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RESEARCH ARTICLE

Effect of farmyard manure and humic acid on growth and yield of rice (*Oryza sativa* L.)

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Abstract

The research work was established to determine the effect of farmyard manure (FYM) and humic acid (HA) on growth, yield, and soil chemical properties for the sustainable production of rice. The experiment was performed in the *Kharif* season of 2023 at the Agronomy Farm, School of Agriculture, Lovely Professional University in Phagwara, Punjab. The Split-plot design was used to set up the experiment, which consisted of sixteen treatment combinations that were replicated thrice. The main plots included four levels of FYM (0, 5, 10, and 15 t ha^{-1}), while the subplots comprised four levels of humic acid (0 %, 2 %, 3 %, and 4 %). The incorporation of FYM at 15 t ha^{-1} with a foliar spray of 4 % humic acid effectively increased growth attributing characteristics (plant height, number of tillers hill^{-1}, root-to-shoot ratio, plant dry weight, crop growth rate, and relative growth rate) and yield of the rice compared to the other levels of farmyard manure and humic acid. Additionally, FYM significantly improved soil chemical properties such as organic carbon, available nitrogen, available phosphorus, and available potassium, whereas foliar sprays of humic acid did not significantly enhance soil chemical properties. There was no interaction impact on soil chemical status. However, incorporating 15 t ha^{-1} FYM with a foliar spray of 4 % humic acid together could be the best nutrient management practice for long-term sustainable rice production and maintaining soil chemical properties.

Keywords

Sustainable production; farmyard manure; humic acid; biostimulants; nutrient management

Introduction

Oryza sativa L. is the most prevalent species in the Poaceae family. Historically, 10,000 years earlier, the river valleys region of Southeast and South Asia cultivated rice extensively, and it is considered India as a native place of rice (1). Rice acts as the most important staple food crop to provide food demand for the world population. It is important to enhance rice production to provide enough food demand for the world's growing population. The world demand for rice has increased from 439 million tons (2010) to 496 million tons (2020), and by 2035 it could be 553 million tons (2). As one of the essential cereal crops, rice is extensively consumed worldwide, chiefly on the Asian and African continents. India and China account for nearly 50 % of trade in rice and act as the largest exporting countries among all others (3). India is the second largest producer of rice after China, which accounts for approximately 22.5 % of the overall rice production in the world (4). In India, rice is produced on over 45 million ha, representing 32.14 % of the country's total net cultivated area (5). Compared to other crops (*i.e.,* wheat, maize, and potato), rice is an excellent source of vitamins (pantothenic acid, folate, vitamin E, and thiamine), carbohydrates, and minerals (Fe, Zn) (4). Although chemical fertilizers have been used to achieve the production of rice in the past time, for long-term sustainable production, it has elevated concerns in the current inspection of decreasing or stagnant yields (6). The soil's physical, chemical, or biological characteristics and fitness are declined by consecutive inorganic fertilizer use. Interest in organic fertilizers used to supply nutrients to the field is rising due to higher prices and the negative effects of chemical-based fertilizers (7).

Moreover, practices of organic manure application act as eco-friendly and sustainable approaches and offer a promising substitute to traditional farming systems for agricultural production. Organic substances like farmyard manure have been used traditionally by rice growers (8). Farmyard manure behaves like mixed fertilizer by supplying all necessary plant nutrients, *i.e.,* macronutrients (nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur), and micronutrients (iron, manganese, copper, and zinc), which are needed for plant growth and yield production (9). Additionally, humic acid (HA) is a key component of organic humus and has a significant impact on plant development and soil quality. It is produced by the biological and physical humification of animal and plant substances and microbial activities. There are different sources from where humic acid is extracted, *i.e.,* soil, lignite, vermicompost, and sediments, which can effectively stimulate the overall growth increment and development of the plant parts (10). Concentration levels and sources, along with the molecular weight of the humus, determine humic matter's effects on plant growth. Humic acid enhances soil properties (physical, biological, and chemical) and promotes root increment as well as the growth of plants. Soil application of humic acid showed the beginning of root increment and improved root growth (11). Humic acid promotes the production of new lateral roots, elongation, and increment of volume and area (12). The impacts were directly related to the increased uptake of plant nutrients, i.e., macronutrients (nitrogen, phosphorus, and sulfur) and micronutrients (iron, zinc, copper, and manganese) (13). The uses of this compound also impact plant nutrients by increasing nitrogen influx in nitrate and ammoniacal form (14), by effectively changing the action of glutamine synthetase and nitrate reductase through the regulation of ammonium and nitrate levels (15), and by improving photosynthesis and biosynthesis of carotenoids and chlorophylls (16). The absorption rate of Fe, P, and S (17) and changes in C- metabolism through changing starch, glucose, and fructose levels (18) are also stimulated by humic acid. Further, some responsive enzyme activities for the metabolism process of tricarboxylic acid and glycolysis can also be effectively regulated by the humic acid, where the organizational and compositional attributes of the humic acid compound regulate the effectiveness (19). Thus, this research aimed to enhance the growth attributing characteristics and sustainable rice yield production by improving soil properties.

