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Dynamics of Soil Physicochemical and Biological Properties Under Integrated Nutrient Management in Maize-grown Vertisols

Urmila Choudhary[1], R. K. Yadav[2*], V. K. Yadav[2], M. K. Sharma[2], K. M. Sharma[2], S. L. Yadav[2], H. P. Meena[2], J. P. Tetarwal[2], C. K. Jadon[2], Sarita Kumari[3], Barkha Kumari Verma[4] and Punita Dhankar[1]

[1]Dept. of Soil Science and Agricultural Chemistry, SKRAU, Bikaner, Rajasthan (334 006), India
[2]Agricultural Research Station, Kota (Agriculture University, Kota, Rajasthan (324 001), India
[3]Dept. of Soil Science & Agri. Chemistry, C.P.C.A., Sardarkrushinagar, Dantiwada Agriculture University, Gujarat (385 506), India
[4]Dept. of Soil Science & Agri. Chemistry, Sri Karan Narendra Agriculture University, Jobner, Jaipur, Rajasthan (303 329), India

Corresponding Author

R. K. Yadav
e-mail: raj91yadav@gmail.com

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Abstract

The experiment was conducted in July 2023 at Research Farm, Agricultural Research Station, Ummedganj- Kota, Rajasthan, India. The experiment consisted ten treatment combination: T_1: Absolute control, T_2: 100% RDF, T_3: STCR (Soil test crop response), T_4: 50% RDF (Recommended dose of Fertilizer)+50% FYM (Farm yard manure), T_5: 100% FYM, T_6: 50% RDF+50% poultry manure, T_7: 100% Poultry manure, T_8: 100% RDF+Biofertilizer (*Azotobacter*+PSB), T_9: 50% RDF+50% FYM+Biofertilizer (*Azotobacter*+Phosphate solubilizing bacteria) and T_{10}: 50% RDF+50% poultry manure+Biofertilizer (*Azotobacter*+Phosphate solubilizing bacteria) was laid out in randomized block design with three replications. Maize hybrid variety PHM-3 was used as the test crop. The soil-test crop response (STCR) approach, which is currently gaining importance for sustainable nutrient management, aims to adjust fertilizers for the desired yield based on soil-test values. The STCR-based experiment was conducted for the desired maize production targets in shallow black (Vertisols) soil. The application of fertilizer through the STCR recorded the highest available nitrogen (256.5 kg ha^{-1}), phosphorus (27.41 kg ha^{-1}) and potassium (386.5 kg ha^{-1}). The highest micronutrient content (Zn, Cu, Fe, and Mn) was recorded in T_7 (100% poultry manure). The application of 100% FYM (T_5) resulted in the highest physico-chemical and biological properties *viz*., organic carbon, cation exchange capacity, water holding capacity, microbial population (bacteria: 6.60 10^8 cfu g^{-1} soil, fungal: 17.37 10^4 cfu g^{-1} soil and actinomycetes: 5.42 10^4 cfu g^{-1} soil) and enzyme activities (alkaline phosphatase: 21.02 µg *p*-nitrophenol g^{-1} soil h^{-1}, dehydrogenase: 23.69 µg TPF g^{-1} soil 24 h^{-1} and urease: 6.79 µg NH_4N g^{-1} soil h^{-1}) respectively.

Keywords: STCR, biofertilizer, integrated nutrient management and farm yard manure

