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Precision nutrient management for enhanced yield and profitability of maize (*Zea mays*)

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ABSTRACT

A three-year study was carried out at six locations in three agro-ecologies representing the areas of irrigation water availability at critical stages during *kharif* maize (*Zea mays* L.) in North Western Plain Zone (NWPZ), North Eastern Plain Zone (NEPZ) and Peninsular Zone (PZ) for optimizing the nutrient requirement and realizing potential yield of the popular genotypes. The study included five popular genotypes/hybrids with three nutrient management practices of RDF, 50% RDF/Farmer Fertilizer Practices (FFP) and nutrient expert based site-specific nutrient management (NE-SSNM) in the split-plot design and replicated thrice. The grain yield of maize was significantly higher at four locations with NE-SSNM however; it was at par with RDF at two locations. The gross returns followed the same trend as of grain yield but the returns over fertilizer cost (ROFC) were significantly higher with NE-SSNM which indicates that the use of these nutrient management practices has the potential to rationalize the nutrient management practices in maize. Hence, it was concluded that the NE-SSNM could be an effective strategy for realizing the potential yield and enhancing net returns of maize production in NWPZ, NEPZ and PZ.

Keywords: Farmer fertilizer practices, Genotype × Management interaction, Multi-location, return over fertilizer cost, Site specific nutrient management

In the world, maize (*Zea mays* L.) has the highest production of all the cereals while India is catching the global trend. In India, the area under maize is increasing, in 2017-18 maize was grown on 9.4 million ha. The productivity of maize in India is still very low (2689 kg/ha), as compared to the world (5500 kg/ha), showing a large gap between potential productivity and actual productivity. About 70% of the total maize area of the country comes under *kharif* maize whose productivity is half of that of *rabi* maize. The *kharif* maize has the potential to sustainably enhance the productivity in assured ecology of North Western Plain Zone (NWPZ), North Eastern Plain Zone (NEPZ) and Peninsular Zone (PZ) representing highest maize acreage and production in the country.

Being grown in a wide range of climatic conditions in India, proper assessment of the limiting conditions for maize production and productivity is difficult but nutrient management is one of the most important factors limiting maize production (Dass *et al.* 2012 and Jat *et al.* 2013). The blanket fertilizer recommendations do not account the change in ecologyand the genetic potential of the genotype (Kumar *et al.* 2014 and Parihar *et al.* 2017). There is a good genotype interaction of maize in varied ecology and management practices (Kumar *et al.* 2015 and 2016). The fertilizer prescription equations are available for the crops. Based on yield potential, soil test crop response (STCR) based equation involves the analysis of soil for nutrients. The available equations have certain limitations of non-availability for higher yield potential in all ecologies. In this context, use of the nutrient expert(TM) based site specific nutrient management (NE-SSNM) developed by IPNI could be advantageous in maize which takes into account the effects of the previous crops, residue management, organic manuring, soil type and soil fertility status along with genotype and seasonal variation for giving the nutrient recommendations (Pooniya *et al.* 2015).

Considering the above facts in mind, it was hypothesized that the use of the NE-SSNM would increase the yield and net returns of the genotypes in assured maize ecologies for decreasing the environmental footprints towards nutrient stewardship.

MATERIALS AND METHODS

A multi-location experiment was conducted (*kharif*) in irrigated ecologies, viz. NWPZ (Delhi and Ludhiana), NEPZ (Ranchi) and PZ (Arbhavi, Hyderabad, and Karimnagar) during 2012-14. The experiments were conducted in split-

