Addressing heterogeneity of maize yield and nitrogen use efficiency in India: Farm-specific fertilizer recommendation from the Nutrient Expert® Tool

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Abstract

Maize is an important contributor to food security in India. It is grown in diversified environments, and under variable management practices. Increasing demand for maize from multiple sectors, and its resilience to abiotic and biotic stresses, have made it a choice crop among farmers. Appropriate fertilizer management is important for sustainably intensifying maize systems in India. However, smallholder farmers' fertilizer management in maize is generally more perception-based than science-based due to lack of appropriate guidance. This often leads to imbalanced fertilizer application by the farmers, with loss of yield and large environmental footprint from fertilizer use. The current study uses a fertilizer recommendation tool, Nutrient Expert® for maize, to provide field specific fertilizer recommendations to farmers of two distinct maize growing ecologies of Eastern and Southern India. The on-farm results, comparing the Nutrient Expert® tool-based recommendation and existing farmers' fertilizer practices, showed that fertilizer recommendation from the tool improved maize yield and nitrogen use efficiency as compared to existing farmers' practices, irrespective of scale of investigation ranging from regions, cropping seasons within regions, and farm typologies within states in a region.

Key Words
Maize, Eastern India, Southern India, partial factor productivity, farm typology

Introduction

Maize (Zea mays L.) is the third most important grain crop in India, after rice and wheat. It is cultivated in 9.1 million hectares (M ha), with an annual production of 24.3 million tonnes (Mt), and an average national productivity of 2.6 tonnes per ha (t/ha) (Yadav et al. 2015). The production of maize increased from 1.7 Mt in 1950-51 to the current level through a 35% increase in cultivated area under maize, and productivity increase by 48% (Yadav et al. 2016). It is estimated that maize production needs to double by 2025 to address the growing demand from the food, feed and industrial sectors, as well as to access the lucrative global export markets. Achieving this targeted maize production would require higher fertilizer use, and addressing the imbalanced fertilizer use by farmers which is adversely impacting productivity goals and nitrogen use efficiency (NUE). Major maize growing areas in South Asia have high regional variations in climate and crop yields, while smallholder farms in the region have high between-farm variability due to differential management. Timsina et al (2010) identified two major agro-ecosystems for maize in India. These are tropical, warm, semi-arid, no winter agro-ecosystem that covers the states of Andhra Pradesh, Karnataka and Tamil Nadu in Southern India; and sub-tropical, sub-humid, warm summer, mild cool winter agro-ecosystem that is found in Bihar, Eastern Uttar Pradesh and West Bengal of Eastern India. Both agro-ecologies allow maize cultivation in rainy, winter and summer seasons. There are, however, fundamental differences in agro-ecological, socio-economic and technology-adoption features between these two regions that influence maize cultivation and productivity (Joshi et al. 2005). Some typical features associated with maize farming in Eastern and Southern India is given in Table 1. Fertilizer application recommendations in such diversified maize growing environments are often missing, challenging maize growers and their advisors. We used a new fertilizer decision support tool, the Nutrient Expert® for maize, to improve on-farm maize productivity and NUE through farm-specific fertilizer recommendation from the tool.

Table 1. Comparative features of maize farming in Eastern and Southern India

Maize farming in Eastern India	Maize farming in Southern India

Traditional maize growing area.	Market driven non-traditional maize growing area.
Small farms with resource poor farmers.	Comparatively bigger farms with higher resource endowed farmers
Alluvial heavy to light textured soils	Red, Lateritic, Black and Alluvial soils
Less sunshine hours in the rainy season due to longer cloudy weather	Sunshine hours are more in the rainy season as compared to eastern region due to less cloudy weather
Winter temperature (<10°C) is lower than the threshold temperature for proper growth and development of maize	The temperature during winter season remains (10-28°C), favourable for proper growth and development of maize
Rain-fed as well as irrigated maize cultivation.	Assured irrigation for maize cultivation.
High possibility of flooding during rainy season.	Likelihood of flooding is less in rainy season.
Low input and fertilizers use for maize cultivation.	High input and fertilizers use for maize cultivation.

