

## Effect on yield, nutrient uptake and quality of potato (*Solanum tuberosum* L.) under integrated nutrient management

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### Abstract

Potato (*Solanum tuberosum* L.) is a heavy feeder and highly responsive to nutrient input, where the proper quantity and timing of nutrient supply is most critical component in achieving high productivity in potato cultivation. To assess the crop response and productivity, the potato variety 'Kufri Jyoti' was taken under different integrated nutrient management practices. The recommended dose of fertilizer was at 150:80:100 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O/ha, 25 kg/ha of ZnSO<sub>4</sub> and 15 kg/ha of Borax were applied during the experiment. The results indicated that there were highly significant effects of higher doses of nitrogen with recommended P and K combined applied with Zinc and Boron on tuber yield, plant NPK uptake efficiency and enzymatic activities. Results from the experiment expressed that the application of 125% RDN along with the application of Zn and B ensured maximum total tuber yield (24.73 t/ha), crop growth rate (5.222 g/m<sup>2</sup>/day), relative growth rate (0.066 g/g/day) at peak growth stages and quality such as starch (15.64%) and sucrose synthase activity (695 µg/g of fresh weight of tuber) of potato grown with the above nutrient management practices. This study indicated that production variation for higher nitrogen doses from inorganic sources of fertilizer existed among 16 different nutrient application treatments, and with better quality parameters.

**Keywords:** crop growth rate; RDN – Recommended Dose of Nitrogen; relative growth rate; sucrose synthase

### Introduction

Potato (*Solanum tuberosum* L.) is an annual herbaceous plant in the nightshade or Solanaceae family, grown for its starchy edible tubers. The underground stem is the edible part of the plant. Between 8000 and 5000 BC, the potato was domesticated in the territory of modern-day Southern Peru and extreme northern Bolivia. Since then, it has expanded worldwide and become a staple crop in many nations (Hai HD, 2015). In the 17<sup>th</sup> century, the Portuguese transported the crop from South America to India and its cultivation was spread over North India by the British. Asia alone accounts for half of the world's potato production, with

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China and India accounting for nearly 38% of that production. China produces 99.12 million tons from 5.815-million-hectare area units produced and is the world's leading producer (Wikipedia, 2020). India ranks third in potato cultivated area and second in production in the world after China. Potato is a high-energy crop that generates more food per unit of area and time than any other major food crop. It is our country's fourth most important crop that yields more dry matter, dietary fiber, and high-quality protein, minerals and vitamins and all-important components of a healthy diet i.e., wheat, maize, and other cereal grains (FAOSTAT, 2020). Potato is thus referred to as a wholesome food that is well-balanced and nutritious.

As potato is a heavy feeder and highly responsive to nutrient input, the proper quantity and timing of nutrient supply is the most critical component in achieving high productivity in potato cultivation (Biswas and Dutta, 2020). Integrated use of all plant nutrients is important for increasing crop productivity as well as for improving soil health crucial to conserving crop productivity in the long term; on the other hand, a judicious combination of organic and inorganic nutrient sources may be helpful to obtain a good economic return (Hensh *et al.*, 2020). Nitrogen supply plays a paramount role in the balance between the vegetative and reproductive stages of potato. Nitrogen is related to the structural constituent of cell walls that plays a pivotal role in many physiological and biochemical processes in plants. It is a component of many important organic compounds ranging from proteins, nucleic acids and constituent of the chlorophyll molecule, which plays an important role in plant photosynthesis. Many enzymes are proteinaceous; hence, N plays a key role in many metabolic reactions. Crop yield is commonly limited by an inadequate supply of nitrogen than any other element and hence this element occupies a unique economic position in crop cultivation. Potato crop responds well to micronutrient application and it has become difficult to get high yields without the application of micronutrients (Sarker *et al.*, 2018). Zinc plays a key role in chlorophyll production, carbohydrate metabolism and cell elongation, which impacts leaf size (Brady and Weil, 2020). Zinc is an important component of various enzymes that are responsible for driving many metabolic reactions in all crops (Acquaah G, 2002). Boron plays a key role in a diverse range of plant functions including cell wall formation and stability, maintenance of structural and functional integrity of biological membranes, movement of sugar or energy into growing parts of plants, and pollination and seed set (Zhao and Oosterhuis, 2002). According to reports, the micronutrients Zn and B have a special role in boosting potato productivity (Trehan and Grewal, 1989). To avoid a disparity between demand and supply in the current context of rapidly growing population and limited agricultural area with no scope for further area expansion, potato cultivation strongly urges for more and more return. Because potato is a heavy feeder and highly responsive to nutrient supply, proper nutrient quantity and timing is the most important factor in achieving high productivity in potato cultivation (Westermann, 2005; Pandit *et al.*, 2008). Previous studies (Raghav and Kamal, 2009; Baishya *et al.*, 2012; Pandit *et al.*, 2008) reported the importance of INM on the quality and quantity of potato crop over sole application of chemical fertilizers. The current experiment was designed considering the importance of the crop and demand to comprehend the best tuber-producing methods to boost potato yield and quality tuber production through careful and balanced administration of micronutrients and macronutrients together with organic and inorganic sources of fertilizers.

## Materials and Methods

### *Site specification*

The present experiment was performed at the research field of Odisha University of Agriculture and Technology (OUAT), Bhubaneswar during *Rabi*, 2021-22. The field of AICRP on the research field of OUAT, Bhubaneswar, Odisha is situated at 20° 15' N latitude and 85° 52' E longitude. It is located about 60 km away from the Bay of Bengal with an elevation of 25.5 m above mean sea level. During the cropping period, the total rainfall received was 72 mm. Mean evaporation was recorded at 3.19 mm/day. The average minimum and maximum temperature recorded during the cropping period was 25.66 °C and 15.53 °C, respectively. The

average relative humidity recorded during the cropping period ranged from 93.08% in the morning to 65.10% in the afternoon. The mean bright sunshine hour during the cropping period was 5.34 hrs/day. The weather was very congenial for the growth and development of the potato crop.

