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Yield, nutrient uptake, nutrient use efficiency of wheat as affected by different sources of nutrients and levels of nutrients in vertisols

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ABSTRACT

Modern crop production technologies require balanced fertilizer use. An experiment was conducted at JNKVV, Jabalpur during the Rabi season of 2019-20 to evaluate the yield, nutrient uptake, and nutrient use efficiency of wheat as affected by different nutrient sources and levels in Vertisols. The main challenges of the study included the non-uniform nutrient release from organic sources, the differing nutrient availability among inorganic, organic and integrated sources which made equal comparison difficult, and the potential risk of nutrient losses or uneven uptake at higher NPK levels. The treatments included three nutrient sources as main plots: inorganic, organic (FYM, vermicompost, and biofertilizers), and integrated sources (50% inorganic + 50% organic). Five NPK levels were tested as sub-plots: control (0-0-0 kg NPK ha^{-1}), 100% NPK (120-60-40 kg ha^{-1}), 150% NPK (180-90-60 kg ha^{-1}), 200% NPK (240-120-80 kg ha^{-1}), and soil test value (STV) NPK (149-176-33 kg ha^{-1}), in a split-plot design with three replications. Results revealed that inorganic nutrient sources produced significantly higher grain yield, NPK uptake (grain and straw), and nutrient use efficiencies- agronomic efficiency, recovery efficiency, physiological efficiency, and factor productivity- compared to organic and integrated sources. Among NPK levels, 150% NPK gave significantly higher yield and nutrient uptake than lower levels and was at par with 200% NPK. Moreover, across all interactions and treatment combinations, the inorganic nutrient source combined with 150% NPK consistently resulted in the highest yield and nutrient use efficiency. The study identifies the most efficient nutrient source and NPK level for Vertisols, providing a practical recommendation that enhances wheat yield and nutrient use efficiency in central India.

Keywords: *Inorganic source, organic source, integrated nutrient management, nutrient use efficiency, nutrients levels, Vertisols.*

1. INTRODUCTION

Wheat is essential for global food security, meeting 40% of the world's food demand (Salim & Raza, 2019). Its production needs to increase by 40% by 2030 (Dixon, Braun, and Crouch, 2009). In India, it is grown in an area of 30.47 m ha with an annual production of 106.84 m t and a productivity of 3.5 t ha^{-1} (DAE). The productivity of wheat (3 t ha^{-1}) in India is lower than China (5.74 t ha^{-1}) (FAOSTAT, 2022), which is the leading country in wheat production. Wheat depletes soil nutrients, so if it isn't adequately fertilized, soil fertility starts to decline [4]. Agricultural soil fertility can only be sustained in the long run if nutrients taken out of the plant are replaced in proportion, and that newly added sources have a higher solubility than those present in the soil [5]. Farmers frequently apply more organic and mineral N to crops in order to maximize yield, which leads to uneven fertilization [6]. Poorly balanced nutrient addition lowers nutrient use efficiency (NUE) and profitability [7]. It also increases environmental risks related to nutrient loss through run-off, emissions, or leaching [8].

The ability of crops to absorb and use nutrients for increased productivity is measured by their nutrient use efficiency [9].

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The plant- and fertilizer-based NUE indices are the most widely used NUE indices [10]. Most of these indices are generally appropriate for short time scales, like growing seasons, although their evaluations can offer insightful crop- and site-specific information [11].

Partial factor productivity (PFP, kg crop yield per kg nutrient applied), agronomic efficiency (AE, kg crop yield increase per kg nutrient applied), apparent recovery efficiency (RE, kg nutrient taken up per kg nutrient applied) and physiological efficiency (PE, kg yield increase per kg nutrient taken up) are the four agronomic indices that are frequently used to describe nutrient use efficiency [12]. To maintain crop yield while lowering economic costs and environmental impact, NUE must be improved [13]. Fertilizer best management practices that apply nutrients at the proper rate, time, and place can maximize the efficiency of fertilizer use [14].

