On-farm Performance of Nutrient Expert® for Maize: Fertiliser Recommendation, Yield, and Nutrient Use Efficiency

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On-farm trials over 500 sites across six maize growing states in India compared the Nutrient Expert® decision support tool-based fertiliser recommendation system against farmers' fertilisation practices and state recommended practices. Results showed significant yield improvement with higher nutrient use efficiency and savings of fertiliser through the tool-based recommendation.

Crop production in India increased radically since the green revolution in the early 1960s. Increased fertiliser use was one of the major drivers that changed the food security scenario in the country since then. The momentum, however, slowed in the past decade. Indian population is expected to be around 1.33 billion by 2020 (GOI, 2014), reaching 1.66 billion by 2050 (USCB, 2014). IFPRI (2012) summarised several studies that showed foodgrain demand in India reaching 293 million tonnes (M t) by 2020 and increasing to 335 M t by 2026. Estimates suggest that at the current level of production (263 M t), an additional 5 M t foodgrain has to be added each year to the national food basket for the next decade or so to feed the increasing population.

Maize, a crop of worldwide economic importance, provides approximately 30% of the food calories to more than 4.5 billion people in 94 developing countries (Jat et al., 2013). Maize is considered as the third most important food crop among the cereals in India and contributes to nearly 9% of the national food basket. Grown in an area of 8.55 M ha with an average productivity of 2.5 t/ha, maize contributes to more than half of the coarse cereal production of the country. The annual maize production in India is about 21.7 M t with an annual growth rate of 3 to 4 % (Jat et al., 2013). The rapid population growth, persistent poverty in areas where maize is a staple crop, rising price of main staples like rice and wheat, and increasing demand for maize as feed due to change in dietary preferences are driving the demand for maize (Majumdar, 2014) in India. Maize yields in India need to be increased significantly to sustain high growth rate to meet India's growing food, feed and industrial needs.

Imbalanced fertiliser application in crops is identified as one of the major reasons for decreasing crop response to fertiliser application and the consequent lower crop production growth rate in India. Despite the proven economic, social and environmental benefits of balanced fertilisation, its adoption at the farm level is low. The generally unbalanced use of fertiliser by farmers has raised concerns about achieving food security goals and also the environmental sustainability of such practice. The lack of appropriate tools and implementation mechanisms has been a major hindrance that restricted wide-scale adoption of balanced fertilisation.

IPNI and its partner organisations in South Asia have jointly developed a dynamic nutrient management tool, Nutrient Expert® (NE), that can generate farm-specific fertiliser recommendation for maize. The tool is based on the site-specific nutrient management (SSNM) principles (Pampolino et al., 2012) and utilises information of the growing environment to provide balanced fertiliser recommendations for maize that are tailored for a particular location, cropping system and farmer resource availability.

The NE tool development in India was followed by a large-scale on-farm validation across different growing environments of maize. The NE-based recommendations were compared to the existing fertiliser recommendation practices such as farmers' fertilisation practices (FFP) and state recommendations (SR). The three treatments were implemented side-by-side in the same farmer's field where each plot size was ≥ 100 m². The current study reports on the pooled data from 510 on-farm trials in maize, spanning three seasons between 2011 and 2013. Since several cooperating Institutes were involved in the validation trials, all the treatments were not implemented in all locations. Besides, unforeseen events sometimes did not allow collection of data from all treatments and questionable data were not included from some trials. The exact number of data for each treatment is given in **Table 1**. The maize trials were done in Bihar, Odisha, Rajasthan, Andhra Pradesh, Karnataka, and Tamil Nadu.

As discussed earlier, the NE tool is based on the SSNM principles. SSNM advocates external application of nutrients to bridge the gap between indigenous soil nutrient supply and crop nutrient requirement for a target yield. In smallholder systems of India, farmers cultivate small pieces of land and management varies widely depending on awareness and resource availability. Such variable management decisions create large spatial and temporal variability in soil nutrient availability. Ideally the fertiliser management in such smallholder landscape should vary and be location-specific to avoid over- or under-use of nutrients. Farmers' fertilisation practices

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium.

Table 1. Modal values of fertiliser application rates, yield and partial factor productivity (PFP) in different treatments in maize validation trials.