#### *Soil description*

Before planting the crop, a composite soil sample was collected from the experimental field to a depth of 15 cm for analysis. The soil of the experimental field was well-drained, non-calcareous, acidic in reaction (pH 5.24) by pH meter method (Jackson ML, 1973) and was found to be sandy loam in texture according to the textural triangle approach, 1927. At the commencement of the experiment, the available nitrogen was analysed by the Alkaline potassium permanganate method (Subbiah and Asija, 1956) which was 120.83 kg/ha indicating the low-N status the of soil. The available phosphorus (12.48 kg/ha), potassium (116.54 kg/ha) and organic carbon (0.23%) of the soil were found to be low and were analysed by Bray's 1 method (Page *et al.*, 1982), Flame photometer (Black, 1965), Walkley and Black's rapid titration (35), respectively. The soil available Zn was estimated by DTPA Extractable (Lindsay and Norvell, 1978) and was found to be 0.56 ppm while, the soil had 0.34 ppm of boron estimated by the Hot water bath method (Berger and Truog, 1939).

#### *Treatment details*

The experiment was conducted in randomized block design with three replications at four levels of nitrogen – RDN, Recommended Dose of Nitrogen (100% RDN, 125% RDN, 75% RDN and 50% RDN) with sixteen treatment combinations of T<sub>1</sub> = 100 % RDN, T<sub>2</sub> = 125% RDN, T<sub>3</sub> = 75% RDN through chemical fertilizer (RDN CF) + 25% RDN as FYM (RDN FYM), T<sub>4</sub> = 50% RDN through chemical fertilizer + 50% RDN as FYM, T<sub>5</sub> = T<sub>1</sub> + B as Borax, T<sub>6</sub> = T<sub>2</sub> + B, T<sub>7</sub> = T<sub>3</sub> + B, T<sub>8</sub> = T<sub>4</sub> + B, T<sub>9</sub> = T<sub>1</sub> + Zn as ZnSO<sub>4</sub>, T<sub>10</sub> = T<sub>2</sub> + Zn, T<sub>11</sub> = T<sub>3</sub> + Zn, T<sub>12</sub> = T<sub>4</sub> + Zn, T<sub>13</sub> = T<sub>1</sub> + B + Zn, T<sub>14</sub> = T<sub>2</sub> + B + Zn, T<sub>15</sub> = T<sub>3</sub> + B + Zn and T<sub>16</sub> = T<sub>4</sub> + B + Zn.

The potato variety 'Kufri Jyoti' was planted at 60 cm row spacing and 20 cm tuber-to-tuber spacing. Before planting, the field was prepared as per the standard procedure and the sprouted tubers were treated with Bavistin @ 2g/l. The standard recommended fertilizer dose was 150: 80: 100 kg of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O/ha, respectively. The total amount of phosphorous and 50 % of potash and 50% nitrogen was applied to the soil as a basal dose before planting. The remaining nitrogen and potash were administered during the first top dressing, i.e., 25 days after planting. Nitrogen and phosphorous were applied in the form of urea and single superphosphate (SSP), respectively and potassium was in the form of Murate of potash (MOP). Plant and soil samples were analysed for nutrient content as per the standard procedure. Before tuber harvesting, the dry matter in shoots and roots per plant was recorded at 15-day intervals. The shoots and roots of the selected plants were held inside the oven after air drying until they reached a constant weight, and the dry weight of the shoots was expressed in grams. For the calculation of the Crop Growth Rate (CGR), the method followed was suggested by (Watson, 1956). The CGR explains the dry matter accumulation per unit of land area per unit of time (g/m<sup>2</sup>/day). CGR of a species is usually closely related to the interception of solar radiation.

$$CGR = \frac{W_2 - W_1}{\rho(t_2 - t_1)} \quad (1)$$

where, W<sub>1</sub> and W<sub>2</sub> are whole plant dry weight at time t<sub>1</sub>-t<sub>2</sub> respectively, and ρ is the ground area on which W<sub>1</sub> and W<sub>2</sub> are recorded.

Similarly, Relative Growth Rate (RGR) was calculated as given by (Williams, 1946) which express the total plant dry weight increase in a time interval to the initial weight or dry matter increment per unit biomass per unit time or grams of dry weight increase per gram of dry weight and expressed as increase in dry weight/unit dry weight/unit time (g/g/day).

$$RGR = \frac{\log_e W_2 - \log_e W_1}{(t_2 - t_1)} \quad (2)$$

Where, W<sub>1</sub> and W<sub>2</sub> are whole plant dry weight at t<sub>1</sub>-t<sub>2</sub> time intervals in days, respectively.

For the estimation of the amount of total soluble sugars, either anthrone or phenol-sulphuric acid method colorimetrically was followed (Hedge and Hofreiter, 1962). To maintain the turgidity of the fresh sampled potato tubers, they were immediately placed in polythene bags and stored in a cold environment for future use.

$$\text{Sugar in the sample (\% mg)} = \frac{\text{Sugar value from graph (mg)} \times \text{Total vol. of extract (mg)}}{\text{Aliquot sample used or weight of sample (0.5 or 1 ml)}} * 100 \quad (3)$$

