PLANT SCIENCE TODAY
Vol x(x): xx–xx
https://doi.org/10.14719/pst.7214

eISSN 2348-1900

RESEARCH ARTICLE

Effectiveness of humic acid, poultry manure and nano urea on the productivity of transplanted basmati rice (*Oryza sativa*)

Nimmala Nanda Kishore Reddy & Anita Jaswal*

Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara 144 411, India

*Correspondence email - anita.27139@lpu.co.in

Received: 14 January 2025; Accepted: 25 May 2025; Available online: Version 1.0: 19 September 2025

Cite this article: Nimmala NKR, Anita J. Effectiveness of humic acid, poultry manure and nano urea on the productivity of transplanted basmati rice (*Oryza sativa*). Plant Science Today (Early Access). https:/doi.org/10.14719/pst.7214

Abstract

The present study was conducted during the autumn (*Kharif*) season from June to October 2024 to evaluate the effects of humic acid derived from coal, plant material and vermicompost, in combination with poultry manure and nano urea, on the growth and yield of transplanted basmati rice. The experiment followed a randomized block design comprising 10 treatments, each replicated three times. The treatments included different types and amounts of humic acid, nano-urea and poultry manure, applied at levels of 0, 3 and 6 t ha^{-1}. The results demonstrated significant improvements in plant growth parameters, including plant height, number of tillers, flag leaf length, leaf area and chlorophyll index. The treatment that used humic acid from vermicompost along with poultry manure at 6 t ha^{-1} and nano urea resulted in the best measurements for plant height (114.50 cm), number of tillers (18.20) and leaf area (98.66 cm^2). Yield-related factors, such as the number of panicles, their length, weight and grain filling, also improved significantly. The longest panicles measured 29.24 cm and the heaviest weighed 2.62 g, both achieved with the same treatment. The combination of humic acids and poultry manure significantly increased the availability of nutrients and plant hormones, enabling the plants to grow more robustly and produce greater yields. Additionally, applying nano urea to the leaves provided a steady supply of nitrogen during critical growth periods, which helped boost productivity. These findings highlight the synergistic potential of integrating organic amendments with nano fertilizers to improve rice cultivation under subtropical climatic conditions.

Keywords: coal-derived humic substances; organic amendments; plant-based biostimulants; sustainable nutrient management

Introduction

Agriculture is a vital component of the Indian economy. It forms the basis of the Indian economy. It is considered a primary occupation worldwide and forms the basis of the global economic system. Rice (*Oryza sativa* L.) is Asia's primary food grain crop. India ranks as the second largest rice producer globally, following China, with a production of 137.83 mT and an average productivity of 2882 kg ha^{-1} across an area of 47.82 m ha. Punjab has the most significant area of 31.68 lakh ha, producing 205.24 lakh tonnes of basmati rice (1). Inorganic fertilizers, organic manures and biofertilizers serve as primary sources of plant nutrients. This geographical region provides all essential macronutrients and micronutrients. Modern agriculture often employs increased fertilizer applications to enhance yields; however, this practice can diminish soil fertility. The continuous and excessive application of chemical fertilizers leads to soil and water pollution, as well as nutrient depletion (2). The application of chemical fertilizers has increased the depletion of soil organic matter, adversely affected the physical and chemical properties of soil and led to deficiencies in micronutrients. In Punjab, the majority of cultivated soils exhibit low levels of organic matter. Due to intense cropping and the use of increased chemical fertilizer amounts with relatively less manure addition, this crucial soil component is gradually decreasing (3). Efficient nutrient management that aligns with plant demand can reduce nitrogen loss by optimizing the supply of nutrients. Organic fertilizers enhance soil quality by replenishing mineral nutrients and improving overall soil health. Organic manures serve as an effective means to enhance soil properties and fertility, thereby promoting soil sustainability while reducing reliance on chemical fertilizers. The exclusive use of synthetic fertilizers in continuous intensive cropping does not effectively sustain crop productivity (4). However, incorporating organic substances alongside chemical fertilizers enhances soil physical properties and maintains higher soil fertility, resulting in improved yield production. Humic acid is a significant organic molecule that plays various essential roles in numerous agronomic parameters and soil properties. Humic acid constitutes a primary component of humic substances (5). Humic substances are formed through the chemical and biological humification of plant and animal matter, aided by microbial activity. Their effect on plant growth varies depending on the source, concentration and molecular weight. Humic acid improves soil's physical, chemical and biological properties, promoting root development and growth (6). The effects exhibited a direct correlation with increased absorption of macronutrients, including nitrogen, phosphorus and sulphur, as well as micronutrients, such as Fe, Zn, Cu and Mn (7). Limited research has explored the use of humic substances as fertilizers and soil conditioners in agriculture. Previous studies showed a significant impact of humic substances on soil structure and plant growth (4, 7). Humic acid at appropriate concentrations can promote the development of plants and roots (8). Humic substances, including humic and fulvic acids, attract positive ions, form chelates with micronutrients and release them gradually as needed by plants. Humic substances act like chelating agents, which helps keep micronutrients in the soil from clumping together, getting lost, or reacting with other elements. Poultry manure serves as a valuable nutrient source and can be integrated into various fertilizer programmes. The application of manures should be conducted within the framework of effective soil fertility management to mitigate nutrient imbalances, reduce associated animal health risks and prevent contamination of surface water and groundwater. A significant reduction in global environmental pollution can be achieved by reducing the application of chemical fertilizers and increasing the use of organic materials, such as cow dung, poultry manure and wheat straw. The main goal of this study is to assess how well humic acid, poultry manure and nano urea help the growth and productivity of transplanted basmati rice (*Oryza sativa*). The research aims to determine how these materials, both individually and in combination, impact key farming characteristics, nutrient absorption and total crop yield, which will help improve sustainable farming practices for rice.

Materials and Methods

The experiment took place during the kharif season of 2024 at the agronomy research fields of Lovely Professional University in Phagwara, Punjab, to study how humic acid from different sources, including poultry manure and nano urea, affects the growth and yield of transplanted basmati rice. The agriculture farm is located at latitude 31.14 °N and longitude 75.42 °E, along with an altitude of 244 m above mean sea level (Fig. 1). The experimental site enjoys a subtropical climate where hot winds in the summer blow for a longer time during the day and temperatures remain high during the night. The hottest months are May, June and July (Fig. 2). The experiment was conducted under a subtropical climate and the average temperature during the crop growth phase (June to October 2024) ranged from 24.5 °C to 36.2 °C. The highest temperatures were recorded during the transplanting and early vegetative stages in June and July, while moderate temperatures prevailed during the reproductive and maturity phases in September and October. These temperature conditions were favourable for the growth and development of basmati rice. At the study site, the soil was classified as sandy loam, slightly acidic and non-saline, with low levels of organic carbon, nitrogen and potassium and medium levels of phosphorus, as shown in Table 1.