Source: Synthesized from Joshi et al. 2005; and Personal Communication Dr. C. M Parihar, Indian Institute of Maize Research, New Delhi, 2016

Methods

The Nutrient Expert® for maize is an easy-to-use, interactive computer-based decision tool that can provide fertilizer recommendation for individual farm fields in presence or absence of soil testing data (Pampolino et al. 2012). The recommendations generated by the tool are based on site specific nutrient management principles, that are tailored to the farmers own yield goal, field management history and prevailing environmental conditions. The tool utilizes information on the growing conditions provided by a farmer or a local extension expert to suggest a meaningful yield goal for a farm. The nutrient balance in the farm based on yield and fertilizer/manure applied in the previous crop, farmer perceived bio-physical characteristics of the farm, and management history are then used by the Nutrient Expert® tool to recommend specific fertilizer rates for the farm required to attain the proposed yield goal in a particular season.
The Nutrient Expert® tool-based recommendations (NE) were compared to the farmers' fertilization practices (FFP) in large-scale on-farm trials across different maize growing environments of India. The current study reports on the pooled data from 909 on-farm trials during 2011-2015. The on-farm trials were done in Bihar, Odisha and West Bengal in Eastern India; and Andhra Pradesh, Karnataka, Tamil Nadu and Telengana in Southern India. The two treatments, NE and FFP, were implemented side-by-side in the same farmer's field where each plot size was at least 100 m^2. Maize yield data were collected from the two plots at harvest. Different sub-sets of the on-farm trial data were used to assess the utility of the NE to address variability at regional, seasonal and farm management scale, as compared to the FFP. For instance, to assess the utility of NE at the farm management scale, a small subset of the data, representing 127 on-farm trials in West Bengal by farm typology, was used. A combination of Principal Component Analysis (PCA) and Cluster Analysis was used earlier to identify typical farm households (Goswami et al. 2014) among the farmers' associated with these trials. The analysis resulted in the identification of six clusters of farms, which were then characterized by a host of socio-economic, crop management and related variables. The delineated farm types were a) Farm Type 1 (Moderate-resourced commercial maize grower), b) Farm Type 2 (Exclusive cultivators with large holding and large family), c) Farm Type 3 (Low-yielding new maize growers), d) Farm Type 4 (Moderately resourced family farms), e) Farm Type 5 (Traditional maize grower), and f) Farm type 6 (Resource-rich commercial seed producers). The NE and FFP for farmers in each farm type was then compared for nutrient use, maize yield, and partial factor productivity of N (PFP_N). The quantitative difference between NE and FFP (NE-FFP) in nutrient use, maize yield and PFP_N at regional, seasonal and farm management scale were estimated and analyzed using Student's t test (Table 2).

Results & Discussion

The Nutrient Expert® tool-based fertilizer recommendation (NE) improved maize yield over the existing farmers' practices (FFP) in both Eastern and Southern India (Figure 1). The maize yields were typically higher in Southern India due to favourable growing environments as described in Table 1. The maize yield improvement by NE (NE-FFP= 677 kg/ha) is small in Southern India (Table 2), suggesting farmers' yields are similar to attainable yield in this region. On the contrary, large difference in maize yields between NE and FFP (≈ 1.5 t/ha) in Eastern India suggests opportunities to improve farmers' yield in this region through field-specific fertilizer management (Table 2). Lack of fertilizer use guidance to farmers is manifested in different ways in the two regions. Resource poor smallholder maize farmers of Eastern India applied less than required quantity of potassium (K) fertilizers, and additional recommendation of K_2O (28 kg/ha) in the

NE seems to be the driver of yield improvement. Relatively better resource endowed South Indian maize farmers apply more than required quantities of nitrogen (N) and phosphorus (P) fertilizers for the yields achieved in their fields. Table 2 showed that NE reduced the N (NE-FFP= -33.8 kg/ha) and P (NE-FFP= -40.8 kg/ha) fertilizer rates and increased maize yield in the on-farm trials as compared to FFP (Table 2).

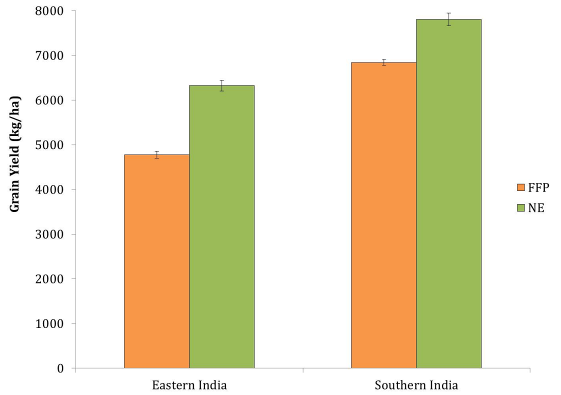

Figure 1. Maize yield improvement through Nutrient Expert® tool -based fertilizer recommendation (NE) over Farmer's Fertilizer Practice (FFP) in Eastern and Southern India.