Parameter	FFP (n=482)	SR (n=296)	NE (n=510)	NE-FFP	NE-SR
N, kg/ha	138 (27 to 550)	100 (80 to 280)	130 (90 to 257)	-8	30
P_2O_5, kg/ha	23 (0 to 280)	60 (22 to 75)	37 (17 to 92)	14	-23
K_2O, kg/ha	0 (0 to 352)	50 (0 to 75)	56 (18 to 143)	56	6
Yield, kg/ha	7,800 (1,024 to 11,766)	4,200 (1,051 to 10,785)	8,400 (2,337 to 12,460)	600	4,200
PFP, kg grain/kg nutrient	12.4 (7 to 78)	21 (6 to 46)	27.5 (10 to 62)	13.1	6.5

in India lack the necessary integration of information on soil nutrient supply and crop nutrient requirement. State fertiliser recommendations are generally based on response studies extrapolated to large areas and the spatial and temporal variability in soil nutrient supply between farms is not addressed adequately. In such a scenario, it is expected that there will be significant differences between the NE, SR and FFP fertiliser recommendations when a large dataset is compared. The expected outcome from the NE-based balanced and location-specific fertiliser recommendation could be several, including improved yield, higher nutrient use efficiency or saving of fertiliser and consequent improved economics of production and environmental stewardship of applied nutrients.

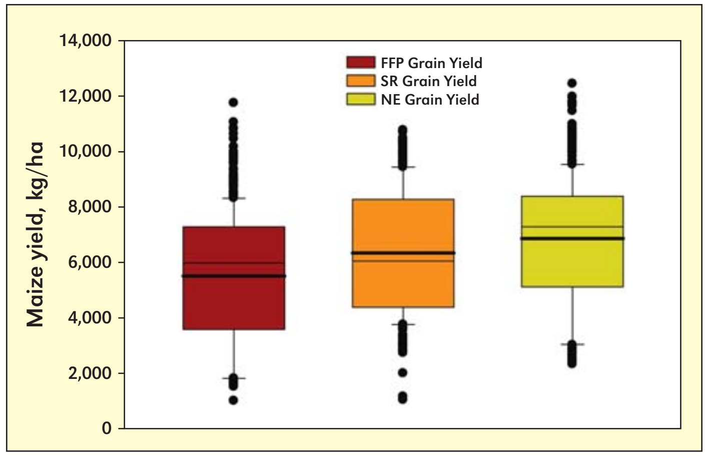

Figure 1. Average maize grain yield in Nutrient Expert® validation trials (n=510) in India. Boxes represent data within the first and third quartiles (interquartile range). The thin line denotes the second quartile or median. Lines extending beyond the interquartile range denote the 10th to 90th percentile of the data. Statistical outliers are plotted as individual points outside these lines.

The comparative data of different treatments from the validation trials for maize are given in **Table 1**. We used the "MODE" values instead of "MEAN" to represent the dataset. The "MEAN" of large on-farm dataset often masks the general trend of the data. On the other hand, "MODE" represents the central tendency of the dataset that is a more realistic representation and easier to explain.

The NE-based fertiliser recommendation for maize improved yield as compared to FFP and SR (**Figure 1**) across multiple locations in India. The NE recommendation produced the highest modal yield (8,400 kg/ha) followed by FFP (7,800 kg/ha) and SR (4,200 kg/ha) (**Table 1**). Other studies using NE showed significant yield, economic and environmental advantage from the tool-based fertiliser recommendation as compared to existing practices (Satyanarayana et al., 2012; Sapkota et al., 2014).

The nutrient use in FFP highlighted the generally imbalanced practices adopted by farmers. The N, P_2O_5 and K_2O application rates varied widely, 27 to 550, 0 to 280 and 0 to 352 kg/ha, respectively (**Table 1**). The modal N, P_2O_5 and K_2O application rates were 138, 23 and 0 kg/ha, respectively, which outlined the lack of K application by farmers even in a crop like maize that removes large amount of K from a field. The lack of K application has been flagged earlier as one of the main reasons for decline in maize yield in major production zones of Bangladesh (Timsina et al., 2013). Some locations showed abnormally high applications rates such as more than 500 kg/ha of N, 250 kg/ha of P_2O_5 and 300 kg/ha of K_2O that may indicate over-use of fertiliser. Maize yield in the FFP was reasonably high (7,800 kg/ha) but the low (12.4 kg grain/kg nutrient) partial factor productivity (PFP) suggested inefficient management of nutrients by farmers (**Table 1**).

