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Effect of NPK and Fym with Biofertilizer on Quality of Potato and Soil Nutrient Dynamics

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An experiment was conducted at the Horticulture Research Farm, Janta College, Bakewar, Etawah during the Rabi season of 2022-23 and 2023-2024. Composite soil samples were collected in a zig-zag manner during the fallow period before the start of the experiment and after the harvesting of the crop. The experiment was laid out in a Randomized Block Design with ten treatments replicated thrice. PSB was used for seed inoculation. The objective of the study is to evaluate the effect of integrated nutrient management practices on the quality and soil nutrient status of potatoes. The results revealed that application of FYM @ 15t/ha + 1/2 of the recommended dose of NPK through chemical fertilizer resulted in maximum carbohydrate percentage. Application of FYM @ 30t/ha + 1/2 of the recommended dose of NPK through chemical fertilizer resulted in maximum proteins, TSS and sugars in potato as compared to other integrated nutrient management treatments. As far as soil nutrient status is concerned, different treatments recorded maximum organic carbon percentage, available N, P and K percentage. The results revealed that the application of integrated nutrient management with the application of FYM @ 30t/ha + 1/2 of the recommended dose of NPK through chemical fertilizer resulted in satisfactory quality parameters in potatoes.

Keywords: Potato, integrated nutrient management, soil nutrient, chemical fertilization, protein, sugar, TSS.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is an important vegetable crop which has acquired the status of staple food in many countries. It is an herbaceous crop and botanically classified as a modified stem that forms underground tubers. These tubers have commercial and food value and are harvested for human use (Navarre and Pavek, 2014). For commercial cultivation, soil with good drainage capacity and acidic reaction is preferred. Since most of the potato roots are found in the top 2 feet (60cm) of soil, soil management is essential for profitable crop production. Although it finds its origin in South America, it is one of the world's most widely cultivated vegetable crops (Spooner *et al.,* 2014). As far as the Asian continent is concerned, it contributes to nearly 46% of global output. Potato is a great source of vitamin C, thiamine, and folic acid, among at least 12 other essential vitamins and minerals (Tolessa, 2018). Diverse studies have demonstrated that potato is an important source of carbohydrates, resistant starch, quality proteins, vitamins C and B_6 as well as potassium (Camire *et al.,* 2009). Potato is also a source of antioxidants that can contribute to preventing both degenerative and age-related diseases with lutein and zeaxanthin being present in high levels in yellow-fleshed potatoes (Burgos *et al.,* 2009) and anthocyanins being present in purple and red-fleshed potato landraces (Burgos *et al.,* 2013). It's a well-rounded meal because it's low in fat and high in carbs. Potatoes have a long history of relieving food

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security problems and contributing to improving people's incomes in difficult times and also under the current population expansion (Devaux *et al.,* 2021). India produces 50.33 million tons of potato with an average yield of 27.31 tons per hectare. Uttar Pradesh accounts for 0.61 million ha area under potato cultivation with an estimated output of 13.9 million tons and a productivity of 22.7 t/ha (Anonymous, 2022). Uttar Pradesh is India's largest potato-producing state, contributing over 30% of the country's output. Its fertile Indo-Gangetic plains, favourable climate, and high agricultural workforce make it a hub for potato farming. Studies here can improve yields, address challenges like climate resilience, and boost food security and rural livelihoods.

