of their current prices in Uruguay. Agronomists and farmers are already concerned about STK in the different regions, as reflected by the increasing soil K analysis demand.

Soil K removal has grown with soybean production, which currently covers approximately 1 million hectares through a wide range of soils with different availability and stocks of K. Quality and management of crop residues, may affect K distribution with soil depth, and it should be considered by soil survey/sampling and fertilizer recommendations.

Current research and experimentation focus on the relationship of K dynamics with soil mineralogy and physical properties, and changes in cropping systems and soil management history in the medium and long term. These studies would be useful to develop K fertilization guidelines. Potassium use efficiency depends on understanding of K dynamics in the soil-plant system, as well as crop and soil responses to soil fertility management. Long-term studies would greatly contribute to finding solutions to existing and anticipated problems.

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Balancing K use in Cereals through Nutrient Expert®: Improved Yield, Higher Profit, and Reduced GHG Emission

Sudarshan Kumar Dutta, Kaushik Majumdar and T. Satyanarayana

Inadequate and imbalanced application of nutrients, especially of K, by the cereal growers of India leads to less crop productivity and foodgrain production of the country. One of the major reasons of this drawback is associated with the lack of recommendation protocol suitable for small-scale resource challenged farmers. Nutrient Expert® (NE) provides balanced fertilizer recommendation suitable for varied yield target and farmer resource availability. The recommendation from NE guides farmers to apply the required amount of K along with other nutrients to increase productivity, enhance economic benefit and reduce green house gas emission from farm fields.

The fertilizer consumption in India has increased significantly since last four decades. The Total NPK (N, P_2O_5, and K_2O) consumption increased twelve times, from nearly 2 million to 25.5 million tonnes between 1969-1970 and 2011-2012 (FAI, 2014). However, there was a disproportion of the consumption ratio among these nutrients. Nitrogenous fertilizer accounted for nearly 66 per cent of total nutrient consumption in the country (Majumdar et al., 2014); while P_2O_5 and K_2O shares were only 26 and 8 per cent, respectively (FAI, 2014). This is a serious concern particularly in cereal-based cropping systems where removal of K is equal to or more than N. Inadequate K application results in a negative input-output budget of K that ultimately leads to the mining of soil K reserve (Dutta et al., 2013), adversely affecting crop productivity.

Imbalanced fertilizer application or more specifically less K application in crops is identified as one of the major reasons for decreasing crop response to fertilizer application and the consequent lower crop production growth rate in India. There are enough scientific evidences that highlight the role of K in the yield improvement. Large number of on-farm trials across the Indo-Gangetic Plains showed that no application of potassium reduced average grain yield of rice, wheat and maize by 621, 723 and 699 kg/ha, respectively (Majumdar et al., 2012). Significant yield improvements (up to 2 t/ha yield increase) were also reported in a rice-wheat cropping system by addition of potassium across Indo-Gangetic plain (Majumdar et al., 2014).

Despite the proven economic, social, and environmental benefits of balanced fertilization, the application of potassic fertilizers is yet to gain the momentum as expected among the cereal growers. This could be attributed to the unavailability of a wide scale recommendation mechanism that is suitable for fertilizer prescription to the small-scale farmers and can be used by the frontline extension professionals.

In smallholder systems of India, farmers cultivate small pieces of land, and crop management varies widely depending on farmer awareness and resource availability. Such variable management decisions create large spatial and temporal variability in soil nutrient availability between farm fields. Ideally the fertilizer management in such smallholder landscape should vary and be location-specific to avoid over- or under-use of nutrients. Among several existing fertilizer use practices in India, farmers' fertilization strategies generally lack the necessary integration of information on soil nutrient supply and crop nutrient requirement. State fertilizer recommendations are based on response studies that are extrapolated to large areas, and the spatial and temporal variability in soil nutrient supply between farms is not addressed adequately. In both cases, potassium remained the neglected element, which caused economic loss due to unrealized crop yields (Singh et al., 2013, 2014).