Chemical fertilizer inputs are necessary to replenish nutrients lost during cropping and preserve a positive nutrient balance [15]. In the 20th century, crop yield was thought to have increased by at least 50% because of fertilizer application [16]. Reduced fertilizer use results in lower yield, and excessive fertilizer use pollutes the land, water, and environment [17]. Uses of organic manures enhance the physical, chemical, and biological properties of soil while also giving plants nutrients [18]. However, the nutrient content of organic manure is relatively low, and it has a low ability to release nutrients quickly enough to meet crop requirements [19]. In organic farming, more importance is given to fertilizing the soil as compared to feeding the plants directly [5].

Therefore, the normal intensity of agricultural production could not be met by the sole application of manure [19]. It is known that mineral and organic inputs cannot be completely replaced by one another [20]. Organic manure as a substitute for chemical fertilizer has drawn a lot of attention [21] as the combined application may increase crop yield, NUE, and soil fertility [22].

Farmers prioritize maximizing profit even though applying less fertilizer improves nutrient use efficiency [23]. Therefore, it's critical to balance crop productivity and nutrient efficiency [2]. Additionally, because of soil health fatigue, applying the generally recommended dose of fertilizer is unable to sustain yields in relation to crop economic returns [24]. To fill in these gaps, the objective of this study was to find out the best sources of nutrients as well as the optimum combination of nitrogen, phosphorus and potassium for improving nutrient use efficiency in wheat.

2. MATERIALS AND METHODS

2.1 Experimental Site

The field experiment was conducted at the research farm of the Department of Soil Science & Agricultural Chemistry, JNKVV, Jabalpur (M.P.) during 2019–2020. The location is at 23º 13' N latitude, 79º 57' E longitude, and 393 m above sea level.

2.2 Treatments

Fifteen treatments combining chemical fertilizers, organic manures, and biofertilizers were tested in a split-plot design with three replications. Main treatments (M) were: M1: Inorganic (NPK fertilizers), M2: Organic (FYM, vermicompost, Azotobacter, PSB), M3: Integrated (50% inorganic + 50% organic) Sub-treatments (S) were NPK levels: S1: Control, S2: 100% RDF, S3: 150% RDF, S4: 200% RDF, S5: Soil test value (STV)-based for target yield of 6 t/ha. Wheat variety GW-366 was sown with 22.5 cm row spacing. Nitrogen was applied in three splits (sowing, 21 DAS, 45 DAS), while full phosphorus and potassium were applied at sowing. Organic manures were mixed into the soil 15 days before sowing. Biofertilizers were applied at 3 kg/ha prior to sowing. RDF was 120-60-40 kg N-P2O5-K2O/ha. STV-based fertilizer rates were calculated using soil nutrient values.

2.3 Soil Sampling

Composite soil samples (0–15 cm depth) were collected randomly from five spots in each plot during 2018–2019, air-dried, sieved (2 mm), and stored for analysis. Soil pH and EC were measured in a 1:2.5 soil–water suspension following the standard method [25]. Organic carbon was determined using the wet oxidation method [26]. Available N was analysed by the alkaline permanganate method [27]. Available P was estimated using the Olsen method [28], and available K was extracted with neutral ammonium acetate and measured by flame photometry [29].

2.5 Plant Analysis

One gram of seed/stover was digested with diacid mixture (HNO_3: perchloric acid, 10:4). Phosphorus was estimated by Vanado molybdate yellow color method, potassium by flame photometer method, and nitrogen by micro-Kjeldahl digestion and distillation [30].

Nutrient Uptake and Efficiency

Nutrient uptake was calculated based on yield. Physiological efficiency (PE), agronomic efficiency (AE), and recovery efficiency (RE) were determined as per Cassman et al. (1996) [31].