Quality production of potato depends on the nutritional inputs, availability of the resources, cultural operations and climatic factors. Although chemical fertilization is able to provide the required amount of nutrients, still a sustained supply of nutrients is essential for production of good quality tubers. Shifting the approach towards organic cultivation is a viable option but due to the limited nutrient pool in organic manures, organic cultivation of the crop is not feasible (Anand *et al.,* 2019). The urgent need to switch to readily available organic resources like manure in addition to fertilizers is countered by ecological concerns about residual toxicity brought on by careless and excessive chemical use in fertilizers and pesticides, and their negative effects on the health of the soil and biodiversity. Organic manures enhance soil physical conditions, leading to increased plant and tuber production (Lucas *et al.,* 2014). Manures are vital to the fertilizer business despite their low analytical value as nutrient carriers. Because consumers like their produce to be chemical-free, organic farming is gaining ground. Current major sources of organic matter and nutrients are poultry manure, vermicompost, and FYM. A 50 percent boost in agricultural output is attributed, in part, to the use of balanced fertilization across a variety of farming contexts (Singh *et al.,* 2007). Integrated Nutrient Management (INM) in potato combines organic manures, chemical fertilizers, and biofertilizers to optimize nutrient availability, improve soil health, and enhance crop yield. It ensures balanced nutrient application, reduces environmental impact, and boosts tuber quality by maintaining sustainable fertility levels, crucial for intensive potato farming systems. Integrated nutrient management can provide a feasible solution for all the anomalies arising out of the rampant use of inorganic fertilizers. Studies have shown that INM group exhibited a 20% increase in yield and enhanced tuber quality, characterized by higher nutrient content and reduced incidence of common diseases. Soil health parameters, including microbial activity, nutrient availability, and organic matter content, were also positively influenced by INM practices (Mia *et al.,* 2024). Based on the literature reviewed and published studies, an experiment was planned to evaluate the effect of integrated nutrient management on growth and yield of potato crop during the two consecutive years (2022-23 and 2023-24) as compared to sole application of inorganic fertilizers in the Etawah region of Uttar Pradesh.

MATERIALS AND METHODS

***Details of experimental area*:** The experiment was conducted at the Horticulture Research Farm, Janta College, Bakewar, Etawah during Rabi season of 2022-23 and 2023-2024. The experimental site is located approximately 23 km east of the district headquarters in Etawah. The site is located at 26.66170°N 79.17230°E at an elevation of 142 m above mean sea level and falls under the sub-tropical climate zone with an average of 1143 mm of rain every year. The soil texture of the research farm is silty loam which makes the soil suite best for growing crops.

***Soil sampling*:** Composite soil samples were collected in a zig-zag manner during the fallow period before the start of the experiment and after the harvesting of the crop. Soil auger and khurpi were used to collect the samples at a depth of 9 inches from the soil surface.

***Agricultural operation*:** The experimental field was well leveled having good irrigation and drainage facilities. The field was prepared by ploughing with the help of a moldboard plow and two cross harrowing were done with the tractor to obtain a well-pulverized condition. After this, the field was divided into three replications. In each replication, 10 plots were made equal to the number of treatments of size 12.96 m^2 (3.6 m × 3.6 m). Paths, borders, bunds, and channels were also prepared as per layout. Recommended doses of NPK (150 kg N, 100 kg P, 100 kg K) with 50% N at the time of planting and 50% at earthing up were used.

***Treatment details and nutrient sources*:** The experiment was laid out in a Randomized Block Design with ten treatments (Table 1) replicated thrice. PSB was used for seed inoculation.

Table 1. Details of the treatments applied.

Symbol	Treatment Details
T_0	Control (RDF)
T_1	Application of FYM @ 30t/ha
T_2	Application of FYM @ 15t/ha
T3	Application of Biofertilizer (PSB) with RDF
T4	Application of FYM @ 7.5 t/ha + recommended dose of NPK through chemical fertilizer (150-100-100 kg NPK/ha)
T5	Application of biofertilizer + 1/2 of the recommended dose of NPK through chemical fertilizer + FYM @ 15t/ha
T6	Application of FYM @ 30t/ha + 1/2 of the recommended dose of NPK through chemical fertilizer
T7	Application of FYM @ 15t/ha + full recommended dose of NPK through chemical fertilizer
T_8	Application of FYM @ 15t/ha + 1/2 of the recommended dose of NPK through chemical fertilizer
T9	Application of Biofertilizer + 1/2 of the recommended dose of NPK through chemical fertilizer.

***Observations recorded during the study*:** Observation was recorded on quality parameters and soil nutrient status before and after the harvest of the potato crop. Carbohydrates were determined as per the Anthrone method (Hodge and Hofreiter, 1962). The TSS content was determined with Zeiss Pocket refractometer (0 to 32.0 brix) by putting a drop of extracted juice of fresh pea grains on the prism and taking the reading (AOAC, 1975). For the determination of total sugars and reducing sugars, methods given by Sadasivam (1996) were followed. Nitrogen content of tuber was multiplied by factor 6.25 to get the crude protein. Nitrogen was estimated by Kjeldahl's digestion and distillation method (Jackson 1967), phosphorus by the Vanadomolybdate method (Jackson, 1973) and potassium by Flame Photometer method (Toth *et al.*, 1948).