Researchers have successfully used the Site-Specific Nutrient Management (SSNM) principles to ascertain the balanced application rate of nutrients to achieve high yields in cereals in on-farm situations (Witt et al., 1999; Setiyono et al., 2010; Chuan et al., 2013). However, large-scale implementation of SSNM strategies in farmers' fields remained a challenge. IPNI recognized that the lack of an appropriate tool to help farmers and their advisors to quickly develop field-specific recommendations is the major hindrance in on-farm implementation of SSNM. This led to the synthesis of historical and current on-farm nutrient response data by IPNI to develop a fertilizer decision support tool that is easy-to-use and can work with or without soil test results. IPNI was supported in this effort by the International Fertilizer Industry Association (IFA), International Maize and Wheat Improvement Center (CIMMYT), and a large number of national partners, ranging from National Research and Extension Institutes, Agricultural Universities, State Agriculture Departments, Fertilizer and Seed Industries, and other Non Governmental Organizations (NGO). The outcome of this effort is a dynamic nutrient management tool, the Nutrient Expert® (NE), that can generate farm-specific fertilizer recommendation for major cereals such as maize, wheat, and rice, based on the principles of SSNM (Pampolino et al., 2012). This tool utilizes information of the growing environment to provide balanced fertilizer recommendations that are tailored for a particular location, cropping system and farmer resource availability. The NE tool advocates external application of nutrients, based on indigenous soil nutrient supply and crop nutrient requirement, to achieve a target yield suitable for an individual farmer. Expected outcome from the NE-based balanced and location-specific fertilizer recommendation could be several including improved yield, higher nutrient use efficiency or saving of fertilizer and consequent improved economics of production, and environmental stewardship of applied nutrients.

The preliminary target crops for NE development were cereals considering that more than three fourth of the cultivated land in India are under the three major cereals, rice, wheat and maize. These three crops are the major contributors to the total fertilizer consumption in India. At present, NE for wheat and hybrid maize is developed, validated, and released for free public use, while NE for rice is under nation-wide validation with government research and extension organizations. Cotton, sugarcane and soybean are the other three target crops for developing NE in near future.

The NE is a MS Access based computer application that consists of four or five different working modules depending upon the crop; for maize there are five modules while for wheat and rice there are four modules. Through the different modules, and based on farmers' inputs to simple questions, the NE tool estimates the indigenous nutrient supplying capacity of the farmer's field (i.e. contribution from crop residue recycling, addition of organic manures, residual benefit from the previous crop), determines yield responses to application of major NPK nutrients and finally arrives at the most appropriate nutrient recommendation adequate for obtaining the targeted attainable yield. There is an option within this dynamic tool to lower down the yield target considering the resource availability and input purchasing ability of the farmer, and the recommendations are generated on the new lower targeted yield. The nutrient recommendation for a particular field is transformed into fertilizer sources available at farmer's doorstep and finally a 4R compliant (Right Source, Right Rate, Right Time and Right Place) recommendation report is provided to the farmer. A cost analysis associated with the SSNM and the farmers' practice suggests whether or not the fertilizer recommendation intervention would be profitable.

Validation trials of NE – Maize and NE – Wheat were

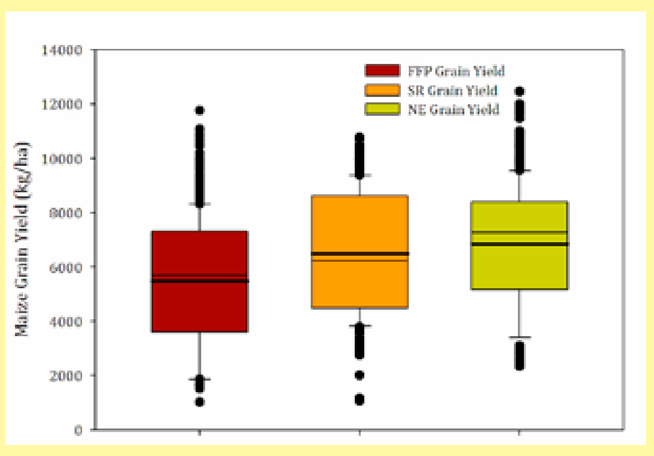

Fig. 1. Average maize grain yield in Nutrient Expert® validation trials (n=535) in India.

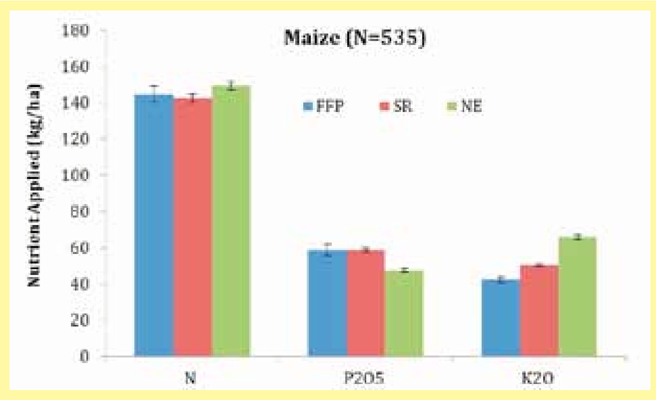

Fig. 2. Comparative nutrient application rates in farmers' fertilisation practices (FFP), state recommendations (SR) and Nutrient Expert®-Maize tool-based recommendations (NE) in validation trials.

