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INFLUENCE OF MAIZE CROP RESIDUE MANAGEMENT PRACTICES AND FERTILITY LEVELS ON GROWTH, YIELD ATTRIBUTES, YIELD AND ECONOMICS OF *RABI* MAIZE IN A MAIZE-MAIZE CROPPING SYSTEM UNDER THE PENINSULAR ZONE

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ABSTRACT

A field experiment was conducted during *Kharif* and *Rabi* seasons of 2020-21 to 2023-24 (four years of study on a sandy clay loam soil at the Agricultural Research Station, Karimnagar to study the growth, yield attributes, yield and economics of *Rabi* maize as influenced by *kharif* maize crop residue management practices and fertility levels in maize-maize cropping system. The experiment was laid out in split-plot design with four maize crop residue management practices (M_1: Residue removal, M_2: Residue incorporation, M_3: Residue incorporation + spray of microbial consortium on residue M_4: Zero-tillage + residue retention and spray of microbial consortia on residue as main plot treatments and three fertility levels (100%RDF of NPK, 100% RDN & RDP and 50% RDK and 90% RDN,75%RDP and 75% RDK) as sub plot treatments. The incorporation of maize stover with rotovator indicated significant effect on growth, yield attributes, yield and economics of maize compared to *kharif* maize residual removal treatment during four years of experiment (2020-21 to 2023-24). Among the three fertilizer levels, application of 100%RDF of NPK significantly improved the growth, yield attributes, yield and economics of maize compared to 90% RDN, 75% RDP and 75% RDK treatment. Combined use of incorporation of maize stover with rotovator along with application of 100% RDF resulted significantly more cob length, higher number of kernels row^{-1}, grain yield, stover yield, gross returns, net returns and B:C ratio, system productivity, production efficiency over residue removal with 100%RDF.

Key words : Maize, Residue management, Fertilizer levels, Physico-chemical properties, Economics.

Introduction

Maize is a miracle crop because of its highest yield potential among cereals and it is third most widely grown crop of India after rice and wheat. It has myriad of uses in food, feed and industrial segment. It can play a vital role in ensuring food and nutritional security for India. Its adaptability and economic uses is probably unmatched by any other cereals. In India, maize covers 9.96 M ha of area, with a production of 32.47 million tonnes and productivity of 3260 kg ha^{-1} (Ministry of Agriculture and Farmers Welfare, 2023-24), while in Telangana it is grown in an area of 4.28 lakh hectares with a production of 24.78 lakh tonnes and productivity of 5791 kg ha^{-1} (Ministry of Agriculture and Farmers Welfare, 2023-24). Maize-maize systems are predominantly practiced in the southern parts of India. High-yielding maize-maize system extracts more nutrients, particularly N, P, or K, than rice-maize systems or rice-wheat (Yadvinder Singh, 2005). India generates 516 mt of total crop residue annually, where of, maize contributes 110 mt, respectively (Sahu *et al*., 2021). Management of stover after maize harvests poses an enormous challenge to all maize farmers around the globe. The maize stover is most often harvested in dried condition and packaged in large heaps to use as fodder in later date or in lean seasons. Now a days, the use of maize stalk as animals fodders gradually decreasing and instances of on field burning of stover increasing due to non-availability of agriculture labor for timely harvesting, increase in transportation costs, lack of sufficient time to take up next season crops. Instead of resorting to such practices, if managed to slash, shred and spread in the field evenly using machinery, this help in protecting soil and land resources from erosion. Fertilizer application is one of the most expensive costs for cereal crops growers and yet much of the N, P and K used to supplement crop needs are lost to the environment due to the low nutrient use efficiency of cereal crops. Over or under nitrogen, phosphorus and potassium fertilizer application can lead to a reduction in crop yield, in addition to creating conditions, which favor nutrient losses to the environment, poor soil quality and plant nutrition. Therefore, there is a need for improved nutrient management strategies, in particular N, P and K under different scenarios like removed, surface retention or incorporated residue management to properly replace nutrients, ensure proper plant nutrition and maintain consistent grain yield.

