**Enhancing Soil Properties through Integrated Use of Chemical Fertilizers, Organic Manure, and Bio-Fertilizers on Rice Crop: A Comprehensive Study**

**Abstract**

Rice (Oryza sativa L.) is the prime food crop for more than 65 percent of the people and provides livelihood security to 70 percent of the Indian population (Kulkarni et al., 2015). With the advent of ever-increasing demand, future projections for rice production are 180 million tons with an average productivity of 4030 kg ha-1 by the year 2020 (Mishra et al., 2006). The major objective of this experiment was to evaluate the effect of the integrated use of chemical fertilizers, organic manure, and bio-fertilizers on soil properties through a field experiment. The experiment was conducted during the kharif season of 2016-2017 at the research plot of the Department of Agricultural Chemistry and Soil Science, Udai Pratap (Autonomous) College, Varanasi. Varanasi is in eastern U.P., India, under a sub-tropical climate. The experiment was designed as a randomized block design (RBD) with six treatment combinations. Treatments were replicated thrice, making a total of 18 plots. The six treatments consisted of various levels of P and PSB. Details of treatments are T1 = Control (no input) ,T2 = 100% NPKS, T3 = 100% NPKS + FYM (10 tons ha-1) + Bio-fertilizer (PSB + BGA), T4 = 125% NPKS, T5 = 150% NPKS, T6 = 50% NPKS + FYM (10 tons ha-1) + Bio-fertilizer (PSB + BGA). The application of 50% NPKS + 10 tons FYM ha-1 + Bio-fertilizers PSB + BGA increased rice yield and improved soil fertility more than inorganic fertilizers alone. Higher nutrient availability was also observed in these treated plots.

**Keywords:** *Chemical Fertilizers, Organic Manure, Bio-Fertilizers, Rice (Oryza sativa L.), Soil Properties*

**Introduction**

“Rice (Oryza sativa L.) is an edible starchy cereal grain and a grass. India has the largest rice farm area (43.9 million ha) followed by China (30.30 mha), Indonesia (13.80 mha), Bangladesh (11.30 mha), and Vietnam (7.86 mha). In 2015-16, India produced 106.5 million tons of rice with a productivity of 3576 kg ha-1” **(Food and Agricultural Organization, STAT 2016). “**Projections for 2020 anticipated rice production to reach 170-180 million tons with an average productivity of 4030 kg ha-1” **(Mishra et al., 2006).** “Rice is cultivated in nearly every Indian state, with concentration in river valleys, deltas, and low-lying coastal areas. Andhra Pradesh, Bihar, Madhya Pradesh, and Uttar Pradesh lead in rice cultivation, while West Bengal, Uttar Pradesh, and Punjab have the highest production shares” **(Directorate of Economics and Statistics DAC and FW).**

“Rice is a high-energy food, primarily providing carbohydrates (80g), along with sugar (0.12g), dietary fiber (1.3g), fat (0.66g), and protein (7.12g) per 100g of grain” **(USDA Nutrient Database, 2015).** Rice bran is also used as feed for cattle and poultry. Cultivation methods vary, but submerging rice in water is the most common practice worldwide. Rice is unique among cereal crops in its ability to grow in standing water for extended periods. Approximately 57% of rice is grown on irrigated land, 25% on rainfed lowland, 10% on upland, 6% in deep water, and 2% in tidal wetlands.

