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Research Paper

Assessment of precise nutrient management through nutrient expert on productivity and profitability of zero-till maize

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ABSTRACT

An experiment was conducted during the rainy (*kharif*) season of 2017 and 2018 at the ICAR-Indian Agricultural Research Institute, New Delhi, to evaluate the effect of tillage and nutrient-management options on yield, nutrient uptake, residual soil-fertility status, and enzymatic activities in maize (*Zea mays* L.). The zero-tillage with crop residue at 3.5 t/ha (ZT + R) and conventional tillage with crop residue at 3.5 t/ha (CT + R) enhanced the grain yield (6.2–17.0%) of maize compared to CT without residue (4.40 t/ha). High cost of cultivation was recorded in CT + R (44.8×10^3 ₹/ha), while high net returns were found in ZT + R (37.6×10^3 ₹/ha). In ZT + R, the addition of wheat residue enhanced N, P, and K uptake in grain by 19.41, 12.81 and 13.92%, respectively over CT. Available N (182 kg/ha), available P (13.8 kg/ha), and exchangeable K (318 kg/ha) were found highest with ZT + R. Nutrient expert system (NES) enhanced the grain yield (5.30 t/ha) and net returns (43.0×10^3 ₹/ha) compared to no application of nutrients (control) (3.35 t/ha and 17.9×10^3 ₹/ha) and recommended dose of fertilizer (RDF) (4.70 t/ha and 34.8×10^3 ₹/ha). Higher activity of dehydrogenase (DHA) (25.9 TPF μg/g/h) and microbial biomass C (130 μg/g) were found with NES. An increase of 57.96–58.4% in N uptake was found with NES over RDF (80.0 kg/ha). The nutrient expert system (NES) and 125% of RDF left higher amount of residual N, P and K in soil than the control. Overall, nutrient expert system under zero-tillage with crop residue at 3.5 t/ha can increase the productivity and profitability in maize.

Key words: Conservation agriculture, Maize, Nutrient expert, Nutrient uptake, Precision crop nutrition, Profit, Yield

In India, maize (*Zea mays* L.) is the third most important crop after rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.), having a 9.2 mha area with a production of 27.3 mt (FAO, 2022). It is considered as a futuristic crop owing to its high yield potential and emerging demand in poultry and starch industries. Maize productivity is low in India (3.5 t/ha) as compared to the USA (7.89 t/ha) and China (6.32 t/ha)(IIMR 2020). The actual maize yield in irrigated ecologies have varied yield gaps due to low yielding genotypes, faulty agronomic management practices including imbalanced, inadequate amount of fertilization and intensive tillage causing low nutrient supplying capacity and fertility in soil. To address these issues, Conservation agriculture (CA), has been promoted to achieve sustainability in intensively cultivated cereal-based systems (Pasuquin *et al.,* 2014). Adoption of zero-tillage (ZT) enhanced the productivity and profitability in rice–wheat (Pampolina *et al*., 2012) and maize–wheat (Sepat *et al*., 2019) cropping systems. In addition, retention of residue on soil surface contributed to high soil organic C (SOC) by 3.4–6.7% in cereal-based system (Sepat and Rana, 2013). In CA, heavy loads of residues are retained (3 to 9 t/ha). So, there are chances that the required amount of nutrients may be less (Sepat *et al*., 2014) or higher (Singh *et al*., 2016).

Site-specific nutrient management (SSNM)-based on crop demand and supply enhances crop productivity, soil-nutrient status, and nutrient-use efficiency as nutrient recommendations are based on soil-test values. In India, nutrient management is widely based on blanket recommendations though scientific recommendations are based on soil-test values, accounting for variety potential or soil-fertility status. Therefore, efficiency of applied nutrient is static as *in-situ* nutrient losses are high from the system.

