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Effect of different doses and stages of biostimulant application on yield of transplanted rice

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Abstract

A field experiment was conducted during the kharif season in the Agricultural Engineering Farm, Department of Agronomy, J.N.K.V.V., Jabalpur (M.P.) under randomized block design with four replications having 7 treatments comprising of different doses of potassium humate at the rate of 136 g, 170 g, and 204 g ha^{-1} at the maturity (MT) and panicle initiation (PI) stages of crop with recommended dose of fertilizer (RDF) (120: 60: 40 N: P: K kg ha^{-1}) and compared with 100% recommended dose of NPK fertilizers, for achieving targeted yield by using variety of rice Kranti. The best response was recorded from the application of treatment T_7 (RDF + Potassium humate @ 204 g ha^{-1} at MT stage + PI stage) for growth parameters of rice (*viz*., plant height, tiller $hill^{-1}$, dry matter accumulation, leaf area index), which were found at par with 136 g and 170 g ha^{-1} at the same stages with RDF. Yield attributing characters *viz*., effective tiller $hill^{-1}$, panicle length, sound grains $panicle^{-1}$ and 1000 grain weight (test weight) and nutrient uptake (N,P,K kg ha^{-1}) by the crop which was significantly higher with the treatment T_7 followed by Potassium humate @ 170 g ha^{-1} at MT+PI stage than remaining treatments. Although test weight was not affected by biostimulant treatments at different levels, among all the doses of biostimulant, the application of potassium humate @ 204 g ha^{-1} at the MT and PI stages produced the highest grain (5632 kg ha^{-1}) and straw (7905 kg ha^{-1}) yields. The harvest index was also found to be higher under treatment T_7. Although the application of potassium humate @ 204 g ha^{-1} at the MT + PI stage included the maximum cost of cultivation and gave the maximum gross monetary return (Rs. 128450) and net monetary return (Rs. 84386), However, the highest B:C ratio (2.93) was calculated under the application of potassium humate @ 170 g ha^{-1} at MT+PI stage along with RDF. Reports on the application of humic acid (HA) to cereal crops are not very common. Therefore, this study aimed to examine the effect of humic acid in combination with chemical fertilizers on rice growth, yield, and quality.

Keywords: Biostimulant, fertilizer, humic acid, potassium humate, nutrient uptake

1. Introduction

In India, rice is the most popular crop and ranks second globally in terms of consumption, despite the fact that many other grain crops are farmed and consumed worldwide as well. It is considered as the "global grain" and is the primary staple food for over half of the world's population. Approximately 90% of the world's rice crop is produced and consumed in Asian nations worldwide (Vasudevan *et al.*, 2014) [14]. According to Choudhary *et al.* (2011) [9], rice contributes 50–80% of an individual's daily calorie consumption. Rice-based agricultural methods are the most common in India. Agro-climatic conditions determine the use of rice production technologies such as transplanting, direct sowing, and SRI (System of Rice Intensification). Weed incidence is a widespread and important problem in all agro-ecosystems, rainfed or irrigated, and transplanting is the most widely used method in irrigated agro-ecosystems.

Biostimulants are referred as positive plant growth regulators or promoters which when added in minimal quantities, promote the growth and overall development of plants. The plant growth hormones are produced indigenously and play a crucial role in regulating gene expression, growth and behavioural process in plant. Consequently, the addition of chemical plant growth regulator has added a new dimension to the possibility of modifying plant growth, development and metabolism (Kumar *et. al.*, 2018) [21].

Cereals require the same amount of potassium as nitrogen (Zorb *et al.*, 2014) [42]. Potassium, a cationic primary nutrient, is involved in many physiological activities, including protein synthesis, photosynthesis, enzyme activation, and the maintenance of water status in plant tissues (Marschner, 2011) [24].

It also influences synthesis, translocation, transformation, storage and division of carbohydrates, product quality, and post-harvest traits as well as plants resistance to stresses and diseases (Zivdar *et al*., 2016; Mardanluo *et al*., 2018) [40, 23]. Potassium is an alkali metal that is normally utilised extensively for plant fertilisation from a variety of inorganic sources (KCl, K2SO4, etc.). Moreover, various forms of organic potassium sources also adopted for agricultural application in which actually K remains as inorganic cation but bounded with bulky organic moiety. Furthermore, application of this forms of organic fertilizers is more consistent with sustainability and environmental issues (Souri 2016; Souri *et al*., 2017) [35, 43].

Potassium humate is the potassium salt of humic acid containing 50% humic and 12% potassium. Potassium humate is highly soluble, 100% organic, non-toxic, environmentally friendly chelating and soil fertility improving substance. Potassium humate is a highly concentrated form of humus in the naturally occurring lignite which is brown coal that accompanies coal deposits. Potassium humate is a highly concentrated form of humus in the naturally occurring lignite, which is brown coal, that accompanies coal deposits. It is a peat material that has not been subjected to high compression to turn it into coal, and from this, potassium humate is produced. In actuality, the use of humic acid in cereals is rare because farmers are least attentive to its beneficial effects. The HA products are usually available in the form of affordable soluble salts, referred to as potassium humate (Fong *et al*., 2007) [12].

Humic acid is a suspension based on potassium humate that can be used to improve soil quality, promote plant growth, and build natural defences against pests and diseases (Scheuerell *et al*., 2004, 2006) [33, 44], improve uptake of nutrients and water, and stimulate plant growth through higher cell division. Furthermore, according to Atiyeh *et al*. (2002) [3] and Chen *et al*. (2004) [7], He also promoted the activity and growth of soil microbes.

