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UNLOCKING THE POTENTIAL OF SPRING MAIZE (*ZEA MAYS* L.) THROUGH THE RESIDUAL EFFECTS OF POLYHALITE APPLIED TO POTATO ON SUBSEQUENT YIELDS, N P K S AVAILABILITY AND NUTRIENT UPTAKE

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ABSTRACT

This study was undertaken during the spring season of 2020-21 at the Crop Research Centre of Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut-250110, focusing on the residual impact of polyhalite applied to a preceding potato crop on maize. The experimental field, characterized by sandy loam soil with a slightly alkaline pH, exhibited low levels of available nitrogen and sulphur, and medium levels of phosphorus and potassium. The experimental design included 13 treatments from the previous potato cultivation, ranging from common fertilizer applications to various proportions of RDF NP with POLY-4 and MOP, arranged in a randomized block design with three replications. To assess the residual effects on maize, 75% of the recommended nitrogen and phosphorus doses were applied. The results indicated that the application of RDF NP and 150% of RDF K by POLY-4 (T7), followed by RDF NP and 25% K by MOP + 75% by POLY-4 (T11) in the preceding crop, significantly enhanced yield, nutrient uptake, nutrient availability in the soil, and economic returns. Polyhalite showed superiority over MOP as a potassium source, with the magnitude of the residual effects varying by potassium source application. The enhanced residual impact of optimal potassium application to the preceding crop suggests that nutrient management strategies should be developed with a focus on crop sequencing, highlighting polyhalite's potential as an effective potassium source.

Keywords: Maize, Polyhalite, Residual, Potassium, Yield, Sustainability.

Introduction

Belonging to the Poaceae family and originating from Central America and Mexico, Maize (Zea mays L.) stands out for its unparalleled genetic yield potential among grains, earning the title "Queen of Cereals." It thrives across various parts of India throughout the year, serving as crucial forage for dairy animals (Bryan, 2019). With its cultivation spreading over about 9.57 million hectares nationwide, maize is celebrated for its C4 photosynthesis efficiency, enabling substantial fodder yield within a brief period. Its remarkable versatility and adaptability have made maize a staple crop under diverse agro-climatic conditions, with a global cultivation footprint of nearly 190 million hectares across 165 countries, contributing to 39% of worldwide grain production. The United States leads in maize production, accounting for 36% of global output and significantly bolstering its economy (Li *et al*., 2022.). In India, maize cultivation is year-round, primarily during the kharif season, covering 85% of its cultivation area. Ranking third after rice and wheat in terms of importance, maize contributes to about 10% of India's total food grain production and serves as a primary raw material in numerous industries, including starch, oil, protein, alcoholic beverages, and more. The nutritional profile of maize grain includes 8-10% protein, 4-5% oil, 70% carbohydrate, 2.3% crude fiber, and essential amino

acids like tryptophan and lysine (Nuss, *et al.*, 2010). Despite its global dominance in grain production, surpassing both wheat and rice, only a fraction of maize is consumed directly by humans, with the bulk being processed into products like corn ethanol and animal feed. In terms of cultivation in India, significant maize-producing states include Karnataka, Madhya Pradesh, and Bihar, each with notable area, production, and productivity figures (Malo, 2020). Maize's adaptability makes it a key player in crop diversification and integral to various cropping systems, including the promising maize-wheat rotation. Its responsiveness to nutrient management, both organic and inorganic, highlights the importance of tailored fertilization practices to meet soil and plant needs efficiently (Ejoh. and Onyeulo, 2022). Innovations in fertilizer technology, like the introduction of POLY-4, a multi-nutrient and low-chloride fertilizer, demonstrate the evolving landscape of agricultural inputs. Derived from the naturally occurring mineral polyhalite, POLY-4 offers a sustainable fertilization option, delivering essential nutrients to crops while minimizing environmental impact (Ashogbon, 2022). The study on the residual effects of nutrients applied to potatoes on subsequent spring maize crops underscores the ongoing research and development efforts to enhance agricultural productivity and sustainability.