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Nutrient expert system (NES) could solve drift in resources for attaining higher yield, a software based on decision-support system (DSS) developed by the International Plant Nutrition Institute for SSNM in cereal-based systems (Pampolina *et al*., 2012). In NES, nutrient management is based on principles of 4R: i.e., applying right source of nutrient at right rate and time and at right place (Pasuquin *et al.,* 2014). In maize, NES enhanced yield (0.9–1.2 t/ha) and profit (US$ 270–379/ha) of farmers in Indonesia and the Philippines (Pampolina *et al*., 2012). Here, estimation of crop need-based nutrient supplying as per target yield is done for nutrient recommendations taking into account of indigenous nutrient-supplying capacity of soil, yield targets capable to maximize yields with restoration of soil fertility. In India, research findings indicated that, on an average, farmer uses 180, 200, 60, 80 and 20–40 kg/ha of N, P_2O_5, and K_2O respectively. However, fertilizer application based on NE reduced N, P_2O_5, and K_2O requirement by 20–30, 35–45 and 40–60 kg/ha respectively. So, saving of 17, 56 and 58% in fertilizer use was found for maize (Singh *et al*., 2016). There is a need to evaluate and consolidate validity of NES in North–Western part of India where maize is considered as futuristic crop for the replacement of rice. Under such circumstances, nutrient-management through advance tool is required to maximize yield with nutrient saving. In maize, economical aspect of yield and nutrient-use efficiency need to be rationalized with NES under conservation agriculture. Therefore, an experiment was carried out to standardize NES with varying tillage and nutrient management for yield, net benefit and nutrient uptake.

MATERIALS AND METHODS

An experiment was conducted during the rainy (*kharif*) season of 2017 and 2018 at the research farm of the ICAR–Indian Agricultural Research Institute, New Delhi, (28°40’ N, 77°12’ E, 228.6 m mean sea-level). The site falls in Trans Indo-Gangetic Plains agro-climatic zone, with subtropical and semi-arid climate, having warm summers and cold winters, with mean annual maximum and minimum temperatures of 40.5° C and 6.5° C, respectively. The mean annual rainfall is 670 mm and approximately 70–80% occurred during 3 months (July–September). The total rainfall received in 2017 and 2018 was 990.9 and 992.2 mm respectively. The mean maximum and minimum temperatures were 33 and 22°C. Soil has sandy loam (Inceptisols) texture, having *p*H (7.3), electricity conductivity (0.45 dS/m) and cation-exchange capacity (10.8 cmol/ kg) in 0–15 cm depth. It has soil organic carbon of 0.38%, available N, P and K of 162 kg/ha, 13.5 kg/ha and 280 kg/ha. Experiment was laid-out in split-plot design with 3 replications. In main plot, 4 tillage practices, viz. conventional tillage (CT), CT with crop residue at 3.5 t/ha (CT + R), zero-tillage (ZT - R) and ZT with crop residue at 3.5 t/ha (ZT + R), and 4 nutrient-management practices such as no nutrient application (control), recommended dose of fertilizers (RDF), 125% of RDF and NES-based nutrient doses were taken in subplots. An additional 25% of RDN was taken considering the higher nutrient requirement in maize in lieu of low soil fertility to achieve higher productivity. Maize (variety ‘PHM 1’) was sown in July at row spacing of 67.5 cm × 15 cm using a seed rate of 20 kg/ha. Harvesting was done manually in October, and grain yield as per plot was weighted at moisture content of 12.5 %. Soil samples were taken from each plot for nutrient uptake analysis after maize harvesting. Soil samples were stored at 5°C, and prior to biological analyses equilibrated at 22–25°C. Soil dehydrogenase activity (Cassida *et al*., 1964) and soil microbial biomass-C was determined by fumigation method (Vance *et al*., 1987).

Standardization of nutrient doses through nutrient expert system

Nutrient expert is easy to operate computer-based tool, given agronomic practices followed for crop production such as i) previous history of cropping systems, ii) soil-fertility status (*p*H, SOC, N, P and K), iii) agronomic management practices, iv) no. of tillage operations (either intensive or zero tillage), v) number of irrigations and stages of crop for irrigation, vi) variety taken and targeted yield, vii) amount of farm yard manure, compost or N, P and K, and micronutrient, viii) residue or no-residue applications, ix) method of application of N, P and K. Based on these inputs, NES gives precise amount of nutrients and stages when it needs to be applied to achieve target yield. Here, targeted yield of maize was taken 7 t/ha as per the potential of variety to calculate N, P and K recommendation (Table 1). In maize, half dose of N, and full dose P and K were applied at the time of sowing, while remaining half dose of N was applied in 2-equal splits at knee-high and tasseling stage.