Similarly, for starch content in the tubers was estimated using the method stated by (Hedge and Hofreiter, 1962). The sampled potato tubers were immediately placed in polythene bags and stored in a cold environment to maintain the turgidity for future use. To find out the starch content in the sample, the standard graph was made and the value was multiplied by a factor 0.9 to arrive at the starch content. For estimation of the enzyme activity, sucrose synthase that is involved in sucrose synthesis, the enzyme was assayed by measuring the amount of sucrose synthesized by measuring the hexoses colorimetrically at 520 nm (Wardlaw and Willenbrink, 1994). The plants were washed and allowed to drain for a short time after harvesting. The plants were then divided into two parts: shoots and tubers. At 70 °C, the plants were oven-dried to a constant weight. With the help of a Wiley Mill grinder and a di-acid mixture of HNO<sub>3</sub>: HClO<sub>4</sub> (3:2), the nutritional content of shoots and tubers samples from potato plants was determined separately for each treatment. The Kjeldahl method (Page *et al.*, 1982) was used to determine total nitrogen in the shoots and tubers. Di-acid digestion followed by Flame photometric determination (Jackson, 1973) and Digestion with di-acid (HNO<sub>3</sub>: HClO<sub>4</sub> at 3:2) followed by spectrophotometric determination (Jackson, 1973) were used to determine potassium and phosphorus, respectively. Nitrogen, phosphorus, and potassium uptake were calculated by multiplying their respective concentration in plant dry matter by crop yield using the following formula.

$$\text{N, P, K uptake} = \text{Nutrient content (\%)} \times \text{Yield or biomass, on oven dry basis (kg/ha)} \quad (4)$$

The atomic absorption spectrophotometry was used to determine Zn and B. All the results were statistically analysed based on their sample means by Standard Error of Variance (ANOVA) test (Gomez and Gomez, 1984). The Standard Error of Means (SEM) and Critical Difference (CD) was calculated at 5% level of significance.

## Results

### *Shoots dry weight per plant*

The data of shoot dry matter accumulation per plant at different stages of crop growth as influenced by different nutrient management practices and nitrogen levels is presented in Table 1 revealing that, the shoot dry weight accumulation per plant at 30, 45, 60 and 75 DAP increased with the advancement of phenophases of the crop up to 75 DAP.

Amongst the different nutrient management practices, the highest shoot dry weight per plant (22.63 g) was recorded under the application of 125% RDN from chemical fertilizer along with zinc and boron which was significantly higher as compared to other nutrient management practices. However, it remained statistically at par with 125% RDN with Zinc (T<sub>10</sub>). The lowest shoot dry weight per plant (16.87 g) was recorded under the application of 50% RDN from chemical fertilizer + 50% RDN from FYM, T<sub>4</sub>.

Further, reference to data revealed that there was an increase of 1.60%, 3.05%, and, 9.85% of shoot dry weight per plant at the application of 125% RDN through chemical fertilizer with boron (T<sub>6</sub>), Zinc (T<sub>10</sub>), and both (T<sub>14</sub>), respectively, over the control (125% RDN through chemical fertilizer) at harvest.

**Table 1.** Effect of INM on shoot dry weight/plant and root dry weight/plant of potato

Treatment	Shoot dry weight/plant (g)				Root dry weight/plant (g)			
	30 DAP	45 DAP	60 DAP	75 DAP	30 DAP	45 DAP	60 DAP	75 DAP
T1-100% RDN	6.12	9.44	17.67	20.17	0.322	0.501	0.635	0.820
T2-125% RDN	6.30	9.80	18.27	20.6	0.328	0.614	0.984	1.210
T3-75% RDN CF+ 25% RDN FYM	6.20	9.72	17.53	19.87	0.313	0.561	0.834	1.127
T4-50% RDN CF+ 50% RDN FYM	5.70	8.71	14.54	16.87	0.301	0.498	0.630	0.731
T5-T1+B	6.80	10.42	17.84	20.30	0.331	0.572	0.834	1.101
T6-T2+B	7.13	10.13	18.27	20.93	0.421	0.671	0.992	1.261
T7-T3+B	6.42	10.22	17.73	20.07	0.336	0.591	0.835	1.154
T8-T4+B	5.94	9.11	16.57	18.90	0.312	0.502	0.632	0.745
T9-T1+Zn	6.81	11.14	17.97	20.37	0.387	0.670	0.901	1.206
T10-T2+Zn	7.23	10.20	18.57	21.23	0.421	0.681	1.011	1.271
T11-T3+Zn	6.46	10.53	17.83	20.17	0.390	0.601	1.023	1.181
T12-T4+Zn	6.51	9.20	16.87	19.20	0.316	0.541	0.646	0.786
T13-T1+B+ Zn	6.82	10.60	18.04	21.00	0.406	0.682	1.130	1.285
T14-T2+B+ Zn	7.64	10.70	20.10	23.26	0.430	0.688	1.145	1.304
T15-T3+B+ Zn	6.53	10.70	17.97	20.30	0.413	0.673	1.121	1.248
T16-T4+B+ Zn	6.83	9.32	16.93	19.27	0.324	0.554	0.684	0.791
<b>SEM±</b>	0.149	0.595	0.503	0.463	0.010	0.012	0.028	0.035
<b>CD (P=0.05)</b>	0.44	1.79	1.51	1.39	0.03	0.03	0.08	0.10

*Root dry weight per plant*

The perusal of data to days to root dry weight per plant (g) in potato as influenced by different integrated nutrient management practices showed that there were marked variations in the root dry weight per plant (g) in potato as depicted in Table 1. The root dry weight per plant (g) was recorded at 30, 45, 60 and 75 DAP. The maximum and minimum root dry weight per plant was observed in 125% RDN with zinc and boron, T<sub>14</sub> (0.430 g), and 50% RDN from chemical fertilizer with 50% RDN from FYM, T<sub>4</sub> (0.301 g) at 30 DAP, respectively. At 60 DAP, the root dry weight ranged between 0.630 g (T<sub>4</sub>) to a maximum of 1.145 g (T<sub>14</sub>). At 75 DAS, the highest root dry weight per plant was reported highest from 125% RDN with zinc and boron, T<sub>14</sub> (1.304 g) which was statistically similar to the treatment combination of 125% RDN with Boron (T<sub>6</sub>), with zinc (T<sub>10</sub>), with 100% RDN with zinc and boron (T<sub>13</sub>).