Materials and Methods

An experiment was conducted during *Kharif* and *Rabi*, 2021-22 to 2023-24 at ARS, Karimnagar situated at 790 51E longitude and 180 301 latitudes with an elevation of 259.15 above mean sea level. It is covered under Northern Telangana agro-climatic zone of Telangana state which falls under semi-arid climate. The experimental site was sandy loam soils having neutral pH 7.65, EC of 0.25 ds/m, OC of 0.53%, low in available N of 161 kg/ha, high in available P of 28 kg/ha and high in available K of 372 kg/ha. The experiment was conducted with four maize crop residue management treatments *viz.*, M_1: Residue removal, M_2 : Residue incorporation , M_3 : Residue incorporation + spray of microbial consortium on residue M_4: Zero-tillage + residue retention and spray of microbial consortia on residue as main plot treatments and three fertility levels (100%RDF of NPK, 100% RDN & RDP and 50% RDK and 90% RDN, 75%RDP and 75% RDK) as sub plot treatments which was replicated thrice. The experiment was carried out on sandy clay loam soils of Agricultural Research station, Karimnagar during *kharif* and *Rabi* seasons of 2020-21 to 2023-24. The test variety used for sowing was DHM-117 and crop was sown at 60 cm and 20 cm inter and intra row distance, respectively and adopted all the standard package of practices. The nutrients, namely urea, diammonium phosphate and muriate of potash, were applied according to the respective treatments. Nitrogen was divided into three equal split doses, which were applied during three stages *viz.*, sowing, knee high and flowering stage. Entire quantity of phosphorus and half dose of potassium were applied at the time of sowing. Remaining dose of potassium was applied at flowering stage of the crop. After harvest of maize cobs, residues of the maize crop were retained. Maize residues were added as per treatment in the four main plots. Microbial consortium: Consists of decomposers belonging to genera *Phanerochaeta*, *Asperigillus*, *Trichoderma*. In residue removal plots, the residues were completely removed after harvest of the crop. The data on growth attributes, yield attributes, yield and economics were recorded as per standard procedures. Measurement of growth parameters, yield attributes, yield and economics. Grain and straw yield were computed by harvesting crop from the net plots leaving border area of 50 cm from each side. Harvested produce was sundried, bundled and brought to thrashing floor and threshed separately. Economics of each treatment were calculated considering the current market price of each input and output during the years of experimentation. Gross returns were computed based on market price of maize grain prevailing during study years. Net return was obtained by subtracting cost of cultivation from the gross return. However, B: C ratio was calculated dividing gross returns by cost of cultivation.

Statistical analysis

All the experimental data were statistically analyzed using OPSTAT software.

Results and Discussion

Growth parameters

The data pertaining to plant height was no significant impact of crop residue incorporation as well as fertilizer levels on plant height of maize over residue removal treatment. Plant height of maize under different maize crop residue management practices was observed between 213.4 and 216.4cm (Table 1). Increase in plant height in residue incorporated plot after spraying of microbial consortium on maize residue may be attributable to greater nutrient availability during crop growth stages, which may have increased nitrogen absorption by the roots for the synthesis of protoplasm necessary for rapid cell division, increasing plant height. The present findings are in similarity with the earlier findings by Harinarayan (2017), Shaikh *et al.* (2020) and Khatri *et al.* (2020).

No significant difference was observed with plant height at harvest due to different nutrient management treatments. Ear height at harvest was not significantly influenced by different maize crop residue management practices and nutrient management treatments.

Table 1 : Growth, Yield attributes of *Rabi* maize as influenced by maize crop residue management practices and fertilizer levels in maize-maize system (Pooled mean of 4 years (2020-21 to 2023-24).