1. Introduction

Maize (*Zea mays* L., 2n=20) is widely known as the “Miracle crop” and the “Queen of cereals” due to its diverse uses as food, livestock feed and industrial raw material. It is a highly versatile crop grown for grain, fodder, silage, baby corn, popcorn and sweet corn (Bhaskar et al., 2024). In India, maize ranks third among cereals after rice and wheat in terms of importance (Mahapatra et al., 2018; Pandey et al., 2016; Suganya et al., 2020). Being a C4 crop, maize has high photosynthetic efficiency and nutrient demand, extracting large amounts of nutrients from the soil due to its high grain and biomass yield (Roy et al., 2023). Globally, maize is cultivated on about 159 mha across more than 150 countries. In India, it is grown on 10.74 mha with a production of 38.09 mt and productivity of 3540 kg ha^{-1} (Anonymous, 2023). In Rajasthan, maize occupies 0.95 mha with a production of 2.04 mt and productivity of 2149 kg ha^{-1} (Anonymous, 2022). About 80% of maize is cultivated during the *kharif* season under rainfed conditions, mostly using medium and long-duration hybrids (Sree et al., 2024). Fertilizers play a crucial role in crop productivity; however, continuous and imbalanced use of chemical fertilizers adversely affects soil health and long-term productivity. Modern agricultural practices have led to reduced use of organic inputs (Bharti and Sharma, 2017). To address this issue, the concept of targeted yield-based fertilizer recommendation was proposed by Truog (1960) and later refined into the Soil Test Crop Response (STCR) approach by Ramamoorthy et al. (1967). The STCR approach is an efficient method for balanced and economic fertilizer use. It uses mathematical equations to recommend fertilizer doses based on soil test values and desired yield targets. This approach considers nutrient contributions from soil, fertilizers and organic sources, ensuring optimal nutrient use efficiency and sustainable crop production (Muttappanavar et al., 2022). It also helps minimize environmental impacts while maintaining soil fertility (Bera et al., 2006; Panday and Srivastava, 2021). Organic manures play a significant role in supplementing crop nutrient requirements and improving soil health. Farmyard manure (FYM) and vermicompost not only supply essential macro and micronutrients but also enhance soil organic matter and microbial activity. These inputs improve soil structure, nutrient availability and plant growth, while increasing resistance to pests and diseases. Organic fertilizers also contain beneficial microorganisms and growth-promoting substances that enhance metabolic activity in plants. The integration of organic and inorganic nutrient sources is essential for sustainable agriculture. It helps reduce dependence on chemical fertilizers, lower production costs and improve soil health forming the basis of the sustainable agriculture triangle. Organic inputs also provide residual benefits to succeeding crops through the gradual release of nutrients. Therefore, developing suitable combinations of chemical fertilizers and organic manures tailored to specific soils and cropping systems is necessary. The present study was undertaken to evaluate the long-term effects of different combinations of organic and inorganic nutrient sources on maize productivity and soil fertility, aiming to achieve sustainable crop production and maintain soil health.

2. Materials and Methods

2.1. Experimental site and climate of the area

The one-year field experiment was conducted at the Research Farm, Agricultural Research Station, Ummedganj-Kota, Rajasthan, during the *kharif* 2023. The station is located in the south-eastern part of Rajasthan at 75°25’ E longitude, 25°13’ N latitude, and an altitude of 258 m above mean sea level. Climate and weather play a great role in the growth and development of crops. Hence, it is important to present the climatic variables of this region. In the Kota region, the wet season is oppressive and mostly cloudy, the dry season is mostly clear, and it is classified as hot around the year. The rainfall ranges from 550 mm to 1400 mm, most of which (80–85%) is received during July to September from the south-west monsoon, whereas winter showers occur occasionally. Taxonomically, the soil of the study area falls in the order ‘Vertisol’. The soil was clay in texture and near to neutral in reaction.

2.2. *Treatment details and treatments of the investigation*

The experiment was laid out in a randomized block design (RBD) with ten treatments and three replications. The experiment comprised ten treatments: T_1: Absolute control, T_2: 100% RDF, T_3: STCR, T_4: 50% RDF+50% FYM, T_5: 100% FYM, T_6 50% RDF+50% poultry manure, T_7: 100% poultry manure, T_8: 100% RDF+Biofertilizer (*Azotobacter*+PSB), T_9: 50% RDF+50% FYM+Biofertilizer (*Azotobacter*+PSB) and T_{10}: 50% RDF+50% PM+Biofertilizer (*Azotobacter*+PSB).

The initial soil samples varied in levels of N, P and K from 219.5, 25.7 and 390.6 kg ha^{-1}, respectively. Additionally, the pH and EC values of the research field were measured to be 7.56 and 0.32 dS m^{-1}, respectively. The STCR equation was taken from Jabalpur, Madhya Pradesh (Anonymous, 2021). The target yield equation developed for the maize crop was used for the calculation of N and P_2O_5, considering the target yield 45q ha^{-1}.

RDF-90:30 kg ha^{-1} N: P_2O_5, respectively.

STCR-The fertilizer adjustment equation is given below:

FN= 4.40 T- 0.23 SN
FP_2O_5=2.38 T-1.40 SP_2O_5
FK_2O=2.07 T-0.08 SK_2O

Where,

T=Target yield (q ha^{-1})

FN=Nitrogen supplied through fertilizer in kg ha^{-1}

FP_2O_5=Phosphorus supplied through fertilizer in kg ha^{-1}
FK_2O=Potassium supplied through fertilizer in kg ha^{-1}

SN, SP_2O_5 and SK_2O=Initial soil test value for available N, P_2O_5, and K_2O in kg ha^{-1}, respectively.

As per the STCR equation, 148 kg ha^{-1} nitrogen and 72 kg ha^{-1} phosphorus have been applied.

2.3. Collection of soil samples

Soil samples were collected from random spots in the field at a depth of 0–15 cm, both before planting and after harvesting the maize crop. The samples were then prepared to check the physical, chemical, and biological properties of the soil. The soil was air-dried, gently crushed, and passed through a sieve. A part of the sample was kept in a deep freezer at 4°C to test for biological properties later.

