



RESEARCH ARTICLE

Weed dynamics, nutrient uptake and crop productivity in wheat under organic, inorganic and integrated nutrient management practices after twenty-six years of experimentation

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Abstract

A long-term field experiment initiated in 1995 at Research Farm of Chaudhary Charan Singh Haryana Agricultural University (CCSHAU), Hisar, India, was selected for research experiment during rabi season of 2021–22 with treatments: recommended dose of nitrogen (N) (150 kg/ha) and phosphorus pentoxide (P₂O₅) (60 kg/ha); farmyard manure (FYM) at 15 t/ha alone and in combination with N (150 kg/ha) and P₂O₅ (30 kg/ha); poultry manure at 5 t/ha alone and in combination with N (150 kg/ha) and P₂O₅ (30 kg/ha); press mud at 7.5 t/ha alone and in combination with N (150 kg/ha) and P₂O₅ (30 kg/ha) in main plot and weed management: pendimethalin at 1.5 kg/ha as pre-emergence alone and its sequential application with clodinafop + metsulfuron methyl (ready mix) at 64 g/ha as post-emergence; weedy check and weed-free in sub-plot with 3 replications in a split-plot design. Application of FYM at 15 t/ha + N (150 kg/ha) and P₂O₅ (30 kg/ha) produced a grain yield of 5341 kg/ha, representing a significant 17.4 % increase over the recommended dose of N (150 kg/ha) and P₂O₅ (60 kg/ha) with lowest weed density of *Anagallis arvensis* and *Melilotus indica*. Conversely, the highest weed density of *Coronopus didymus*, *Rumex dentatus* and *Phalaris minor* was observed under press mud at 7.5 t/ha + N (150 kg/ha) and P₂O₅ (30 kg/ha). Furthermore, the sequential application of pendimethalin at 1.5 kg/ha followed by clodinafop + metsulfuron methyl (ready mix) at 64 g/ha significantly increased yield and resulted in the lowest weed density. Under weedy check conditions, weeds removed 10.71, 5.87 and 73.22 kg/ha of N, phosphorus (P) and potassium (K) respectively reducing grain yield by 34.5 % compared to weed free conditions.

Keywords: long term experiment; nutrient uptake; organic manure; weeds density; yield

Introduction

Wheat (*Triticum aestivum* L.) stands as the second most crucial staple food globally, closely following rice and holds immense significance in the world economy. India ranks second in terms of wheat area and production, with cultivation ranging from 10° N to 37° N latitude. In India, wheat is produced on 34.8 mha, with a total production and productivity of 113 mt and 3217 kg/ha respectively (1). It sustains approximately one-third of the global population, playing a pivotal role in ensuring food and nutritional security, not only in India but also worldwide. The limited arable land and scarce resources, expanding the cultivation area for wheat presents a challenge. Therefore, the primary emphasis lies in enhancing wheat production through meticulous agronomic practices and effective weed management (2).

Besides optimising agronomic practices and preventive measures, chemical weed management stands out as a crucial element in boosting wheat yield and productivity. In various wheat-growing regions of India, significant yield reductions of up to 20–32 % due to weed infestation have been documented (3). The competitive

dynamics between crops and weeds can be influenced by factors such as the amount of nitrogen (N) fertiliser applied, the timing of application and application methods. Livestock manure may exert different effects on the competitive interactions between crops and weeds compared to N fertiliser (4), possibly due to variations in N release rates or the N type.

Long-term studies on fertilisers and manure application can serve as valuable tools for assessing weed density in crops, analysing yield trends, detecting changes in yield and estimating nutrient dynamics. Organic manures, such as farmyard manure (FYM), goat manure and poultry manure, offer promising alternatives to chemical fertilisers for crop production (5). Combining organic manures with inorganic fertilisers in long-term experiments significantly boosts grain yield, water usage and soil chemical properties compared to either no treatment or using only inorganic N and phosphorus (P) fertilisers; this combined approach is essential for sustainable production (6). Furthermore, the application of organic manures alongside mineral fertilisers plays a crucial role in optimising soil nutrient levels (both macronutrients and

micronutrients), enhancing crop yield and improving water use efficiency (7, 8), nutrient use efficiency and grain quality (9). At lower rates of chemical fertiliser application, FYM and press mud serve as excellent sources of plant nutrients (10). The quality and quantity of manure fertilisation likely influence the composition of weed species due to varying weed competitiveness and responsiveness to N supply (11). The weed seeds found in FYM mostly result from fodder that passed through the digestive tract of animals. Consequently, manure-particularly FYM can enhance weed density if poor quality is applied. Increased weed density causes greater competition for more nutrients, which reduces crop yield. Adequate manuring results in a strong crop plant cover and reduced weed density, as all plants in the field have sufficient growth factors, minimising competition. Among various treatments, combining chemical fertiliser application with different organic sources can effectively substitute 25 to 50 % of N (12). Numerous studies have demonstrated that long-term application of organic manures in conjunction with balanced chemical fertilisers enhances soil health, crop management and weed control more effectively than either method used alone (13).

A deeper comprehension of how organic manures and inorganic fertilisers influence weeds and crops when grown together in competitive environments could aid in developing fertilisation strategies as integral parts of comprehensive, integrated weed control programs. Additionally, it could offer insights into discrepancies observed across research findings. Although the long-term effects of manures and fertilisers on soil properties are well known, there were limited information on the effects of organic manures, chemical fertilisers and integrated nutrient management on weed dynamics and yield. Therefore, our present research work was designed with the aim of investigating the influence of weed management on wheat yield, economic aspects and nutrient uptake under long-term organic, inorganic and integrated nutrient management practices.

