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Effect of Integrated Nutrient Management on Growth and Productivity of Wheat (*Triticum aestivum* L.) in Typic Ustochrepts Soils of Western U. P., India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted during *Rabi* seasons to determine the effect of different sources of nutrient on growth, yield and yield of wheat for improving crop productivity in western U.P. The experiment was laid out in Randomized Block Design (RBD) with three replications and the treatments assigned in this study are fourteen *viz.,* Control T_1, 100% Recommended NPK (150: 75: 60 kg ha^{-1}) $T_{2,}$ 50% Recommended N + FYM @10t/ha $T_{3,}$ 50% Recommended N + 50% N through Vermicompost + Bio-stimulant-G@ 20kg/ha $T_{4,}$ 50% Recommended N + Bio-stimulant-G@ 20kg/ha $T_{5,}$ 75% Recommended N + 50% N through Vermicompost $T_{6,}$ 75% Recommended N + FYM @10t/ha + Bio-stimulant-G 20kg/ha $T_{7,}$ FYM @10t/ha + Bio-stimulants Toggle (Containing marine extracts) @ 2.9 l/ha $T_{8,}$ FYM @10t/ha + Bio-stimulant Voyagro (containing proline, glycine betaine and glutamic acid) @ 585 ml/ha $T_{9,}$ 100% Recommended N + FYM @10t/ha $T_{10,}$ FYM @10t/ha + NPK-bio-fertilizer + Urea @20 kg/ha $T_{11,}$ FYM @10t/ha + Bio-fertilizer mixture (*A.chrococcum* + AMF + *B.circulans*) + Bio-stimulant-L @ 625 ml/ha foliar spray each at 45 & 60 DAS $T_{12,}$ 100% Recommended N + FYM @10t/ha + Azatobacter $T_{13,}$ 50% Recommended N + FYM @10t/ha + 25% N through Vermicompost T_{14}. Among the different treatments, the treatment T_{13} was observed significantly higher in growth characters, physiological parameters and yield parameters of the year compared to other treatments. T_{13} recorded 113.7, 93.6 and 151.5 plant height, number of tillers m^{-1}row length and dry matter accumulation (g/m^1) than T_1 control with no nutrient application respectively. Crop fed with treatment T_{13} registered highest CGR 90 days till harvest (3.27 g m^{-2} area d^{-1}) and RGR 90 days till harvest (0.0002 g $g^{-1}d^{-1}$). Treatment T_7 recorded maximum NAR at 90DAS-at harvest stage (0.86 g m^{-2} leaf area day^{-1})), which was at par with treatment T_9. Treatment T_{13} recorded significantly highest grain yield (47.5 Kg ha-1), straw yield (64.0 kg ha-1), biological yield (111.5 kg ha-1) and harvest index (42.6 %) while the lowest was recorded under control T_1.

Keywords: Bio-stimulants; vermicompost; FYM; biofertilizer; azatobacter.

1. INTRODUCTION

Wheat (*Triticum aestivum* L*.)* is the staple food of 40 percent human population across the globe and second most important cereal after rice. Wheat provides 21% of the food calories and 20% of the protein for more than 4.5 billion people in 94 countries. The world acreage under wheat crop accounts 215.48 million ha with production of 731.4 million metric tonnes with an average productivity of 3390 kg/ha [1]. In India also wheat plays a key role in food and nutritional security with an area 29.65 million ha and production of 99.9 million metric tonnes with an average productivity of 3371 kg/ha [1] and contributes nearly one third of the total food grain production [2]. The current world population of 7.7 billion is expected to reach 9.7 billion in 2050. Recently, India is the second most populous country (1.3 billion) after China (1.41 billion) and expected to surpass that of China in roughly seven years and touching a peak 1.7 billion by 2050 (The UN World Population Prospects: The 2019 Revision). Accordingly, wheat is likely to continue to be vital in ensuring food security across the globe.

In India, Uttar Pradesh is leading wheat growing state with an area of 9.75 million ha, production of 32.59 million tonnes and productivity of 3100 kg/ha (Anonymous, 2021). Wheat productivity in the state is however far lower than that in Punjab (4.3 tonnes/ha) and Haryana (4 tonnes /ha) accounted to late sowing after long duration rice varieties and harvest of sugarcane, poor seed replacement rate, lack of quality seed, imbalanced fertilization, unscientific water management and poor mechanization etc. In western Uttar Pradesh wheat sowing is delayed up to end of December and sometimes even to 1st week of January leading to severe yield reduction. Delayed sowing install maturity under the influence of high temperature and by and large, farmers attempt to make amend it by excessive application of nutrients particularly nitrogen ignoring yield physiology in constrained environments. In the backdrop of escalating fertilizer prices and environmental implications of imbalanced fertilizer use, fertilizer recommendations based on soil test values, residual effect and yield targets have become highly important and imminent [3]. Low nutrient use efficiency (NUE) is a key concern while designing and evaluating various crop production systems. It can be greatly impacted by fertilizer, soil and water management to provide economically optimum nourishment to the crop for maximizing production and minimizing nutrient losses from the field [4]. The indiscriminate use of inorganic fertilizer for the past 50 years without any addition of organic manures resulted in the large-scale deficiency of micro-nutrients which play an important role in enhancing the quality and quantity of the agriculture produce through their increment in enzyme system and photosynthesis.

