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Fertilizer prescription for achieving targeted rice yield in inceptisol soils

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Abstract
A fertility field experiment was conducted in Persiya village, Chandauli district, to study the correlation between soil test values and fertilizer doses of nitrogen, phosphorus, and potassium on rice yield in Inceptisol soil. Fertilizer adjustment equations were developed by the All India Coordinated Research Project, Institute of Agricultural Science, Banaras Hindu University, Varanasi. The results showed that targeted rice yields of 38 q ha^{-1} and 43 q ha^{-1} were achieved using plant nutrients based on the targeted yield concept, known as soil test crop response (STCR) technology. This approach increased yields by 12.75% and 27.77% compared to general fertilizer recommendations. The highest net returns (Rs. 34,695 and Rs. 43,360) were recorded in treatments where fertilizers were applied according to soil test values (STCR treatment). This method also preserved the availability of soil nutrients. Therefore, applying plant nutrients based on soil test values (STCR technology) is crucial for maximizing returns and maintaining soil fertility. Fertilizer doses were validated for achieving the target yields of 38 and 43 q ha^{-1} in farmers' fields, with yields falling within a 10% deviation, confirming the superiority of soil test-based fertilizer recommendations. This approach can be adopted in regions with similar soils and agro-climatic conditions worldwide to enhance rice production.

Keywords: Target yield, soil test crop response, economics and B:C ratio etc.

Introduction

Rice serves as a staple food for nearly half the global population, including 60% of India's people, who are particularly vulnerable to rising rice prices. It also underpins the livelihoods of most Indian farmers. Over the past five decades, rice production in India has nearly tripled, playing a vital role in the country's nutritional security. However, the annual compounded growth rate (ACGR) of rice production has declined, from 3.55% during 1981-1990 to 1.74% during 1991-2000, despite achieving a record production of 99.50 million tons with a productivity of 2.20 tons per hectare in 2008-2009. Rice is cultivated in nearly all Indian states, with West Bengal, Uttar Pradesh, Madhya Pradesh, Bihar, Odisha, Andhra Pradesh, Assam, Tamil Nadu, Punjab, Maharashtra, and Karnataka contributing 92% of the total area and production. Yet, India remains among the countries with the lowest rice yields. Seventy percent of the 414 rice-growing districts report yields below the national average, indicating that even after the advent of high-yield technologies, a significant portion of rice-growing areas remains low-producing. States like Bihar, Odisha, Assam, West Bengal, and Uttar Pradesh account for 60% of these low-productivity areas. Alarmingly, 32% of irrigated rice lands also produce low yields (Tiwari, 2002) [12]. Rice-based cropping systems significantly contribute to food production, but current systems often involve imbalanced and inadequate fertilizer use, with blanket recommendations that overlook soil fertility and productivity variations. Achieving future productivity gains and improving input efficiency will require tailored soil and crop management technologies designed for individual farms or fields. Research has highlighted significant field variability in soil nutrient supply, nutrient use efficiency, and crop responses. Managing this variability remains a critical challenge for enhancing the productivity of intensive rice-cropping systems (Rao, 2011) [7].

Materials and Methods

On-farm testing trials were conducted in the village of Parsiya, Naugarh block, Chandauli district, Uttar Pradesh, India, during the Rabi season of 2022-23 on alluvial soil (Inceptisol). Soil samples from the 0-15 cm depth were collected, dried, sieved through a 2 mm mesh, and analyzed for physico-chemical properties as per Jackson (1973) [3]. Available nitrogen was determined using the alkaline permanganate method (Subbiah and Asija, 1956) [11], available phosphorus by the Olsen method (Olsen *et al*., 1954) [5], and available potassium by the ammonium acetate method (Hanway and Heidal, 1952) [2], all described in Jackson (1973) [3]. Five fertilizer treatments were tested: Control, Farmers' practice, General recommended fertilizer dose, Soil Test Crop Response (STCR) for 38 q ha^{-1}, and STCR for 43 q ha^{-1}, using the rice variety HUR-917 (Malviya Sugandha Dhan 917). The targeted yields for the crop were set at 38 q ha^{-1} and 43 q ha^{-1} based on the variety's yield potential. Pre-sowing soil samples were analyzed following standard procedures. The soil resource inventory of the study area is provided in Table 1. The required quantities of nitrogen, phosphorus, and potassium were calculated using fertilizer adjustment equations (Singh *et al*., 2014a) [8].

FN = 4.74 T-0.49 SN-0.34 ON

FP_2O_5 =1.53 T-0.09 SP-0.06 OP

FK_2O = 2.92 T-0.35 SK-0.11 OK

Where: The fertilizer doses were determined based on soil test values for nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) available in the soil, and applied according to the soil test crop response (STCR) method for various yield targets. The treatments included: (i) a control group, (ii) farmer's practices, (iii) the general recommended dose, (iv) STCR-based fertilizer doses for a yield target of 38 q ha^{-1}, and (v) STCR-based fertilizer doses for a yield target of 43 q ha^{-1}. The fertilizer application was calculated based on the grain yield target (T), which was adjusted using the available N, P, and K from the soil, and the quantities of N, P_2O_5, and K_2O to be added via fertilizers (FN, FP_2O_5, and FK_2O, respectively).