Materials and Methods

Site characteristics

In 1995, a long-term field experiment was started at the Research Farm of the Department of Soil Science, Chaudhary Charan Singh Haryana Agricultural University (CCSHAU), Hisar, Haryana, India. The study aimed to investigate the impact of various combinations of organic manures and chemical fertilisers on soil productivity and fertility within the pearl millet-wheat cropping sequence. The experiment site is located at 29°16' N latitude and 75°7' E longitude in North-Western India. The experimental soil is classified as coarse-loamy *Ustochrept* particularly in this region. The region experiences an average annual rainfall of 443 mm, primarily occurring during the South-West monsoon season from July to September, supplemented by occasional cyclonic rains in late spring or winter. The mean annual temperature stands at 24.8 °C. Significant

temperature variations are observed between summer and winter months, with maximum temperatures reaching up to 48 °C during the scorching summer, while winter temperatures can drop to 0 °C or even lower, accompanied by frost. Relative humidity remains relatively constant from July to March, averaging around 80 to 90 %, before decreasing to approximately 40–50 % for the remaining period of the year.

Experiment layout and treatment details

The experiment was carried out during the rabi season of 2021–22 with 7 different nutrients practices: the recommended dose of N (150 kg/ha) and phosphorus pentoxide (P_2O_5) (60 kg/ha); FYM alone at 15 t/ha; FYM at 15 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha); poultry manure alone at 5 t/ha; poultry manure at 5 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha); press mud alone at 7.5 t/ha; press mud at 7.5 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha) in main plot and 4 weed management: pendimethalin (30 % EC) at 1.5 kg/ha (formulated dose) as pre-emergence; pendimethalin at 1.5 kg/ha as pre-emergence followed by clodinafop + metsulfuron methyl (ready mix) at 64 g/ha as post-emergence; weedy check and weed free in sub-plot. All treatments were replicated 3 times in permanent plots. Before sowing, soil samples were collected to analyse the physico-chemical properties of each plot (Table 1). All manure was incorporated into the soil 1 month prior to wheat sowing. The average value of nutrient (N, P, potassium (K) content was 1.19, 0.95, 1.88 % in FYM; 2.52, 1.83, 1.74 % in poultry manure and 3.20, 1.09, 0.87 % in press mud. Half the dose of N and full dose of P were applied via urea and DAP at the time of wheat sowing; the remaining N was applied during the first irrigation (21 days after sowing (DAS)). Wheat variety WH 1105 was sown on 15th November at a depth of 5–6 cm using a seed drill, with a seeding rate of 100 kg/ha and a row spacing of 20 cm. A pre-emergence herbicide was applied immediately after sowing using a knapsack sprayer with a flat fan nozzle, with 625 L/ha of water. Post-emergence herbicide application occurred at 32 DAS using the same equipment with 375 L/ha of water. Throughout the growing season, manual weeding was carried out regularly in the weed-free plots. Irrigation was applied with canal water using the flood irrigation method. Harvesting and threshing were done in the first fortnight of April. The crop was harvested manually in each plot separately; bundles were formed and allowed to dry in the sun in the field. Biological yield (grain + straw) was recorded for each net plot before threshing and grain weight was measured for each plot after threshing.

Sampling and analysis

After crop harvest, plant samples were gathered for analysis. Subsequently, the grain and straw samples were dried in an oven at 65 ± 2 °C to a constant weight. These dried samples were then crushed using a stainless-steel grinder and stored in polythene bags for chemical analysis. Digestion of the grain and straw samples was performed in a digestion chamber utilising a di-acid mixture comprising sulphuric acid (H_2SO_4) and perchloric acid ($HClO_4$) in a 9:1 ratio for nutrient analysis purposes. The total N, P and K contents

Table 1. Physico-chemical properties of soil before sowing of wheat in 2021–22

Treatments	N (kg/ha)	P (kg/ha)	K (kg/ha)	OC (%)	EC	pH
Recommended dose of N (150 kg/ha) and P_2O_5 (60 kg/ha)	126.3	24.4	328.5	0.48	0.35	8.09
FYM alone at 15 t/ha	163.8	61.2	692.8	1.08	0.57	8.12
FYM at 15 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha)	168.4	64.9	758.3	1.12	0.64	8.09
Poultry manure alone at 5 t/ha	151.3	53.3	456.1	0.88	0.51	7.97
Poultry manure at 5 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha)	154.5	74.7	461.9	0.84	0.65	7.93
Press mud alone at 7.5 t/ha	140.9	70.4	441.3	0.75	0.63	8.03
Press mud at 7.5 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha)	162.1	58.9	473.4	1.02	0.66	8.00

in the digested samples were determined and the uptake of these elements was calculated by multiplying the nutrient concentration by the respective yield. The concentration of N, P and K were determined by using Nessler's reagent technique (14), the ammonium molybdate yellow colour method (15) and flame emission spectroscopy (16), respectively. Similar procedures were applied for analysis of weed samples. Weed density was calculated using the quadrat approach (17). Weeds collected within the quadrat were also dried in an oven at 65 ± 2 °C to determine the dry matter accumulation, which was measured in grams per square meter (g/m^2). Economic analysis was based on the authorised market prices for inputs and outputs set by the Directorate of Farm, CCSHAU Hisar, India. These calculations involved determining the cost of cultivation and gross revenue (Rs/ha) for various treatments. Net returns (Rs/ha) were computed by deducting the total from the gross revenue for each treatment.