Materials and Methods

During the *Kharif* season of 2023, an investigation was carried out at the Agronomy Farm, School of Agriculture, Lovely Professional University in Phagwara, Punjab. The agricultural farm is located at latitude 31°15.435'N and longitude 75°42.426'E, which places it under the central plain zone of Punjab's agro-climatic zones. It is elevated approximately 252 m above the mean sea level, with an average yearly rainfall of 436 mm, lowest temperatures of 0 to 6 °C in January, and highest temperatures of 40 to 45 °C in June. The nature of the soil is sandy clay loam, having a pH value of 7.06, electrical conductivity of 0.250 dS m^{-1}, organic carbon 0.582 %, available nitrogen 273.42 kg ha^{-1}, available phosphorus 21.65 kg ha^{-1}, and available potassium 257.81 kg ha^{-1}.

The split-plot design was used to set up the experiment, which consisted of sixteen treatments and three replications. The main plots included four levels of FYM (0, 5, 10, and 15 t ha^{-1}) while the subplots comprised four levels of humic acid (HA) (0 %, 2 %, 3 %, and 4 %). The combinations of treatments were:

T1 - Control
T2 - 0 t ha^{-1} of FYM + 2 % of HA
T3 - 0 t ha^{-1} of FYM + 3 % of HA
T4 - 0 t ha^{-1} of FYM + 4 % of HA
T5 - 5 t ha^{-1} of FYM + 0 % of HA
T6 - 5 t ha^{-1} of FYM + 2 % of HA
T7 - 5 t ha^{-1} of FYM + 3 % of HA
T8 - 5 t ha^{-1} of FYM + 4 % of HA
T9 - 10 t ha^{-1} of FYM + 0 % of HA
T10 - 10 t ha^{-1} of FYM + 2 % of HA
T11 - 10 t ha^{-1} of FYM + 3 % of HA
T12 - 10 t ha^{-1} of FYM + 4 % of HA
T13 - 15 t ha^{-1} of FYM + 0 % of HA
T14 - 15 t ha^{-1} of FYM + 2 % of HA
T15 - 15 t ha^{-1} of FYM + 3 % of HA
T16 - 15 t ha^{-1} of FYM + 4 % of HA

PR 130 variety (growing period of 110–120 days) was transplanted in fully prepared land with two-disc harrow ploughings followed by planking. The seed rate was 20 kg ha^{-1} for nursery seedlings, which were transplanted after 30 days at a distance of 20 cm × 15 cm. The recommended dose of fertilizers (RDF) (105 kg N: 30 kg P2O5: 30 K2O kg/ha) was applied as a three-split dose for nitrogen (basal, 30 DAT, and 60 DAT) and a full basal dose of phosphorus and potassium. During the cropping period, the field was kept moist by providing intermittent irrigation once every three days up to the ripening stage. This irrigation schedule was chosen as sufficient for maintaining the desired moisture level in the field. The three-hand weeding was done throughout the growing period, and 2 % neem oil was sprayed for plant protection. All the collected data and their statistical analysis are presented in the results and discussion section. The crop growth rate, relative growth rate, and harvest index (%) were calculated by using the following formulas:

Crop growth rate (CGR)

It represents dry weight gained by a unit area of crop in a unit time expressed as g $m^{-2}day^{-1}$ (20). The values of plant dry weight at 60 to 90 DAT intervals were used for calculating the CGR.

$$\text{Crop growth rate} = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{P} \quad (\text{g m}^{-2}\ \text{day}^{-1}) \qquad .....(\text{Eqn. 1})$$

Where, W_1: Initial dry weight of plant (g); W_2: Final dry weight of plant (g); t_1: Initial time; t_2: Final time; P : Spacing in m^2

Relative growth rate (RGR)

It was described by Blackman (21) and indicates the increase in dry weight per unit of dry matter over any specific time interval, and the following equation calculated it:

$$\text{Relative growth rate (RGR)} = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1} \quad (\text{g g}^{-1}\ \text{day}^{-1}) \qquad ....(\text{Eqn. 2})$$

Where, W_1: Initial dry weight of plant (g); W_2 : Final dry weight of plant (g); t_1: Initial time; t_2: Final time

It is also called efficiency index (y) and can be expressed in g g^{-1} day^{-1}. This parameter was calculated for the time intervals, *i.e.,* 60 to 90 DAT intervals, using the data obtained from the dry weight of plants.