“Decreasing land availability, increasing land use intensity, and the imbalanced use of chemical fertilizers without organic manure have led to severe soil fertility deterioration, resulting in stagnant or declining crop productivity” **(Shormy et al., 2013).** “The integrated use of inorganic fertilizers, bio-fertilizers, and farmyard manure (FYM) is seen as a practical alternative for sustainable agriculture. FYM, a traditional, cheap, and proven nutrient source, plays a vital role in soil fertility improvement and yield enhancement. Blue-green algae serve as natural fertilizers by improving soil fertility and increasing growth and yield” **(Song et al., 2005).** “Phosphate-solubilizing bacteria (PSB) solubilize and mineralize residual or fixed phosphorus, increasing its availability in the soil” **(Farouue and Takeya, 2007).**

“However, continuous application of organic fertilizers alone, such as FYM, PSB, and blue-green algae, results in low yields and low nitrogen and potassium content at the mid-tillering stage of rice plants” **(Javier et al., 2004).** “The combined use of organic manure and inorganic fertilizers helps maintain yield stability by correcting marginal deficiencies of secondary and micronutrients, enhancing nutrient efficiency, and improving soil physical conditions” **(Gill and Walia, 2014)**. “Continuous use of inorganic fertilizers alone deteriorates soil chemical, physical, and biological properties, and overall soil health. The negative impacts of chemical fertilizers, along with rising prices, have spurred interest in organic fertilizers. Organic materials like FYM, traditionally used by rice farmers, supply all major nutrients (N, P, K, Ca, Mg, S) necessary for plant growth, as well as micronutrients (Fe, Mn, Cu, Zn). FYM improves soil structure, water-holding capacity, and overall soil health, fostering a better environment for root development. The integrated use of chemical fertilizers combined with organic manure is essential for improving soil health and sustainability in agriculture” **(Bajpai et al., 2006).**

**Materials and Methods**

The study, titled *Enhancing Soil Properties through Integrated Use of Chemical Fertilizers, Organic Manure, and Bio-Fertilizers on Rice Crop: A Comprehensive Study*, involved a field experiment conducted during the Kharif season of 2016-2017. The experiment was carried out at the research plot of the Department of Agricultural Chemistry and Soil Science, Udai Pratap (Autonomous) College, Varanasi. The soils of Varanasi are alluvial in origin, deposited by the river Ganga, with a predominance of illite, quartz, and feldspar minerals. Illite minerals are partly inherited from micas, which are abundant in the sand and silt fractions. The physico-chemical properties of the experimental soil were, Organic carbon (%): 0.61, Available nitrogen (kg ha⁻¹): 213.8, Available phosphorus (kg ha⁻¹): 9.50, Available potassium (kg ha⁻¹): 219.36, Available sulphur (kg ha⁻¹): 8.00, pH: 7.50, and EC (dS m⁻¹): 0.50.

Varanasi has a subtropical climate, located in eastern Uttar Pradesh, India. The precipitation in this region is mainly distributed over three to four months, from the last week of June to the second week of October. The period from November to February is generally cool and dry, while the summer season (March to June) is hot and dry. The annual average rainfall is 96.65 mm, with its distribution as follows, June to September: 80%, October to December: 5.7%, January to February: 3.3%, March to May: 3.0%

The experiment was conducted using a Randomized Block Design (RBD) with six treatment combinations, each replicated three times, making a total of 18 plots. Experimental Layout are , Experimental design: RBD, Number of treatments: 6 Number of replications: 3, Total number of plots: 18, Plot size: 2 × 2 m², Net plot area: 4 m², Gross plot area: 72 m² (18 × 4 m²), Width of main irrigation channel: 1 m, Width of sub-irrigation channel: 0.50 m, Plant spacing (row × plant): 20 × 15 cm, Test crop: Rice (*Oryza sativa*), variety *Narendra Mansuri.*

Treatment Combinations are, T₁: Control (no input), T₂: 100% NPKS, T₃: 100% NPKS + FYM (10 tons ha⁻¹) + Bio-fertilizer (PSB + BGA), T₄: 125% NPKS, T₅: 150% NPKS, T₆: 50% NPKS + FYM (10 tons ha⁻¹) + Bio-fertilizer (PSB + BGA) Recommended Dose of Fertilizer (RDF): 120 kg N ha⁻¹, 60 kg P₂O₅ ha⁻¹, and 60 kg K₂O ha⁻¹. The field was prepared by ploughing, followed by three cross-harrowings and planking at the onset of monsoon. Bunds were made around each plot, ensuring uniform leveling and removal of grasses. The fertilizers were applied as per the treatment schedule, Half of the nitrogen dose (60 kg ha⁻¹) and full doses of phosphorus and potassium were applied as basal application at the time of sowing. The remaining half of the nitrogen (60 kg ha⁻¹) was applied at the ear head initiation stage as a top dressing. PSB and BGA bio-fertilizers were applied at the time of transplanting.