Experiment details

The experiment was conducted during the 2024 Kharif season. The experiment was laid out using a randomized block design with three replicates and ten treatments. The total number of plots was 30. The net plot size was 5 × 4 m = 20 m^2. The treatments were T0: control, T1: Coal derived humic acid + Poultry manure (0 t ha^{-1}) + Nano urea, T2: Coal derived humic acid + Poultry manure (3 t ha^{-1}) + Nano urea, T3: Coal derived humic acid + Poultry manure (6 t ha^{-1}) + Nano urea, T4: Vermicompost derived humic acid + Poultry manure (0 t ha^{-1}) + Nano urea, T5: Vermicompost derived humic acid + Poultry manure (3 t ha^{-1}) + Nano urea, T6: Vermicompost derived humic acid + Poultry manure (6 t ha^{-1}) + Nano urea, T7: Plant derived humic acid + Poultry manure (0 t ha^{-1}) + Nano urea, T8: Plant derived humic acid + Poultry manure (3 t ha^{-1}) + Nano urea,T9: Plant derived

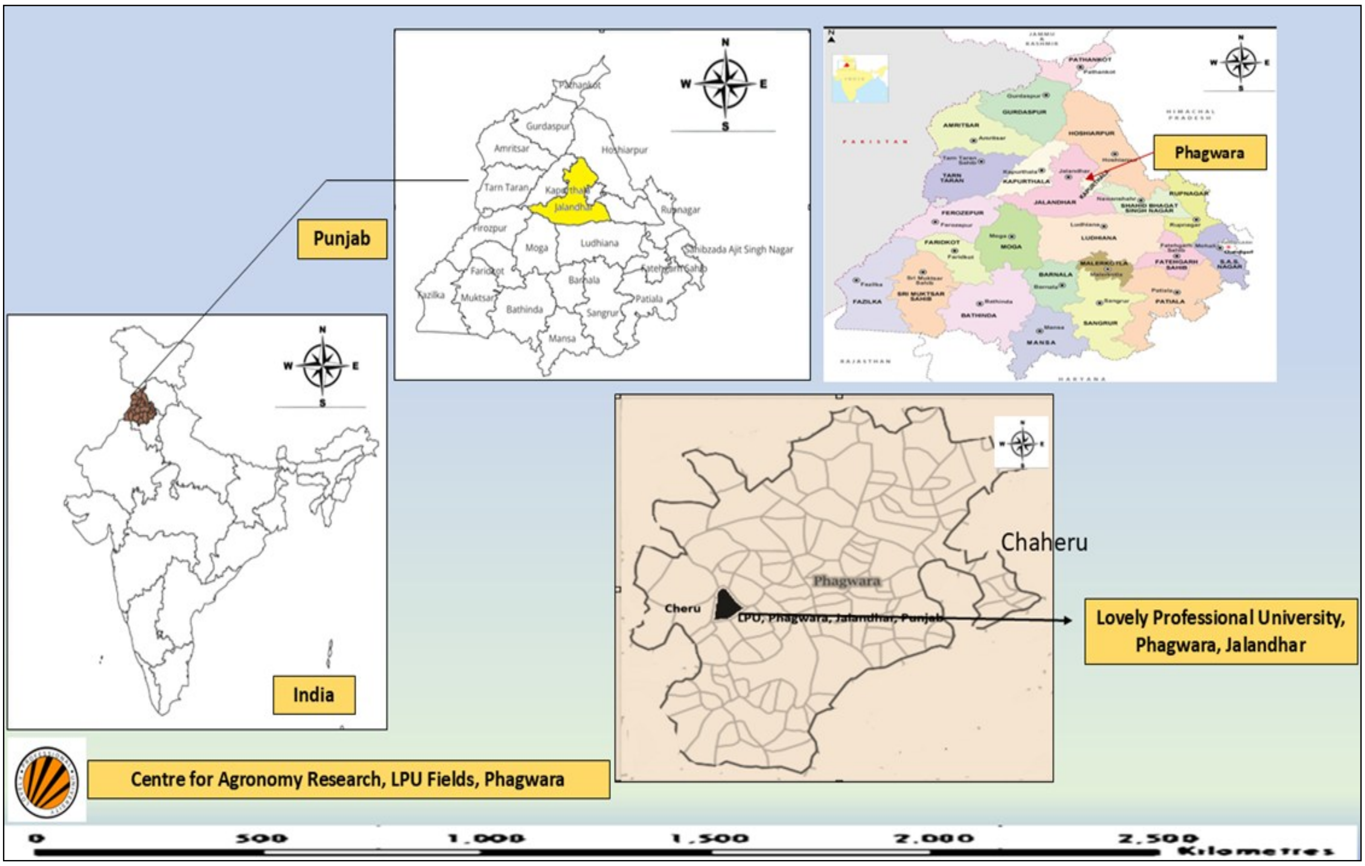


Fig. 1. Geographical location of field experiment.

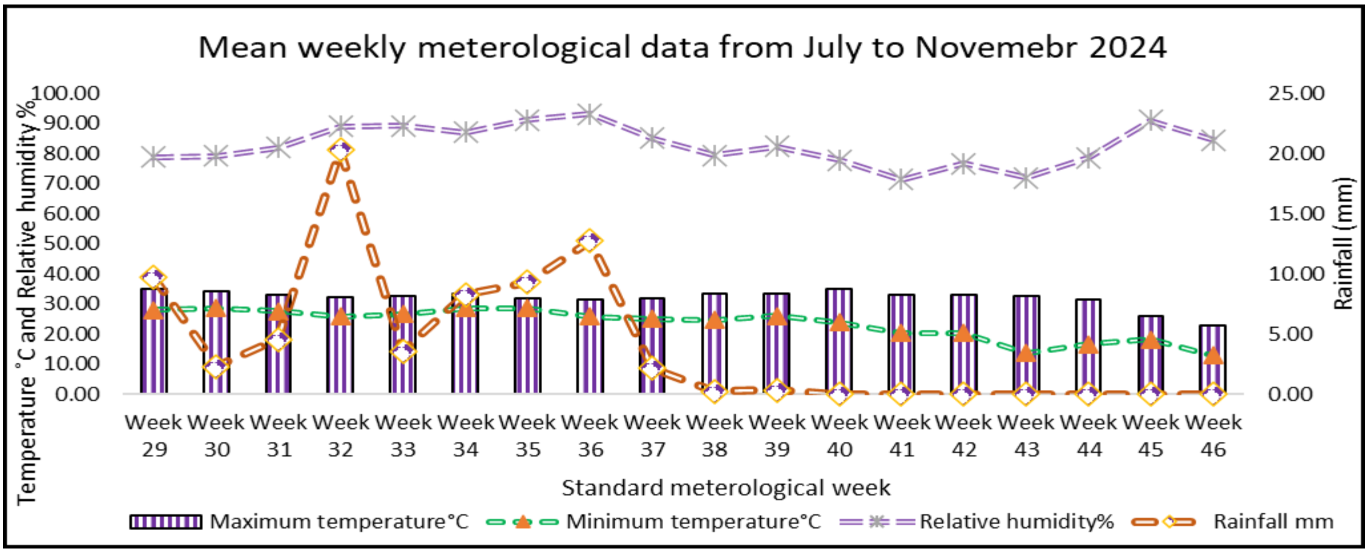


Fig. 2. Mean meteorological data of LPU field from July to November 2024.

Table 1. Physico-chemical characteristics of soil (0-15 cm depth) before the beginning of experiment

S.No.	Soil characteristics	Values
1.	pH (1.2.5)	6.18
2.	Electrical conductivity(dSm^{-1})	0.18
3.	Organic carbon (%)	0.47
4.	Available N (kg ha^{-1})	147
5.	Available P (kg ha^{-1})	15.71
6.	Available K (kg ha^{-1})	172

humic acid+ Poultry manure (6 t ha^{-1}) + Nano urea. Pusa Basmati 1509 for rice used as planting material. Pusa Basmati 1509 is a basmati rice variety developed by the Division of Genetics, Indian Agricultural Research Institute, New Delhi, which is a semi-dwarf variety with a sturdy stem. The rice nursery was first prepared 30-35 days before transplanting and 25-30-day-old seedlings were transplanted in the main field by adopting 20 × 15 cm spacing. The grain yield was determined from the central 16 lines, which comprise the net plot area. Humic acid was applied at a rate of 6 L per hectare. Nano urea was applied at 4 mL in 1 L of water as a foliar application twice: once at tillering and once at panicle initiation. Poultry manure is applied at the time of land preparation. Urea, SSP, DAP and MOP are used as sources of nitrogen, phosphorus and potash for rice crops. All intercultural operations were conducted by the package and practices of PAU, Ludhiana, for the normal growth of crops (9). Vermicompost was taken from the vermicomposting unit at Lovely Professional University. Coal was obtained from the coal depot of Phagwara. Wheat straw is used for plant-derived humic acid obtained from the agronomy field of the department.