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plot design wherein the main plot fertility levels, viz. N1: RDF (Recommended dose of fertilizer), N2: 50% RDF/ FFP (Farmers fertilizer practice), N3: NE-SSNM (Nutrient expert(TM) -Site Specific Nutrient Management) were kept and in subplot treatment, five hybrids (G1 to G5) were taken. RDF (N1) dose for Delhi, Ludhiana, Ranchi, Arbhavi, Hyderabad and Karimnagar were 150:60:40 125:60:00 150:60:40 150:75:37.5 200:60:50 200:60:50, respectively. While the fertilizer dose in FFP (N2) and SSNM (N3) dose got varied over the years. At Delhi PMH 1, PMH 3, HQPM 1, Bio-9637 and DHM 117 were grown all three years. At Ludhiana, in 2012, PMH 1, Parkash, PMH 4, JH 3956 and JH31244 were grown, whereas in 2013 and 2014 PMH 1, PMH 3, PMH 4, CoH (M)8 were grown. Similarly, at Ranchi, PMH 1, PMH 3, HQPM 1, DHM 117 were grown in 2012, and PMH 1, PMH 3, CoH (M)7, CoH (M)8 and CoH (M)9 were grown in 2013 and 2014. At Arbhavi, PMH 1, PMH 3, HQPM 1, Arjun and DHM 117 were grown in 2012, whereas, in 2013 and 2014 PMH 1, PMH 3, HQPM 1, CoH (M)7, CoH (M)8 were sown. At Hyderabad, in 2012, PMH 1, PMH 3, HQPM 1, KNMH 1 and DHM 117 were sown and PMH 1, PMH 3, HQPM 1, CoH (M)8 and DHM 117 were sown in 2013 and 2014. At Karimnagar PMH 1, PMH 3, HQPM 1, 30 V 92 and DHM 117 were grown all three years.

The soil of studied locations was suitable for growing maize. Soil texture was sandy loam at Delhi and Karimnagar. While it was Loamy sand at Ludhiana, Sandy clay loam at Ranchi and Hyderabad, Clay loam at Arbhavi. Soil *p*H ranges from 6.2 at Ranchi and Karimnagar to 8.2 at Arbhavi. About soil fertility status of soil, all centres were low in available nitrogen and medium in available phosphorus except Ranchi, which has high available phosphorus in the soil. However, available potassium in soil was medium at Delhi, Ludhiana and Ranchi while other centres, viz. Arbhavi, Hyderabad and Karimnagar had high potassium status. The bulk density at the centres varied from 1.40 kg/m^3 at Delhi to 1.67 kg/m^3 at Ranchi. Climate change is showing its effect on rainfall and a lot of variabilities were found in rainfall received at the same centre for three years of experimentation. In all three years, the highest rainfall was received at Karimnagar while the lowest was at Arbhavi. The temperature and relative humidity at all the locations were favourable for the maize growth and development.

The data on the yield was recorded and reported at 14.5% moisture content. The cost of the fertilizer input in each location was calculated based on the standard prices of the fertilizer in three years of the study. The returns from the maize grain produce were calculated using the minimum support prices announced for the respective cropping seasons by the government of India. The return over fertilizer cost (ROFC) from grain yield was estimated as the product of subtraction of fertilizer nutrient cost from returns of the maize grain yield obtained in particular treatment combination in the respective year and location. The data obtained on the grain yield, gross returns and returns over fertilizer costs for each location and year were analyzed statistically using the general linear model in SAS 9.3 software. The means were compared statistically using the least significant difference (LSD) test at 5% probability. The probability and the significant LSD values of the main and interaction effects reported for the main and interaction effects comparisons.

RESULTS AND DISCUSSION

Effect of nutrient management on grain yield: The maize grain yield was significantly affected by the application of various nutrient management practices and the hybrids during all three years of the experimentation at five locations (Table 1). However, the performance varied across the years. The significantly highest yield of maize hybrids was obtained in NE-SSNM across locations in various zones, viz. NWPZ, NEPZ and PZ. The balanced application of the nutrients in the NE-SSNM lead to enhanced growth that increased the plant growth and yield attributes and ultimately had a better source-sink relationship. This might have led to increased yield of the maize under NE-SSNM. The balanced applications of the nutrients in NE-SSNM not only increase the yield but also have positive soil nutrients, energy balance, and soil moisture (Parihar *et al.* 2017, 2017a). Almost similar findings of the enhanced yield with NE-SSNM were also reported in many earlier studies in India (Kumar *et al.* 2015, Pooniya *et al.* 2015, Parihar *et al.* 2017). State recommendation of fertilizer application enhanced maize yield significantly at Karimnagar and Hyderabad in all the years which remained at par with FFP during 2014. The more awareness and application of the nutrients by the farmers in the Andhra Pradesh might have the reason for not much yield gains by NE-SSNM as evident by our survey and data used in this study.