Treatment	Plant height (cm)at harvest	Ear height (cm) at harvest	Cob length (cm)	Cob girth (mm)	Number of kernel rows cob^{-1}	Number of kernels row^{-1}	Shelling %	Test weight (g)
Residue management								
M_1: Residue removal	215.1	108.7	18.67	53.31	15.1	35.7	76.8	35.16
M_2: Residue incorporation	213.8	106.0	20.01	53.12	15.5	37.2	76.9	35.43
M_3: Residue incorporation + spray of microbial consortium on residue	216.4	108.0	20.42	53.80	15.6	38.8	76.9	36.17
M_4: Zero-tillage + residue retention and spray of microbial consortia on residue	214.5	107.4	19.66	54.05	15.5	37.7	76.5	35.46
SEm±	2.5	0.8	0.20	0.30	0.1	0.3	0.3	0.47
CD (p=0.05)	NS	NS	0.70	NS	NS	0.9	NS	NS
Nutrient management								
N1:100%RDF of NPK	216.8	108.7	20.35	53.60	15.4	38.7	76.8	35.79
N2: 100% RDN & RDP and 50% RDK	214.6	107.1	19.46	53.44	15.5	36.8	76.7	35.25
N3: 90% RDN,75% RDP and 75% RDK	213.4	106.8	19.26	53.67	15.4	36.6	76.9	35.62
SEm ±	1.3	0.7	0.15	0.34	0.1	0.3	0.2	0.35
CD (p=0.05)	NS	NS	0.46	NS	NS	1.0	NS	NS
Interaction (N XR)								
SEm ±	4.4	1.3	0.35	0.52	0.2	0.5	0.6	0.81
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (R XN)								
SEm ±	3.3	1.4	0.32	0.63	0.2	0.6	0.5	0.73
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Yield attributes of maize

Among the various maize crop residue management practices influence significant effect on yield attributing characters of maize crop except cob girth, number of kernel rows cob^{-1} , Shelling %, 100 grain weight.

Pooled data (2020-21 to 2023-24) indicated that, among different crop residue management treatments, significantly higher cob length, number of kernels row^{-1} of *Rabi* maize in maize-maize cropping system was recorded with Residue incorporation + spray of microbial consortium on residue (20.42 cm and 38.8, respectively) which was on par with Residue incorporation (20.01 cm and 37.2, respectively) and Zero-tillage + residue retention and spray of microbial consortia on residue (19.66 cm and 37.7, respectively) compared to residue removal treatment (18.67cm and 35.7, respectively). Among different nutrient management treatments, significantly higher cob length, number of kernels row^{-1} of *Rabi* maize in maize-maize cropping system was recorded with 100%RDF of NPK (20.35cm and 38.7 respectively) over 90% RDN & 75% RDP & K (19.26 cm and 36.6, respectively). It might be attributed to a steady supply of sufficient nitrogen and its solubilization, which may have aided in more rapid cell division and expansion (Khatri *et al.*, 2020). Among the various fertilizer levels influence significant effect on yield attributing characters of maize crop except cob girth, number of kernel rows cob^{-1}, Shelling %, 100 grain weight during 2020-21 to 2023-24 years of experiment. However, cob length and number of kernels row^{-1} recorded significantly more with application of 100% RDF of NPK over 90% RDN & 75% RDP & K. This might be due to increase in more number of kernels row^{-1} coupled with higher nutrient uptake. These findings are in corroboration with those reported by Arif *et al.* (2011), Meena *et al.* (2015), Reddy *et al.* (2017) and Raghavendra *et al.* (2018). During all the years (2020-21 to 2023-24) of the experiment, the interaction effect between maize crop residue management practices and fertilizer levels was shown to be non significant.

Grain and stover yield

Among different crop residue treatments, significantly higher grain and stover yield of maize was recorded with Residue incorporation + spray of microbial consortium on residue (7990 kg ha^{-1} and 9362 kg ha^{-1}, respectively) which was on par with Zero-tillage + residue retention and spray of microbial consortia on residue (7739 kg ha^{-1} and 9070 kg ha^{-1}, respectively) over residual removal treatment (6892 kg ha^{-1} and 8568 kg ha^{-1}, respectively). This may be due to the fact that crop residues are rich in C, N and the cumulative release rates of crop residues were rapid within 90 days of incorporation, respectively (Wu *et al.*, 2011). Crop residues that are mixed with soil particles decompose faster than residues that are left on the soil surface. Through microbial degradation, incorporated maize stalks are transformed into different easily mineralizable form of soil organic matter. Plants absorb mineralized plant nutrients from soil solution both directly and indirectly. Incorporating crop residues recycles nutrients and increases soil organic matter. These results are consistent with the findings of Singh *et al.* (2011), Davari *et al.* (2012).