For soil sample analysis, pH was estimated using pH meter (Labtronics make). Soil organic carbon was estimated by Walkley and Black Method (1934). Nitrogen was estimated by Kjeldahl's digestion and distillation method (Jackson 1967), phosphorus by the Vanadomolybdate method (Jackson, 1973) and potassium by Flame Photometer method (Toth *et al.*, 1948).

***Statistical analysis*:** Observations recorded on different variables (parameters) during 2022-23 and 2023-24 were tabulated and pooled for statistical analysis using OPSTAT software (Sheoran *et al.*, 1998). The significance of various treatments was evaluated using the F-test in two ways ANOVA (analysis of variance) at 0.05 significance level ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Tuber quality characteristics *Carbohydrate (%)*: Under integrated nutrient management, maximum carbohydrate percentage of 75.44 per cent, 75.50 per cent and 75.47 per cent was recorded under the treatment T_8 in the first two years and in pooled estimates. (Table 2). Treatments with integrated application of the nutrients recorded higher carbohydrate percentage as compared to the control treatment. Carbohydrates in potatoes are primarily stored as starch in the tubers, and their synthesis and accumulation depend on the plant's ability to photosynthesize efficiently and translocate sugars to the tubers. Potassium is a key nutrient that enhances carbohydrate synthesis and transport in potato plants and it facilitates the movement of sugars (in the form of sucrose) from the leaves to the tubers where starch is stored. Adequate potassium ensures efficient carbohydrate synthesis and improves the rate at which these sugars are converted into starch in the tubers, resulting in a higher carbohydrate content in potatoes. Bashir and Qureshi (2014) reported that the highest carbohydrate (22.92%), crude protein (2.93) and ascorbic acid (17.20 34 mg 100-1g quality of potato) was obtained in treatment combination of N180F24 which was found superior over all other treatment combination

***Protein (%)*:** Maximum protein percentage of 1.26 per cent, 1.29 percent and 1.28 per cent was recorded under the treatment T_6 during both the years and in pooled estimates (Table 2) which was closely followed by treatment T_7 and T_8. The protein content in potatoes is closely related to nitrogen (N) availability, as nitrogen is a key component in the synthesis of amino acids, which are the building blocks of proteins. Nitrogen is an essential element in amino acids, which combine to form proteins. In plants, nitrogen is absorbed primarily in the form of nitrate (NO_3^-) or ammonium (NH_4^+) and is used to synthesize amino acids like glutamine and asparagine, which are then converted into proteins. When nitrogen is sufficiently available, the potato plant can produce more amino acids, leading to an increase in the synthesis of proteins, both in the leaves and tubers. High nitrogen levels encourage protein synthesis, while reduced nitrogen leads to a higher focus on carbohydrate accumulation. However, when nitrogen is balanced with other

Table 2. Effect of integrated nutrient management on carbohydrate percentage and protein percentage in potato.

Treatments	Carbohydrate (%)			Protein (%)			TSS (°Brix)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_0	73.96	74.02	73.99	1.10	1.13	1.12	3.12	3.17	3.15
T_1	74.88	74.94	74.91	1.16	1.19	1.18	3.18	3.23	3.20
T_2	74.79	74.85	74.82	1.15	1.18	1.17	3.17	3.22	3.20
T_3	74.67	74.73	74.70	1.12	1.15	1.14	3.16	3.21	3.19
T_4	75.12	75.18	75.15	1.18	1.21	1.20	3.25	3.30	3.28
T_5	74.98	75.04	75.01	1.18	1.21	1.20	3.22	3.27	3.25
T_6	75.38	75.44	75.41	1.26	1.29	1.28	3.61	3.66	3.63
T_7	75.28	75.34	75.31	1.25	1.28	1.26	3.48	3.53	3.51
T_8	75.44	75.50	75.47	1.21	1.24	1.23	3.33	3.38	3.36
T_9	75.16	75.22	75.19	1.19	1.22	1.20	3.27	3.32	3.29
S.Em. (±)	0.82	0.69	0.79	0.11	0.09	0.11	0.005	0.004	0.05
C.D. (at 5%)	1.21	1.14	1.38	0.24	0.18	0.20	0.11	0.09	0.09

nutrients (especially potassium), both carbohydrate and protein levels can be optimized.