2.4. Soil analysis

Soil tests were done using different standard methods. Water holding capacity was measured using Keen’s box method. Organic carbon was tested using the Walkley and Black method 1934. Available nitrogen was measured with the alkaline potassium permanganate method (Subbiah and Asijia, 1956). Available phosphorus was checked using a sodium bicarbonate solution at pH 8.5 (Olsen, 1954). Available potassium was measured using ammonium acetate at pH 7.0 (Hanwey and Heidel, 1952). Micronutrients like zinc, copper, iron, and manganese were tested using the DTPA method (Lindsay and Norwell, 1978). Soil microbes were counted using the serial dilution plate method (Koch, 1883). Dehydrogenase activity was measured using the method by Klein et al. (1971). Urease activity was tested using the method by Tabatabai and Bremner (1972).

3. Results and Discussion

3.1. Physico-chemical properties

The application of farmyard manure (FYM) significantly improves soil physical properties. The lowest bulk density (1.30

Mg m^{-3}), lowest particle density (2.66 Mg m^{-3}), highest porosity (51.26%), highest water holding capacity (41.85%), highest organic carbon (0.60%), and highest cation exchange capacity (23.52 Col (P$^+$) kg^{-1}) were recorded with the application of 100% FYM (Result showed in Table 1) . This was due to the high organic matter content in FYM, which enhances soil physical properties. The application of fertilizer through the STCR resulted in maximum available nitrogen in soil (256.5 kg ha^{-1}), available phosphorus (27.41 kg ha^{-1}) and available potassium (386.5 kg ha^{-1}). Results of available nitrogen, phosphorus and potassium are shown in Table 2 the higher available nitrogen, phosphorus and potassium in the soil after the harvest of crops in the STCR approach can be attributed to several factors. Firstly, the STCR approach ensures balanced fertilization by applying fertilizers based on the specific nutrient requirements of the crop and the nutrient status of the soil, which minimizes nutrient losses and enhances nutrient use efficiency. By matching fertilizer application with the crop's nutrient demand, the STCR approach reduces nutrient losses through leaching, volatilization and denitrification, leading to more efficient nutrient uptake by plants and less nutrient wastage (Sellamuthu et al., 2015). Results from Table 3 showed that the highest levels of micronutrients were found with the application of 100% poultry manure, including available zinc 0.74 mg kg^{-1}, copper 1.36 mg kg^{-1}, iron 5.62 mg kg^{-1}, and manganese 3.90 mg kg^{-1}, respectively. Poultry manure releases a significant quantity of micronutrients into the soil during mineralization. The application of poultry manure enhances micronutrient levels in soil through the decomposition of organic matter. Zn plays a significant part

Table 1: Effect of integrated nutrient management on physico-chemical properties of soil

Treatment	BD Mg	PD Mg	Porosity	WHC	Soil pH	Soil EC	OC	CEC
T_1	1.35	2.71	50.03	36.85	7.71	0.41	0.49	20.76
T_2	1.33	2.69	50.43	38.65	7.69	0.38	0.52	21.78
T_3	1.34	2.70	50.24	38.27	7.54	0.39	0.50	21.61
T_4	1.31	2.67	50.94	39.71	7.65	0.35	0.57	22.61
T_5	1.30	2.66	51.26	41.85	7.56	0.34	0.60	23.52
T_6	1.32	2.68	50.68	39.13	7.67	0.37	0.55	22.36
T_7	1.30	2.67	51.24	41.21	7.58	0.36	0.59	23.41
T_8	1.32	2.68	50.62	38.93	7.68	0.39	0.54	22.26
T_9	1.31	2.67	51.12	40.35	7.62	0.36	0.58	22.87
T_{10}	1.31	2.68	51.05	40.28	7.60	0.37	0.56	22.77
SEm±	0.02	0.04	0.98	0.65	0.04	0.02	0.01	0.19
CD (p=0.05)	NS	NS	NS	1.94	NS	NS	0.03	0.56

Table 2: Effect of integrated nutrient management on available nitrogen, phosphorus and potassium in soil

Treatment	Available nitrogen (kg ha^{-1})	Available phosphorus (kg ha^{-1})	Available potassium (kg ha^{-1})
T_1	235.4	18.96	360.9
T_2	252.6	24.07	379.5
T_3	256.5	27.41	386.5
T_4	244.3	20.71	366.7
T_5	238.5	19.72	363.2
T_6	246.5	21.56	370.9
T_7	240.6	20.49	364.3
T_8	254.8	25.47	381.8
T_9	249.4	22.47	375.8
T_{10}	251.8	23.48	378.3
SEm±	2.9	0.46	5.1
CD (p=0.05)	8.8	1.36	15.3