Statistical analysis

The data collected regarding weed dynamics, nutrients and yield parameters of wheat during the study underwent analysis of variance using the online statistical analysis package of OPSTAT (18). Calculations and graphical presentations were done using Microsoft Excel.

Results and Discussion

Weed studies

The details of weed density, dry matter accumulation and nutrient uptake by weeds were recorded and are mentioned below:

Weed density

Weed species were collected and identified within the experimental

field. *Phalaris minor*, *Anagallis arvensis*, *Melilotus indica*, *Coronopus didymus*, and *Rumex dentatus* were among the major weed species found in the experimental field, while *Avena ludoviciana*, *Chenopodium album*, *Chenopodium murale*, and *C. arvensis* were among the minor weed species. The density of weeds (No./m^2) such as *P. minor*, *A. arvensis*, *M. indica*, *C. didymus*, *R. dentatus*, and miscellaneous periodic plants were differed significantly ($p=0.05$) under various treatments at the time of harvest (Table 2).

Weed density of *A. arvensis* and *M. indica* was higher under organic manure alone treatment than integrated nutrient management (INM), whereas *P. minor*, *C. didymus*, *R. dentatus* and miscellaneous weed density were observed more under INM treatment than the treatment with organic manures alone. The weed density of *A. arvensis* and *M. indica* was lower at harvest (2.98 and 3.15 respectively) when FYM at 15 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha) was applied, while it was higher where press mud alone at 7.5 t/ha was used. Conversely, the weed density of *C. didymus*, *R. dentatus*, and *P. minor* were observed to be higher at harvest (5.02, 4.05 and 3.07 respectively) when press mud at 7.5 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha) was applied compared to other treatments. This occurrence may be attributed to the abundance of micro and macro nutrients found in press mud (19). In FYM at 15 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha) treatment, some miscellaneous weeds (*Medicago denticulate*, *Fumaria parviflora* and *Lathyrus sativus*) were observed, possibly due to the cumulative effect of FYM on the weed seed bank (20).

The weed density of *A. arvensis*, *M. indica*, *C. didymus*, *R. dentatus*, *P. minor* and miscellaneous weeds were significantly lower at harvest (1.41, 1.47, 1.82, 1.47, 1.27 and 1.41 respectively) under the sequential application of pendimethalin at 1.5 kg/ha followed by clodinafop + metsulfuron methyl (ready mix) at 64 g/ha

Table 2. Effect of different weed management and long-term nutrient management practices on weed density (No./m^2) at harvest in wheat crop

Treatments	<i>Phalaris minor</i>	<i>Anagallis arvensis</i>	<i>Melilotus indica</i>	<i>Coronopus didymus</i>	<i>Rumex dentatus</i>	Miscellaneous
Nutrient management practices						
Recommended dose of N (150 kg/ha) and P_2O_5 (60 kg/ha)	3.03 (14.47)	3.12 (15.98)	3.3 (18.38)	4.95 (46.31)	3.99 (28.09)	2.82 (12.04)
FYM alone at 15 t/ha	2.73 (11.6)	3.46 (19.93)	3.67 (22.92)	4.45 (37.12)	3.59 (22.52)	2.77 (11.63)
FYM at 15 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha)	2.99 (14.07)	2.98 (14.51)	3.15 (16.69)	4.89 (45.05)	3.94 (27.33)	2.92 (13.02)
Poultry manure alone at 5 t/ha	2.61 (10.53)	3.41 (19.39)	3.62 (22.3)	4.24 (33.7)	3.43 (20.44)	2.75 (11.45)
Poultry manure at 5 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha)	3.05 (14.73)	3.06 (15.43)	3.25 (17.74)	5.00 (47.15)	4.03 (28.6)	2.86 (12.44)
Press mud alone at 7.5 t/ha	2.69 (11.2)	3.49 (20.30)	3.7 (23.34)	4.37 (35.84)	3.53 (21.74)	2.69 (10.93)
Press mud at 7.5 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha)	3.07 (14.87)	3.04 (15.20)	3.22 (17.48)	5.02 (47.62)	4.05 (28.88)	2.9 (12.78)
SE(m)±	0.03	0.08	0.09	0.14	0.02	0.03
LSD ($p=0.05$)	0.08	0.26	0.28	0.43	0.07	0.10
Weed management practices						
Pendimethalin (1.5 kg/ha)	2.28 (4.21)	2.51 (5.29)	2.66 (6.08)	3.65 (12.29)	3.03 (8.18)	2.22 (3.94)
Pendimethalin (1.5 kg/ha) followed by clodinafop + metsulfuron methyl (64 g/ha ready mix)	1.27 (0.6)	1.41 (1.00)	1.47 (1.15)	1.82 (2.32)	1.47 (1.17)	1.41 (0.98)
Weedy check	6.96 (47.43)	7.98 (62.62)	8.54 (72.01)	12.4 (152.7)	9.65 (92.11)	6.65 (43.24)
Weed free	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
SE(m)±	0.07	0.40	0.43	0.48	0.06	0.09
LSD ($p=0.05$)	0.22	0.19	1.27	1.47	0.19	0.29

Original data given in parenthesis were subjected to square root ($\sqrt{X+1}$) transformation before analysis

treatment compared to other herbicidal treatments. This reduction could be attributed to the efficient weed control achieved through the post-emergence application of clodinafop + metsulfuron methyl. Additionally, weed density decreased under the sequential application of pendimethalin at 1.5 kg/ha followed by clodinafop + metsulfuron methyl (ready mix) at 64 g/ha in comparison to the application of pendimethalin alone. Our findings corroborate earlier research showing that the sequential application of pendimethalin 1500 g/ha followed by clodinafop + metsulfuron methyl (60 + 4 g/ha) effectively minimised weed density in the wheat crop (21).