Vermicompost, plant and coal characterization

The main chemical properties of the vermicompost and coal utilized for the isolation of humic acids are presented in Table 2. The characterization of vermicomposting was analyzed using the following methods: available nitrogen *via* the Kjeldahl method (10), available phosphorus (P) through the Olsen method (11), available potassium (K) utilizing the flame spectrophotometer method (12). The pH was determined at a ratio of 1:5 (vermicompost to coal or distilled water), and electrical conductivity (EC) was measured according to the previously established methodology (13).

Extraction of humic acid from plants

10 g of air-dried plant samples were placed in a 250 mL conical flask with 50 mL of 0.1 N NaOH and shaken for 24 hr. The supernatant was collected by centrifugation and the extraction was repeated three times with a fresh extractant to ensure complete humic acid extraction. The combined supernatants were centrifuged at 15000 rpm for 15 min to remove colloidal clays. The pH of the supernatant was adjusted to 2 using 2 N HCl to precipitate humic acid, followed by settling for 24 hr. The coagulated humic acid was collected and dried using a hot water bath (14).

Extraction of humic acid from vermicompost

Humic acid was extracted from vermicompost derived from cow dung and crop residues (1:1 ratio). Air-dried, sieved vermicompost was subjected to extraction using 0.1 M KOH (500 g in 850 mL) for 6 hr at room temperature (15). The extract was filtered and 6 M HCl was added to adjust the pH to 2.0, then kept at 5 °C for 24 hr to

Table 2. Vermicompost coal and plant characterization used for extraction of humic acid

Parameter	Vermicompost	Coal	Plant residue
pH	8.2	8	7.3
EC (dS m^{-1})	0.223	0.07	0.15
Organic carbon (%)	36	39.6	38.6
Available N (g kg^{-1})	9.8	4.08	1.2
Available P (g kg^{-1})	16.5	7.38	2.6
Available K (g kg^{-1})	12.5	8.35	5.2
Humification index (HA/FA)	1.52	1.26	1.18
Ash content (%)	24.8	17.5	14.2
C/N Ratio	18.4	55.2	56.3
Lignin content (%)	12.1	5.4	18.7
Cellulose content (%)	23.3	17.2	29.4
Elemental composition (%)	C – 36.0, H - 4.6, O - 29.7, N - 1.96, S - 0.22	C - 43.8, H - 3.8, O - 10.2, N - 0.82, S - 1.1	C - 38.6, H - 5.1, O - 33.0, N - 0.69, S - 0.15

precipitate humic acid. The precipitate was filtered, dried, powdered and washed twice with 200 mL of water.

Extraction of humic acid from coal

About 20-30 kg of sub-bituminous coal was brought to the lab. This coal was chosen for its relatively high humic substance content and its everyday use in agricultural humic acid extraction. Using mortar and pestle, 2-3 kg samples were crushed. After sieving through 60 mesh (0.25 mm), the coal samples were stored in a 1 kg sterilized plastic bag. A fresh HNO_3 working solution was prepared for coal pre-treatment. A 2 % working solution of HNO_3 was prepared using 65 % laboratory-grade concentrated HNO_3. Approximately 50 g of each coal sample was oxidized in 100 mL of freshly prepared 2 % HNO_3 in a beaker for 24-48 hr at 30 °C after gentle stirring for 1 hr. To remove unreacted acid, the coal was filtered and washed repeatedly with distilled and deionized water at 8000 rpm for 5 min (16). The pH of the mixture, prepared for field application, was measured immediately after mixing and was found to be 6.8, indicating a near-neutral reaction. This pH level is considered favourable for nutrient availability and microbial activity, ensuring optimal conditions for rice plant growth.

Data recording

Plant data such as height, tiller number, flag leaf length, leaf area, chlorophyll index, crop growth rate (CGR) and relative growth rate (RGR) were recorded (17). Data related to yield attributes were collected following established protocols (18). Following the final harvest, the rice crop underwent sun-drying for a few days, after which their weights were recorded to determine the biological yield. Subsequently, the grain yield was determined. The straw yield was calculated by deducting the grain yield from the total biological yield. All recorded yields, including grain, straw and biological yield, were converted into kg ha^{-1}.

Statistical analysis

The recorded data was tabulated treatment-wise under three replications. The differences between the mean values were estimated by one-way ANOVA (analysis of variance) with the Grapes software (General R-based Analysis Platform empowered by statistics) launched in 2020. The significant differences among the means were calculated based on LSD (least significant difference) at a 5 % level of significance.

Results and Discussion

Effects of humic acid derived from diverse substances, poultry manure and nano urea on the growth of transplanted basmati rice

The results from the experiment evaluating the effects of different treatments on plant height, number of tillers per plant, flag leaf length, leaf area and chlorophyll index (SPAD) are presented below.

Plant height (cm)

Plant height was significantly influenced by the different nutrient treatments (Table 3). The tallest plants (114.50 cm) were recorded under the combined application of vermicompost-derived humic acid, poultry manure (6 t ha^{-1}) and nano urea, while the shortest (86.56 cm) was observed under 100 % RDF. The increased plant height may be attributed to improved nutrient uptake and soil fertility resulting from the combined use of organic amendments and nano-urea. Humic acid helps nutrients dissolve better and boosts hormone activity, especially auxins and gibberellins, which allow cells grow longer. Poultry manure improves soil organic matter and microbial activity, contributing to better root development. Nano urea, which releases nutrients slowly and is easily absorbed by leaves, probably provides a steady supply of nitrogen during significant growth periods, helping the plants grow taller. The enhanced plant height is due to improved nutrient availability, as demonstrated by previous studies who reported that the combination of several fertilizers enhances mineral nutrient absorption (19, 20). The application of nano-nitrogen fertilizers also resulted in increased plant height (21).

Number of tillers per plant

The number of tillers per plant, an essential indicator of plant growth, was significantly affected by the different treatments. The maximum number of tillers (18.20) was observed in the treatment comprising vermicompost-derived humic acid, poultry manure (6 t ha^{-1}) and nano urea. In contrast, the 100 % RDF treatment showed the minimum number (13.04), as shown in Table 3. The enhanced tillering can be attributed to improved nitrogen efficiency and balanced nutrient availability from the combined treatments. Vermicompost and poultry manure supply macro- and micronutrients and stimulate microbial activity, which

Table 3. Effects of humic acid derived from diverse substances, poultry manure and nano urea on growth attributes of transplanted basmati rice