Application of humic material in agriculture as fertilizer and soil conditioner was tried on a small scale. The significant impact of these humic compounds on soil structure and plant growth was showed earlier by Ihsanullah and Bakhashawin (2013) [17]. HA in proper quantity can enhance plant and root growth (Ahmed *et al*., 2013) [1]. Humic substances (humic and fulvic acid) attract positive ions, form chelates with micronutrients, and release them slowly when required by plants. According to Kadam *et al*. (2010) [20], humic compounds function as chelating agents by preventing precipitation, fixation, leaching and oxidation of micronutrients in soil.

2. Materials and Method

During the 2021 kharif season, an experiment was carried out to investigate the “Effect of different doses and stages of biostimulant application on yield of transplanted rice” under the edaphic and climatic conditions of Jabalpur (M.P.). The details of the materials used and methods employed during the investigation are cited in this chapter and described under the appropriate headings.

2.1 Experimental site

The experiment was conducted at the Agricultural Engineering Farm, Department of Agronomy, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.) during kharif season 2021. All physical facilities, *viz*., labour, agrochemicals, equipment, irrigation water, etc., were available as and when needed at the research farm. The laboratory work was conducted in the Department of Agronomy, College of Agriculture, JNKVV Jabalpur. Jabalpur is located at 23º90' North latitude and 79º58' East longitude, with an elevation of 411.78 metres above sea level.

2.2 Climate

The climate of locality is typically semi humid and tropical, which is featured by hot dry summer and cool dry winter. According to the National Agriculture Research Program's norms, it is classified as “Kymore Plateau and Satpura Hills" agro-climatic zone. According to the National Bureau of Soil Science and Land Use Planning (NBSS&LUP) Nagpur, Jabalpur are classified as hot sub-humid (dry) eco-regions in Agro ecological region number 10, named as Central High Land (Malwa and Bundelkhand) sub region number 10.1. (Malwa plateau, Vindhyan Scarpland and Narmada Valley). The annual average rainfall in Jabalpur is 1350 mm, with the majority of rain falling between mid-June and the end of September, with a little rain falling during the rest of the year. During the winter, the average monthly temperature drops to 4 °C, while the highest temperature reaches 45 °C during the summer. In general, relative humidity is low in the summer (15 to 30 percent), moderate in the winter (60 to 75 percent), and high in the rainy season (80 to 95 percent).

The climate of the area is generally semi-humid and tropical, with hot, dry summers and cool, dry winters. It is categorised as an agro-climatic zone of "Kymore Plateau and Satpura Hills" in accordance with the standards of the National Agriculture Research Programme. According to the National Bureau of Soil Science and Land Use Planning (NBSS&LUP), Nagpur, Jabalpur are classified as hot sub-humid (dry) eco-regions in Agro-ecological region number 10, named Central High Land (Malwa and Bundelkhand) sub-region number 10.1 (Malwa plateau, Vindhyan Scarpland, and Narmada Valley). The majority of Jabalpur's 1350 mm of annual rainfall falls between mid-June and the end of September, with sporadic showers during the remaining months. The average monthly temperature decreases to 4°C in the winter and reaches a maximum of 45°C in the summer. Relative humidity is generally low (15–30%) in the summer, moderate (60–75%) in the winter, and high (80–95%) during the rainy season.

2.3 Weather Conditions

During the crop season of 2021, the maximum temperature ranged from 26.8 °C to 35.7 °C and minimum temperature from 10.5 °C to 26.7 °C. During the crop season, relative humidity in the morning was lowest 75% and highest 95% respectively, while relative humidity in evening was 33% to 85%. The maximum rainfall was 130.40 mm and minimum 3.80 mm received in five and one rainy days in cropping season. In the cropping season crop was exposed to a maximum of 9.0 hours of sunlight each day while vapour pressure in the morning ranging from 22.8 mm to 10.4 mm and in evening from 23.1 mm to 9.5 mm.

In the agricultural season of 2021, the highest temperature recorded was 26.8 °C to 35.7 °C, while the lowest temperature recorded was 10.5 °C to 26.7 °C. Relative humidity ranged from 33% to 85% in the evening during the crop season, with the lowest values occurring in the morning

(75% and maximum, respectively). During the cropping season, the maximum rainfall recorded was 130.40 mm, while the minimum was 3.80 mm, which was obtained in five and a one rainy days. The crop received a maximum of 9.0 hours of sunlight per day during the cropping season, with morning vapour pressure ranging from 22.8 mm to 10.4 mm and evening vapour pressure from 23.1 mm to 9.5 mm.

2.4 Experimental details

Location: Agricultural Engineering Farm, Department of Agronomy, J.N.K.V.V., Jabalpur (M.P.)

Treatments: Seven treatments comprised of six combinations of biostimulants (Potassium humate) with RDF compared with 100% RDF treated as control.