Dry matter accumulation

The total dry matter accumulation (g/m^2) by weeds observed at harvest was significantly lower (8.83 g/m^2) in the poultry manure alone (5 t/ha) treatment compared to other treatments at both observation stages (Table 3). Conversely, the total dry matter accumulation by weeds was highest at harvest (10.49 g/m^2) under the press mud at 7.5 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha) treatment. This increase could be attributed to the high nutrient content of press mud as compared to other manures, which increases soil fertility and enhances nutrient uptake by weeds (22). Furthermore, poultry manure application has been shown to reduce weed density (23).

Among weed management treatments, maximum dry matter accumulation of weeds was observed under the weedy check treatment at harvest (27.11 g/m^2). Significantly, lower dry matter accumulation of weeds was observed under the sequential application of pendimethalin at 1.5 kg/ha followed by clodinafop + metsulfuron methyl (ready mix) at 64 g/ha at harvest

(3.21 g/m^2) compared to other herbicidal management treatments. Application of pendimethalin at 1.5 kg/ha followed by clodinafop + metsulfuron methyl (ready mix) at 64 g/ha reduced weed dry matter accumulation by 88.2 % at harvest compared to the weedy check. This reduction might be due to decreased weed density and reduced weed growth. Present results are in corroboration with earlier findings which reported that sequential application of pendimethalin at 0.75 kg/ha followed by clodinafop-propargyl + metsulfuron methyl 0.4 kg/ha performed better compared to other treatments (24).

Interaction effects of different nutrient and weed management treatments on total weed dry matter accumulation (Table 4) revealed that the increase in dry matter accumulation attributed to various nutrient applications was significant. At harvest, highest total weed dry matter accumulation (28.913 g/m^2) was observed under weedy check conditions with the application of press mud at 7.5 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha). Conversely, the lowest total weed dry matter accumulation (2.92 g/m^2) was observed with poultry manure at 5 t/ha at harvest. Contrary results were observed, wherein the application of press mud combined with inorganic fertilisers significantly decreased the weed density and weed dry matter accumulation compared to the application of inorganic fertilisers alone (25).

Nutrient uptake by weeds

The application of various organic manures along with inorganic fertilisers led to a significant increase in the N, P, and K contents and uptake by weeds compared to the application of organic manures and inorganic fertilisers alone (Fig. 1). The highest uptake of N (6.40 kg/ha), P (3.62 kg/ha), and K (44.96 kg/ha) was observed with

Table 3. Effect of different weed management and long-term nutrient management practices on total dry matter accumulation at harvest by weeds

Treatments	Dry matter (g/m^2)
Nutrient management practices	
Recommended dose of N (150 kg/ha) and P_2O_5 (60 kg/ha)	10.34 (223.78)
FYM alone at 15 t/ha	9.27 (179.39)
FYM at 15 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha)	10.2 (217.7)
Poultry manure alone at 5 t/ha	8.83 (162.87)
Poultry manure at 5 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha)	10.44 (227.83)
Press mud alone at 7.5 t/ha	9.11 (173.21)
Press mud at 7.5 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha)	10.49 (230.11)
SE(m)±	0.09
LSD ($p=0.05$)	0.28
Weed management	
Pendimethalin (1.5 kg/ha)	8.14 (65.2)
Pendimethalin (1.5 kg/ha) followed by clodinafop + metsulfuron methyl (64 g/ha ready mix)	3.21 (9.33)
Weedy check	27.11 (733.8)
Weed free	1.00 (0.00)
SE(m)±	0.26
LSD ($p=0.05$)	0.8

Table 4. Interaction effect of different weed management and long-term nutrient management practices on total weed dry weight at harvest

Weed management	Pendimethalin (1.5 kg/ha)	Pendimethalin (1.5 kg/ha) followed by clodinafop + metsulfuron methyl (64 g/ha ready mix)	Weedy check	Weed free
Nutrient management				
Recommended dose of N (150 kg/ha) and P_2O_5 (60 kg/ha)	8.552 (72.18)	3.365 (10.33)	28.513 (812.39)	1 (0)
FYM alone at 15 t/ha	7.662 (57.74)	3.043 (8.263)	25.505 (649.83)	1 (0)
FYM at 15 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha)	8.437 (70.22)	3.323 (10.05)	28.123 (790.32)	1 (0)
Poultry manure alone at 5 t/ha	7.315 (52.54)	2.918 (7.52)	24.330 (591.27)	1 (0)
Poultry manure at 5 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha)	8.629 (73.49)	3.393 (10.52)	28.769 (827.1)	1 (0)
Press mud alone at 7.5 t/ha	7.539 (55.87)	2.999 (8)	25.090 (628.81)	1 (0)
Press mud at 7.5 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha)	8.671 (74.22)	3.409 (10.62)	28.913 (835.37)	1 (0)
Factors			LSD ($p=0.05$)	SE(m)±
Weed management at same level of nutrient management			0.614	0.219
Nutrient management at same level of weed management			0.532	0.186