Harvest index (%)

The harvest index was obtained by dividing the economic yield (grain) by the biological yield (grain + straw). It was calculated for each of the plots and was represented in percentage. The following formula was used (22).

$$\text{Harvest index (\%)} = \frac{\text{Economic yield (t ha}^{-1})}{\text{Biological yield (t ha}^{-1})} \times 100 \qquad ....(\text{Eqn. 3})$$

Data recording

Five randomly selected hills from each plot were marked to measure (at 60–90 DAT) the growth-attributing characters of the transplanted rice. By using a measuring scale and weighing balance, the growth parameters were determined. To determine the grain and straw yield, 1 m^2 areas for each plot were harvested, and then the weight was taken after sun drying. Additionally, soil samples were taken from 0 to 20 cm depth in each plot, and the dry soil sample was used to analyze the chemical properties of the soil.

Chemical analysis of soil

The chemical analysis was conducted on a composite soil sample that was obtained from 0 to 20 cm depth after crop harvest. The soil sample was analyzed for organic carbon, available nitrogen, phosphorus, and potassium content of the soil. Soil organic carbon was determined based on the Walkley and Black method (23). The alkaline permanganate technique described by Subbiah and Asija (24) was used to estimate the amount of available soil nitrogen. Olsen's method (25) was used to measure the amount of available phosphorus in soil using a spectrophotometer (660 nm wavelength). The flame photometer was used to determine the potassium concentration of the solution, while available potassium was obtained using neutral normal ammonium acetate (26).

Statistical analysis

The collected experimental data were statistically analyzed using Fisher's technique of analysis of variance, which was described by Gomez and Gomez (27). Critical difference (CD) values were given for each character in respective tests at a 5 % level of significance, wherever the “F” test was found significant. The analysis was done by using Microsoft Excel and the figures were made by using R software and Origin Pro.

Results

Effect of different levels of FYM and humic acid on the growth attributes of rice

The growth attributing characters of the plants enhanced significantly with the increment in every level of FYM. The highest plant height (119.83 cm) and number of tillers $hill^{-1}$ (17.62) were recorded from FYM@ 15 t ha^{-1}, whereas the lowest plant height (107.89 cm) and number of tillers $hill^{-1}$ (11.62) were obtained from the control (M_1). Similarly, the foliar spray of 4 % humic acid produced the highest plant height (116.11 cm), whereas the lowest plant height was obtained from the control (111.54 cm). A significantly higher number of tillers $hill^{-1}$ (15.72) was observed in 4 % humic acid, which was on par with 3 % humic acid (15.22) as compared to the lowest number of tillers $hill^{-1}$ (12.97) at control. The combination of 15 t ha^{-1} FYM + 4 % humic acid (T_{16}) significantly produced the highest plant height (123.90 cm) and number of tillers $hill^{-1}$ (20.10), whereas the lowest plant height (105.50 cm) and number of tillers $hill^{-1}$ (9.55) were produced from the control (T_1). The highest plant dry weight (41.42 g $hill^{-1}$), and crop growth rate (CGR) @18.32 g m^{-2} day^{-1} were recorded from FYM@ 15 t ha^{-1}, whereas the lowest plant dry weight (29.28 g $hill^{-1}$), CGR (11.94 g m^{-2} day^{-1}) were obtained from the control. The higher relative growth rate (RGR) @0.01692 g g^{-1} day^{-1} was recorded at 15 t ha^{-1} FYM, which was on par with 10 t ha^{-1} FYM (RGR@0.01662 g g^{-1} day^{-1}), and the lower RGR (0.01525 g g^{-1} day^{-1}) was recorded at control. Similarly, significantly higher plant dry weight (37.19 g $hill^{-1}$), and CGR (16.13 g m^{-2} day^{-1}) were observed at 4 % humic acid, whereas the control produced the lowest plant dry weight (33.92 g $hill^{-1}$), and CGR (13.98 g m^{-2} day^{-1}). The RGR was not significantly affected by humic acid. The interaction effect of FYM and humic acid was significant for plant dry weight, whereas CGR and RGR were non-significant.