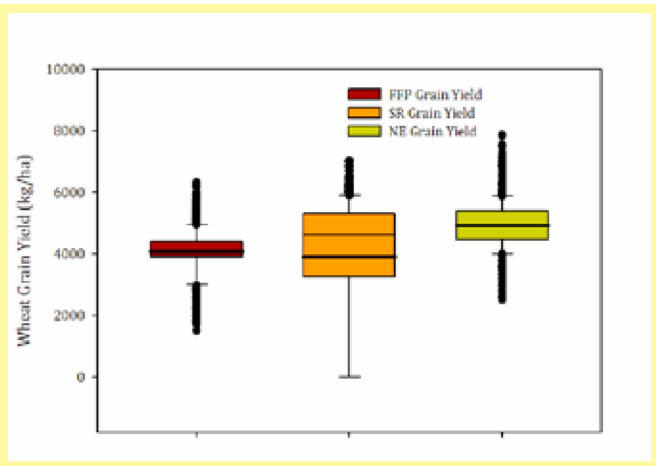

Fig. 3. Average wheat grain yield in Nutrient Expert® validation trials (n=858) in India.

conducted across the major wheat and maize growing areas of India. The NE-based recommendations were compared to the existing fertiliser recommendation practices such as farmers' fertilisation practices (FFP) and state recommendations (SR) in these trials. The three treatments were implemented side-by-side in the same farmer's field where each plot size was ≥ 100 m2.

The NE - Maize based fertilizer recommendation significantly improved grain yield as compared to FFP and SR across 535 different locations of India

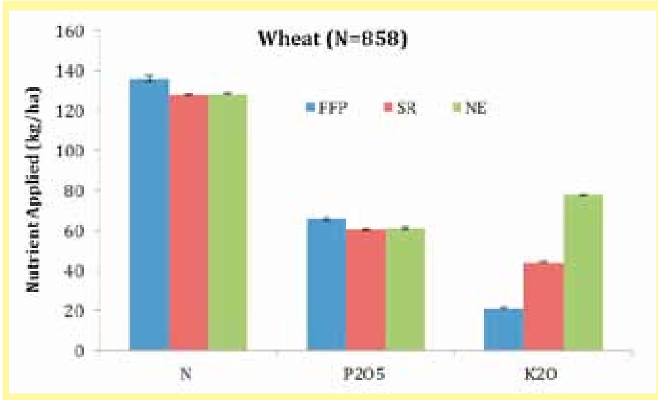

Fig. 4. Comparative nutrient application rates in farmers' fertilisation practices (FFP), state recommendations (SR) and Nutrient Expert®-Wheat tool-based recommendations (NE) in validation trials.

(**Figure 1**). The nutrients recommended by NE slightly increased N application and decreased P rates over the existing practices. However, NE recommended significantly higher amount of K than FFP or SR; 24 kg/ha over FFP and 15 kg/ha over SR (data not shown). The Nutrient Expert® tool assesses the cropping system nutrient balance based on nutrient application in previous crop (fertilizer + organic manure) and yield of previous crop, and recommends fertilizer rates based on target yield of the current crop. In most situations across 535 sites, the NE tool estimated less than required potassium application in FFP and SR in the cropping system and recommended higher K_2O rates. The results outlined the lack of K application by existing fertilizer management practices even in a crop like maize that removes large amount of K from the soil. 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).

In the case of wheat, average grain yield was highest (4927 kg/ha) in the NE-based recommendation as compared to FFP (4079 kg/ha) and SR (3897 kg/ha) in the farmers' field validation trials (n = 858) (**Fig. 3**). The effect of adequate K application on wheat grain is clearly shown in **Figure 4**. Across all sites, the N and P2O5 rates recommended by NE are either equivalent or less than FFP and SR. However, NE recommended additional 57 and 34 kg/ha of K_2O than the FFP and SR recommendations. This highlights significant imbalance in wheat nutrient management adopted by farmers and balancing application rates with required amount of potassium increased grain yield by about 1 t/ha. Most of the validation trials in wheat were done in the Trans-Gangetic Plain region of India including the states of Punjab and Haryana. The farmers in this region typically apply inadequate amounts of K to crops because of the perception that the soils in this region has adequate available potassium due to its illitic mineralogy and high K addition through irrigation water. However, the results of our study clearly indicate significant yield advantage in wheat with balanced and adequate K application.

