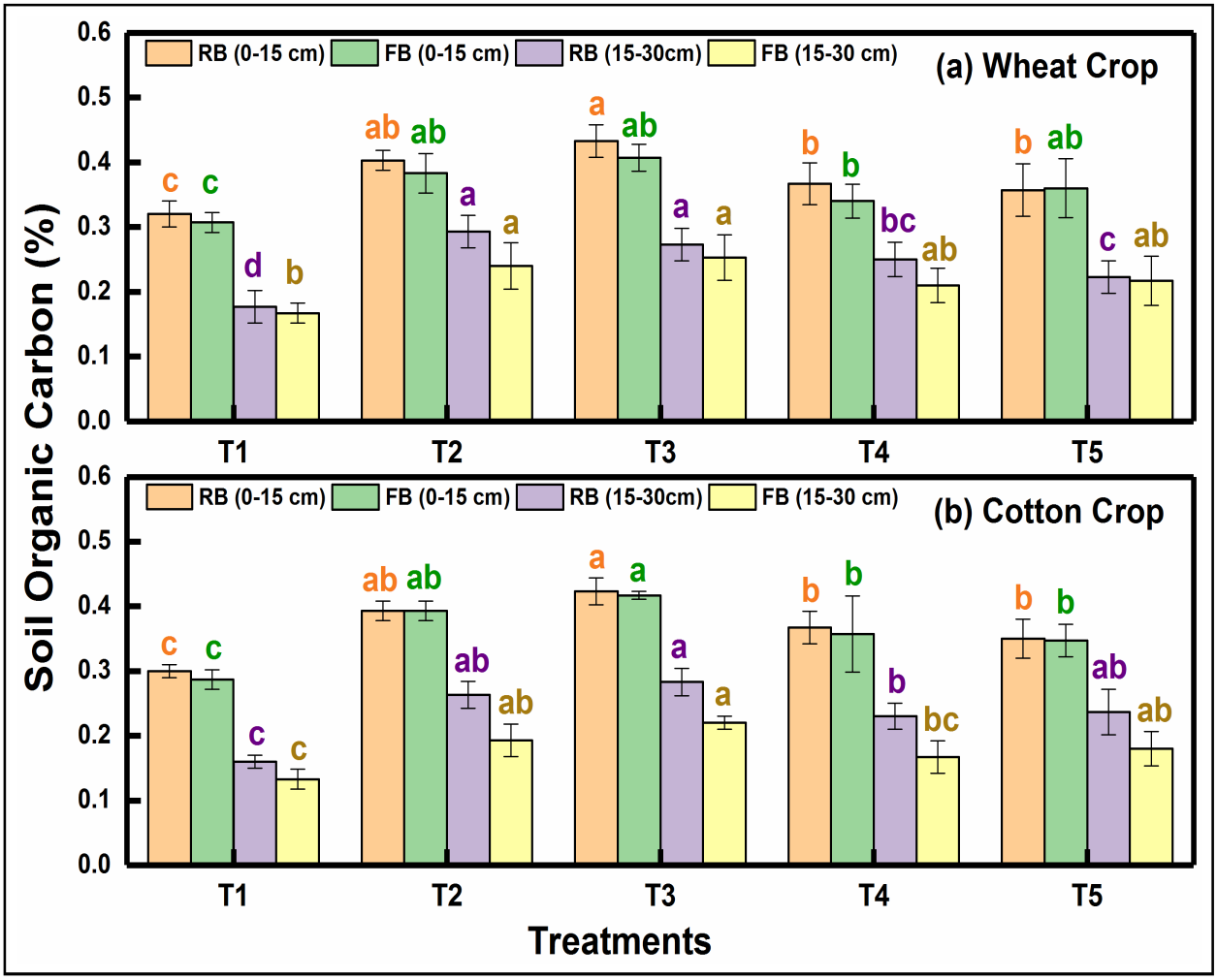


Fig. 2. Effect of nutrient management and planting system on soil organic carbon (%) at varying depth under cotton-wheat cropping system.

RB-Raised bed; FB- Flat Bed; (Error bars denote±1SD) (Treatments with same letters are not different significantly at p≤0.05).

manures on a regular basis was reported under different nutrient management studies for different cropping systems (Rani *et al.*, 2022; Sharma *et al.*, 2022; Yadav *et al.*, 2023).