Experimental Design: Randomized Block Design

Replications: 04

Table 1: Treatment details of the experiment

Symbol	Treatments
T_1	Recommended dose of fertilizers only (120: 60: 40 N: P: K kg ha^{-1})
T_2	RDF + Potassium humate @ 136 g ha^{-1} at PI stage
T_3	RDF + Potassium humate @ 136 g ha^{-1} at MT stage + PI stage
T_4	RDF + Potassium humate @ 170 g ha^{-1} at PI stage
T_5	RDF + Potassium humate @ 170 g ha^{-1} at MT stage + PI stage
T_6	RDF + Potassium humate @ 204 g ha^{-1} at PI stage
T_7	RDF + Potassium humate @ 204 g ha^{-1} at MT stage + PI stage

Soil: The texture of the soil in the experimental field was clay loam, with a medium level of organic carbon (0.56 percent), available phosphorus (16.25 kg ha^{-1}) and potassium (305.40 kg ha^{-1}) and a low level of available nitrogen (238.2 kg ha^{-1}). The soil has a normal electrical conductivity reaction (0.27 ds/m) and a neutral pH of 7.1.

2.5 Agronomic characteristics of rice variety "Kranti"

Kranti is the most popular and widespread variety of rice cultivated in the region. It is a medium-maturing cultivar (118-122 days). The plants are semi-dwarf (115-130 cm), fertilizer-responsive, and produce coarse grains, making them ideal for poha production. The test weight of variety "Kranti" is 23-25 g. Kranti has a yield potential of 58–62 q ha^{-1} with proper agronomic management.

2.6 Schedule of agronomic operations

2.6.1 Nursery management

To prepare the bed for nursery, two cross harrowing operations were performed using a disc harrow. A disc harrow was used to carry out two cross-harrowing operations in order to get the bed ready for the nursery. The nursery field was levelled with a planker after 10 tonnes of FYM were put evenly there. We removed stones, weeds, and other rubbish. The size of the manually prepared nursery beds was 15 metres long by 1 metre wide and 15 centimetres high. After being treated with Bavistin at a rate of 2 g kg^{-1} seed, healthy rice seeds (variety Kranti) were sown in the nursery bed.

2.6.2 Preparation of experimental field

Experimental field was prepared after the harvest of previous crop, using a tractor-drawn cultivator followed by two cross harrowing to break up clods and mix the previous crop's residues into the soil. Before transplanting, water was applied in the field and puddled by using a tractor-mounted puddler and then levelled with a leveler.

2.6.3 Fertilizer application

The recommended amounts of nitrogen, phosphorus, and potassium were applied using urea, single super phosphate, and murate of potash, respectively. Half of the nitrogen (60 kg N ha^{-1}) and the complete doses of potassium (40 kg K_2O ha^{-1}) and phosphorus (60 kg P2O5 ha^{-1}) were applied as a basal before transplanting, and the remaining nitrogen (two equal split doses of N) was applied through top dressing during the crop's tillering and panicle initiation stages.

2.6.4 Transplanting

Manual transplantation was performed in the field on rice seedlings that were twenty-five days old. The planting geometry for all experimental sites was 20 cm x 20 cm. Two robust seedlings from hill^{-1} were evenly transplanted.

2.6.5 Application of biostimulant (Potassium humate)

The potassium salt of humic acid is denoted as potassium humate. Foliar application of potassium humate was conducted in accordance with the treatments, at maximal tillering and panicle initiation stages, at rates of 134, 170, and 204 g ha^{-1} per spray. The recommended doses of fertilisers were also applied. For the application of all stages and quantities of biostimulant, 500 litres ha^{-1} of water were utilized. Utilising a knapsack sprayer equipped with a flat-fan nozzle, the aqueous solution of the biostimulant was applied.

2.7 Observation on crop

2.7.1 Pre harvest observations

2.7.1.1 Plant population (m^{-2})

The plant population per meter of row length was recorded at 20 DAT and harvested randomly from five randomly selected rows. Then the mean value was computed and transformed into plant population m^{-2}.

2.7.1.2 Plant height (cm)

The measurement of the plant's height was starting from its base at the surface of the ground and extending to the tip of the flag leaf stage. Furthermore, the height of the plant was recorded from the lower node of the panicle at the initial stage of the panicle. The average plant height was calculated by dividing the total plant height by the number of plants and expressing the result in centimetres.

2.7.1.3 Number of tillers hill^{-1}

The number of tillers from the five randomly selected hills plot^{-1} was recorded at 30, 60, 90 DAT and harvest. Then the average number of tillers was calculated.

2.7.1.4 Number of leaves hill^{-1}
Out of the randomly selected hills in each plot, the number of leaves was recorded at 30, 60 and 90 DAT. Then the average number of leaves hill^{-1} was calculated.

2.7.1.5 Dry matter accumulation (g hill^{-1})
Plant samples were taken at 30, 60, 90 DAT and harvest. Three samples from each plot were sun dried before being dried in an oven at 650 °C until a constant weight was obtained. Thereafter their dry weight was recorded using an electronic balance. Then mean data was determined.

2.7.1.6 Leaf area index (LAI)
Leaf area index expresses the ratio of leaf surface to the ground area occupied by the plant or crop stand worked out as per specifications of Gardner *et al*. (1985) [51]. At 30, 60 and 90 DAT, it was figured out. At 30 and 60 DAT, three leaves from five plants were randomly selected from the upper, middle and bottom portions of the plants for each treatment. These leaves were placed in polybags according to their treatment and the area of three leaves was measured using a leaf area meter. It was then multiplied by the number of leaves plant^{-1} and the mean leaf area plant^{-1} was calculated. The mean leaf area plant^{-1} at 90 DAT was calculated using a similar technique. Then calculate the leaf area index using formula proposed by Gardner *et al*. (1985) [51].

$$\text{Leaf area index} = \frac{\text{Total leaf area of the crop}}{\text{Total ground area under the crop}}$$

2.8 Post harvest observations
2.8.1 Effective tillers (hill^{-1})
Tillers with grain-bearing panicles are referred to as effective tillers. From five randomly selected hills plot^{-1}, the number of effective tillers hill^{-1} was counted.