Healthy rice seedlings were transplanted in rows with a spacing of 20 × 15 cm. Irrigation was provided as required to maintain optimal moisture levels. Weeding and intercultural operations were performed manually to ensure proper crop growth. Observations were recorded at different growth stages (30, 60, and 90 days after transplanting, DAT), Plant Height: The height of four marked plants per plot was measured from the base to the tip of the uppermost fully matured leaf. The average was calculated and recorded as mean plant height. Number of Tillers, Tillers were counted from the marked plants in each plot at 30, 60, and 90 DAT. Yield Measurement, The crop was harvested at maturity, sun-dried, and bundled separately for each plot. The bundles were weighed, threshed manually, and the grain and straw yields were recorded in q ha⁻¹.

The Soil Chemical Analysis are pH Measurement A soil-water suspension (1:2.5 ratio) was prepared (10 g soil + 25 ml distilled water), and pH was recorded using a glass electrode digital pH meter (Jackson, 1967). Electrical Conductivity (EC), Measured in a 1:2.5 soil-water suspension at 25°C using a TDS meter (Bower and Wilcox, 1965). Organic Carbon, Determined using the modified Walkley and Black’s rapid titration method **(Walkley and Black, 1934).** Available Nitrogen, Estimated by the alkaline permanganate method **(Subbiah and Asija, 1956)**. Available Phosphorus, Determined by Olsen’s method **(Olsen et al., 1954).**

This study aimed to assess the impact of integrated nutrient management on soil properties and rice crop productivity under the given agro-climatic conditions.

**Result and Discussion**

“Effect of integrated use of chemical fertilizers, organic manure and bio-fertilizers on soil properties under rice crop. The soil organic carbon, one of the crucial factors in sustaining agricultural production, also improved under integrated nutrient management (Table-1) Organic carbon content of rice plots showed a continuously decreasing trend from 30 DAT to harvesting of the crop under all treatments. Application of fertilizers alone or in combination with organic manures increased the organic carbon content significantly over control (Table-1). Application of 50% NPKS + FYM (10 ton ha-1 )+bio-fertilizers recorded significantly maximum organic carbon content as compared to other treatments. The organic carbon content in T4 was statistically at par with T2 treatment showing equal effect of 100% and 125% NPKS. Its values varied from 0.54 percent under control (T1) to 0.64 percent under the treatment receiving 50% NPKS through chemical fertilizers +FYM (10 ton ha-1 ) + bio-fertilizers to rice followed by 100% NPKS +FYM (10 ton ha-1 ). The data revealed a definite build up of organic carbon in all the treatments except T1 (control) over the initial value of 0.59 percent recorded at the start of the experiment. Improvement in soil organic carbon status in treatment receiving FYM and bio-fertilizers may be due to their stimulating effect on growth and activity of micro-organisms. The effect was further enhanced by the addition of fertilizers that improved the root and shoot growth highest production of root biomass might have increased organic carbon content” **(Bajpai et al. 2006 and Sharma et al. 2014).**

**Table-1 Effect of integrated use of chemical fertilizers, organic manure and bio-fertilizers on soil organic carbon percentage under rice crop**

|  |  |  |
| --- | --- | --- |
| **Treatment** | **Days after transplanting (DAT)** | |
| **30 DAT** | **90 DAT** |
| T1 | 0.64 | 0.62 |
| T2 | 0.63 | 0.62 |
| T3 | 0.61 | 0.60 |
| T4 | 0.60 | 0.59 |
| T5 | 0.60 | 0.57 |
| T6 | 0.58 | 0.54 |
| **SEm±** | **0.009** | **0.010** |
| **CD (P=0.05)** | **0.029** | **0.033** |

The data related to available nitrogen under rice crop as influenced by integrated use of chemical fertilizers, organic manure and bio-fertilizers have been shown in table-2.