The combination of 15 t ha^{-1} FYM + 4 % humic acid (T$_{16}$) significantly produced the higher plant dry weight (42.27 g hill^{-1}), which was on par with 41.83 g hill^{-1} at 15 t ha^{-1} FYM + 3 % humic acid (T$_{15}$), followed by 41.63 g hill^{-1} at 15 t ha^{-1} FYM + 2 % humic acid (T$_{14}$), whereas the lower plant dry weight (28.98 g hill^{-1}) was obtained from the control (T$_1$). The root to shoot ratio of the plants improved significantly with the increment in every level of FYM. The highest root to shoot ratio (0.198) was recorded from FYM@ 15 t ha^{-1}, whereas the lower root to shoot ratio (0.083) was obtained from the control. Among the various levels of humic acid, the foliar application of 4 % humic acid showed a higher root to shoot ratio (0.148), which was on par with the foliar spray of 3 % humic acid (0.143), followed by the foliar spray of 2 % humic acid (0.135), whereas the lower root to shoot ratio (0.120) was obtained from control. Additionally, the combination of 15 t ha^{-1} FYM + 4 % humic acid (T$_{16}$) significantly recorded the higher root to shoot ratio (0.203), which was on par with 0.200 at 15 t ha^{-1} FYM + 3 % humic acid (T$_{15}$), followed by 0.198 at 15 t ha^{-1} FYM + 2 % humic acid (T$_{14}$), 0.194 at 15 t ha^{-1} FYM + 4 % humic acid (T$_{13}$), 0.192 at 15 t ha^{-1} FYM + 4 % humic acid (T$_{12}$), 0.182 at 15 t ha^{-1} FYM + 4 % humic acid (T$_{11}$), whereas the control (T$_1$) produced the lower root to shoot ratio (0.078). A statistical analysis was performed on measurements of growth attributes, which are represented in Table 1 and Table 2.

Effect of different levels of FYM and humic acid on the yield attributes of rice

It has been recorded that the grain yield and straw production enhanced significantly with the increment in every level of FYM. The highest grain yield (6.79 t ha^{-1}) and straw yield (10.09 t ha^{-1}) were recorded from FYM@ 15 t ha^{-1}, whereas the control recorded the lowest grain yield (4.94 t ha^{-1}) and straw yield (8.23 t ha^{-1}). Significantly highest grain yield (6.16 t ha^{-1}) and straw yield (9.46 t ha^{-1}) were recorded in 4 % humic acid, whereas the lowest grain yield (5.60 t ha^{-1}) and straw yield (8.90 t ha^{-1}) were recorded at control. The combined effect of FYM and humic acid was also significant. The combination of 15 t ha^{-1} FYM + 4 % humic acid (T$_{16}$) significantly recorded the highest grain yield (7.09 t ha^{-1}) and straw yield (10.39 t ha^{-1}), whereas the lower grain yield (4.76 t ha^{-1}) and straw yield (8.03 t ha^{-1}) were obtained from the control (T$_1$). The higher harvest index (40.22 %) was recorded from FYM@ 15 t ha^{-1}, whereas the control recorded the lowest harvest index (37.49 %). Among the levels of humic acid, a significantly higher harvest index (39.33 %) was recorded from 4 % humic acid, whereas the lowest harvest index (38.52 %) was recorded at control. Additionally, the combination of 15 t ha^{-1} FYM + 4 % humic acid (T$_{16}$) significantly produced a higher harvest index (40.56 %), which was on par with 40.23 % at 15 t ha^{-1} FYM + 3 % humic acid (T$_{15}$). The lower harvest index (37.23 %) was recorded at control (T$_1$).

Effect of different levels of FYM and humic acid on the chemical properties in soil

The chemical properties in the soil raised significantly with the increment in FYM levels, which are mentioned in Table 3. The highest organic carbon (0.658 %), available nitrogen (331.41 kg ha^{-1}), phosphorus (32.95 kg ha^{-1}), and potassium (246.09 kg ha^{-1}) in the soil were recorded from FYM@ 15 t ha^{-1}, whereas the control recorded the lowest organic carbon (0.563 %), available nitrogen (257.67 kg ha^{-1}), phosphorus (19.98 kg ha^{-1}), and potassium (177.15 kg ha^{-1}) in the soil. Additionally, humic acid did not significantly impact the chemical properties of the soil. The impacts of FYM + humic acid were also non-significant on the chemical properties of the soil.

Table 1. Effect of different levels of farmyard manure (FYM) and humic acid (HA) on the growth and yield attributes of rice.

