BETTER CROPS SOUTH ASIA

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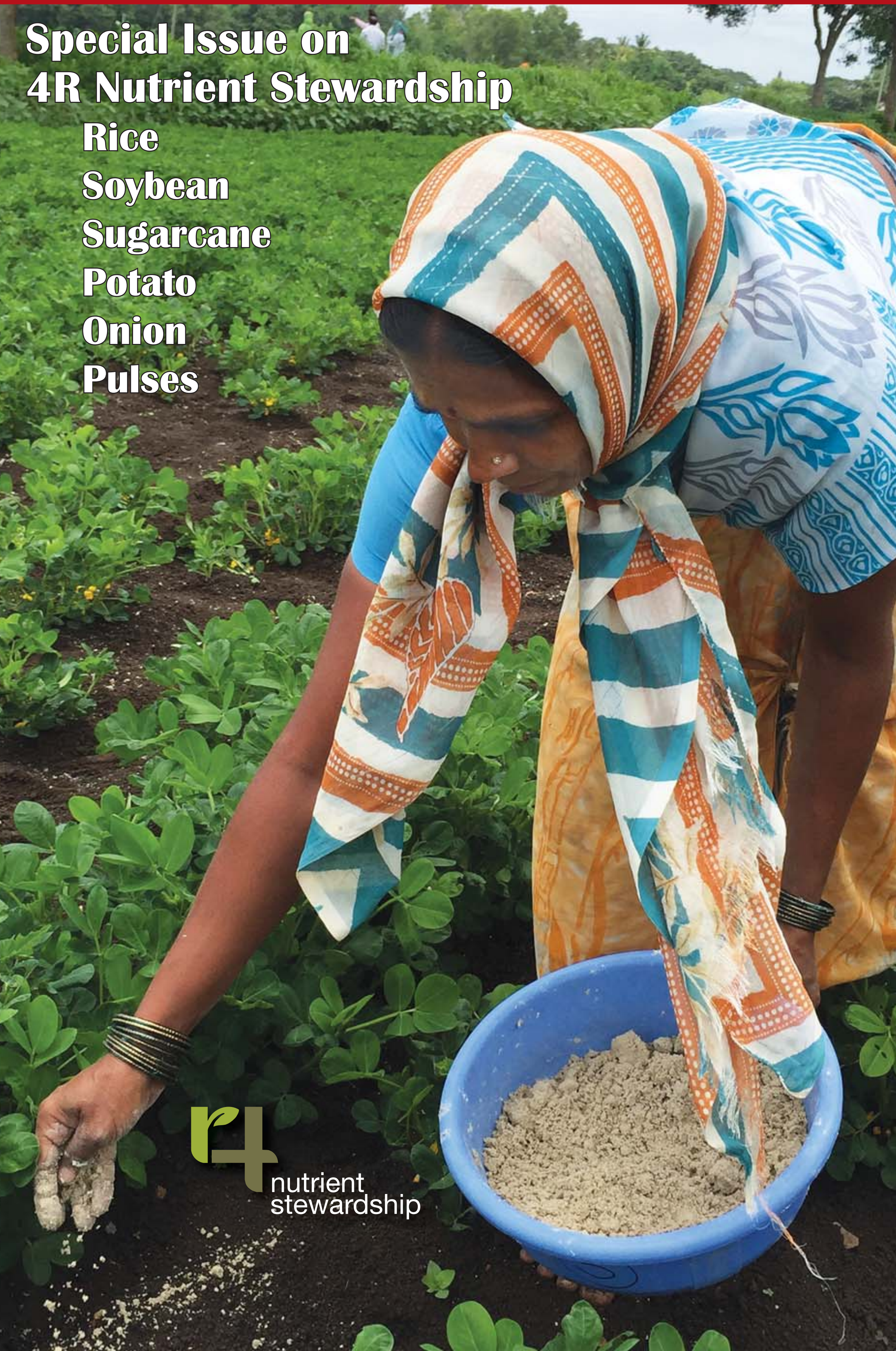
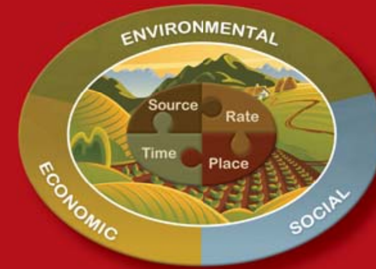


Special Issue on 4R Nutrient Stewardship

Rice
Soybean
Sugarcane
Potato
Onion
Pulses

In This Issue...

The Concept of 4R



Crop-specific 4R Practices

4Rs: Agent of Change?

Also:

2016 IPNI Scholars Featured!

...and much more

IPNI

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BETTER CROPS–SOUTH ASIA

Volume 10, Number 1, November 2016

Our cover: Applying gypsum as a source of S and Ca to peanut 30-35 days after planting (the right time) at a farm in the University of Agricultural Sciences, Dharwad, Karnataka. Application of gypsum at this stage helps in keeping the soil loose and friable, which leads to good development of pods.

Photo by: T. Satyanarayana/IPNI

BETTER CROPS–SOUTH ASIA is a publication of the International Plant Nutrition Institute (IPNI). The mission of IPNI is to develop and promote scientific information about the responsible management of plant nutrition for the benefit of the human family.

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C O N T E N T S

Note to Readers: **Articles which appear in *BETTER CROPS–SOUTH ASIA* can be found as PDF files at http://ipni.info/bettercrops**

Welcome...

You are reading the tenth annual issue of *Better Crops South Asia*. This publication is released in the fourth quarter of each year, and follows a format similar to our flagship publication *Better Crops with Plant Food*.

Our 2016 issue is focused on 4R Nutrient Stewardship.

The research featured in this issue is a tribute to the scientific progress that is continually being made in the fields and laboratories throughout South Asia. Once again, we at IPNI wish to congratulate and thank the many cooperators, researchers, farmers, industry representatives, and others who are working for the benefit of agriculture in South Asia.

Dr. Terry L. Roberts, President, IPNI

IPNI Scholar Award Recipients (South Asia) - 2016

The International Plant Nutrition Institute (IPNI) has selected the winners of the 2016 Scholar Awards. A total of 36 graduate students, representing 14 countries, were chosen as IPNI Scholar Award recipients. Each winner receives the equivalent of US$2,000. IPNI selected seven Scholars from the South Asia region whose details are provided below.

"The selection committee was encouraged by the number and quality of applications it received," said Terry L. Roberts, IPNI President. "Many countries and institutions were represented. The students are doing impressive work and will contribute immensely to the field of plant nutrition," said Roberts.

Graduate students attending a degree-granting institution located in any country within an IPNI regional program are eligible. The award is available to graduate students in science programs relevant to plant nutrition science and the management of crop nutrients including: agronomy, horticulture, ecology, soil fertility, soil chemistry, crop physiology, environmental science, and others.

Regional committees of IPNI scientific staff select the recipients of the IPNI Scholar Award. The awards are presented directly to the students at a preferred location and no specific duties are required of them. Funding for the scholar award program is provided through support of IPNI member companies, primary producers of nitrogen, phosphate, potash, and other fertilizers.

More information is available from IPNI staff, individual universities, or the IPNI website http://www.ipni.net/awards.

Ridham Kakar

Ms. Ridham Kakar, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India, is working towards her Ph.D. in integrated nutrient management. Her dissertation title is *"Integrated Nutrient Management Under Ginger-Cauliflower Cropping Sequence in North-West Himalayas."* Ridham's research has been undertaken to improve nutrient use efficiency, organic matter content, and optimization of fertilizer application. This research is working towards increased soil health and productivity and overall living standards for farmers. Her career goals are to continue with farmer-oriented research work in order to help the farming community with increasing their living standards.

Kiran K.R

Mr. Kiran K.R., Indian Agricultural Research Institute, New Delhi, India, is pursuing a Ph.D. in soil science and agricultural chemistry. His dissertation title is *"Mobilization of Soil Iron to Minimize Iron Deficiency Chlorosis of Soybean Under Ambient and Elevated CO_2 and Temperature Conditions."* The objectives of Kiran's research are to study the basis of iron (Fe) deficiency chlorosis in soybean genotypes, evaluate the effectiveness of different strategies to mobilize soil Fe and its impact on Fe deficiency chlorosis tolerance by soybean genotypes, and to study the effect of Fe mobilization strategy in enhancing bioavailability of Fe to soybean genotypes under ambient and elevated CO_2 and temperature conditions. After his Ph.D., one of Kiran's goals is to conduct research on the transformation and dynamics of nutrients, especially in arid and semi-arid agro-ecosystems with respect to changing climate scenarios.

Rumesh Ranjan

Mr. Rumesh Ranjan, Indian Agricultural Research Institute, New Delhi, India, is pursuing his Ph.D. in genetics and plant breeding. His dissertation title is *"Genetic Analysis and Identification of QTL's Influencing Nitrogen Use Efficiency in Wheat."* The objectives of Rumesh's research are to identify the traits influencing nitrogen use efficiency, study the extent of variability existing for these traits in the germplasm, study the inheritance of traits influencing nitrogen use efficiency in wheat, and identify the putative QTLs for nitrogen use efficiency in wheat. Rumesh plans to disseminate the new era of technology to farmers, which will serve both them and their communities for economic prosperity and betterment as a whole.

Pragyan Paramita Rout

Ms. Pragyan Paramita Rout, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India, is pursuing her Ph.D. in soil science and agricultural chemistry. Pragyan's dissertation title is *"Development and Standardization of Sensors for Soil Moisture Monitoring and Precision Nutrient Management for Growing Flower Crops Under Fertigation and Matric Suction Irrigation."* Her research work aims at developing and standardizing various cost effective sensors for soil moisture monitoring and precision nutrient management (for flower crops in both greenhouse and field conditions). Upon completing her degree and pursuing a post-doctoral fellowship, Pragyan would like to build a career in precision agriculture using sensors for water management and nutrient management.

Vijayakumar Shanmugam

Mr. Vijayakumar Shanmugam, Indian Agricultural Research Institute, New Delhi, India, is working towards a Ph.D. in agronomy. His dissertation title is *"Potassium Management in Aerobic Rice–Wheat Cropping System."* The objectives of Vijayakumar research are to find out the effect of rate, method, and time of potassium (K) application on growth and productivity of aerobic rice and wheat crops; assess the effect of K fertilization on grain quality and nutrient use efficiency of aerobic rice and wheat crops; estimate the residual effect of K fertilization on soil fertility; and work out the economics of different treatments. One of Vijayakumar's future goals is to establish a career in agricultural research, with strong fundamentals in agronomy and soil science.

Arunbabu Talla

Mr. Arunbabu Talla, Indian Institute of Technology, Kharagpur, West Bengal, India, is earning a Ph.D. in agronomy. His dissertation title is *"Planting Time and Nitrogen Management for Improving Hybrid Rice Production under Changing Climate of Subtropical India."* His research is focused on mitigating the adverse impact of climate change on hybrid rice production in sub-tropical climates, by addressing location specific agro-adaptation technologies. Mr. Talla's long-term goals involve the improvement of sustainable agricultural productivity in farmers' fields, through precision agriculture. This includes site specific nutrient management, measuring nutrient losses, and improving nutrient management plans for higher input use efficiency.

Abdul Rehman

Mr. Abdul Rehman, University of Agriculture, Faisalabad, Pakistan, is completing a Ph.D. in agronomy. His dissertation title is *"Exploring the Role of Zinc Nutrition in Yield Improvement, Grain Biofortification and Resistance against Abiotic Stresses in Wheat."* The outcomes of this research will improve wheat productivity by encouraging zinc application in wheat and developing a cost effective technique. After completing his Ph.D., Abdul wants to pursue additional research in improving biofortification and resistance against abiotic stresses in rice, wheat, and chickpea through the application of micronutrients.

IPNI Appoints Potassium Program Director

The International Plant Nutrition Institute (IPNI) has appointed Dr. T. Scott Murrell as Director of its new Potassium Program.

For the past 20 years, Dr. Murrell has worked for IPNI (2007 to present) and its predecessor the Potash & Phosphate Institute (PPI; 1996 to 2007) as IPNI Director of the North America Program and PPI Regional Director of the Northcentral U.S. Program, respectively. Most recently, Dr. Murrell's focus within the IPNI North American Program has been on the improvement of nutrient management within corn-soybean cropping systems, data management for soil testing and crop nutrient uptake, and soil potassium assessment. Dr. Murrell will continue his work with data management as that is an integral component of potassium plant nutrition and management.

"All IPNI scientists' activities include agronomic programs that address potassium, nitrogen, phosphorus, and other plant nutrients as part of the Institute's regional and global tactical plans," explained IPNI President Dr. Terry L. Roberts. "Our addition of a Potassium Program Director completes our team of Directors that will have primary and global focus on each of the major nutrients." BC-SA

Dr. T. Scott Murrell, Director of the IPNI Potassium Program.

4R Nutrient Stewardship in Indian Agriculture

By T. Satyanarayana, Kaushik Majumdar, and Sudarshan Kumar Dutta

Agriculture is an integral part of the overall economic development in India. More specifically, agriculture and its allied activities contribute to nearly 50% of India's national income. Ensuring food security for India's growing population, expected to be around 1.33 billion by 2020 (Anonymous, 2014), continues to be a major challenge. IFPRI (2012) summarized several studies that showed foodgrain demand in India will reach 293 million (M) t by 2020 and 335 M t by 2026. The declining per capita land availability and limited scope for horizontal expansion of cultivated area requires the intensification of agricultural production through higher crop yield per unit area.

Increasing food demand from limited land resources in the coming decades requires increased use of fertilizers. Application of fertilizers following proven scientific principles is required to ensure improved productivity of crops without adding to environmental concerns. The contribution of fertilizers to total grain production in India has increased from 1% in 1950 to 58% in 1995 (Subba Rao and Srivastava, 1998). However, imbalanced fertilizer 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 the country (Majumdar et al., 2014a). Despite the proven economic, social, and environmental benefits of balanced fertilization, its adoption at the farm level is low. The lack of appropriate tools and implementation mechanisms restricted its wide-scale adoption by farmers. The generally unbalanced fertilizer use by farmers in India has raised concerns about the environmental sustainability of such practice.

Fertilizer Best Management practices (FBMPs), are agricultural production techniques and practices developed through scientific research and verified in farmer fields to maximize economic, social, and environmental benefits (IFA, 2009). FBMP is aimed at managing the flow of nutrients in the course of producing affordable and healthy food in a sustainable manner, that protect the environment, conserve natural resources, and at the same time become profitable to producers. With FBMPs, farmers implement, under specific site, crop, and soil conditions, the concepts and elements of balanced fertilization, site-specific nutrient management (SSNM), integrated plant nutrient management (IPNM), among others (Bruulsema et al., 2009). On a broader scale, FBMPs are components of product stewardship and integrated farming. The benefits that can be derived from fertilizers are maximized through FBMPs, while the losses and negative effects of over/under/or misuse of fertilizers are minimized. The application of such scientific principles of FBMPs form the basis of the globally accepted concept called ***4R Nutrient Stewardship***.