Treatments	Plant height (cm)	No. of tillers per plant	Flag leaf length (cm)	Leaf area (cm²)	Chlorophyll index (SPAD)
100 % RDF	86.56 ± 1.00 ^{g}	13.04 ± 0.64 ^{e}	25.20 ± 0.70 ^{f}	85.80 ± 0.95 ^{e}	32.50 ± 1.10 ^{f}
Coal derived humic acid+ Poultry manure (0 t ha^{-1}) + Nano urea	94.06 ± 0.55 ^{f}	13.11 ± 0.69 ^{de}	25.36 ± 0.68 ^{f}	86.70 ± 2.10 ^{e}	33.37 ± 0.71 ^{ef}
Coal derived humic acid+ Poultry manure (3 t ha^{-1}) + Nano urea	102.50 ± 2.91 ^{d}	14.20 ± 0.65 ^{d}	26.63 ± 0.66 ^{de}	91.36 ± 0.96 ^{cd}	36.39 ± 1.50 ^{cde}
Coal derived humic acid+ Poultry manure (6 t ha^{-1}) + Nano urea	110.33 ± 1.05 ^{b}	16.80 ± 0.55 ^{bc}	28.83 ± 0.57 ^{b}	96.53 ± 1.25 ^{ab}	38.02 ± 0.79 ^{ab}
Vermicompost derived humic acid+ Poultry manure (0 t ha^{-1}) + Nano urea	98.60 ± 0.55 ^{e}	13.84 ± 1.00 ^{de}	25.93 ± 0.75 ^{ef}	89.40 ± 5.48 ^{de}	35.36 ± 1.00 ^{de}
Vermicompost derived humic acid+ Poultry manure (3t ha^{-1}) + Nano urea	105.90 ± 0.91 ^{c}	16.23 ± 0.45 ^{c}	27.86 ± 0.68 ^{c}	95.00 ± 2.10 ^{abc}	37.45 ± 0.26 ^{bc}
Vermicompost derived humic acid+ Poultry manure (6 t ha^{-1}) + Nano urea	114.50 ± 0.90 ^{a}	18.20 ± 0.43 ^{a}	30.46 ± 0 .65 ^{a}	98.66 ± 0.55 ^{a}	39.77 ± 0.97 ^{a}
Plant derived humic acid+ Poultry manure (0 t ha^{-1}) + Nano urea	95.50 ± 0.72 ^{f}	13.44 ± 0.51 ^{de}	25.66 ± 1.33 ^{f}	87.46 ± 1.30 ^{e}	34.04 ± 0.85 ^{ef}
Plant derived humic acid+ Poultry manure (3 t ha^{-1}) + Nano urea	104.16 ± 1.25 ^{cd}	15.93 ± 0.65 ^{c}	27.46 ± 0.68 ^{cd}	94.36 ± 1.15 ^{bc}	37.05 ± 1.81 ^{cd}
Plant derived humic acid+ Poultry manure (6 t ha^{-1}) + Nano urea	112.43 ± 0.80 ^{a}	17.83 ± 0.85 ^{ab}	29.56 ± 0.68 ^{ab}	97.33 ± 1.31 ^{ab}	39.24 ± 0.56 ^{ab}

*The means with different Letters as superscripts are significant ($P < 0.05$). The means with same letters or having common letter(s) are not significantly different

enhances root proliferation. Nano urea ensures efficient nitrogen delivery at key vegetative phases. This integrated approach enhances cytokinins and auxin production, leading to increased tiller initiation (22, 23).

Flag leaf length (cm)

The longest flag leaf measured 30.46 cm in the treatment that used humic acid from vermicompost, poultry manure (6 t ha^{-1}) and nano urea, while the second longest, at 29.56 cm, was in the treatment with plant-derived humic acid, poultry manure (6 t ha^{-1}) and nano urea. The minimum flag leaf length (25.20 cm) was observed in the 100 % RDF treatment. The increase in flag leaf length is likely due to better nitrogen availability and hormonal stimulation from humic acid, which promotes cell elongation. The flag leaf is essential for making food during the grain-filling stage and its growth is improved by better soil health, nutrient uptake and hormone balance (24, 25).

Leaf area (cm^2)

Significant differences were observed in the leaf area between the treatments. The treatment that included vermicompost-derived humic acid, poultry manure (6 t ha^{-1}) and nano urea produced the biggest leaf area (98.66 cm^2), while the treatment with 100 % RDF had the smallest leaf area (85.80 cm^2). The larger leaf area, which is a result of better nutrition management, shows enhanced photosynthetic ability and improved plant health. This increase is likely due to enhanced nutrient availability, particularly nitrogen, which promotes leaf expansion. Humic acid increases cation exchange capacity (CEC), improving nutrient retention and uptake. Poultry manure contributes to soil organic matter, water retention and microbial activity, all of which support healthy leaf development (24, 25).

Chlorophyll index (SPAD)

The maximum chlorophyll index (39.77 SPAD) was observed in the treatment combining vermicompost-derived humic acid, poultry manure (6 t ha^{-1}) and nano urea. The minimum SPAD value (32.50) was recorded in the 100 % RDF treatment. Higher SPAD values indicate better chlorophyll content and, consequently, enhanced photosynthetic capacity. This may be attributed to the improved uptake of nitrogen and micronutrients facilitated by humic acid and poultry manure. Nano urea ensures sustained nitrogen supply, supporting chloroplast development and delaying senescence (26).

Dry weight (g)

The treatments had a significant influence on plant dry weight, as represented in Table 4. The maximum dry weight (90.23 g) was observed in the treatment incorporating vermicompost-derived humic acid, poultry manure (6 t ha^{-1}) and nano urea, closely followed by the treatment with plant-derived humic acid, similar poultry manure quantity and nano urea (89.83 g). The minimum dry weight (81.63 g) was recorded with the 100 % RDF treatment. Enhanced biomass accumulation reflects improved nutrient absorption and assimilation. Adding organic materials helps improve the soil and boost the activity of beneficial microbes, which aids in root growth and the movement of nutrients. Meanwhile, nano urea efficiently supplies nitrogen during key growth periods.

Crop Growth Rate (CGR) and Relative Growth Rate (RGR)

Crop Growth Rate (CGR) and Relative Growth Rate (RGR) showed significant differences among the treatments. The highest Crop Growth Rate (CGR) of 1.19 g m^{-2} day^{-1} was found in the treatment that included vermicompost-derived humic acid, poultry manure (6 t ha^{-1}) and nano urea, while the lowest CGR of 0.97 g m^{-2} day^{-1} was seen in the 100 % RDF treatment, showing that using organic materials helps plants grow faster. Similarly, the highest RGR (0.0185 g g^{-1} day^{-1}) was observed in the same humic acid treatment, with the lowest RGR (0.012 g $g^{-1}day^{-1}$) in the 100 % RDF treatment, as shown in Table 4. These growth rates suggest enhanced metabolic efficiency and biomass accumulation. The steady nutrient availability from nano urea, in combination with the improved soil health from organic inputs, promotes sustained growth (5, 26).

Effects of humic acid derived from diverse substances, poultry manure and nano urea on the yield and yield attributes of transplanted basmati rice

Number of panicles per plant

Humic acid and poultry manure both significantly affected the number of panicles per plant. The treatment that includes vermicompost-derived humic acid, poultry manure (6 t ha^{-1}) and nano urea yielded the maximum number of panicles (16.66), followed by the treatment with plant-derived humic acid, poultry manure (6 t ha^{-1}) and nano urea (15.76). The 100 % RDF treatment recorded the lowest number of panicles (10.77), as shown in Table 5. The maximum panicle number (16.66) occurred under the integrated treatment of humic acid, poultry manure and nano urea. This advantage may be attributed to improved tiller survival and enhanced nutrient translocation to reproductive organs facilitated by balanced nutrition and hormonal regulation. Organic sources, including poultry

Table 4. Effects of humic acid derived from diverse substances, poultry manure and nano urea on Dry matter accumulation, CGR and RGR