Among different nutrient management treatments, significantly higher grain yield of maize was recorded with 100% RDF of NPK (7970 kg ha^{-1} and 9337 kg ha^{-1}, respectively) over 90% RDN & 75% RDP & K (7331 kg ha^{-1} and 8657 kg ha^{-1}, respectively). The interaction between the residual treatments and nutrient management treatments was non-significant.

Higher grain yield might be due to higher availability of nutrients as evidenced from N, P and K content in grain and straw at harvest subscribes to the view that increased availability of growth inputs involved in the formation and development of yield components. This is due to the slow release and continuous supply of balanced amounts of nutrients during the different growth stages, allowing maize to absorb sufficient photosynthetic products and thus, increases the dry matter and source capacity, resulting in higher grain and straw yield.

Economics

The results pertaining to gross returns, net returns and B:C ratio of maize with different maize crop residue management practices and fertilizer levels indicated that there was significant difference among treatments (Table 2). Significantly increase in the gross returns (Rs. 1,54,413), net returns (Rs. 90,075) and B:C (2.40) by the incorporation of maize stover with rotovator after spray of microbial consortium on residue (M_3) was statistically comparable with Zero-tillage + residue retention and spray of microbial consortia on residue (M_4) recorded gross returns (Rs. 1,49,601), net returns (Rs. 88,957) and B:C ratio (2.47). The treatment removal of maize crop residue (M_1) recorded the least gross return, net return and B: C ratio was significantly inferior compared to other treatments during all successive years of study (2020-21 to 2023-24). Among the fertilizer levels, higher gross returns (Rs. 1,53,975), net returns (Rs. 89,971) and B:C ratio (2.41) application of 100% RDF (N_1) was ascribed to more monetary return owing to higher yield than the other treatments.

Table 2 : Grain yield,stover yield, gross return (Rs. ha^{-1}), net return (Rs. ha^{-1}), B:C ratio, System productivity and Production efficiency of *Rabi* maize as influenced by maize crop residue management practices and fertility levels in maize-maize system (Pooled mean of 4 years(2020-21 to 2023-24).

Treatment	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Gross returns (Rs. ha^{-1})	Net returns (Rs. ha^{-1})	B:C Ratio	System productivity (kg ha^{-1})	Production efficiency (kg ha^{-1} day^{-1})
Residue management							
M_1: Residue removal	6892	8568	132847	68732	2.07	13079	59.6
M_2: Residue incorporation	7595	8807	146513	83558	2.33	13686	62.2
M_3: Residue incorporation + spray of microbial consortium on residue	7990	9362	154413	90075	2.40	14387	65.6
M_4: Zero-tillage + residue retention and spray of microbial consortia on residue	7739	9070	149601	88957	2.47	14268	65.0
SEm±	85	77	1719	1719	0.03	143	0.6
CD (p=0.05)	298	271	6064	6064	0.10	504	2.2
Nutrient management							
N1:100%RDF of NPK	7970	9337	153975	89971	2.41	14377	65.5
N2: 100% RDN & RDP and 50% RDK	7361	8861	142270	79741	2.28	13704	62.4
N3: 90% RDN,75%RDP and 75% RDK	7331	8657	141286	78780	2.26	13485	61.5
SEm±	82	75	1605	1605	0.03	142	0.7
CD (p=0.05)	249	226	4852	4852	0.08	430	2.0
Interaction (N XR)							
SEm±	146	133	2977	2977	0.05	248	1.1
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS
Interaction (R XN)							
SEm±	159	144	3134	3134	0.05	273	1.2
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS

