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EFFECT OF INTEGRATED NUTRIENT MANAGEMENT UNDER STCR APPROACH ON SOIL PROPERTIES IN FODDER CROPS – A REVIEW

RAJNI YADAV[1]*, K. K. BHARDWAJ[1], VISHAL GOYAL[1], SATPAL[2] AND M. K. SHARMA[1]

[1]Department of Soil Science, [2]Department of Genetics & Plant Breeding (Forage Section)
CCS Haryana Agricultural University, Hisar-125 004 (Haryana), India
(e-mail: rajniyadav211295@gmail.com)
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SUMMARY

The imbalanced uses of inorganic fertilizers deteriorates soil health, declines the soil nutrient status, increased environmental pollution and also boost the cost of production of fodder crops. Application of organic sources alone to fulfill the demand of plant essential nutrient is also complex because an enormous amount of manure is required. Therefore, to sustain soil health and production, balanced use of fertilizer based on soil test crop correlations (STCR) approach with integration of organic manures is very essential. The integrated nutrient management (INM) system includes prudent application of organic, inorganic and biofertilizer in fodder crop to achieve optimal yields without causing harm to ecosystem. Application of integrated nutrient management practices improves availability of soil macro and micronutrient content in soil. The soil organic carbon, microbial biomass carbon,microbial population, urease, dehydrogenase and phosphatase activity were found highest under integrated treatments as compared to devoid of manures in fodder production. Hence it may be concluded that soil physical, chemical and biological properties are efficiently improved by adopting the integrated nutrient management practices.

Key words: Fodder, fertilizer, integrated nutrient management and soil test crop response

Fodder crop production varies throughout the India and its utilization dependent on factors such as cropping patterns, socio-economic conditions and the type of livestock being raised. In India, approximately 4.9% of agricultural land is utilized for cultivating green fodder, with a deficit of 26 and 35.6% in dry fodder and green fodder, respectively. Punjab and Haryana accounts 8% of their total cultivable land to fodder crops (Jemimah *et al.* 2015; Bhardwaj *et al.* 2023). Fodder sources in India include crop residues, cultivated fodder and communal resources such as permanent pastures and grazing lands. The country faces a significant gap between fodder availability and demand due to various forage crops grown across different seasons and regions, the non-commercial nature of crops and the minimal input in forage production from degraded and marginal lands (Ghosh *et al.* 2016). Amplifying fodder production proves challenging due to increasing human pressure on land for oilseed, pulse and cereal production.

The pressure on land cause intensive use of inorganic fertilizers in agricultural fields and resulted in environmental pollution. To produce high-quality fodder crops without damaging the environment, it is necessary to adopt INM. Integrated nutrient management involves the use of a combination of organic, inorganic and biological components to enhance soil fertility and provide essential nutrients to plants (Nabi *et al.* 2021). Organic fertilizers provide nutrients to plants in limited quantities and exhibit a gradual release compared to synthetic fertilizers. However, they contain growth hormones and enzymes that contribute to soil health, thereby enhancing agricultural output and soil fertility (Usman *et al.* 2013). They enhance the soil physical, chemical and biological properties, augmenting the accessibility of both native and applied nutrients. Moreover, organic fertilizers encourage soil aggregation, rendering it more porous and conducive to air and water movement, as well as nutrient absorption (Yadav *et al.,* 2023). Additionally, during the decomposition of organic matter, nutrients are released into the soil, acting on insoluble nutrient reserves and rendering them biologically available while nourishing beneficial soil microbes (Abhishek *et al.* 2023). By adopting INM, it is possible to promote sustainable agriculture and ensure that the environment is not degraded by chemical fertilizers. Although chemical fertilizers give in an immediate benefits in terms of crop production (Krasilnikov *et al.* 2022; Satpal *et al.* 2021a), while their prolonged use can compromise soil stability by reducing macro and micro-aggregate formation, impeding moisture retention and increasing bulk density, thereby diminishing productivity. Therefore, to uphold soil sustainability and productivity, it is necessary to integrate organic and inorganic fertilizer sources and adopt balanced fertilization practices (Bayu, 2020; Satpal *et al.* 2020).