Materials and Methods

The field experiment was conducted during the 2020–2021 season at the Crop Research Centre, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India. The experimental site is located at 29°04′ N latitude and 77°42′ E longitude, at an elevation of 228 m above mean sea level. The area is characterized by semi-arid subtropical climate, flat topography and good drainage conditions. During winter, minimum temperature may fall to 3°C, whereas summer temperatures during June may rise up to 36–38°C. During the maize growing period, weekly temperatures ranged between 24.9°C and 38.5°C. The mean maximum temperature varied from 38.5°C in May to 38.1°C in June, whereas minimum temperatures ranged from 11.3°C to 27°C. Weekly relative humidity ranged from 22.0% to 94.8%, total rainfall during the cropping period was 136.4 mm, and weekly sunshine hours varied from 6.3 to 11.0 h. Before sowing, a composite soil sample (0–15 cm depth) was collected from each plot of the experimental field, air-dried, processed and analyzed for physical and chemical characteristics using standard procedures. The soil of the experimental site was sandy loam, slightly alkaline in reaction, medium in available phosphorus and potassium, but low in organic carbon, available nitrogen and sulphur. The experiment was laid out in a Randomized Block Design (RBD) comprising 13 treatment combinations with three replications, resulting in a total of 39 plots. Each plot size was 4.0 m × 3.6 m (14.4 m²), with 2.0 m wide irrigation channels. The crop was planted at spacing of 60 cm × 20 cm using maize variety Pioneer 1844 with a seed rate of 25 kg ha⁻¹. Furrows were opened using a junior planter at 7–8 cm depth and sowing was done manually to maintain approximately 5 plants per meter row length. The treatment structure was designed to evaluate the effect of potassium sources and sulphur management under recommended fertilization schedule. The treatments consisted of nutrient application through common fertilizers and combinations of potassium supplied through POLY-4 and MOP, along with sulphur supplementation through betonies. The treatment T1 received the full recommended dose of fertilizers (RDF) of N, P, K and S through conventional fertilizers. Treatment T2 consisted of RDF of N and P only, excluding potassium and sulphur (no-K, no-S). Treatment T3 received RDF of N, P and S, without potassium (no-K), while T4 received RDF of N, P and K, excluding sulphur (no-S). Treatments T5, T6 and T7 were designed to replace potassium using POLY-4, where RDF of N and P was applied along with 50% (T5), 100% (T6) and 150% (T7) of RDF K supplied through POLY-4. Treatments T8, T9 and T10 were kept as comparative treatments for T5, T6 and T7, respectively, where RDF of N and P was applied and potassium was supplied through MOP, while sulphur requirement equivalent to the respective POLY-4 based treatments was supplemented through bentonite sulphur. Specifically, T8 received 50% RDF K through MOP plus sulphur equal to T5 via bentonite, T9 received 100% RDF K through MOP plus sulphur equal to T6 via bentonite, and T10 received 150% RDF K through MOP plus sulphur equal to T7 via bentonite. Treatments T11, T12 and T13 were designed to study partial replacement of MOP with POLY-4 at different ratios, where RDF of N and P was applied and potassium was supplied as 25% through MOP + 75% through POLY-4 (T11), 50% through MOP + 50% through POLY-4 (T12) and 75% through MOP + 25% through POLY-4 (T13). Nitrogen was applied through urea and phosphorus through DAP as per the treatment schedule. Nitrogen was applied in split doses, with 50% as basal at sowing and the remaining at knee-high stage (30–35 DAS), while phosphorus was applied completely as basal. Yield observations were recorded as per standard procedures. Grain yield was recorded by harvesting all cobs from net plot area, shelling,