Treatments	Dry weight(g)	CGR (g m^{-2} day^{-1})	RGR (g g^{-1} day^{-1})
100 % RDF	81.63 ± 0.90^{f}	0.97 ± 0.012^{e}	0.012 ± 0.002^{d}
Coal derived humic acid+ Poultry manure (0 t ha^{-1}) + Nano urea	82.96 ± 0.46^{ef}	1.01 ± 0.030^{e}	0.014 ±0.001^{bc}
Coal derived humic acid+ Poultry manure (3 t ha^{-1}) + Nano urea	85.13 ± 1.01^{cde}	1.02 ± 0.010^{e}	0.015 ±0.001^{ab}
Coal derived humic acid+ Poultry manure (6 t ha^{-1}) + Nano urea	88.96 ± 1.6^{ab}	1.13 ± 0.012^{b}	0.015 ± 0.001^{ab}
Vermicompost derived humic acid+ Poultry manure (0 t ha^{-1}) + Nano urea	84.46 ± 0.54^{de}	1.01 ± 0.006^{e}	0.015 ± 0.002^{ab}
Vermicompost derived humic acid+ Poultry manure (3t ha^{-1}) + Nano urea	87.56 ± 0.99^{bc}	1.12 ± 0.044^{bc}	0.016 ± 0.001^{ab}
Vermicompost derived humic acid+ Poultry manure (6 t ha^{-1}) + Nano urea	90.23 ± 2.30^{a}	1.19 ± 0.035^{a}	0.0185 ±0.001^{a}
Plant derived humic acid+ Poultry manure (0 t ha^{-1}) + Nano urea	83.76 ± 0.94^{ef}	1.02 ± 0.049^{e}	0.014 ± 0.001^{bc}
Plant derived humic acid+ Poultry manure (3 t ha^{-1}) + Nano urea	86.43 ± 1.37^{cd}	1.07 ± 0.015^{cd}	0.015 ± 0.001^{ab}
Plant derived humic acid+ Poultry manure (6 t ha^{-1}) + Nano urea	89.83 ± 0.34^{ab}	1.14 ± 0.031^{b}	0.016 ± 0.001^{ab}

*The means with different Letters as superscripts are significant ($P < 0.05$). The means with same letters or having common letter(s) are not significantly different

manure and vermicompost, provide more balanced nutrition, including essential micronutrients, which improves tiller growth and overall plant productivity (27, 28).

Panicle length (cm)

Panicle length showed significant variation among the treatments. The longest panicle length (29.24 cm) was observed in the treatment that used vermicompost-derived humic acid, poultry manure (6 t ha^{-1}) and nano urea, while the shortest panicle length (23.42 cm) was seen in the treatment with 100 % RDF. Panicle length was significantly greater (29.24 cm) in the integrated treatment. This improvement is probably due to better cell growth and spikelet formation, made possible by a steady supply of nutrients, especially nitrogen and potassium, thanks to the slow release of organic materials and the effectiveness of nano urea when applied to leaves. The results align with those of a previous study, which reported an increase in panicle length following the foliar application of Nano Super Micro Plus fertilizer, a combination of nano-nitrogen, phosphorus and potassium fertilizers, along with commercial fertilizers (24). Moreover, the presence of humic acid reduces nitrogen loss, enhancing vegetative development. This also contributes to an increase in panicle length in rice plants. This observation aligns with the findings reported in studies (23, 29).

Panicle weight (g)

The maximum panicle weight (2.62 g) was recorded in the treatment combining vermicompost-derived humic acid, poultry manure (6 t ha^{-1}) and nano urea, signifying enhanced grain filling and overall panicle viability. The minimum panicle weight (1.85 g) was observed in the 100 % RDF treatment. The treatment with humic acid, poultry manure and nano urea produced the heaviest panicles (2.62 g), which is indicative of superior grain filling. The enhanced source-to-sink relationship driven by higher photosynthetic activity (as reflected in SPAD values) and better nutrient translocation under optimal soil conditions contributed to increased grain biomass. These findings align with the research of those who documented improvements in plant growth attributes using vermicompost carrier-based inoculants (30).

Number of filled grains per panicle

There was a significant difference in the number of filled grains per panicle among the treatments. The treatment with vermicompost-derived humic acid, poultry manure (6 t ha^{-1}) and nano urea had the most filled grains (75.40). The observed increase may be due to reduced spikelet sterility and enhanced nutrient uptake, particularly phosphorus and nitrogen, which play crucial roles in the flowering and grain-filling stages. Humic acid improves hormonal balance, particularly that of cytokinins and auxins, thereby enhancing floret fertility (27, 31).

Test weight (g)

Test weight indicated significant variance among the treatments. The highest test weight (26.24 g) was found in the treatment that combined vermicompost-derived humic acid with 6 t ha^{-1} of poultry manure and nano urea, which was much better than the control treatment (18.51 g). Significant improvement in test weight (26.24 g) was observed with the integrated nutrient treatment. Improved seed filling and kernel development under nutrient-rich conditions explain the higher test weight. The increase also reflects improved physiological maturity of grains due to enhanced photosynthate availability. These findings corroborate those who concluded that nutrition availability during the reproductive phase improves grain filling, resulting in increased grain weight (22, 32).

Grain yield (kg ha^{-1})

Grain yield showed significant variation among treatments, with the maximum yield (4012.50 kg ha^{-1}) observed in the treatment containing vermicompost-derived humic acid, 6 t ha^{-1} of poultry manure and nano urea, as represented in Table 6. This was followed by the application of plant-derived humic acid combined with 6 t ha^{-1} of poultry manure and nano urea treatment, resulting in 3926.03 kg ha^{-1}. The yield advantage is a cumulative effect of improvements in all yield attributes, especially panicle numbers and grain filling. The synergistic effect of nano urea (rapid nitrogen assimilation), poultry manure (slow nutrient release and organic carbon enrichment) and humic acid (nutrient chelation and microbial stimulation) contributed to better crop performance. The lowest yield (3631.53 kg ha^{-1}) was recorded in the 100 % RDF control treatment. These results align with those of previous studies who reported similar findings (32-34).

Table 5. Effects of humic acid derived from diverse substances, poultry manure and nano urea on the yield attributes of transplanted basmati rice

Treatments	No. of panicles per plant	Panicle length (cm)	Panicle weight (g)	No. of filled grains per panicle
100 % RDF	10.77 ± 0.387 ^{e}	23.42 ± 0.97 ^{d}	1.85 ± 0.030 ^{g}	61.27 ± 0.9 ^{h}
Coal derived humic acid+ Poultry manure (0 t ha^{-1}) + Nano urea	11.11 ± 0.697 ^{de}	23.61 ± 0.63 ^{d}	1.94 ± 0.015 ^{f}	64.40 ± 1.25 ^{g}
Coal derived humic acid+ Poultry manure (3 t ha^{-1}) + Nano urea	12.267 ± 0.751 ^{d}	24.37 ± 0.56 ^{d}	2.00 ± 0.040 ^{ef}	69.23 ± 0.90 ^{ef}
Coal derived humic acid+ Poultry manure (6 t ha^{-1}) + Nano urea	14.76 ± 0.681^{bc}	26.33 ± 0.51 ^{bc}	2.16 ± 0.061 ^{c}	71.43 ± 1.26 ^{c}
Vermicompost derived humic acid+ Poultry manure (0 t ha^{-1}) + Nano urea	11.77 ± 1.072 ^{de}	23.93 ± 0.299^{d}	1.96 ± 0.049 ^{def}	69.47 ± 1.25 ^{def}
Vermicompost derived humic acid+ Poultry manure (3t ha^{-1}) + Nano urea	14.23 ± 1.079 ^{c}	26.73 ± 0.97 ^{bc}	2.09 ± 0.021 ^{cd}	71.17 ± 0.25^{c}
Vermicompost derived humic acid+ Poultry manure (6 t ha^{-1}) + Nano urea	16.66 ± 0.577 ^{a}	29.24 ± 0.979 ^{a}	2.62 ± 0.059 ^{a}	75.4 ± 1.100 ^{a}
Plant derived humic acid+ Poultry manure (0 t ha^{-1}) + Nano urea	11.61 ± 0.788 ^{de}	23.99 ± 0.570 ^{d}	1.95 ± 0.032 ^{f}	68.30 ± 1.00 ^{f}
Plant derived humic acid+ Poultry manure (3 t ha^{-1}) + Nano urea	13.93 ± 0.651 ^{c}	26.17 ± 0.273 ^{c}	2.06 ± 0.030 ^{de}	70.76 ± 0.45 ^{cde}
Plant derived humic acid+ Poultry manure (6 t ha^{-1}) + Nano urea	15.76 ± 0.862 ^{ab}	27.47 ± 0.835^{b}	2.267 ± 0.031^{b}	73.36 ± 1.15 ^{b}

*The means with different Letters as superscripts are significant ($P < 0.05$). The means with same letters or having common letter(s) are not significantly different

Straw yield (kg ha^{-1})

The straw yield followed the grain yield, with the highest straw yield (5821.06 kg ha^{-1}) recorded in the treatment that included vermicompost-derived humic acid, 6 t ha^{-1} of poultry manure and nano urea. This was considerably more than the control treatment (5432.76 kg ha^{-1}). The highest straw yield in the combined treatment was probably because it helped plants grow better and gather more biomass, thanks to a good balance of nutrients and better photosynthesis. Previous research indicates similar improvements in vegetative growth and straw yield with the use of organic fertilizers and nano urea (33, 34).