RESULTS AND DISCUSSION

Yield attributes and yield

Tillage practices significantly influenced the grain rows/cob in 2018 and grains/grain row in 2017 and 2018 (Table 2). Decomposition of residue enhanced the available soil water and plant nutrients to maize crop (Sepat *et al.,* 2019). Therefore, ZT + R and CT + R were found at par for grain rows/cob (15.45 and 14.6) and grains/grain row (26.35 and 25.55), followed by CT (13.8 and 23.6). The ZT–R recorded the lowest values for grain rows/cob and grains/grain row as no residue retention enhanced the soil-moisture depletion, and thereby low nutrient utilization resulted in formation of low photosynthates for formation of

Table 1. Amount of nutrients (N : P : and K) in maize crop during 2017 and 2018

Parameters	ZT + R	CT + R	CT	ZT – R
Control	–	–	–	–
RDF	150 : 80 : 60	150 : 80 : 60	150 : 80 : 60	150 : 80 : 60
125% of RDF	187 : 100 : 75	187 : 100 : 75	187 : 100 : 75	187 : 100 : 75
NES	167 : 54 : 71	167 : 54 : 71	172 : 60 : 80	172 : 60 : 80

RDF, Recommended dose of fertilizer; NES, nutrient expert system; ZT + R, zero-tillage with crop residue @ 3.5 t/ha; CT + R, conventional tillage + crop residue @ 3.5 t/ha; CT, conventional tillage; ZT-R, zero-tillage without crop residue.

Table 2. Effect of tillage and nutrient management on yield attributes of maize in 2017 and 2018

Treatment	Cob length (cm)		Grain rows/cob		Grains/grain row		Test weight (g)	
	2017	2018	2017	2018	2017	2018	2017	2018
Tillage and crop establishment								
CT	16.2	15.8	14.2	13.4	24.3	22.9	219	224
CT + R	16.0	16.1	14.2	15.0	26.9	24.2	221	227
ZT –R	15.9	15.3	12.5	12.2	22.8	20.8	215	220
ZT + R	16.6	15.6	14.7	16.2	27.5	25.2	222	231
SEm±	0.24	0.25	0.32	0.36	0.28	0.31	6.7	7.2
CD (P=0.05)	NS	NS	1.02	1.15	0.90	0.99	NS	NS
Nutrient management								
Control	14.5	13.8	9.0	11.5	18.3	19.0	202	205
RDF	16.2	16.2	13.3	13.7	24.0	23.5	220	227
125% RDF	17.0	16.4	16.0	15.2	29.0	25.3	225	232
NES	17.0	16.4	17.3	16.4	30.2	25.3	230	238
SEm±	0.11	0.16	0.22	0.28	0.18	0.22	4.3	3.2
CD (P=0.05)	0.35	0.51	0.70	0.90	0.58	0.70	13.7	9.92

Details of treatments are given under Materials and Methods

higher grains. Cob length and test weight of maize were not influenced with tillage practices.

Nutrient-management options significantly influenced all the yield parameters of maize, viz. cob length, grain rows/cob, grains/grain row and test weight, in maize during 2017 and 2018 (Table 2). In maize, adequate supply of N, P and K enhanced the photosynthates formation and accumulation (Singh *et al.,* 2016), which resulted in increased cob length (16.2–17.0 cm), grain rows/cob (13.4–17.3), grains/grain row (23.5–30.2) compared to the control. A higher amount of K application through NES attributed to higher cell-division and turgidity, leading to increased grain weight in maize. NES and 125% of RDF remained at par for cob length, grain rows/cob, grains/grain row and test weight in both the years. The NES registered an increase of 4.9, 6.4, 5.5 and 15.2%, respectively, for cob length, grain rows/cob, grains/grain row and test weight compared to RDF over the years. A significant influence of tillage practices was observed on grain, straw and biological yields of maize in 2017 and 2018 (Table 3). The ZT + R resulted higher grain (5.2 t/ha), straw (6.3 t/ha) and biological yields (11.5 t/ha), followed by CT + R (4.85, 6.0 and 10.85 t/ha) and CT (4.4, 5.5 and 9.9 t/ha). In ZT, retention of residue enhanced the microbial parameters, viz. microbial biomass C and dehydrogenase activity in soil. Therefore, a higher activity of soil microbial community in ZT enhanced the mineralization of nutrients and efficient utilization to maize crop (Sepat *et al*., 2014) which gave additional yield compared to CT. In 2017 and 2018, an increase of 20.9 and 13.3%, respectively was noted in grain yield with ZT + R (5.2 and 5.1 t/ha) over CT (4.3 and 4.5 t/ha). Interaction of tillage and nutrient-management options on grain yield of maize was found significant during 2018 (Table 6). The ZT + R with NES (6.01 t/ha) recorded at par yield to ZT + R with 125% of RDF followed by CT + R with NES.