Among the methods of establishing crops, slightly higher organic carbon was observed in raised bed systems compared to flat-bed systems which may be attributed to better root development (Gaurav *et al.*, 2018).

Soil available macro nutrients (NPK)

The available NPK was found to be higher in the FYM and FYM + Biofertilizer + Cow Urine based formulation treatments followed by the fertilizer treatment (STCR) and lowest under control treatment in raised bed as well as flat bed planting systems for both cotton and wheat crop as represented in Fig. 3 and Fig. 4. This may be due to the addition of organic matter which improves the biological and chemical processes during its decomposition, leading to the dissolution of nutrient ions and thus making more nutrients available to crops. Furthermore, FYM may increase the activity of soil microbes, converting the organically bound nutrients into a more readily available inorganic form (Kumar et al., 2021, Sharma *et al.*, 2023; Yadav *et al.*, 2024).

The highest available N in the wheat crop was found in treatments T3 (115.23 & 111.43 kg/ha) and T2 (110.17 & 108.19 kg/ha), followed by T4 (108.17 & 102.89 kg/ha) and T5 (109.20 & 105.00 kg/ha) in fertilizer treatments, while the lowest amount was observed in the control (95.58 to 87.47 kg/ha) in both raised bed and flat bed systems, respectively, at 0-15 cm soil depth (Fig. 3). The increase in the accessibility of phosphorus due to organics can be attributed to

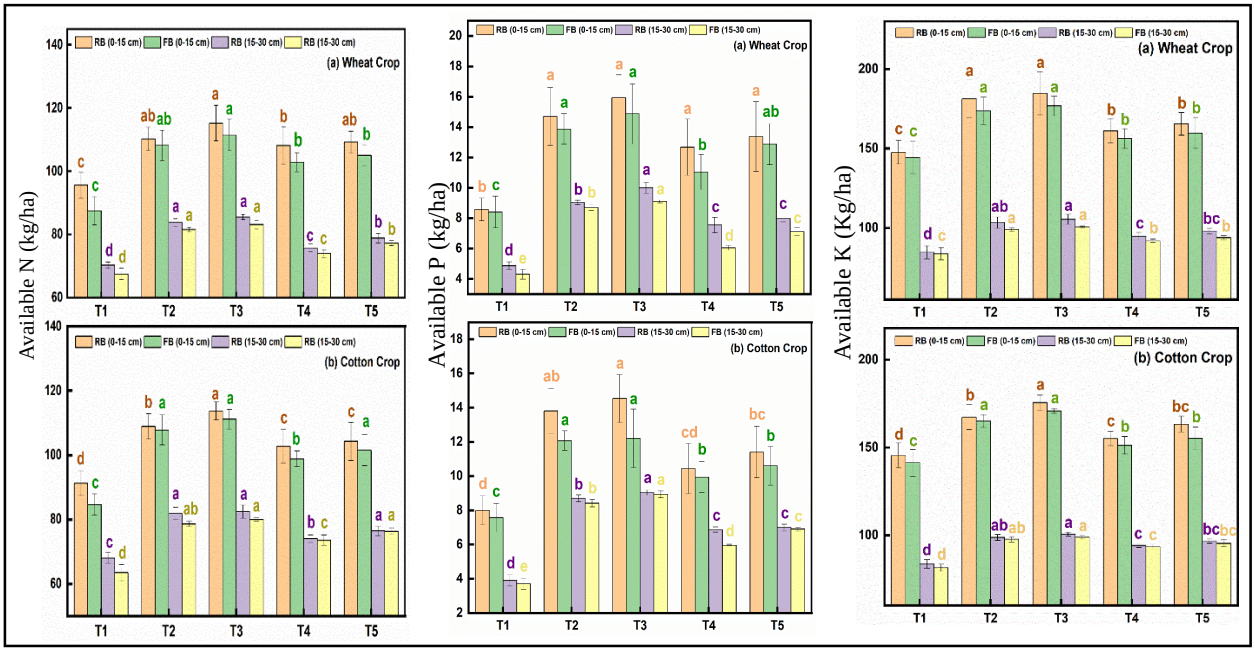


Fig. 3. Effect of nutrient management and planting system on soil available N, P and K (kg/ha) at varying depth under cotton-wheat cropping system