Dutta et al., (2014) reported on-farm validation trials (n = 109) of NE-Wheat that assessed the

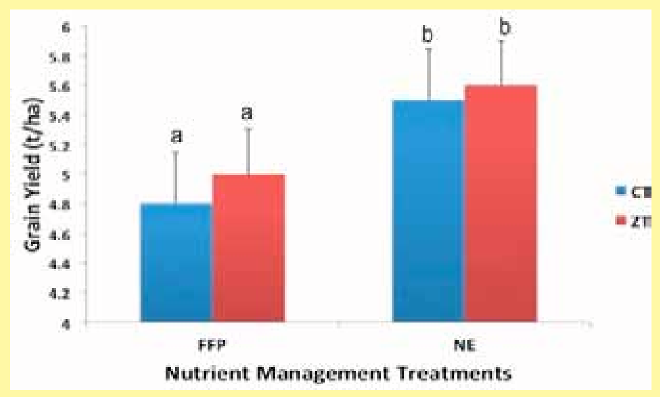

Fig. 5. Grain yield of wheat across different nutrient management and tillage practices. Yield with different letters are significantly ($p \leq 0.01$) different

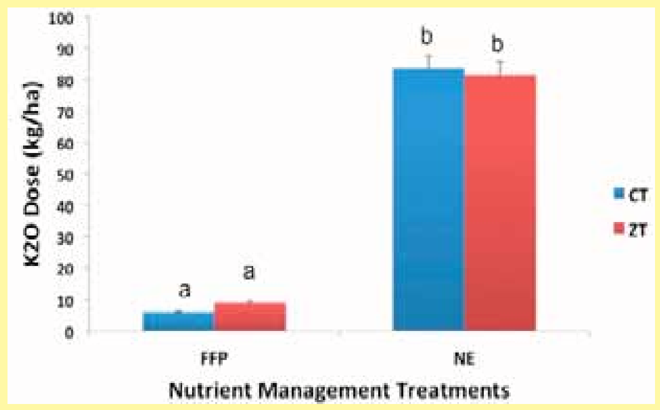

Fig. 6. Fertilizer K_2O rates across different treatments while considering all the locations. Dose with different letters are significantly ($p \leq 0.05$) different.

suitability of the Nutrient Expert® tool to provide recommendation for conventional and zero-till wheat. Establishment of wheat under zero-till conditions is gaining popularity to reduce the turn-over time between rainy season rice and winter wheat. Several new innovations in machinery now allow smallholder farmers to plant wheat on standing residue of the previous rice crop. The reported study assessed 65 on-farm trials under conventional tillage (CT) and 44 trials under zero tillage (ZT) condition, and compared the results of farmers' fertilizer practices with NE-based recommendations. Results showed a significant ($p \leq 0.01$) increase in wheat yield through NE recommendations over FFP (**Figure 5**). It was also observed that there were significant increase in K application through NE based recommendation over FFP under both ZT and CT situation (**Figure 6**). The B:C ratio of NE treatment was four fold higher than that of FFP (Dutta et al., 2014).

Apart from yield improvement and improving economics, the NE-based recommendations also reduced the Greenhouse Gas (GHG) emission from farm fields in Northwestern India. A recent study (Sapkota et al., 2014) in wheat highlighted that NE recommendation reduced the emission of the GHGs that leads to less Global Warming Potential (GWP). The study showed that the estimated GWP per unit wheat grain yield as well as per USD net return was significantly ($P< 0.01$) affected by nutrient management strategies. Farmers' fertilization practices

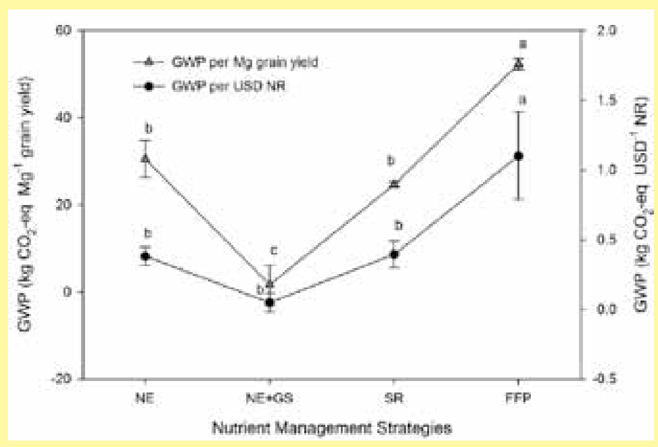

Fig. 7. Total Global Warming Potential (GWP) per Mg grain yield and per USD net return (NR) under different nutrient management strategies in no-till based wheat production in Haryana. NE: nutrient expert, NE+GS: nutrient expert supplemented with GreenSeeker, SR: state recommendation and FFP: farmers' fertilizer practice.