What is 4R Nutrient Stewardship?

The concept of 4R Nutrient Stewardship is defined as applying the **right** source of plant nutrients at the **right** rate, at the **right** time, and in the **right** place, for sustainably managing plant nutrients and increasing crop productivity (**Figure 1**). The 4Rs encompass FBMPs within cropping systems that are proven to optimize production potential, input efficiency, and environmental protection. The idea of 4Rs was first introduced to the fertilizer industry in 2007, and the concept, developed by the global fertilizer industry, is now considered as an essential tool towards sustainable agricultural systems.

Abbreviations and notes: N = nitrogen; N_2O = nitrous oxide.

IPNI agronomist (left) promoting the concept of applying the right sources of plant nutrients for cotton.

Importance of 4R in Indian Agriculture

The smallholder farmers of the intensively cultivated areas in India often over or under use nutrients or apply them in an imbalanced manner, at an inappropriate time, or by wrong methods. Such practices result in low crop productivity and economic returns and often leave a large environmental foot print of fertilizer use. Several reviews of research (Johnston et al. 2009; Majumdar and Satyanarayana, 2011) demonstrated

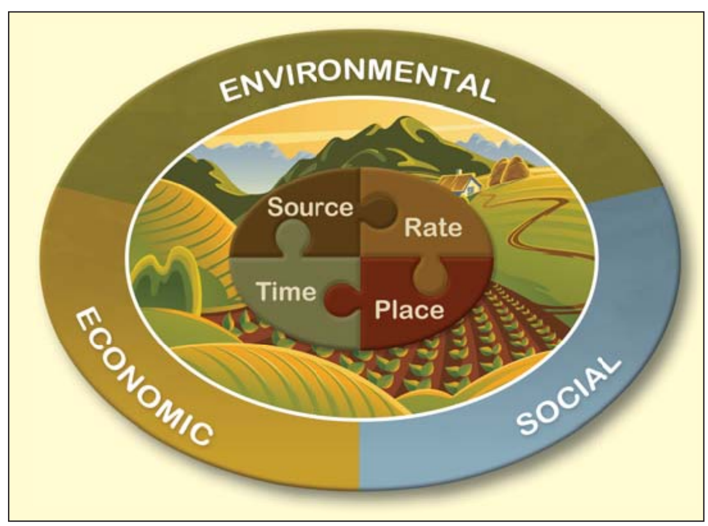

Figure 1. The 4R Nutrient Stewardship concept defines the right source, rate, time, and place for fertilizer application as those producing the economic, social, and environmental outcomes desired by all stakeholders to the plant ecosystem.

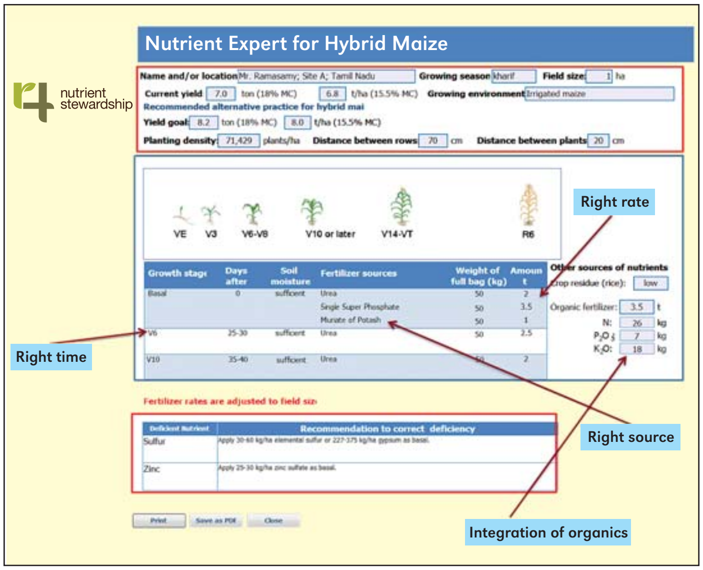

Figure 2. Example of a 4R compliant Nutrient Expert® based fertilizer recommendation, providing guidance on the application of fertilizer application to maize.

limitations of blanket fertilizer recommendations commonly used in India. Such blanket recommendations, made for large areas, have resulted in inefficient use of fertilizer, low crop productivity, and farm profitability. On the contrary, the 4R Nutrient Stewardship framework promotes the application of nutrients to ensure higher crop yields, better nutrient use efficiency, and profitability of small holder farmers through the above stated four "rights" of nutrient management (Majumdar et al., 2013).

Relationship between 4R and Climate Smart Agriculture

Climate smart agriculture (CSA) has recently achieved much prominence in India, given the adaptation and mitigation challenges facing humanity. CSA is defined by three objectives: firstly, increasing agricultural productivity to support increased incomes, food security and development; secondly, increasing adaptive capacity at multiple levels (from farm to nation); and thirdly, decreasing greenhouse gas emissions and increasing carbon sinks. Fertilizer, particularly fertilizer N use, is often cited as a causal factor of climate change, while its adaptive or mitigation potential to climate change impacts have often been overlooked. For example, negative effects of N fertilizers on increased N_2O emissions is well highlighted while its role in promoting carbon sequestration (i.e., removing CO_2 from the air) by stimulating plant growth leading to greater carbon storage in plant residues and roots is less discussed. Evidence across the globe suggests that research and extension efforts on precise 4R recommendations in crops and cropping systems have provided rich dividends in terms of increased crop productivity and farm income, while adapting and mitigating climate change.

IPNI Initiatives in Promoting 4R Nutrient Stewardship

The International Plant Nutrition Institute (IPNI) has incorporated the concept of 4Rs into the institute's strategic planning, and has invested significant resources towards capacity building of stakeholders and partners around the world. Some of the significant outcomes of IPNI efforts on 4R is given below:

- The Institute has developed a comprehensive *4R Plant Nutrition Manual* that is considered as a very significant contribution towards 4R education. The manual is available in hard copy and electronic formats, and has been translated into eight different languages.
- The Certified Crop Adviser (CCA) program of the American Society of Agronomy has created a *4R Nutrient Management Specialization* within the CCA program and IPNI is soon to release a training manual to help CCAs prepare for the exam.
- The North American 4R Fund, through generous support by the fertilizer industry, has created a network of 40 leading scientists engaged in 4R research across North America.

The South Asia program of IPNI has strongly emphasized the 4R concept in its research and education program. A total of 40% of the research projects are aimed at developing 4R nutrient management guidelines for predominant cereal-cereal cropping systems of India. About 20% of the projects are focused on determining the right rate and right timing of nutrient application in soybean and cotton. The outcome of such studies also provided additional information on right sources of nutrients, based on the nutrient limitations identified through soil testing during the course of the implementation of the projects. The remaining 40% of projects promote dissemination of improved 4R fertilizer recommendations to farmers through on-farm demonstrations and education through training. Some of the significant outcomes of the above research and education programs are given below:

Development of Nutrient Expert® fertilizer decision support tools: The site-specific fertilizer recommendation tools for rice, wheat, and maize are 4R compliant, and provides recommendations to individual farmers on right source, right rate, and right time of application that are tailored for his/her farm (**Figure 2**). The recommendations from Nutrient Expert® for rice (Mandal et al., 2015), maize (Majumdar et al., 2014; Satyanarayana et al., 2014) and wheat (Dutta et al, 2014; Bhende et al., 2014) have significantly improved the cereal yields, farm profits, and nutrient use efficiency when compared to existing nutrient management practices.

Collaboration with NARES and regional stakeholders to develop and promote 4R nutrient management strategies through research and education: The IPNI South Asia program is strongly engaged with partners from National Agricultural Research and Extension System (NARES), State Agricultural Universities (SAU's), Government Departments of Agriculture (DOA), industry, NGOs to disseminate 4R Nutrient Stewardship in diverse crops and cropping systems.

Videos developed for disseminating information on 4R nutrient management: IPNI South Asia program staff has developed crop and nutrient specific 4R videos in different Indian regional languages. These simple videos are expected to help fertilizer industry and public extension systems to convey simple messages about the importance of specific nutrients as a part of balanced fertilization, or the right ways of managing nutrients for specific crops for higher yields, farmer profitability, and better environmental stewardship of nutrients. 4R videos on sugarcane, rice, wheat, and cotton are available in multiple regional languages

Awareness on 4R Nutrient Stewardship through workshops/seminars: IPNI staff demonstrated 4R as a means of practicing efficient nutrient management for improving soil health and outlined 4R Nutrient Stewardship principles for adaptation and mitigation of climate change impacts on agriculture at the events organized in commemoration of International Year of Soils during 2015. In the training workshops, principles of 4R Nutrient Stewardship were thoroughly discussed citing examples of each R and explained the importance of practicing 4R in a crop nutrient management program. Scientists recognized the importance of 4R and convinced to design the nutrient management program of a crop integrated with the 4R perspective while addressing researchable issues of crop nutrient management.

Scientific papers and publications on 4R: IPNI staff, in collaboration with partners, has published book chapter on 4R (Majumdar et al., 2014b) and scientific articles (Dutta et al., 2015; Pattanayak et al., 2015, Sapkota et al., 2014; Majumdar et al., 2013; Jat et al., 2013; Satyanarayana et al., 2011; Johnston et al., 2009) that discussed the scientific principles and application of the 4Rs. Such initiatives help in improving the understanding of 4R Nutrient Stewardship across wide range of stakeholders.

Ownership of 4R Nutrient Stewardship by partners: Partners of IPNI research and education programs in South Asia has contributed significantly to the dissemination of the 4R concept. NARES partners has adopted the concept and application tools in their research and extension program. The International Maize and Wheat Improvement Centre (CIMMYT), development partner of the Nutrient Expert® tool, has recognized the concept of 4R Nutrient Stewardship, and the Nutrient Expert® fertilizer decision support tool is currently being used by CIMMYT in their global flagship programs such as CRP MAIZE and CCAFS. A recent video (https://www.youtube.com/watch?v=BAtwJAlZpqI) developed by CIMMYT India on smallholder precision nutrient management is a practical example of endorsing 4R through the use of Nutrient Expert® in conjunction with GreenSeeker® technology.

Summary

Nutrient management within the framework of the 4R Nutrient Stewardship promotes the application of nutrients using the right source at the right rate, right time, and right place and is aimed at ensuring the economic, social, and environmental goals of sustainable farming in India. The concept is well recognized among the stakeholders of Indian agriculture; it is such a rare occasion in any meeting where fertilizer or nutrient management issues are discussed and the 4Rs are not mentioned in the program. Going forward, there still exists a need for bringing nutrient management under the 4R perspective. Continuous efforts of developing and promoting 4R guidelines in diverse crops through research and education programs and strengthening effective partnerships in this dimension would be the way forward for successful implementation of 4R Nutrient Stewardship in Indian Agriculture. BC-SA

Educating a farmer (left) on using the right rate for potash application.

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References

Anonymous, 2014. United States Census Bureau http://www.census.gov/population/international. Accessed on 11th April, 2014.

Bhende, S.N. and A. Kumar. 2014. Better Crops South Asia 8:21-23.

Bruulsema, T., J. Lemunyon, and B. Herz. 2009. Crop Soils 42:13-18.

Dutta, S.K., K. Majumdar, V. Shahi, A. Kumar, V. Kumar, N. Gupta, T. Satyanarayana, M.L. Jat, M. Pampolino, and A. Johnston. 2014. Better Crops South Asia 8:11-13.

Dutta, S., K. Majumdar, T. Satyanarayana, and A.K. Singh. 2015. SATSA Mukhapatra – Annual Technical Issue 19:19-35.

IFA, 2009. Online. Fertilizer Best Management Practices (FBMPs).

IFPRI. 2012. Demand and Supply of Cereals in India: 2010-2025, IFPRI Discussion Paper 01158, Environment and Production Technology, IFPRI, New Delhi.

Jat, M.L., T. Satyanarayana, K. Majumdar, C.M. Parihar, S.L. Jat, J.P. Tetarwal, R.K. Jat, and Y.S. Saharawat. 2013. Fertiliser Best Management Practices for Maize Systems. Indian Journal of Fertilisers 9(4):80-94.

Johnston, A.M., H.S. Khurana, K. Majumdar, and T. Satyanarayana. 2009. J. Indian Soc. of Soil Sci. 57(1):1-10.

Majumdar, K. and T. Satyanarayana. 2011. Karnataka J. Agric. Sci. 24(1):81-85.

Majumdar, K., P. Dey, and R.K. Tewatia. 2014a. Indian J. Fert. 10(5):14-27.

Majumdar, K., S.K. Dutta, and T. Satyanarayana. 2014b. *In* Text Book of Plant Nutrient Management. R. Prasad, D. Kumar, D.S. Rana, Y.S. Shivay, and R.K. Tewatia (eds.), Indian Society of Agronomy, Indian Agricultural Research Institute. pp.361-385.

Majumdar, K., A.M. Johnston, S. Dutta, T. Satyanarayana, and T.L. Roberts. 2013. Indian J. Fert. 9(4):14-31.

Pattanayak, S.K., T. Satyanarayana, and K. Majumdar. 2015. Better Crops South Asia 9:35-37.

Satyanarayana, T., K. Majumdar, and D.P. Biradar. 2011. Karnataka J. Agric. Sci. 24(1):86-90.

Satyanarayana, T., K. Majumdar, S. Dutta, M.L. Jat, S.K. Pattanayak, D.P. Biradar, Y.R. Aladakatti, M. Pampolino, and A. Johnston. 2014. Better Crops South Asia 8(1):7-10.

Sapkota, T.B., K. Majumdar, M.L. Jat, A. Kumar, D.K. Bishnoi, A.J. McDonald, and M. Pampolino. 2014. Field Crops Res. 155: 233-244.

Subba Rao, A. and S. Srivastava. 1998. Role of plant nutrients in increasing crop productivity. Agro-Chemicals News in Brief, April-June 1998, FADINAP, Bangkok.

4R Nutrient Management for Onion in India

By A. Thangasamy

The right source of nutrient for onion must consider the soil type and all the limiting nutrients in the soil.
Determining right rate depends on the growing season, yield target, and method of nutrient application.
Right timing of nutrients during active vegetative growth is critical to ensure high productivity and nutrient use efficiency.
Right method of nutrient application through drip fertigation seemed to be most promising for onion farmers.