2.8.2 Panicle length (cm)
Five panicles were taken from hills of each plot during harvest. The panicle length was calculated from the base to the tip and mean length of the panicle was then measured and expressed in centimetres (cm). The length of each panicle was measured from the bottom to the tip. The panicle's mean length was then computed and represented in centimetres (cm).

2.8.3 Grains panicle^{-1}
The total sound grains from each of the five selected panicle were removed plot^{-1} individually. After that mean number of sound grains panicle^{-1} was computed.

2.8.4 Test weight (g)
Random grain sample were drawn from each plot and 1000 gains were counted manually. These grains were weighed on electronic balance and expressed as test weight in gram (g).

2.8.5 Biological yield (kg ha^{-1})
The harvested produce from each plot was sun dried for three to four days. Thereafter dry weight was recorded in kg ha^{-1}.

2.8.6 Grain yield and Straw yield (kg ha^{-1})
Each net plot's total grain produce was cleaned, winnowed, and then weighed on a double pan balance according to the plots. By multiplying the value by the relevant factor, it was transformed to grain yield kg plot^{-1}.

Straw yield of each plot was calculated by subtracting the grain yield of a plot from the biological yield of the respective plot. The values so obtained were converted into straw yield plot^{-1} by multiplying with appropriate factor as done in case of grain yield and expressed in kg ha^{-1}.

2.8.7 Harvest index (%)
It is the ratio of economic yield to the biological yield and is expressed in percentage. It was calculated as per the formula proposed by Snyder and Carlson (1984) [45].

$$\text{Harvest index (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

2.9 Plant analysis
2.9.1 Nutrients uptake by crop
Nutrient uptake for all the major nutrients was calculated by the formula mentioned below.

$$\text{Uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient concentration (\%) x Grain/Stover yield (kg ha}^{-1}\text{)}}{100}$$

2.9.2 Nitrogen content and uptake in grain
The Kjeldahl technique of digestion and distillation, as reported by Tondon (1999) [38] and Jackson (1973) [19], was used to determine the N-content in grain or straw. The nitrogen uptake (kg ha^{-1}) was estimated through nitrogen content multiplied by grain or straw yield of crop.

2.9.3 Phosphorus content and uptake in grain
Fine crushed grain sample was digested in a diacid mixture HNO_3:$HClO_4$ in a ratio of 9:4 on volume basis. The phosphorus content in extractant of grain was determined by spectrometer using 440 nm filter following vanadomolybdate nitric acid yellow colour method (Jackson, 1973) [19]. Then phosphorus content of grain was multiplied by grain yield to get P-uptake (kg ha^{-1}) by grain. And same procedure is followed for straw uptake.

2.9.4 Potassium content and uptake in grain
Potassium content in grain and straw was calculated by flame photometer from the same extractant which is used for phosphorus as described by Jackson (1973) [19]. Thereafter, the potassium content of grain and straw was multiplied with grain and straw yield to determining K-uptake (kg ha^{-1}).

2.10 Quality Analysis
2.10.1 Protein percent (%) in grain
The protein content in grain sample was determined by using a conventional micro Kjeldahl digestion and distillation process which is given in AOAC (1984) [2]. Weighed 100 mg of the sample (containing 1 to 3 mg Nitrogen) and transferred to a 30 ml digestion flask. It is digested with 10 ml concentrated Sulphuric acid after adding catalyst mixture (3 g per sample) and digestion had done for about 3 hrs till the liquid became colourless. The digestion tube was allowed to cool and the content carefully diluted to 100 ml with distilled water. The solution was then transferred quantitatively to a distillation apparatus. 40% Sodium Hydroxide (15 ml) was added and the liberating Ammonia was collected in a flask containing 10 ml of 2% Boric acid with 2 drops of mixed indicator (Bromocresol green + Methyl red). And then

distillation process was continued for 5 minutes appearance of green colour to ensure the complete evaluation of Ammonia. After distillation solution was titrated with 0.1N H_2SO_4.

2.11 Economic analysis
2.11.1 Cost of cultivation
The cost of cultivation for each treatment is calculated on a one-hectare basis using various inputs used to grow the crop under various treatments.

2.11.2 Gross monetary returns (GMR)
The values obtained from the crop produced under each treatment were estimated as gross monetary returns (GMR) per hectare based on the recent market price of the product (both grain and straw).

Gross monetary returns = value of grain + value of straw

2.11.3 Net monetary returns (NMR)
The net monetary return (NMR) per hectare under each treatment was computed by subtracting the cost of cultivation from the gross monetary return of that same treatment.
Net monetary returns = Gross monetary returns - Cost of cultivation

2.11.4 Benefit-cost ratio (B:C)
The benefits obtained for each rupee invested under various treatments were computed as follows:

$$\text{Benefit cost ratio} = \frac{\text{Gross monetary return (Rs ha}^{-1}\text{)}}{\text{Total cost of cultivation (Rs ha}^{-1}\text{)}}$$

2.12 Statistical Analysis
The data from the numerous observations were tabulated and then statistically analysed according to analysis of variance (ANOVA) methods, with the F test used to assess the treatment. To assess the differences between treatment means, a critical difference (CD) was computed for each character at a 5% level of significance. Before carrying out analysis of variance, the data on weed population and weed dry weight were square root transformed, i.e., $\sqrt{x+0.5}$ and only transformed values were compared.