Harvest index (%)

The Harvest Index (HI) values indicated minimal variations among treatments. The highest HI (40.80 %) was recorded in the treatment that integrated vermicompost-derived humic acid, 6 t ha^{-1} of poultry manure and nano urea, suggesting a more efficient distribution of biomass towards grain yield. This conclusion indicates an efficient partitioning of assimilates toward grain production, reflecting improved reproductive efficiency and nutrient use under the combined influence of organic and nano inputs. Similar results have been reported in previous studies (35).

Correlation and regression

The majority of variables exhibit strong positive correlations, as evidenced by the intense shades of green and high values of coefficients (approaching 1). Filled grains and grain yield exhibit a strong correlation of 0.99. Panicle length and panicle weight show a high correlation of 0.98. Some correlations are moderate, as represented by lighter shades of green and coefficient values ranging from 0.5 to 0.85. No noticeable low or negative correlations exist, as the majority of values are near 1 or significantly higher. The chlorophyll index and relative growth rate exhibit a moderate relationship of 0.72. Strong relationships among yield-related parameters (e.g., grain yield, panicle weight and filled grains) suggest that enhancing one feature may beneficially influence others, as indicated in Fig. 3. The R^2 (coefficient of determination) signifies that 95 % of the variance in the dependent variable can be explained by the independent variable(s) in the regression model from Fig. 4 & 5. This value indicates a strong correlation between the model and the data. The image shows a scatter plot with a regression line, where the points are closely clustered around the line, signifying a strong linear relationship between the variables.

Conclusion

In conclusion, the study demonstrates that using a combination of humic acid from vermicompost, poultry manure (6 t ha^{-1}) and nano urea significantly enhances the growth, health and yield of transplanted basmati rice. This combination resulted in the highest plant height, tiller number, chlorophyll content, grain yield (4012.50 kg ha^{-1}) and straw yield (5821.06 kg ha^{-1}), along with superior yield attributes such as panicle length, panicle weight and number of filled grains. The synergistic effects of organic amendments and nanonitrogen improved nutrient uptake, hormonal balance and soil health. These findings confirm that integrated nutrient management, utilizing humic acid, poultry manure and nano-urea, is a sustainable and effective approach to maximizing basmati rice productivity under subtropical conditions.

Acknowledgements

Authors are thankful to Lovely Professional University, Phagwara for providing us the necessary facility.

Authors Contributions

NNKR prepared the research plan, conducted the analysis, contributed to manuscript writing and participated in proofreading. AJ provided guidance throughout the research, supported the development of the methodology and assisted in writing and proofreading the manuscript. All authors have read and approved the final version of the manuscript.

Table 6. Effects of humic acid derived from diverse substances, poultry manure and nano urea on the yield of transplanted basmati rice

Treatments	Test weight(g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest Index (%)
100 % RDF	18.51 ± 0.30 ^{g}	3631.53 ± 17.24^{f}	5432.76 ± 2.57 ^{h}	40.06 ± 0.127 ^{cd}
Coal derived humic acid+ Poultry manure (0 t ha^{-1}) + Nano urea	19.41 ± 0.17 ^{f}	3652.0 ± 5.89^{f}	5464.46 ± 4.050 ^{g}	40.06 ± 0.052 ^{cd}
Coal derived humic acid+ Poultry manure (3 t ha^{-1}) + Nano urea	20.05 ± 0.402 ^{ef}	3718.2 ± 5.58 ^{e}	5525.46 ± 9.176 ^{ef}	40.22 ± 0.076 ^{bcd}
Coal derived humic acid+ Poultry manure (6 t ha^{-1}) + Nano urea	21.63 ± 0.627 ^{c}	3852.3 ± 30.57 ^{c}	5700.06 ± 10.08 ^{c}	40.32 ± 0.151 ^{bc}
Vermicompost derived humic acid+ Poultry manure (0 tha^{-1}) + Nano urea	19.63 ± 0.48 ^{f}	3672.86 ± 23.02 ^{f}	5514.96 ± 6.058 ^{ef}	39.97 ± 0.123 de
Vermicompost derived humic acid+ Poultry manure (3t ha^{-1}) + Nano urea	20.96 ± 0.188 ^{cd}	3778.53 ± 30.12 ^{d}	5567.96 ± 8.641^{d}	40.42 ± 0.211^{b}
Vermicompost derived humic acid+ Poultry manure (6 t ha^{-1}) + Nano urea	26.24 ± 0.597 ^{a}	4012.50 ± 10.14 ^{a}	5821.06 ± 5.552 ^{a}	40.80 ± 0.081 ^{a}
Plant derived humic acid+ Poultry manure (0 t ha^{-1}) + Nano urea	19.54 ± 0.346 ^{f}	3663.73 ± 4.46 ^{f}	5509.9 ± 29.838 ^{f}	39.93 ± 0.111 ^{e}
Plant derived humic acid+ Poultry manure (3 t ha^{-1}) + Nano urea	20.62 ± 0.315 ^{de}	3726.36 ± 15.76 ^{e}	5534.2 ± 10.013 ^{e}	40.23 ± 0.134 ^{bcd}
Plant derived humic acid+ Poultry manure (6 t ha^{-1}) + Nano urea	22.67 ± 0.322 ^{b}	3926.033 ± 48.76 ^{b}	5795.3 ± 10.545 ^{b}	40.38 ± 0.262 ^{b}

***The means with different Letters as superscripts are significant ($P < 0.05$). The means with the same letters or having a common letter(s) are not significantly different