The practice of prescribed fertilizer applications according to soil test values and crop requirements is essential for maintaining sustainable productivity which is site specific. Right proportioned and optimally quantity of fertilizers are imperative for effective nutrient management for specific site, as neglecting this aspect can lead to a decline in soil fertility and overall productivity. Achieving balanced fertilization requires the adoption of an integrated approach to plant nutrient supply (Saxena *et al.* 2008; Chatterjee *et al.* 2010).

The concept of using targeted yield equations to recommend fertilizer doses based on soil test values contributes to balanced fertilizer and nutrient application in the soil. This approach not only accounts for the nutrient demands of the crop but also considers the soil's fertility status, a crucial factor for successful crop cultivation at specific site. The theory of targeted-yield-based optimum fertilizer prescription was initially proposed by Trong (1960) and later refined by Ramamurthy *et al.* (1967) as the inductive cum targeted-yield model. Equations of soil test-based fertilizer for achieving targeted yields of pearl millet and maize crops present in table 1. The targeted-yield approach provides a scientific base for balanced fertilization by incorporating nutrients from external sources and those available in the soil (Gayathri *et al.* 2009; Satpal *et al.* 2021b). Therefore, this article emphasizes the impact of integrated nutrient management on various physico-chemical and biological soil properties under fodder crops using balanced fertilizer equations.

TABLE 1

Soil test based fertilizer equations for targeted yield

Pearl millet crop	Maize crop
F (N) = 10.48(T) – 1.60S(N) – 0.13 (FYM)	F (N) = 3.36(T) –0.535 S(N) – 0.72 (FYM)
F (P_2O_5) = 4.39(T) – 5.64S(P) – 0.14 (FYM)	F (P_2O_5) = 0.70(T) –0.965 S(P) – 0.52 FYM
	F K_2O = 0.63(T) –0.065 S(K) –0.11(FYM)

where, F(N) and F(P_2O_5) are fertilizer N and P_2O_5 (kg/ha) rates, S(N) and S(P) are the soil test values (kg/ha) for $KMNO_4$-N and Olsen's P, FYM (N) and FYM (P_2O_5) are the N and P_2O_5 in FYM (kg/ha) and T is the targeted yield (Mg/ha).

Effect on soil physico-chemical properties

Rani *et al.* (2022) observed that soil pH decreased slightly in the treatments where FYM was applied either alone or integrated with the fertilizers while electrical conductivity was increased significantly over the control. Continuous practices of FYM (Farm yard manure) in integrated & organic treatment SOC (Soil organic carbon) increased by 72.99 & 69.66% respectively and in only fertilizer treatments improved by 26.09-30.40% from its initial value. However, after 10 years of experiment the SOC was decreased by 40.46% in control. Available N and P were positively influenced by various nutrient management practices including organic and integrated treatments, which showed a significant increasing trend in available N and P compared to fertilizer alone and control treatments. The P content in soil was increased by 68-125%, 56-112% and 5-42% in integrated, organic and fertilizer treatments, respectively while in control available P was decreased by 18-26% as compared to initial values. In control and chemical treatments, available K was decreased significantly, whereas it increased significantly in organic and integrated treatments where FYM was applied to the soil. The soil micronutrients (Zn, Fe and Mn) increased significantly over the control in the organic and integrated treatments. However, Cu concentration had showed no significant differences among the various nutrient management practices in the pearl millet-wheat cropping system.

Sharma *et al.* (2022) reported that various nutrient management approaches resulted in different levels of total phosphorus accumulation. Notably, the NPKM treatment exhibited the highest increase (30%), followed by FYM (25%), BFSTCR (19%) and NPK (19%) in comparison to the control treatment at a surface depth of 0–15 cm. Application of organic manures significantly augmented the available phosphorus concentration by 182% and 162% in surface soils under NPKM and FYM treatments, respectively as compared to initial concentration (7.5 mg/kg). Throughout the soil profile (0–90 cm), the total phosphorus increased by 5.21, 6.30, 6.32, and 8.79% in FYM, NPK, BFSTCR and NPKM treatments, respectively. The available phosphorus levels were surged by 86.85, 30.02, 63.26 and 101.89% in FYM, NPK, BFSTCR and NPKM treatments, respectively as compared to the control.