No NPK application with ZT – R (3.12 t/ha) and CT (3.15 t/ha) recorded the lowest grain yield compared to ZT + R (3.58 t/ha) and CT + R (3.75 t/ha).

A total of 14.5 kg/ha wheat residues were added in CT + R and ZT + R grown maize in 2 years. The CT, CT + R and ZT + R were found at par with biological yield of maize during both years. No residue retention in ZT was found worst practice and recorded the lowest grain yield (4.05 t/ha) and biological yield (9.3 t/ha) during 2017 and 2018.

In 2017 and 2018, NES gave the highest grain yield (5.2 and 5.4 t/ha) over RDF (4.6 and 4.8 t/ha) (Table 3). In RDF (150 kg N, 80 kg P_2O_5 and 60 kgK_2O/ha), pre-determined rates of major nutrients remained constant over the time. An additional dose of applied 17–22 kg N and 15–20 kg K_2O/ha was found beneficial for yield enhancement in NES as compared to RDF. It was proven based on the findings that for yield enhancement, nutrients need to be based on balanced amount depending on crop demand and supply (Sepat *et al*., 2015). A higher amount of 20 kg N, 20 kg P_2O_5 and 15–20 kg K_2O/ha in 125% of RDF was applied compared to NES. However, both NES and 125% of RDF remained at par for grain, straw and biological yields of maize in 2017 and 2018.

In 125% of RDF, an additional amount of nutrient increased the utilization pattern, thereby enhanced the grain yield and found comparable with NES. However, in NES, nutrient uptake was efficiently converted to achieve production with minimal nutrient losses over to 125% of RDF.

Straw and biological yields followed the same trend as in the case of grain yield of maize. Biological yield exhibited an increase of 35.4–54.5% through nutrient application compared with the control. Besides, an increase of 13–12.5% was recorded with NES over to RDF. It highlights that higher amount of fertilizer through 125% of RDF was not efficiently utilized by the maize crop. The NES gives effective fertilizer recommendations by considering yield responses and contribution of nutrients from indigenous sources (Sepat *et al*., 2019).

Economics

Higher number of tillage operations in CT + R and ZT + R incurred high cost of cultivation due to more consumption of inputs (diesel and labour) over to CT. In ZT + R, tillage was confined to seed sowing; however, cost was highly inculcated mainly owing to precious wheat straw retention. Hence, higher cost of cultivation was recorded in ZT + R over to all tillage combination. The ZT without any cost of tillage and residue recorded the lowest cost of cultivation.

High grain yield compensated high economic cost of cultivation, and therefore higher gross and net returns were recorded (71.8 and 37.6 × 10^3 ₹/ha) in ZT + R. The second practice was CT + R in terms of high gross and net returns of maize (67.6 and 28.8 × 10^3 ₹/ha). An additional net income of 2900 ₹/ha was recorded with ZT + R and CT + R as compared to CT (34.7 × 10^3 ₹/ha). This highlights that if suitable machinery is available than ZT + R or CT + R can be adopted by the farmers as both are equally economically beneficial.