Treatments	Growth attributes						Yield attributes		
	Plant height (cm)	Number of tillers hill^{-1}	Plant dry weight (g hill^{-1})	Crop growth rate (g m^{-2} day^{-1})	Relative growth rate ((g g^{-1} day^{-1})	Root to shoot ratio	Grain yield (t ha^{-1})	Straw yield (t ha $^{-1}$)	Harvest index (%)
Farmyard manure (FYM)									
M1: 0 t ha^{-1} FYM	107.89	11.62	29.28	11.94	0.01525	0.083	4.94	8.23	37.49
M2: 5 t ha^{-1} FYM	111.89	13.97	33.95	14.00	0.01543	0.105	5.65	8.95	38.67
M3: 10 t ha^{-1} FYM	115.28	15.3	38.86	16.97	0.01662	0.160	6.29	9.59	39.58
M4: 15 t ha^{-1} FYM	119.83	17.62	41.42	18.32	0.01692	0.198	6.79	10.09	40.22
SEd(±)	0.85	0.33	0.51	0.45	0.00049	0.015	0.05	0.06	0.06
C.D (p=0.05)	2.07	0.79	1.25	1.10	0.00120	0.036	0.13	0.14	0.15
Humic acid									
N1: 0 % HA	111.54	12.97	33.92	13.98	0.01540	0.120	5.60	8.90	38.52
N2: 2 % HA	113.18	14.61	36.04	15.48	0.01619	0.135	5.90	9.20	38.97
N3: 3 % HA	114.06	15.22	36.35	15.64	0.01622	0.143	6.01	9.31	39.14
N4: 4 % HA	116.11	15.72	37.19	16.13	0.01641	0.148	6.16	9.46	39.33
SEd(±)	0.36	0.30	0.43	0.56	0.00057	0.007	0.06	0.06	0.09
C.D (p=0.05)	0.75	0.62	0.90	1.16	NS	0.015	0.13	0.12	0.18
Interaction (M × N)									
SEd(±)	0.73	0.60	0.87	0.12	0.00115	0.015	0.12	0.12	0.18
C.D (p=0.05)	1.50	1.24	1.79	NS	NS	0.030	0.25	0.25	0.36

Table 2. Interaction effect of different levels of FYM and humic acid (HA) on the growth and yield attributes of rice.

Treatments		Growth attributes			Yield attributes		
		Plant height (cm)	Number of tillers hill^{-1}	Root to shoot ratio	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
M1: 0 t ha^{-1} FYM	N1: 0% HA	105.50	9.55	0.078	4.76	8.03	37.23
	N2: 2% HA	107.40	11.70	0.082	4.95	8.26	37.46
	N3: 3% HA	108.60	12.60	0.083	5.00	8.30	37.58
	N4: 4% HA	110.08	12.64	0.088	5.05	8.35	37.68
M2: 5 t ha^{-1} FYM	N1: 0% HA	110.10	12.62	0.095	5.08	8.38	37.74
	N2: 2% HA	112.10	14.30	0.106	5.65	8.95	38.70
	N3: 3% HA	112.25	14.45	0.107	5.90	9.20	39.07
	N4: 4% HA	113.11	14.52	0.110	5.96	9.27	39.17
M3: 10 t ha^{-1} FYM	N1: 0% HA	113.15	14.37	0.112	5.97	9.29	39.11
	N2: 2% HA	114.70	15.60	0.154	6.30	9.60	39.61
	N3: 3% HA	115.90	15.62	0.182	6.35	9.65	39.68
	N4: 4% HA	117.35	15.63	0.192	6.54	9.84	39.92
M4: 15 t ha^{-1} FYM	N1: 0% HA	117.40	15.35	0.194	6.59	9.89	39.98
	N2: 2% HA	118.50	16.85	0.198	6.69	9.99	40.10
	N3: 3% HA	119.50	18.20	0.200	6.80	10.10	40.23
	N4: 4% HA	123.90	20.10	0.203	7.09	10.39	40.56
N at the same level of M	SEd(±)	0.73	0.60	0.015	0.123	0.121	0.175
	CD (p=0.05)	1.50	1.24	0.030	0.253	0.249	0.362
M at the same or different levels of N	SEd(±)	1.06	0.61	0.019	0.119	0.120	0.164
		2.17	1.26	0.040	0.246	0.247	0.339

Table 3. Effect of different levels of FYM and humic acid (HA) on the organic carbon (%), available nitrogen, available phosphorus and available potassium in soil.

Treatments	Post-harvest soil status			
	Organic carbon (%)	Available nitrogen in soil (kg ha^{-1})	Available phosphorus in soil (kg ha^{-1})	Available potassium in soil (kg ha^{-1})
Farmyard manure (FYM)				
M1: 0 t ha^{-1} FYM	0.563	257.67	19.98	177.15
M2: 5 t ha^{-1} FYM	0.596	299.76	26.35	214.76
M3: 10 t ha^{-1} FYM	0.626	313.88	28.48	232.34
M4: 15 t ha^{-1} FYM	0.658	331.41	32.95	246.09
SEd(±)	0.006	2.36	1.20	1.60
C.D (p=0.05)	0.015	5.78	2.93	3.92
Humic acid				
N1: 0% HA	0.602	296.54	25.84	216.77
N2: 2% HA	0.611	300.28	26.88	217.12
N3: 3% HA	0.614	302.40	27.27	217.95
N4: 4% HA	0.617	303.49	27.77	218.49
SEd(±)	0.013	2.68	0.67	5.85
C.D (p=0.05)	NS	NS	NS	NS
Interaction (M × N)				
SEd(±)	0.025	5.35	1.34	9.35
C.D (p=0.05)	NS	NS	NS	NS

Discussion

Effect of different levels of FYM and humic acid on the growth attributes of rice

The use of FYM has proven to be more advantageous for the growth of rice plants. FYM released nutrients slowly and continuously, enhancing cell division, elongation, and other metabolic processes that ultimately increased plant height and number of tillers (28, 29) and also helped to produce more number of leaves and greater photosynthates accumulation, leading to more plant dry weight, CGR, and RGR (30). Similarly, the application of FYM enhanced the soil fertility status by adding essential macro and micronutrients into the soils, which helped in greater uptake of essential nutrients through the plant root system, and it contributed to better root and shoot growth (31).

