Soil spatial variability assessment and precision nutrient management in Maize (*Zea mays* L.)

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Abstract. *Investigations on soil spatial variability and precision nutrient management based targeted yield approach in maize was carried out at Agricultural research station (ARS), Mudhol (Karnataka), India under irrigated condition during 2013-14, 2014-15 and 2015-16. ARS, Mudhol is located in northern dry zone of Karnataka at 16^0 20^I N latitude, 75^0 15^I E longitude and at an altitude of 577.6 meter above mean sea level. To assess the spatial variability, the study area was divided into 20 x20 m size grids and subjected to soil nutrient analysis. Spatial variability of available nitrogen, phosphorus and potassium was assessed and soil fertility map was prepared. Management zones were delineated based on soil fertility status as LMH and LHH by using nearest neighborhood technique. Five target yields - 60, 80, 100, 120 and 140 q ha^{-1} were evaluated with RDF and absolute control in the designated management zones. Nutrient prescription maps were generated based on site specific nutrient management concept and target yield. Nitrogen was applied in five splits (10, 20, 30, 30 and 10 % each at basal, 20 (V5), 35 (V10), 50 (V14) and 65 (R1) days after sowing, respectively) as per recommendations. The entire dose of phosphorus and potassium was applied as basal. Treatments differed significantly with respect to precision nutrient management through target yield approach. Significantly higher SPAD chlorophyll readings (57.6) and NDVI values (0.58) were recorded with target yield of 140 q ha^{-1} over target yield of 60, 80 q ha^{-1}, RDF (49.7 and 0.47,* *respectively) and absolute control (28.9 and 0.19, respectively) at 60 DAS. Target yield levels achieved with 60, 80, 100, 120 and 140 q ha^{-1} treatments were 78.6, 88.0, 112.9, 117.6 and 127.4 q ha^{-1} in LHH management zone and 76.5, 87.9, 101.4, 115.0 and 126.9 q ha^{-1}, respectively in LMH management zone whereas, absolute control recorded significantly lower grain yield (27.7 q ha^{-1}). Target yield of 60, 80, 100 and 120 q ha^{-1} were achieved over the years irrespective of management zones. Nutrient dynamics in soil indicated net gain in N and K and net loss of P in all target yield treatments.*

Keywords. *Irrigated Maize, Site specific nutrient management, Soil spatial nutrient variability, Precision Nutrient management.*

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Introduction

Globally maize is grown on an area of 187.9 million ha with production of 1060.1 million tonnes whereas; in India it’s grown on an area of 10.2 million ha with production of 26.26 million tonnes. On productivity front, Indian average productivity is very low compared to world and leading maize producing countries (FAOSTAT, 2018). In India maize is third important cereal crop which is presently valued as food, feed, starch and agro based industry input. State wise and national average productivity trends have shown an increasing trend over years, yet lower than the global average and the potential of the crop. Growing demand in India requisite for increased sustainable maize production. Sustainable maize production requires better understanding of crop nutrient demand, soil nutrient supply capacity and best agronomic practices. However wide yield gap exists between the potential and average yield of maize in India. Large gap in yield levels at farmers’ field is mainly due to imbalance nutrient application (Majumdar et al*.,* 2016). Pasquinade et al*.* (2014) indicated exploitable yield gap between attainable yield and current farmers’ yield to the tune of 0.9 t ha^{-1}. Yield responses to fertilizer application in maize is in the order N>P>K.