TSS**:** Maximum TSS among all the potato samples under different treatments (Table 2) was recorded under the treatment T_6 (Application of FYM @ 30t/ha + 1/2 of the recommended dose of NPK through chemical fertilizer) where a TSS value of 3.61-degree brix, 3.66-degree brix and 3.63-degree brix was recorded in the first two years and in pooled estimates. Minimum TSS was recorded under the treatment control (T_0). The key to optimizing TSS in potatoes is a balanced nutrient application. Potassium, nitrogen, phosphorus, and micronutrients work together to ensure that the plant has enough energy and resources to produce and transport sugars to the tubers. Total Soluble Solids (TSS) in potatoes, often measured to assess the quality of tubers, is an indicator of the concentration of sugars, organic acids, and other dissolved substances. The TSS level is influenced by various factors, including nutrient application, which affects the plant's metabolic processes. Potassium plays a critical role in regulating carbohydrate metabolism, particularly the synthesis and translocation of sugars. Potassium helps move carbohydrates (in the form of sugars) from the leaves to the tubers, which directly impacts the TSS. Sufficient potassium in the soil enhances the synthesis of sugars through improved photosynthesis and the efficient transport of these sugars to the tubers. As a result, potatoes with higher potassium availability often show an increase in TSS, meaning more soluble sugars and better-quality tubers.

Sugars (%)**:** Table 3 presents the data related to the sugar percentage in potato under integrated nutrient management. Maximum total sugars were recorded under the treatment T_6 (Application of FYM @ 30t/ha + 1/2 of the recommended dose of NPK through chemical fertilizer) where 0.57 per cent, 0.59 per cent and 0.58 per cent of total sugars was recorded during the two years of the experiment and in pooled estimates. Minimum total sugar percentage was recorded under the treatment T_0 (Control). Maximum amount of reducing sugars (0.49%), 0.51 per cent and 0.50 per cent of reducing sugars were recorded under treatment T_6. Minimum reducing sugars were recorded under the treatment T_0 (Control). Maximum amount of non-reducing sugars (0.13%, 0.13 per cent and 0.13 per cent) was recorded under the treatment T_1, T_3, T_4 and T_9 during the first year, second year and in pooled estimates under integrated nutrient management in potato.

The evident high-quality characteristics of potatoes under integrated nutrient management treatments may be attributed to the fact that the integration of organic manures not only provides a sustained supply of nutrients but also keeps the soil aerated for better growth of the tubers. Similar findings have been reported by Patel *et al.* (2022) where the application of 75% RDF + 25% Vermicompost + Azotobacter+ PSB was the best application of organic manure and biofertilizers with different levels of RDF doses and had the best yield and quality parameters in potato compared to all other treatments. The use of organic sources of nutrients such as vermicompost and yeast vinasse in INM options induced a better root system of potato (Barman *et al.*, 2018) resulting in greater uptake of nutrients than the sole application of chemical fertilizers. Vermicompost is a rich source of nutrients and an excellent factor for the improvement of soil bio-physical health which enhances root proliferation of crops and helps in higher availability and uptake of nutrients (Khan *et al.*, 2017). Higher availability of nutrients for crops on the application of vermicompost has been also reported earlier by Vasanthi and Kumaraswamy (1996). Enhanced soil microbial activity by application of vermicompost on improvement of uptake nutrients (Alam *et al.*, 2014) might be another reason for such results. Increased nutrient uptake by application of yeast vinasse over the sole application of chemical fertilizers was earlier reported by Komdorfer and Anderson (1993) in sugarcane, maize, wheat and pigeon peas.