As evident from results available nitrogen content of soil continuously decreased with advancement of crop growth stage under all treatments. The effect of different treatments of fertilizers, organic manure and bio-fertilizers on available nitrogen content of soil was found in the order T6>T3>T5>T4>T2>T1 and value of available nitrogen content of soil varied from 255.36 to 267.61, 251.06 to 264.58, 242.15 to 254.72, 238.63

to 249.38, 232.38 to 245.09 and 217.71 to 236.04 kg ha-1 under respective treatments. The available nitrogen content differed significantly due to addition of various treatments. Like organic carbon, significantly higher available nitrogen content was recorded in treatment consisting of chemical fertilizers, organic manure and bio-fertilizers. Significantly higher available nitrogen content was recorded 50% NPKS +FYM (10 ton ha-1)+ bio-fertilizers treated plot as compared to other treatments. Application of fertilizers either alone or in combination with organism were significantly superior to control. The lowest value of available nitrogen in T1 may be due to mining of nutrient with cropping without fertilization. Increase in available N with organic is attributed to its direct addition through organic as FYM. The results are corroborate the findings of ***Urkurkar et al* 2010**, ***Kumar et at* 2012** and ***Sharma et al* 2014**.

**Table-2 Available nitrogen content (kg ha-1) of soil as influenced of the integrated use of chemical fertilizers, organic manure and bio-fertilizers under rice crop.**

|  |  |  |
| --- | --- | --- |
| **Treatment** | **Days after transplanting (DAT)** | |
| **30 DAT** | **90 DAT** |
| T1 | 236.04 | 217.71 |
| T2 | 245.09 | 232.38 |
| T3 | 264.58 | 251.06 |
| T4 | 249.38 | 238.63 |
| T5 | 254.72 | 242.15 |
| T6 | 267.61 | 255.36 |
| **SEm±** | **0.308** | **0.104** |
| **CD (P=0.05)** | **0.971** | **0.327** |

The results obtained in respect of the effect of integrated use of chemical fertilizers, organic manure and bio-fertilizers on available phosphorus content of soil measured at 30 and at harvesting have been presented in table-3.

Data showed that available phosphorus content of rice plots decreased continuously with age of crop under all treatments. The value of available phosphorus content of rice plots at harvesting was 21.58, 20.09, 17.21, 15.60, 13.74 and 9.78 kg ha-1 under T6>T3>T5>T4>T2 and T1

treatments, respectively. There was an increase in available phosphorus content over initial value of all treatments. The available content of soil increased significantly in the plots that had received chemical fertilizers, organic manure and bio-fertilizers than in the plots that have received chemical fertilizers alone. In general integrated application of with fertilizers recorded higher available phosphorus content over the application of inorganic fertilizers alone. Build-up in available phosphorus with the conjoint use of fertilizers with organic was ascribed to the release of organic acids during decomposition which is turn help in releasing native phosphorus through solubilizing action of these acids. Also organic matter form a coating on sesquioxides and makes them inactive and thus reduces the phosphate fixing capacity of soil, which ultimately help in the release of sample quantity of plant available P. These findings are in agreement with those of ***Urkurkar et al* (2010)** and ***Sharma et al* (2014)**

**Table-3 Effect of integrated use of chemical fertilizers, organic manure and bio-fertilizers on available phosphorus content (kg ha-1) of rice plots.**

|  |  |  |
| --- | --- | --- |
| **Treatment** | **Days after transplanting (DAT)** | |
| **30 DAT** | **90 DAT** |
| T1 | 16.81 | 9.78 |
| T2 | 20.05 | 13.74 |
| T3 | 26.05 | 20.09 |
| T4 | 21.25 | 15.60 |
| T5 | 23.72 | 17.21 |
| T6 | 27.36 | 21.58 |
| **SEm±** | **0.091** | **0.075** |
| **CD (P=0.05)** | **0.286** | **0.235** |

The results obtained in respect of the effect of integrated use of chemical fertilizers, organic manure and bio-fertilizers on available potassium content of rice plots measured at 30 and 90 days after transplanting DAT have been presented in table-4.