On account of continuing world energy crisis and spiraling price of chemical fertilizer, the use of organic manure as a renewable source of plant nutrient is assuming importance. In this endeavor proper blend of organic and inorganic fertilizer is important not only for increasing yield but also for sustaining soil health [5,6]. Wheat is an important cereal crop and requires a good supply of nutrients especially nitrogen for its growth [7] and yield. Application of farm manure ameliorates the soil permeability [8] and improve soil fertility. Application of organic materials alone or in combination with inorganic fertilizers helped in the proper nutrition and maintenance of soil fertility [9]. Hussain et al. [10] reported that the efficiency of chemical fertilizers increased with the use of organic manures.

Continuous use of chemical fertilizer is assumed to be a major cause of deterioration of soil health and water pollution. To maintain high productivity and sustainability of soil and crop, balanced use of both mineral fertilizer and organic manures is indispensable. Under such a condition, there is a great urgency to explore an alternate source, which can supplement partially or wholly the use of costly input *i.e.,* chemical fertilizer and also to protect the fragile ecosystem. Farmyard manures is a valuable amendment and may replace the chemical fertilizers. It stimulates plant growth and may help to prevent plant disease, besides increasing the quality of the produce.

Farmyard manure improves the physical condition of soil and increases water holding capacity for maximum utilization of water. It also improves the chemical and biological condition of soil by increasing cation exchange capacity and providing various hormones and organic acids which are very important for soil aggregation and for beneficial soil micro-organism which are involved in various biochemical processes and release of nutrients. Integration of FYM with inorganic N sources increases productivity and monetary returns of wheat and improves soil fertility [11].

Over the years, India has been able to increase food grain production by five times at the cost of remarkable 322 times increase in fertilizer consumption and staggering 'net negative nutrient balance' of 10 million tonnes which is anticipated to reach 15 million tonnes by 2025. Biofertilizers are low cost, environment-friendly, an essential and renewable sources of plant nutrients. These are selected strains of beneficial soil microorganisms cultured in the laboratory and packed in suitable carrier. Biofertilizers are gaining momentum recently due to the increasing emphasis on maintenance of soil health, minimum environmental pollution and cut down on the use of the chemicals in agriculture. Organic manures and bio-fertilizer can go a long way in augmenting nutritional needs of the crops for better yield and better soil health. Bio-fertilizers like *Azotobacter* and *Azospirillum* alone or in combination have great prospect for increasing productivity of wheat [12]. This calls for conjunctive use of all possible sources of nutrients including inorganic fertilizers, organic manures, crop residues, bio-fertilizers etc. for sustainable agriculture. Timely application of fertilizers using appropriate methods and developing and practicing integrated plant nutrient supply system using chemical fertilizers, organic manures, crop residues and bio fertilizers are equally important. Vermiculture is the culture of earthworms or sericulture means the production of earths used for a basement of organic material in to rich soil amendment known as Vermicompost. The goal is to continually increase the number of worms in order to obtain a sustainable harvest. Application of vermicompost helps to increase the dry matter production, leaf area, yield and nutrient uptake by wheat [13].

The use of bio effectors, formally known as bio stimulants is loosely defined as an organic material and microorganism that is applied to enhance plant resilience, and also to improve nutrient uptake, stimulate growth and increase stress tolerance or crop quality. It is applied to plants with the aim to enhance nutrients efficiency, abiotic stress tolerance and crop quality traits, regardless of its nutrients content. Bio stimulant Toggle is super value concentrated liquid bio stimulant specifically developed for Broadfield crops containing marine extracts that can trigger reactions in a plant ranging from stress alleviation to yield enhancement. Bio stimulant Voyagro containing proline, glycine betaine and glutamic acid. It's derived from seaweed and enhances root growth, promotes synthesis of antioxidants and improves photosynthesis by increasing chlorophyll.

Voyagro bio stimulant fertilizer links potassium with amino acids and peptides to aid in the movement of product within the plant. Bio-stimulant Z^{++} is a Seaweed Granules, fortified by seaweed extract (Red & Brown Algae) containing proteins, carbohydrates, inorganic salts & other inherent nutrients. The seaweed is mixed with a carrier used to formulate a product rich in Sulphur, Calcium, Zinc and Boron. The seaweeds are cultivated and naturally harvested from warm, tropical regions (Indian Ocean) and therefore is endowed with more bio-stimulant substances. It is an organic product and works as a soil conditioner. Suitable for all field crops, pulses, oilseed, horticulture & vegetable crops, sugar & fiber crops, plantation crops, medicinal and aromatic crops. It increases yield and quality of produce by increasing the metabolic function of plant. It activates the soil bacteria, especially rhizosphere bacteria that are responsible for better growth of root-system and nutrient movement. It helps plant in cell division, internodes elongation and seed development. It promotes better tillering, root growth and nutrient uptake. It also provides resistance to plants against drought conditions and extreme temperature. Seaweed has been found effective for enhancing yield, pest and frost resistance in vegetable, fruits, flowers, cereals and pulses. Seaweed extracts had beneficial effect on seed germination and plant growth [14]. To overcome the problem of nutrient deficiency and to increase wheat yield, the farmers are applying chemical fertilizer. However, the chemical fertilizers are expensive and the small farmers cannot afford to use these fertilizers in suitable amount and balanced proportion. Under such condition integrated use of chemical and organic fertilizer/manures can play an important role to sustain soil fertility and crop productivity. Therefore, the study was designed to analyses the growth, yield, yield attributes, nutrient uptake, soil health and profitability of wheat. The objectives of the study were (i) To study the impact of different nutrients management approaches on growth, yield and yield attributes of wheat. (ii) To find out the different nutrients management approaches on nutrient uptake and soil health by wheat. (iii) To assess economic feasibility of different nutrients management strategies on wheat crop.