Onion is an important commercial crop that is grown around the world and consumed in various forms. In India, it is cultivated as a vegetable, spice, or condiment. On a global scale, India ranks second in area and production, but the productivity of onion (15.9 t/ha) is below the world average (19.3 t/ha) (FAOSTAT, 2014). This mainly due to the use of traditional varieties, lack of appropriate water, nutrient management practices, and improper crop protection measures.

Onion is a highly nutrient responsive crop. Nutrient requirement varies with cultivars, yield potential, season, and location. In absence of proper guidance, farmers' generally practice perception-based fertilizer application, leading to the over or under use of plant nutrients. The steady depletion of native soil fertility and the occurrence of multiple nutrient deficiencies in farmers' fields, identified nutrient management as a key factor limiting sustainable onion production. The 4R Nutrient Stewardship approach to nutrient management considers the right fertilizer source in combination with the right application rate, timing, and placement. This is to produce the most economical outcome, in any given crop, in addition to providing desirable social and environmental benefits essential to sustainable agriculture (Bruulsema et al., 2009).

Dr. Thangasamy observing the onion growth at 36 DAT through drip fertigation method of fertilizer application.

Right Source

Onion responds to a wide range of fertilizers and those commonly applied include: urea, diammonium phosphate (DAP), ammonium sulphate [$(NH_4)_2SO_4$], single super phosphate (SSP), potassium chloride (KCl), potassium sulphate (K_2SO_4), gypsum (source of sulphur), elemental sulphur, and other fertilizer grades (e.g., 10:26:26, 20:20:0, 19:19:19, 16:8:24, etc.) as major sources of nutrients. The selection of the fertilizer source depends on soil type, soil characteristics, plant root system, and method of fertilizer application. Wherever fertilizers are applied through drip irrigation (fertigation), water soluble fertilizers such as urea and fertilizer grades such as 19:19:19 and 16:8:24, seemed to the best choice for onion. The above fertilizers can be applied either alone or mixed with other fertilizers before transplanting.

In addition to the above sources, the use of manures is suggested (Ngullie et al., 2011). However, their effectiveness is potentially limited by nutrient release patterns that often do not coordinate with crop demand, large variability in source quality, field distribution, and food safety. The yield of onion bulbs decreased by 30 to 45% with organic sources over conventional methods of production with inorganic fertilizers (Thangasamy et al., 2016). The integrated use of organic and inorganic fertilizers increased bulb production, improved biochemical quality and soil organic carbon status as compared to inorganic fertilizer alone (Thangasamy and Lawande, 2015). Given the good supply of quality manures, Ngullie et al. (2011) favoured the combined application of inorganic fertilizers and manures over sole application of either nutrient source. Contribution from other sources, such as irrigation water and native soil, may also be considered when developing nutrient management strategies for onion.

Right Rate

Onion requires a large quantity of plant nutrients compared to cereals and vegetables. Studies conducted at different locations in India showed that onion removes 2.1, 0.75, 2.2, and 0.28 kg N, P_2O_5, K_2O, and S (DOGR, 2015) to produce 1 t of

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulphur; Cu = copper; Fe = iron; Mn = manganese; Zn = zinc.

Table 1. Yield and nutrient uptake of onion varying with crop seasons and method of applications. Source: DOGR, 2015.

Yield/Nutrient	--- Kharif ---		------- Late kharif -------			--------- Rabi ---------		
uptake	NPK*	N**	NPK*	N**	Broadcast	NPK*	N**	Broadcast
Yield, t/ha	20	16	43	36	36	43	42	41
N, kg/ha	73	66	80	86	83	97	89	95
P, kg/ha	14	13	18	19	17	25	24	18
K, kg/ha	74	71	74	73	71	87	74	72
S, kg/ha	22	20	14	10	12	25	20	20
Zn, g/ha	105	94	131	119	138	164	136	127
Cu, g/ha	45	37	59	52	54	65	65	58
Mn, g/ha	262	260	305	240	255	214	186	164
Fe, g/ha	980	899	2,094	1,907	1,987	907	824	849

*NPK fertilizer applied through fertigation
**N fertilizer applied through fertigation

bulb yield. These findings were similar to the reports of Dogliotti (2003) and Zhao et al. (2011) from other countries, which indicated that the nutrient requirement was more or less similar at varied locations and for different varieties. The yield potential and total nutrient requirement of onion crop varied with season, yield level, and method of application. Results in **Table 1** showed that bulb yield and nutrient requirement varied with cropping seasons, with significantly less productivity in kharif (18 t/ha) as compared to late kharif (38 t/ha) and rabi season (42 t/ha). Based on the results in **Table 1**, AINRPOG (2011) revised the nutrient recommendation of onion to 75:40:40:30 kg/ha N:P:K:S in kharif and 110:40:60:30 kg/ha N:P:K:S in rabi season,

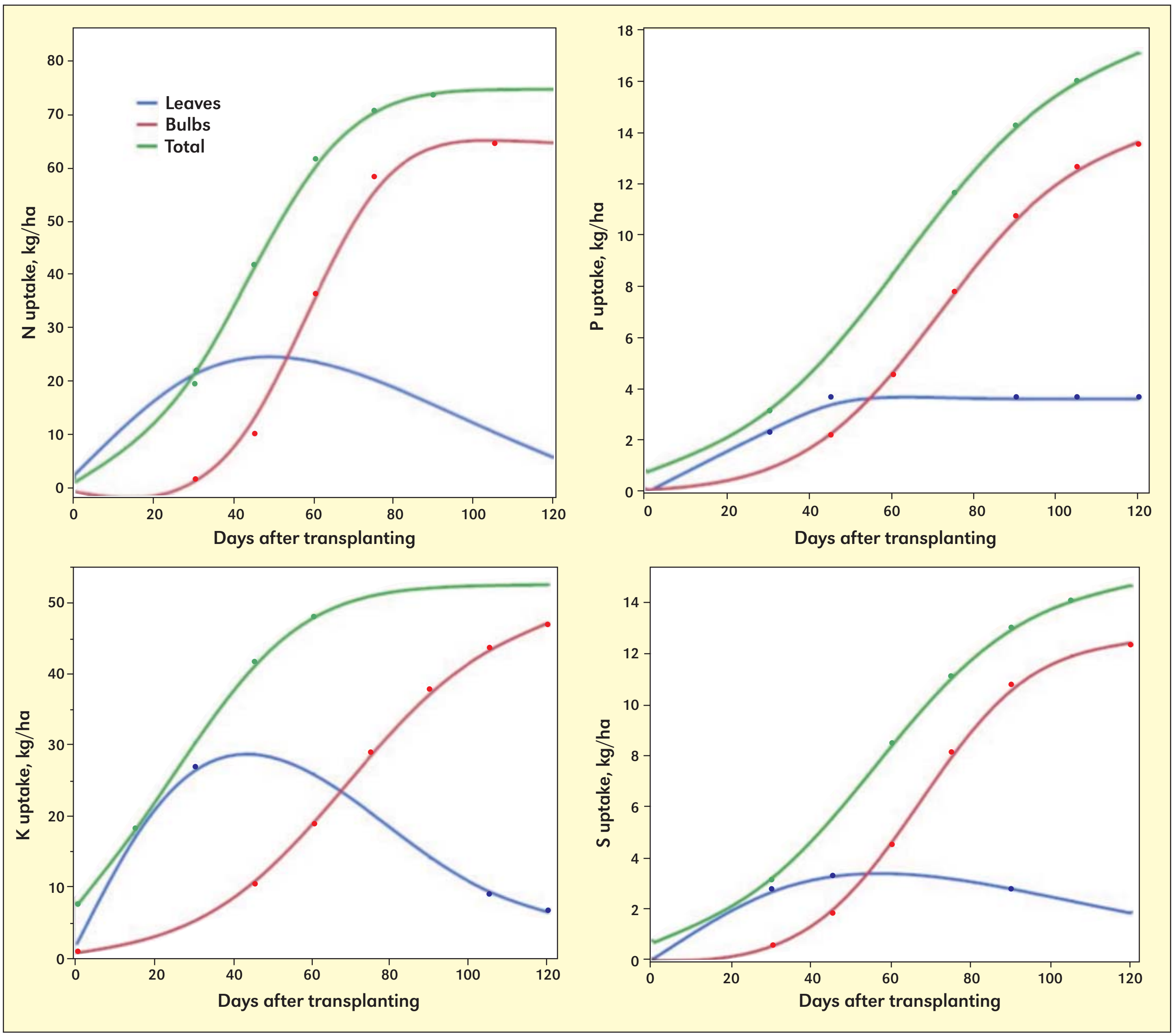

Figure 1. N, P, K, and S uptake pattern during onion growth period. (Thangasamy, 2016)

Table 2. Nutrient uptake of onion (cv. Bhima Kiran, bulb yield target, 45 t/ha). Source: Ganeshamurthy and Thangasamy (2016).

Parameters	Leaves	Bulbs	Total
Dry matter yield, kg/ha	709	3,604	4,313
Nutrient uptake			
N, kg/ha	6.1	74	80
P, kg/ha	0.5	15	16
K, kg/ha	16	53	68
S, kg/ha	1.7	13	15
Fe, g/ha	543	592	1,135
Zn, g/ha	17	90	108
Mn, g/ha	43	65	108
Cu, g/ha	2.7	11	14
B, g/ha	407	1,273	1,680

in addition to applying 75 kg/ha N through organic manures in both the seasons.

Excessive or inadequate rates of nutrient application affect onion yield. Palaniappan and Thangasamy (2015) reported an increase in collar and pseudo-stem thickness, occurrence of twin bulbs and bolters, and reduced storage quality with decreased onion bulb yield due to excessive rates of nutrient application. The total nutrient uptake in onion for a yield target of 45 t/ha (**Table 2**), indicated that onion accumulated 92, 96, 77, and 89% N, P, K, and S in bulbs. Ganeshamurthy and Thangasamy (2016) suggested that nutrient management for onion should consider replacing the quantity of nutrients removed through bulbs and recycling nutrients accumulated in the leaves through reincorporation of the leaves into soil after harvest. Sustainable onion production should aim at determining the right rate of nutrients considering the crop requirement based on yield target, growing season. and method of nutrient application.

Right Time

The timing of nutrient application in onion is governed by the nutrient uptake pattern during crop growth stages. N, P, K, and S are mobile in the plant system and nutrients accumulated in the leaves are remobilized and translocated to bulbs during bulb enlargement and maturity stages. Ensuring the rapid uptake of these nutrients during active vegetative growth stages through right timing of application is critical for onion production.

The NPKS uptake from planting to 15 days after transplanting (DAT) was low and coincides with establishment stage. Low nutrient uptake at initial stages could be due to slower adaptation of seedlings to their new environment. Excess application of fertilizers during this period may be leached beyond the root zone through irrigation water and become unavailable to plants. Thangasamy (2016) reported that the rate of total uptake of N and K increased rapidly from 15 DAT and reached maximum at 45 DAT, with peak uptake recorded during 33 to 40 DAT. The total peak uptake of P and S was observed during 45 to 50 DAT (**Figure 1**). The study indicated that the peak N, P, K, and S uptake occurs during 15 to 60 DAT, and fertilizers should be applied before 60 DAT for increasing bulb yield and nutrient use efficiency. Application of fertilizers after 60 DAT delayed bulb development, increased collar thickness, number of twin and multicentre bulbs, and reduced storage quality (Thangasamy, 2016).

Uptake of micronutrients such as Zn, Mn, and Cu in the leaves increased at faster rate and reached peak at 30 DAT

Dr. Thangasamy demonstrating the right rate of nutrient application to onion.

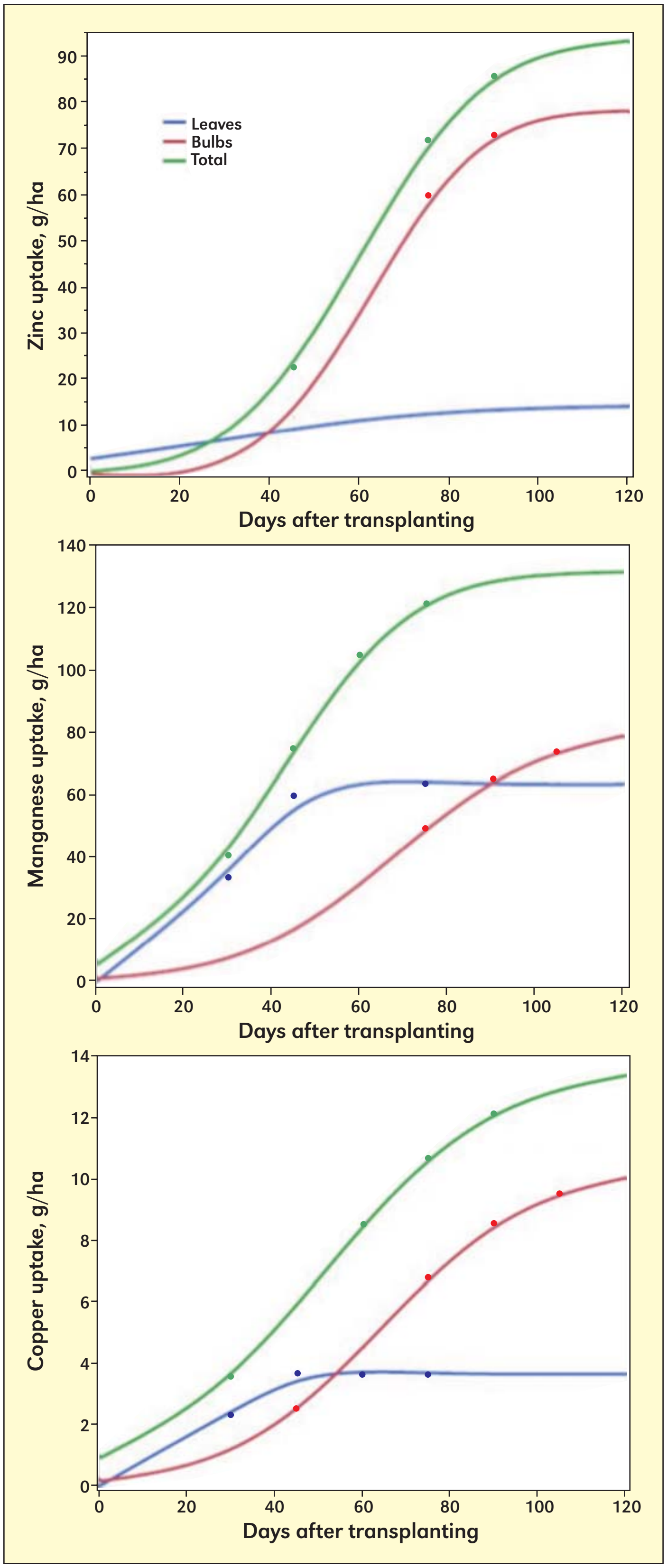

Figure 2. Zn, Mn, and Cu uptake pattern during onion growth period. (Thangasamy, 2016).