The Result indicated that the available potassium content of soil of rice plot decreased continuously with advancement in growth stages up to harvest under all treatment. In respect of available potassium content of soil, the treatments could be arranged in the order T6>T3>T5>T4>T2>T1 and the value varied from 262.37 to 283.63, 257.63 to 279.31, 248.71 to 272.63,

244.38 to 269.07, 241.48 to 265.45 and 224.39 to 249.48 under the respective treatments. The data further revealed that the application of either fertilizer alone or in combination with organic matter recorded on increase in the available potassium content of the soil over control. Increase in available due to addition of organic matter may be ascribed to the reduction of K fixation and release of K due to interaction of organic matter with clays, beside the direct K addition to the soil (***Urkurkar et al* 2010**, ***Subehia and Spehya* 2012**). In case of chemical fertilizers alone, the available K significantly increased with increasing level of NPKS might be due to higher amount of unused potassium of higher level.

**Table-4 Effect of chemical fertilizers, organic manure and bio-fertilizers on available potassium content (kg ha-1) of soil under rice crop.**

|  |  |  |
| --- | --- | --- |
| **Treatment** | **Days after transplanting (DAT)** | |
| **30 DAT** | **90 DAT** |
| T1 | 249.48 | 224.39 |
| T2 | 265.45 | 241.48 |
| T3 | 279.31 | 257.63 |
| T4 | 269.07 | 244.38 |
| T5 | 272.63 | 248.71 |
| T6 | 283.63 | 262.37 |
| **SEm±** | **0.220** | **0.102** |
| **CD (P=0.05)** | **0.692** | **0.320** |

The data related to the influence of chemical fertilizers, organic manure and bio-fertilizers on available sulphur content of soil measured at 30 and at harvesting of rice crop have been presented in table-5.

The available sulphur content of soil of rice plots under various treatments varied from 20.30 to 26.32 kg ha-1. Further, the available sulphur content of soil decreased with days of transplanting. The available sulphur content of the soil was significantly influenced by application of different treatments. The data further revealed that the application of organic manures recorded an increase in the available S content of the soil over control. Addition of 50% NPKS + FYM (10 ton ha-1) +bio-fertilizers (PSB+BGA) have shown a remarkable significantly increase in available sulphur content of experimental soil. The superiority of T6 (50% NPKS + FYM (10 ton ha1) + bio-fertilizers (PSB+BGA) T3 (100% NPKS + FYM (10 ton ha-1) + bio-fertilizers (PSB+BGA) has been found at all growth stages of rice during experiments. Treatment T6 recoded maximum available sulphur followed by T3, T5, T4, T2 and T1. The increase in available sulphur content of soil due to the low S content in control could be due to no addition of S and its removed by crops and secondly because of low organic carbon content in these treatments as S is known to be an integral part of soil organic matter. Incorporation of organic manure may be attributed to the direct addition of sulphur. Addition of FYM contributed on appreciable amount of sulphur to the soil at 50% substitution rate which resulted in increased S content of soil over control. The increase in the available S with the application of fertilizers might be due to addition of SSP contained about 12% **(*Sharma et al* 2014).**