drying and weighing plot-wise, and then converting to hectare basis expressed as t ha^{-1}. Stover yield was recorded by cutting maize plants close to ground level from net plot, weighing plot-wise and converting to hectare basis on dry matter basis, expressed as t ha^{-1}. Harvest index was computed using the formula: Harvest Index (%) =Economic yield (kg ha^{-1})/Biological yield (kg ha^{-1}) ×100.Soil samples collected before sowing and after harvest were analyzed for available nutrients. Available nitrogen was determined using alkaline $KMnO_4$ method (Subbiah and Asija, 1956), available phosphorus by Olsen's sodium bicarbonate method (Olsen *et al.*, 1954), available potassium using neutral ammonium acetate extraction (Hanway and Heidal, 1952) and available sulphur using $CaCl_2 \cdot 2H_2O$ extractant followed by spectrophotometric estimation. Plant samples (grain and stover) were analysed for nutrient content. Total nitrogen was estimated using an automatic N analyzer, while for P, K and S, samples were wet digested in di-acid mixture. Phosphorus was estimated by vanado-molybdo phosphoric yellow colour method, potassium using flame photometer, and sulphur using spectrophotometer (Jackson, 1973). Nutrient uptake was calculated by multiplying nutrient content with respective dry matter yield. Economic analysis was carried out using local market rates of inputs and outputs. Cost of cultivation was computed treatment-wise (Rs. ha^{-1}), gross returns were calculated using MSP of maize grain for the subsequent year and stover was priced as per local market, and net returns were obtained by subtracting cost of cultivation from gross returns. Benefit: cost ratio (B:C) was calculated using :B:C=Net returns (Rs. ha^{-1})/Cost of cultivation (Rs. ha^{-1}). The recorded data were statistically analysed using the procedure described by Gomez and Gomez (1984).

Result and Discussion

Effect on Yield and Yield Attributes

The residual effect of different nutrient management treatments significantly influenced maize grain yield, stover yield, biological yield and harvest index (Graph 1). Among all treatments, RDF NP + 150% RDF K through POLY-4 (T7) produced the maximum grain yield (5.9 t ha^{-1}), stover yield (7.2 t ha^{-1}) and biological yield (13.1 t ha^{-1}), with a harvest index of 45.0%, indicating that increased residual K supply through POLY-4 substantially improved maize productivity. In contrast, the imbalanced fertilization treatment RDF N and P (T2; no-K, no-S) recorded the lowest yields, highlighting the importance of balanced NPKS nutrition for optimum crop performance.

Treatments receiving sulphur through bentonite, particularly in combination with MOP and POLY-4, also improved yield expression compared to non-sulphur treatments, suggesting a supportive role of residual sulphur in nutrient use efficiency. The superior performance of T7 may be attributed to improved residual availability of major nutrients (N, P, K and S), which enhanced vegetative growth, photosynthesis and dry matter accumulation. Potassium plays a key role in assimilate translocation and grain filling, while nitrogen enhances leaf area and photosynthetic capacity (Watson, 1952). Stover yield under T7 increased by about 50% over T3 (RDF NP + S; no-K), likely due to improved plant height, functional leaves and biomass accumulation. Similar trends for yield improvement under balanced fertilization and enhanced nutrient sources have been reported by Bindraban *et al.* (2018; 2020), Baloyi *et al.* (2012), Verma *et al.* (2022), Goyal *et al.* (2023) and Voss *et al.* (2024). The harvest index remained non-significant across treatments, possibly due to proportional increases in grain and stover yields, as also reported by Mahala *et al.* (2006), Tetarwal *et al.* (2011) and Mukherjee (2014).

Effect on Nutrient Content and Uptake (NPKS) in Maize

The residual effect of fertilizer management practices significantly influenced N, P, K and S content and uptake in maize grain and stover (Table 1). Among treatments, RDF NP + 150% RDF K through POLY-4 (T7) recorded the highest nutrient concentration and uptake, indicating superior nutrient assimilation under enhanced residual potassium availability. Under T7, nitrogen content was maximum in grain (1.74%) and stover (0.51%), resulting in the highest total N uptake (140.2 kg ha^{-1}). Similarly, the maximum uptake of P (44.0 kg ha^{-1}), K (141.7 kg ha^{-1}) and S (35.0 kg ha^{-1}) was also recorded in T7. These results suggest a synergistic interaction among NPKS nutrients under POLY-4, leading to improved crop growth and nutrient use efficiency. In contrast, treatments without potassium and sulphur (no-K, no-S) showed comparatively lower nutrient uptake, confirming that imbalanced fertilization reduces nutrient absorption and crop nutritional status. Higher nutrient uptake under T7 was mainly attributed to improved vegetative growth and biomass production, as nutrient uptake is directly related to dry matter accumulation and yield formation. Bentonite-based treatments (especially with MOP + POLY-4) also improved nutrient uptake over non-sulphur treatments, likely due to enhanced nutrient retention and gradual release; however, the effect remained lower than higher POLY-4 substitutions,

indicating POLY-4 as the major factor. Similar improvements in nutrient uptake under balanced and efficient fertilization have been reported by El-Fouly *et al*. (2012), Ayeni *et al*. (2012), Keerthi *et al*. (2013) and Sofyan *et al*. (2019). Uptake through stover also varied significantly, with the highest NPKS uptake under T7 due to better plant growth attributes and higher dry matter accumulation, which is consistent with earlier reports of Parmar and Sharma (2001), Karki *et al*. (2004), Mahala *et al*. (2006), Jamwal (2006), Meena *et al*. (2011) and Kumar and Hiremath (2015).