(**Figure 2**), but decreased sharply at 60 DAT (Thangasamy, 2016). The total uptake by the onion plant and bulbs remained more or less same upto 90 DAT, indicating that Zn, Mn, and Cu accumulated after 60 days directly moved to the bulbs (**Figure 2**). Micronutrients (Zn, Mn, Cu, B, and Fe) are immobile in

The right source of nutrients for onion.

phloem and not remobilized and translocated to bulbs. Due to this, plants remove these micronutrients directly from soil through crop maturity to harvest. Deficiency of micronutrients at any point of time can reduce bulb yield, indicating that season long supply of micronutrients is essential for producing high bulb yield. Organic manures contain appreciable amounts of micronutrients and application of such sources can alleviate micronutrient deficiency during the entire crop growth.

Right Place

Onion has a shallow root system that is mainly distributed within the top 10 to 30 cm of soil. Being a closely spaced crop, fertilizer nutrients need to be applied near the root zone to increase the nutrient use efficiency. In general, fertilizers are applied through various methods including broadcasting, banding, fertigation, foliar application, and microinjection. **Table 1** showed that the application of NPK through drip system increased NPK uptake over application of N, through drip system and broadcasting method (DOGR, 2015). Rajput and Patel (2006) reported that application of N fertilizers through drip irrigation system increased the bulb yield significantly and reduced nitrate leaching to sub-surface soil. Dawelbeit and Ritcher (2004) observed that the drip fertigation system in onion produced higher yields compared to drip irrigation with fertilizer broadcasting. Other studies reported that N application through drip system, up to 70 days after transplanting, produced 22% higher bulb yield over broadcasting of fertilizers (NRCOG, 2006). This was compared to the flood irrigation system with broadcasting of fertilizers, which increased collar thickness and number of double bulbs (AINRPOG, 2015).

Summary

Implementation of improved nutrient management can not only improve onion yield, but also enhance nutrient use efficiency coupled with better economic returns to farmers while reducing environmental risks. The actual nutrient needs of onion largely depends on growing season, variety, yield goal, and soil fertility status. Appropriate fertilizer timing and placement must coincide with onion growth stages for maximum nutrient uptake, higher bulb yield and better quality. The 4R Nutrient Stewardship approach provides a framework to identify the best options to meet onion's nutrient demands. BC-SA

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References

AINRPOG. 2015. Annual report, Directorate of Onion and Garlic Research, Rajgurunagar. Pune.

Bruulsema, T., J. Lemunyon, and B. Herz. 2009. Crop Soils 42:13-18.

Dawelbeit, S. and C. Richter. 2004. Deutscher Tropentag, October 5-7, Berlin.

Dogliotti, S. 2003. Ph.D. Thesis, Wageningen University, Wageningen, The Netherlands.

DOGR. 2015. Directorate of Onion and Garlic Research, Rajgurunagar, Pune.

FAOSTAT. 2014. Comparison of onion productivity of India with world average. http://faostat.fao.org/beta/en/#compare.

Ganeshamurthy, A.N. and A. Thangasamy. 2016. *In* V. Mahajan, P.C. Tripathi, P.S. Srinivas, S.J. Gawande, S. Anandhan, A. Thangasamy, S.S. Gadge, and R.P Singh (eds). Souvenir and abstracts. 2nd National Symp on Edible Alliums: Challenges and strategies for sustainable production, Jalna, Maharashtra, November 7-9, 2016, P. 102.

Mishra, R.K., R.K. Jaiswal, D. Kumar, P.R. Saabale, and A. Singh. 2014. J. Plant Breeding and Crop Sci. 6(11):160-170.

Ngullie, E., V.B. Singh, A.K. Singh, and H. Singh. 2011. Better Crops, 95(1):7-9.

NRCOG. 2006. National Research Center for Onion and Garlic, Rajgurunagar, Pune.

Palaniappan, R. and A. Thangasamy. 2015. ICAR-DKMA, Indian Council of Agricultural Research, New Delhi.

Rajput, T.B.S. and N. Patel. 2006. J. Agr. Water Management, 79:293-311.

Thangasamy, A. and K.E. Lawande. 2015. Indian J. Horticulture, 72:347-352.

Thangasamy, A. 2016. Communications in Soil Science and Plant Analysis, 47:246-254.

Thangasamy, A., G. Kalyani, T.P. Shabeer Ahammed, R.S. Kavith, K. Banerjee, V. Sankar, and M.C. Kisho. 2016. *In* V. Mahajan, P.C. Tripathi, P.S. Srinivas, S.J. Gawande, S. Anandhan, A. Thangasamy, S.S. Gadge, and R.P. Singh (eds). Souvenir and abstracts. 2nd National Symposium on Edible Alliums: Challenges and strategies for sustainable production, Jalna, Maharashtra, November 7-9, 2016, P.228.

Zhao, K., K. Xu, N. Xu, and Y.G. Wang. 2011. Plant Nutrition and Fertilizer Science, 15:241-246.

Update on IPNI South Asia Program Staff

Recent IPNI staff appointments include Dr. Kaushik Majumdar, Vice President, Asia, Africa & Middle East Group (left) and Dr. T. Satyanarayana, Director, South Asia Program (right).

Dr. T. Satyanarayana was named Director of the IPNI South Asia program effective July 1, 2016. Dr. Kaushik Majumdar, who had previously served as Program Director, has been named IPNI Vice President Asia, Africa & Middle East programs effective July 1, 2016. Dr. Majumdar has replaced Dr. Adrian Johnston, past Vice President, Asia and Africa. The program office remains in Gurgaon, India. The South Asia region includes India, Pakistan, Bangladesh, Nepal, and Sri Lanka.

"We expect a smooth transition during this time and plan to maintain positive and productive programs in this important region," noted IPNI President Dr. Terry Roberts. "Dr. Majumdar has accomplished significant and lasting advances for the agriculture and people of all the areas he served. His positive influence extended to our programs worldwide." He added, "We are confident Dr. Satyanarayana will move the South Asia program forward as we work to improve nutrient management in this region."

"Because Dr. Satyanarayana has the benefit of more than 7 years' experience as Deputy Director, IPNI programs will continue to progress," expressed Dr. Johnston. Dr. Satyanarayana, a native of Yanam, Pondicherry, joined the IPNI staff in 2008. He completed undergraduate studies at Pandit Jawaharlal Nehru College of Agriculture (PAJANCOA), Karaikal in 1998, then earning his M.Sc. degree in 2001 at Dr. Y.S. Parmar University of Horticulture & Forestry (YSPUH&F), Nauni, Solan in Himachal Pradesh. Dr. Satyanarayana completed his Ph.D. program at Indian Agricultural Research Institute (IARI), New Delhi during 2005.

In 1999, Dr. Majumdar joined the staff of the Potash & Phosphate Institute (PPI), the predecessor of IPNI. A native of West Bengal, he completed undergraduate training in agriculture at the Visva Bharati University before earning his M.Sc. (Ag) from B.C.K.V Agricultural University in 1987 and his Ph.D. at the Rutgers University in 1993. He later held important responsibilities with the Potash Research Institute of India in Gurgaon working on potassium mineralogy of Indian soils. BC-SA

4R Nutrient Stewardship of Potato: A Major Cash Crop in Eastern India

By Hirak Banerjee, Sudarshan Dutta, Sukamal Sarkar, T. Satyanarayana, and Kaushik Majumdar

4R guidelines are needed to enhance potato growth stages and increase yields.

Potato is one of the major staple crops produced throughout the world. Average potato yields in countries such as the U.S.A., Germany, Netherlands, and France range between 38 to 44 t/ha, while yields average 23 t/ha in India (FAOSTAT, 2015). One of the major constraints to a higher yield of potato in India is inadequate and unbalanced nutrient use (Banerjee et al., 2016). Along with temperature variation, nutrient management plays a major role in potato yield improvement. Nitrogen, P, and K requirements of potato are high and the optimum supply of these nutrients improves yield and quality of potato tubers in areas where native soil supplies are limited. These nutrients are key to optimum plant growth, essential for regulating plant water status and osmotic pressure, increasing nitrate reductase activity, and raising photosynthesis and transpiration. Therefore, all these nutrients are to be applied in the right amount, at the right rate, at the right time, and at the right place for better nutrient uptake, nutrient use efficiency, and increased economic return. This study provides guidelines for the 4R management of the three major nutrients for potato, under an Indian context.

Nitrogen

Nitrogen is the major limiting nutrient in most Indian soils. It is responsible for increasing vegetative growth, tuber size, tuber number, and the tuber bulking rate (TBR) in the potato plant. Among the different sources of nitrogenous fertilizer, urea is the most easily available and cheapest accounting for 78% of total N fertilizers produced in India (Trehan et al., 2008). However, its efficiency is less than other sources such as calcium ammonium nitrate (CAN) and ammonium sulphate. Ammonium sulphate has been found to be the best source for potato production because of its S supplementation along with N (Dua, 2014), producing 1.2, 9.2, 11, 41, and 63% higher tuber yields than ammonium nitrate, ammonium chloride, CAN, urea, and sodium nitrate respectively at the same N rate (Grewal and Trehan, 1984). However, it is comparatively expensive amongst all the other N sources and unaffordable for small and marginal potato growers. Swaminathan (1972) observed that performance of CAN and ammonium chloride, as N sources, closely follows ammonium sulphate; whereas, urea and sodium nitrate were poor sources of N. Urea has an adverse effect on plant emergence and sodium nitrate reduces the final plant stand. Due to its low cost, attempts have been made to increase the efficiency of urea through optimized rate, time, and placement of application. Higher number of split applications can increase N use efficiency from urea and moisture management during pre-emergence stage counteracts the detrimental effects of urea on crop emergence.

The N rate varies across different potato growing regions

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

Dr. Banerjee inspecting potato plots in West Bengal.

depending upon the soil type, variety, and yield target. In the Indo-Gangetic alluvial plains of West Bengal, Banerjee et al. (2016) reported 70% tuber yield reduction in potato with N omission when compared to an application rate of 200:150:150 of N, P_2O_5 and K_2O/ha, respectively. On the contrary, the excess application of N delays the tuber initiation which leads to excessive vegetative growth resulting in poor yield. The N requirement is as high as 240 kg/ha in the alluvial soils of Punjab, Uttar Pradesh, Bihar, and Jharkhand (Dua, 2014), 203 kg/ha in West Bengal (**Figure 1**), 120 to 155 kg/ha in the acidic soils of Himachal Pradesh, Jammu and Kashmir, and north eastern hills, and 600 kg/ha under riverbed cultivation in Gujarat (Sud and Sharma, 2003). Banerjee et al. (2016) recorded significantly higher tuber yield for long duration

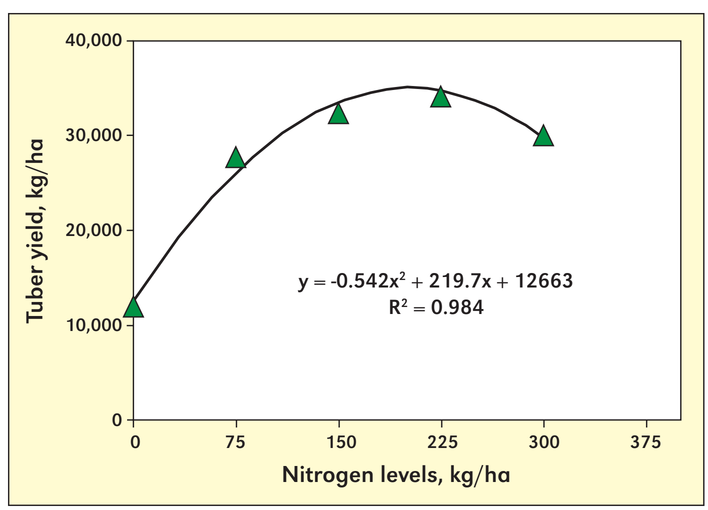

Figure 1. Potato response to nitrogen application in Indo-Gangetic plains of West Bengal (Mozumder et al., 2014).

cultivar (cv. Kufri Himalini) with 225 kg N/ha, suggesting N requirement increases with increase in crop duration. These findings suggest that location specific N rate estimation needs to be taken into account for growing conditions, yield target and soil nutrient supplying capacity.

The efficiency of nitrogenous fertilizer in potato is greatly influenced by the time and method (place) of its application. Tuber development, commercially the most important phase in potato production, could be extended (65 to 85 days in hills and 40 to 60 days in plains) by providing sufficient N at early growth stages to prolong the growth stages. The efficiency of N can be increased by applying fertilizer 5 to 10 days before planting and mixed with soil properly (Mondal and Chatterjee, 1993). Split application of N, half at planting and half at 30 days after planting, is generally recommended in potato for better efficiency, higher tuber yield, and reduction in leaching loss of N (Mozumder et al., 2014; Banerjee et al., 2016). In hilly areas, where the duration of crop is 4 to 5 months, three split applications of N is better than two. The foliar application of urea at 50 to 60 DAP (1 to 1.5% solution) can improve or correct the N-deficiency at mid-crop growth stages. The N use efficiency (NUE) of potato also depends on the method of application because there is a strong relationship between sources of N and method of application (Trehan et al., 2008). Broadcasting of CAN and ammonium sulphate is better than hand placement in furrows below the tubers, as it helps the quick emergence of crops; whereas, in case of urea, side banding 5 cm away and 10 cm deep was found to be the best (Sharma and Upadhayaya, 1991). Row placement of nitrogenous fertilizer has been found to be a better choice in silt loam soil rather than sandy loam soil (Sud and Sharma, 2003).

Earthing up of soil after top dressing of N at 30 days after seeding.

Phosphorus

Phosphorus is the second limiting nutrient responsible for potato production in different agro-climatic zones of India. Application of P improves tuber yield of potato by increasing the tuber number, as well as the size. It counteracts excessive crop growth due to application of heavy doses of N and accelerates maturity. There are different sources of phosphatic fertilizers that have varying efficacy in different soil types for potato. In the alluvial soils, readily available phosphatic fertilizers such as single super phosphate (SSP) and diammonium phosphate (DAP), are suitable for potato production. The recovery of P by the first crop of potato from SSP is about 20% (Rana, 2014). In general, superphosphate, mono-ammonium phosphate, di-ammonium phosphate and pyrophosphate are considered better sources of P than rock phosphate and bone meal. The Mussorie rock phosphate is less effective when applied alone compared to when it is applied in combination with superphosphate, particularly in the hilly regions (Sahota and Sharma, 1986) where phosphate fixation is a major problem due to the acidic nature of the soils. The SSP was found to be more effective in sulphur deficient soils, whereas DAP at lower rate was found to be more effective in producing higher tuber yield in soils containing sufficient sulphur.