Effect of genotypes on grain yield: Amongst genotypes, G1 (PMH 1) produced significantly higher yield at Ludhiana (2013), Arbhavi (2012), Karimnagar (2012, 2013, 2014) and Hyderabad (2013), respectively. While, G2 (PMH 3) found significantly superior at Delhi (2012, 2013), Ranchi (2012), Karimnagar (2012, 2013, 2014).The genotype G1 and G2 found at par at Karimnagar in all the years. The HQPM 1 hybrid shown significant increase only at Ludhiana (2012), Ranchi (2013) and Hyderabad (2012), while, Bio 9637 was found superior at Delhi (2014), Ranchi (2012), Arbhavi (2014), Hyderabad (2014) and Karimnagar (2014). However, Bio 9637 was found at par with DHM 117 at Delhi (2013), Ranchi (2014) and with PMH 3 at Ludhiana (2014). DHM 117 was found significantly superior at Ranchi (2014) at par with Bio 9637, Karimnagar (2014) at par with Bio 9637.The genotype × environment interactions reported by Kumar *et al.* (2016). Hence, the best genotype at various locations needs to be exploited for enhancing the yield. In general, the yields of the various genotypes used in the study had higher yield in PZ compared to NWPZ and NEPZ locations. It was due to better weather conditions (Table 1) along with better soil texture that might help in better moisture retention and crop growth, which lead to higher maize yields in the PZ compared to other regions.

Table 1 Interaction effect of genotypes and nutrient management practices on yield (kg/ha) of maize in various agro-ecologies during 2012-14