*Unmarketable yield*

The response of potato for total unmarketable tuber yield per hectare was found significant i.e., Table 2. It revealed that different integrated nutrient management practices have substantial variations in the unmarketable yield of potato plants per hectare. Unmarketable yield (ton/ha) was significantly decreased with increasing nitrogen rates from 150 to 187.5 kg K<sub>2</sub>O/ha in potato. The maximum unmarketable yield was reported from 100% RDN with Zinc (2.96 t/ha) that was statistically similar with the application of 100% RDN (2.85 t/ha). The minimum yield was reported from the application of 125% RDN from chemical fertilizer (1.23 t/ha), 100% RDN with boron (1.45 t/ha) followed by the application of 125% RDN with Zinc and Boron (1.67 t/ha).

*Marketable yield*

A trend of marketable tuber yield increase per plant was noticed among the treatments with increasing levels of nitrogen as depicted in Table 2. Statistically, the highest marketable tuber yield per hectare (23.06 t/ha) recorded from the application of 125% RDN from chemical fertilizer with Zinc and Boron which was

65.54% higher than the minimum marketable tuber yield per hectare (13.93 t/ha) observed from the application of 50% RDN from chemical fertilizer + 50% RDN from FYM.

**Table 2.** Effect of INM on unmarketable, marketable and total yield of potato

Treatment	Unmarketable yield (t/ha)	Marketable yield (t/ha)	Total yield (t/ha)
T1-100% RDN	2.85	15.02	17.87
T2-125% RDN	1.23	17.92	19.15
T3-75% RDN CF+ 25% RDN FYM	2.23	15.98	18.21
T4-50% RDN CF+ 50% RDN FYM	2.34	13.93	16.27
T5- T1+ B	1.45	16.42	17.87
T6- T2+ B	1.53	21.96	23.49
T7- T3+ B	2.59	18.06	20.65
T8- T4+ B	2.47	14.17	16.64
T9- T1+ Zn	2.96	19.84	22.80
T10- T2+ Zn	1.61	22.35	23.96
T11- T3+ Zn	2.22	19.71	21.93
T12- T4+ Zn	2.29	14.36	16.65
T13- T1+ B+ Zn	2.21	20.68	22.89
T14- T2+ B+ Zn	1.67	23.06	24.73
T15- T3+ B+ Zn	2.27	19.97	22.24
T16- T4+ B+ Zn	2.45	14.37	16.82
<b>SEM±</b>	0.052	0.594	0.713
<b>CD=P (0.05)</b>	0.15	1.78	2.15

#### *Total yield per hectare*

The total tuber yield (t/ha), as influenced by different nutrient management practices, recorded a significant variation among the different treatments (Table 2). A perusal of data indicated that among the various nutrient management practices followed, the application of 125% RDN through chemical fertilizer with zinc and boron recorded the highest yield (24.73 t/ha) which was noticed to be statistically at par with the treatment combination of the application of 125% RDN through chemical fertilizer with zinc (23.96 t/ha) and with boron (23.49 t/ha) but was significantly higher than the other nutrient management practices followed. The lowest yield (16.27 t/ha) was recorded with the application of 50% RDN through chemical fertilizer along with 50% RDN through FYM. The results revealed that the treatments (T<sub>9</sub> = 100% RDN + Zn, T<sub>10</sub> = 125% RDN + Zn, T<sub>11</sub> = 75% RDN through chemical fertilizer (RDN CF) + 25% RDN as FYM (RDN FYM) + Zn, T<sub>12</sub> = 50% RDN through chemical fertilizer + 50% RDN as FYM + Zn) with the application of the zinc along with nitrogen from an inorganic source alone or integrated sources resulted in a higher average yield of 21.34 t/ha than the treatment combinations with Boron with an average yield of 19.66 t/ha (T<sub>5</sub> = 100% RDN + B, T<sub>6</sub> = 125% RDN + B, T<sub>7</sub> = 75% RDN through chemical fertilizer (RDN CF) + 25% RDN as FYM (RDN FYM) + B, T<sub>8</sub> = 50% RDN through chemical fertilizer + 50% RDN as FYM + B) but were lower than the treatments which had both zinc and boron application with an average yield of 21.67 t/ha (T<sub>13</sub> = 100% RDN + Zn + B, T<sub>14</sub> = 125% RDN + Zn + B, T<sub>15</sub> = 75% RDN through chemical fertilizer (RDN CF) + 25% RDN as FYM (RDN FYM) + Zn + B, T<sub>16</sub> = 50% RDN through chemical fertilizer + 50% RDN as FYM + Zn + B).