RB-Raised bed; FB- Flat Bed; (Error bars denote±1SD) (Treatments with same letters are not different significantly at p≤0.05)

their ability to dissolve the native soil P that lead to the mineralization of organic P due to microbial activity and increased mobility of P (Kumar *et al.*, 2020). Organic compounds like FYM and vermicompost lower the phosphate fixation capacity of soil by forming a protective layer over the sesquioxides (Tolanur and Badanur, 2003). The activity of alkaline phosphatase also influences the availability of phosphorous in soil (Sharma et al., 2022). Thakare and Wake (2015) noted that increase in the application of organic manures led to significant enhancement in potassium availability in comparison to the control treatment. This is due to the potential reduction in K fixation as a result of applying organic manure.

The raised bed system had higher available potassium (146 to 176 kg/ha) as compared to the flat bed system (141 to 171 kg/ha) in the surface soil after the cotton harvest. The corresponding values of available potassium at the subsurface depth ranged from 84 to 101 kg/ha for the raised bed system and 81 to 99 kg/ha for the flat bed system (Fig. 3). This is likely due to the reduced weed population and minimal nutrient loss from weeds, leading to increased soil nutrient availability (Gaurav *et al.*, 2018; Singh and Kler 2005).

Soil available micronutrients (Zn, Cu, Fe and Mn)

The organic treatments that involved the application of FYM alone or in combination with cow urine based formulation and biofertilizer (T2 & T3) showed a higher concentration of micronutrients such as Zn, Fe and Mn due to the conversion of nutrients from the exchange/bound site into a soluble form. On the other hand, an increase in the percentage of organic carbon resulted in a decrease in the Cu content, as Cu could become unavailable to crops due to being bound with organic matter in both planting systems under *kharif* as well as *rabi* season crop. The highest values of Zn, Fe and Mn were found in the organic treatments (T2-T3), followed by fertilizer treatments (T4-T5) whereas lowest in the control (T1) (Fig 4). The available Zn in wheat was 0.85 and 0.88 mg kg^{-1} in organic treatments (T2-T3), while it was 0.79 and 0.80 mg/kg in fertilizer treatments (T4-T5) at a soil depth of 15-30 cm in the subsurface and the concentration of micronutrients also decreased with increased soil depth from 15-30 cm (Kumar et al 2020). The concentration of micronutrients was found to be higher in the raised bed system compared to the flat bed system, possibly due to the reduced weed population and decreased nutrient loss through weeds, resulting in an overall increase in soil nutrients (Gaurav *et al.*, 2018). The Fe concentration in the soil ranges from 5.82 to 7.02 mg/kg and 3.43 to 4.23 mg/kg in the raised bed system and 6.92 to 7.02 mg/kg and 3.38 to 4.15 mg/kg in the flat bed system at the surface and sub-surface levels, respectively. At deeper levels,