Yield gains achieved on nutrient-starved soils owing to crop management interventions other than adequate nutrient input would be temporary; leaving the soil further depleted of its native nutrients reserves. This necessitates for supplementing plant nutrients in adequate amounts and in balanced proportions to reduce native soil fertility drain and sustain high crop productivity. Fertilizer prescriptions on regional basis for wide geographical area don’t address soil spatial fertility variability and managerial differences in attainable yield potential (Dwivedi et al*.,* 2016). Advent of high yield potential single cross hybrid, stay green traits which are highly responsive to applied nutrients need to be evaluation for the response. Precision nutrient management is one of such tools which offer scope for the improvement of yield levels. Thus employing the strategies through precision nutrient management (PNM) principles will ensure a better synchrony between nutrient supply and crop demand. Spatial soil fertility variability assessment and preparing nutrient prescriptions are prerequisites to PNM. Site specific nutrient management (SSNM) is an approach of supplying nutrients to optimally match their inherent spatial availability with supplemental nutrients to achieve a desired yield (Buresh and Witt, 2007). SSNM based “target yield” approach was used in the study with an aim to achieve desired yield and sustainability. SSNM has the potential to close existing yield gaps in the maize production systems by improving yield, nutrient use efficiency, and profitability (Pasquinade et al*.,* 2014). The experimental site was located in nontraditional maize growing area (Southern India) which has higher yield potential area than the traditional maize growing area of India (Eastern India). Southern India zone of maize is endowed with favorable soil, sunshine hours and temperature regime (Majumdar et al*.,* 2016) hence; its ideal location for assessing spatial soil nutrient variability and evaluating response to SSNM based target yield approach in Maize. Scope for adoption on small scale precision nutrient management technology is often considered as challenge yet it’s a potential approach. An attempt was made in this regard to study the soil spatial variability assessment and precision nutrient management in maize under irrigated conditions at University of Agricultural Sciences, Dharwad of northern dry zone of Karnataka.

Material and methods

A field experiment was conducted at Agricultural Research Station, Mudhol, Karnataka, India to study the spatial variability in soils for enhancing productivity and sustaining in maize through precision nutrient management during *kharif* 2013-14, 2014-15 and 2015-16. The experimental site was distributed from 16^{0} 23' 56.4" - 16^{0} 20.467’ North latitude, 75^{0} 6' 33" - 75^{0} 15.868’ East longitude at an altitude of 577.6 m above MSL. Soil type of the experimental site was deep vertisol (depth >1.20 m). Experimental site (5 ha) was divided into 90 grids each of 20 x 20 m size. The GPS reading for all the grids were recorded at each corner point of the grid. Maize hybrid NK 6240 (Syngenta) with spacing of 0.6 x 0.2 m was used in study.

Soil sampling and analysis

Soil samples (from centre of each grid) were drawn upto 0.3 m depth before conduct of the experiment. Soil spatial variability were assessed as per the procedure using Alkaline potassium permanganate method (Subbaiah and Asija, 1956), Olsen method (Jackson, 1973) and Ammonium acetate method (Jackson, 1973) for available N, P_2O_5 and K_2O, respectively. Soil spatial variability was observed with respect to analyzed nutrients. Initial soil available nutrients of the experimental site are presented in table 1. Experimental site was low in available nitrogen (<280 kg ha^{-1}), medium to high in available phosphorus (12.5- 25 kg ha^{-1}) and high in potassium (> 335 kg ha^{-1}). Grid wise soil fertility variability maps were prepared (Fig 1).

Table 1. Initial soil chemical properties at the experimental site

Soil Chemical Properties	pH	EC (dS m^{-1})	OC (%)	N kg ha^{-1}	P_2O_5 kg ha^{-1}	K_2O kg ha^{-1}	Ca (me 100 g^{-1})	Mg (me /100 g^{-1})	S (kg ha^{-1})	Zn (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)
Minimum	8.02	0.16	0.27	86	3.5	356	**20**	**9.1**	**9.8**	0.17	0.31	0.98	1.51
Maximum	9.03	1.52	0.71	176	37.5	1733	29	23.8	34.7	0.69	0.90	5.0	9.17
Average	8.58	0.45	0.46	114	14.8	808	25	13.9	22.2	0.29	0.51	2.04	3.57

Based on the soil fertility status, management zones were delineated by using nearest neighborhood technique. Grid wise management zones were denoted as L- low, M- medium and H- high indicating the status of available N, P_2O_5 and K_2O. Management zones were delineated using nearest neighborhood technique (Schowengerdt, 2008). Correspondingly experimental site was delineated into one management zone (LMH) in 2013-14, two management zones i.e. LMH and LHH during 2014-15 and 2015-16. Soil spatial variability for 3 years indicated all grids under LMH during 2013-14. Whereas 57 grids under LMH and 33 grids under LHH were observed during 2014-15 and 2015-16. Seven treatments comprising SSNM based target yield of 60, 80, 100, 120 and 140 q ha^{-1}, recommended dose of fertilizer (RDF) and absolute control were studied for three years.