Rate of P application in potato varied from 80 to 100 kg/ha in acidic hill soils of Himachal Pradesh, North-Eastern States of India, and Kashmir (Dua, 2014). The requirement of P_2O_5 varied from 50 to 150 kg/ha in the alluvial soils of Punjab, Uttar Pradesh, and Bihar. Potato responded well up to 150 kg P_2O_5/ha (Mozumder et al., 2014) in the alluvial soils of West Bengal. Banerjee et al. (2016) reported 10% tuber yield reduction in potato with P omission, when compared to full NPK application (200:150:150 N, P_2O_5, and K_2O/ha). However, Grewal et al. (1992) reported that potato grown in heavy textured black soils hardly requires any P application.

Similar to N, the efficiency of phosphatic fertilizer in potato also depends on the time and place of application. Owing to shallow root system, proper placement of phosphatic fertilizer is very important as it affects its use efficiency. Potato needs most of the P at early growth stages. Thus, the entire amount of P fertilizer should be applied in furrows at 5 to 6 cm below the seed tubers at the time of planting (Mozumder et al., 2014). Furrow placement near the active root zone or near the tuber is recommended mainly in the acidic soils and has been found to be more successful than broadcasting for higher tuber yield (**Table 1**). Sahota et al. (1988) reported that the point place-

Table 1. Effect of various method of phosphatic fertilization (48 kg/ha) in a responsive sandy soils at Jalandhar.

Method of fertilizer placement	Average yield increment over control (no P), t/ha	% increase over control
Broadcast before planting and incorporation in the soils in the final ploughing	1.37	12.7
Placed in furrows, in two rows, each about 15 cm from the seed piece in row	1.74	16.4
Placed in furrow on each side of the seed piece but about 3 cm from the seed piece in a row	3.80	36.5

Source: Das, P. C. 2000

ment of SSP had better results than application in furrows of acidic soils in Shillong. In the highly acidic soils of Shillong, P application at 2 to 3 cm above seed tubers was better than its application below seed tubers (Sharma and Grewal, 1989). Compared to soil application foliar application of phosphatic fertilizer resulted in higher tuber yield, provided the crop did not suffer due to P deficiency at early growth stages (Trehan et al., 2008). Before planting, soaking of tubers in 30% SSP + 0.5% urea + 0.2% mancozeb for four hours and basal application of P_2O_5 at 50 kg/ha, could partially meet the phosphate requirement of the crop and economize the phosphate requirement of the crop.

Potassium

Potassium plays an important role in the translocation and accumulation of photosynthates (carbohydrates) from the leaves to the tubers and increasing the size, yield, and quality of tuber. It is essential for starch formation, which accounts for the major portion of dry matter of potato and increases resistance against water stress, frost, and diseases. Potato responds well to K fertilizers and also removes large amounts of K, N, and P from the soil (Banerjee et al., 2016).

Muriate of potash (MOP), or potassium chloride (KCl), and potassium sulphate (K_2SO_4) are the two sources of K largely used by potato farmers for basal application. Tuber yield and quality of potato improved with the application of potassium sulphate (Dua, 2014) compared to MOP. However, MOP is the commonly used K source in potato due to its comparatively lower cost and accounts for 97% of K fertilizer consumption in the potato growing areas of the country (Dua, 2014). In addition, KCl showed better frost resistance in potato over K_2SO_4 (Tiwari et al., 1980). Beside these sources, another source of K, potassium scheonite (having salts of potassium sulphate and magnesium sulphate), has also been found to be equally effective in producing higher tuber yield in the acid and alluvial soils of different growing zones of the country (Trehan et al., 2008). Potassium nitrate (KNO_3) application at a rate of 2 g/L (2% solution) has also proven its effectiveness as source of K when applied through foliar application (Brar and Kaur, 2007).

Although Indian soils are considered high in K, several studies have shown K responses for potato in omission plot trials. This might be due to the fact that the high uptake requirement of K for potato is not matched by the slow rate of K release from the strongly held K pools in the soil (Majumdar et al., 2016). Potato requires K from early growth stages to the tuber development stage. Potato grown in the hills and plains of India requires 80 to 100 kg K_2O/ha. In the hills of Shillong, K_2O application at 60 kg/ha produced higher tuber yield over control (zero K). Studies also demonstrated maximum tuber yield with 60 kg K_2O/ha in Garhwa district of Jharkhand, producing 63% more yields over the control. In the Indo-Gangetic plains of West Bengal, tuber yield of potato is significantly increased with the application of K up to 150 kg/ha. Banerjee et al. (2016) demonstrated about a 6% tuber yield reduction in potato with K omission when compared to a dose of 150 K_2O/ha.

Potassium fertilizer should be applied at the right time and place so it can be fully utilized by the potato plant, further increasing the efficiency of K fertilizer. Generally, the entire dose of K is applied at the time of planting (Mozumder et al., 2014), although there is some evidence showing the positive effect on tuber yield when applied in split application (half at planting and half at the time of top dressing) of N in combination with urea (Trehan et al., 2008). Studies also support foliar application of K_2O in potato. Two foliar sprays of K at 2% solution of KNO_3 at 50 and 70 DAP was effective in long duration varieties, like Kufri Badshah. For short duration varieties, spraying of K through KNO_3 should be done at 45 and 60 DAP in order to get effective results (Trehan et al., 2008). However, foliar spray cannot be comparable to soil application. Furrow method of application for K is considered the better option over broadcasting in rainfed and irrigated conditions. Use of K through broadcasting is as effective as furrow method when potato is grown under light-textured soil (Sharma and Upadhayaya, 1991).

Conclusion

The present study provides a general guideline of 4R Nutrient Stewardship of potato under varied agro-climatic situations. Site specific nutrient management strategies with the support of 4R Nutrient Stewardship concept needs to be adapted for different growing conditions for higher productivity and better economics while maintaining environmental sustenance.

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References

Banerjee, H., L. Rana, K. Ray, S. Sarkar, K. Bhattacharyya, and S. Dutta. 2016. Indian J. Plant Physio. 21(2):129-136.

Brar, M.S. and N. Kaur. 2007. Indian J. Agric. Sci. 76(12):740-743.

Das, P.C. 2000. Kalyani Publishers, New Delhi. pp. 42-62.

Dua, V.K. 2014. CPRI, Shimla. pp 71-76.

FAOSTAT. 2015. Food and Agriculture Commodities Production. (http://faostat.fao.org/site/339/default.aspx. (Date accessed on 25th May, 2016)

Grewal, J.S. and S.P. Tehran. 1984. Fertilizer News, 29(4):34-41.

Grewal, J.S., S.P. Trehan, and R.C. Sharma. 1992. Tech. Bull., No. 31, CPRI, Shimla.

Majumdar, K., S.K. Sanyal, S.K. Dutta, T. Satyanarayana, and V.K. Singh. 2016. *In*: Biofortification of Food Crops (Eds.) U. Singh, C.S. Praharaj, S.S. Singh, and N.P. Singh, Springer India. pp. 177-198. DOI 10.1007/978-81-322-2716-8_14.

Mondal, S.S. and B.N. Chatterjee. 1993. Naya Prakasha, Cal – 6, pp. 382-469.

Mozumder, M., H. Banerjee, K. Ray, and T. Paul. 2014. Indian J. Agron. 59(2):327-335.

Rana, L. 2014. M.Sc. Thesis submitted to Bidhan Chandra Krishi viswavidyalaya, West Bengal. pp. 50-54.

Sahota, T.S. and R.C. Sharma. 1986. J. Agric. Sci., Cambridge, 107:155-159.

Sahota, T.S., M.S. Virk, and P.M. Govindakrishnan. 1988. J. Agric. Sci., Cambridge, 111:191-192.

Sharma, R.C. and N.C. Upadhyaya. 1991. Tech. Bull. No. 32, CPRI, Shimla, pp. 74.

Sharma, U.C. and J.S. Grewal. 1989. Indian J. Agric. Sci., 59:237-239.

Sud, K.C. and R.C. Sharma. 2003. Mehta Publishers, New Delhi. pp. 136-147.

Swaminathan, K. 1972. J. Agric. Sci., Camb., 72:183-191.

Tiwari, P.N., N.P Sukumaran, and K.P Sharma. 1980. J. Indian Potato Assoc., 7:89-91.

Trehan, S.P., N.C. Upadhayay, K.C. Sud, M. Kumar, M.K. Jatav, and S.S. Lal. 2008. Tech. Bull. No. 90:2-25.

4R Nitrogen Management for Sustainable Rice Production

By K. Surekha, R. Mahender Kumar, V. Nagendra, N. Sailaja, and T. Satyanarayana

Research conducted on N management in rice at the ICAR-Indian Institute of Rice Research was aimed to increase the productivity while improving N use efficiency.

Bringing the current N management in rice under the concept of 4R Nutrient Stewardship can further help in achieving better economic, social, and environmental performance of N.

Rice is the most important staple food crop for more than half of the global population. In India, rice production has increased five-fold from about 20 million tonnes (Mt) in 1950-51 to more than 106 Mt in 2013-14. This increase in production is attributed to the development of fertilizer-responsive, high-yielding varieties. Fertilizer consumption, which contributes to nearly 50% of rice varietal yield potential, showed a phenomenal increase during this period [i.e., 69,800 t in 1950-51 to 25.6 Mt by 2014-15 (FAI, 2015)]. However, declining factor productivity in many intensive rice systems is a concern and this may be due to imbalanced fertilizer application by farmers.

Nitrogen is the key nutrient element required in large quantities by rice. In modern agro-ecosystems, it was estimated that the removal of as much as 300 kg N/ha/yr in the above-ground portions of the harvested produce requires substantial inputs of N either through fertilizers, manure, or N-fixation to maintain the productivity (Cassman et al., 2002). Indian soils are inherently low in soil organic matter, N is the major limiting plant nutrient, and N availability is routinely supplemented through the application of fertilizers. Though the yield increase due to N fertilization in rice has been substantial (47%), the average agronomic efficiency of N is only 11.4 kg grain/kg N (Prasad, 2011). It was earlier estimated, a 1% increase in the efficiency of N use for cereal production worldwide would lead to N fertilizer savings of 0.49 Mt, which accounts for US$0.24 billion savings in N fertilizer costs (Raun and Johnson, 1999).

Proper management of N is essential for achieving higher productivity, maximizing nutrient use efficiency (NUE), and improving environmental safety by ensuring minimal losses of applied N. In this context, promoting the 4R Nutrient Stewardship concept of applying the right fertilizer source, at the right rate, at the right time, and in the right place can help farmers maximize the economic, social, and environmental performance of N use. The research work conducted so far at the ICAR–Indian Institute of Rice Research (IIRR) and elsewhere in India, though aimed at achieving higher rice productivity while improving NUE, has not exactly followed the principles of the 4R approach. Considering the importance of bringing nutrient management for rice under the 4R perspective, an attempt was made to review the existing information to define 4R principles for N management in rice.

Right N Source

The choice of selecting the right source of N fertilizer depends on soil properties, nutrient content and cost of the fertilizer, and water management. However, efficiency of applied N fertilizer primarily depends on the form of N applied and the ecosystem in which they are used. Several studies have reported the superiority of amide and ammonical sources of N (urea and ammonium sulphate) for rice over nitrate forms (Prasad et al., 1980; Surekha et al., 1999). These sources have more stable ammonia-N held by the soil cation exchange complex, which helps in the gradual release of N throughout the active growth stages of rice. This contributes to a higher grain yield under flooded conditions when it is compared to nitrate-N, which is highly mobile and subjected to losses through leaching and denitrification. Urea has been challenged as a N source for rice due to leaching losses in coarse-textured soils and surface runoff, which could be offset with the use of slow-release neem-coated urea (NCU). The co-ordinated studies conducted by the IIRR showed an increase in N response (33.1 kg grain/kg N) with NCU at Ghaghraghat (Uttar Pradesh), while the lowest N response (4.3 kg grain/kg N) was recorded with prilled urea (PU) at Chinsurah in West Bengal

Dr. Surekha (on right) determining right timing of N application in the rice field using leaf colour chart.

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

Table 1. Effect of right source of N on grain yield response of rice (DRR, 1988-89).

Location	MRPU	NCU	GCU	PU
	---- Response, kg grain/kg N ----			
Bhubaneswar, Odisha	20.0	25.5	26.4	18.4
Chinsurah, West Bengal	10.4	8.8	9.2	4.3
Faizabad, Uttar Pradesh	20.0	18.9	21.3	14.2
Ghaghraghat, Uttar Pradesh	22.9	33.1	27.9	17.8
Mean (All locations)	19.1	21.1	22.0	17.5

MRPU = Mussorie rock phosphate coated urea; NCU = Neem-coated urea; GCU= Gypsum-coated urea; PU = Prilled urea.

(**Table 1**). The recent urea policy by the government of India, introduced in January 2015, made it mandatory for all domestic urea manufactures to be neem coated. Use of NCU helps in the sustained slow release of N, by about 10 to 15%, and results in increased rice yields. Suganya et al. (2007) assessed the influence of NCU on yield and N use efficiency in rice and reported a 20% higher grain yield and the highest apparent N recovery with NCU over prilled urea in the Noyyal and Madukkur soil series of Tamil Nadu. NCU helped in reducing leaching and volatilization losses by inhibiting the nitrification process and accelerated the N availability while saving the N use by 20 kg/ha, indicating that NCU could be a right source of N fertilizer for sustaining rice production.

Chemical fertilizers that are high-grade in their N supply and are easily soluble in nature, release N at a rapid rate when applied to rice. On the other hand, organic manures with a low concentration of nutrients paired with other challenges such as a slow-releasing nature, have high transport costs and limited availability that may not be beneficial for rice when applied as the sole N source. However, a judicious combination of these two sources improves the use efficiency for applied N if compared to the sole use of either organic manure or N fertilizer. Many long-term fertilizer experiments reported the beneficial role of farmyard manure (FYM), indicating a positive yield growth of about 100 kg/ha/yr across different locations with a supplementary dose of 5 t FYM, or poultry manure, along with recommended rates of fertilizers (DRR, 1994, 2004, 2014). Thus, the supply of both manures and fertilizers in optimum combination would help in improving NUE while achieving higher productivity.

Right Rate of N

On average, rice needs about 15 to 20 kg of N to produce 1 t of grain yield (IRRI, 2016). This indicates an uptake requirement of approximately 100 kg N both from soil and fertilizer sources to produce 5 t/ha of grain yield. Thus, a soil with indigenous N supporting 2.5 t/ha rice yield would need an external N supply of 50 kg/ha. However, considering (i) an agronomic efficiency for N fertilizer of 25 to 40%, (ii) N off-take with grain and straw, and (iii) the need to compensate for low N fertility status of Indian soils, 100 to 125 kg N/ha is recommended to achieve a target yield of 5 t/ha.