2. MATERIALS AND METHODS

2.1 Investigation Site Characteristics

The experiment was carried out for couple of consecutive growing during *rabi* seasons from November to April at Crop Research Centre of the Sardar Vallabhbhai Patel University of Agriculture & Technology in Meerut, which is situated on NH-58, Delhi to Mana, about 65 km from Delhi in Indo-Gangetic plains of Western Uttar Pradesh. The Crop Research Centre is about 2 km in the west of the highway and connected by pucca link road. The experimental field was situated at latitude of 29^0 40′ N and longitude of $77^0$42′ E at an altitude of 230 meters above the mean sea level. The climate in the area is subtropical and semiarid. The study's title is "Efficient Integrated Nutrient Management in Wheat (*Triticum aestivum* L.) for Improving Fertilizer Use Efficiency, Crop Productivity and Sustaining Soil Health in Western U.P."

2.2 Soil Properties

The soil at the experimental site had a sandy loam texture, was low in organic carbon and available nitrogen, medium in available phosphorus and available potassium and was alkaline in reaction.

2.3 Fertilizer Application

Farm yard manure was applied according to the treatments. NPK- Biofertilizer were applied through seed inoculation. 150:75:60 (kg ha^{-1}) of nitrogen, phosphorus and potassium, respectively was applied under recommended NPK. The fertilizer sources used for nitrogen, phosphorus and potassium were Urea (46% N), DAP (18% N & 46% P_2O_5), MOP (60% P_2O_5), NPK (12:32:16), and Bio-stimulants respectively. Full doses of Bio-stimulants-G @20 kg ha^{-1} were applied as basal while spray of Bio-stimulants-L were administered at 45 and 60 days after sowing according to treatments.

2.4 Irrigation

The irrigations were applied as per the requirement of the wheat and the prevailing weather conditions. A total of four or five irrigations were applied.

2.5 Treatments and Experimental Design

Field experiment consist fourteen treatments, which includes control viz. Control T_1, 100 % Recommended NPK (150: 75: 60 kg ha^{-1}) T_2, 50 % Recommended N + FYM @10t/ha T_3, 50 % Recommended N + 50 % N through Vermicompost + Bio-stimulant-G@ 20kg/ha T_4, 50 % Recommended N + Bio-stimulant-G@

20kg/ha $T_{5,}$ 75 % Recommended N + 50 % N through Vermicompost $T_{6,}$ 75 % Recommended N + FYM @10t/ha + Bio-stimulant-G 20kg/ha $T_{7,}$ FYM @10t/ha + Bio-stimulants Toggle (Containing marine extracts) @ 2.9 l/ha $T_{8,}$ FYM @10t/ha + Bio-stimulant Voyagro (containing proline, glycine betaine and glutamic acid) @ 585 ml/ha $T_{9,}$ 100% Recommended N + FYM @10t/ha $T_{10,}$ FYM @10t/ha + NPK-bio-fertilizer + Urea @20 kg/ha $T_{11,}$ FYM @10t/ha + Bio-fertilizer mixture (*A.chrococcum* + AMF + *B.circulans*) + Bio-stimulant-L @ 625 ml/ha foliar spray each at 45 &60 DAS $T_{12,}$ 100% Recommended N + FYM @10t/ha + Azatobacter $T_{13,}$ 50% Recommended N + FYM @10t/ha + 25 % N through Vermicompost $T_{14.}$ Treatments were arranged in a randomized block design with three replications. The gross plot size for the command is 36.0 m^2 (8.0 m X 4.5 m). The wheat was sown with the spacing of 22.5 cm between rows. For data collection and measurement, twenty central rows with a net plot size 21.6 m^2 (6.0 m X 3.6 m) were used

2.6 Weed Management

Under irrigated conditions, weeds pose a major threat to crops because they compete with them for resources like sunlight, nutrients, water, and space. For the rest of the growing season, the plots remained weed-free. For the manual removal of weeds with the help of *Khurpi*, two intercultural operations - one at the 30-day stage and the other at the 45-day stage were carried out.

2.7 Variety Description

The Wheat Variety 'HD 3226' is released for commercial cultivation in North Western Plain Zone comprising of Punjab, Haryana, Delhi, Western Uttar Pradesh under irrigated, timely sown condition developed by ICAR-IARI New Delhi with an average plant height of 101-110 cm with distinguishing morphological characters *i.e.,* semi-spreading growth habit, dark green erect foliage with long leaves, tapering and medium lax ear head. Ears are tapering, waxy and oblong in shape. Its grain width and grain crease are medium. It is a medium late variety as it takes about 97 days (seeding to flowering) and 142 days (seeding to seed). It is highly resistant to yellow, brown and black rust, karnal bunt, powdery mildew, loose smut and foot rot diseases. HD-3226 has perfect Glu-1 score (10) with highest bread quality score (6.7) and bread leaf volume indicating its suitability for various end use products. HD-3226 has highest protein content 12.8% average, high dry and wet gluten, average zinc content- 36.8 ppm, good grains appearance, high sedimentation value, high extraction rate where average yield of 57.5 q/ha and genetic yield of 79.60 q/ha under normal conditions.