For the STCR treatments, one-third of the nitrogen (N) was applied as basal fertilizer along with the full dose of P_2O5 and K_2O, while the remaining half of the nitrogen was applied 27 days after sowing. The final nitrogen dose was applied at the panicle initiation stage. Urea was used for nitrogen, single super phosphate for phosphorus, and muriate of potash for potassium. The rice variety used for both the STCR and other treatments was HUR-917, also known as Malviya Sugandha Dhan 917.

Results and Discussion

Soil characteristics

The soil in the study was alluvial (Inceptisol) with a pH ranging from 7.50 to 7.65. The organic carbon content varied between 0.33% and 0.37%. The soil was classified as medium in available nitrogen, with values ranging from 209.00 to 210.80 kg ha^{-1}, low to medium in available phosphorus, ranging from 16.70 to 17.10 kg ha^{-1}, and medium to high in available potassium, ranging from 183.90 to 155.90 kg ha^{-1}, as shown in Table 1. While these soils are generally considered fertile, they are deficient in nitrogen and organic matter (humus), but they have moderate levels of phosphorus and potassium.

Table 1: Physico-chemical properties of the experimental area

Locations	Physico chemical properties			Fertility status		
	pH	EC (dSm^{-1})	OC (%)	Av-N (kg ha^{-1})	Av-P (kg ha^{-1})	Av-K (kg ha^{-1})
Location-I	7.65	0.39	0.49	204.80	15.90	180.20
Location-II	7.48	0.38	0.47	205.30	16.10	180.11
Location-III	7.60	0.39	0.47	204.90	15.70	180.10

***** Av = Available

Table 2: Economics of Verification Trails for Rice (HUR-917, Malviya Sugandha Dhan 917)

Treatments	Fertilizer dose NPK (kg ha^{-1}) and FYM (t ha^{-1})	Actual mean yield (kg ha^{-1})	Additional yield (kg ha^{-1})	Value of additional yield (Rs.)	Cost of fertilizer (Rs.)	Net benefit (Rs.)	B/C ratio
	Location-I: Name-Sri. Devraj S/O. Sri. Ramvilash Village-Jharigawan						
T_1-Control	0-0-0	1645	-	-		-	-
T_2-FP	100-35-35	2415	770	15400	4626.9	10773.15	2.33
T_3-GRD	120-60-60	3235	1590	31800	7037.4	24762.60	3.52
T_4-38 q/ha	76-57-47-2	3785	2140	42800	6762.1	36037.89	5.33
T_5-43 q/ha	100-64-62-2	4290	2645	52900	7967.1	44932.88	5.64
	Location-II: Name-Sri. Dhurmari Singh S/O Sri. Udayee, Village-Jharigawan						
T_1-Control	0-0-0	1666	-	-		-	-
T_2-FP	100-35-35	2427	761	15220	4626.85	10593.15	2.29
T_3-GRD	120-60-60	3289	1623	32460	7037.4	25422.6	3.61
T_4-38 q/ha	76-57-47-2	3775	2109	42180	6762.11	35417.89	5.24
T_5-43 q/ha	100-64-62-2	4312	2646	52920	7967.12	44952.88	5.64
	Location-II: Name-Sri. Ramesh S/O. Sri Udayee, Village-Jharigawan						
T_1-Control	0-0-0	1636	-	-		-	-
T_2-FP	100-35-35	2525	889	17780	4626.85	13153.15	2.84
T_3-GRD	120-60-60	3288	1652	33040	7037.40	26002.60	3.69
T_4-38 q/ha	76-57-47-2	3818	2182	43640	6762.11	36877.89	5.45
T_5-43 q/ha	100-64-62-2	4266	2630	52600	7967.12	44632.88	5.60

Note: Rice @ Rs. 20.00/kg, N @ Rs. 17.39/kg P_2O_5 @ Rs. 56.25/kg, K_2O @ Rs. 26.66/kg.

A minor modification was made to the ready reckoner. FP refers to the farmer's practice, which represents the fertilizer doses typically applied by farmers in the area. GRD stands for the general recommendations provided by the agricultural department of the district, based on soil test values. B:C ratio refers to the benefit-cost ratio, which measures the profitability of the inputs used in farming.

Yield targeting of Rice based on soil test

Experimental data from follow-up trials conducted as frontline demonstrations in farmers' fields during the 2022-23 period are provided in Table 2. The data from these field experiments helped determine the nutrient requirements for producing one quintal of rice grain yield, as well as the percentage contribution of nutrients from soil (%CS) and fertilizer (%CF). These parameters were used to develop fertilizer prescription equations for NPK alone. The nutrient requirements for producing one quintal of rice were 6.26 kg of N, 1.12 kg of P_2O_5, and 3.78 kg of K_2O. The contributions of nutrients from soil and fertilizers were found to be as follows: for nitrogen (N), 25.41% from soil and 117.03% from fertilizers; for phosphorus (P_2O_5), 40.99% from soil and 35.42% from fertilizers; and for potassium (K_2O), 19.67% from soil and 45.47% from fertilizers.