Earlier studies (Satyanarayana et al., 2012) have suggested that fertiliser recommendations developed for open pollinated varieties (OPV) are being used for hybrid maize varieties as well. Hybrid maize has far higher yield potential than OPVs and would require higher quantities of plant nutrients for proper expression of yield. The experimental data (**Table 1**) showed modal value of N, P_2O_5 and K_2O application at 100, 60 and 50 kg/ha, respectively for the SR treatment that produced the lowest modal yield of 4,200 kg/ha among the treatments. The NE validation trials solely used hybrid varieties and apparently the state recommended fertiliser rates were inadequate to achieve high yields. Maize is rapidly replacing other traditional crops in several areas in India and farmers are increasingly adopting hybrid varieties. The absence of appropriate fertiliser recommendations for hybrid maize for different ecology and seasons are prompting farmers to adopt unscientific fertiliser application strategies that may affect sustainability of maize production systems.

The NE-based fertiliser recommendation produced the

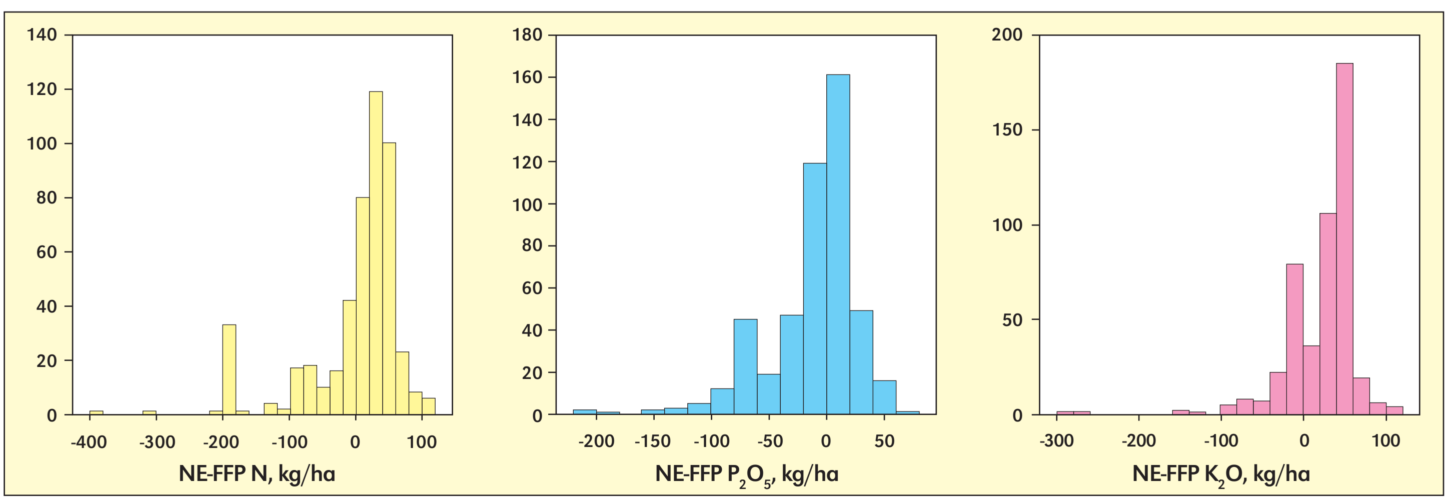

Figure 2. Frequency distribution diagrams of the difference between N, P and K application rates in NE and FFP.