On the other hand, humic acid enhances the absorption of critical nutrients by plants and promotes soil fertility due to its chelating properties (32). The use of humic acid may result in accelerated physiological processes, greater cell division, and cell elongation, which might lead to improved plant height (33). Additionally, the application of humic acid increases nutrient availability, which leads to a greater transformation of protein from carbohydrates. This protein then elaborates into protoplasm, and the material in the cell wall enhances the cell dimension, which is reflected morphologically in the tiller number (34). Similarly, humic acid enhances the availability of nutrients to the plants through the conversion of essential elements (N, P, K, Fe, Zn, and other trace elements), enhancing nitrogen (N) uptake by plants, which leads to greater dry matter accumulation and increased CGR and RGR of the plants (35). In the case of root to shoot ratio, this might be the reason that the foliar spraying of humic acid improved the micronutrient's uptake, which contributed to root and shoot growth. The supply of humic acid to the plant helps in both root and shoot growth but creates more beneficial effects on root growth compared to shoot growth, which leads to greater root development rather than shoot system by increasing humic acid levels (36).

In the case of treatment combination, the essential nutrient uptake and their efficiency are enhanced by the increment of the FYM + HA levels, which may cause greater plant height and number of tillers hill^{-1} (37). The combined application of FYM + HA significantly enhanced nitrogen uptake in the plants, which is involved with enzyme activation and protein synthesis, and finally increased biomass production in the crops (38). In the same way, FYM + humic acid contributed to more nutrient uptake in the plant system and increased the micronutrient availability in the root zone, which enhanced the root and shoot growth efficiently and increased the root to shoot ratio.

Effect of different levels of FYM and humic acid on the yield attributes of rice

The improved translocation of nutrients in the sink resulting from an enhanced rate of photosynthesis and efficient metabolic activities may cause a yield increase (39). The consistent breakdown of FYM and the release of nutrients throughout the crop's growth period and improved nutrient absorption contributed to the increase in yield production (40). Increased post-flowering photosynthesis and nutrient assimilation through apoplast and symplast translocation might have been caused by improved assimilate translocation to the sink, which is reflected in the greatest values in yield components (41, 42). Additionally, the rapid adsorption and assimilation of more nitrogen, phosphorous, potassium, and micronutrients found in FYM and humic acid materials was the cause of the yield enhancement. This results in improved morphological and physiological traits ultimately reflected in greater yield production (37). The increment in harvest index might be due to the greater grain yield corresponding to the biological yield (43).

Effect of different levels of FYM and humic acid on the chemical properties in soil

The incorporation of FYM in soil increased microbial activities effectively, which helped in the soil's organic matter degradation, and finally, the decomposed materials released organic carbon, nitrogen, phosphorus, and potassium (44) in the soil. The foliar sprays of humic acid do not significantly change soil chemical properties in the soil (45, 46). The impacts of FYM + humic acid were also non-significant on the soil chemical properties.

Fig. 1 shows that in the control plot (M_1) (application of RDF alone), post-harvest availability of nutrients in soil was decreased due to greater plant nutrient uptake. However, in FYM applied plots (M_2, M_3, and M_4) with RDF, the soil organic carbon, available nitrogen, and available phosphorus were significantly increased, but the available potassium was decreased due to the higher