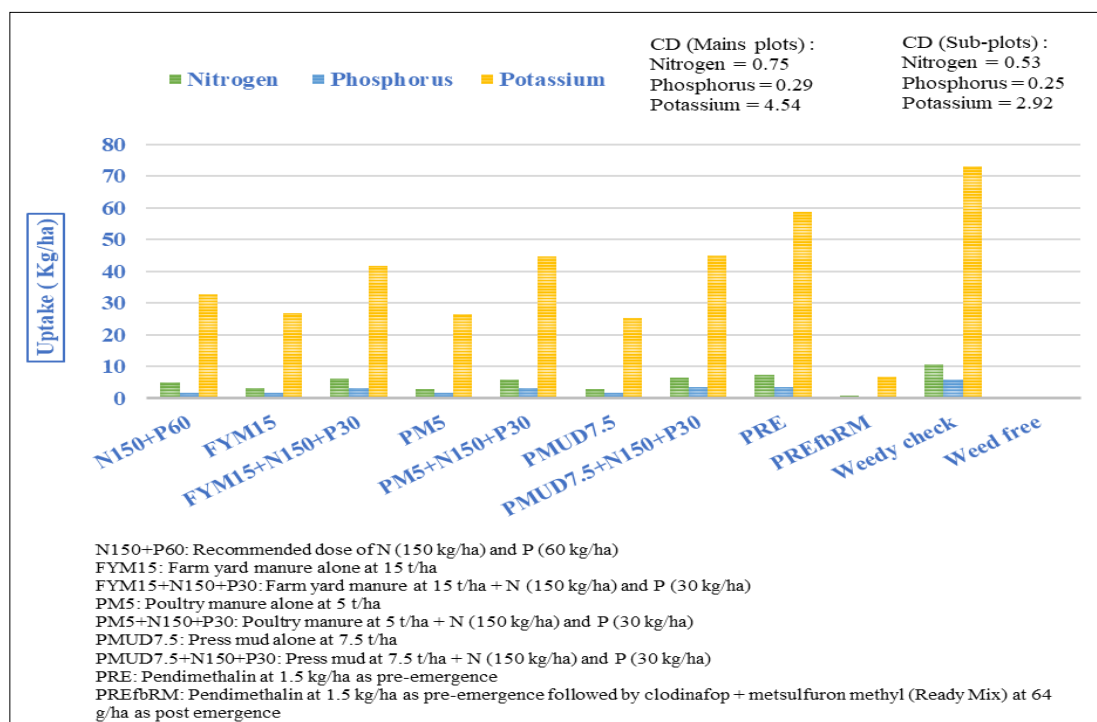


Fig. 1. Effect of different weed management and long-term nutrient management practices on NPK uptake by weeds.

the application of press mud at 7.5 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha), which was attributed to the greater dry matter of weeds. The highest percentages of total N, P, and K removed by weeds were 6.4, 10.3 and 22.1 % respectively, in this treatment. These observations were consistent with earlier findings, indicating increased nutrient loss by weeds alongside improvements in soil fertility (22).

Significantly higher nutrient uptake of N (10.71 kg/ha), P (5.87 kg/ha) and K (73.22 kg/ha) was observed in the weedy check, followed by the pendimethalin at 1.5 kg/ha as pre-emergence treatment, possibly due to lower crop-weed competition. Among the herbicidal treatments, pendimethalin at 1.5 kg/ha as pre-emergence resulted in significantly higher nutrient uptake by weeds (N- 7.37 kg/ha, P- 3.68 kg/ha and K- 58.69 kg/ha) compared to pendimethalin at 1.5 kg/ha as pre-emergence followed by clodinafop + metsulfuron methyl (ready mix) at 64 g/ha treatment. The higher nutrient uptake by weeds was due to higher weed density and weed growth. Similar results were recorded in the unweeded control followed by the application of herbicides alone rather than pre-mix herbicides or sequential application of herbicides (26).

Crop studies

The observations regarding yield, nutrient content, nutrient uptake and economics has been recorded and are mentioned below:

Yield of wheat

The application of various organic manures along with inorganic fertilisers significantly increased grain, straw, and biological yields compared to treatments with only organic manures or inorganic fertilisers alone (Table 5). Wheat grain and straw yields under various treatment combinations ranged from 2428 to 5341 and 4314 to 9436 kg/ha respectively. The application of either 15 t/ha FYM or 5 t/ha poultry manure or 7.5 t/ha press mud alone resulted in the lowest grain and straw yield of wheat. The highest grain (5341 kg/ha) and straw yields (9436 kg/ha) of wheat were observed under the FYM at 15 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha) treatment, followed by the press mud at 7.5 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha) and poultry manure at 5 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha) treatments. Application of FYM at 15 t/ha along with 150 kg/ha N and 30 kg/ha P_2O_5 significantly increased grain yield by 17.4 % and straw yield by 16.9 % compared to recommended dose of fertilisers (RDF). Sole application of organic manures resulted in the lower crop yield

Table 5. Effect of different weed management and long-term nutrient management practices on grain and straw yield of wheat

Treatments	Yield (kg/ha)	
	Grain	Straw
Nutrient management practices		
Recommended dose of N (150 kg/ha) and P_2O_5 (60 kg/ha)	4549d	8074d
FYM alone at 15 t/ha	2669e	4768e
FYM at 15 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha)	5341a	9436a
Poultry manure alone at 5 t/ha	2708e	4838e
Poultry manure at 5 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha)	4845c	8559c
Press mud alone at 7.5 t/ha	2428f	4314f
Press mud at 7.5 t/ha + N (150 kg/ha) and P_2O_5 (30 kg/ha)	5050b	8972b
Weed management practices		
Pendimethalin (1.5 kg/ha)	3828b	6873b
Pendimethalin (1.5 kg/ha) followed by clodinafop + metsulfuron methyl (64 g/ha ready mix)	4393a	7732a
Weedy check	2986c	5389c
Weed free	4559a	7984a

Note: Different lowercase letters within columns indicate significance at $p < 0.05$.

compared to using only inorganic fertilisers or a combination of organic manures with inorganic fertilisers, even after 26 years of experiment. The gradual and continuous supply of plant nutrients from both fertilisers and organic manures meets the crop's requirements, including readily available macro and micronutrients. As a result, the improved plant canopy leads to higher rates of photosynthesis, ultimately enhancing productivity. The superior crop yield in treatments combining organic manures and inorganic fertilisers may be attributed to the immediate availability of nutrients in the proper amount and form. This is also related to the slower release of nutrients from organic sources along with improvement in soil physical and biological properties (10). Similarly, higher productivity of the pearl millet-wheat cropping system was observed with the combined application of FYM and RDF compared to the application of fertilisers alone (27).