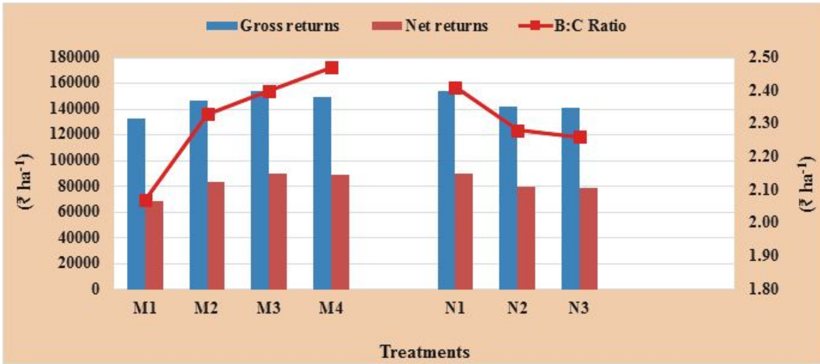

Fig. 1 : Gross return (` ha), net return (` ha) and B: C ratio of *Rabi* maize as influenced by *Kharif* maize crop residue management practices and nutrient levels.

Initial values	pH	EC (dS/m)	Organic carbon (%)	Available N (kg/ha)	Available P_2O_5 (kg/ha)	Available K_2O (kg/ha)
7.65	0.25	0.53	161	28	372	

Table 3 : Post -harvest status of available nutrients in soil of maize as influenced by different crop residue and nutrient management treatments of maize in maize – maize cropping system during *Rabi*, 2020-21, *Rabi*, 2021-22, *Rabi*, 2022-23 and *Rabi*, 2023-24.

Treatment	pH				EC(dSm^{-1})			
Residue management	**2020-21**	**2021-22**	**2022-23**	**2023-24**	**2020-21**	**2021-22**	**2022-23**	**2023-24**
M_1: Residue removal	7.39	7.32	7.27	7.5	0.20	0.19	0.25	0.21
M_2: Residue incorporation	7.09	7.04	7.16	7.46	0.21	0.20	0.26	0.24
M_3: Residue incorporation + spray of microbial consortium on residue	7.01	7.01	7.13	7.46	0.22	0.22	0.24	0.24
M_4: Zero-tillage + residue retention and spray of microbial consortia on residue	7.16	7.08	7.17	7.48	0.24	0.25	0.24	0.22
SEm±	0.05	0.05	0.05	0.05	0.00	0.00	0.01	0.01
CD (p=0.05)	0.17	0.16	NS	NS	0.01	0.01	NS	NS
Nutrient management								
N_1:100%RDF of NPK	7.09	7.04	7.18	7.46	0.20	0.20	0.24	0.22
N_2: 100% RDN & RDP and 50% RDK	7.25	7.15	7.19	7.47	0.26	0.25	0.26	0.24
N_3: 90% RDN,75%RDP and 75% RDK	7.15	7.14	7.17	7.5	0.20	0.19	0.24	0.22
SEm ±	0.07	0.07	0.06	0.07	0.00	0.00	0.01	0.01
CD (p=0.05)	NS	NS	NS	NS	0.01	0.01	NS	NS
Interaction (R XN)								
SEm ±	0.08	0.08	0.09	0.09	0.01	0.00	0.02	0.01
CD (p=0.05)	NS	NS	NS	NS	0.02	0.01	NS	NS
Interaction (N XR)								
SEm ±	0.12	0.12	0.12	0.12	0.01	0.00	0.01	0.01
CD (p=0.05)	NS	NS	NS	NS	0.02	0.01	NS	NS

Table 4 : Post-harvest status of available nutrients in soil of maize as influenced by different crop residue and nutrient management treatments of maize in maize – maize cropping system during *Rabi,* 2020-21, *Rabi,* 2021-22, *Rabi,* 2022-23 and *Rabi,* 2023-24.