**Table-5 Effect of integrated use of chemical fertilizers, organic manure and bio-fertilizers on available sulphur content (kg ha-1) of soil under rice crop**

|  |  |  |
| --- | --- | --- |
| **Treatment** | **Days after transplanting (DAT)** | |
| **30 DAT** | **90 DAT** |
| T1 | 12.00 | 8.68 |
| T2 | 15. 07 | 11.00 |
| T3 | 22.79 | 18.45 |
| T4 | 17.00 | 14.03 |
| T5 | 18.61 | 15.61 |
| T6 | 26.32 | 20.30 |
| **SEm±** | **0.064** | **0.105** |
| **CD (P=0.05)** | **0.200** | **0.330** |

**Summary and Conclusion**

Observations recorded at different growth stages (30, 60, and 90 days after transplanting) indicated that integrating organic manure and bio-fertilizers with chemical fertilizers significantly improved soil fertility parameters such as organic carbon, available nitrogen, phosphorus, potassium, and sulphur. Among all treatments, **T₆ (50% NPKS + FYM + Bio-fertilizers)** recorded the highest improvement in soil properties, followed by **T₃ (100% NPKS + FYM + Bio-fertilizers)**.

Organic Carbon, increased under integrated nutrient treatments, with T₆ showing the highest buildup (0.64%). Available Nitrogen, decreased over time but was highest under T₆ (255.36 kg ha⁻¹ at 90 DAT). Available Phosphorus, improved significantly under integrated treatments, with T₆ showing the highest retention (21.58 kg ha⁻¹ at 90 DAT). Available Potassium, Highest under T₆ (262.37 kg ha⁻¹ at 90 DAT). Available Sulphur, increased under integrated treatments, with T₆ recording the highest (20.30 kg ha⁻¹ at 90 DAT).

The study concludes that integrated use of chemical fertilizers, organic manure, and bio-fertilizers enhances soil fertility and sustainability compared to chemical fertilizers alone. The highest soil organic carbon, nitrogen, phosphorus, potassium, and sulphur levels were observed in treatments that combined fertilizers with organic manure and bio-fertilizers (T₆ and T₃). This indicates that integrated nutrient management (INM) improves soil health, microbial activity, and nutrient availability, making it a viable approach for sustainable rice cultivation.

Thus, **T₆ (50% NPKS + FYM + Bio-fertilizers)** is recommended as the most effective treatment for maintaining soil fertility and improving rice productivity under the agro-climatic conditions of Varanasi.

**COMPETING INTERESTS DISCLAIMER**:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper. Dear Sir this paper is based on Inhancing soil Properties only , so I not mention, any competitive financial instrests.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