2.8 Statistical Analysis

The experimental data collected from different treatments with three replications were subjected to the analysis of variance (ANOVA) in a randomized block design as prescribed by Gomez & Gomez, [15]. Window-based SPSS (Statistical Product and Service Solutions) Version 10.0, SPSS, Chicago, IL. The SPSS technique was used for the analysis of variance to define the statistical least significant difference at the 5 % probability level. Furthermore, crucial difference (CD), as described by Gomez & Gomez, [15], was used to analyze the F-test and the significance of the difference between treatments.

2.9 Methods of Measuring

2.9.1 Growth studies

Morphological characteristics: The effect of treatments on crop growth, observations on plant height, number of tillers and dry matter accumulation were recorded at harvest as under:

1. Plant height

Five plants were tagged randomly in each net plot and their individual height was measured in centimeters using a meter scale from the ground surface to the tips of fully expanded leaves. In order to indicate plant height in centimeters, the heights of all five plants were added summed and averaged.

2. Number of tillers m^{-1}row length

In each plot, number of tillers were counted using 0.25 m^{-1} row length from three places and average of three places was used for analysis.

3. Dry matter accumulation (g/m^1)

Three plants from the randomly selected places in each plot were cut close to the ground from the 50 cm row length from each plot from sampling area and dried in oven for 5-6 days. Samples were first dried in the sun and then oven dried at 70^0 C till to attained constant weight. After drying, the samples were weighed to record their dry weight.

Physiological studies: Physiological parameters were computed from the data obtained on dry weight of different plant parts recorded at harvest of wheat crop. Several physiological parameters were calculated using the information on dry weight of different plant parts and the following CGR, NAR, and RGR values were estimated at 90 DAS-at harvest:

1. Crop Growth Rate (CGR)

The increase in dry weight of plant material from a unit area per unit of time is referred to as the mean crop growth rate of a plant during a time "t". From periodic dry matter observed at various stages, it was computed using the method shown below [16]:

$$CGR\ (g\ m^{-2} day^{-1}) = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{A}$$

Where,

W_1 = Total dry weight of plant at time t_1
W_2= Total dry weight of plant at time t_2
t_1 = Time at first observation, and
t_2 = Time at second observation
A = represents the ground area (m^2)

2. Relative Growth Rate (RGR)

The increase in dry weight of plant material per unit of material present per unit of time is referred to as the relative growth rate of a plant at an instant for a time interval "t". The following formula was used to calculated the crop mean relative growth rate (RGR) [16].

$$RGR\ (g\ g^{-1} day^{-1}) = \frac{\text{Loge}\ W_2 - \text{Loge}\ W_1}{t_2 - t_1}$$

Where,

W_1 = Total dry weight of plant at time t_1
W_2 = Total dry weight of plant at time t_2
t_1 = Time at first observation
t_2 = Time at second observation

3. Net assimilation rate (NAR)

It is an increase in plant material per unit leaf area per unit time. The following equation was used to calculated NAR [16].

$$NAR\ (g\ m^{-2}\ \text{leaf area}\ day^{-1}) = (\log_e L_2 - \log_e L_1)\ (W_2 - W_1) / (L_2 - L_1)\ (t_2 - t_1)$$

Where,

L_1 = Total leaf area at time t_1
L_2 = Total leaf area at time t_2
W_1 = Total dry matter of plant at time t_1
W_2 = Total dry matter of plant at time t_2
t_1 = Time of first observation
t_2 = Time of second observation

Harvesting: At maturity, wheat crop was harvested and the grain and straw yield were calculated from the 5.4 m^2 net area sown in the centre of each plot out of the 12 m^2 gross plot area. The grains were threshed using a plot thresher, dried in a batch grain dryer, and weighed. The weight of the straw was measured after sun drying.

1. Grain yield (kg/ha)

Produce of net plot was threshed and grains thus obtained were winnowed, cleaned and weighed. The yield recorded in kg/plot.

2. Straw yield (kg/ha)

The wheat plant from the net plot was removed just near to the ground with the help of sickle and weight of straw obtained from the net plot area was recorded. Finally, the straw yield was computed on hectare basis using the dry matter content on oven dry weight basis, which was then expressed in kg/ha.

3. Biological yield (kg/ha)

After harvest, the produce excluding root mass of each net plot was allowed to sun dry and weighed to record the biological yield (grains + straw) for each plot.

4. Harvest Index

The ratio of economic yield (grain yield) to biological yield was worked out to estimate harvest index [17].