Treatment	**OC (%)**				**Available N (kg ha^{-1})**			
Residue management	2020-21	2021-22	2022-23	2023-24	2020-21	2021-22	2022-23	2023-24
M_1: Residue removal	0.52	0.52	0.54	0.48	141.7	140.0	140.6	139.3
M_2: Residue incorporation	0.54	0.55	0.55	0.55	166.3	164.0	161.7	157.7
M_3: Residue incorporation + spray of microbial consortium on residue	0.53	0.53	0.57	0.58	172.1	171.0	176.7	171.0
M_4: Zero-tillage + residue retention and spray of microbial consortia on residue	0.53	0.54	0.52	0.51	159.1	155.0	154.7	155.0
SEm±	0.01	0	0.01	0	1.3	1.0	1.1	1.1
CD (p=0.05)	NS	0.01	0.02	0.01	4.6	3.6	3.9	3.8
Nutrient management								
N1:100%RDF of NPK	0.54	0.55	0.55	0.53	164.8	162.0	163.0	161.3
N2: 100% RDN & RDP and 50% RDK	0.52	0.52	0.56	0.52	153.8	152.0	159.7	156.0
N3: 90% RDN,75%RDP and 75% RDK	0.53	0.54	0.54	0.52	160.8	158.0	152.5	150.0
SEm ±	0.01	0.01	0.01	0.01	1.6	1.5	1.5	1.4
CD (p=0.05)	NS	0.02	0.02	NS	4.7	4.4	4.4	4.3
Interaction (R XN)								
SEm ±	0.02	0.01	0.01	0.01	2.2	1.8	1.9	1.9
CD (p=0.05)	NS	0.03	NS	NS	NS	NS	NS	NS
Interaction (N XR)								
SEm ±	0.01	0.01	0.01	0.02	2.9	2.6	2.6	2.6
CD (p=0.05)	NS	0.03	NS	NS	NS	NS	NS	NS

System productivity

Among different crop residue treatments, significantly higher system productivity of maize-maize cropping was recorded with Residue incorporation + spray of microbial consortium on residue (14387 kg ha^{-1}), which was comparable with Zero-tillage + residue retention and spray of microbial consortia on residue (14268 kg ha^{-1}) compared to residue removal treatment (13079 kg ha^{-1}). Among different nutrient management treatments, significantly higher system productivity of maize-maize cropping was recorded with 100%RDF of NPK (14377 kg ha^{-1}) over 90% RDN & 75% RDP & K (13485 kg ha^{-1}). This is in accordance with Vijayalakshmi *et al.* (2020).

Production efficiency (kg ha^{-1} day^{-1})

Among different crop residue treatments, significantly higher production efficiency of maize-maize cropping was recorded with Residue incorporation + spray of microbial consortium on residue (65.6 kg ha^{-1} day^{-1}), which was on par with Zero-tillage + residue retention and spray of microbial consortia on residue (65.0 kg ha^{-1} day^{-1}) compared to residue removal treatment (59.6 kg ha^{-1} day^{-1}). Among different nutrient management treatments, significantly higher production efficiency of maize-maize cropping was recorded with 100%RDF of NPK (65.5 kg ha^{-1} day^{-1}) over 90% RDN & 75% RDP & K (61.5 kg ha^{-1} day^{-1}). This is in accordance with Vijayalakshmi *et al.* (2020).

Post harvest soil fertility status

pH

The soil pH of *Rabi* maize after harvest in response

Table 5 : Post -harvest status of available nutrients in soil of maize as influenced by different crop residue and nutrient management treatments of maize in maize – maize cropping system during *Rabi,* 2020-21, *Rabi,* 2021-22, *Rabi,* 2022-23 and *Rabi*,2023-24.

Treatment	**Available P_2O_5 (kg ha^{-1})**				**Available K_2O (kg ha^{-1})**			
Residue management	2020-21	2021-22	2022-23	2023-24	2020-21	2021-22	2022-23	2023-24
M_1: Residue removal	26.0	27.0	26.6	26.3	339.0	335.0	334.7	334.0
M_2: Residue incorporation	33.3	35.0	33.9	30.0	352.0	350.0	349.7	366.0
M_3: Residue incorporation + spray of microbial consortium on residue	38.0	37.0	37.0	31.3	376.0	376.0	376.0	378.0
M_4: Zero-tillage + residue retention and spray of microbial consortia on residue	28.7	32.0	31.0	27.7	349.0	346.0	335.3	332.0
SEm±	0.2	0.2	0.2	0.3	3.0	2.2	2.4	2.0
CD (p=0.05)	0.7	0.8	0.7	1.1	10.0	7.9	8.6	9.0
Nutrient management								
N1:100%RDF of NPK	34.3	35.0	33.4	30.2	365.0	362.0	355.7	358.0
N2: 100% RDN & RDP and 50% RDK	32.3	33.0	32.4	28.8	342.0	340.0	353.5	351.0
N3: 90% RDN,75% RDP and 75% RDK	28.0	30.0	30.6	27.5	355.0	353.0	337.5	348.0
SEm ±	0.3	0.3	0.3	0.5	3.0	3.3	3.2	3.0
CD (p=0.05)	0.9	0.9	0.9	1.4	9.0	9.9	9.7	NS
Interaction (R XN)								
SEm ±	0.4	0.4	0.4	0.5	5.0	3.9	4.2	4.0
CD (p=0.05)	1.9	1.9	NS	NS	NS	NS	NS	NS
Interaction (N XR)								
SEm ±	0.5	0.5	0.5	0.8	6.0	5.8	5.8	6.0
CD (p=0.05)	1.7	1.7	NS	NS	NS	NS	NS	NS