Fertilizer calculation

Average uptake of nutrients with respect to N, P and K (2.4:0.89:0.84 kg N: P_2O_5: K_2O ha^{-1}) to produce 100 kg grain yield was considered based on previous studies (Hirpa, 2012 and Pagad, 2014) in the similar agro climatic zone (northern dry zone). The amount of nutrient required to achieve target yield were calculated by using the following formulae (Biradar et al*.,* 2012) for working out required quantity of nutrient based on the target yield. The nutrient applied based on the soil fertility management zone against the targeted yield are presented in table 2.

Nutrient required {kg q^{-1} maize seed yield} = {Nutrient uptake by crop (kg q^{-1}) x T} ± per cent ENR

Where, T- Target of seed cotton yield (q ha^{-1})

ENR- Extra nutrient recommendation

Soil nutrient status	Per cent ENR
Low	20 per cent more than the calculate value
Medium	As Per the calculated value
High	20 per cent less than the calculated value

Fertilizer application

N, P_2O_5 and K_2O were applied based on uptake studies in the form of Urea, Di-ammonium phosphate, 10: 26:26 and Muriate of potash. Variable rate of nutrient as per nutrient prescription maps were applied to each grid manually (Table 2 and Fig 1). Recommended dose of fertilizer treatment was applied with 150:65:65 kg N: P_2O_5: K_2O ha^{-1}. Nitrogen as per the treatment was applied in five splits {(10, 20, 30, 30 and 10 %) each at basal, 20 (V_5 -Collar of 5th leaf visible), 35 (V_{10}-Collar of 10th leaf visible), 50 (V_{14}- Collar of 14th leaf visible) and 65 (V_{16} to R1- Collar of 16th leaf visible, appearance of tassel) days after sowing, respectively)} as per recommendations. The entire dose of phosphorus and potassium was applied as basal.

Observations on influence of the SSNM based target yield treatment under spatially variable plots were recorded in terms of SPAD values (SPAD-502-Chlorophyll meter Konica Minolta, Japan), NDVI values (Green Seeker RT-100 Hand held Trimble USA), yield attributes and yield. Efficiency indicators like agronomic efficiency and partial factor productivity were evaluated (Dobermann, 2007). Nutrient balance sheet was worked out with respect to major nutrients.

Agronomic efficiency (kg kg^{-1}) = (Yield in treated plot- Yield in control plot)/nutrient added

Partial Factor Productivity (kg kg^{-1}) = Yield of treatment plot/ nutrient added

Table 2. Nutrients required to achieve target yields in two management zones

Target yield (q ha^{-1})	Soil fertility management zones					
	LMH			LHH		
	Nutrients required (kg ha^{-1})					
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
60	172.8	53.4	40.3	172.8	42.7	40.3
80	230.4	71.2	53.8	230.4	57.0	53.8
100	288.0	89.0	67.2	288.0	71.2	67.2
120	345.6	106.8	80.6	345.6	85.4	80.6
140	403.2	124.6	94.1	403.2	99.7	94.1
RDF	150.0	65.0	65.0	150.0	65.0	65.0

Results

SPAD Value

Influence on the nutrient supplied as per the targeted yield on SPAD values at peak growth stage indicated increase in the SPAD values with increase in target yield levels (Table.3) Higher values of 52.7 (LMH), 57.6 (LMH), 48.8 (LHH), 49.3 (LMH) and 51.8 (LMH) were recorded with target yield of 140 q ha^{-1} during 2013-14, 2014-15 and 2015-16, respectively. Corresponding lower SPAD values were recorded in absolute control. SPAD values increased with increase in nitrogen application linked with higher target yield levels.

NDVI value

Effect of precision nutrient management indicated differential response in maize with respect to NDVI. Higher NDVI values were recorded in LHH management zone in comparison to LMH. Higher NDVI was recorded with target yield in 140 q ha^{-1} compared to RDF and absolute control over years. Irrespective of management zones absolute control recorded lower NDVI values.