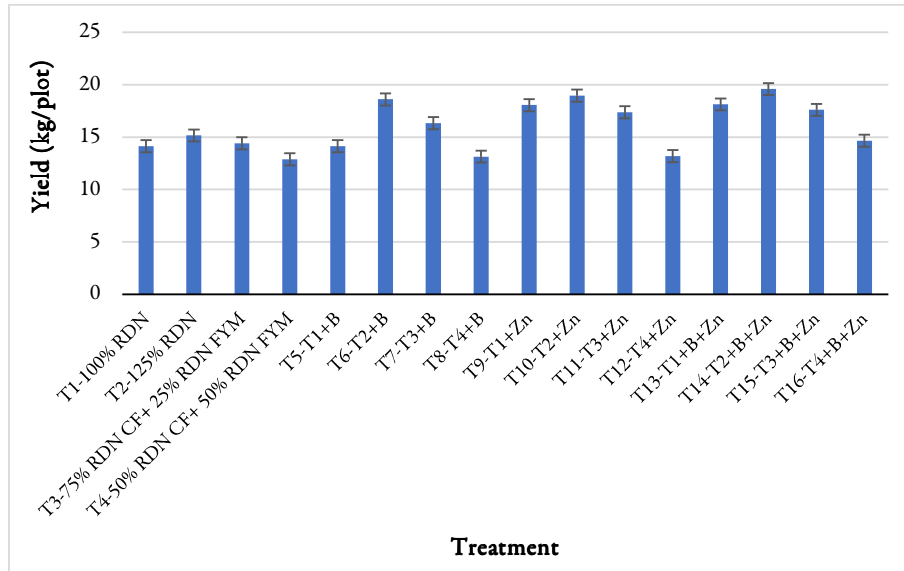
It was found that there was an increase in yield of 10.11% with the application of B, 19.41% with the application of Zinc, and 21.26% with the combination of zinc and boron over the average yield of treatments (T<sub>1</sub> = 100% RDN, T<sub>2</sub> = 125% RDN, T<sub>3</sub> = 75% RDN through chemical fertilizer (RDN CF) + 25% RDN as FYM (RDN FYM), T<sub>4</sub> = 50% RDN through chemical fertilizer + 50% RDN as FYM). However, the treatment combinations with the application of 50% RDN through chemical fertilizer and 50% RDN through FYM

along with Boron (16.64 t/ha), with Zinc (16.65 t/ha) and zinc and boron applied together (16.82 t/ha) recorded statistically similar results with that of 50% RDN through chemical fertilizer and 50% RDN through FYM.

The analysis in Table 3 and Figure 1 to total yield in kg/plot reveals that treatments 1, 2, 3, 5, 8, 12, 16 are statistically at par as they all belong to group 'E'. The statistical comparison indicates no significant difference between treatments 1, 3, 4, 5, 8, 12, 16 as they all fall under same group 'F'. The data suggests that treatments 2, 3, 7, 16 have non-significant means, being all categorized under group 'D'. Upon examination, it is evident that treatments 6, 9, 10, 13, 14, 15 exhibit similar effects (non-significant differences) since they are all part of group 'A'. Upon examination, it is evident that treatments 6, 9, 10, 11, 13, 15 exhibit similar effects (non-significant differences) since they are all part of group 'B'. The data suggests that treatments 7, 9, 11, 13, 15 have non-significant means, being all categorized under group 'C'. Treatment no 14 stands out with the highest mean of 19.587 among all treatments. Treatment 4 exhibits the lowest mean of 12.884, indicating a lesser effect compared to other treatments.

**Table 3.** Effect of INM on total yield of potato

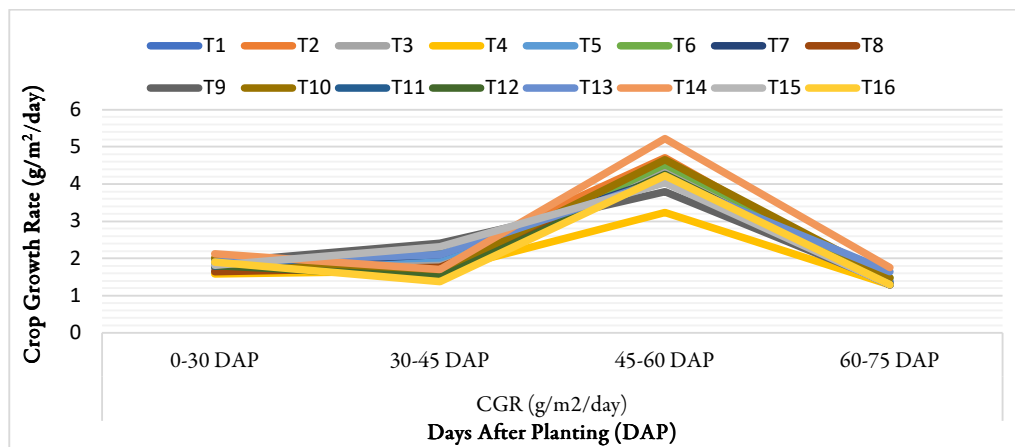
Treatment No.	Treatment	Yield (kg/plot)
1	T1-100% RDN	14.150 <sup>ef</sup>
2	T2-125% RDN	15.167 <sup>de</sup>
3	T3-75% RDN CF+ 25% RDN FYM	14.423 <sup>def</sup>
4	T4-50% RDN CF+ 50% RDN FYM	12.884 <sup>f</sup>
5	T5-T1+B	14.150 <sup>ef</sup>
6	T6-T2+B	18.602 <sup>ab</sup>
7	T7-T3+B	16.346 <sup>cd</sup>
8	T8-T4+B	13.147 <sup>ef</sup>
9	T9-T1+Zn	18.058 <sup>abc</sup>
10	T10-T2+Zn	18.974 <sup>ab</sup>
11	T11-T3+Zn	17.367 <sup>bc</sup>
12	T12-T4+Zn	13.187 <sup>ef</sup>
13	T13-T1+B+Zn	18.130 <sup>abc</sup>
14	T14-T2+B+Zn	19.587 <sup>a</sup>
15	T15-T3+B+Zn	17.610 <sup>abc</sup>
16	T16-T4+B+Zn	14.667 <sup>def</sup>