3. Results
3.1 Studies on crop growth
3.1.1 Plant population (m^{-2})
Statistical analysis of data presented in Table 2 showed that none of the treatment combination found to affect the plant population neither at 20 DAT nor at harvest of crop. However, plant population recorded at harvest was slightly reduced over initial stage.

3.1.2 Plant height (cm)
Plant height was measured at 30, 60, and 90 DAT, and harvest stages under different biostimulant treatments are shown in Table 2. Plant height is a genetically controlled characteristic, but several studies have indicated that plant height is influenced by the application of biostimulants. The results of the study indicated that application of potassium humate at 204 g ha^{-1} at the MT + PI stage was found to be effective in increasing the plant height at all the 30, 60, and 90 DAT and harvest intervals of the crop recorded at 45.5, 87.2, 105.5, and 105.3 cm, respectively. It was probably due to the enhanced availability of nitrogen with the application of potassium humate resulted in an expansion of leaf area, which in turn enhanced photoassimilation and thereby increased plant height. Similar results were reported by Prakash *et al*. (2007) [32] and Mollasadeghi *et al*. (2011) [28], who described an increase in plant height due to proper nutrient availability, which resulted in an increase in vegetative growth of the plants.

3.1.3 Number of tillers ($hill^{-1}$)
Tillers counted at 30, 60, and 90 DAT and harvest are given in Table 2. The number of tillers is the genetically controlled attribute; however, improvement in this trait is a common phenomenon, which is due to better nutrient management. The tillering of the crop initially did not change significantly due to the application of potassium humate at both stages. However, the remaining intervals showed a markable difference due to the application of 204 g ha^{-1} at MT + PI and recorded 7.0, 10.3, 12.2, and 12.0 tillers $hill^{-1}$ at 30, 60, and 90 DAT, respectively. The increase in the number of tillers might be due to the acceleration of auxin activity, which helps promote nitrogen supply and ultimately the proliferation of tillers. Similar findings were reported by Mirza and Sahu (2010) [25] and Venkateshprasath *et al*. (2017) [46], who reported that the increase in the number of tillers in rice plants is due to the balanced nutrition of plants, especially micronutrients, which activated the tillering in plants with the application of biostimulants along with RDF.

3.1.4 Dry matter accumulation (g $hill^{-1}$)
Dry matter accumulation of rice as influenced by various treatments at different time intervals and harvests is depicted in Table 2. Analysis of data pertaining to the dry weight of rice showed that at the initial level, treatment with potassium humate did not change the dry matter accumulation significantly, but with advancement in interval, it had a significant effect on dry matter accumulation. The higher value of dry matter $hill^{-1}$ was recorded at 47.0, 81.0, and 86.3 g $hill^{-1}$ under T_7 closely followed by T_5 (46.7, 80.5 g $hill^{-1}$) and T_3 (43.8, 78.6 g $hill^{-1}$) at 60 and 90 DAT, respectively.
However, the dry matter accumulation at harvest of the crop increased over previous intervals of 90 DAT, but treatment T_5 was found to be at par with T_7. These findings confirm the observations made by Dobermann and Fairhurst (2000) [11] and Hoang and Bohme (2001) [16].

3.1.5 Leaf Area Index
The leaf area index represents the photosynthetic efficiency of plants, which has a significant effect on the growth and production of photosynthates. The LAI data recorded under various biostimulant treatments at 0–30, 30–60, and 60–90 DAT are provided in Table 4.5.
At 60 and 90 DAT, it was easy to see how the biostimulant treatment changed the leaf area index. Using potassium humate @ 204 g ha^{-1} as a foliar spray at maximum tillering and panicle initiation stage (T_7) recorded the highest LAI (3.55), which is at par with potassium humate @ 170 g ha^{-1} at maximum tillering + panicle initiation stage (T_5) and significantly enhanced leaf area index at 90 DAT. The significantly lower leaf area index was found in the 100% RDF treatment (control). The increment in leaf area might be due to improved nutrient mobilisation and its partitioning in plants, thereby resulting in an increased leaf area index

(Zodape *et al*., 2009) [41], who reported that biostimulants increase biologically active cytokinin and promote cell division. Similar results were also found by Miyauchi *et al*. (2012) [27], Daur and Bakhashwa (2013) [10], Pramanik *et al*., (2014) [47], and *et al*. (2021) [48].

3.1.6 Yield attributing characters
The data on yield attributing characters as influenced by different treatments of biostimulant are shown in Table 3. Direct yield contributing traits are effective tillers hill^{-1}, panicle length, grain panicle^{-1}, and 1000 grain weight, which are important parameters that played a significant role in enhancing yield. Results of the study (Table 3) reveal that application of potassium humate along with RDF significantly increases the counts of effective tillers, panicle length, and grain panicle^{-1} over RDF alone. The higher dose of potassium humate @ 204 g ha^{-1} followed by 170 g ha^{-1} foliar spray at the MT and PI stages proved superior over the lower doses, i.e., 136 g ha^{-1} and without potassium humate, along with RDF, and recorded 10.8, 26.4 cm, and 178.6 cm, respectively.
A higher test weight of 25.5 g was recorded under 204g ha^{-1} at the MT and PI stages, while the lowest (23.7g) was recorded under RDF alone. The differences were non-significant. The increase in yield attributes due to the foliar application of potassium humate might be due to the fact that among the nutrients applied at the recommended dose, the losses of nitrogen in the presence of potassium humate are in minor quantities. Hence, the applied nitrogen is fully utilized with higher efficiency. These results are in agreement with the findings of Mishra and Srivastava (1988) [26] and Bama and Selvakumari (2005) [5], who reported that the application of potassium humate @ 20 kg ha^{-1} promoted panicle length, grains per panicle, as well as the test weight of rice.