Treatment	Delhi			Ludhiana			Ranchi			Arbhavi			Hyderabad			Karimnagar		
	2012	2013	2014	2012	2013	2014	2012	2013	2014	2012	2013	2014	2012	2013	2014	2012	2013	2014
N1G1	4.3^{a}	4.3^{ab}	4.9^{abc}	8.2^{abc}	8.4^{b}	8.0^{abc}	6.9^{ab}	6.2^{d}	6.4^{e}	9.4^{a}	6.9^{bc}	9.6^{abcd}	7.0^{a}	7.2^{b}	7.8^{ab}	9.3^{ab}	9.1^{bc}	9.3^{ab}
N1G2	4.7^{a}	4.5^{ab}	5.1^{abc}	7.0^{bcd}	8.1^{b}	7.9^{abc}	7.0^{ab}	6.9^{bcd}	7.3^{cd}	8.4^{abc}	7.1^{b}	7.9^{fgh}	8.2^{a}	6.7^{b}	7.1^{def}	9.2^{abc}	8.4^{fg}	8.9^{abcd}
N1G3	4.1^{a}	3.6^{bc}	3.4^{cd}	9.3^{a}	6.3^{h}	6.5^{fg}	5.7^{bc}	7.6^{b}	7.0^{de}	7.5^{c}	4.6^{e}	7.4^{gh}	6.2^{a}	5.6^{cd}	6.3^{h}	7.3^{f}	7.5^{j}	7.0^{f}
N1G4	3.9^{a}	4.2^{ab}	6.3^{a}	6.7^{cd}	6.8^{fg}	7.6^{bcde}	7.5^{ab}	6.6^{cd}	7.2^{cd}	9.2^{ab}	7.4^{ab}	10.3^{ab}	8.1^{a}	6.7^{b}	7.9^{a}	8.8^{bcd}	7.7^{ij}	8.7^{bcd}
N1G5	4.5^{a}	5.0^{a}	5.0^{abc}	8.3^{abc}	7.0^{ef}	7.0^{def}	-	7.1^{bc}	7.8^{bcd}	4.4^{d}	6.1^{cd}	8.6^{cdefg}	5.8^{a}	7.0^{b}	7.4^{bcd}	7.1^{f}	8.5^{ef}	9.2^{abc}
N2G1	4.2^{a}	3.9^{abc}	4.8^{abc}	7.0^{bcd}	7.6^{c}	7.3^{cde}	3.7^{d}	4.1^{ef}	4.2^{f}	9.1^{ab}	5.9^{cd}	7.3^{gh}	6.2^{a}	5.3^{de}	7.7^{ab}	7.5^{ef}	9.4^{ab}	8.7^{bcd}
N2G2	4.6^{a}	4.4^{ab}	4.3^{bcd}	7.3^{bcd}	7.4^{cd}	7.0^{def}	4.9^{cd}	4.1^{g}	4.3^{f}	7.9c	6.0^{cd}	7.9^{efgh}	4.1^{a}	4.5^{fg}	7.0^{ef}	8.3^{de}	8.9^{cde}	8.3^{cd}
N2G3	4.0^{a}	2.6^{c}	3.4^{cd}	8.6^{ab}	5.6^{i}	5.9^{g}	4.6^{cd}	4.7^{e}	4.0^{f}	8.1^{bc}	4.4^{e}	6.8^{h}	6.5^{a}	4.0^{g}	6.5^{gh}	5.9^{g}	7.5^{j}	7.0^{f}
N2G4	3.9^{a}	3.9^{abc}	5.1^{abc}	6.1^{d}	6.3^{h}	6.4^{fg}	4.9^{cd}	3.7^{f}	4.7^{f}	8.3^{abc}	7.3^{ab}	9.1^{bcdef}	4.2^{a}	4.7^{f}	7.7^{ab}	7.0^{f}	7.9^{hi}	8.2^{de}
N2G5	4.4^{a}	3.5^{bc}	2.8^{d}	7.1^{bcd}	6.4^{gh}	6.4^{fg}	-	4.6^{e}	4.7^{f}	3.6^{d}	5.3^{de}	7.9^{fgh}	6.1^{a}	5.0^{ef}	7.6^{abc}	5.6^{g}	8.7^{def}	8.7^{bcd}
N3G1	4.4^{a}	3.9^{ab}	5.1^{abc}	8.7^{ab}	8.9^{a}	8.1^{ab}	7.8^{a}	7.1^{bc}	7.1^{cde}	9.1^{ab}	7.65^{ab}	9.9^{abc}	4.7^{a}	7.7^{a}	7.4^{bcd}	9.7^{a}	9.5^{a}	8.7^{bcd}
N3G2	4.8^{a}	5.2^{a}	5.1^{abc}	7.4^{bcd}	8.9^{a}	8.3^{a}	8.0^{a}	7.6^{b}	7.9^{bc}	8.6^{abc}	7.3^{ab}	9.4^{abcde}	6.5^{a}	6.7^{b}	6.9^{fg}	9.6^{ab}	9.0^{cd}	9.4^{ab}
N3G3	4.3^{a}	3.5^{bc}	3.5^{cd}	8.7^{ab}	6.7^{fg}	6.9^{ef}	6.4^{abc}	8.8^{a}	7.8^{bcd}	7.7^{c}	5.7^{d}	8.3^{defg}	7.3^{a}	6.0^{c}	6.2^{h}	7.2^{f}	7.6^{ij}	7.3^{ef}
N3G4	4.1^{a}	5.0^{a}	6.2^{a}	8.2^{abc}	7.3^{de}	8.2^{ab}	7.9^{a}	7.4^{b}	8.5^{ab}	8.6^{abc}	8.2^{a}	10.9^{a}	7.1^{a}	7.1^{b}	7.7^{ab}	8.4^{cd}	8.1^{gh}	8.6^{bcd}
N3G5	4.6^{a}	4.1^{ab}	5.3^{ab}	8.5^{abc}	7.6^{cd}	7.6^{abcd}	-	8.5^{a}	8.9^{a}	3.5^{d}	6.1^{cd}	9.7^{abcd}	6.5^{a}	7.1^{b}	7.3^{cde}	7.4^{f}	9.0^{cd}	9.7^{a}

Means followed by a similar lowercase letter within a column are not significantly different (at $P < 0.05$) according to LSD test.