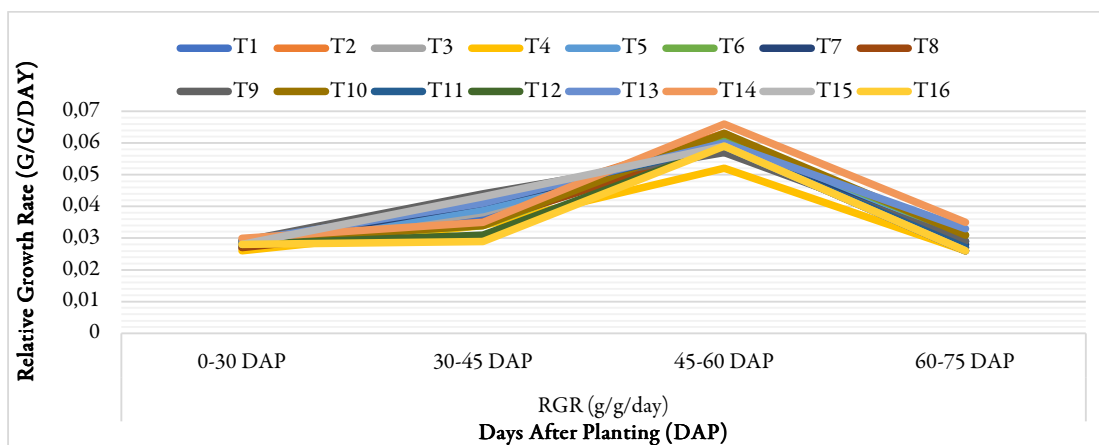
**Figure 1.** Effect of different nutrient management practices on total yield (kg/plot) of potato. The ANOVA results indicate that there is a significant difference among the treatment means at 1% level of significance.

*CGR and RGR*

The data crop growth rate and relative growth rate at different stages of crop growth as influenced by different nutrient management practices and nitrogen levels revealed that the CGR increased with the advancement of phenophases of crop up to 60 DAP and thereafter it declined (Figure 2). The RGR recorded the highest value at 60 DAP and gradually declined thereafter up to harvest (Figure 3). Amongst the different nutrient management practices, the highest CGR ( $\text{g}/\text{m}^2/\text{day}$ ) (5.222) was recorded under 125% RDN through chemical fertilizer with zinc and boron which was higher as compared to other nutrient management practices at 60 DAP. The lowest CGR ( $\text{g}/\text{m}^2/\text{day}$ ) (3.239) was recorded under the application of 50% RDN through chemical fertilizer with 50% RDN through FYM. However, the highest RGR ( $\text{g}/\text{g}/\text{day}$ ) (0.066) was reported with 125% RDN with zinc and boron followed by application of 100% RDN, 125% RDN and 125% RDN with Zinc at 0.062  $\text{g}/\text{g}/\text{day}$  RGR while the lowest RGR ( $\text{g}/\text{g}/\text{day}$ ) (0.052) was reported under the application of 50 % RDN through chemical fertilizer with 50 % RDN through FYM at 60 DAP.



**Figure 2.** Effect of integrated nutrient management on crop growth rate (CGR) of potato. The CGR was derived based on the data in shoots and root dry weights of the potato tuber and the data was analyzed in Excel to obtain technical line graphs for the same.



**Figure 3.** Effect of integrated nutrient management on relative growth rate (RGR) of potato  
The RGR was derived based on the data in shoots and root dry weights of the potato tuber and the data was analyzed in Excel to obtain technical line graphs for the same

*Sugar content in tuber*

The effect of different nutrient levels and sources for sugar content in tuber (%) reported significant variations as depicted in Table 4. The combined application of 100% RDN with Zinc and Boron recorded the maximum sugar content (0.42%) in the potato followed by 125% RDN with Zinc and Boron and 75% RDN CF with 25% RDN FYM which reported a sugar content of 0.40%.

The lowest sugar content in the tubers was obtained from the application of 100% RDN from chemical fertilizer (0.31%).

**Table 4.** Effect of INM on sugar, starch and sucrose synthase activity in potato tuber

Treatment	Sugar (%)	Starch (%)	Sucrose synthase (µg/g of fresh weight)
T1-100% RDN	0.31	12.60	410
T2-125% RDN	0.34	12.64	535
T3-75% RDN CF+ 25% RDN FYM	0.34	13.44	485
T4-50% RDN CF+ 50% RDN FYM	0.35	13.13	450
T5-T1+B	0.38	14.66	640
T6-T2+B	0.41	14.87	685
T7-T3+B	0.36	14.43	680
T8-T4+B	0.37	14.24	610
T9-T1+Zn	0.34	13.63	510
T10-T2+Zn	0.35	13.78	620
T11-T3+Zn	0.33	13.61	630
T12-T4+Zn	0.33	13.45	550
T13-T1+B+Zn	0.42	15.44	655
T14-T2+B+Zn	0.40	15.64	695
T15-T3+B+Zn	0.40	15.32	630
T16-T4+B+Zn	0.39	14.49	615
<b>SEm±</b>	0.011	0.413	15.576
<b>CD (P=0.05)</b>	0.03	1.24	49.94

*Starch content in tuber*

In the experiment, there were significant differences in the starch content in tubers grown with different nutrient management practices as shown in Table 4. The mean starch content of the controls was observed at

12.95% which increased to 14.44% with the application of boron, 13.61% with the application of zinc and 15.22% with the combined application of zinc and boron. The lowest tuber starch content was reported under the application of 100% RDN from chemical fertilizer, T<sub>1</sub> (12.60%) followed by the application of 125% RDN from chemical fertilizer, T<sub>2</sub> (12.64%).

*Sucrose synthase in tuber*

A wide range of variation was observed in Sucrose synthase activity (µg/g of fresh weight) in tubers and the range varied from 410 to 695 with an average value of 587.5 as in Table 4. In the experiment, there were significant differences in the sucrose synthase content at different nutrient sources and nitrogen level combinations. The highest Sucrose synthase (µg/g of fresh weight) in tubers was recorded in tubers supplemented with 125% RDN from chemical fertilizer with zinc and boron (695) followed by boron (685) and with 100% RDN from chemical fertilizer with zinc and boron (655). The application of boron with the controls reported an average increase of 13.2% sucrose synthase in tuber over the application of zinc with the controls. However, the lowest sucrose synthase in the tuber was recorded from the application of 100% RDN from chemical fertilizer.