2.6.1 Recovery efficiency (RE)

$$RE = \frac{\begin{array}{c}\text{Nutrient uptake by crop (kg/ha) with nutrient applied} - \\ \text{Nutrient uptake by crop (kg/ha) with no nutrient applied}\end{array}}{\text{Amount of nutrient applied (kg/ha)}} \text{ X } 100$$

2.6.2. Physiological efficiency (PE)

$$PE = \frac{\begin{array}{c}\text{Grain yield (kg/ha) with nutrient applied} - \\ \text{Grain yield with no nutrient applied}\end{array}}{\begin{array}{c}\text{Nutrient uptake (kg/ha) with nutrient applied} - \\ \text{nutrient uptake (kg/ha) without nutrient applied}\end{array}}$$

2.6.3. Agronomic efficiency (AE)

$$AE = \frac{\begin{array}{c}\text{Grain yield (kg/ha) with nutrient applied} - \\ \text{Grain yield with no nutrient applied}\end{array}}{\text{Amount of nutrient applied (kg/ha)}}$$

2.6.4. Factor productivity (FP)

$$FP = \frac{\text{Grain yield in contro (kg/ha)}}{\text{Amount of nutrient applied (kg/ha)}} + AE$$

1.1 Statistical Analysis

The experimental data were subjected to statistical analysis using a split-plot design in the statistical package SAS software. The treatments were compared using the least significant difference at the 5% level of significance.

2. RESULTS

2.1 Grain and straw yield

Data presented in Fig. 1 (A) indicated that the maximum grain and straw yield (7.04 t ha^{-1}) was found in inorganic sources (M1), which was significantly over organic (M2) and integrated sources (M3). Integrated sources (2.02 and 3.25 t ha^{-1}) was also found significant organic sources (3.04 and 4.71 t ha^{-1}).

All the levels were found to be significant over the control. Maximum grain and straw yield (3.83 and 6.80 t ha^{-1}) was found in 200% NPK, which was at par with 150% NPK (3.49 and 6.04 t ha^{-1}) and significantly over 100% NPK (2.56 and 4.88 t ha^{-1}) and STV-based NPK (3.09 and 4.75 t ha^{-1}).

All the levels of inorganic and integrated sources were found to be significant over their controls, except 100% NPK with integrated source for grain and STV-based NPK with integrated sources for straw yield. Application of 150% and 200% NPK with inorganic sources was found to be significant over their control. Maximum grain and straw yield (5.01 and 9.12 t ha^{-1}) were found in 200% NPK with inorganic source, and at par with 150% NPK with inorganic sources for grain yield and 150% NPK and STV-based NPK with inorganic source for straw yield. All the levels of inorganic and integrated sources were found to be significant over the organic source, except for 100% NPK with integrated sources. Application of 150% and 200% NPK with inorganic sources was found to be significant over their 100% NPK and STV-based NPK. Inorganic fertilizers produce higher yields than organic and integrated nutrient management (INM) due to their rapid nutrient availability [32]. Organic fertilizers like FYM release nutrients slowly because of high lignin and polyphenol content, which limits nitrogen mineralization and reduces yield [33]. Combining inorganic fertilizers with organic materials improves nutrient use efficiency and yield compared to organic inputs alone [34]. Studies confirm that inorganic fertilizers increase grain and straw yields more than organic and INM methods [35], [36].

Higher NPK levels (150% and 200%) enhance growth, delay leaf senescence, and increase nutrient accumulation, leading to improved yields [37], [38]. This is attributed to greater nutrient availability and uptake at elevated fertilizer doses [24], [39].

2.2 N uptake (kg ha^{-1})

Fig. 1 (B) showed that the application of inorganic source (M1) and integrated sources (M3) significantly increased the uptake of N by grain, straw, and total uptake by wheat over the organic source (M2). Maximum N uptake by grain, straw, and total uptake by wheat N 81.35, 42.56, and 123.91 kg ha^{-1} were found with M1, followed by M3 (62.07, 27.69, and 89.76 kg ha^{-1}) and M2 (38.31, 16.33 and 54.64 kg ha^{-1}).