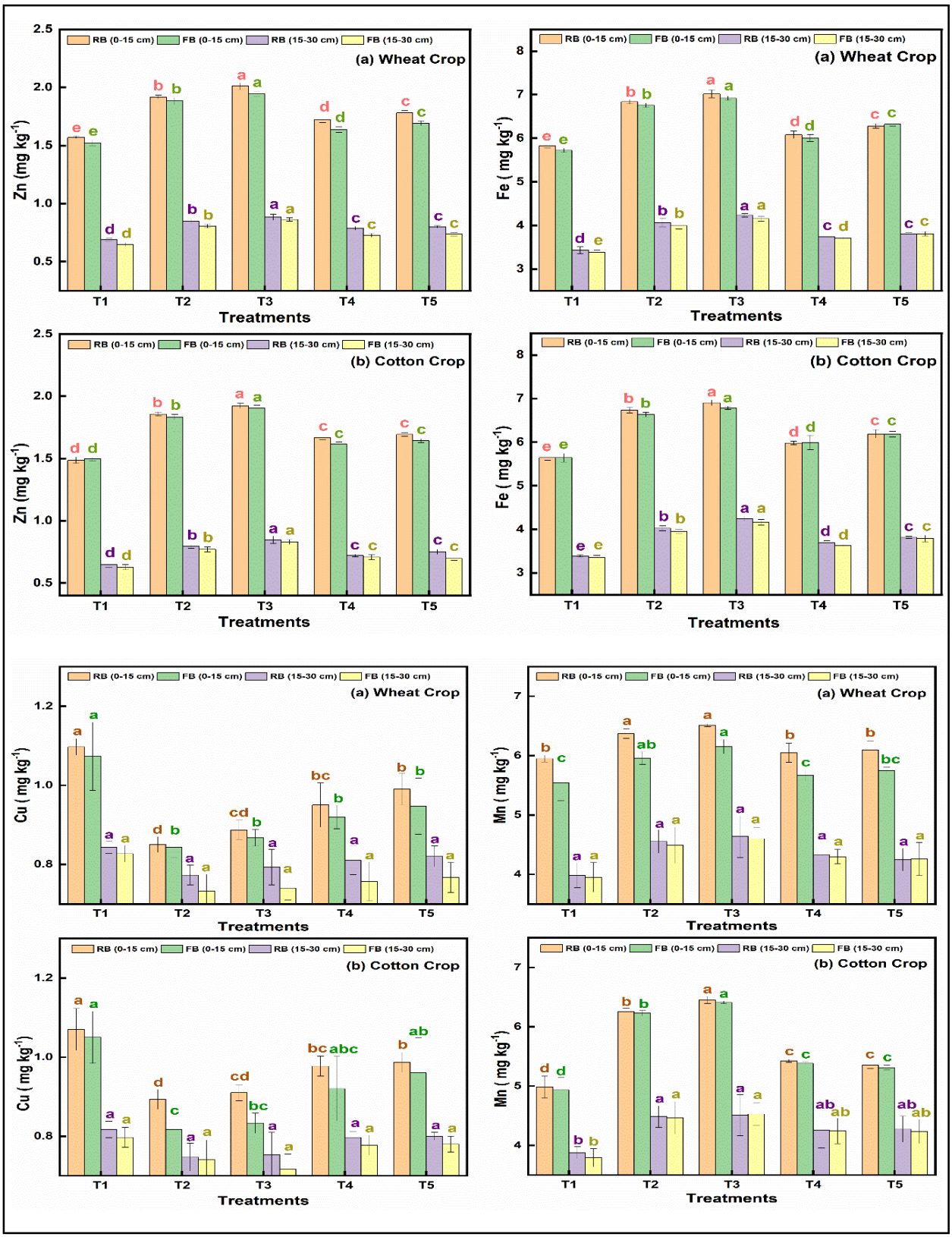


Fig. 4. Effect of nutrient management and planting system on soil available micronutrient (mg/kg) at varying depth under cotton-wheat cropping system.

RB-Raised bed; FB- Flat Bed; (Error bars denote±1SD) (Treatments with same letters are not different significantly at p≤0.05).

TABLE 3
Effect of nutrient management practices under different planting system on yield and nutrient uptake of wheat under cotton-wheat cropping system

Treatment		Yield (t/ha)		Per cent deviation
		Grain	Straw	
Wheat (Raised bed)				
T1	(Control)	1878[c]	2943[d]	-
T2	(FYM)	2002[c]	3310[d]	-
T3	(FYM+biofertilizer +cow urine based formulation)	2587[b]	4113[c]	-
T4	(STCR 5.5)	5716[a]	8502[b]	+3.93
T5	(STCR 6.0)	5905[a]	9447[a]	-1.58
	SE(m)	87.46	183.51	
	LSD (p<0.05)	290	608	
Flat bed				
T1	(Control)	1850[c]	2895[d]	-
T2	(FYM)	2010[c]	3266[d]	-
T3	(FYM+biofertilizer +cow urine based formulation)	2580[b]	4055[c]	-
T4	(STCR 5.5)	5680[a]	8468[b]	+3.27
T5	(STCR 6.0)	5885[a]	9401[a]	-1.92
	SE(m)	94.97	189.70	
	LSD (p<0.05)	315	628	

Values followed by similar letters in a column indicate non-significant difference (p<0.05) according to Duncan Multiple Range test (DMRT) for separation of means; (mean ±SE, n=3).

the micronutrient concentration follows a similar pattern as observed at the surface.