Pandey and Srivastava (2021) concluded that the combined application of organic manures with chemical fertilizers under STCR approach of maize crop enhanced the water holding capacity, available N, P and K. The application of green manures with STCR treatments showed the highest organic carbon content i.e. 0.99%. The percentage increase of water holding capacity were (24.21% and 30.88%), organic carbon (18.67% and 41.27%) available N (22.22% and 29.41%), P (18.94% and 43.96%) and K(0.42% and 12.03%) with application of fertilizer along with FYM@10tonnes as compared to chemical fertilizer alone using STCR approach and recommended doses of fertilizers, respectively.

Kumar *et al.* (2021) found that sole (FYM) or integrated application of FYM increased the soil organic carbon by 148% and 62% while in fertilizer nutrient treatments SOC decreased by 63.0% and 6.5% in as compared to control at 0–15 and 15–30 cm, respectively. The application of organic manure or chemical fertilizers either alone or in combination significantly enhanced soil saturated hydraulic conductivity (Ks) and water stable aggregates (WSA) over the control treatment while penetration resistance was observed lowest in organic manure or integrated nutrient management practices and highest under the control. The study further demonstrated that the continuous application of FYM, fertilizers or integrated nutrient management practices increased the infiltration rates by 36.3–78.9% in wheat and 45.8–91.9% in pearl millet. Plant available water content was found to be increased by 8.0 and 16.0% in surface and subsurface soils, respectively in FYM alone or integrated treatment as compared to the control. However, in fertilizer-treated plots, available water increased by 1.3 to 5.2%.

The result of integrated nutrient management practices with various treatments of STCR was studied by Kumar *et al.* (2020).They concluded that the application of FYM showed a non-significant effect on pH and EC under pearl millet crop both surface and sub-surface soils. The application of FYM alone or combined with fertilizer (STCR-IPNS) resulted in a more than 100% increase of soil organic carbon content in surface soil, whereas it increased by 63 to 77% in RDN&P and STCR treatments compared to the control. In the lower soil depth (15-30 cm), organic carbon increased by 48 to 62% with FYM and STCR-IPNS treatment and by 7-27% with RDN&P and STCR treatments. The soil available N, P and K significantly increased with the enhancement of organic carbon content, likely due to balanced nutrition from FYM aiding in the buildup or maintenance of these nutrients over time. In sub-surface soil, available N, P and K decreased as compared to surface soils. The DTPA extractable micronutrient (Zn, Fe, Cu and Mn) increased with the organic carbon content of the soil. The highest Zn content in pearl millet was observed in the STCR-IPNS treatment (2.52 & 2.23 mg/kg in surface soils and 1.09 & 1.24 mg/kg in sub-surface soil), followed by FYM, RND&P, STCR and the lowest in control treatment. Similarly, Fe, Cu and Mn concentrations were highest in the STCR-IPNS treatment and lowest in the control.