Nutrient application had profound effect on net returns of maize (Table 4). An additional amount of nutrients through 125% of RDF (37.6 × 10^3 ₹/ha) and NES (37.3 × 10^3 ₹/ha) escalated the cost of cultivation compared to RDF (36.7 × 10^3 ₹/ha). In general, nutrient application mounted the cost of cultivation by 4,000/- /ha over control (33.5 × 10^3 ₹/ha). However, higher grain and straw yield with fertilization recorded higher gross (70.2 × 10^3 ₹/ha) and net returns (39.1 × 10^3 ₹/ha) compared to control (46.7

Table 3. Effect of tillage and nutrient management on yield and economics of maize in 2017 and 2018

Treatment	Yield (t/ha)						Cost of cultivation (×10^3 ₹/ha)	Gross returns (×10^3 ₹/ha)	Net returns (×10^3 ₹/ha)	Nitrogen–use efficiency (kg grain/kg N applied)	
	Grain		Stover		Biological						
	2017	2018	2017	2018	2017	2018	Mean of two years*			2017	2018
Tillage and crop establishment											
CT	4.3	4.5	5.4	5.6	9.8	10.0	32.1	61.4	34.7	20.9	22.0
CT + R	4.8	4.9	6.0	6.0	10.8	10.9	44.8	67.6	28.8	23.2	23.2
ZT –R	3.9	4.2	5.0	5.5	8.8	9.8	27.8	56.6	34.1	18.3	20.3
ZT + R	5.2	5.1	6.4	6.2	11.6	11.3	40.5	71.8	37.6	25.4	25.1
SEm±	0.24	0.20	0.11	0.13	0.32	0.36	–	2.89	2.89	0.45	0.51
CD (P=0.05)	0.74	0.62	0.33	0.40	0.99	1.15	–	9.26	9.26	1.56	1.75
Nutrient management											
Control	3.4	3.4	5.0	4.4	8.4	7.7	33.5	46.7	17.9	-	-
RDF	4.6	4.8	5.7	5.9	10.3	10.7	36.7	65.7	34.8	30.6	32.0
125% RDF	5.0	5.2	6.0	6.4	11.0	11.6	37.6	71.1	39.6	26.7	27.6
NES	5.2	5.4	6.1	6.6	11.3	12.0	37.3	73.9	43.0	30.5	31.1
SEm±	0.14	0.13	0.09	0.11	0.30	0.32	–	1.56	1.56	0.31	0.37
CD (P=0.05)	0.43	0.40	0.28	0.33	0.93	0.99	–	4.81	4.81	0.91	1.08

Details of treatments are given under Materials and Methods
*Mean data of 2017 and 2018

Table 4. Effect of tillage and nutrient management on nutrient uptake (kg/ha) in maize in 2017 and 2018

Treatment	N (kg/ha)				P (kg/ha)				K (kg/ha)			
	Grain		Total		Grain		Total		Grain		Total	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Tillage and crop establishment												
CT	68.8	78.0	109	102	23.76	24.85	35.36	37.75	28.1	28.9	131	122
CT + R	79.2	83.5	112	112	25.34	26.17	38.84	39.77	30.6	31.6	139	130
ZT –R	58.8	64.3	90.5	101	21.78	24.10	32.68	35.90	26.1	27.6	114	115
ZT + R	88.3	87.0	120	116	27.68	26.83	41.58	40.53	32.4	32.4	142	148
SEm±	1.82	1.76	4.2	3.8	0.18	0.22	0.36	0.38	0.38	0.42	3.92	3.65
CD (P=0.05)	5.82	5.63	13.4	12.2	0.58	0.70	1.15	1.25	1.22	1.34	12.64	11.68
Nutrient management												
Control	49.6	47.5	80.4	77.0	19.82	18.91	29.82	29.91	22.9	22.2	112.8	109.2
RDF	72.7	79.7	103	112	24.60	25.36	36.80	37.66	28.6	30.1	130	130
125% RDF	83.3	89.4	123	120	26.45	28.25	39.85	42.15	32.2	32.9	140	132
NES	89.4	96.1	127	122	28.20	29.44	42.20	44.24	33.4	35.3	143	134
SEm±	1.20	1.24	2.82	2.50	0.11	0.13	0.22	0.26	0.25	0.22	2.50	2.11
CD (P=0.05)	3.84	3.97	9.02	8.0	0.35	0.42	0.70	0.83	0.80	0.70	8.0	6.75

Details of treatments are given under Materials and Methods

and 17.9 × 10^3 ₹/ha). In 125% of RDF, higher amount of nutrient and yield gain was not sufficient to compensate the cost of cultivation and thus recorded lower net and gross returns over to NES (73.9 and 43.0 × 10^3 ₹/ha). NES recorded additional net gain of 8,200 /ha compared to RDF (34.8 × 10^3 ₹/ha).