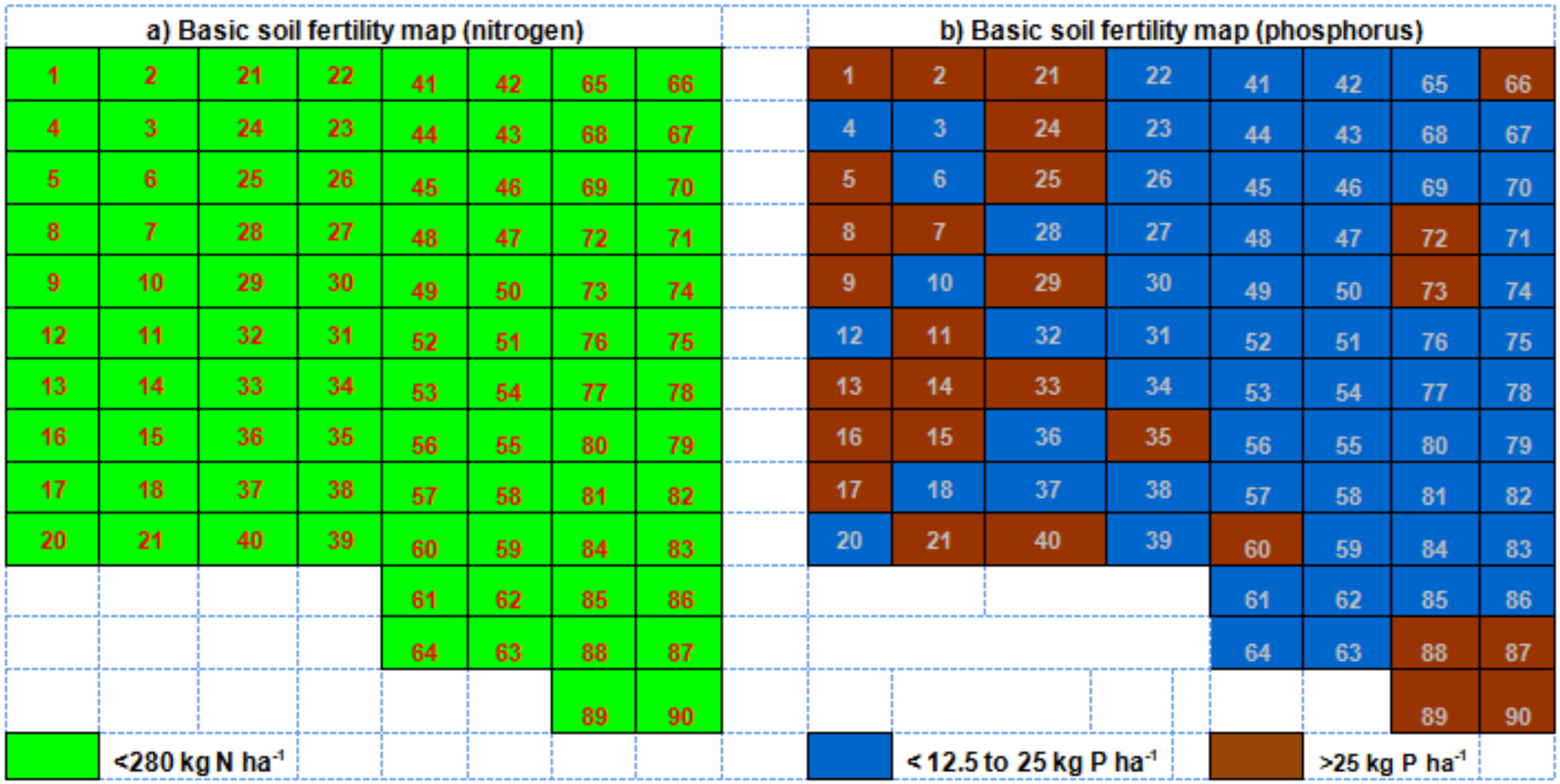

Fig.1 Basic soil fertility maps of experimental site (gridwise) **1a.** Nitrogen **1b.** Phosphorus

Fig. 1c. Basic soil fertility maps of experimental site (gridwise) potassium **Fig 1d.** Delineation of management zones of experimental site (gridwise)

Table 3. Influence of precision nutrient management on SPAD values in two management zones

Target yield (q ha^{-1})	SPAD values				
	2013-14	2014-15		2015-16	
	Management zones				
	LMH	LMH	LHH	LMH	LHH
60	46.2	52.1	40.6	46.4	45.1
80	51.2	54.3	42.2	46.6	46.2
100	51.1	55.2	44.3	47.7	47.8
120	50.9	56.7	46.0	48.7	48.1
140	52.7	57.6	48.8	49.3	51.8
RDF	39.3	49.7	37.1	39.9	39.7
Absolute control	35.2	29.0	29.2	35.8	34.1