Kurbah and Dixit (2019) observed a significant increase in soil available potassium with the use of Integrated Plant Nutrient Systems (IPNS) with target yields compared to the general recommended dose and soil test-based treatments. The various forms of potassium, including water-soluble K, exchangeable K and non-exchangeable K, exhibited the highest levels under the Soil Test Crop Response IPNS treatment for a target yield of 35 q/ha. Non-exchangeable potassium levels were notably lower in unfertilized plots compared to all other treatments. The application of FYM in treatments with target yields of 25 and 35 q ha^{-1} led to significant improvements in available K & water-soluble K content, with increases of 1.5 & 3.3% and 7.8% & 10.6%, respectively, compared to the same treatments without FYM. Exchangeable K & non-exchangeable K levels were also significantly higher with the application of the general recommended dose and soil test-based treatments, showing increases of 29.9 & 37.7% and 8.8 & 9.1%, respectively, over the control. Under the STCR IPNS approach for target yields of 25 and 35 q/ha, exchangeable K was slightly increased by 0.9 and 1.8% when FYM was added compared to the corresponding treatments without FYM. The integrated nutrient management approach also enhanced soil organic carbon content by 0.44 to 0.66%, available nitrogen by 152.8 to 164.9 kg/ha, phosphorus by 22.8 to 31.4 kg/ha, potassium by 140.6 to 168.0 kg ha^{-1}, and the DTPA-extractable and total micronutrients (Zn, Cu, Fe and Mn) status of soil with FYM application.

Moharana *et al.* (2017) reported that consistent application of organic manure either alone or in combination with fertilizer observed significant alterations in soil physico-chemical properties of soil than that of unfertilized control and NPK treated plots. The pH and bulk density were found lower for the soils in which FYM @ 20 t/ha was applied in pearl millet and wheat crop. While the SOC content, cation exchange capacity, Zn and Fe content were increased with application of organic manure as compared to the control treatments where no fertilizer or manure was applied. The SOC build-up under sole FYM and with combination of fertilizer were increased by 43.1 and 27.5% over treatment receiving only fertilizer and increased by 49.0 and 32.7% over control treatment (no fertilizer or manures). However, no significant differences in EC, Cu and Mn content were observed among the treatments.

Sharma *et al.* (2016) conducted a study where they found that the application of STCR based fertilizer, along with 10 tonnes of FYM/ha, led to a significant increase in the available N, P and K content as compared to the RDF (recommended dose of fertilizer) and STCR alone. They observed that higher levels of available nitrogen (235 kg/ha) and available potassium (288.8 kg/ha) were found with the application of 20 tonnes of FYM/ha. The application of organic manure (10 tonnes of FYM ha^{-1}) alone, with combination of STCR-based fertilizer and STCR-based chemical fertilizer enhanced the soil available phosphorus content in as compared to the treatment with no manure or fertilizer (control). However, the available phosphorus showed non-significant effect among organic manure alone or in combination with STCR and STCR-based chemical fertilizer treatment. The application of organic manure (20 tonnes of FYM/ha) alone and STCR-based fertilizer with 10 tonnes of FYM/ha showed statistically similar levels of available K content.

Sharma *et al.* (2015) studied the effect of STCR-IPNS under pearl millet-wheat cropping system and observed an increment of 46.7% for N and 56.3% for K with the application of FYM at 20 t ha?1 over the control, while STCR-IPNS increased the soil available N and K by 20.57% and 13.40%, respectively over the STCR-based fertilizer application. The application of STCR-based fertilizer recommendations and organic manure had a significant effect on EC. The application of inorganic fertilizer slightly increased the EC of the soil compared to organic and integrated treatments. The treatments that received FYM @ 20 tonnes ha?1 and STCR-IPNS showed a greater accumulation of available micronutrients in the surface soil compared to recommended doses of fertilizer and control treatment.

The integrated nutrient management using FYM + 100% NPK resulted in the highest soil quality index (2.45), followed by 150% NPK of the recommended dose (2.15) and FYM alone (2.16). Conversely, the control treatment observed the lowest quality index (1.14), followed by 50% recommended dose of fertilizer (1.45), indicating improved soil quality with integrated nutrient management practices (Katkar *et al.*, 2012).

Moharana *et al.* (2012) observed the significant increase in total organic carbon (52.5% & 47.1%), Walkley and Black organic carbon (49.0% & 32.7%), and labile organic carbon (51.9% & 72.2%) in surface layers with the application of FYM & FYM + NPK treatments as compared to the unfertilized control while they were 35.0 & 30.3%, 43.1 & 27.5% and 27.7 & 44.7% greater over NPK treatment, respectively. In the sub-surface soil, Walkley and Black organic carbon were higher in plots treated with FYM alone (4.1 g/kg) and FYM + NPK fertilizer (3.8 g/kg) compared to plots receiving only NPK fertilizer (3.0 g/kg) and the control (2.5 g/kg). Moreover, higher variations in labile organic carbon with the combined application of FYM + NPK fertilizer signify that this pool of organic carbon is more sensitive to alter due to the application of manure and fertilizer.