The grain and straw yield of wheat crops were significantly reduced by uncontrolled weeds. Significantly higher grain (4559 kg/ha) and straw yield (7984 kg/ha) of wheat crops were observed in weed-free treatments, which were statistically at par with the sequential application of pendimethalin at 1.5 kg/ha followed by clodinafop + metsulfuron methyl (ready mix) at 64 g/ha, while the minimum grain (2986 kg/ha) and straw (5389 kg/ha) yield were observed under the weedy check treatment. In the weedy check treatment, 34.5 and 32.5 % reductions in grain and straw yield respectively were observed as compared to the weed-free treatment. The improved yield performance of these treatments can be attributed to reduced crop-weed competition. Weeds prevalent throughout the crop season in the weedy check treatment caused significant losses in production and yield characteristics. Weed-free conditions resulted in optimal crop availability of moisture, nutrients, light, and space, leading to higher values of crop yield attributes and crop yield (13, 21, 28).

A significant interaction between nutrient sources and weed management practices resulted in the highest grain and straw yield with FYM at 15 t/ha + N (150 kg/ha) and P₂O₅ (30 kg/ha) under weed free conditions (Table 6). It was observed that the improvement in wheat grain and straw yield due to various organic manure applications was greater when effective weed management was used. Under weed-free conditions, the maximum grain yield (6178 kg/ha), and straw yield (10771 kg/ha) were observed with the

application of FYM at 15 t/ha + N (150 kg/ha) and P₂O₅ (30 kg/ha) treatment. Conversely, in weedy check conditions, the minimum grain yield (1840 kg/ha), and straw yield (3324 kg/ha) were measured with the application of press mud alone at 7.5 t/ha treatment. Regarding weed management treatments, the maximum grain and straw yield were measured under sequential application of pendimethalin at 1.5 kg/ha followed by clodinafop + metsulfuron methyl (ready mix) at 64 g/ha conditions, combined with the application of FYM at 15 t/ha + N (150 kg/ha) and P₂O₅ (30 kg/ha).

Nutrient content and uptake by wheat crop

The nutrient content (Table 7) and uptake (Fig. 2a and 2b) by grain and straw under different treatment combinations differ significantly ($p=0.05$). The combined application of organic manure and chemical fertilisers resulted in significantly higher nutrient content and uptake by the wheat crop compared to the sole application (9, 29).

The FYM at 15 t/ha + N (150 kg/ha) and P₂O₅ (30 kg/ha) treatment produced a significantly higher N content (1.48 %) and uptake (79.11 kg/ha) in grain, which were statistically comparable to press mud at 7.5 t/ha + N (150 kg/ha) and P₂O₅ (30 kg/ha) and poultry manure at 5 t/ha + N (150 kg/ha) and P₂O₅ (30 kg/ha) in N content (1.46 and 1.44 % respectively) and uptake (72.92 and 70.04 kg/ha respectively). Similar trends were observed in P and K contents and uptake, except for P uptake in grain, which was statistically comparable to press mud at 7.5 t/ha + N (150 kg/ha) and P₂O₅ (30 kg/ha). The FYM at 15 t/ha + N (150 kg/ha) and P₂O₅ (30 kg/ha) treatment also resulted in a significantly higher N content (0.24 %) in wheat straw, statistically comparable to press mud at 7.5 t/ha + N (150 kg/ha) and P₂O₅ (30 kg/ha) in N content (0.23 %), with similar trends in P and K contents. Regarding N, P, and K uptake by straw, maximum uptake (22.24, 12.97 and 148.83 kg/ha respectively) was observed in the FYM at 15 t/ha + N (150 kg/ha) and P₂O₅ (30 kg/ha) treatment, although P uptake was statistically comparable to press mud at 7.5 t/ha + N (150 kg/ha) and P₂O₅ (30 kg/ha). This could be attributed to the mineralisation, solubilisation effect, and longer release of nutrients by FYM (30–32).

Significantly higher N content and uptake by grain (1.45 % and 63.42 kg/ha respectively) and straw (0.22 % and 17.50 kg/ha respectively) were observed in weed-free treatment, followed by sequential application of pendimethalin (1.5 kg/ha) followed by