Nutrient uptake and nutrient use efficiency

Tillage practices in maize significantly influenced the uptake of N, P and K in grain and total (grain + straw) at the end of 2 years (Table 4). Decomposition of residue with high availability of nutrient in soil caused higher N, P and K uptake in grain with ZT + R (87.65, 27.25, 32.4 kg/ha) and CT + R (81.35, 25.75 and 31.1kg/ha), followed by CT (73.4, 24.31 and 28.5 kg/ha). In ZT + R, an addition of wheat straw residue @ 16 kg/ha ensured a significant increase of K uptake in grain (21.08%) over CT. Total uptake in maize also followed the same trend. The ZT + R (118, 41.05 and 145 kg/ha) and CT + R (112, 39.30 and 134.5 kg/ha) recorded higher total N, P and K uptake in maize compared to CT (105.5, 36.55 and 126.5 kg/ha). Unavailability of available forms of nutrient in ZT – R resulted in to low uptake of nutrients in grain and total (95.75 and 114.5 kg/ha). The ZT + R recorded (25.3 kg grain/kg N) higher nitrogen-use efficiency (NUE) than to CT (21.5 kg grain/kg N). Retention of residue in ZT and higher grain yield with/unit of applied nutrient enhanced the NUE in maize.

Nutrient management significantly influenced the grain and total uptake of N, P and K in maize during both years (Table 4). Availability of optimized and balanced nutrient from the soil in NES exhibited higher uptake of N, P and K than 125% of RDF. An increase of 21.7, 15.37 and 25.8% was registered with N, P and K in grain with NES over RDF. Similarly, RDF registered a 56.9, 29.02 and 54.1% increase of N, P and K in grain with RDF compared with the control. Optimized nutrient application, addition and decomposition of residues reversed the immobilization effect of nutrients (Pasuquin *et al.,* 2014) over the years, and therefore higher availability of soil nutrient enhanced the nutrient uptake in maize. In NES, an addition of 17 kg N, 24 kg P and 11 kg K/ha compared to RDF practice led to higher nutrient uptake. The NUE was significantly influenced by nutrient-management practices (Table 4). The RDF and NES recorded at par values of NUE, followed by 125% of RDF. In 125% of RDF, higher grain yield with extra amount of nutrient was unable to increase NUE which indicates wastage of nutrient. However, comparable NUE in NES and RDF highlight the efficiency of NES, where lesser amount of nutrient than RDF was found optimum for high grain yield and NUE.

Post fertility status and enzyme activity

After completion of 2-year cropping cycle, a significant amount of nutrient was noticed in the soil (Table 5). Higher residue addition and maize total biomass production showed higher amount of N, P and K in the soil with ZT + R, followed by CT + R and CT practices. This indicates that, addition of residue not only enhanced the nutrient uptake in maize but also left a significant amount of nutrients in soil. An additional (22 kg/ha) N and K (34 kg/ha) was found with ZT + R compared to CT. In addition, a gain of 20, 0.3 and 38 kg/ha of N, P, and K was found with ZT + R over initial soil status. In ZT + R, higher amount of soil microbial biomass C (132 mg/kg) and dehydrogenase activity (16.6 TPF µg/g/h) slowly mineralized nutrients and

Table 5. Effect of tillage and nutrient management on residual soil fertility and microbial activity in plough layer (0–15 cm) after 2 cropping cycles