All the levels were found significant over control (S1) with 30.68, 10.89, and 41.57 kg ha^{-1}. The application of 200% NPK (S4) with 83.95, 40.40, and 124.34 kg ha^{-1} found significant over 100% (S2), 150% (S3), and STV-based NPK (S5). However, the application of S3 (74.20, 36.22, and 110.42 kg ha^{-1}) was also found to be significant over S2 and S5.

The interaction between sources of nutrients and levels of NPK was found to be significant for grain, straw, and total uptake by wheat. Different levels of NPK with inorganic and integrated sources were found to be significant over their control. Application of 200% and 150% NPK with inorganic and integrated sources was found to be significant over their 100% and STV-based NPK. However, 200% of NPK with inorganic fertilizers was also found to be significant over their 150% NPK.

Increasing levels of NPK and STV-based NPK levels with inorganic and integrated sources were found to be significant over the same level of organic sources. Levels with inorganic sources were also found to be significant over the same level of NPK with integrated source.

2.3 P uptake (kg ha^{-1})

Fig. 1 (C) indicates that the application of inorganic (M1) and integrated sources (M3) significantly increased the P uptake by grain, straw, and total uptake over the organic source (M2). However, the application of M1 was also found to be significant over M3. The data showed that the maximum uptake of P by grain with M1 (12.13, 4.60, and 16.90 kg ha^{-1}), followed by M3 (8.02, 2.71, and 10.77 kg ha^{-1}) and M2 (5.13, 1.69, and 6.91 kg ha^{-1}).

Among the different levels, P uptake by grain, straw, and total uptake ranged from 3.64, 1.08, and 4.75 kg ha^{-1} in control to 12.37, 4.76, and 17.31 kg ha^{-1} in S4 (200% NPK), having the significant highest N uptake followed by S3 (150% NPK), S5 (STV based NPK) and S2 100% NPK). However, the application of S3 (10.60, 3.80, and 14.37 kg ha^{-1}) was also found to be significant over S2 and S5.

Different NPK levels with inorganic and integrated sources of nutrients were found to be significant over their control for grain, straw, and total uptake. In the organic source, 200% and 150% of NPK were found to be significant over their control. However, the application of 150% and 200% NPK with inorganic and integrated sources was found to be significant over their 100% NPK and STV-based NPK. Among the different combinations, M1S4 (18.38, 7.07, and 25.91 kg ha^{-1}) was significant over all remaining treatments, which were found at par with M1S3 for grain.

All the NPK levels with inorganic and integrated sources were found significantly over the same level of organic sources. Inorganic sources were also found to be significant over the same level of NPK with integrated sources for grain, straw, and total uptake**.**

2.4 K uptake (kg ha^{-1})

Data presented in Fig. 1 (D) showed that the maximum uptake of K by grain, straw and total with inorganic source (M1) 25.00, 176.51 and 201.51 kg ha^{-1}, followed by integrated sources (M3) 17.79, 121.14, and 130.49 kg ha^{-1}, which were found significant over organic source (M2) 11.36, 74.20, and 85.70 kg ha^{-1}. However, uptake of K by grain in M3 was also found to be significant over M2.

All the different levels were found to be significant over control. The maximum uptake of K in straw and total uptake (160.36 and 191.70 kg ha^{-1}) with 200% NPK (S4), and the minimum in the control (8.86, 51.93, and 57.72 kg ha^{-1}). However, maximum grain uptake (22.69 kg ha^{-1}) was found in S3 (150% NPK). Application of 200% NPK and 150% NPK (S3) was found to be significantly over 100% NPK (S2) and STV-based NPK (S5).

Different NPK levels with inorganic and integrated sources of nutrients were found to be significant over their control for grain, straw, and total uptake of K. In organic sources, 200%, 150% and 100% NPK were found to be significant over their control. However, the application of 150%, 200% NPK and STV based on inorganic and integrated sources was found significant over their 100% NPK and found at par among themselves for straw and total uptake. In grain maximum uptake (34.48 kg ha^{-1}) of K found in 150% NPK, which was significant over all remaining treatments, but found non-significant with 200% NPK (34.48 kg ha^{-1}). Among the different combinations, M1S4 (231.36 and 261.44 kg ha^{-1}) gave the maximum uptake by straw and total uptake, which was found to be at par with M1S3 (224.16 and 258.64 kg ha^{-1}) significant over all remaining treatments for straw and total uptake.