3.2 Studies on yield parameters
3.2.1 Grain yield and straw yield (kg ha^{-1})
It is obvious from the data given in Table 3 that the yields (grain and straw) of rice improved with an increasing dose of potassium humate. Spraying potassium humate @ 204 g ha^{-1} each at the maximum tillering and panicle initiation stages resulted in significantly higher grain (5632 kg ha^{-1}) and straw (7905 kg ha^{-1}) yields, followed by @ 170 g ha^{-1} at both stages (5603 kg, 7882 ha^{-1} grain and straw yields, respectively. The grain and straw yields of rice were considerably increased by the application of biostimulants along with fertilizers. This could be attributed to the increase in effective tillers hill^{-1}, panicle length, and sound grain panicle^{-1}. The result suggested that biostimulants offered a balance of nutrition when supplemented with fertilizers, which provided the maximum yield. Similar findings were given by Osman *et al.*, 2013 [31] who reported that the increase in yield may be due to the fact that humic substances constitute a stable fraction of carbon and release of nutrients, including nitrogen, phosphorus, and sulphur, which decrease the need for inorganic fertilizer for plant growth. The results are also in agreement with the findings of Bama and Selvakumari (2005) [5], Ananthi *et al*., 2012 [49], Natarajan *et al*., 2016 [30], Kunjammal *et al*., 2016 [22].

3.2.2 Harvest index (%)
The data in relation to the harvest index (%) of rice, calculated and presented in Table 3, indicated that among treatments, foliar application of potassium humate @ 204 g ha^{-1} at the MT and PI stages registered the highest harvest index of 41.60%, whereas the lowest was 39.52% under control. It might be due to a better grain yield with a corresponding biological yield. Through the variations, there was no significant yield. The present findings are in close conformity with the findings of Swaminathan (1977) [36].

3.3 Plant analysis
3.3.1 Nitrogen uptake in grain and straw
Application of potassium humate along with RDF at maximum tillering and panicle initiation stages significantly affected nitrogen uptake by grain and straw, as shown in Table 4. The highest nitrogen uptake by grain (77.7 kg ha^{-1}) and straw (29.25 kg ha^{-1}) was recorded with the application of potassium humate @ 204 g ha^{-1} followed by @ 170 g ha^{-1} at the MT + PI stage. While the lowest nitrogen uptake in grain and straw was found in the case of the control treatment, where only RDF was given, it recorded 60.39 kg and 21.85 kg ha-^{1}, respectively. The uptake of nitrogen increases with the application of humate, which might be due to the increase in nitrogen use efficiency of the applied recommended dose of fertilizers in the presence of humic substances (Guminski, 1968) [14]. Humic substances would have sustained the flow of ammonical nitrogen for a longer period of time. Nitrogen availability was coupled with enhanced activation of roots, which led to better utilization of nitrogen by crops. The results are in agreement with the findings of Govindasamy *et al*. (1989) [13] and Nardi *et al*., (2002) [29].

3.3.2 Phosphorus uptake in grain and straw
Data related to phosphorus uptake by the grain and straw of rice has been presented in Table 4. Potassium humate application had a significant effect on P uptake by grain and straw. The highest P uptake in grain (23.70 kg ha^{-1}) and straw (10.21 kg ha^{-1}) of rice was recorded with potassium humate @ 204 g ha^{-1} applied at the MT + PI stage along with RDF. However, the lowest P uptake by grain (15.69 kg ha^{-1}) and straw (7.25 kg ha^{-1}) was recorded in the control plot, in which only 100% RDF was given. The results point out that the use of potassium humate had a beneficial effect on P uptake by grain and straw. The present findings are similar to those of Ayuso *et al*., (1996) [4], Bama *et al*., (2003) [6] and Guppy *et al*., (2005) [15], who reported that humic acid is likely to increase P availability and uptake by inhibiting calcium phosphate precipitation rates and forming phosphohumates.

3.3.3 Potassium uptake in grain and straw
Data in relation to potassium uptake by grain and straw are given in Table 4. Application of potassium humate with RDF significantly affected potassium uptake by rice grain and straw. The highest uptake of potassium was recorded in grain (16.89 kg ha^{-1}) and straw (90.88 kg ha^{-1}) under the application of 204 g ha^{-1} potassium humate at the MT + PI stage, closely followed by @ 170 g ha^{-1} at both stages. The lowest potassium uptake by grain and straw of rice was observed under treatment where only RDF was given. The higher uptake of potassium in grain and straw might be due to the fact that the grain and straw contain a higher percentage of potassium, and the production of grain and straw was higher (Tisdale *et al.*, 1977) [37]. In the present study, the application of potassium humate contributed to the increased absorption of K by crops. Similar results have also been reported by Rizk and Mashhour (2008) [50].