The site-specific decision on right application rate for N requires knowledge of the expected crop yield response to applied N, the function of N removal by the crop, the supply of N from indigenous sources, and the dynamics of the applied N fertilizer in the soil. Satyanarayana et al. (2012) considered yield response, agronomic efficiency (AE_N), and return on investment of N fertilizer (ROI_N) while determining the right rate of N to rice across the Indo-Gangetic plain. The right N rate can prevent the current imbalanced use of N fertilizers in India and can minimize its adverse effects on soil, climate, and the crop (Ray et al., 2000).

Application of right N rate in rice is also governed by crop duration, the nature of the variety, and the growing season. Studies conducted through the All India Coordinated Research Project on Rice (AICRP) showed that 90 to 120 kg N/ha increased grain yield in short and medium duration varieties, while N applied at 80 to 100 kg/ha proved to be optimum for long duration varieties (DRR, 1981-85). The high N requirement tested in the short and medium duration varieties was due to a high N response, which was 13 to 44 kg grain/kg N in short duration and 10 to 29 kg grain/kg N in medium duration varieties. The long duration varieties in the study showed a relatively low response of 8 to 22 kg grain/kg N, which resulted in application of low N rates in the long duration varieties. It was also observed that the long duration varieties were subjected to lodging with the higher rates of N application. Evaluation of N rates at AICRP centres revealed significant N response up to 120 kg/ha high-yielding varieties (HYVs). Few hybrids responded up to 150 kg/ha at most of the locations, while other hybrids responded up to 225 kg/ha indicating a variable N requirement to varying rice genotypes (IIRR, 2014). The higher N requirement of rice hybrids over HYVs is due to higher biomass of hybrids, higher number of panicles, larger panicle size, and more spikelets per panicle over HYVs.

Nitrogen requirement varies from field-to-field due to high variability in soil fertility across farmer fields and in cases the conventional blanket fertilizer recommendations may not be adequate enough to meet the N requirement of recently introduced HYVs and hybrids. Site-specific nutrient management (SSNM), an improved approach for determining right application rates, aims to apply nutrients at optimal rates and times to achieve high yield and high efficiency of nutrient use by rice. This leads to high economic return per unit of fertilizer invested. SSNM has shown the potential to close existing yield gaps in the intensive rice cropping systems of Asia (Dobermann et al., 2002), but widespread adoption of SSNM in smallholder farmer fields is challenged with limited acceptance due to the complex and knowledge-intensive nature of the approach. Agronomists and extension agents lacked confidence in using the approach that called for a scientifically robust, user friendly, and simple to use decision support tool for widespread adoption of SSNM. In response, the International Plant Nutrition Institute (IPNI), in collaboration with IIRR and other national partners, developed the *Nutrient Expert®* (NE) fertilizer decision support tool. NE is a 4R compliant tool that provides field-specific fertilizer recommendations to smallholder farmers.

IIRR and IPNI compared NE-based fertilizer recommendations with that of the generally recommended dose of fertilizer (RDF), farmer fertilizer practice (FFP), and an absolute control. The summarized results of four rice cropping seasons, spread over three years, in 18 locations indicated that SSNM based on NE yielded highest (5.5 t/ha). Yield under NE was 7%, 18%,

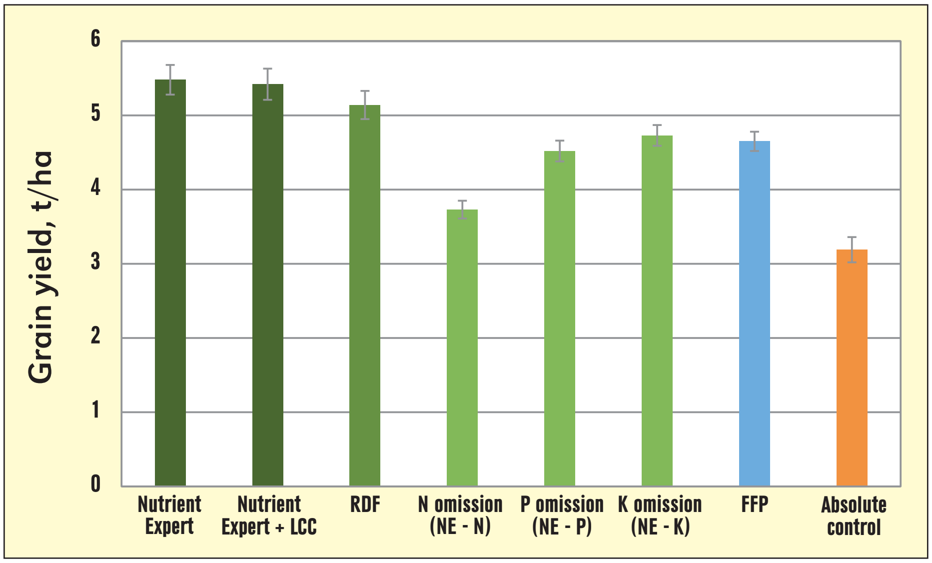

Figure 1. Comparative performance of SSNM-based Nutrient Expert® on grain yield of rice (summarized results of four cropping seasons, spread over three years, in 18 locations). Source: IIRR and IPNI joint collaborative research (2013-16).

Notes on Figure 1

NE = Nutrient Expert® based recommendation, which used an average N rate of 123 kg/ha.

NE+LCC (leaf colour chart) used same N rate as NE, but 50% was applied basally and remainder was guided through the use of LCC.

RDF = Recommended Dose of Fertilizer used an average N rate of 104 kg/ha.

-N; -P, and -K are omission plots derived from the NE treatment.

FFP = Farmer Fertilizer Practice used an average N rate of 140 kg/ha.

Absolute control = zero N, P, and K.

and 72% higher than RDF, FFP, and control, respectively (**Figure 1**). The comparison of N fertilizer use between RDF and NE revealed that N use in RDF varied from 80 to 120 kg/ha, with an average of 104 kg/ha. The corresponding N use, based on NE recommendation, varied from 90 to 150 kg/ha with an average of 123 kg/ha (data not shown). The NE-based individual field-specific fertilizer recommendation increased the average N fertilizer rate by 19 kg/ha, an increase of 18% over RDF. Similar studies were also conducted by Mandal et al. (2016) across 323 locations in West Bengal and reported an additional rice yield of 1.2 t/ha and additional gross benefit over fertilizer cost (US$235/ha) with the use of NE-based fertilizer recommendations over FFP.

Right Time of N Application

Rice requires N at different growth stages and N fertilizers should be applied at these physiological stages (right time). This may help in the availability and absorption of N during the critical growth stages of rice leading to better utilization of the nutrient. Application of N, when not matched with the demands of rice, may result in considerable loss of applied N causing yield and economic loss. Several multi-location experiments conducted for determining the right timing of N suggested that the application occur in three splits, one-third at transplanting, one-third at tillering, and the final third at panicle initiation for achieving high grain yield (particularly for medium and long duration varieties) (**Table 2**). Patnaik and Mohanty (1985) instead suggested to apply 75 to 80% of the total N during the vegetative stage followed by the remaining being top-dressed during internode elongation and emergence of boot leaf. Nitrogen absorbed by the plant in the vegetative stage is used for formation of the 'source' and the N supply at tillering and the reproductive or panicle initiation stage improves the formation and filling up of the 'sink.'

In view of the existing interactions among the timing of N application, soil conditions, duration of the rice crop, and method of rice culture, the review by Rao (1985) suggests N application in two splits for tall ***indica*** varieties, three splits for dwarf *indicas*, a heavy basal application for Ponlei varieties (tropical *japonicas*), and low N dose (one-third) at seeding followed by heavy application (two-thirds) at tillering for direct seeded rice. For hybrid rice with higher sink capacity, an additional fourth N split was reported for the flowering stage. Surekha et al. (1999) observed an increase in the yield of rice hybrids (about 8%), when N was applied in four splits coinciding the last split with flowering, compared to the usually recommended three splits. The higher yield due to N application in four splits was ascribed to combine the favorable effects of improved leaf N concentration, rubisco content, photosynthetic rate of flag leaves, and increased grain filling percentage by delayed leaf senescence.

Recently, the chlorophyll meter (SPAD-502) has been used to diagnose the N status of a standing rice crop as a means of deciding the timing for N top dressing. Being a quick, simple and non-destructive method, it is preferred for predicting the N status of rice leaves with the ultimate goal of estimating the need for the side-dressing of fertilizer N as a part of precision N management. John Kutty and Palaniappan (1996) found a high linear regression ($y = 0.466 + 0.111x$; $r = 0.79$) between SPAD values and grain yield of rice. A positive correlation

Table 2. Effect of right timing of N application on grain yield of rice (Meelu and Morris, 1987).

Timing of N[1] application			Grain yield, t/ha		
Transplanting	Tillering	Panicle initiation	Ludhiana	Rajendranagar	Pantnagar
-	100%	-	4.73	-	-
100%	-	-	-	6.59	4.71
50%	50%	-	5.24	-	-
75%	25%	-	-	6.66	-
75%	-	25%	-	-	4.76
33%	33%	33%	5.50	7.27	
50%	25%	25%	-	-	6.00

[1]A uniform N rate of 120 kg/ha was applied at all the three locations.

Table 3. Integrated effect of right source and method of N application on grain yield of rice (De Datta, 1987).

N source	Method of application	Water depth, cm, at basal fertilizer application	- - - Grain yield, t/ha - - - Dry season	Wet season
Prilled Urea	Researcher's split	0	6.4 a	4.4 a
Prilled Urea	Researcher's split	5	5.5 b	3.9 b
Prilled Urea	Farmer's split	0	5.4 b	5.4 b
Prilled Urea	Farmer's split	5	5.2 b	5.2 b
Urea super granules	Basal, placement	5	6.6 a	4.5 a

between the SPAD values and rice yields, and between SPAD values and the leaf colour chart (LCC) (DRR, 1997-98), indicated that farmers can appropriately adjust the timing of N application to rice by using the inexpensive LCC.

Right Place of N Application

Rice-growing farmers in India generally broadcast urea directly into the floodwater after transplanting. However, Craswell et al. (1981) reported that broadcasting urea into floodwater resulted in low recovery of fertilizer N (only up to 30%) by rice, both in the dry and wet seasons. They also suggested to apply two-thirds of the required N by broadcasting and incorporating before transplanting and the remainder at panicle initiation (called best split), which increased N recovery to 40%. In the studies conducted at IRRI, fertilizer N application through incorporation in the mud, without standing water, resulted in only 13% of the applied N being detected in the subsequent floodwater. This was compared to the normal farmers' practice where 59% of the N was recorded in the floodwater. Similarly, yields from plots where N was applied to the soil without standing water were significantly higher (0.9 and 0.5 t/ha in the dry and wet season, respectively) than yields recorded after application of the fertilizer into standing water (**Table 3**).

As N recovery by rice is inversely related to the ammonical-N concentration in the floodwater immediately after fertilizer application (De Datta, 1987), deep placement of urea super granules (USG) through manual and/or by mechanical means recorded very low floodwater ammonical-N concentrations and increased yields of rice grain, indicating a better N recovery (**Table 3**). Fertilizer N application through deep placement method releases ammonical-N in the reduced layer, which remains stable and contributes to increased yield on account of its high recovery in comparison to broadcast-N on the surface, which is unstable due to losses associated with denitrification and/or ammonia volatilization. Among the right methods of N fertilizer application, deep placement of USG proved to be more effective followed by application of N through mud balls and as efficient as USG. This is because it results in partial placement effect caused by sinking in the soft puddled soil due to its high weight and partially due to the slow dissolution through less exposed specific surface area.

Conclusion

Nitrogen management in rice within the framework of 4R Nutrient Stewardship proved to be helpful in the sustainable management of rice production. The use of the right source of N, applied at right rate, in the right time, and at the right place demonstrated significant yield improvement of rice while improving N use efficiency. The reduction in leaching and volatilization losses as a result of practicing 4R principles of N management could contribute to improving the environmental performance of N use. However, in the majority of rice growing regions of India, N, P, K, and Zn are considered as the major limiting nutrients. Even though, this paper discusses only the 4R guidelines of N management in rice, the concept of bringing nutrient management under the 4R perspective may not be confined to N application alone, rather a cumulative 4R approach for all the essential nutrients of rice may be followed in ensuring sustainable rice production for the country. BC-SA

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References

Cassman, K.G., A. Dobermann, and D. Walters. 2002. Ambio. 31:132-140.
Craswell, E.T., S.K. De Datta, M. Hartantyo, and W.N. Obcemea. 1981. Fert. Res. 2:247-259.
De Datta, S.K. 1987. *In* Proceedings of the Meeting of the International Network on Soil Fertility and Fertilizer Evaluation for Rice. Griffith, New South Wales, Australia, 10-16 April 1985. pp 27-42.
Dobermann, A., C. Witt, D. Dawe, G.C. Gines, R. Nagarajan, S. Satawathananont, T.T. Son, P.S. Tan, G.H. Wang, N.V. Chien, V.T.K. Thoa, C.V. Phung, P. Stalin, P. Muthukrishnan, V. Ravi, M. Babu, S. Chatuporn, M. Kongchum, Q. Sun, R. Fu, G.C. Simbahan, and M.A.A. Adviento. 2002. Field Crops Res. 74:37-66.
DRR. 2014. Annual Report, Directorate of Rice Research, Hyderabad.
DRR. 2004. Annual Report, Directorate of Rice Research, Hyderabad.
DRR. 1997-1998. Annual Report, Directorate of Rice Research, Hyderabad.
DRR. 1994. Annual Report, Directorate of Rice Research, Hyderabad.
DRR. 1988-1989. Annual Report, Directorate of Rice Research. Hyderabad
DRR. 1981-1985. Quinquennial Report, Directorate of Rice Research. Hyderabad.
FAI. 2015. Fertiliser Statistics, 2014-15, Fertiliser Association of India, New Delhi.
IIRR. 2014. Progress Report. ICAR-Indian Institute of Rice Research, Hyderabad.
IRRI, 2016. http://www.knowledgebank.irri.org/ericeproduction/IV.3_Nutrient_calculator.htm. Last verified Nov. 14, 2016.
John Kutty, I. and S.P. Palaniappan. 1996. Fert. Res. 45:21-24.
Mandal, M.K., S. Dutta, and K. Majumdar. 2016. SATSA Mukhapatra–Annual Technical Issue 20, 113-119.
Meelu, O.P. and R.A. Morris. 1987. *In* Proceedings of the Meeting of the International Network on Soil Fertility and Fertilizer Evaluation for Rice. Griffith, New South Wales, Australia, 10-16 April 1985. pp. 185-194.
Patnaik, S. and S.K. Mohanty. 1985. *In* P.L. Jaiswal (ed.), Rice Research in India, ICAR, New Delhi. pp. 257-279.
Prasad, R. 2011. Indian J. Fert. 7(12):66-76.
Prasad, R., I.C. Mahapatra, and H.C. Jain. 1980. Fertilizer News 25(9):13-18.
Rao, M.V. 1985. *In* P.L. Jaiswal (ed.), Use of Fertilisers. Rice Research in India, ICAR, New Delhi, pp. 417-434.
Raun, W. R. and G.V. Johnson. 1999. Agron. J. 91(3):357-363.
Ray, P.K., A.K. Jana, D.N. Maitra, M.N. Saha, J. Chaudhury, S. Saha, and A.R. Saha. 2000. J. Indian Soc. Soil Sci. 48:79-84.
Satyanarayana, T., K. Majumdar, V. Shahi, A. Kumar, M. Pampolino, M.L. Jat, V.K. Singh, N. Gupta, V. Singh, B.S Dwivedi, D. Kumar, R.K. Malik, V. Singh, H.S Sidhu, and A. Johnston. 2012. Indian J. Fert. 8(8):62-71.
Suganya, S., K. Appavu, and A. Vadivel. 2007. Asian J. Soil Sci. 2(2):29-34.
Surekha, K., M. Narayana Reddy, R. M. Kumar, and C.H.M. Vijayakumar. 1999. Indian J. Agric. Sci. 69(7):477-481.