**Reference**

1. **Babar, S., & Dongale, J. H. (2013**). Effect of organic and inorganic fertilizers on soil fertility and crop productivity under mustard-cowpea-rice cropping sequence on lateritic soil of Konkan. *Journal of the Indian Society of Soil Science, 61*(1).
2. **Bajpai, R. K., Chitale, S., Upadhyay, S. K., & Urkurkar, J. S. (2006**). Long-term studies of physicochemical properties and productivity of rice-wheat system as influenced by integrated nutrient management in Inceptisol of Chhattisgarh. *Journal of the Indian Society of Soil Science, 54*, 24-29.
3. **Baskar, K. (2003).** Effect of integrated use of inorganic fertilizers and FYM or green leaf manure on uptake and nutrient use efficiency of rice-rice system on an Inceptisol. *Journal of the Indian Society of Soil Science, 51*(1), 47-51.
4. **Begum, M., Narayanasamy, G., Rai, R. K., & Biswas, D. R. (2007).** Influence of integrated nutrient management on nitrogen and phosphorus in soil under wheat-mungbean-maize cropping system. *Journal of the Indian Society of Soil Science, 55*, 175-183.
5. **Begum, Z. N. T., Mandal, R., & Islam, M. S. (2009).** Effect of blue-green algae and urea-N on growth and yield performance of traditional variety of rice. *Journal of Phytological Research, 22*, 211-214.
6. **Bhoite, S. V. (2005).** Integrated nutrient management in basmati rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agronomy, 50*, 99-101.
7. **Chand, S., Singh, V., Anwar, M., & Patra, D. D. (2002).** Influence of integrated nutrient management on soil fertility and productivity of mint-mustard cropping system. *Journal of the Indian Society of Soil Science, 50*(3), 277-280.
8. **Chaudhary, S. K., & Thakur, R. B. (2007).** Efficient farmyard management for sustained productivity of rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agricultural Science, 77*, 443-444.
9. **Chesti, M. H., Kohli, A., Mujtaba, A., Sofi, J. A., Qadri, T. N., Peer, Q. J. A., Dar, M. A., & Bisati, I. A. (2015).** Effect of integrated application of inorganic and organic sources on soil properties, yield, and nutrient uptake by rice (*Oryza sativa L.*) in the intermediate zone of Jammu and Kashmir. *Journal of the Indian Society of Soil Science, 63*(1), 88-92.
10. **Desai, R. M., Patel, G. G., Patel, T. D., & Das, A. (2009).** Effect of integrated nutrient supply on yield, nutrient uptake, and soil properties in rice-rice crop sequence on a Vertic Haplustepts of South Gujarat. *Journal of the Indian Society of Soil Science, 57*(2), 172-177.
11. **Dixit, K. G., & Gupta, B. R. (2000).** Effect of farmyard manure, chemical, and biofertilizers on yield and quality of rice (*Oryza sativa L.*) and soil properties. *Journal of the Indian Society of Soil Science, 48*, 773-780.
12. **Duhan, B. S., & Singh, M. (2002).** Effect of green manuring and nitrogen on yield and uptake of micronutrients by rice. *Journal of the Indian Society of Soil Science, 50*(2), 178-180.
13. **Urkurkar, J. S., Tiwari, A., Chitale, S., & Bajpai, R. K. (2010).** Impact of long-term nutrient management on soil fertility, productivity, and sustainability of rice-wheat cropping system in Inceptisol. *Journal of the Indian Society of Soil Science, 58*(4), 409-418.​
14. **Kumar, A., Singh, A. K., & Agrawal, S. K. (2012).** Effect of different nutrient management practices on soil available nutrients and yield under rice-wheat cropping system. *Journal of Agronomy and Crop Science, 198*(1), 70-78.​
15. **Sharma, S. N., & Sharma, R. K. (2014).** Integrated nutrient management for sustainability of rice-wheat cropping system. *Indian Journal of Agronomy, 59*(4), 567-573.
16. **Bajpai, R. K., Chitale, S., Upadhyay, S. K., & Urkurkar, J. S. (2006).** Long-term studies of physicochemical properties and productivity of rice-wheat system as influenced by integrated nutrient management in Inceptisol of Chhattisgarh. *Journal of the Indian Society of Soil Science, 54*, 24-29.
17. **Subehia, S. K., & Sepehya, S. (2012).** Effect of integrated nutrient supply on yield, nutrient uptake and soil fertility in rice-wheat cropping system in an acid Alfisol. *Journal of the Indian Society of Soil Science, 60*(3), 237-244.
18. **Olsen, S. R., Cole, C. V., Watanabe, F. S., & Dean, L. A. (1954).** Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *United States Department of Agriculture Circular No. 939*, U.S. Government Printing Office, Washington, D.C.
19. **Subbiah, B. V., & Asija, G. L. (1956).** A rapid procedure for estimation of available nitrogen in soils. *Current Science, 25*(8), 259-260.
20. **Gill, J. S., & Walia, S. S. (2014).** Influence of FYM, brown manuring, and nitrogen levels on direct seeded and transplanted rice (*Oryza sativa L.*): A review. *Research Journal of Agriculture and Environmental Management, 3*, 417-426.
21. **U.S. Department of Agriculture, Agricultural Research Service. (2015).** *USDA National Nutrient Database for Standard Reference, Release 28*.
22. **Mishra, V. K., Singh, Y. V., & Mishra, V. K. (2017).** GPS and GIS based soil fertility mapping for precise agriculture. *Journal of the Indian Society of Soil Science, 65*(1), 50-56.