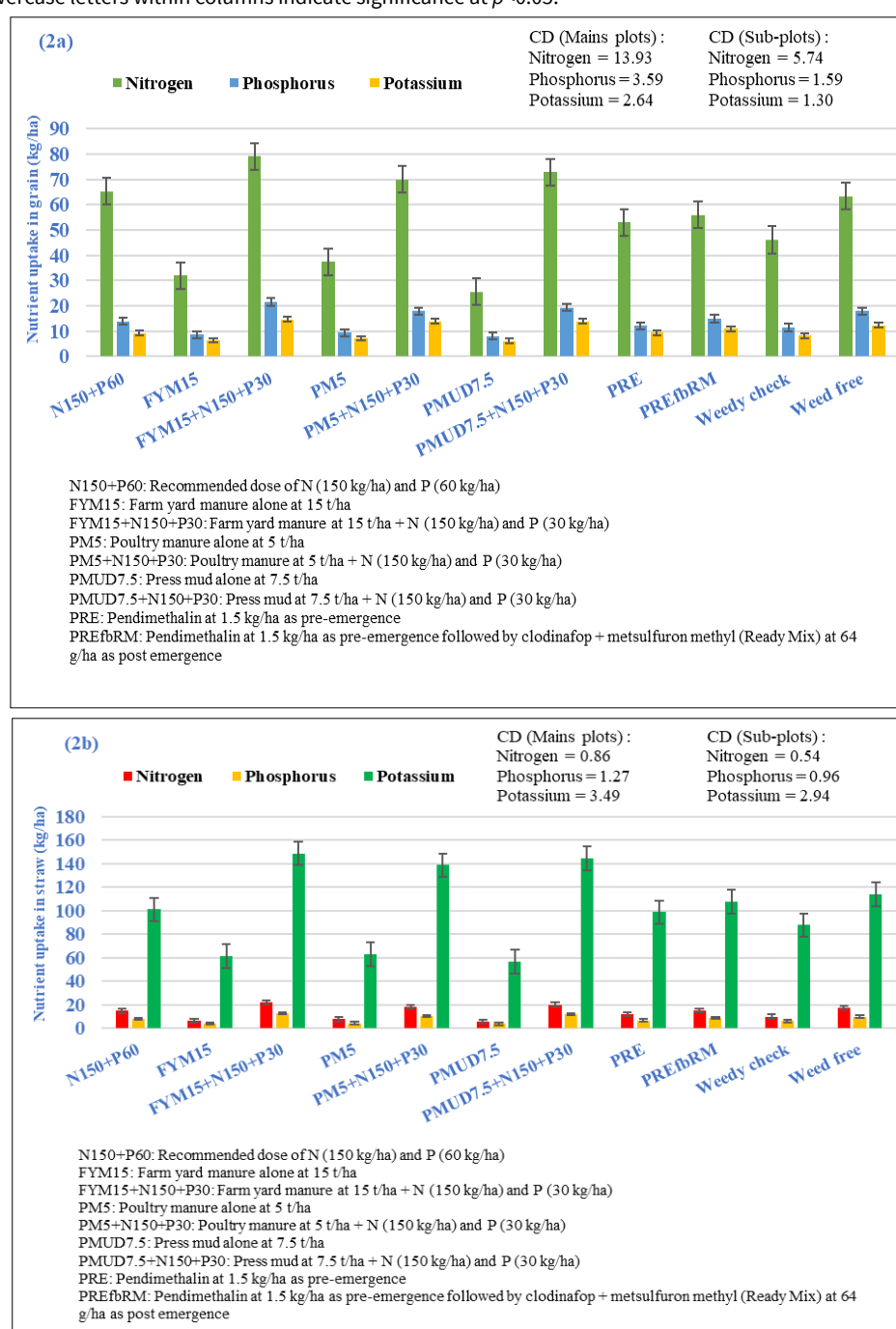
Table 6. Interaction effect of different weed management and long-term nutrient management practices on grain and straw yield (kg/ha) of wheat

Weed management	Pendimethalin (1.5 kg/ha)		Pendimethalin (1.5 kg/ha) followed by clodinafop + metsulfuron methyl (64 g/ha ready mix)		Weedy check		Weed free		Mean	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Nutrient management										
Recommended dose of N (150 kg/ha) and P ₂ O ₅ (60 kg/ha)	4418	7934	5070	8924	3447	6221	5262	9215	4549	8074
FYM alone at 15 t/ha	2592	4686	2974	5270	2022	3674	3087	5443	2669	4768
FYM at 15 t/ha + N (150 kg/ha) and P ₂ O ₅ (30 kg/ha)	5187	9273	5953	10431	4047	7271	6178	10771	5341	9437
Poultry manure alone at 5 t/ha	2630	4755	3018	5348	2052	3728	3132	5522	2708	4838
Poultry manure at 5 t/ha + N (150 kg/ha) and P ₂ O ₅ (30 kg/ha)	4705	8411	5399	9461	3671	6595	5604	9770	4845	8559
Press mud alone at 7.5 t/ha	2358	4239	2706	4769	1840	3324	2809	4925	2428	4314
Press mud at 7.5 t/ha + N (150 kg/ha) and P ₂ O ₅ (30 kg/ha)	4904	8816	5628	9918	3826	6912	5841	10241	5050	8972
Mean	3828	6873	4393	7732	2986	5389	4559	7984		
Factors	LSD ($p=0.05$)								SE(m)±	
	Grain		Straw		Grain		Straw		Grain	Straw
	472.83		747.071		152.007		240.171			
Weed management at same level of nutrient management	409.843		663.946		143.078		231.786			
Nutrient management at same level of weed management										

Table 7. Effect of different weed management and long-term nutrient management practices on NPK content by wheat grains and straw