All the NPK levels with inorganic and integrated sources were found to be significant over the same level of organic source. Inorganic sources were also found to be significant over the same level of NPK with integrated sources for grain, straw, and total uptake.

Yields and nutrient concentrations in plants influence nutrient uptake [40]. Inorganic fertilizer application results in the highest nutrient uptake, while organic treatments show the lowest, as nutrients in inorganic fertilizers are already mineralized and readily available for plant assimilation [40], [41]. Organic manures have low nutrient availability due to high C: N ratios, causing nitrogen immobilization and reduced N availability to plants [42]. Slow mineralization rates from organic sources lead to lower nutrient availability over time; for example, nitrogen mineralization from manure decreases from 13.2% in the year of application to 3.9% by the fifth year [43]. Phosphorus and potassium mineralization rates also decline significantly after the first year.

Combined application of inorganic fertilizers and organic manure enhances yield by promoting interactions that improve nutrient mineralization, possibly by narrowing the compost's C: N ratio due to the high nitrogen content in inorganic fertilizers [44]. Increasing NPK fertilizer levels raises soil nutrient availability, resulting in enhanced nutrient uptake [2]. Higher fertilization supports vigorous early growth and a high photosynthetic rate, which further boosts nutrient uptake [45]. Significant increases in N, P, and K uptake in grain and straw under 150% and 200% recommended fertilizer doses were reported, with super-optimal doses yielding the highest nutrient uptake [37], [47].

2.5 Agronomic efficiency (AE)

Data in Table 1 revealed that the maximum AE (9.31 kg ha^{-1}) was found with the application of inorganic (M1) sources, which was significant over the integrated and organic source (M2). Integrated sources (3.75 kg ha^{-1}) also found significant over organic sources (1.14 kg ha^{-1}).

Maximum AE (5.64 kg ha^{-1}) was found with 150% NPK (S3) and minimum (4.06 kg ha^{-1}) in STV-based NPK (S5). The application of 150% (S3) was found to be significant over STV-based NPK, 100%, and 200% NPK. Application of 200% NPK was also found to be significant over 100% and STV-based NPK.

The interaction between sources of nutrients and levels of NPK was found to be significant for AE. Maximum AE (10.78 kg ha^{-1}) was found under 150% with an inorganic source (M1S3), and minimum in STV-based NPK with an inorganic source (M2S5). M1S3, which was found at par with 100% NPK (M1S2) of the same source, and these two treatments were significantly superior over the rest of the treatments. All the NPK levels with inorganic and integrated sources were found to be significant over the same level of organic source. Inorganic sources were also found to be significant over the same level of NPK with the integrated source.

2.6 Physiological efficiency (PE)

In Table 1 maximum PE recorded with integrated sources (M3) significantly increased the PE (10.88 kg ha^{-1}) over the inorganic source (M1) and the organic source (M2). M1 (9.64 kg ha^{-1}) was also found to be significant over the organic source (5.81 kg ha^{-1}). The application STV-based NPK level (S5) recorded maximum PE, which was significantly over 100% (S2), 150% (S3), and 200% (S4) NPK. Application of 150% (8.98 kg ha^{-1}) and 200% NPK (9.22 kg ha^{-1}) was also found to be significant over 100% NPK (5.61 kg ha^{-1}).

The interaction between sources of nutrients and levels of NPK was found to be significant for PE. Maximum PE (21.72 kg ha^{-1}) was found in STV-based NPK with integrated source (M3S5), which was significant over all treatments and minimum in STV-based NPK with organic sources (3.55 kg ha^{-1}). Application of 150% and 200% NPK with inorganic fertilizers was found to be significant over their STV-based NPK. In organic, 150% and 200% significant over STV-based NPK and 100% NPK of the same source. In the integrated source, 150%, 200% and STV-based NPK were found significantly over 100% NPK of the same source. All the levels were significant over the same levels of organic source.