Table 4. Influence of precision nutrient management on plant NDVI in two management zones

Target yield (q ha^{-1})	NDVI				
	2013-14	2014-15		2015-16	
	Management zones				
	LMH	LMH	LHH	LMH	LHH
60	0.43	0.48	0.53	0.49	0.51
80	0.49	0.50	0.55	0.52	0.53
100	0.52	0.54	0.56	0.54	0.54
120	0.54	0.57	0.58	0.56	0.57
140	0.56	0.58	0.59	0.58	0.58
RDF	0.43	0.47	0.46	0.48	0.49
Absolute control	0.20	0.19	0.20	0.21	0.18

Grain yield

Influence of the soil fertility in interaction to precision nutrient management on seed yield was significant (Table 6 and Fig 2). Target yield of 60 q ha^{-1} recorded seed yield levels similar to that of the RDF. Improvement in the yield levels were observed above target yield of 80q ha^{-1} across the years. Irrespective of the management zones, target yields of 60, 80, 100 and 120 q ha^{-1} were achieved across the years (Fig. 3). Target yield of 140 q ha^{-1} was not achieved which witnessed shortfall in actual yield. Yield levels in two management zones were on par with each other indicating effective management of the spatial variability with desired prescription dosage of major nutrients. Maize is highly responsive to nitrogen is clearly expressed in target yield treatments in comparison to the absolute control. Precision nutrient management treatments induced progressive improvement in yield levels upto 120 q ha^{-1}.

Table 6. Influence of precision nutrient management on grain yield in two management zones

Target yield (q ha^{-1})	Grain yield (q ha^{-1})									
	Management zones									
	2013-14		2014-15				2015-16			
	LMH	Difference	LMH	Difference	LHH	Difference	LMH	Difference	LHH	Difference
60	82.2	+22.2	60.4	+0.4	60.1	+0.1	76.5	+16.5	78.6	+18.6
80	96.1	+16.1	80.1	+0.1	81.9	+1.9	88.0	+8.0	87.95	+7.95
100	108.7	+8.7	100.2	+0.2	100.2	+0.2	101.4	+1.4	112.9	+12.9
120	119.8	-0.2	113.9	-6.1	116.0	-4.0	115.0	-5.0	117.6	-2.4
140	128.3	-11.7	126.1	-13.9	127.1	-12.9	126.9	-13.1	127.4	-12.6
RDF	79.4	--	61.3	--	61.3	--	74.3	--	77.1	--
Absolute control	28.2	--	28.0	--	31.0	--	27.7	--	27.7	--

Table 7. Influence of precision nutrient management on stover yield in two management zones

Target yield (q ha^{-1})	Stover Yield (q ha^{-1})				
	2013-14	2014-15		2015-16	
	Management zones				
	LMH	LMH	LHH	LMH	LHH
60	88.5	91.4	92.7	95.6	117.3
80	105.4	111.6	116.0	103.5	106.4
100	115.3	122.4	124.5	104.8	107.8
120	129.9	140.6	140.2	118.5	111.8
140	134.3	146.4	150.2	126.9	146.4
RDF	83.9	91.0	91.0	94.6	84.5
Absolute control	47.2	54.1	57.8	52.7	52.7