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

3. RESULTS AND DISCUSSION

3.1 Growth Parameters

FYM enhances plant growth directly or indirectly as the addition of large amount of macro and micro nutrients, organic matter and humic substances all of which are produced in the soil by the decomposition of organic material and this material is very useful for the growth of the plant [18]. Plant height is an important parameter which can be used to study the effect of different treatments on crop growth. Data on plant height was recorded at harvest as influenced by different treatment are presented in Table 1 and depicted in Fig. 1. At harvest stage, maximum height (113.7 cm) of plants was obtained under T_{13} 100% Recommended N + FYM @ 10 t ha^{-1}+ Azatobacter treatment, being significantly taller than those for the rest of the different nutrient management treatments and least (88.8 cm) under T1 “Control”. Treatments T_7 “75% Recommended N + FYM @ 10 t ha^{-1} + Bio-stimulant- G 20 kg ha^{-1}”, T_{10} “100% Recommended N + FYM @ 10 t ha^{-1}”, T_2 “100% Recommended NPK (150: 75: 60 kg ha^{-1})” and T_6 “75% Recommended N + 50% N through Vermicompost” were at par. Enhanced fertilizer doses coupled with greater concentration of bio-stimulant improved the nutrient supplying capacity to the wheat plants, which in turn resulted in higher growth rates. Similar findings were reported by Kavitha et al. [19] and Khan et al. [20]. The results of present investigation are in close conformity with findings of several researchers, including [21] and [22]. Tillers count per unit area is an important parameter for determining the effect of any treatment on growth and yield of a crop like wheat. Effective tillers are the major source influencing the yield of the crop. The number of effective tillers m^{-1} row length *i.e.,* tillers with fertile spike is an important yield attribute which accounts for major variation in grain yield of the cereal crop like wheat. Different nutrient management practices had significantly influenced number of effective tillers (m^{-1}) row length at harvest. The data on effective tillers m^{-1} were derived and presented in Table 1 and Fig. 1 as significantly higher effective tillers m^{-1} were recorded of experimentation with 100% Recommended N + FYM @ 10 t ha^{-1}+ Azatobacter (T13) treatment followed by 75% Recommended N + FYM @ 10 t ha^{-1} + Bio-stimulant- G 20 kg ha^{-1} (T7) treatment and 100% Recommended N + FYM @ 10 t ha^{-1} (T10) treatment. The findings of Katyal et al. [23] and Kumar et al. [24] are closely congruent with these findings. The higher accumulation of dry matter was observed with the incorporation of FYM which could be possibly due to the rapid mineralization of FYM that supply large portion of N, P and K [25]. Dry matter accumulation indicates towards the photosynthates left behind after respiration. So, it is the best indicator of growth of a crop. Data on dry mater *g/m^1* is presented in Table 1 and Fig 1. Among different nutrient management practices 100% Recommended N + FYM @ 10 t ha^{-1}+ Azatobacter (T_{13}) accumulated significantly more dry matter *g/m^1* as compared to all other treatments. However, (T_1) control recorded lowest dry matter accumulation during experimentation.

3.2 Physiological Parameters

Physiological parameters were computed from the data obtained on dry weight of different plant parts recorded at 90-DAS- at harvest of wheat crop. Several physiological parameters were be computed from the data obtained on dry weight of different plant parts and CGR, NAR and RGR were be estimated at 90 DAS-at harvest. The application of inorganic fertilizers might have supplied adequate amount of nutrients that helped in the expansion of leaf area which might have accelerated the photosynthesis rate and resulted in increased supply of carbohydrates available to the plants. Crop growth rate (CGR) was significantly influenced by different nutrient management practices at all the crucial stages during the years. Wheat plants grown under nutrient management practices significantly recorded higher CGR over control at all stages during the years of trial. Crop fed with 100% Recommended N + FYM @ 10 t ha^{-1}+ Azatobacter (T_{13}) registered highest 90 days till harvest (3.27 g m^{-2} area d^{-1}) and was at par with treatment involving application of 75% Recommended N + FYM @ 10 t ha^{-1} + Bio-stimulant- G 20 kg ha^{-1} (T_7) and 100% Recommended NPK (150: 75: 60 kg ha^{-1}) (T_2) and superior over rest of the treatments during the year. The least value of CGR was recorded in control plot during the year. Similar results were also observed by Jat et al. [26] and [27]. Relative growth rate (RGR) was significantly influenced among different nutrient management practices at 90DAS-at harvest of growth during year. Perusal of data in Table 2 revealed that RGR declined consistently till the crop maturity during the course of study. Observations indicated that the wheat crop fertilized with 100% Recommended N + FYM @ 10 t ha^{-1}+ Azatobacter (T_{13}), 50% Recommended N + FYM @ 10 t ha^{-1} + 25% N through Vermicompost (T_{14}), 100% Recommended N + FYM @ 10 t ha^{-1} (T_{10}), FYM @ 10 t ha^{-1} + Bio- stimulant Toggle (Containing marine extracts) @ 2.9 l ha^{-1} (T_8), (T_7), (T_6), (T_5), (T_4) and (T_2) at 90 DAS till harvest, highest RGR 0.0002 g g^{-1}d^{-1} was recorded during year of investigation. Lowest value of RGR was recorded in control over rest of the treatments during the year. Net assimilation rate (NAR) in wheat was significantly affected among different nutrient management practices at 90DAS-at harvest of wheat in year. Nutrient management practice involving the application of 75% Recommended N + FYM @ 10 t ha^{-1} + Bio- stimulant- G 20 kg ha^{-1} (T_7) recorded maximum NAR at 90DAS-at harvest stage (0.86 g m^{-2} leaf area day^{-1})), which was at par with treatment FYM @ 10 t ha^{-1} + Bio-stimulant Voyagro (Containing proline, glycine betaine and glutamic acid) @ 585 ml ha^{-1} (T_9). Wheat grown in control plots recorded least NAR over rest of the treatments at 90DAS-at harvest during the year of trial.

Further, application of bio-stimulant resulted in increased value of crop growth rate (CGR) while relative growth rate (RGR) and net assimilation rate (NAR) showed a declining trend from initial phase till the maturity of crop. This might be the result of the application of bio-stimulant which favored vegetative growth, resulting in a higher leaf area then the lower leaves of plant which were unable to photosynthesize and began to grow below the compensation point (when rate of respiration is higher than rate of photosynthesis) and the photosynthates synthesized by the upper leaves were utilized by themselves, thus lowering down the RGR and NAR.