Available NPKS in soil after harvest of maize crop

The residual effect of different fertilization treatments influenced the availability of N, P, K and S in soil after maize harvest (0–15 cm). The treatment RDF NP + 50% K through MOP + 50% K through POLY-4 (T12) recorded the highest available nitrogen (248.3 kg ha^{-1}) and available potassium (170.2 kg ha^{-1}), indicating improved nutrient retention through integrated use of conventional and POLY-4 sources. POLY-4 based treatments generally enhanced sulphur availability, and the highest available sulphur (12.6 mg kg^{-1}) was observed under RDF NP + 50% RDF K through POLY-4 (T5). Bentonite-based treatments also improved soil sulphur status, suggesting its role in nutrient retention and gradual sulphur release. Available phosphorus showed relatively small and inconsistent variation among treatments. Statistical analysis indicated significant differences in available K and S, whereas variations in available N and P were non-significant. Similar improvements in soil fertility and residual nutrient availability under balanced fertilization have also been reported by Kakar *et al*. (2014), Karki *et al*. (2005), Ojo *et al*. (2011) and Asghar *et al*. (2010).

Economics

Economic analysis of maize cultivation under different fertilization treatments revealed wide variation in net returns and benefit–cost (B:C) ratio, indicating the strong influence of nutrient management strategy on profitability (Graph 2). Among the treatments, RDF NP + 150% of RDF K through POLY-4 (T7) proved most remunerative and recorded the highest net return (Rs. 85,378 ha^{-1}) along with the maximum B:C ratio (2.18). This clearly indicates that higher substitution of potassium through POLY-4 enhanced economic gains due to improved crop performance and yield advantage. In contrast, the conventional treatment RDF N and P (no-K, no-S) resulted in the lowest net return (Rs. 41,913 ha^{-1}) and minimum B:C ratio (1.07), reflecting the economic limitation of imbalanced fertilization and the importance of K and S in improving yield and profitability. The economic trend further showed that net realization generally increased with increasing fertilizer efficiency and improved productivity under POLY-4 based treatments. Treatment T11 also performed well and recorded net returns of Rs. 82,775 ha^{-1}, ranking second after T7. The higher profitability in T7 was mainly attributed to increased grain yield and improved yield attributes under enhanced potassium management, which increased gross returns sufficiently to offset the higher input cost. These results emphasize that while economics must be considered for sound recommendations since high input cost may sometimes make effective treatments uneconomical the POLY-4 based strategy remained economically superior under the present study. Similar findings on improved profitability and economic viability under efficient and innovative fertilizer management have been reported by Bindraban *et al*. (2020), Kumar (2008), Chandel *et al*. (2014), Kumar *et al*. (2020) and Kumar and Dhar (2010). Overall, the study confirms that adoption of POLY-4 based potassium management, particularly at higher levels, is economically viable and offers a sustainable approach to maximize returns in maize cultivation.

Conclusion

This study conclusively demonstrates the significant residual effects of polyhalite applied to potato crops on the subsequent performance of spring maize (*Zea mays* L.). By meticulously analyzing yields, nutrient uptake, NPKS availability and economics we've identified a clear correlation between prior nutrient applications and enhanced growth parameters in maize. Specifically, the application of a balanced nutrient regimen in potato cultivation has been shown to positively impact the yield and nutrient dynamics of the following maize crop, highlighting the importance of strategic nutrient management across crop rotations. The findings suggest application of RDF NP and 150% of RDF K by POLY-4 followed by RDF NP and 25% K by MOP + 75% by POLY-4 careful planning and execution in a crop sequence can lead to sustainable improvements in crop productivity, soil health and Economics. This study paves the way for future research focused on optimizing crop rotation strategies to enhance overall agroecosystem efficiency.