Efficient Nutrient Management of Soybean in Shrink and Swell Soils of Western India

By R.N. Katkar, V.K. Kharche, R.P. Gore, B.A. Sonune, N.M. Konde, and K. Majumdar

Application of the right source of nutrients for soybean recommends the inclusion of K and S in the fertilization program.

Critical assessment of N application rates in soybean is required to achieve and maintain optimum yield, particularly in highly deficient soils.

Split application of right rate of K, and banding it at 5 cm to the side and 5 cm below the seed are suggested to maintain soil fertility and address abiotic stresses.

Growth of soybean in the ample NPK treatment. Inset photo shows Dr. Satyanarayana along with Drs. Kharche and Katkar show the improved root growth achieved with ample NPK (right) versus N omission (left).

Soybean, referred to as the "golden bean" or "miracle bean", is the third most important oilseed crop in India (next to rapeseed/mustard and groundnut). It is a major source of vegetable oil, protein, and animal feed. In India, soybean contributes to 43% of all oilseeds and 25% of the total oil production. During the last few decades, soybean has shown phenomenal growth in planted area, increasing from 0.6 million (M) ha in 1980-81 to about 11.7 M ha in 2013-14. Consequently, soybean production increased during this timeframe from 0.5 to 11.9 M t (FAI, 2015). This sharp increase is associated with soybean's replacement of less profitable crops like sorghum and minor millets due to soybean's diverse adaptability, improved oil quality, and multiple uses.

While the progress in soybean production in India is impressive, the increased production is largely driven by area expansion. The average productivity (1 t/ha) of soybean in India is only one-third of the world average (FAI, 2015). More than 70% of soybean is grown in areas under rain-fed conditions with poor fertility and limited fertilizer use. To a large extent, the low productivity of soybean in India is due to inadequate and imbalanced fertilizer application.

Soybean is grown as a monsoon season crop under rain-fed conditions in Vertisols and associated soils in central and western India. Soybean has increased both cropping intensity and profitability for farmers in the region. However, most farmers grow soybean without adequate fertilizer application (Behera et al., 2007), which has resulted in insufficient nutrient levels to sustain high yields or replenish crop nutrient removal. This article discusses the 4R guidelines for practicing efficient nutrient management to improve the productivity of soybean in the Vidarbha and Marathwada regions of Maharashtra.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulphur; Ca = calcium; Fe = iron; Zn = zinc.

Right Source

A survey of the fertility status of the major soybean-growing soils of Vidarbha and Marathwada showed deficiencies in N (80 to 97%), P (30 to 70%), S (20 to 50%), Zn (35 to 68%), and Fe (15 to 19%), which are posing threats to the sustainability of soybean production in the region (Katkar et al., 2013). A similar survey was also conducted by Dr. Panjabrao Deshmukh Krishi Vidyapeeth (Dr. PDKV), Akola, and the International Plant Nutrition Institute (IPNI) in the soybean-growing region of Akola, Maharashtra. Implemented over three cropping seasons at 45 locations, the survey reported 100% of soils to

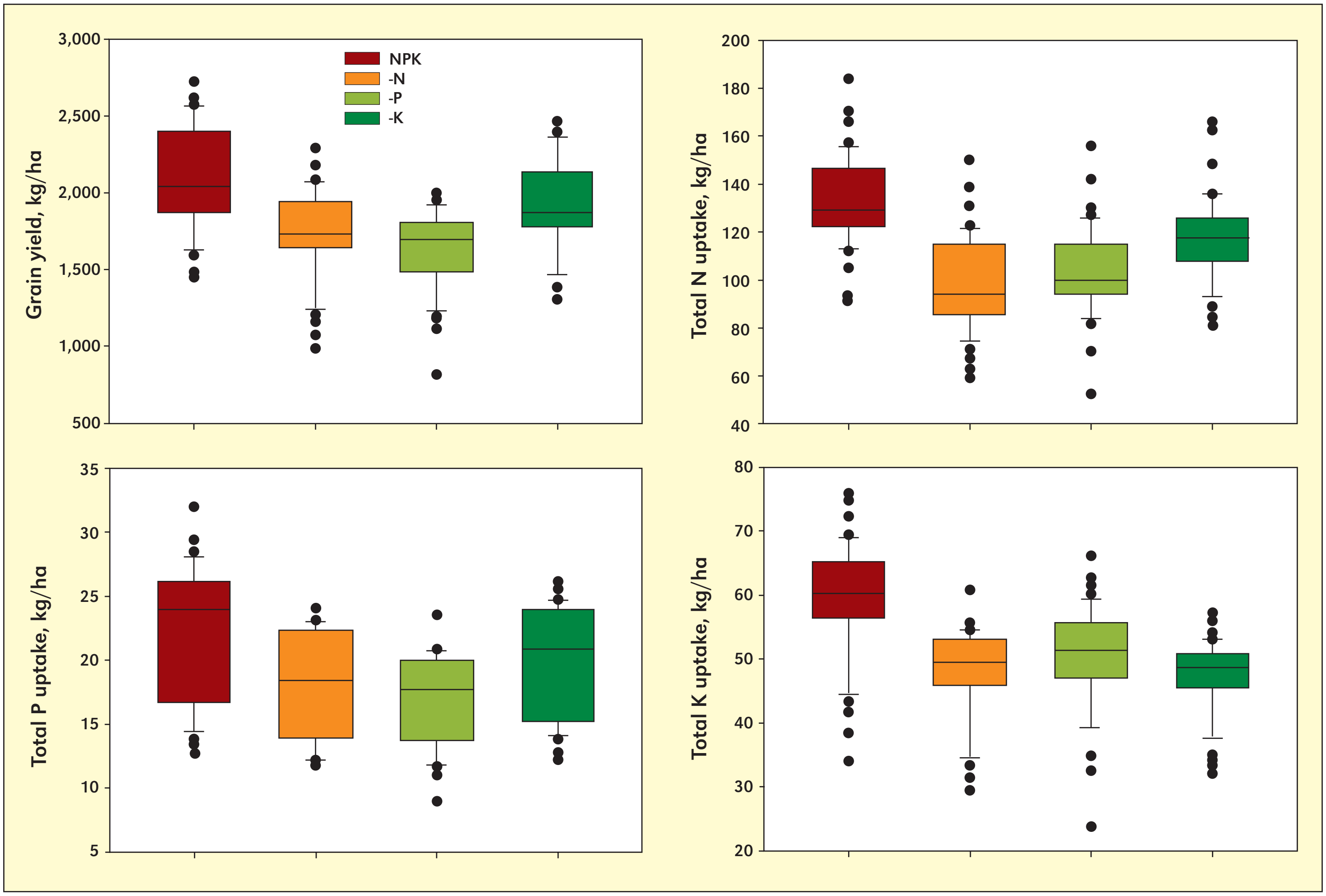

Figure 1. Yield and nutrient uptake of soybean in Maharashtra (Source: IPNI-Dr. PDKV, Akola collaborative on-farm research, 2014-15)

Table 1. Initial soil properties at the on-farm experimental sites.

	- - Observations - -	
Soil property	Mean	S.E.
pH	8.0	0.05
Organic C	0.4	0.02
Available N, kg/ha	198	6.47
Available P_2O_5, kg/ha	15	0.66
Available K_2O, kg/ha	414	5.55
Available S, kg/ha	13	0.44
Available Zn, mg/kg	0.7	0.01
Available Fe, mg/kg	10	0.79
Available Mn, mg/kg	5.2	0.56
Available Cu, mg/kg	2.6	0.31

Source: IPNI-Dr. PDKV, Akola collaborative on-farm research, 2014-15.

to be deficient in N, 13% deficient in P, and 95% deficient in S (**Table 1**).

Even though the selection of the right sources of fertilizers should be based on the native soil fertility status and the nutrient limitations therein, farmers' choice of fertilizer sources in this region depends on their own perception and availability of fertilizer sources. Farmers growing soybean in Maharashtra predominantly apply urea, diammonium phosphate (DAP), and NP complexes as N and P sources to meet the crop demand. The soil available K status is reported to be high (**Table 1**) and farmers seldom apply potash to soybean. However, the application of K to soybean not only improves yields but also influences several quality aspects such as oil content, protein content, and larger seed size. Potassium also helps in better nodulation and resistance to pests and diseases (Imas and Magen, 2008). It should be noted that soils testing high in available K may become K deficient due to heavy and continuous removal by soybean. Therefore, the inclusion of K in the fertilization program is suggested to maintain native K fertility levels in the soil. Katkar et al. (2014) reported S deficiency in the mono-cropping areas of soybean, especially where DAP is used continuously as a P source. In S-deficient soils, the application of single superphospate (SSP) as a P source provides 12% S and the application of bentonite S or gypsum may be considered as an option when DAP is used for the P source. Chaurasia et al. (2009) reported that SSP recorded higher soybean yields, followed by gypsum. The protein and oil content of the seed and its yield were significantly influenced by the addition of different sources of S (**Table 3**). SSP and gypsum are reported to be better sources of S for soybean over others due to the presence of both Ca and S. For Zn and Fe deficiencies, Katkar et al. (2013) found that zinc sulphate and ferrous sulphate may be used in areas where the limitation of these nutrients are high. Application of manure or compost, along with fertilizers, is suggested to improve soil physical properties and to enhance nutrient use efficiency.

Right Rate

Nutrient requirements of soybean vary according to soil and climatic conditions, cultivar, yield level, cropping system, and management practices. A soybean crop yielding 3

Table 2. Yield, nutrient uptake, and post-harvest soil nutritional status of soybean in Maharashtra

Treatments	Yield, t/ha	Nutrient uptake, kg/ha				Post-harvest soil status, kg/ha			
		N	P_2O_5	K_2O	S	N	P_2O_5	K_2O	S
Ample NPK	2.1	126	48	58	15	228	21	464	13
N omission	1.7	97	43	58	13	192	20	441	12
P omission	1.6	104	40	61	11	215	18	448	12
K omission	1.9	118	47	57	15	211	21	394	13
CD (5%)	0.4	3	5	2	0.4	7	0.8	14	0.4

Source: IPNI-Dr. PDKV, Akola collaborative on-farm research, 2014-15.

t/ha extracted 240 kg N/ha, 45 kg P_2O_5/ha, and 100 kg K_2O/ha (Imas and Magen, 2008). A collaborative study by Dr. PDKV, Akola and IPNI, for two consecutive years (2014-15), reported that the application of 30 kg N, 100 kg P_2O_5, and 80 kg K_2O (ample NPK) resulted in a grain yield of 2.1 t/ha, where uptake was 126 kg N/ha, 48 kg P_2O_5/ha, and 58 kg K_2O/ha, respectively (**Figure 1**). The omission of N, P, and K from the ample NPK treatment reduced soybean yield by 18, 22, and 9%, indicating that soybean yield was primarily influenced by P application followed by N (**Table 2**). **Figure 1** also shows that soybean yield was significantly lower due to N omission, as compared to the ample NPK treatment. An earlier study by Patel and Chandravanshi (1996) showed that there is increasing requirement of N, beyond the starter dose of 25 to 30 kg N/ha due to poor and inefficient nodulation. In a recent study in the U.S.A., soybean yield was increased with the addition of fertilizer N by 8 to 15% across a wide range of management practices, thus proving that N supplied by N_2 fixation to soybean may not be sufficient enough to maximize yield (Ray et al., 2006).

Phosphorus is taken up throughout the growing season by soybean. The period of greatest demand begins just before the pod formation stage and continues until about 10 days before the seeds are fully developed. The majority of the P used in seed development is taken up early, stored temporarily in leaves, stems, and petioles and then is translocated into the seed (Imas and Magen, 2008). Phosphorus has major role in ATP-synthesis, and is thereby involved in several metabolic processes including nodule development and N_2-fixation in soybean. Singh et al. (1995) found yield improvement of over 1.2 t/ha with 60 kg P_2O_5/ha, as compared to no application of P. The largest yield loss was seen with the omission of P (**Figure 1**). Generally, 60 to 80 kg of P_2O_5 is recommended for Indian soils.

The yield reduction of soybean, due to omission of K, was 9%. Farmers seldom apply potash to soybean and the study indicated K_2O removal to be 57 kg/ha when K is not applied (**Table 2**). This resulted in the decline in initial soil K status from 414 kg/ha (**Table 1**) to 394 kg/ha (**Table 2**), indicating mining of soil K. Several on-farm studies in Central India showed that the application of 100 kg K_2O/ha can achieve and sustain 2.5 t/ha of grain yield in soybean (Bansal et al., 2001). Field demonstrations also found a strong response to K application where yield was increased on average by 29% (500 kg/ha) and 35% (624 kg/ha) with the application of 50 and 100 kg K_2O/ha (Imas and Magen, 2008). The field demonstrations indicated that adequate K fertilization was highly profitable, achieving value-cost ratios (VCRs) of 11 to 18. The benefits of K nutrition in providing resistance to both insect infestations and incidence of plant diseases in soybean were shown at field experiments in Indore, Madhya Pradesh (Imas and Magen, 2008). Applying K markedly decreases insect infestation in the case of blue beetle and the defoliators expressed by the number of insects per meter row length (mrl). This was also the case for the incidence of stem fly and the girdle beetle. Similarly, increased K application depressed the percentage mortality by collar rot (caused by the fungus *Sclerotium rolfsii*) and leaf spot and petiole rot (resulting from the pathogen *Myrothecium roridum*) in soybean. There is a clear need to educate farmers about the necessity of adequate K application, along with N and P_2O_5 for ensuring sustainable yields of soybean.