Interaction effect of genotypes and nutrient on maize yield: A significant interaction was found between genotypes and nutrient management practices in different years (except 2012 at Delhi and Hyderabad) across the location concerning grain yield in NWPZ, NEPZ and PZ. In NWPZ at Delhi during 2013, N1G5, N3G2 and N3G4 produced significant highest yield that was at par with all other genotypes × nutrient management practice except combination with G3 genotype (Table 1). During 2014, significantly highest yields were recorded with N1G4 and N3G4, which remained at par with N1G1, N1G2, N1G5, N2G1, N2G4, N3G1, N3G2 and N3G5, respectively. At Ludhiana, N1G3 produced significantly higher yield during 2012, however, it remained at par with N1G1, N1G5, N2G3, N3G1, N3G3, N3G4 and N3G5 respectively, but during 2013, N3G1 and N3G2 were significantly superior over all other treatment combinations. During 2014, N3G2 produced significantly higher yield, however, it remained at par with N1G1, N1G2, N3G1, N3G4 and N3G5 respectively. The NWPZ being an assured ecology with good yield potential had given the best yields across genotype and the nutrient management practices. In NEPZ at Ranchi during 2012 significant yield enhancement was obtained under N3G1, N3G2 and N3G4, which remained at par with N1G1, N1G2, N1G4 and N3G3 respectively. During 2013, a significant yield increase was found with N3G3 and N3G5. While during 2014, the significantly higher yield was found with N3G5 that remained at par with N3G4.

In PZ at Arbhavi during 2012, the significantly higher yield was obtained with N1G1, which remained at par with N1G2, N2G1, N2G4, N3G1, N3G2 and N3G4, respectively. While during 2013 and 2014 significantly higher yield was obtained with N3G4 that remained at par with N1G4, N2G4, N3G1 and N3G2, respectively in 2013 while during 2014 it remained at par with N1G1, N1G4, N3G1, N3G2 and N3G5, respectively. In Hyderabad, during 2013 significantly higher yield was obtained withN3G1while in 2014 it was with N1G4 that remained at par with N1G1, N2G1, N2G4, N2G5 and N3G4. However, at Karimnagar during 2012 significantly higher yield was obtained with N3G1 that remained at par with N1G2 and N3G2. Significantly, the higher yield was found with N3G1 in 2013 and N3G5 in 2014 that remained at par with N2G1 in 2013 while with N1G1, N1G2, N1G5 and N3G2 in 2014. Most of the genotype expects the genotype G3 that was QPM. However, the QPM genotype HQPM 1 used in the study had lower-yielding capacity compared to the rest of the genotype that could be the reason for the lower yield of this genotype across the locations. Genotype × management interactions play an important role in maximizing the productivity of the crops (Kumar *et al*. 2016). The changing behaviour of the genotype in response to the change in nutrient management and locations needs attention for maximizing productivity. The best management with the best genotype if adopted can help in minimizing the yield gaps.

Returns over fertilizer cost (ROFC): The results obtained in the gross reruns were not replicated for returns over fertilizer cost in our study where a differential response

Table 2 Effect of genotypes and nutrient management practices on returns over fertilizer cost (×10^3 ₹/ha) of maize in various agro-ecologies during 2012-14