It was observed that the contribution of potassium from fertilizer was higher than from the soil. This increased potassium uptake could be due to the interaction effects of higher nitrogen (N) and phosphorus (P) doses, combined with the priming effect of starter potassium (K) doses applied in the treated plots. This likely facilitated the release of soil potassium, leading to higher uptake from native soil sources (Ray *et al*., 2000) [6]. Similar findings of higher potassic fertilizer efficiency were also reported for rice in alluvial soils (Ahmed *et al*., 2002) [1].

The yield targets of 38 and 43 q ha^{-1} were achieved with lower applications of N and P_2O_5 fertilizers, but higher applications of K_2O, compared to the doses applied in farmer's practices and soil-based recommendations. For example, in the alluvial soil of West Bengal during the winter season, the highest rice yield reached 6.0 t ha^{-1} regardless of nitrogen levels, but this could be increased to 7.4 t ha^{-1} with higher applications of potassium fertilizers (Tiwari, 2002) [12]. This improvement is likely due to higher nitrogen use efficiency and better nitrogen recovery by the crop with increased potassium application (Marschner, 1995) [4].

For rice variety HUR-917 (Malviya Sugandha Dhan 917), the target yields of 38 and 43 q ha^{-1} were successfully achieved, as shown in Table 2, with yields surpassing the expected targets in all cases. In all locations, grain yields of rice based on the general fertilizer recommendations (GRD) were lower than those achieved with the 38 and 43 q ha^{-1} targets. These results align with findings from Singh *et al*. (2014) [8] and Singh *et al*. (2015) [9]. Among the two yield targets, the 43 q ha^{-1} target showed a higher response ratio compared to the 38 q ha^{-1} target, though both targets resulted in higher yields. This could be attributed to better efficiency of applied NPK fertilizers at lower yield target levels (Singh *et al*., 2014; Singh *et al*., 2015) [8, 9].

3.2 Post harvest soil fertility status

Post-harvest soil analysis showed a significant build-up and maintenance of available nitrogen (SN), phosphorus (SP), and potassium (SK) under the STCR treatment, compared to farmer practices and general fertilizer recommendations. Despite the higher nutrient removal in the STCR treatment due to the increased yield, post-harvest soil fertility was better preserved in the STCR plots. The highest post-harvest soil nitrogen was observed in Location-1 (Smt. Phuleshari W/O Sri. Bhagwandas, Village-Parsiya) with 240.00 and 233.00 kg ha^{-1} for the 38 and 43 q ha^{-1} targets, respectively. Soil potassium was highest in Location-2 (Smt. Phulmati Devi W/O Sri. Jayshankar, Village-Parsiya) with 215.00 and 210.00 kg ha^{-1}, and soil phosphorus was highest in Location-1 (Smt. Phuleshari W/O Sri. Bhagwandas, Village-Parsiya) with 19.50 and 18.1 kg ha^{-1} for the respective yield targets, as shown in Table 3. The increased nutrient build-up under the STCR treatment was attributed to the balanced application of chemical fertilizers in combination with organic manure. The combined use of inorganic fertilizers improved both the chemical and physical properties of the soil, potentially contributing to enhanced and sustainable production. Greater profits, along with the maintenance of soil fertility, were achieved when fertilizers were applied according to the appropriate yield targets year after year using the STCR approach (Singh *et al*., 2015) [9].

Table 3: Post harvest soil fertility status of various treatments under different locations of Villege-Hadahi, Naugarh block in district Chandauli.

Treatments	Location 1			Location 2		
	N	**P**	**K**	**N**	**P**	**K**
Control	209	17.5	206	218	17.4	194
Farmer's practice	228	16.1	188	226	18.3	181
GRD	232	17.2	198	231	19	191
STCR 38 q ha^{-1}	240	18.1	208	233	16.5	210
STCR 43 q ha^{-1}	245	19.5	212	239	18.5	215
CD at 5%	1.30	1.05	0.53	0.59	1.05	0.71

Where: GRD-General recommended dose and STCR-Soil teat crop response

For the efficient use of applied fertilizers, it is important to consider additional factors such as soil pH, organic carbon content, and other parameters that influence soil nutrient retention. These factors play a crucial role in developing an effective fertilizer schedule and ensuring optimal nutrient absorption and assimilation by the plants.

This study aims to provide guidelines for the appropriate amount of fertilizer to use in rice cultivation. A yield equation based on soil health will not only promote sustainable crop production but also help farmers optimize the use of costly fertilizers, taking into account their financial situation and the prevailing market prices of the crop.

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