Table 3. Effect of integrated nutrient management on total sugars (%), reducing sugars (%) and non-reducing sugars (%) in potato.

Treatments	Carbohydrate (%)			Protein (%)			TSS (°Brix)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_0	0.49	0.51	0.50	0.38	0.40	0.39	0.11	0.11	0.11
T_1	0.52	0.54	0.53	0.39	0.41	0.40	0.13	0.13	0.13
T_2	0.51	0.53	0.52	0.39	0.41	0.40	0.12	0.12	0.12
T_3	0.50	0.52	0.51	0.37	0.39	0.38	0.13	0.13	0.13
T_4	0.54	0.56	0.55	0.41	0.43	0.42	0.13	0.13	0.13
T_5	0.52	0.54	0.53	0.40	0.42	0.41	0.12	0.12	0.12
T_6	0.57	0.59	0.58	0.49	0.51	0.50	0.09	0.09	0.09
T_7	0.56	0.58	0.57	0.47	0.49	0.48	0.09	0.09	0.09
T_8	0.55	0.57	0.56	0.44	0.46	0.45	0.11	0.11	0.11
T_9	0.55	0.57	0.56	0.42	0.44	0.43	0.13	0.13	0.13
S.Em. (±)	0.008	0.010	0.009	0.005	0.006	0.005	0.001	0.001	0.002
C.D. (at 5%)	0.016	0.019	0.018	0.009	0.010	0.008	NS	NS	NS

Table 4. Effect of integrated nutrient management on soil pH under potato cultivation.

Treatments	Soil pH			
	Before sowing (2022)	**After sowing (2022)**	**Before sowing (2023**	**After sowing (2023)**
T_0	8.05	7.97	8	7.93
T_1	8.05	7.93	8	7.90
T_2	8.05	8.00	8	7.93
T_3	8.05	8.00	8	7.97
T_4	8.05	8.07	8	8.13
T_5	8.05	8.03	8	8.07
T_6	8.05	8.00	8	8.00
T_7	8.05	8.07	8	7.97
T_8	8.05	8.00	8	8.00
T_9	8.05	8.00	8	7.93
S.Em. (±)	NS	0.0009	NS	0.0006
C.D. (at 5%)	NS	NS	NS	NS

Table 5. Effect of integrated nutrient management on soil organic carbon (%) under potato cultivation.

Treatments	Soil Organic carbon (%)			
	Before sowing (2022)	**After sowing (2022)**	**Before sowing (2023**	**After sowing (2023)**
T_0	2.87	2.83	2.83	2.87
T_1	3.30	3.05	3.33	3.12
T_2	3.20	3.00	3.23	3.07
T_3	3.17	2.98	3.20	3.05
T_4	2.87	2.83	2.90	2.90
T_5	2.97	2.88	2.93	2.92
T_6	3.10	2.95	3.13	3.02
T_7	3.07	2.93	3.03	2.97
T_8	3.03	2.92	3.07	2.98
T_9	3.03	2.92	3.00	2.95
S.Em. (±)	0.06	0.05	0.06	0.04
C.D. (at 5%)	0.11	0.11	0.11	0.09

High concentrations of K and moderate concentrations of P and N in yeast vinasse exerting a positive influence on soil properties and nutrient uptake were also stated by Zhou *et al*. (2009); Rajagopal *et al*. (2014); Mahmoud *et al*. (2019).

***Soil nutrient status*:** Data pertaining to the soil pH in soil under integrated nutrient management treatments was found to be non-significant (Table 4).

There was an increment in the soil organic carbon percentage with maximum soil organic carbon being recorded under the treatment T_1 (3.30% and 3.33 %) during the first and second year of the experiment (Table 5). Maximum soil available nitrogen was recorded under the treatment T_4 (145.67 kg per ha and 145.33 kg per ha) during both years of the experiment (Table 6). Minimum soil available nitrogen was recorded under the treatment T_0 (Control). Maximum available soil phosphorus was recorded under the treatments T_5 and T_6 (15.07 kg per ha and 15.03 kg per ha each) during the two years of the experiment, respectively (Table 6). Maximum soil available potassium was recorded under the treatment T_7 (242.67 kg per ha and 242.33 kg per ha during the two years of the experiment, respectively) (Table 6). Minimum soil available potassium (237.33 kg per ha and. Minimum soil available potassium was recorded under the treatment T_0.