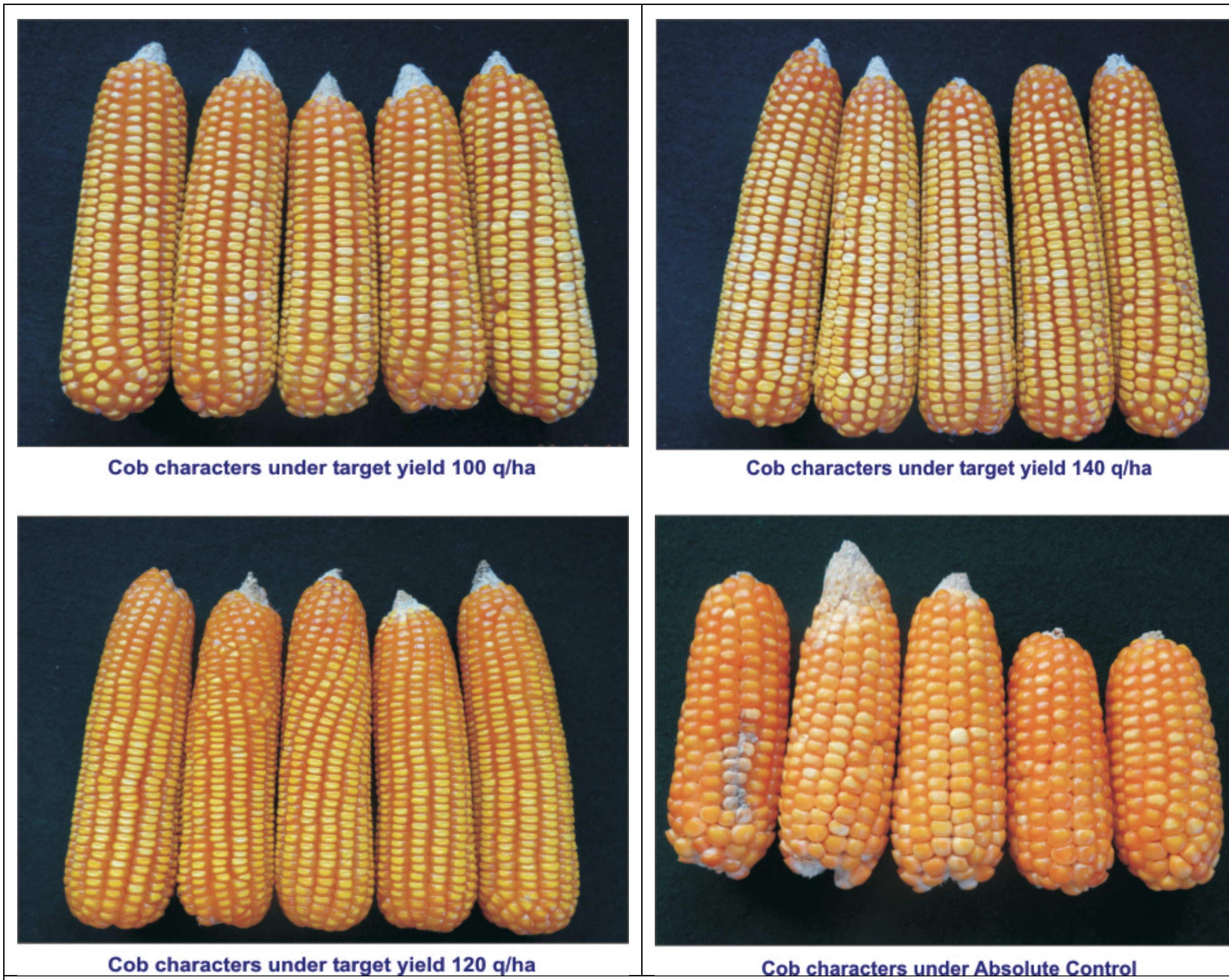

Fig 2. Influence of the target yield treatments on yield attributes in maize

Stover yield

Stover is important source of cattle feed. Effect of the precision nutrient management treatments on Stover yield was significant (Table 7). Increase in the stover yield was observed across all the target yield treatments in comparison to RDF and absolute control. Application of nutrients to achieve target yield of 140 q ha^{-1} recorded higher stover yield over other treatments. Similar trend was recorded across the management zones over the years.