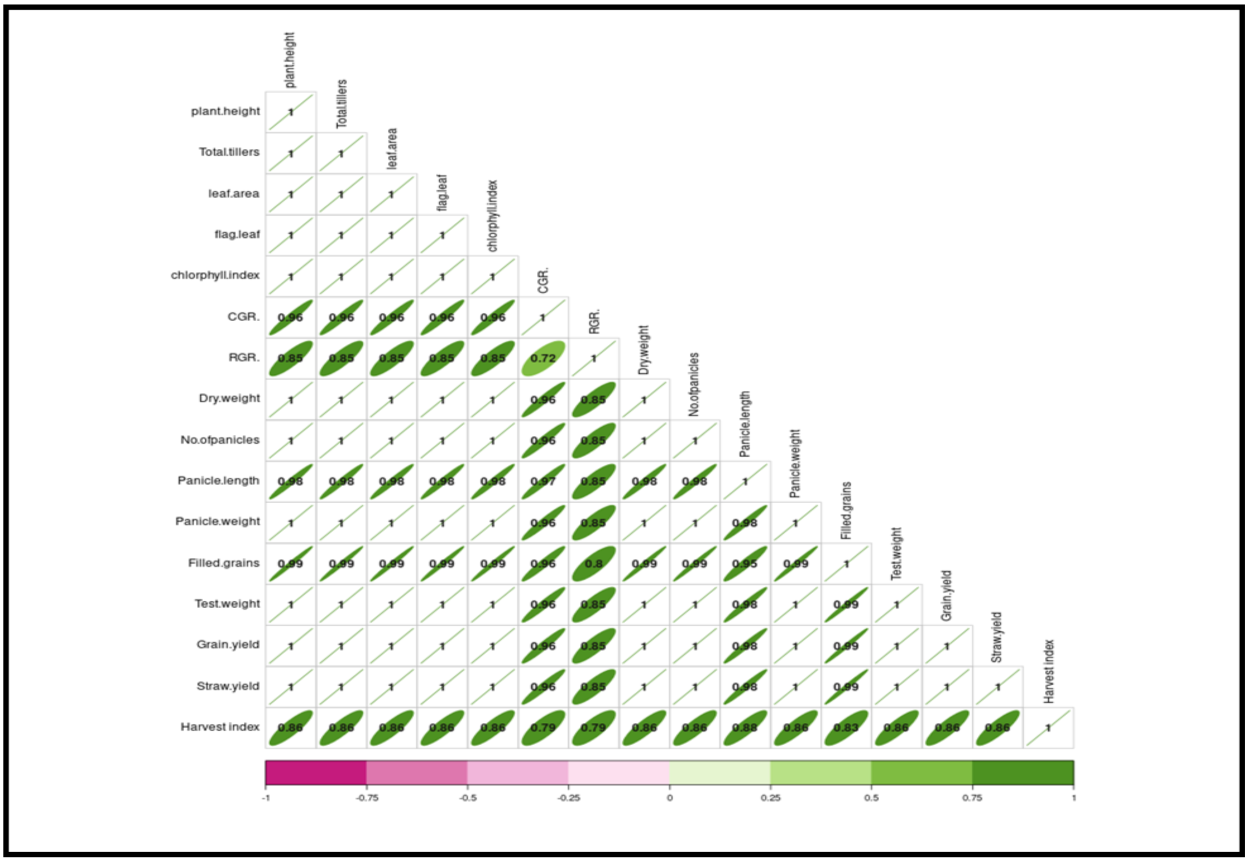
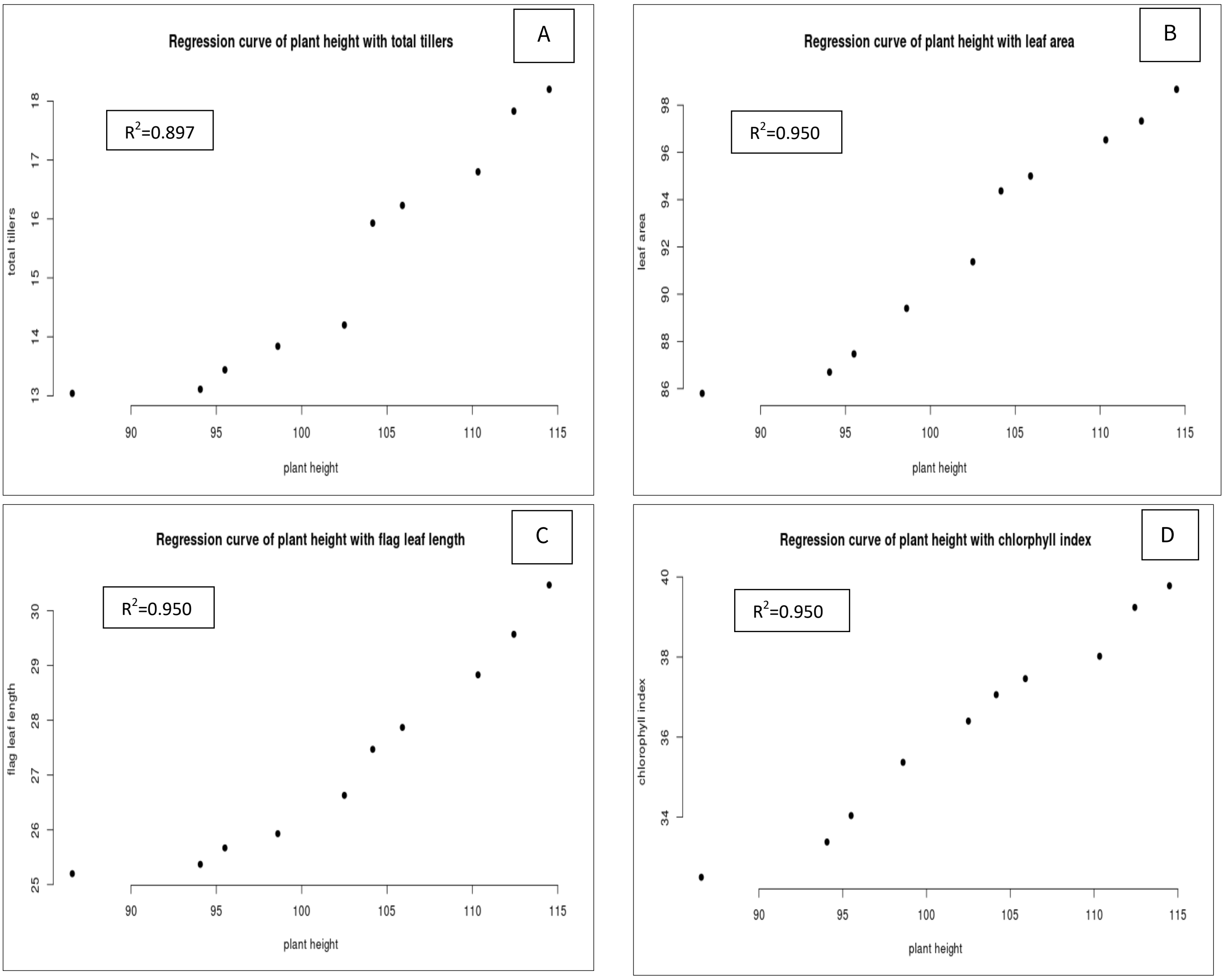


Fig. 3. Correlation matrix represented as a correlogram. It displays the correlation coefficients between different agronomic traits or variables measured in a study.