*Plant uptake*

The data the nutrient uptake by the crop as influenced by different nutrient management practices and nitrogen levels revealed that among various integrated nutrient management practices, the highest macronutrient uptake by crop (312.21 kg/ha) was recorded under the application of 125% RDN from chemical fertilizer with Zinc and Boron, while the lowest nutrient uptake by crop (212.00 kg/ha) was recorded with the use of 50% RDN from chemical fertilizer with 50% RDN from FYM as shown in Table 5.

Among the different micronutrients, the highest nutrient uptake by crop (1210.07 g/ha) was recorded with the application of 125% RDN from chemical fertilizer with zinc and boron, whereas the lowest nutrient uptake by crop (754.98 g/ha) was recorded under the application of 50% RDN from chemical fertilizer with 50% RDN from FYM.

**Table 5.** Effect of INM on nutrient uptake in potato

Treatment	N uptake (kg/ha)			P uptake (kg/ha)			K uptake (kg/ha)			Zn uptake (g/ha)			B uptake (g/ha)		
	Shoot	Tuber	Total	Shoot	Tuber	Total	Shoot	Tuber	Total	Shoot	Tuber	Total	Shoot	Tuber	Total
T <sub>1</sub> -100%RDN	44.40	65.19	110.31	5.64	12.27	17.91	22.08	78.38	100.47	190.03	190.95	380.99	162.40	308.47	470.87
T <sub>2</sub> -125%RDN	49.14	77.21	126.35	5.43	14.41	19.84	22.04	80.67	102.71	199.92	210.85	410.77	173.48	328.63	502.11
T <sub>3</sub> -75%RDN CF+25%RDN FYM	41.85	60.26	102.11	5.26	12.75	18.01	21.93	78.28	100.21	193.25	193.33	386.59	150.75	290.96	441.72
T <sub>4</sub> -50%RDN CF+50%RDN FYM	42.16	55.41	97.57	5.21	10.11	15.32	23.23	75.88	99.11	167.19	161.35	328.54	147.38	279.06	426.44
T <sub>5</sub> -T <sub>1</sub> +B	45.70	65.53	111.23	5.89	13.75	19.64	22.45	79.54	101.99	190.09	189.11	379.20	161.62	310.67	472.30
T <sub>6</sub> -T <sub>2</sub> +B	47.01	87.77	134.78	5.84	15.97	21.81	20.25	86.96	107.21	237.56	278.99	516.55	215.71	418.74	634.46
T <sub>7</sub> -T <sub>3</sub> +B	41.13	63.18	104.31	5.36	12.79	18.15	20.63	82.04	102.67	217.47	225.27	442.74	159.55	309.71	469.27
T <sub>8</sub> -T <sub>4</sub> +B	41.83	57.41	99.24	5.01	10.74	16.25	23.70	75.98	99.68	172.39	167.90	340.29	152.38	285.75	438.13
T <sub>9</sub> -T <sub>1</sub> +Zn	47.64	78.08	125.72	5.58	14.27	19.86	20.56	82.28	102.84	231.30	262.09	493.39	204.22	398.38	602.60
T <sub>10</sub> -T <sub>2</sub> +Zn	48.53	91.77	140.30	5.95	16.94	22.89	23.25	100.87	124.12	241.37	285.75	527.12	220.19	429.35	649.55
T <sub>11</sub> -T <sub>3</sub> +Zn	42.04	68.01	110.05	5.17	13.08	18.25	21.94	82.28	103.87	222.33	247.41	469.74	186.96	352.62	539.58
T <sub>12</sub> -T <sub>4</sub> +Zn	42.15	57.52	99.67	5.59	11.11	16.71	23.34	77.49	100.83	176.62	173.19	349.82	153.01	287.86	442.87
T <sub>13</sub> -T <sub>1</sub> +B+Zn	45.81	82.23	128.04	5.48	14.73	20.21	20.73	83.48	104.21	233.29	267.77	501.06	206.03	401.91	607.95
T <sub>14</sub> -T <sub>2</sub> +B+Zn	50.03	97.13	147.16	6.18	17.76	23.94	25.43	115.78	141.21	250.26	301.21	551.48	223.13	435.46	658.59
T <sub>15</sub> -T <sub>3</sub> +B+Zn	43.56	71.13	114.69	5.34	13.48	18.82	23.57	80.81	104.38	224.58	254.47	479.05	199.08	386.28	585.36
T <sub>16</sub> -T <sub>4</sub> +B+Zn	46.27	64.46	110.73	5.68	11.83	17.51	23.29	77.93	101.22	178.71	176.36	355.07	198.1	374.67	572.81
<b>SEM ±</b>	1.346	1.324	2.687	0.451	0.463	0.559	1.121	0.985	2.220	2.120	1.011	4.167	1.211	0.986	1.515
<b>CD=P (0.05)</b>	4.04	3.97	8.09	1.36	1.39	1.68	3.37	2.96	6.69	6.46	3.03	12.56	3.62	2.96	4.56