resulted in higher GWP per Mg of wheat yield while NE-based recommendation, in conjunction with "Green Seeker"(GS) based N application, resulted in the lowest GWP per Mg of wheat (**Figure 7**). NE in combination with GS helps in better nutrient use efficiency from in-season precision N application i.e. rate and number of splits matching physiological demand of the crops. This probably reduced the residual NO3-N in soil profile thereby minimizing the N loss as N2O emission. In addition, the adequate K application recommended by NE helps in better utilization of other nutrients, particularly N, that improves N utilization by the crops and reduces the possibility of volatilization loss of the nutrient.

Overall, Nutrient Expert® (NE) based fertilizer recommendation helped the farmers to increase the yield and improve economics through site-specific balanced application of nutrients. The on-farm results clearly highlighted the critical role played by K in improving cereal productivity in India. Balanced and adequate application of potassic fertilizer not only helped in yield improvement but may also reduce K mining from soils. Therefore, wide scale adoption of Nutrient Expert® could be the way forward towards balanced fertilizer application in smallholder systems in India for sustainable food security.

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Soil K increases from cash crops in China

Ping He, Fang Chen, Shutian Li, Shihua Tu, Adrian M. Johnston

Understanding soil K status is important when developing appropriate K nutrient management. Reports have indicated that K deficiency is a worldwide problem. However, with the development of agricultural mechanization and implementation of policies by the Chinese central government promoting the return of crop straw to fields after harvest, and increased use of organic (compost) fertilizers, soils have been shown to have increased soil K levels. However, some contradictory reports on soil available K changes have raised concerns of scientists and the fertilizer industry. These contradictory results may be attributed to differences in soil sampling points, number of samples, time of sampling, and analytical methods. Up to now, the effects of K fertilizer use have not attracted concerns like N and P. The historic national soil survey conducted in the early 1980s in China could not reflect current soil K status in reality. The current soil K balance in China is influenced by the imbalance of K relative to N and P fertilizers, and crop K removal by new and high-yielding genotypes. This lack of understanding needs to be evaluated.

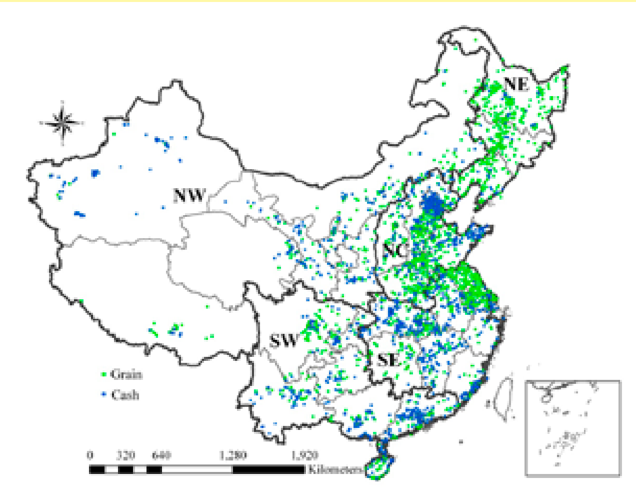

Fig. 1. Distribution of experimental sites for five production regions of China from 1990 to 2002. The green and blue dots represent grain and cash crops, respectively.

The objectives of this study were to evaluate the temporal and spatial variation of soil available K and crop yield response to K fertilizer in China from 1990 to 2012.

Materials and Methods

Datasets for soil available K and crop yield were compiled from published and unpublished data sources in 1990-2012 from the Inational Plant Nutrition Institute (IPNI) China Program database. In total, 58,559 soil available K records (**Fig.1**) and 2055 yield records were collected from this database. These experiments were conducted in farmers' fields, and crop yield was obtained from the first season harvested crops from N, P and K application plots (NPK, the rates of N, P, and K fertilizers were recommended based on soil testing) and only N and P treatment (NP, no K fertilizer was applied based on NPK treatment).

To evaluate spatial variation of soil available K in China, five agricultural regions were grouped based on geographical locations and China's administrative