to different crop residue and nutrient management treatments is presented in Table 3. The soil pH after harvest of maize ranged from 7.01 to 7.39 during 2020-21, 7.01 to 7.32 during 2021-22, 7.13 to 7.27 during 2022-23 and 7.46 to 7.50 during 2023-24. Interaction effect was also found to be non-significant. Similar results were also reported by Das *et al*. (2001) and Mukesh (2019).

Electrical conductivity (dS m^{-1})

During four years of study, the electrical conductivity of maize after harvest in response to different crop residue and nutrient management treatments is presented in Table 3. The soil pH after harvest of maize ranged from 0.20 to 0.24 during 2020-21, 0.19 to 0.25 during 2021-22, 0.24 to 0.26 during 2022-23 and 0.22 to 0.24 during 2023-24. These results are in conformity with the findings of Singh and Yadav (2006). Interaction effect was also found to be non significant.

Soil organic carbon (%)

The soil organic carbon of *Rabi* maize after harvest in response to different crop residue and nutrient management treatments is presented in Table 4. The soil organic carbon after harvest of maize ranged from 0.52 to 0.54 during 2020-21, 0.52 to 0.55 during 2021-22, 0.52 to 0.57 during 2022-23 and 0.48 to 0.58 during 2023-24. These results are similar with the findings of Verma *et al*. (2006) and Mukesh (2019).

Available nitrogen (kg ha^{-1})

The soil available nitrogen of *Rabi* maize after harvest in response to different crop residue and nutrient management treatments is presented in Table 4. The soil available nitrogen after harvest of maize ranged from 141.7 to 172.1 kg ha^{-1} during 2020-21, 140 to 171 kg ha^{-1} during 2021-22, 140.6 to 176.7 kg ha^{-1} during 2022-23 and 139.3 to 171 kg ha^{-1} during 2023-24. Similar findings were also reported by Mukesh (2019).

Available phosphorus (kg ha^{-1})

The soil available phosphorus of *Rabi* maize after harvest in response to different crop residue and nutrient management treatments is presented in Table 5. The soil available phosphorus after harvest of maize ranged from 26 to 38 kg ha^{-1} during 2020-21, 27 to 37 kg ha^{-1} during 2021-22, 26.6 to 37 kg ha^{-1} during 2022-23 and 26.3 to 31.3 kg ha^{-1} during 2023-24.

Available potassium (kg ha^{-1})

The soil available potassium of *Rabi* maize after harvest in response to different crop residue and nutrient management treatments is presented in Table 5. The soil available potassium after harvest of maize ranged from 339 to 376 kg ha^{-1} during 2020-21, 335 to 376 kg ha^{-1} during 2021-22 , 334.7 to 376 kg ha^{-1} during 2022-23 and 334 to 378 kg ha^{-1} during 2023-24. These results are in complete agreement with the findings of Hussaini *et al*. (2008) and Kumar (2009).

Conclusion

On the basis of four years of study (2020-21 to 2023-2024), it may be concluded that, Incorporation of maize stover with rotovator along with application of 100% RDF and Zero-tillage + residue retention and spray of microbial consortia on residue with application of 100% RDF were found to be more effective and sustainable approach to enhance the growth, yield attributes, yield, profitability of *Rabi* maize in maize-maize cropping system.

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