3.3 Yield

Grain yield, straw yield, biological yield and harvest index of wheat were significantly influenced by different nutrient management practices (Table 3 and Fig. 3.) Greater wheat yield was obtained by applying inorganic fertilizers and organic nutrient sources together. The grain yield of wheat was significantly influenced by different nutrient management practices (Fig. 3). Among the different treatments, 100% Recommended N + FYM @ 10 t ha^{-1}+ Azatobacter (T_{13}) was recorded with highest yield followed by 75% Recommended N + FYM @ 10 t ha^{-1} + Bio- stimulant- G 20 kg ha-1 (T_7) and 100% Recommended N + FYM @ 10 t ha^{-1} (T_{10}), while lowest was under control (T_1). This clearly evident that using of organic manures in addition to chemical fertilizers significantly increases crop yields. These results are in close conformity with findings of Jaga and Upadhyay, [28]. Sharma et al. [29] claims that if FYM was added along with chemical fertilizer, it supplemented all crop nutrients and boost the agricultural productivity. Similar findings were also given by Meena et al. [30]. Application of fertilizers registered significantly higher straw yield over control during the years of experimentation. The highest straw yield was observed with the application of 100% Recommended N + FYM @ 10 t ha^{-1}+ Azatobacter (T_{13}) which were recorded as superior treatments to the rest of the treatments, while the lowest was recorded under control (T_1). Similar findings by Mishra et al. [31], they found that the beneficial effect of combined use of organic and inorganic nutrients resulted in increasing crop yields while also enhancing soil health. The biological yield (sum of grain and straw yield) of wheat is an important index indicating the photosynthetic efficiency of crop and photosynthetic left behind after respiration which ultimately influenced the crop yield. The data depicted in Fig. 3 indicated that significant increase in biological yield of wheat with application of nutrients. Among the different treatments, 100% Recommended N + FYM @ 10 t ha^{-1}+ Azatobacter (T_{13}) recorded significantly highest biological yield which were statistically superior to the rest of the other nutrient management treatments, while the lowest was recorded under control (T1). There exists a positive interaction between the combination of organic manures and NPK, according to a study by Pong and Letey, [32]. In order to boost up crop production per unit area, the application of inorganic fertilizers is applied with organic fertilizers to maintain the soil fertility and balance the supply of nutrients [33,34]. The harvest index of wheat ranged from 38.20 to 42.60 percent among different nutrient management practices. Among the different treatments, 100% Recommended N + FYM @ 10 t ha^{-1}+ Azatobacter (T_{13}) recorded significantly highest harvest index while the lowest was recorded under control (T1) as indicated in Fig. 3. However, 100% Recommended N + FYM @ 10 t ha^{-1}+ Azatobacter (T13) was reported as superior treatment which was statistically at par with 75% Recommended N + FYM @ 10 t ha^{-1} + Bio-stimulant- G 20 kg ha^{-1} (T7), 100% Recommended N + FYM @ 10 t ha^{-1}(T10), 75% Recommended N + 50% N through Vermicompost (T6) and 100% Recommended NPK (150: 75: 60 kg ha^{-1}) (T2) and which were statistically superior to the rest of the other nutrient management treatments during the years of study. (T13) was recorded 9.52% higher harvest index over control (T1).

Table 1. Effect of integrated nutrient management on plant height (cm), number of tillers m^{-1}row length and dry matter accumulation (g/m^1) at harvest of wheat crop

Symbol	Treatments	Plant Height (cm)	Number of tillers m^{-1}row length	Dry matter accumulation (g/m^1)
T_1	Control	88.8	58.85	95
T_2	100% Recommended NPK (150: 75: 60 kg ha^{-1})	111.1	90.25	131.15
T_3	50% Recommended N + FYM @ 10 t ha^{-1}	105.6	78.45	117.15
T_4	50% Recommended N + 50% N through Vermicompost + Bio-stimulant- G @ 20 kg ha^{-1}	107.4	81.1	120.5
T_5	50% Recommended N + Bio- stimulant+ G @ 20 kg ha^{-1}	98.9	67.4	107.25
T_6	75% Recommended N + 50% N through Vermicompost	109.9	88.45	137.9
T_7	75% Recommended N + FYM @ 10 t ha^{-1} + Bio- stimulant- G 20 kg ha^{-1}	112.4	92.1	146.2
T_8	FYM @ 10 t ha^{-1} + Bio- stimulant Toggle (Containing marine extracts) @ 2.9 l ha^{-1}	99.85	70.1	108.65
T_9	FYM @ 10 t ha^{-1} + Bio- stimulant Voyagro (Containing proline, glycine betaine and glutamic acid) @ 585 ml ha^{-1}	105.7	71.1	110.55
T_{10}	100% Recommended N + FYM @ 10 t ha^{-1}	112.2	91.9	144.3
T_{11}	FYM @ 10 t ha^{-1} + NPK- Bio-fertilizer + Urea @ 20 kg ha^{-1}	102.8	75.5	112.95
T_{12}	FYM @ 10 t ha^{-1} + Bio- fertilizer mixture (*A. chrococcum* + *AMF* + *B. circulans*) + Bio- stimulant- L @ 625 ml ha^{-1} foliar spray each at 45 & 60 DAS	104.9	76.1	115.2
T_{13}	100% Recommended N + FYM @ 10 t ha^{-1}+ Azatobacter	113.7	93.6	151.5
T_{14}	50% Recommended N + FYM @ 10 t ha^{-1} + 25% N through Vermicompost	108.7	85.25	128.1

Table 2. Effect of integrated nutrient management on crop growth rate (g m^{-2} land area d^{-1}), relative growth rate (g g^{-1} day^{-1}) and net assimilation rate (g m^{-2} leaf area day^{-1}) at 90DAS-at harvest of wheat crop