Yield

The data on grain and straw yield, per cent deviation of the target yield treatment under different planting system in wheat and cotton is shown in Table 3 & 4. The mean grain yield of wheat in control increased by 40 & 38% in FYM and/or cow urine formulation with biofertilizer treatments (T2-T3) and 218 & 215% in STCR treatments (T3-T5) under raised bed & flat-bed system of planting, respectively. The corresponding increment in grain yield was 22 & 31% of FYM (T2-T3) treatments and by 99 & 96% in fertilizer amended treatments (T4-T5) compared to control treatment T1 (1539 & 1504 kg/ha) in raised bed and flat-bed system, respectively. In FYM alone treatment, the yield was low as compared to fertilizer treatments. This may be because the nutrient release from FYM is a slow process but the plants need the nutrients in high amount during the initial period of its growth. Singh et al. (2017), and Kumar *et al.* (2017) reported the significant increase in grain and straw yield of wheat in FYM treatment over the control. Also, maximum impact on increase in grain yield was observed in treatment where NPK was applied @ 150 % of the recommended. The highest grain yield of wheat (5905 kg/ha) & (5885 kg/ha) and in cotton (3012 kg/ha) & (2987 kg/ ha) was found in STCR treatment which was significantly higher than organic amended and control treatment under raised bed & flat-bed system, respectively (Goyal and Singh 2018, Goyal et al., 2023). The wheat grain yield targets of 5.5 and 6.0 t ha^{-1} were achieved with the deviation of + 3.93 to -1.58 and + 3.27 to -1.92%, respectively in raised bed and flat- bed system of planting. However, in cotton the grain yield targets of 2.8 & 3.2 t/ha was achieved with the deviation of 3.98 to -6.65 and 6.29 to -5.88% in raised bed and flat-bed system, respectively (Goyal *et al.*, 2020, Rani *et al.*, 2026, Sharma *et al.*, 2024).

Sharma et al, (2026) observed the increment of the wheat productivity on raised beds due to exposure of more surface area to incident solar radiation in raised bed than in flat conventional treatments. The higher temperature on raised bed planting method can help in early germination and seedling emergence, particularly in winter season crops such as wheat.

CONCLUSION

The study found that the availability of macronutrients and micronutrients improved when FYM and NPK fertilizer were used with a targeted yield approach based on STCR. Even though pH marginally decrease and EC slightly increase with the addition of FYM and the effect of various nutrient management strategies adopting the STCR technique

TABLE 4
Effect of nutrient management practices under different planting system on yield and nutrient uptake of cotton under cotton-wheat cropping system

Treatment		Yield (t/ha)		Per cent deviation
		Cotton seed	Straw	
Cotton (Raised bed)				
T1	(Control)	1539[c]	3078[e]	-
T2	(FYM)	1805[b]	3294[d]	-
T3	(FYM+biofertilizer +cow urine based formulation)	1872[b]	3578[c]	-
T4	(STCR 2.8)	2976[a]	5136[b]	3.98
T5	(STCR 3.2)	3012[a]	5385[a]	-6.65
	SE(m)	23.425	39.17	
	LSD (p<0.05)	77.579	129.72	
Flat bed				
T1	(Control)	1504[c]	2987[e]	-
T2	(FYM)	1874[b]	3225[d]	-
T3	(FYM+biofertilizer +cow urine based formulation)	1968[b]	3369[c]	-
T4	(STCR 2.8)	2911[a]	5167[b]	6.29
T5	(STCR 3.2)	2987[a]	5288[a]	-5.88
	SE(m)	53.699	25.868	
	LSD (p<0.05)	177.84	85.668	

Values followed by similar letters in a column indicate non-significant difference (p<0.05) according to Duncan Multiple Range test (DMRT) for separation of means; (mean ±SE, n=3).

was found to be non-significant. A proper nutrition through FYM may have contributed to the accumulation or maintenance of these nutrients over time, as shown by the fact that available N, P and K improved significantly as the organic carbon content of the soil increased. In comparison to surface soils, the amount of accessible N, P and K decreases in subsurface soil. The amount of DTPA extractable Zn, Fe, and Mn increased as the soil's organic carbon content increased, while Cu content declined as a result of the likelihood that Cu would get attached to organic matter and unavailable to crops. Raised bed planting increased soil availability of macronutrients and micronutrients, which was significantly superior to conventional flat bed sowing method.

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