Treatments	Nutrient content (%)					
	Grain			Straw		
	N	P	K	N	P	K
Recommended dose of N (150 kg/ha) and P ₂ O ₅ (60 kg/ha)	1.42ab	0.34b	0.25b	0.18c	0.10b	1.30c
FYM alone at 15 t/ha	1.26c	0.28c	0.23c	0.15d	0.09c	1.29c
FYM at 15 t/ha + N (150 kg/ha) and P ₂ O ₅ (30 kg/ha)	1.48a	0.40a	0.28a	0.24a	0.14a	1.62a
Poultry manure alone at 5 t/ha	1.37b	0.33b	0.24bc	0.16d	0.09c	1.30c
Poultry manure at 5 t/ha + N (150 kg/ha) and P ₂ O ₅ (30 kg/ha)	1.44a	0.39a	0.27a	0.22b	0.11b	1.58b
Press mud alone at 7.5 t/ha	0.94d	0.24d	0.20d	0.13e	0.08c	1.25d
Press mud at 7.5 t/ha + N (150 kg/ha) and P ₂ O ₅ (30 kg/ha)	1.46a	0.39a	0.27a	0.23ab	0.13a	1.61a
Weed management practices						
Pendimethalin (1.5 kg/ha)	1.33c	0.33c	0.24bc	0.17c	0.10b	1.42b
Pendimethalin (1.5 kg/ha) followed by clodinafop + metsulfuron methyl (64 g/ha ready mix)	1.37b	0.35b	0.25b	0.20b	0.11ab	1.44ab
Weedy check	1.22d	0.31d	0.23c	0.15d	0.09b	1.38c
Weed free	1.45a	0.37a	0.28a	0.22a	0.12a	1.45a

Note: Different lowercase letters within columns indicate significance at $p < 0.05$.

**Fig. 2.** Effect of different weed management and long-term nutrient management practices on NPK uptake in wheat. a) Grain, b) Straw

clodinafop + metsulfuron methyl (64 g/ha). Similar trends were observed in P and K content and uptake in grain and straw, except for P and K content in straw, which were statistically comparable to the application of pendimethalin at 1.5 kg/ha followed by clodinafop + metsulfuron methyl (64 g/ha). In the weedy check, nutrient uptake in grain was significantly lower than in the weed-free treatment-N (27.3 %), P (36.4 %), and K (34.3 %) which resulted in a 34.5 % reduction in grain yield. The improved nutrient uptake by the wheat crop in weed-free treatment was attributed to the reduction of competition for nutrients between the crop and weeds (33).

Economics

The economic analysis of the study (Table 8) indicated that minimum gross returns (Rs. 51464/ha), and net returns (Rs. 1717/ha) were observed under the press mud alone (7.5 t/ha) treatment. Conversely, the maximum gross returns (Rs. 110141/ha), and net returns (Rs. 58387/ha), were obtained with the application of the FYM at 15 t/ha + N (150 kg/ha) and P₂O₅ (30 kg/ha) treatment. The application of the FYM at 15 t/ha + N (150 kg/ha) and P₂O₅ (30 kg/ha) treatment increased crop yield, resulting in better gross returns. The application of FYM at 15 t/ha also increased gross returns, likely attributed to improved yields leading to greater returns (13, 34).

Different weed control techniques also had an impact on the total cost of cultivation, gross returns, and net returns. Higher gross returns (Rs. 100711/ha) were obtained under weed-free conditions, followed by sequential application of pendimethalin (1.5 kg/ha) followed by clodinafop + metsulfuron methyl (64 g/ha). For almost all combinations, net returns were increased with the weed control treatment for the entire season under weed-free conditions (13, 21).

Conclusion

The study findings indicate that the combined application of different organic manures with inorganic fertilisers outperforms the sole application of either, even after 26 years of application. The combined use of FYM at 15 t/ha + N (150 kg/ha) and P₂O₅ (30 kg/ha), along with the sequential application of pendimethalin at 1.5 kg/ha followed by clodinafop + metsulfuron methyl (ready mix) at 64 g/ha, resulted in significantly higher grain and straw yields, better nutrient uptake and effective suppression of major weeds in the wheat crop. Based on these findings, farmers are advised to adopt integrated nutrient management along with sequential herbicide application to achieve maximum yield, improved nutrient use efficiency and enhanced economic returns in wheat production systems.

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Authors' contributions

The study was conceptualised by PK and VSH. The methodology was developed by PK, VSH and DR. Validation was carried out by PK and VSH. Formal analysis was performed by PK, TM and J. Data curation was conducted by PK, NK and A. The original draft of the manuscript was written by PK, A and Y. The manuscript was reviewed and edited by J, NK, Y and R. Supervision was provided by PK, VSH, DR, A and R. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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Table 8. Effect of different weed management and long-term nutrient management practices on economics of wheat

Treatments	Economics		
	Gross returns (Rs/ha)	Cost of cultivation (Rs/ha)	Net returns (Rs/ha)
Nutrient management practices			
Recommended dose of N (150 kg/ha) and P ₂ O ₅ (60 kg/ha)	94182	52035	42147
FYM alone at 15 t/ha	56300	49373	6928
FYM at 15 t/ha + N (150 kg/ha) and P ₂ O ₅ (30 kg/ha)	110141	51754	58387
Poultry manure alone at 5 t/ha	57106	49560	7546
Poultry manure at 5 t/ha + N (150 kg/ha) and P ₂ O ₅ (30 kg/ha)	100106	51941	48165
Press mud alone at 7.5 t/ha	51464	49748	1717
Press mud at 7.5 t/ha + N (150 kg/ha) and P ₂ O ₅ (30 kg/ha)	104237	52129	52108
Weed management practices			
Pendimethalin (1.5 kg/ha)	84953	52635	32318
Pendimethalin (1.5 kg/ha) followed by clodinafop + metsulfuron methyl (64 g/ha ready mix)	97124	53160	43964
Weedy check	66838	52035	14803
Weed free	100711	67535	33176

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