2.7 Factor productivity (FP)

Data in Table 1 indicated that the maximum FP (9.31 kg ha^{-1}) was found with the application of inorganic (M1) sources, which was significant over integrated (M3) and organic sources (M2). Integrated sources (9.90 kg ha^{-1}) also found significant over organic sources (6.51 kg ha^{-1}).

Maximum FP (11.65 kg ha^{-1}) was found in 100% NPK, and minimum (10.59 kg ha^{-1}) in 200% NPK. The application of 100% (S1) and 150% NPK (S3) significantly increased the FP over 200% NPK (S4) and STV-based NPK level (S5).

The interaction between sources of nutrients and levels of NPK was found to be significant for FP. Maximum FP (16.35 kg ha^{-1}) found in 100% NPK with inorganic source (M1S2), at par with 150% NPK with inorganic source (M1S3). M1S2 and M1S3 were found to be significant over all remaining treatments. All the increasing levels of NPK with inorganic and integrated nutrients were found to be significant over the same level of NPK with an organic source, except for 100% NPK with an inorganic source. Application of 150% (M1S3) and 100% NPK (M1S2) with inorganic sources was also found to be significant over the same levels of NPK with integrated source (M3S3 and M3S2).

2.8 Recovery efficiency (RE)

Data presented in Table 1 revealed that the treatment involving the application of inorganic (M1) and integrated sources of nutrients (M3) significantly increased the RE (96.02 and 38.87%, respectively) over the organic source (M2), with the RE of 18.24%. However, the application of M1 was also found to be significant over M3.

The maximum RE (59.31%) was recorded with 150% NPK (S3), and the minimum (37.09%) was in STV-based NPK (S5). 150% NPK was also found to be significant over 200% NPK (52.12%) and at par (55.89%) with 100% NPK (S1).

The interaction between sources of nutrients and levels of NPK was found to be significant for RE. Maximum RE was found in 100% NPK with an inorganic source (108.40%), which was non-significant with 150% NPK (106.85%). These treatments were found to be significantly superior to overall rest treatments. In inorganic, organic, and integrated sources 100%, 150% and 200% NPK were found to be significant over their STV-based NPK, except 200% NPK of the inorganic source. Increasing levels of NPK with inorganic and integrated sources were found to be significant over the same level of organic source. However, all the NPK levels with an inorganic source were also found to be significant over the same levels of NPK with an integrated source.

Increasing and maintaining crop productivity requires applying essential nutrients in the right amount, ratio, timing, and method [48]. This study found that the nutrient use efficiency (NUE) of inorganic fertilizers was significantly higher than that of organic and integrated nutrient management (INM) sources. The faster release of nitrogen from mineral fertilizers allows crops to utilize it fully, while nitrogen from organic sources is less synchronized with crop demand, leading to lower partial factor productivity (PFP), agronomic efficiency (AE), and recovery efficiency (RE) [49]. Higher nitrogen leaching losses in organic systems occur due to the asynchrony between nitrogen release and crop uptake [50].

Combined application of organic and inorganic fertilizers improves synchronization of nitrogen availability with plant uptake through enhanced mineralization and immobilization dynamics, resulting in higher NUE under INM compared to organic manure alone [51].

NUE tends to increase as fertilizer rates decrease [52]. Maximum recovery efficiency (RE) and agronomic efficiency (AE) were observed at 150% NPK compared to 100% and 200% NPK rates, while the highest factor productivity (FP) was noted at 100% NPK. Physiological efficiency (PE) peaked with soil test value (STV) based NPK levels [53].

Nitrogen remobilization during grain filling is crucial for NUE, with 60–92% of cereals' nitrogen needs supplied from senescing vegetative tissues [54]. Low NPK levels accelerate senescence and improve NUE, whereas higher NPK levels delay senescence, potentially increasing yield but reducing NUE [55].