Treatment	Delhi			Ludhiana			Ranchi			Arbhavi			Hyderabad			Karimnagar		
	2012	2013	2014	2012	2013	2014	2012	2013	2014	2012	2013	2014	2012	2013	2014	2012	2013	2014
Nutrient management																		
RDF	44.96	51.04	59.71	88.48^{b}	91.13^{b}	92.45^{a}	73.86^{a}	84.88^{b}	93.44^{b}	85.65	78.25^{ab}	108.37	76.99^{a}	80.57^{a}	89.35	92.04^{a}	102.30	106.87
50% RDF/FFP	45.97	45.22	50.73	82.45^{c}	85.20^{b}	81.51^{b}	50.42^{b}	52.54^{c}	57.37^{c}	83.96	72.48^{b}	97.68	60.79^{c}	58.65^{b}	88.00	77.53^{b}	102.44	100.59
SSNM	48.42	51.62	60.59	92.54^{a}	98.35^{a}	95.30^{a}	81.97^{a}	96.69^{a}	105.45^{a}	79.16	85.54^{a}	120.28	70.23^{b}	84.92^{a}	87.27	93.67^{a}	105.98	106.6
Genotypes																		
G1	46.27^{abc}	48.47^{b}	60.69^{b}	89.87^{b}	104.97^{a}	96.24^{a}	66.90^{bc}	71.00^{c}	77.12^{d}	101.92^{a}	83.95^{b}	111.59^{b}	65.26^{c}	83.62^{a}	93.20^{ab}	98.65^{a}	115.06^{a}	109.83^{a}
G2	54.74^{a}	56.74^{a}	58.45^{b}	81.14^{c}	102.39^{a}	95.63^{a}	73.09^{ab}	76.23^{bc}	85.26^{bc}	90.98^{bc}	84.13^{b}	104.67^{b}	68.74^{bc}	73.06^{b}	85.56^{c}	100.95^{a}	107.51^{ab}	109.15^{a}
G3	42.24^{bc}	37.71^{c}	40.61^{c}	100.20^{a}	77.06^{c}	79.08^{c}	60.54^{c}	87.37^{a}	82.07^{cd}	85.66^{c}	59.77^{d}	92.73^{c}	73.89^{a}	63.57^{c}	76.89^{d}	75.18^{c}	91.98^{c}	86.70^{b}
G4	38.05^{c}	53.04^{ab}	72.54^{a}	78.40^{c}	85.25^{b}	91.56^{ab}	74.47^{a}	72.39^{c}	89.12^{ab}	96.51^{ab}	95.05^{a}	126.39^{a}	71.23^{ab}	75.79^{b}	94.79^{a}	90.38^{b}	96.36^{c}	104.04^{a}
G5	50.96^{ab}	50.50^{b}	52.76^{b}	89.50^{b}	88.12^{b}	86.26^{bc}	-	83.19^{ab}	93.53^{a}	39.55^{d}	70.88^{c}	108.51^{b}	67.55^{bc}	77.55^{ab}	90.91^{b}	73.58^{c}	106.95^{b}	113.70^{a}
P-value (nutrient)	0.5354	0.0961	0.3125	0.0046	0.0148	0.002	0.0017	0.0007	0.0004	0.2528	0.0401	0.1183	0.0042	0.0006	0.089	0.0004	0.5137	0.4487
P-value (genotype)	0.0122	<.0001	<.0001	<.0001	<.0001	0.0024	0.0009	0.0006	0.0004	<.0001	<.0001	<.0001	0.0045	<.0001	<.0001	<.0001	<.0001	0.0004
P-value (interaction)	0.5696	0.0459	0.1444	0.0021	0.9902	0.9653	0.0317	0.8531	0.6867	0.7969	0.0479	0.2567	<.0001	0.9505	0.6768	0.7409	0.9995	0.9487
LSD (nutrient)	NS	NS	NS	3.81	6.8	4.37	9.45	10.38	9.69	NS	9.1	NS	5.97	6.24	NS	3.44	NS	NS
LSD (genotype)	9.68	5.89	9.34	5.26	5.22	8.82	6.41	7.64	6.72	9.18	4.45	8.72	4.35	6.52	3.21	5.72	7.82	11.27
LSD (interaction)	NS	10.21	NS	9.1	NS	NS	11.11	NS	NS	NS	7.71	NS	7.54	NS	NS	NS	NS	NS

Means followed by a similar lowercase letter within a column are not significantly different (at $P<0.05$) according to LSD test.