Treatment	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)	Soil organic C (%)	Dehydrogenases activity (TPF µg/g/h)	Microbial biomass C (µg/g)
Tillage and crop establishment						
CT	160	12.0	284	0.37	24.2	128
CT + R	174	12.8	308	0.38	25.2	130
ZT –R	152	10.0	274	0.37	20.8	120
ZT + R	182	13.8	318	0.40	26.6	132
SEm±	4.5	0.08	6.05	0.04	1.11	1.25
CD (P=0.05)	14.4	0.26	19.36	NS	3.55	4.0
Nutrient management						
Control	156	10.4	265	0.35	21.7	122
RDF	168	12.2	295	0.39	24.0	128
125% RDF	172	12.8	312	0.39	25.2	130
NES	172	13.2	312	0.39	25.9	130
SEm±	3.8	0.06	4.42	0.02	0.89	0.92
CD (P=0.05)	12.2	0.19	14.14	0.06	2.85	2.94

Details of treatments are given under Materials and Methods

gradually availability of nutrients over the life-cycle of maize main reason behind higher nutrient uptake and residual soil fertility compared to CT + R (130 and 15.2) and CT (128 and 14.2). In case of ZT – R, the lowest activity of soil microbial biomass C and DHA was noticed, and therefore a depletion of 8, 2 and 14 kg/ha of N, P and K was recorded compared to CT.

Available soil N, P and K increased after incorporating crop residues at 3.5 t/ha with ZT + R and CT + R (Table 5). The soil organic C was not influenced by nutrient and tillage practices after 2 years. The build-up of SOC required consistent amount of residues, fertilization and longer time in semi-arid regions. In general, nutrient application enhanced the available N (14.6 kg/ha), P (2.3 kg/ha) and K (41.3 kg/ha) over the control. Initial starter dose was lacking in the control to boost microbial communities, and therefore recorded the lowest amount of soil microbial biomass C (122 mg/kg) and DHA (21.7). No fertilization recorded the lowest amount. In NES, addition of extra amount of 17 kg N and 11 kg K/ha over RDF increased mineralization and availability of nutrients to crop, and thereby left significant amount of soil nutrients (168, 12.2 and 295 kg/ha). In NES, additionally, higher activity of soil microbial biomass C (130) and DHA (25.9) played pivotal role to curtail initial lock-up of nutrient in soil. In NES, production of higher crop biomass and efficient decomposition enhanced the enzymatic activity, as the release of nutrient was sufficient to meet out the food requirement of DHA (Sepat and Rana, 2013). The highest available P (13.2 kg/ha) and available K (312 kg/ha) were recorded in NES in soil owing to direct K supply with carry-over effects and release of K + ion from inorganic soil components (Pasuquin *et al.,* 2014). Addition of 25% extra nutrient dose in 125% of RDF was not advisable, though it left high amount of soil nutrients but it failed to compensate high cost with extra amount of yield. Here, additional dose of inorganic nutrient gave significant amount of soil microbial biomass C (130) and DHA (25.2).

Overall, research highlighted that nutrient management through NES has the potential to enhance crop productiv-

Table 6. Interaction of tillage and nutrient-management options on grain yield (t/ha) of maize during 2018

Nutrient management	Tillage and crop establishment				
	CT	CT + R	ZT–R	ZT + R	Mean
Control	3.15	3.75	3.12	3.58	3.40
RDF	4.72	5.04	4.27	5.15	4.80
125% of RDF	5.19	5.27	4.50	5.66	5.16
NES	4.92	5.59	4.92	6.01	5.36
Mean	4.50	4.91	4.20	5.10	4.68
SEm±	0.13				
CD (P=0.05)	0.38				

Details of treatments are given under Materials and Methods ity, nutrient-use efficiency and soil fertility with minimal harmful effects on environment. Nutrient management through NES follows systematic approach of capturing site-specific information for developing individual farm-based nutrient. So, it is concluded that nutrient management throgh NES is a better option to enhance productivity, profitability and nutrient-use efficiency of maize with retention of residue at 3.5 t/ha in ZT maize under semi-arid regions of India.

Thus, nutrient expert system (NES) in zero-tillage with crop residue at 3.5 t/ha enhances maize yield and net returns. Zero-tillage with NES recorded higher post-soil fertility status with increased activity of dehydrogenase and microbial biomass C in sandy-loam soils.

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