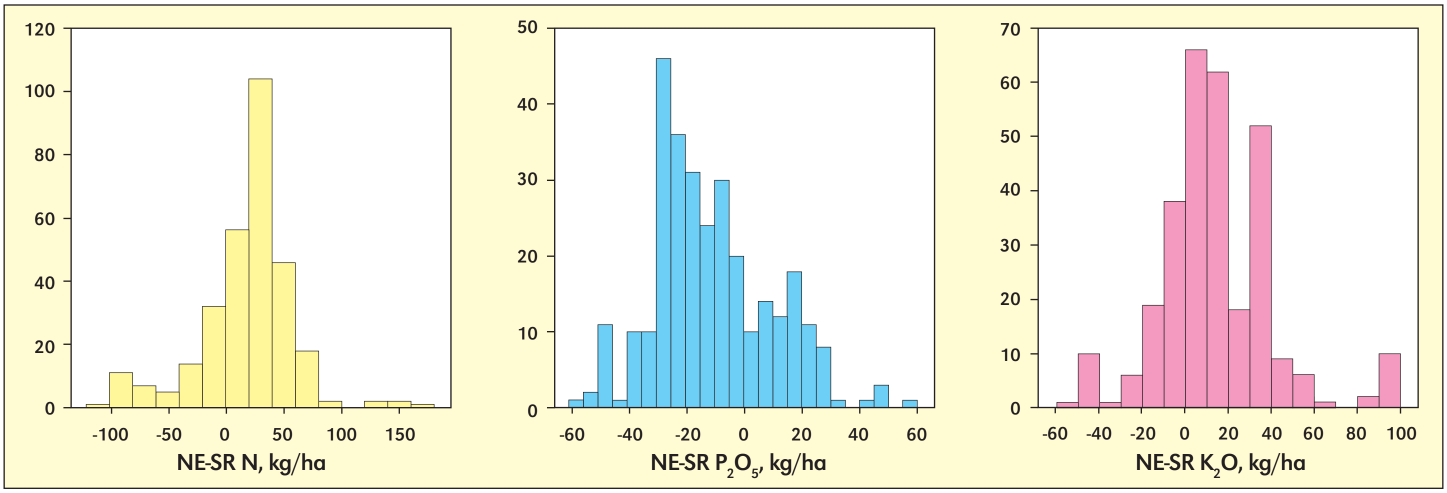

Figure 3. Frequency distribution diagrams of the difference between N, P and K application rates in NE and SR.

highest maize yield (8,400 kg/ha) among the three treatments (**Figure 1, Table 1**). This has been achieved at a PFP of 27.5 kg grain/kg nutrient, the highest among the three treatments. The NE recommendations for individual farm fields were developed using information on attainable yield, cropping system nutrient balance based on nutrient input and off-take from the field, previous crop history, local constraints etc. that allowed optimisation of nutrient application rates. This ensured high yield and high nutrient use efficiency and may provide an opportunity to sustainably intensify maize production systems around the country.

We used the frequency distribution diagrams to bring more clarity on the difference between nutrient application rates among the treatments. The differences in N, P_2O_5 and K_2O application rates (kg/ha) between the 'NE and FFP' (**Figure 2**) and 'NE and SR' (**Figure 3**) were plotted as frequency distribution diagrams. The figures reveal that NE recommendations for N, P and K are lower than SR or FFP application rates in a large number of trials.

Analysis of the data revealed that of the 484 on-farm trials that compared the NE recommendations with the FFP, N, P_2O_5 and K_2O recommendations by NE were lower than FFP in 146 (30%), 254 (52%) and 124 (26%) cases, respectively. The difference in NE-FFP rates ranged from (-) 400 to (+) 113 kg/ha for N, (-) 209 to (+) 60 kg/ha for P_2O_5 and (-) 297 to (+) 113 kg/ha for K_2O.

Similarly, 301 on-farm trials compared the NE recommendations with the SR, and N, P_2O_5 and K_2O recommendations by NE were lower than SR in 69 (23%), 221 (74%) and 74 (25%) cases, respectively. The difference in NE and SR rates ranged from (-) 110 to (+) 170 kg/ha for N, (-) 58 to (+) 57 kg/ha for P_2O_5 and (-) 53 to (+) 93 kg/ha for K_2O. The range of differences between NE and FFP are wider than NE and SR, suggesting more imbalances in fertiliser application by farmers.

The wide range of difference seen above between NE recommended, and FFP and SR rates probably arises from the fact that NE developed fertiliser application rates for individual farm fields are based on an estimated attainable yield and the nutrient balance in cropping systems followed by the farmer. An objective assessment of nutrient input from crop residues, organic manure, irrigation water, and residual fertility from the application of nutrients in the previous crop helped improved estimation of fertiliser rates by the NE tool. A recent study (Singh et al., 2014) also showed significant improvement in yield, profitability and nutrient use efficiency when farm-specific fertiliser recommendations were developed based on reciprocal internal efficiency of the crop (i.e., kg nutrient uptake in above-ground plant dry matter per t grain produced) and nutrient inputs through external sources other than fertilisers.

The current study showed that location-specific fertiliser recommendation from the NE tool significantly improved maize yield and nutrient use efficiency over farmers' practice and state recommendations across a wide range of growing environments in India. The comparative analysis revealed that fertiliser application in maize based on NE provides significant opportunity for saving fertiliser, which may improve farm profitability and environment stewardship of applied nutrients. BC-SA

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