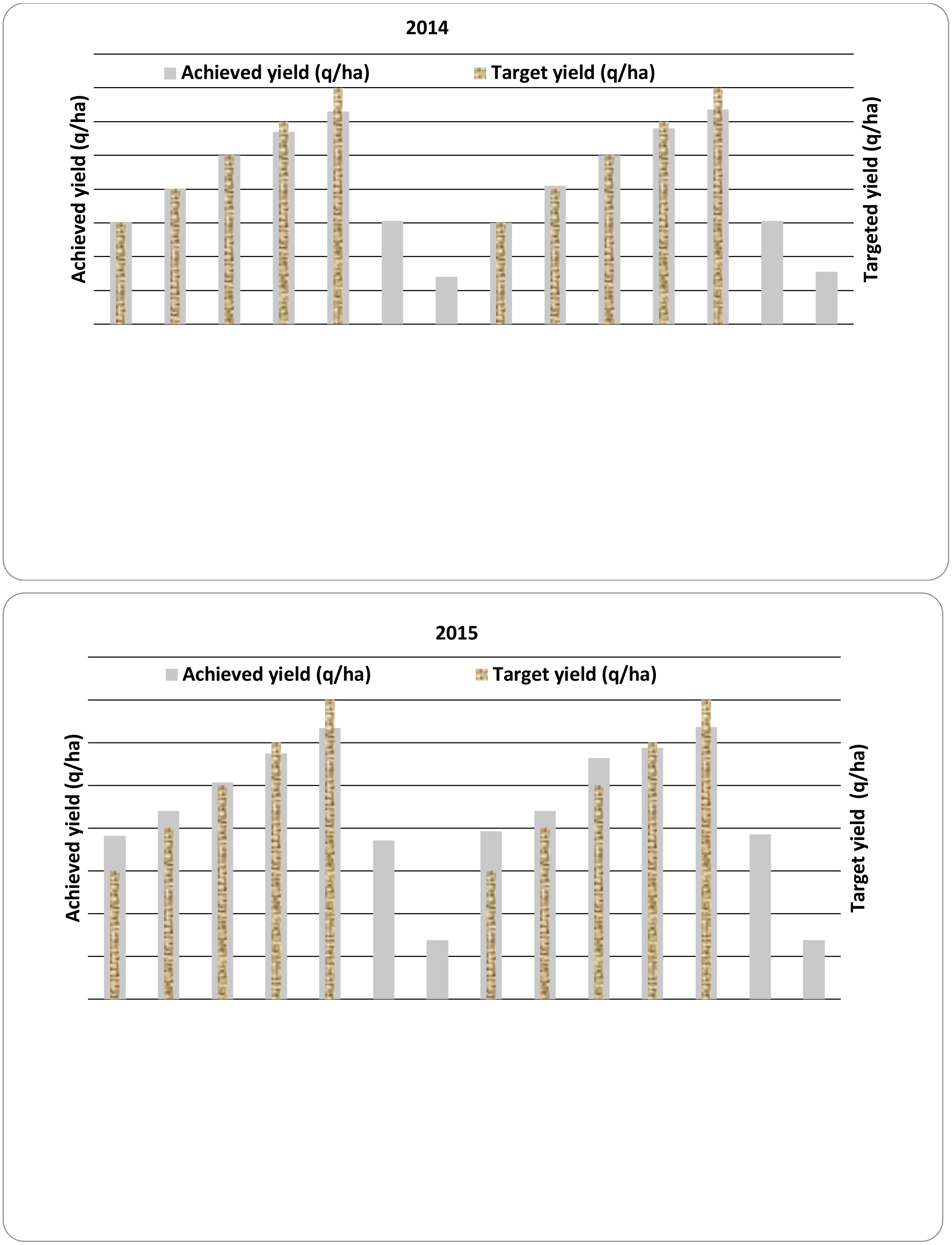

Fig 2. Influence of precision nutrient management on yield achieved against target yield

Nutrient use efficiency indicators

Agronomic efficiency

Studies on effect of precision nutrient management on agronomic efficiency indicated higher agronomic efficiency for nitrogen (AE_N) even at the higher levels of nitrogen in order with target yield on account of balanced phosphorus and potassium applied (Table 8). AE_N ranged in between 16.8 kg kg^{-1} (LHM- 60 q ha^{-1}) and 29.6 kg kg^{-1} (LHH- 100 q ha^{-1}). Agronomic efficiency for phosphorus (AE_P) and potassium (AE_K) recorded higher values across target levels, management zones and year of experiment in comparison to RDF. Effect of precision nutrient management on AE_N and AE_K was similar across the management zones at particular target yield. However, higher AE_P were recorded in LHH management zone in comparison to LMH zone indicating profuse effect of native phosphorus.

Partial factor productivity

Partial factor productivity for nitrogen (PFP_N) was lower in the target yield treatments in comparison to RDF (Table 9). PFP_N reduced with increase in target yield levels from 60 to 140 q ha^{-1}. On the contrary partial factor productivity for phosphorus (PFP_P) was higher in target yield treatments in comparison to RDF. However PFP_P reduced marginally with increased target yield levels. Correspondingly partial factor productivity for potassium (PFP_K) recorded similar trend with that of phosphorus. Higher PFP_P and PFP_K are indicative of functional role of balanced nutrient application (NPK) which induced prolific effect on increase in yield due to increased nitrogen applied in target yield treatments.