Higher phosphorus application decreases agronomic efficiency due to potential nutrient imbalances, though increased P may enhance root density and photosynthesis, improving nutrient absorption [56]. Potassium absorption efficiency declines with excessive K application, but appropriate K fertilization enhances root traits, nitrogen metabolism, and overall nutrient use efficiency [57], [35].

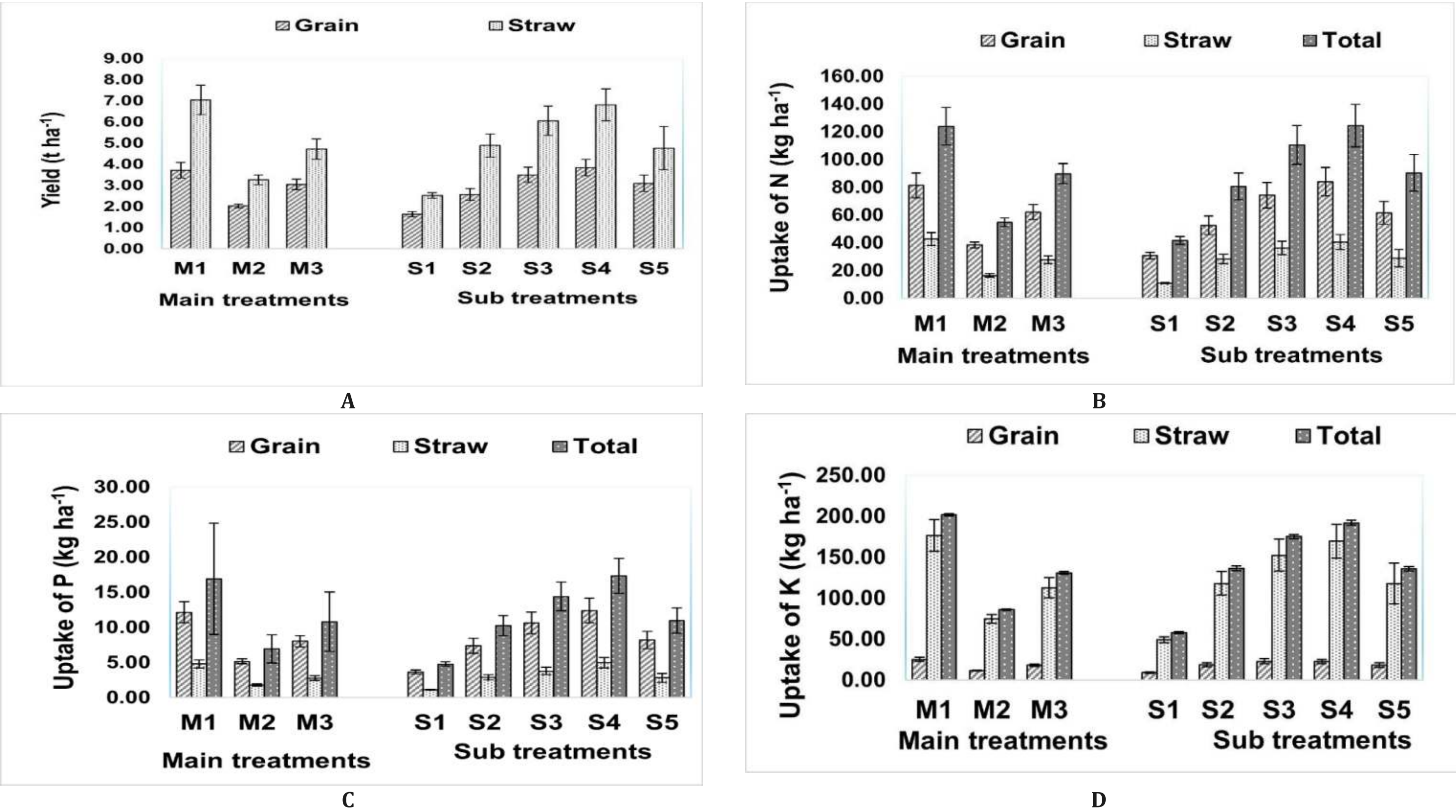

Fig. 1: *Effect of different sources of nutrient and levels on grain and straw yield (A), Uptake of N (B), P (C) and K (D) by grain, straw and total. Results are the mean of three replicates, and error bars indicate standard deviation. M1- Inorganic sources (NPK fertilizers), M2- organic sources and M3- Integrated sources (50% Inorganic + 50% organic) as main treatments and 5 NPK levels S1- control, S2- 100% RDF, S3- 150% RDF, S4- 200% RDF, S5- Based on soil test value for target yield*

Table 1: Effect of different source and NPK levels on nutrient use efficiency

M/S	Nutrient Use Efficiency															
	Recovery Efficiency (kg ha-1)				Physiology Efficiency (kg ha-1)				Agronomic Efficiency (kg ha-1)				Factor Productivity (%)			
	M1	M2	M3	Mean	M1	M2	M3	Mean	M1	M2	M3	Mean	M1	M2	M3	Mean
S2	108.40	23.85	35.41	**55.89**	9.83	3.75	3.26	**5.61**	10.65	0.89	1.16	**4.23**	16.35	8.61	9.99	**11.65**
S3	106.85	24.22	46.84	**59.31**	10.10	7.72	9.11	**8.98**	10.78	1.87	4.27	**5.64**	14.58	7.01	10.17	**10.59**
S4	85.27	19.61	51.46	**52.12**	10.02	8.20	9.43	**9.22**	8.54	1.61	4.85	**5.00**	11.39	5.47	9.27	**8.71**
S5	84.26	5.27	21.74	**37.09**	8.61	3.55	21.72	**11.29**	7.25	0.21	4.72	**4.06**	10.76	4.95	10.15	**8.62**
Mean	**96.20**	**18.24**	**38.87**	**51.10**	**9.64**	**5.81**	**10.88**	**8.78**	**9.31**	**1.14**	**3.75**	**4.73**	**13.27**	**6.51**	**9.90**	**9.89**
SEm±	1.602				0.215				0.274				0.228			