Fig. 1: Effect of residual nutrients on yield of maize.

Table 1: Effect of residual nutrients on NPKS content and uptake by maize

Treatments	Nitrogen content (%)		Nitrogen uptake (kg ha⁻¹)			Phosphorus content (%)		Phosphorus uptake (kg ha⁻¹)			Potassium content (%)		Potassium uptake (kg ha⁻¹)			Sulphur content (%)		Sulphur uptake (mg ha⁻¹)		
	Grain	Stover	Grain	Stover	Total	Grain	Stover	Grain	Stover	Total	Grain	Stover	Grain	Stover	Total	Grain	Stover	Grain	Stover	Total
DF NPK and S (Common fertilizers)	1.58	0.35	73.4	17.8	91.2	0.32	0.18	14.8	9.1	24.0	0.31	1.53	14.4	78.0	92.4	0.33	0.09	15.3	4.6	19.9
DF N and P (no-K, no-S) (Common fertilizers)	1.48	0.32	57.0	15.4	72.5	0.30	0.16	11.5	7.7	19.2	0.29	1.48	11.1	71.3	82.5	0.31	0.08	11.9	3.8	15.8
DF NP and S (no-K)(Common fertilizers)	1.43	0.30	53.2	14.4	67.6	0.29	0.15	10.7	7.2	18.0	0.28	1.47	10.4	70.5	80.9	0.30	0.07	11.1	3.4	14.5
DF NP and K (no-S)(Common fertilizers)	1.53	0.33	62.7	16.4	79.1	0.31	0.17	12.7	8.4	21.2	0.30	1.51	12.3	75.0	87.3	0.31	0.08	12.7	4.0	16.6
DF NP and 50% of RDF K by POLY-4	1.63	0.40	85.2	27.3	112.5	0.34	0.21	17.7	14.3	32.1	0.34	1.56	17.7	106.7	124.4	0.36	0.11	18.8	7.5	26.3
DF NP and 100% of RDF K by POLY-4	1.67	0.44	90.2	31.4	121.7	0.36	0.24	19.4	17.1	36.6	0.36	1.59	19.4	113.6	133.1	0.38	0.12	20.5	8.5	29.1
DF NP and 150% of RDF K by POLY-4	1.74	0.51	103.4	36.8	140.2	0.40	0.28	23.8	20.2	44.0	0.38	1.65	22.6	119.1	141.7	0.42	0.14	24.9	10.1	35.0
DF NP+ 50% of RDF K by MOP+50% of DF S equal to T5 by Bentonite	1.62	0.38	81.3	20.7	102.0	0.33	0.20	16.6	10.9	27.4	0.33	1.57	16.6	85.5	102.1	0.32	0.09	14.6	4.9	19.5
DF NP+ 100% of RDF K by MOP+100% of DF S equal to T6 by Bentonite	1.60	0.39	79.3	21.5	100.9	0.31	0.19	15.4	10.5	25.9	0.32	1.55	15.9	85.5	101.4	0.34	0.10	16.8	5.5	22.3
DF NP+ 150% of RDF K by MOP+150% of DF S equal to T7 by Bentonite	1.61	0.40	82.3	22.0	104.2	0.33	0.21	16.8	11.5	28.4	0.36	1.59	18.4	87.4	105.8	0.35	0.09	17.8	4.9	22.8
DF NP and 25% K by MOP + 75% by POLY	1.72	0.47	100.0	33.3	133.3	0.39	0.26	22.7	18.4	41.1	0.37	1.63	21.5	115.5	137.1	0.41	0.13	23.8	9.5	33.0
DF NP and 50% K by MOP + 50% by POLY	1.69	0.49	95.3	34.3	129.6	0.38	0.25	21.4	17.5	38.9	0.37	1.61	20.8	112.8	133.7	0.39	0.12	22.0	8.4	30.4
DF NP and 75% K by MOP + 25% by POLY	1.65	0.42	87.4	28.5	115.9	0.35	0.23	18.5	15.6	34.1	0.35	1.58	18.5	107.2	125.8	0.37	0.11	19.6	7.4	27.0
SEm±	0.05	0.02	2.9	0.9	3.9	0.01	0.008	0.6	0.4	1.1	0.012	0.05	0.6	3.4	4.1	0.013	0.005	0.65	0.23	0.89
CD (at 5%)	0.17	0.05	8.7	2.7	11.5	0.03	0.02	1.8	1.4	3.3	0.03	NS	1.8	10.1	12.0	0.038	0.007	1.93	0.68	2.62

Table 2: Effect of residual nutrients on Available NPKS in soil after harvest of maize crop.