## Discussion

### *Yield and yield attributing parameters-*

Maximum tuber yield (24.73 t/ha) was recorded under nutrient management with 125% RDN with zinc and boron which was 28.28% higher than the yield recorded under the application of 100% RDN and 42.87% from the application of 50% RDN through chemical fertilizer with 50% RDN through FYM, which recorded the lowest yield. This could be possibly due to better growth and photosynthates accumulation with the increased nitrogen availability and improved starch translocation through B application, inducing formation and growth of stolon with improved IAA activity by Zn application favouring the crop to express its optimum yield potential. The results conform with the earlier findings of Baghla *et al.* (2009); Sarkar *et al.* (2017); Lenka and Das (2019). The poor performance of the treatments involving the organic sources to supplement the nitrogen requirement is mostly because of the low NPK status and very low organic carbon content in the experimental site. Potato is a nitrogen-loving crop with a high demand for nitrogen which is reflected in better tuber yield when 25% extra nitrogen was applied through chemical fertilizer than the RDN. On the contrary, the release of nutrients from the organic sources is very slow which may not suffice the periodical requirements of nutrients by the potato crop. The results revealed that the treatment combinations with 125% RDN resulted in significantly higher than the other treatments. It was found that the treatment combinations with 125% RDN resulted in significantly higher than the other treatments. Tuber yield is indirectly influenced by crop growth and yield attributes, both of which are influenced by soil fertility and nutrient status. Increased values in these yield parameters with a higher dose of nitrogen could be attributed to an overall improvement in more assimilation and accumulation of photosynthates and enhanced vegetative growth resulting in more tuber number per plant and tuber weight per plant. The results are in corroboration of the findings of Adhikari and Sharma (2004); Arafa (2004); Abbasi *et al.* (2009).

### *Quality parameters*

Starch, total sugar content (glucose and fructose) and sucrose synthase activity are all well-known quality traits for potatoes. Tuber maturity, growing conditions, water and nutrient uptake were the other factors that determined potato tuber dry matter and reducing sugars.

The total sugar content, starch, and sucrose synthase of tubers were recorded and calculated. Starch is the primary storage carbohydrate in plants, accounting for the majority of the dry matter in potato tubers. More starch accumulation occurs in the tuber during the tuberization stage, representing a high demand for carbohydrates (Subba *et al.*, 2017) and these concentrations tend to decrease as they reach physiological maturity. Sucrose synthase (SuSy) is a glycosyl transferase enzyme that is important in sugar metabolism, particularly in sink tissues. SuSy catalyzes the reversible conversion of sucrose to fructose i.e., either uridine diphosphate glucose (UDP-G) or adenosine diphosphate glucose (ADP-G). SuSy cleavage products are available for many metabolic pathways, including energy production, primary metabolite production, and complex carbohydrate synthesis. Plants with low SuSy activity have lower growth, lower starch and altered shoot apical meristem function and leaf morphology (Zrenner *et al.*, 1995).

The lowest total sugar content was reported with the application of 100% RDN through chemical fertilizer. The probable reasons for obtaining lower sugar content might be due to the less nutrient availability and uptake by the crop. In treatment combinations of application of 125% RDN with Zinc and Boron, the starch content was recorded as the highest which might be due to a higher dose of nitrogen and higher uptake of nutrients in reproductive tissues resulting in increased metabolic activities by increasing RNA and DNA contents (Sarkar *et al.*, 2017), that ultimately increased the translocation of photosynthates from source to sink i.e., tubers (Singh *et al.*, 2014).

Among the different integrated nutrient management practices, the maximum tuber dry matter and sucrose synthase was recorded from the combined application of 125 % RDN with Zinc and Boron. The

increase in the dry matter and sucrose synthase content might be due to higher production of photosynthesis, resulting in greater accumulation of dry matter and more translocation of nutrients (N, P, K, Zn and B) from soil to plant in the storage part i.e., tuber (Rai *et al.*, 2021; Banjare *et al.*, 2002; Lenka *et al.*, 2020).

#### *Nutrient uptake*

Throughout the growing season, potatoes require optimal levels of essential nutrients. Nutrient uptake rates are frequently slow early in the season, rapidly increase during the tuber bulking phase and then gradually slow as the plant matures (Rai *et al.*, 2021). Higher nutrient uptake is a measure of higher photosynthesis activity in the crop, better plant growth, and higher production.

Among the different integrated nutrient management practices, a significant difference was observed in nutrient uptake by potato. Nutrient uptake is always a function of yield. When yield is higher uptake will be higher. The highest N (147.16 kg/ha), P (23.94 kg/ha) and K (141.21 kg/ha) uptake by crop were recorded with the application of 125% RDN from chemical fertilizer along with zinc and boron.

This was due to increased photosynthetic activity in the plant as a result of subsequent dry matter accumulation, resulting in increased nutrient availability from the soil environment to aerial portions with increased nitrogen application and synergistic effect of zinc and boron on the crop. These findings corroborate the results of Singh and Lal (2012); Lenka and Das (2019). Among the fertility levels, the lowest nutrient uptake was recorded from the combined application of 50% RDN from chemical fertilizer and 50% RDN from FYM which might be due to very low initial soil organic carbon status and low fertility due to which the crop may have responded negligibly on uptake and yield. And similar results were also studied by Kumar *et al.* (2008).

#### **Conclusions**

Nitrogen plays a vital role in potato production. In the current study, increased nitrogen levels to 125% RDN along with the application of zinc and boron through chemical sources of fertilizers significantly enhanced crop productivity and yield with better quality tubers. Thus, optimizing the N rate at 125% RDN improved the efficiency of N fertilizer applications, while the synergy of the application of Zn and B increased the marketable tuber yield. The exploration of an application of 125% RDN i.e., at the rate of 187.5 kg/ha with zinc at 25 kg/ha and boron at 15 kg/ha is recommended to enhance the crop marketable yield along with improve tuber quality parameters and enzyme activity that can facilitate the scaling-up of high remunerative management practices for the farmers.

#### **Authors' Contributions**

Conceptualization: SK, BSR, AM; Methodology: SK, BSR; Validation: MRS, AM; Formal analysis: SK; Investigation: SK, BSR, AM; Data curation: BSR, AM; Writing: SK, BSR; Review and editing: MRS, AM. All authors read and approved the final manuscript.

#### **Ethical approval** (for researches involving animals or humans)

Not applicable.

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## Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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