Effect on soil biological properties

Pandey and Srivastava (2021) found that with the application of FYM along with STCR based NPK fertilizers enhance the enzymatic and microbial activities in soil. The application of STCR based fertilizer along with 10 tonnes FYM/ha recorded the increment in dehydrogenase activity (8.09 and 13.17%), urease activity (14.38 and 19.71%) & microbial biomass carbon (6.17 and 26.47%) as compared to STCR based on fertilizers alone and recommended doses of fertilizers, respectively.

Kumar *et al.* (2020) recorded that the microbial biomass carbon in soils increased by 71 to 80% and 47 to 77% at 0-15 and 15-30 cm soil depth, respectively where organic manure was applied either alone or integrated with chemical fertilizers in both the crop. The pearl millet crop exhibited an increase of 2% and 12% in the surface soil under the RDN&P and STCR treatments.

Mageshen *et al.* (2020) concluded that the treatment receiving STCR-NPK alone @ 160 q/ha exhibited the highest urease activity (11.66 µg NH4-N/g/h), while the control showed the lowest urease activity (10 µg NH_4-N/g/h). For phosphatase enzyme, the highest activity was recorded in the treatment receiving STCR-NPK alone @ 180 q/ha (13.90 µg PNP/g/h), whereas the lowest was observed in FYM

@ 12.5 t/ha (12.22?g PNP/g/h). The dehydrogenase activity on the 0th day after incubation, the treatment receiving STCR + IPNS @ 180 q/ha was observed the highest activity (2.23 µg TPF/g/day), followed by FYM @ 12.5 t/ha (2.12 µg TPF/g/day) and STCR + IPNS @ 170 q/ha (2.06 µg TPF/g/day).

Sharma *et al.* (2015) observed that highest soil microbial biomass carbon (318.4 µg/g dry soil) was found in soil where STCR based integration fertilizer recommendation was applied while lowest was in control *i.e.* 163.5 µg dry soil. In INM treatment, the dehydrogenase activity (9.2 µg TPF/g/day) was recorded significantly higher as compared to other treatments. The dehydrogenase activity was increased by 8 and 51% due to integration of FYM and STCR based fertilizer recommendation over FYM @ 20 t/ha and fertilizer recommendation based on STCR, respectively.

Mohrana *et al.* (2012) found that the microbial biomass carbon contents significantly increased in plots treated with FYM + NPK and FYM alone as compared to the plots treated with NPK fertilizer and control. The MBC values were increased by 56.3 under FYM and 76.5% under FYM + NPK treatments as compared to the control in surface soil. Furthermore, there were 26.7 and 43.0% increase in MBC over the NPK fertilizer, respectively. The synergistic effect of FYM and NPK fertilizer applications was stimulated higher root biomass turnover, leading to the increased MBC under FYM + NPK treatment.

CONCLUSION

The imbalanced use of chemical fertilizers over a long period of time degraded the soil health and productivity which can be improved by adopting INM with STCR approach. The integratedapplication of manures and fertilizers based on STCR approach improves the soil physical (water stable aggregates, penetration resistance and infiltration rate), chemical (pH, EC, SOC and nutrient status) and biological properties (microbial count, microbial biomass carbon, urease, dehydrogenase and phosphatase activity) of soil. The integration of organic manures withfertilizers increased the SOC, available N, P, K and DTPA extractable micronutrients. Organic manures also acts as a source of energy for proliferation of microbes and enzyme activities. Therefore, the integration of INM with balanced fertilizer with STCR approach maintains the soil health and provides a healthier environment for growing plants through enhanced soil properties, nutrient status and their translocation.

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