Treatments	Available N (Kg ha⁻¹)	Available P (kg ha⁻¹)	Available K (kg ha⁻¹)	Available Sulphur (mg ha⁻¹)
RDF NPK and S (Common fertilizers)	176.4	12.1	161.2	9.9
RDF N and P (no-K, no-S) (Common fertilizers)	204.0	11.8	126.9	9.1
RDF NP and S (no-K) (Common fertilizers)	208.6	13.5	138.1	10.0
RDF NP and K (no-S)(Common fertilizers)	204.8	10.3	154.9	8.8
RDF NP and 50% of RDF K by POLY-4	215.3	13.6	141.4	12.6
RDF NP and 100% of RDF K by POLY-4	209.4	13.5	157.9	10.5
RDF NP and 150% of RDF K by POLY-4	196.5	14.1	167.2	12.1

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RDF NP+ 50% of RDF K by MOP+50% of RDF S equal to T5 by Bentonite	192.3	13.0	157.5	10.9
RDF NP+ 100% of RDF K by MOP+100% of RDF S equal to T6 by Bentonite	212.4	12.6	156.8	11.2
RDF NP+ 150% of RDF K by MOP+150% of RDF S equal to T7 by Bentonite	224.9	14.9	153.4	11.8
RDF NP and 25% K by MOP + 75% by POLY-4	201.1	12.5	159.7	11.9
RDF NP and 50% K by MOP + 50% by POLY-4	248.3	12.9	170.2	11.7
RDF NP and 75% K by MOP + 25% by POLY-4	217.4	12.6	168.7	11.2
SEm±	11.6	1.46	8.24	0.43
CD (at 5%)	NS	NS	24.1	1.26
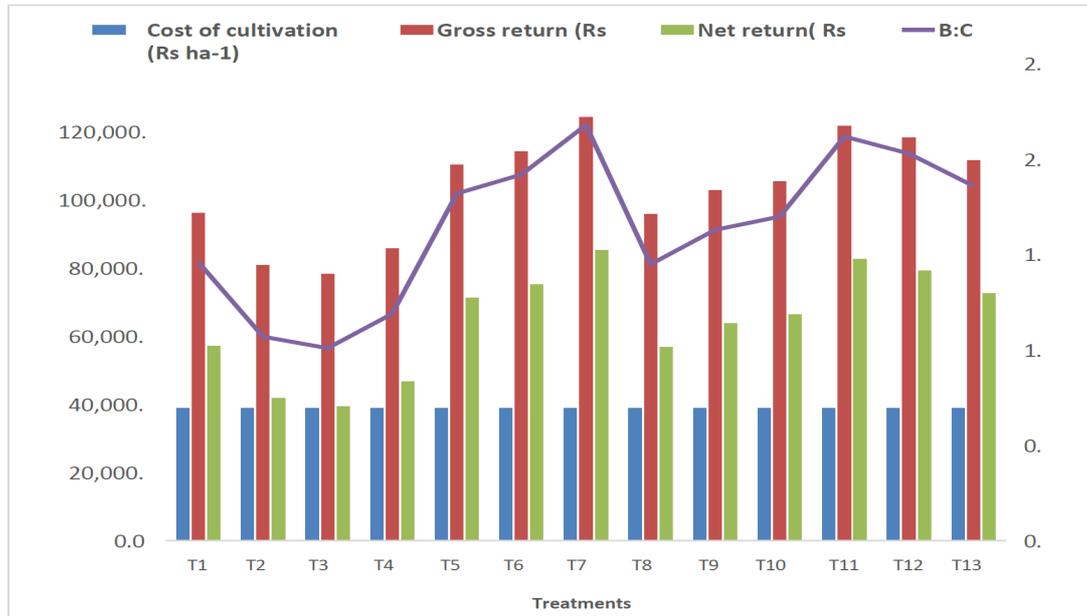
Fig. 2: Effect of residual nutrients on economics of maize

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