Symbol	Treatments	Crop growth rate (g m^{-2} land area d^{-1})	Relative growth rate (g g^{-1} day^{-1})	Net assimilation rate (g m^{-2} leaf area day^{-1})
T_1	Control	0.01	0.0001	0.42
T_2	100% Recommended NPK (150: 75: 60 kg ha^{-1})	0.03	0.0002	0.70
T_3	50% Recommended N + FYM @ 10 t ha^{-1}	0.01	0.0001	0.57
T_4	50% Recommended N + 50% N through Vermicompost + Bio-stimulant- G @ 20 kg ha^{-1}	0.02	0.0002	0.60
T_5	50% Recommended N + Bio- stimulant+ G @ 20 kg ha^{-1}	0.02	0.0002	0.46
T_6	75% Recommended N + 50% N through Vermicompost	0.02	0.0002	0.69
T_7	75% Recommended N + FYM @ 10 t ha^{-1} + Bio- stimulant- G 20 kg ha^{-1}	0.03	0.0002	0.86
T_8	FYM @ 10 t ha^{-1} + Bio- stimulant Toggle (Containing marine extracts) @ 2.9 l ha^{-1}	0.02	0.0002	0.45
T_9	FYM @ 10 t ha^{-1} + Bio- stimulant Voyagro (Containing proline, glycine betaine and glutamic acid) @ 585 ml ha^{-1}	0.01	0.0001	0.83
T_{10}	100% Recommended N + FYM @ 10 t ha^{-1}	0.02	0.0002	0.76
T_{11}	FYM @ 10 t ha^{-1} + NPK- Bio-fertilizer + Urea @ 20 kg ha^{-1}	0.02	0.0001	0.53
T_{12}	FYM @ 10 t ha^{-1} + Bio- fertilizer mixture (*A. chrococcum* + *AMF* + *B. circulans*) + Bio- stimulant- L @ 625 ml ha^{-1} foliar spray each at 45 & 60 DAS	0.02	0.0001	0.51
T_{13}	100% Recommended N + FYM @ 10 t ha^{-1}+ Azatobacter	0.04	0.0002	0.79
T_{14}	50% Recommended N + FYM @ 10 t ha^{-1} + 25% N through Vermicompost	0.02	0.0002	0.65

Table 3. Effect of integrated nutrient management on grain yield (kg ha^{-1}), straw yield (kg ha^{-1}), biological yield (kg ha^{-1}) and harvest index (%) of wheat crop

Symbol	Treatments	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	Harvest index (%)
T_1	Control	26.4	42.5	69	38.2
T_2	100% Recommended NPK (150: 75: 60 kg ha^{-1})	41.1	58.3	99.4	41.3
T_3	50% Recommended N + FYM @ 10 t ha^{-1}	37.2	54.6	91.8	40.4
T_4	50% Recommended N + 50% N through Vermicompost + Bio-stimulant- G @ 20 kg ha^{-1}	38.7	56.3	95.0	40.7
T_5	50% Recommended N + Bio- stimulant+ G @ 20 kg ha^{-1}	32.2	49.9	82.1	39.2
T_6	75% Recommended N + 50% N through Vermicompost	40.9	57.6	98.5	41.4
T_7	75% Recommended N + FYM @ 10 t ha^{-1} + Bio- stimulant- G 20 kg ha^{-1}	44.7	61.0	105.7	42.2
T_8	FYM @ 10 t ha^{-1} + Bio- stimulant Toggle (Containing marine extracts) @ 2.9 l ha^{-1}	34.2	52.4	86.6	39.5
T_9	FYM @ 10 t ha^{-1} + Bio- stimulant Voyagro (Containing proline, glycine betaine and glutamic acid) @ 585 ml ha^{-1}	35.7	54.2	89.9	39.6
T_{10}	100% Recommended N + FYM @ 10 t ha^{-1}	41.7	57.6	99.4	41.9
T_{11}	FYM @ 10 t ha^{-1} + NPK- Bio-fertilizer + Urea @ 20 kg ha^{-1}	36.2	54.1	90.3	40.0
T_{12}	FYM @ 10 t ha^{-1} + Bio- fertilizer mixture (*A. chrococcum* + *AMF* + *B. circulans*) + Bio- stimulant- L @ 625 ml ha^{-1} foliar spray each at 45 & 60 DAS	36.4	54.4	90.9	40.0
T_{13}	100% Recommended N + FYM @ 10 t ha^{-1}+ Azatobacter	47.5	64.0	111.5	42.6
T_{14}	50% Recommended N + FYM @ 10 t ha^{-1} + 25% N through Vermicompost	39.6	57.0	96.7	40.9