***Conclusion*:** In conclusion, it can be summarized that application of FYM @ 30t/ha + 1/2 of the recommended dose of NPK through chemical fertilizer resulted in superior overall quality parameters in potato as compared to all the treatments under consideration. The data related to soil nutrient status was variable with no treatment standing out clearly. However, this integrated nutrient application approach in potato can overcome the quality related issues in potato.

However, including more viable sources of nutrients for enhancing the scope of the nutrient pool can be looked in to in the future research studies. Exploring more readily available and rich sources of organic nutrients can be fruitful in quenching the nutrient hunger of the plants and making the cultivation less dependent on inorganic fertilizers. Also organic manures being a non-standard source of nutrients, the

Table 6. Effect of integrated nutrient management on available N, available P and available K percentage under potato cultivation.

Treatments	Available Nitrogen (Kg per ha)				Available Phosphorus (Kg per ha)				Available Potassium (Kg per ha)			
	Before sowing (2022)	**After sowing (2022)**	**Before sowing (2023**	**After sowing (2023)**	**Before sowing (2022)**	**After sowing (2022)**	**Before sowing (2023**	**After sowing (2023)**	**Before sowing (2022)**	**After sowing (2022)**	**Before sowing (2023**	**After sowing (2023)**
T_0	130.00	130.17	131.00	130.83	14.20	14.47	14.10	14.43	230.00	237.33	232.00	238.00
T_1	130.00	131.00	131.00	131.67	14.20	14.53	14.10	14.47	230.00	240.33	232.00	240.00
T_2	130.00	131.67	131.00	131.83	14.20	14.73	14.10	14.70	230.00	240.67	232.00	240.33
T_3	130.00	133.17	131.00	134.00	14.20	14.90	14.10	14.87	230.00	239.67	232.00	239.33
T_4	130.00	136.83	131.00	137.67	14.20	14.97	14.10	14.90	230.00	241.33	232.00	241.00
T_5	130.00	136.17	131.00	136.83	14.20	15.07	14.10	15.03	230.00	241.67	232.00	241.33
T_6	130.00	134.83	131.00	135.83	14.20	15.07	14.10	15.03	230.00	240.33	232.00	240.00
T_7	130.00	134.17	131.00	135.50	14.20	14.97	14.10	15.00	230.00	242.67	232.00	242.33
T_8	130.00	134.33	131.00	134.33	14.20	14.90	14.10	14.90	230.00	240.33	232.00	240.67
T_9	130.00	133.83	131.00	134.67	14.20	14.83	14.10	14.80	230.00	240.33	232.00	240.00
S.Em. (±)	NS	0.51	NS	0.56	NS	0.11	NS	0.59	NS	1.06	NS	0.69
C.D. (at 5%)	NS	1.11	NS	1.12	NS	0.20	NS	1.02	NS	2.21	NS	1.24

study highlights the results based on specific organic manures and nutrient carrying capacity of similar organic manures may differ at different locations. Govt. has initiated various policies like Strengthening of Organic Fertilizer Production Laboratories / Program to Encourage the Use of Organic Fertilizer to encourage organic production of crops. Extension workers can take a lead role in guiding the local farming community through extension programs and front-line demonstrations (FLDs) so that integrated nutrient management can be adopted on a larger scale. Long term studies will reflect the effect of integrated nutrient management strategies on soil health and crop production. Soil microbe interaction studies can be taken up for efficient uptake of nutrients from the soil. Enrichment of organic manures using bio cultures can be a new window to making organic manures more effective.

***Authors contributions statement*:** Devesh Tiwari and Sanjeev Kumar designed, completed the experiments; Digvijay Dubey, Sharad Sachan and Jitendra Singh prepared the draft, Sunil Kumar, Deepak Kumar and Atin Kumar reviewed and finalized the draft.

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***SDGs addressed*:** Zero Hunger, Good Health and Well-being, Responsible Consumption and Production and Climate Action.

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