Table 3: Effect of integrated nutrient management on micronutrient (Zn-Cu-Fe-Mn) of soil

Treatment	DTPA Zn	DTPA Cu	DTPA Fe	DTPA Mn
T_1	0.53	1.09	5.23	3.58
T_2	0.61	1.19	5.36	3.63
T_3	0.56	1.16	5.30	3.60
T_4	0.67	1.25	5.45	3.72
T_5	0.72	1.34	5.59	3.86
T_6	0.68	1.26	5.48	3.78
T_7	0.74	1.36	5.62	3.90
T_8	0.64	1.22	5.41	3.68
T_9	0.69	1.31	5.51	3.79
T_{10}	0.70	1.33	5.54	3.81
SEm±	0.02	0.02	0.02	0.04
CD (p=0.05)	0.05	0.06	0.06	0.11

in several physiological processes in plant like transformation of carbohydrates, chlorophyll and protein synthesis (Aktar et al., 2024) This decomposition gradually releases nutrients, including micronutrients, making them more available for plant uptake (Wailare and Kesarwani, 2017).

3.2. Biological properties

Results from Table 4 and showed that the application of FYM significantly increases microbial and enzymatic activity in the soil. Treatment 100% FYM resulted in the highest microbial activity for bacteria (6.60 10^8 cfu g^{-1} soil), fungi (17.37 10^4 cfu g^{-1} soil) and actinomycetes (5.42 10^4 cfu g^{-1} soil), respectively. The highest enzymatic activity, *viz*. alkaline phosphatase activity (21.02 µg *p*-nitrophenol g^{-1} soil h^{-1}), dehydrogenase activity (23.69 µg TPF g^{-1} soil 24 h^{-1}) and urease activity (6.79 µg NH_4N g^{-1} soil h^{-1}), respectively, were observed with application of FYM. Enzymatic activity is higher in treatments with higher organic matter, as higher organic carbon in the soil leads to greater multiplication of soil microbes (Meena et al., 2016). The increased microbial population is crucial for the conversion of organically bound nutrients into inorganic forms and facilitates the rapid transformation and mineralization of nutrients. This leads to improved physical, chemical and biological properties of the soil, which ultimately enhance productivity. Dehydrogenase and urease enzymes are biologically significant as they aid in the biological cycling of nutrients, which is influenced by the microbial population in the soil. With the application of organic manures, there was a build-up of organic carbon in the soils. The soil microbial biomass, carbon and enzymatic activity were reported to be higher under treatments containing higher organic matter. Since higher organic carbon in soil leads to greater multiplication of soil microbes, which ultimately converts organically bound nutrients into inorganic form and also helps in rapid transformation and mineralization of nutrients. Dehydrogenase activity, alkaline phosphatase activity and urease enzymes have biological significance as they help in the biological cycling of nutrients, which is affected by the microbial population in soil. The readily available carbon fraction of FYM and green manure supported more microbial growth and increased the soil microbial biomass carbon and also enzymatic activity in soil. The readily available carbon fraction in FYM supports more microbial growth and increases soil enzymatic activity (Selvi et al., 2004). Similar results were found by Singh et al. (2023) and Panday and Srivastava (2021).

Table 4: Effect of integrated nutrient management on biological properties

Treatment	Bacteria population	Fungal population	Actinomycetes population	Alkaline phosphatase activity	Dehydrogenase activity	Urease activity
T_1	5.38	15.92	3.93	15.03	16.80	5.66
T_2	5.87	16.45	4.42	16.59	17.59	6.05
T_3	5.53	16.25	4.29	16.31	17.28	5.85
T_4	6.38	16.58	5.08	17.72	19.42	6.37
T_5	6.60	17.37	5.42	21.02	23.69	6.79
T_6	6.26	16.50	4.89	17.17	18.69	6.23
T_7	6.57	17.20	5.34	20.06	22.95	6.74
T_8	6.49	16.77	5.15	18.05	20.07	6.50
T_9	6.54	17.09	5.22	19.73	21.57	6.62
T_{10}	6.53	16.91	5.18	18.95	21.02	6.57
SEm±	0.11	0.23	0.05	0.44	0.46	0.05
CD (*p*=0.05)	0.32	0.68	0.14	1.31	1.36	0.16

4. Conclusion

In conclusion, the findings from the one-year experiment provide compelling evidence that the STCR approach significantly enhances the nutrient status of the soil. Furthermore, the application of 100% FYM sustains the biological properties of the soil, including enzyme activity and microbial population. Based on these results, it was clear that employing the STCR approach to target higher yield was optimal for achieving greater productivity while simultaneously enhancing soil fertility and nutrient status in soil.

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