CD	**6.297**				**0.846**				**1.078**				**0.898**			
SEm±	1.864				0.269				0.165				0.200			
CD	**5.441**				**0.798**				**0.481**				**0.583**			
Int I	3.228				0.466				0.285				0.346			
	9.423				**1.383**				**0.833**				**1.010**			
Int II	3.939				0.549				0.535				0.496			
	11.496				**1.631**				**1.563**				**1.449**			

Effect of different sources of nutrient and levels on Agronomic use efficiency (AE) (A), Physiological use efficiency (PE) (B), Factor productivity (FP) (C) and Recovery use efficiency (RUE) of Wheat. M1- Inorganic sources (NPK fertilizers), M2- organic sources and M3- Integrated sources (50% Inorganic + 50% organic) as main treatments and 5 NPK levels S1- control, S2- 100% RDF, S3- 150% RDF, S4- 200% RDF, S5- Based on soil test value for target yield

3. CONCLUSION

The study suggests that crop growth is influenced by inorganic fertilizers, as they provide immediate nutrient uptake. Increasing yield by using inorganic fertilizer has been found to be effective in the short term but demands consistent use on a long-term basis. Combining organic and inorganic fertilizers can improve soil fertility and reduce fertilizer requirements. Yield, efficiency, and uptake are comparatively low in INM, but using yield data from one harvest is not valid for a proper evaluation. The study found that crops responded to higher fertilizer rates than recommended, indicating that current fertilizer recommendations are inadequate. The increased rate of fertilizers, such as 150% NPK, maintained higher yields and uptake compared to lower doses of nutrients. More studies and long-term fertilizer experiments should be conducted for proper evolution.

4. ACKNOWLEDGMENTS

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5. CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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