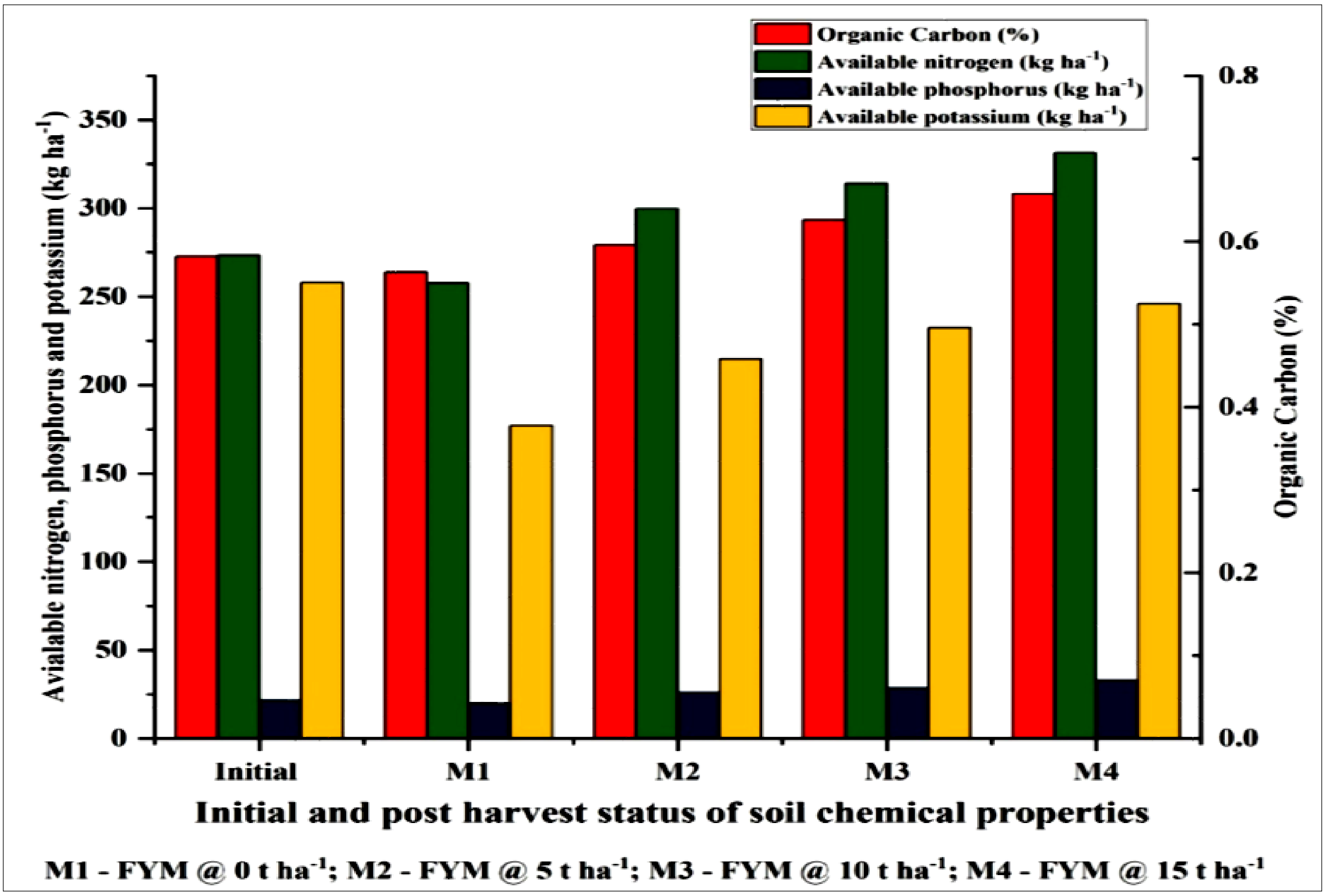
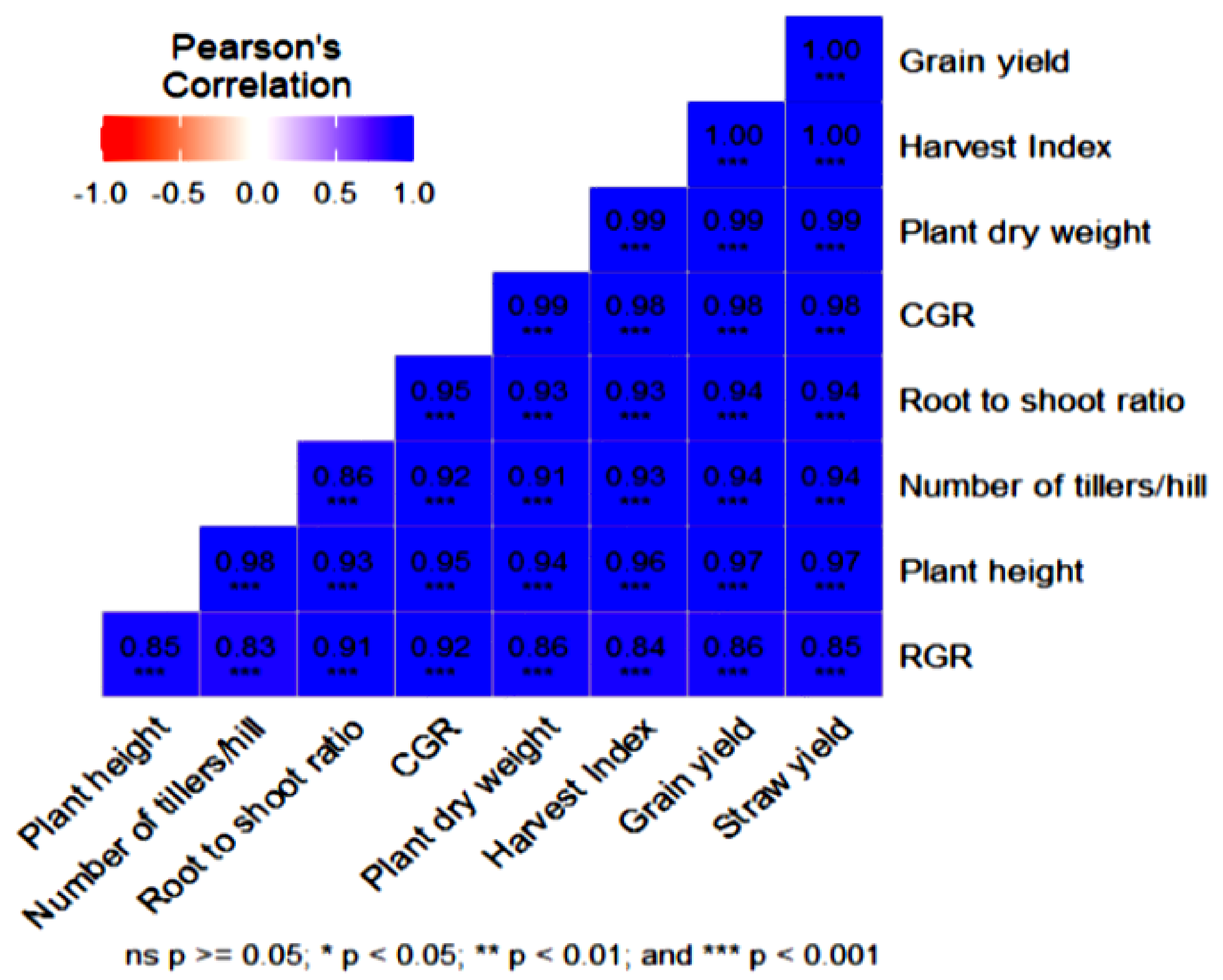