3.4 Quality analysis

3.4.1 Protein content in rice grain

Data related to the quality of rice with respect to protein as affected by the application of potassium humate are given in Table 3. Protein contents in grains of rice were found to increase significantly as a result of all the potassium humate treatments over control. The lowest protein content was recorded under the control plot (7.27%). Spraying of potassium humate with increasing doses and stages significantly increased protein content in grain. The higher content of protein was noted with 204 g ha^{-1} at both stages (7.65%), followed by 170 g ha^{-1} at both stages (7.60%). This might be explained in terms of the role of humic substances in increasing the concentration of messenger ribonucleic acids in plant cells. Messenger ribonucleic acids are essential for a number of biochemical processes within cells. Activation of several biochemical processes results in an increase in enzyme synthesis and an increase in protein content (Cheng *et al*., 1998) [8]. The findings are in close conformity with the findings of Jacklin *et al*., (2011) [18], who reported that the application of humic substances significantly increased crude protein in rice.

3.4.2 Economic analysis of the treatments

Data related to the economic analysis of different biostimulant treatments, *viz*., cost of cultivation, gross monetary returns, net monetary returns, and benefit-cost ratio, are presented in Table 5. The economic analysis affected by different treatments is given under different headings.

3.4.3 Cost of cultivation (Rs ha^{-1})

The data presented in Table 5 clearly shows that the minimum cost of cultivation was recorded under the control treatment, which was Rs. 41600, and increased from Rs. 42340 to Rs. 44064 with the addition of different doses of biostimulant from 136 g to 204 g at different stages of the crop as per the treatments. The higher cost of cultivation of Rs. 44064 ha^{-1} was observed under a higher dose of biostimulant, i.e., 204 g ha^{-1} at both stages. The increase in cost of cultivation is due to the fact that increasing the dose of biostimulant increases the cost of cultivation.

3.4.4 Gross monetary returns (Rs ha^{-1})

The gross monetary return refers to the total value of marketable produce that is obtained for a rice crop on one hectare of land under different treatments. The GMR increased with increasing doses of biostimulant applied at different stages. The maximum value of Rs. 128450 was recorded with the application of potassium humate @ 204 g ha^{-1} at the MT and PI stages, along with RDF, followed by 170 g ha^{-1} at the MT and PI stages (Table 5). The increase in GMR is due to an increase in grain and straw yields due to the application of biostimulants over other treatments, which resulted in a higher gross monetary return.

3.4.5 Net monetary returns (Rs ha^{-1})

The NMR of a treatment was calculated by subtracting the total cost of cultivation from its GMR. The NMR is the actual amount of money the growers made. The maximum NMR (Rs.84386) was recorded under T_7, in which potassium humate @ 204 g ha^{-1} at maximum tillering and panicle initiation stage, along with RDF, were given and proved superior over other treatments (Table 5). However, the minimum NMR was obtained under control treatment, where only 100% RDF has been given. This might be due to higher yields obtained under T_7 treatment.

3.4.6 Benefit-cost ratio

It refers to the net monetary return on investment for each rupee. The different treatments of biostimulants influenced the benefit-cost ratio. Data given in Table 5 reveal that the lowest benefit-cost ratio of 2.55 was recorded in the control plot, while it was highest in the treatment T5 application of potassium humate @ 170 g ha^{-1} and proved more remunerative as it fetched a 2.93 B:C ratio.

Table 2: Effect of bio stimulant on crop growth

	Treatments	Plant Population m^{-2}		Plant height (cm)				Number of tillers hill^{-1}				Dry matter accumulation(g hill^{-1})				Leaf Area Index		
		20 DAT	At harvest	30 DAT	60 DAT	90 DAT	At harvest	30 DAT	60 DAT	90 DAT	At harvest	30 DAT	60 DAT	90 DAT	At harvest	30 DAT	60 DAT	At harvest
T_1	Recommended dose of fertilizers only (Control)	25.0	23.5	43.3	78.0	96.9	96.7	6.2	7.9	9.0	8.8	10.2	39.5	71.4	10.2	39.5	71.4	73.8
T_2	RDF + Potassium humate @ 136 g ha^{-1} at PI stage	25.0	23.3	42.6	78.5	99.5	99.4	6.5	8.2	9.6	9.5	10.5	40.7	74.2	10.5	40.7	74.2	77.4
T_3	RDF + Potassium humate @ 136 g ha^{-1} at MT stage + PI stage	25.0	23.5	43.8	84.1	103.2	103.0	6.7	9.1	11.2	10.9	11.4	43.8	78.6	11.4	43.8	78.6	82.5
T_4	RDF + Potassium humate @ 170 g ha^{-1} at PI stage	25.0	23.8	44.2	77.4	101.3	101.1	6.0	8.3	10.0	9.8	11.3	39.9	76.7	11.3	39.9	76.7	80.1
T_5	RDF + Potassium humate @ 170 g ha^{-1} at MT stage + PI stage	25.0	24.3	45.3	86.6	104.9	104.8	6.9	9.8	11.8	11.7	11.6	46.7	80.5	11.6	46.7	80.5	85.6
T_6	RDF + Potassium humate @ 204 g ha^{-1} at PI stage	25.0	24.0	44.7	78.7	102.6	102.5	6.3	8.6	10.6	10.4	10.9	40.3	77.6	10.9	40.3	77.6	81.2
T_7	RDF + Potassium humate @ 204 g ha^{-1} at MT stage + PI stage	25.0	24.3	45.5	87.2	105.5	105.3	7.0	10.3	12.2	12.0	11.8	47.0	81.0	11.8	47.0	81.0	86.3
	SEm±	0.00	0.47	1.04	2.41	0.87	0.66	0.43	0.47	0.52	0.40	0.60	1.81	0.84	0.60	1.81	0.84	0.94
	CD(P=0.05)	NS	NS	NS	7.16	2.59	1.97	NS	1.39	1.55	1.19	NS	5.37	2.49	NS	5.37	2.49	2.80