was recorded at various locations. The analysis of ROFC revealed that in NWPZ (Ludhiana) and NEPZ (Ranchi) significantly highest returns were found in SSNM over 50% RDF/FFP but it was at par with RDF in 2014 at Ludhiana and 2012 at Ranchi (Table 2). While in PZ, the SSNM gave significantly higher ROFC during 2013 at Arbhavi and Hyderabad and 2012 at Karimnagar that was on par with RDF in respective years and locations. However, in 2012 significantly higher ROFC was obtained with RDF at Hyderabad. In contrast to this, the ROFC for the genotypes had similar trends as of the gross returns. The optimized nutrient recommendations helped in enhancing yield and balancing the nutrient requirement of the maize that might increase returns from maize production. The higher returns of maize with the use of NE-SSNM also reported in earlier studies (Pooniya *et al.* 2015, Kumar *et al.* 2015 and Parihar *et al*. 2017a).

Based on the three years multi-location study it was concluded that the application of the NE-SSNM based nutrition could be effective for enhancing yield and returns in NWPZ and NEPZ while it also showed promise in Karnataka but it was at par with RDF in Telangana. Hence, the NE-SSNM is recommended for enhancing yield and returns over fertilizer cost in these ecologies for lesser environmental footprints and nutrient stewardship.

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REFERENCES

Dass S, Jat S L, Chikkappa G K, Kumar B, Kaul J, Parihar C M, Kumar A, Kumar R, Kamboj M C, Singh V, Yatish K R, Jat M L and Singh A K. 2012. Genetic Enhancement and crop management lead maize revolution in India. *Maize Journal* **1**(1): 7-12.

Jat M L, Satyanarayana T, Majumdar K, Parihar C M, Jat S L,Tetarwal J P, Jat R K and Saharawat Y S. 2013. Fertilizer best management practices for maize systems. *Indian Journal of Fertilisers* **9**(4): 80-94.

Kumar V, Singh A K, Jat S L, Parihar C M, Pooniya V, Sharma S and Singh B. 2014. Influence of site-specific nutrient management on growth and yield of maize (*Zea mays*) under conservation tillage. *Indian Journal of Agronomy* **59**(4): 657-60.

Kumar V, Singh A K, Jat S L, Parihar C M, Pooniya V, Singh B and Sharma S. 2015. Precision nutrient and conservation agriculture practices for enhancing productivity, profitability, nutrient-use efficiencies and soil nutrient status of maize (*Zea mays*) hybrids. *Indian Journal of Agricultural Sciences* **85**(7): 926-30.

Kumar B, Guleria S K, Khanorkar S M, Dubey R B, Patel J M, Kumar V, Parihar C M, Jat S L, Singh V, Yathish K R, Das A, Sekhar J C, Bhati P, Kaur H, Kumar M, Singh A K, Varghese E and Yadav O P. 2016. Selection indices to identify maize (*Zea mays* L.) hybrids adapted under drought stress and normal ecologies in tropical climate. *Crop and Pasture Science* **67**: 1087-95.

Parihar C M, Jat S L, Singh A K, Ghosh A, Rathore N S, Kumar B, Pradhan S, Majumdar K, Satyanarayana T, Jat M L, Saharawat Y S, Kuri B R and Saveipune D. 2017. Effects of precision conservation agriculture in a maize-wheat-mungbean rotation on crop yield, water-use and radiation conversion under a semiarid agro-ecosystem. *Agricultural Water Management* **192**: 306-19.

Parihar C M, Jat S L, Singh A K, Majumdar K, Jat M L, Saharawat Y S, Pradhan S and Kuri B R. 2017a. Bio-energy, water-use efficiency and economics of maize-wheat-mungbean system under precision-conservation agriculture in semi-arid agro-ecosystem. *Energy* **119**: 245-56.

Pooniya V, Jat S L, Choudhary A K, Singh A K, Parihar C M, Bana R S, Swarnalakshmi K and Rana K S. 2015. Nutrient expert' assisted site–specific–nutrient–management: An alternative precisionfertilization technology for maize-wheat cropping system in South-AsianIndo–Gangetic Plains. *Indian Journal of Agricultural Sciences* **85**(8): 996–1002.