Fig. 1. Comparison between initial and post harvest on soil chemical properties.

uptake of potassium by the crops. A similar result was also reported in pearl millet (*Pennisetum glaucum* L.) (44).

Correlation studies between growth and yield attributing characteristics

All the growth parameters of rice were positively correlated with grain and straw yield. Fig. 2 showed that grain yield was strongly correlated to plant height (r = 0.97), number of tillers hill^{-1} (r = 0.94), plant dry weight (r = 0.99), crop growth rate (r = 0.98), relative growth rate (r = 0.86), root to shoot ratio (r = 0.94), and harvest index (r = 1.00). Similarly, straw yield was also strongly correlated to plant height (r = 0.97), number of tillers hill^{-1} (r = 0.94), plant dry weight (r = 0.99), crop growth rate (r = 0.98), relative growth rate (r = 0.85), root to shoot ratio (r = 0.94), and harvest index (r = 1.00). This study indicates that greater growth of the crop always promotes better output production (47, 48).



	Plant height	Number of tillers/hill	Root to shoot ratio	CGR	Plant dry weight	Harvest Index	Grain yield	Straw yield
Grain yield								1.00 ***
Harvest Index							1.00 ***	1.00 ***
Plant dry weight						0.99 ***	0.99 ***	0.99 ***
CGR					0.99 ***	0.98 ***	0.98 ***	0.98 ***
Root to shoot ratio				0.95 ***	0.93 ***	0.93 ***	0.94 ***	0.94 ***
Number of tillers/hill			0.86 ***	0.92 ***	0.91 ***	0.93 ***	0.94 ***	0.94 ***
Plant height		0.98 ***	0.93 ***	0.95 ***	0.94 ***	0.96 ***	0.97 ***	0.97 ***
RGR	0.85 ***	0.83 ***	0.91 ***	0.92 ***	0.86 ***	0.84 ***	0.86 ***	0.85 ***

ns $p >= 0.05$; * $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$

Fig. 2. Correlation between various growth and yield attributes of rice.

Conclusion

This research article has revealed that FYM and HA have greater potential impacts on various agronomical attributes of rice and soil chemical properties. The incorporation of 15 t ha^{-1} FYM with a foliar spray of 4 % humic acid can be a better alternative for long-term sustainable rice production compared to the use of synthetic fertilizer alone. Although there can be an initial expense, the long-term advantages to soil health and production exceed it. However, the results of this research indicate that cropping practices using humic acid and farmyard manure could play a vital role in the development of sustainable and productive agricultural systems.

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Authors' contributions

BB and KB have selected the research topic for research conduct and prepared the framework of the research paper. B and TTR collected all the field data, analyzed it, and completed the paper writing. The final editing and proofreading were carried out by K B, and AGB.

Compliance with ethical standards

Conflict of interest: The authors declare no conflict of interest.

Ethical issues: None.

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