Table 3: Effect of bio stimulant on Yield attributing characters, Yield parameters and Protein content (%)

	Treatments	Yield attributing characters				Yield parameters			Protein content (%)
		Effective tillers hill^{-1}	Panicle length (cm)	Sound grains panicle^{-1}	Test weight (g)	Grain yield (Kg ha^{-1})	Straw yield (Kg ha^{-1})	Harvest index (%)	
T_1	Recommended dose of fertilizers only (Control)	7.6	21.3	128.6	23.7	4610	7054	39.52	7.27
T_2	RDF + Potassium humate @ 136 g ha^{-1} at PI stage	8.1	22.5	142.8	24.1	5020	7268	40.85	7.32
T_3	RDF + Potassium humate @ 136 g ha^{-1} at MT stage + PI stage	9.6	24.6	160.3	24.8	5437	7720	41.32	7.54
T_4	RDF + Potassium humate @ 170 g ha^{-1} at PI stage	8.8	23.2	151.8	24.6	5230	7490	40.11	7.38
T_5	RDF + Potassium humate @ 170 g ha^{-1} at MT stage + PI stage	10.4	25.7	172.9	25.3	5603	7882	41.55	7.60
T_6	RDF + Potassium humate @ 204 g ha^{-1} at PI stage	9.2	24.0	159.7	25.2	5338	7622	41.19	7.49
T_7	RDF + Potassium humate @ 204 g ha^{-1} at MT stage + PI stage	10.8	26.4	178.6	25.5	5632	7905	41.60	7.65
	SEm±	0.34	0.54	5.48	0.65	46.85	60.57	-	0.08
	CD(P=0.05)	1.01	1.61	16.27	NS	139.21	179.98	-	0.25

Table 4: Effect of biostimulant on nutrient uptake (N, P, K) in grain and straw

	Treatments	Nitrogen uptake (Kg ha^{-1})		Phosphorus uptake (Kg ha^{-1})		Potassium uptake (kg ha^{-1})	
		Grain	Straw	Grain	Straw	Grain	Straw
T_1	Recommended dose of fertilizers only (Control)	60.39	21.85	15.69	7.25	11.98	76.18
T_2	RDF + Potassium humate @ 136 g ha^{-1} at PI stage	66.27	23.90	17.04	8.96	13.55	81.43
T_3	RDF + Potassium humate @ 136 g ha^{-1} at MT stage + PI stage	73.98	27.28	21.40	9.79	15.65	87.35
T_4	RDF + Potassium humate @ 170 g ha^{-1} at PI stage	69.56	25.20	20.30	9.46	14.95	84.75
T_5	RDF + Potassium humate @ 170 g ha^{-1} at MT stage + PI stage	76.58	28.30	22.75	10.05	16.77	89.60
T_6	RDF + Potassium humate @ 204 g ha^{-1} at PI stage	72.09	26.60	20.85	9.73	15.16	86.40
T_7	RDF + Potassium humate @ 204 g ha^{-1} at MT stage + PI stage	77.70	29.25	23.70	10.21	16.89	90.88
	SEm±	0.73	0.40	0.28	0.29	0.39	0.47
	CD(P=0.05)	2.17	1.20	0.84	0.87	1.17	1.40

Table 5: Effect of biostimulant on economical yield

	Treatments	Cost of cultivation (Rs. ha^{-1})	GMR (Rs. ha^{-1})	NMR (Rs. ha^{-1})	B:C Ratio
T_1	Recommended dose of fertilizers only (Control)	41600	106308	64708	2.55
T_2	RDF + Potassium humate @ 136 g ha^{-1} at PI stage	42340	114936	72596	2.71
T_3	RDF + Potassium humate @ 136 g ha^{-1} at MT stage + PI stage	43080	124180	81100	2.88
T_4	RDF + Potassium humate @ 170 g ha^{-1} at PI stage	42600	119580	76980	2.81
T_5	RDF + Potassium humate @ 170 g ha^{-1} at MT stage + PI stage	43600	127824	84224	2.93
T_6	RDF + Potassium humate @ 204 g ha^{-1} at PI stage	42832	122004	79172	2.85
T_7	RDF + Potassium humate @ 204 g ha^{-1} at MT stage + PI stage	44064	128450	84386	2.91

Conclusion

The crop of rice (cv. Kranti) was thriving substantial growth with the treatment T_7 through foliar application of potassium humate @ 204 g ha^{-1} twice during maximum tillering as well as panicle initiation stage, which was found suitable for getting a higher yield (5632 kg ha^{-1}), followed by 170 g ha^{-1} at the same stages (5603 kg ha^{-1}). The dual application of Potassium humate @ 204 g ha^{-1} at maximum tillering and panicle initiation stage proved superior with respect to growth and yield attributing traits. Foliar spray of Potassium humate @ 170 g ha^{-1} at maximum tillering and panicle initiation stage gave high remunerative NMR (Rs. 84224 ha^{-1}) and fetched Rs. 2.93 per rupee investment. The findings presented in this study showed that the combination of potassium humate and chemical fertilizer can be effective in enhancing crop yields while maintaining sustainable agricultural practices.

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