Nutrient budget

Consolidated nutrient balance sheet as influenced by precision nutrient management to achieve target yield indicated net gain in nitrogen and potassium and net loss in phosphorus (table 10). Nitrogen balance sheet studies indicated net gain in nitrogen across the management zones, target yield treatments and year of experiment. Nitrogen applied as per target yield was sufficient to meet the crop nitrogen demand. Similar studies on phosphorus balance indicated negative balance mainly because of phosphorus fixation in clay lattice. Phosphorus fixation is common problem encountered in vertisols. Irrespective of treatments, management zones across the years resulted in net loss of phosphorus. On the contrary potassium balance studies indicated net gain across the target yield levels in both LMH and LHH management zone over the years. However LMH management zone recorded relatively higher net gain in nitrogen and potassium compared to LHH management zone.

Table 8. Influence of precision nutrient management on Agronomic efficiency in two management zones

Target yield (q ha^{-1})	Agronomic efficiency (kg kg^{-1})														
	2013-14			2014-15						2015-16					
	Management zones														
	LMH			LMH			LHH			LMH			LHH		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
60	31.3	101.1	134.0	18.8	60.7	80.4	16.8	68.1	72.2	28.2	91.4	121.1	29.5	119.2	126.3
80	29.5	95.4	126.2	22.6	73.2	96.8	22.1	89.3	94.6	26.2	84.7	112.1	26.2	105.7	112.0
100	28.0	90.4	119.8	25.1	81.1	107.4	24.0	97.2	103.0	25.6	82.8	109.7	29.6	119.7	126.8
120	26.5	85.8	113.6	24.9	80.4	106.6	24.6	99.5	105.5	25.3	81.7	108.3	26.0	105.3	111.5
140	24.8	80.3	106.4	24.3	78.7	104.3	23.8	96.4	102.1	24.6	79.6	105.4	24.7	100.0	106.0
RDF	34.1	78.8	78.8	22.2	51.2	51.2	20.2	46.6	46.6	31.1	71.7	71.7	32.9	76.0	76.0

Table 9. Influence of precision nutrient management on Partial factor productivity in two management zones

Target yield (q ha^{-1})	Partial factor productivity (kg kg^{-1})														
	2013-14			2014-15						2015-16					
	Management zones														
	LMH			LMH			LHH			LMH			LHH		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
60	47.6	153.9	204.0	35.0	113.1	149.9	34.8	140.7	149.1	44.3	143.3	189.8	45.5	184.1	195.0
80	41.7	135.0	178.6	34.8	112.5	148.9	35.5	143.7	152.2	38.2	123.6	163.6	38.2	154.3	163.5
100	37.7	122.1	161.8	34.8	112.6	149.1	34.8	140.7	149.1	35.2	113.9	150.9	39.2	158.6	168.0
120	34.7	112.2	148.6	33.0	106.6	141.3	33.6	135.8	143.9	33.3	107.7	142.7	34.0	137.7	145.9
140	31.8	103.0	136.3	31.3	101.2	134.0	31.5	127.5	135.1	31.5	101.8	134.9	31.6	127.8	135.4
RDF	52.9	122.2	122.2	40.9	94.3	94.3	40.9	94.3	94.3	49.5	114.3	114.3	51.4	118.6	118.6

Table 10. Consolidated nutrient balance sheet as influenced by the precision nutrient management to achieve target yields

Target yield (q ha^{-1})	Soil fertility management zones					
	LMH (three years)			LHH (two years)		
	Nutrient balance sheet (kg ha^{-1})					
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
60	-11.2	+0.3	-0.8	-1	-0.5	-5.5
80	+4.7	+0.3	-2.8	+5.6	+1.6	-0.1
100	+67.8	+0.6	+2.2	+44.9	+4.3	-18.5
120	+110.1	+0.5	+20.8	+72.3	+2.5	-7.1
140	+184.6	+0.2	+20.2	+146.4	+2.3	+5.8
RDF	-22.6	+0.8	+20.1	-25.6	+0.1	-1.3

Conclusion or Summary

Target yield of 60, 80, 100 and 120 q ha^{-1} were achieved over the years irrespective of management zones. Nutrient dynamics in soil indicated net gain in N and K and net loss of P in all target yield treatments. SSNM based target yield approach under irrigated condition offers potential tool for increasing the average productivity over and above the recommended dose of fertilizer.

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