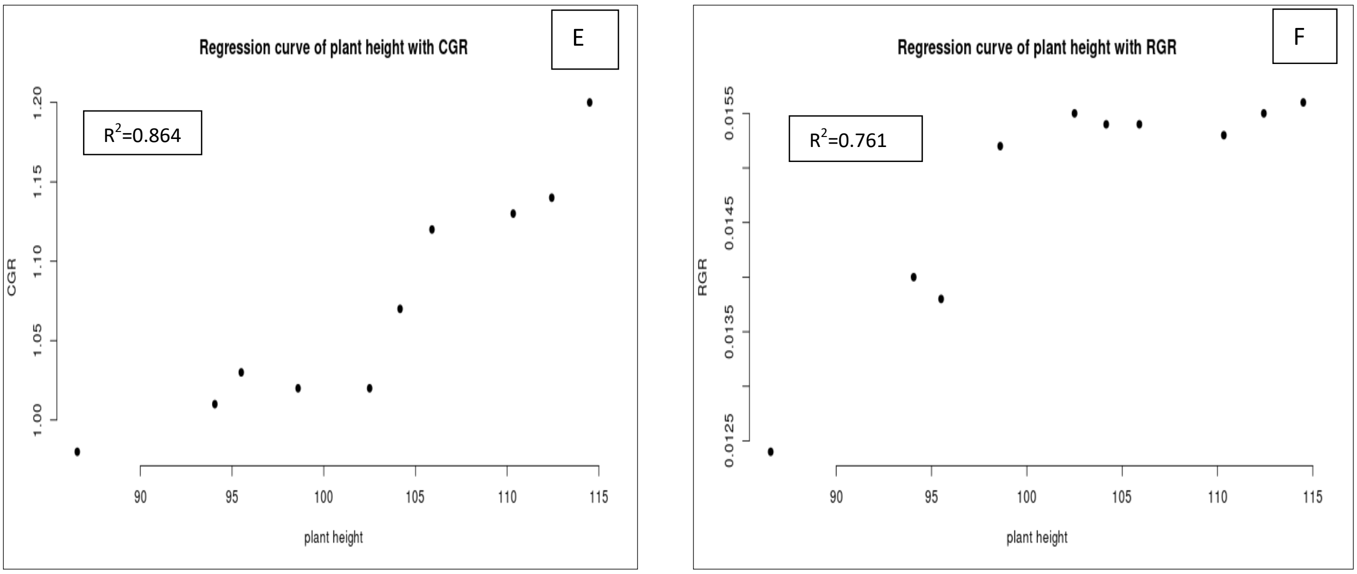
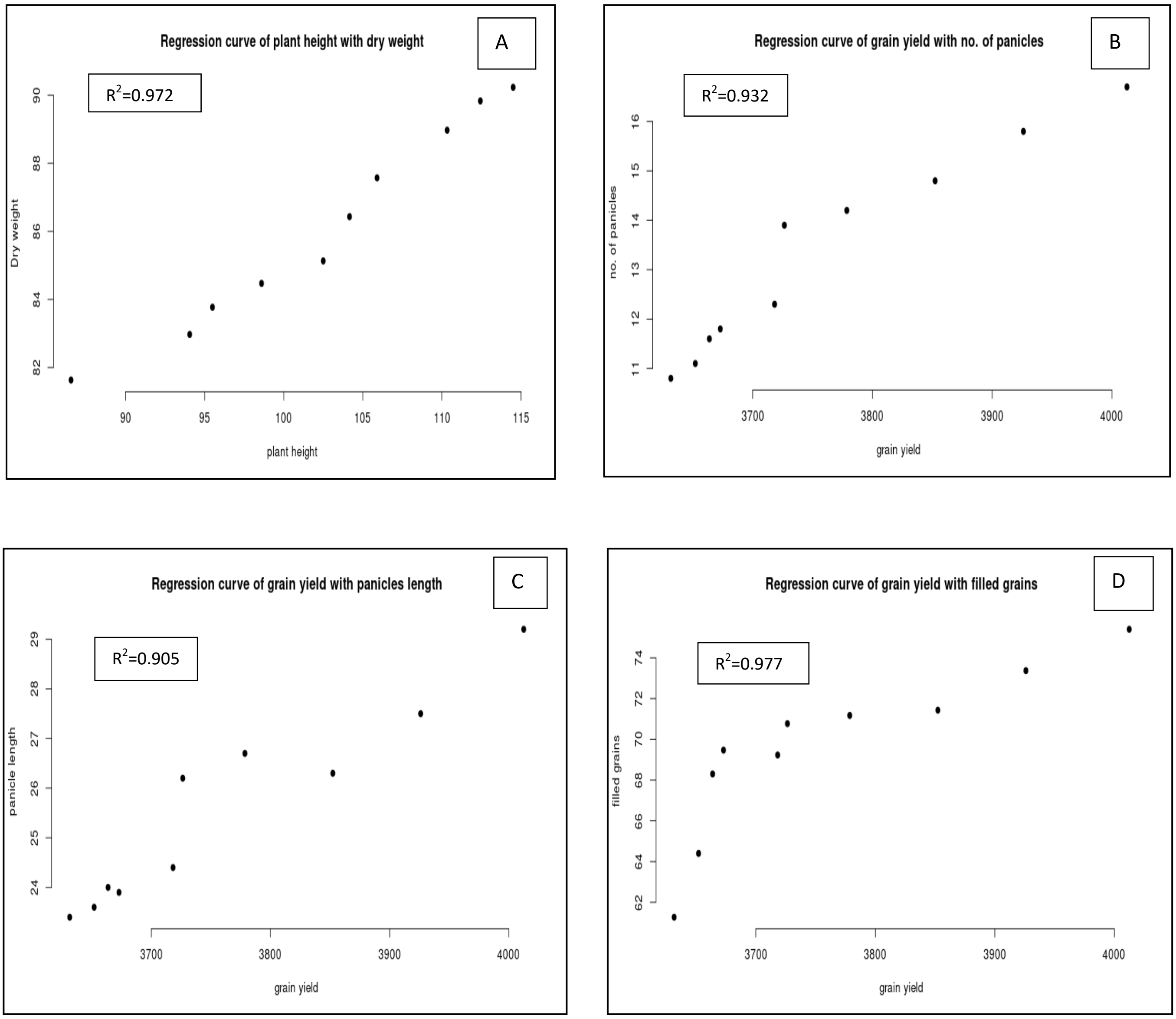
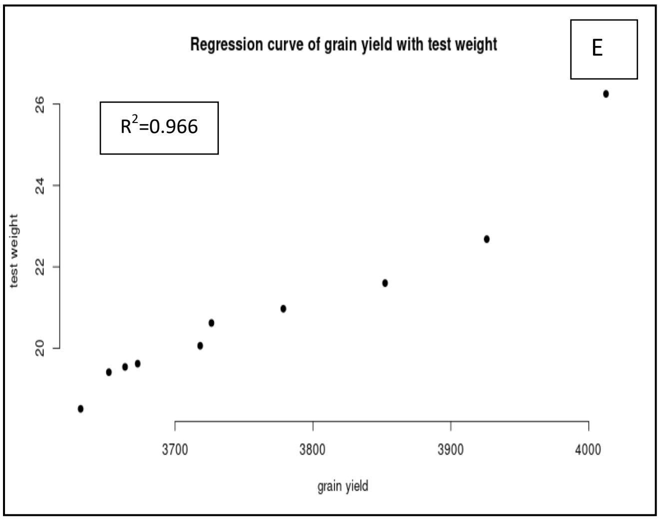


Fig. 4A-F. The images represent scatter plots with linear regression lines, likely illustrating the relationships between plant height and various variables, including the number of tillers, leaf area, flag leaf length, chlorophyll index and growth rates (CGR and RGR).





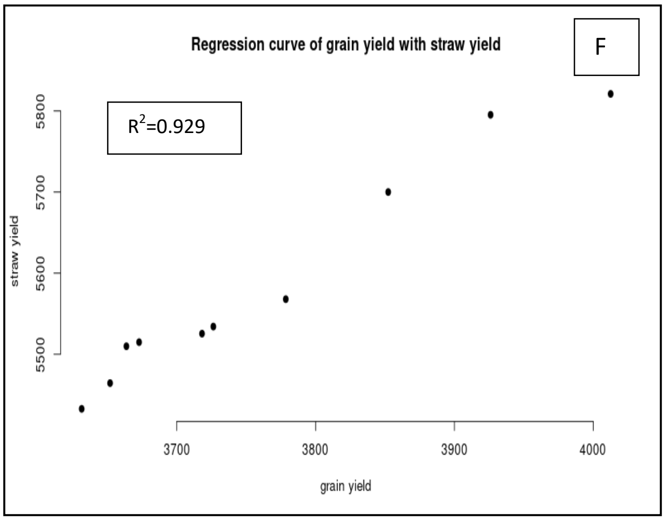


Fig. 5A-F. The images show a set of scatter plots with regression lines. The main finding is that the variables represented on the y-axis (no. of panicles, panicle length, filled grains, test weight and straw yield) exhibit a positive correlation with the grain yield.

Compliance with ethical standards

Conflict of Interest: The authors declared that they have no conflict of interest concerning this work.

Ethical issues: None

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Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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