The present study estimated the partial factor productivity of N (PFP_N) as the performance indicator of efficient N use at different scales. At the regional scale, the NE improved PFP_N over the FFP by 4.3 and 6.0 kg grain/kg N in South and East India, respectively (Table 2). This may not look attractive enough to change existing practices but for a region like South India, producing nearly 10 Mt of maize grain, the small improvement in PFP_N may translate to a savings of ≈ 20,000 tonnes of N. At the state level, NE significantly reduced N use in both rainy and winter season maize in Andhra Pradesh (Table 2). Reduced N recommendation (NE-FFP= -43 kg/ha) by the Nutrient Expert® tool as compared to the FFP in the rainy season, and N (NE-FFP= -49 kg/ha) and P (NE-FFP= -63 kg/ha) in the winter season, still significantly improved maize yield in Andhra Pradesh. This was achieved by field specific balanced nutrient recommendation by the tool and better timing of fertilizer N application. The PFP_N, in both rainy and winter seasons (16 and 11 kg grain/kg N, respectively) increased significantly by NE, driven by reduced N use and yield improvement as compared to FFP.
The PFP_N improvement in the rainy maize season of Bihar was small but significant (Table 2). The rainy season maize in Bihar is risk-prone due to possibility of drought and flood. Farmers generally do not apply enough fertilizer required to achieve high yield goals. So the maize yield improvement in the rainy season was driven by increased N, P and K recommendation in NE over FFP, leading to only small increase in PFP_N.

Table 2. Quantitative difference between NE and FFP (NE-FFP) in nutrient use, maize yield and PFP_N at regional, seasonal and farm management scale

Location/Farm Type	N use (kg/ha)	P_2O_5 use (kg/ha)	K_2O use (kg/ha)	Yield (kg/ha)	PFP_N (kg grain/kg N
		Nutrient Expert addressing regional differences			
Southern India	-33.8***	-40.8***	8.7**	677**	4.3*
Eastern India	6.5*	-15**	28**	1482***	6.0***
		Nutrient Expert addressing seasonal differences within States			
Andhra Pradesh Rainy season	-43***	-6NS	8NS	1541***	16***
Andhra Pradesh Winter season	-49**	-66***	11NS	1192***	11***
Bihar Rainy season	25***	15***	51***	1345***	4.2***
Bihar Winter season	-1.6***	-6.3***	44.5***	1163***	6.9***
		Nutrient Expert addressing typological differences among farmers in West Bengal			
Type 1	-11.5NS	-69.7***	4.2NS	1871***	11.5*
Type 2	-71.3NS	-73.2**	4.8NS	1749**	23.6*

Type 3	39.7***	-52.0***	-17.8***	1592***	0.47***
Type 4	21.3***	-3.2***	18.2***	1436***	5.6*
Type 5	-38.4***	-12.8***	47.7***	2708***	28.8*
Type 6	-78.0***	-141.0***	-30.2***	2272***	27.3***

NE = Nutrient Expert® tool-based fertilizer recommendation; FFP = farmers' fertilization practices; $^{*}p \leq 0.05$, $^{**}p \leq 0.01$, $^{***}p \leq 0.001$, NS = Difference between NE and FFP is not significantly different at 5 % of confidence level.

Higher N and P fertilizer use by farmers growing winter maize in Bihar was evident in Table 1. However, lack of K use by farmers', even in the high yielding winter season, was highlighted by higher K recommendation (44.5 kg/ha) by the Nutrient Expert® tool.
Finally, the NE improved maize yield for farmers of the six farm typologies (Table 2) as compared to FFP. Large improvements in PFP_N through NE were achieved in farm Type 2 (Exclusive cultivators with large holding and large family), Type 5 (Traditional maize grower), and Type 6 (Resource-rich commercial seed producers). The farmers belonging to these three groups have higher resource endowment within the broader group, that generally translated into imbalanced application of nutrients, particularly of N. Farm specific fertilizer recommendations, based on production history and inherent nutrient supplying capacity of these farms, allowed significant reduction in N use with increased productivity, leading to large improvement in PFP_N (Table 2). Farm Type 3 (Low-yielding new maize growers) and Farm Type 4 (Moderately resourced family farms) represented maize growers applying inadequate N fertilizer. The maize yield increase in these two farm types was achieved through higher application of N that led to significant but small improvement in PFP_N.

Conclusion

Farm-specific fertilizer recommendation from the Nutrient Expert® tool improved maize yield and nitrogen use efficiency as compared to farmers' fertilizer practices in two intensive maize growing areas in India. The tool-based recommendations, tailored for farms, seasons and yield levels, were able to address regional and seasonal differences in maize growing environments, and differences in fertilizer management among maize farmers. The Nutrient Expert® tool provides opportunities to promote efficient N use in maize growing areas of India.

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