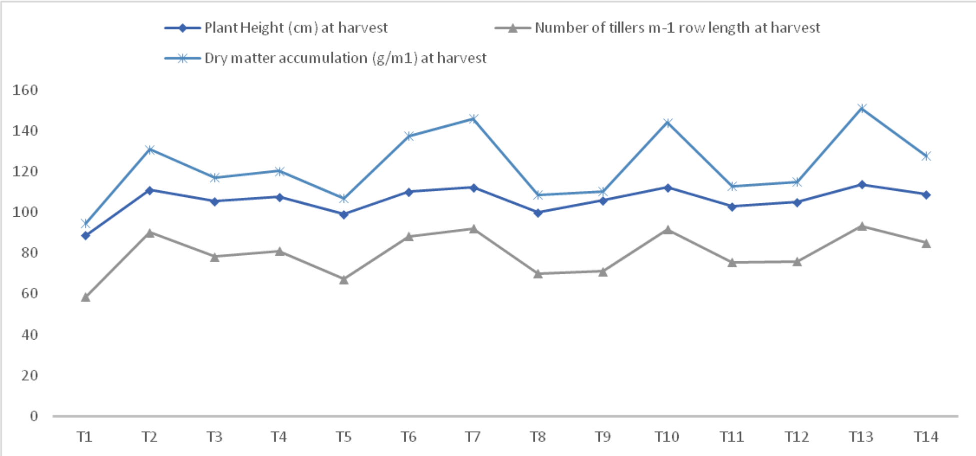

Fig. 1. Effect of integrated nutrient management on plant height (cm), number of tillers m^{-1}row length and dry matter accumulation (g/m^1) at harvest of wheat crop

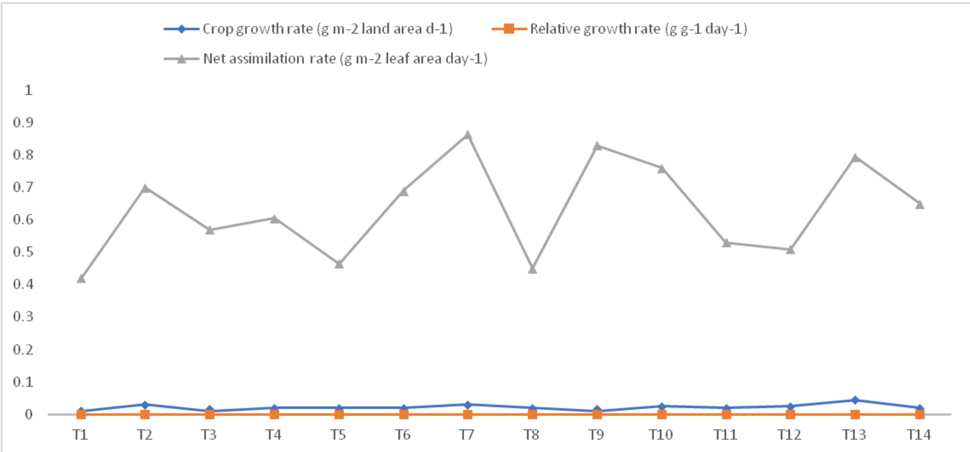

Fig. 2. Effect of integrated nutrient management on crop growth rate (g m^{-2} land area d^{-1}), relative growth rate (g g^{-1} day^{-1}) and net assimilation rate (g m^{-2} leaf area day^{-1}) at 90DAS-at harvest of wheat crop

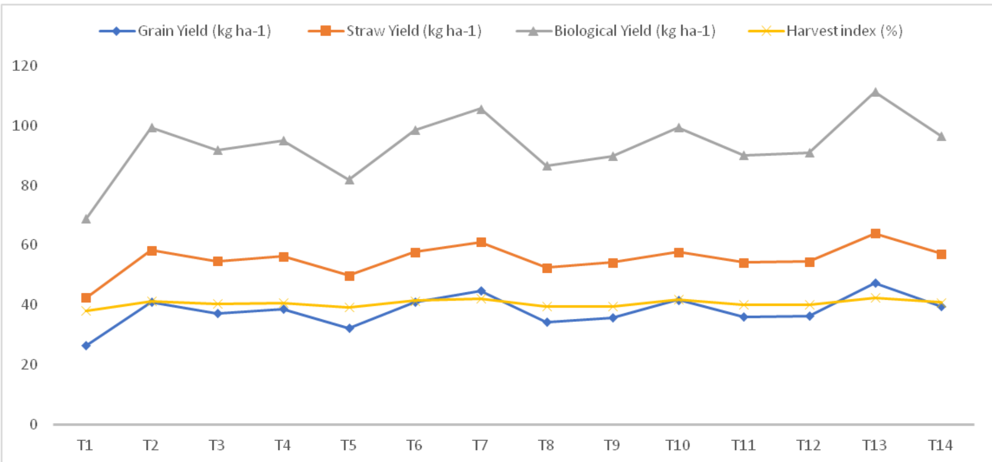

Fig. 3. Effect of integrated nutrient management on grain yield (kg ha^{-1}), straw yield (kg ha^{-1}), biological yield (kg ha^{-1}) and harvest index (%) of wheat crop

4. CONCLUSION

The results obtained from the experiment provide us major findings on the Effect of different integrated nutrient management on growth, physiological, yield and yield attributes of wheat (*Triticum aestivum* L.) for improving crop productivity in western U.P. From the present study, it is possible to draw the conclusion from the current study that the nutrient management with organic nutrients in combination with chemical fertilizers improves the parameters which were studied in this consideration compared to their individual application. Among the different nutrient management practices, 100% Recommended N + FYM @ 10 t ha^{-1}+ Azatobacter were found to be superior to RDF alone and in conjugation with other treatments. In addition, improving soil conditions will ultimately increase wheat productivity and profitability. Thus, the addition of FYM and azotobacter with chemical fertilizers is essential for enhancing nutrient use efficiency, soil health, productivity, and profitability. This is the only way to achieve increased production while maintaining sustainability in the current agricultural environment. Research should be focused on increasing fertilizer use efficiency, crop productivity, and sustaining soil health through proper integrated nutrient management practices in higher productivity zones like the Indo-Gangetic plains, where the current study was done.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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