In Maharashtra, the recent official fertilizer recommendations have a revised K_2O application rate from 0 to 30 kg/ha and the final N, P_2O_5, and K_2O recommendations have now become 30, 75, and 30 kg/ha, respectively.

A study on response of soybean to variable rates of S application showed that yield of soybean, increased significantly with an increase in S up to 30 kg/ha (2,270 kg/ha) and remained at par (2,294 kg/ha) at 40 kg/ha (**Table 3**). Even though, the nutrient uptake (N, P, K, and S) increased with increasing rates of S application up to 40 kg/ha, significant response of soybean to yield and quality suggested for application of S only up to 30 kg/ha (**Table 3**). Sulphur is an essential element for

Table 3. Yield, nutrient uptake and quality of soybean as influenced by right source and right rate of application of S.

Treatment	Yield, kg/ha	Uptake, kg/ha				Protein quality		Oil quality	
		N	P	K	S	Content, %	Yield, kg/ha	Content, %	Yield, kg/ha
Sources									
Gypsum	2,075	142	32	95	13	40.2	850	19.3	407
Pyrite	1,954	138	31	92	13	39.2	779	18.8	374
SSP	2,129	147	33	98	14	41.5	902	19.9	432
CD (5%)	87	4	1	3	0.4	1.1	61	0.4	29
Sulphur levels, kg/ha									
0	1,738	118	20	77	5.8	37.7	664	18.4	325
10	1,891	130	26	86	9.6	39.3	756	18.9	363
20	2,071	143	32	95	14	40.5	853	19.4	408
30	2,270	154	38	104	18	41.7	962	19.8	456
40	2,294	167	44	113	19	42.2	984	20.2	470
CD (5%)	138	12	6	9	3.3	1.1	79	0.5	36

Source: Chaurasia et al., 2009.

Joint collaborative project between Dr. PDKV, Akola and IPNI in Maharashtra is aimed at developing 4R guidelines in soybean.

oilseed crops due to its direct involvement in the synthesis of oil and is expected to increase the oil content and oil yield of soybean. Increased N, P, K, and S uptake by soybean with increasing rates of S addition is expected due to the low supply of native S from the soil (16 kg/ha) (**Table 3**). The results suggest 30 kg S/ha as the optimum rate of S application to soybean (Chaurasia et al., 2009).

Right Time

Nitrogen application in soybean at the time of planting helps in maintaining the initial vigour of the plant. The plant begins to fix substantial amounts of N approximately four weeks after germination, thus N application has to be restricted prior to the commencement of N_2 fixation. Soybean derives between 25 and 75% of its N by fixation, which is inhibited by application of high levels of N in the soil. Phosphorus plays an important role in the growth and development of soybean. An adequate supply of P in the early growth stages helps in initiating reproductive growth, hastens maturity, and improves the quality of the seed. In soybean, P is taken up throughout the growing season. The period of greatest demand starts just before the pods begin to form and continues until about 10 days before the seeds are fully developed. Much of the P used in seed development is taken up early, stored temporarily in leaves, stems, and petioles, which is then translocated into the seed (IFA, 1992).

Potassium accumulation in soybean follows a pattern similar to that of dry matter, with slow accumulation at early vegetative growth stages, and an almost constant, more rapid K accumulation at later vegetative and early to mid-reproductive stages. In highly leachable soils or soils that fix large amounts of K, potash fertilizer may be split into two or more applications, but in non-sandy soils, a single application at the time of planting meets the crop requirement (IFA, 1992). However, to avoid luxury consumption of K, split application is always better than a single basal application.

Collaborative on-farm research studies between Dr. PDKV, Akola and IPNI suggest basal application of the entire recommended dose of N and P to meet the needs of soybean during the initial grand growth stage. Application of 50% of K at the time of planting and remaining at 30 days after seeding, helped in meeting the K requirement at both grand growth and flowering, and pod development stages of soybean.

Right Place

Right placement of fertilizers ensures its ready to access by roots leading to reduced losses of fertilizer. Farmers growing soybean in India apply fertilizers through broadcasting at planting or in the standing crop. Drilling the fertilizer mixture just below the seed is recommended while planting soybean. Soybeans generally prefer broadcast placement of P. They respond best to an overall high P fertility in the root zone, which is usually best accomplished by incorporating broadcasted P. Under drier conditions and low P soils, some Canadian researchers have found banding P below the seed will produce better yields than broadcasting (IPNI, 1999). Mallarino et al. (1998) found that early growth responses of soybean to P were larger for the planter-band placement (starter), but decreased for the deep-band placement and further decreased with broadcast placement. The effects of banded P fertilizer on early growth did not translate into higher soybean yield. The researchers also found that deep-banded K fertilization increased grain yields of soybeans managed with no-tillage, as compared to broadcasted K. Soybean is very susceptible to fertilizer salt injury and if K is applied in a band at planting time, special care should be taken to locate the band at 5 cm to the side and 5 cm below the seed to avoid fertilizer injury (Imas and Magen, 2008). There are limited studies in India on the right placement of fertilizers in soybean and there is a need to focus attention in this field of study.

Summary

Nutrient management based on the 4R Nutrient Stewardship principles provide options to improve productivity of soybean in the Vertisols of central and western India. Educating farmers on the 4R principles of nutrient management and enabling them knowledge of balanced and adequate fertilization through 4R, is the key to address the current issue of stagnant soybean yields. BC-SA

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References

Bansal, S.K., A.K. Dixit, P. Imas, and H. Magen. 2001. Fertiliser News 46:45-52.

Behera, U.K., A.R. Sharma, and H.N. Pandey. 2007. Plant and Soil 297:185-199.

Chaurasia, A.K., G.P. Richharia, and S. Chaurasia 2009. Indian J. Agri. Sci. 79(5):356-358.

FAI, 2015. The Fertiliser Association of India, New Delhi.

IFA, 1992. International Fertiliser Industry Association, Paris, pp.632.

Imas, P. and H. Magen. 2008. *In* Proceedings of Regional Seminar on Recent Advances in Potassium Nutrition Management for Soybean based Cropping System. pp.1-20.

IPNI. 1999. Better Crops, 83(1):34-39.

Katkar, R.N., V.K. Kharche, A.B. Age, A.K. Shukla, G.S. Lahria, and D.B. Tamgadge. 2014. Research highlights on micro and secondary nutrients, Research Bulletin, Dr. PDKV/Pub/371/2014.

Katkar, R.N., V.K. Kharche, P. Dey, S.R. Lakhe, S.D. Jadhao, R.D. Chaudhari, P.R. Damre, U.D. Ikhe, and B.A. Sonune. 2013. Department of Soil Science and Agricultural Chemistry, Dr. PDKV, Akola.

Mallarino, A., D.W. Barker, R. Borges, and J.C. North. 1998. Iowa State Univ. Extension. Ames, pp.231-237.

Patel, S.R. and B.R. Chandravanshi. 1996. Indian J. Agron. 41:601-603.

Ray, J.D., L.G. Heatherly, and F.B. Fritschi. 2006. Crop Sci. 46:52-60.

4R Nutrient Stewardship for Sugarcane

By B. Patil, R. Mahesh, B.T. Nadagouda, M.P. Potdar, G. Balol, S.K. Dutta, and T. Satyanarayana

Practicing 4R principles of Nutrient Stewardship can help achieve higher productivity and sustainability of sugarcane cultivation.
Right timing of N at ratoon initiation is essential to ensure adequate soil available N, while foliar fertilization and fertigation proved to be the emerging right methods of fertilizer application for increased productivity of sugarcane.

Sugarcane is one of the major commercial crops of India. It is cultivated on 5.3 million (M) ha, with an annual production of 352 M t of cane and an average productivity of 70.5 t/ha (FAI, 2015). Currently, India consumes about 18.5 M t of sugar, but projections suggest that demand could reach 28 M t by 2020. Hence, sugarcane production systems are facing significant motivation to meet a growing demand for higher production. The major concern of cane growers, and the sugar industry, is the ability to achieve higher sugarcane productivity and high sugar recovery that supports maximum economic returns. Integrated nutrient management through 4R Nutrient Stewardship holds great promise in meeting the nutrient demands of intensive sugarcane systems—maintaining productivity at higher levels while sustaining soil health.

Farmer's choice of right sources of fertilizer application in sugarcane.

Right Source

For sugarcane, N, P, K, micro, and secondary nutrients are all commonly required. Gopalasundaram et al. (2012) has explained the roles of these nutrients in cane production. Nitrogen influences the yield and quality of cane, and the response to applied N is universal. It also increases the source capacity of the leaf due to its role in increasing the leaf area, and the rate of photosynthesis. Phosphorus is essential to hasten the formation of shoot roots and to increase tillering. Improved yield following P application is attributed to an increase in tiller production, weight per cane, and final stalk population. At the optimum level of P application, sugar content and purity of juice are also enhanced. Potassium plays an important role in plant growth and metabolism. It helps in regulating the uptake of water and leaf stomatal opening, maintenance of cell turgidity, and formation of proline during moisture stress. Potassium is also essential for the synthesis and translocation of proteins and carbohydrates, and accumulation of sucrose. Agronomic value of K rests with increased cane volume, girth and weight per cane, drought and disease resistance, and reduced lodging. Potassium application often increases the percentage of sugar in the cane and juice recovery, particularly when harvest is delayed.

The right source of fertilizer for sugarcane should include all these nutrients, in a balanced quantity essential for cane production. The right source could be a proportionate application of fertilizers, farmyard manure (FYM), and compost to supply these nutrients. Different forms of manure have traditionally been important inputs for maintaining soil fertility and crop yield stability. Long-term studies have indicated the necessity for basal application of FYM or compost to maintain optimum soil fertility status. Integrated use of fertilizers with manures also helps to prevent the decline in cane yield. Several experiments have been conducted in the majority of the sugarcane-growing states to study the response to the application of 25 t FYM/ha. The mean response ranged from 3.7 t/ha in Bihar and Gujarat to 11.7 t/ha in Andhra Pradesh. The overall average response was 8 t/ha of cane. During the three years of experimentation, diammonium phosphate (DAP) yielding 97.9 t/ha proved to be superior over single superphosphate (SSP) yielding 95.8 t/ha. This could be due to a higher percent of germination and initial vigor of the cane plants that led to an even higher number of millable canes at harvest with the application of DAP as a source of P (Devi et al., 2012).

Right Rate

Sugarcane is a long duration crop with C_4 metabolism that produces a very heavy biomass and demands large amounts of moisture, nutrients, and sunlight for its optimum productivity (Gopalasundaram et al., 2012). It has been estimated that a 100 t cane/ha crop removes an average of 208 kg N, 53 kg P, 280 kg K, 30 kg S, 3.4 kg Fe, 1.2 kg Mn, and 0.2 kg Cu (Singh and Yadav, 1996). Nutrient requirement varies with varietal differences in nutrient use efficiency (Gopalasundaram et al., 2012).

Besides common farmer fertilization practice, other less common practices can be based on a state recommendation, a soil test-based recommendation, a recommendation based on tissue analysis, and a determination via site-specific nutrient management through omission plot techniques. The state fertilizer recommendations for sugarcane in the major sugarcane-growing states of India vary from across states depending on the soil type, crop duration, yield level, and irrigated or rain-fed conditions. The recommended rates range from 70 to 400 kg N, 0 to 80 kg P_2O_5, and 0 to 141 kg K_2O/ha (Singh and Yadav, 1996). The fertilizer rates recommended are generally higher

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Mg = magnesium; Cu = copper; Mn = manganese; C = carbon.

Farmer weighing exact amount for arriving at the right rate of application.

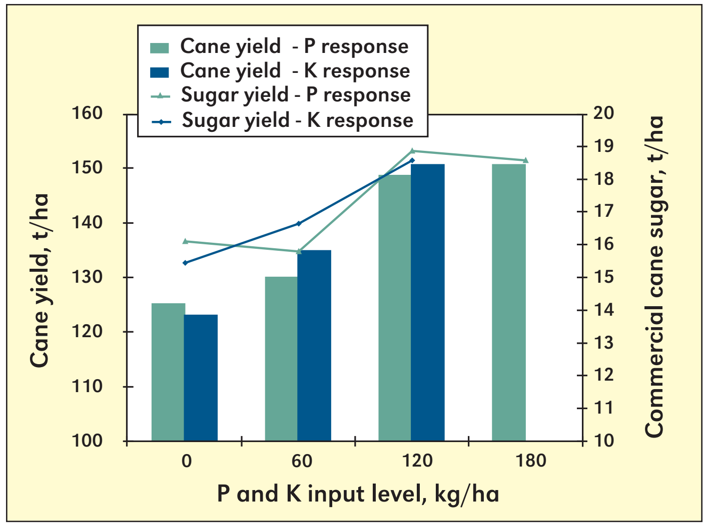

Figure 1. Effect of P and K levels on cane and sugar yield (Source: Phonde et al., 2005).

in tropical states compared to subtropical states. Saini et al. (2006) also reported that application of nutrients up to 400 kg N, 170 kg P_2O_5, and 180 to 190 kg K_2O/ha is recommended for sugarcane depending upon its duration and fertility status of the soil. In several experiments, applied P did not influence yield or quality of sugarcane ratoon to an appreciable extent. This was due to the fact that in most of the cases the soils were high in available P status (Gopalasundaram et al., 2012). However, the need for phosphate application ranging from 30 to 100 kg P_2O_5/ha has been reported to maintain productivity.

In general, and as observed at Mandya (Karnataka), pockets of Haryana, and Jalandhar and Kheri in Punjab, a ratoon crop is relatively more responsive to P application than a planted crop, (Gopalasundaram et al., 2012). Based on a critical review of the response of sugarcane to K fertilizers, Verma (2004) recommended application of 50 to 200 kg K_2O/ha in tropical states where significant response is observed, but responses were very limited in subtropical states. However, application of 66 kg K_2O/ha with irrigation water in standing, subtropical planted cane improved bud sprouting, dry matter accumulation, and nutrient uptake in following ratoon crop (Shukla et al., 2009).

Phonde et al. (2005) reported that site-specific nutrient management produced significantly higher yields compared to a generalized state recommendation, a state lab soil test-based recommendation, and farmer practice. Cane yield was significantly influenced by both P and K. A yield of 150.6 t cane/ha was recorded with 180 kg P_2O_5/ha, but this was statistically equal to the 148.6 t/ha produced with 120 kg P_2O_5/ha (**Figure 1**). Yields produced with 0 and 60 kg P_2O_5/ha were 125 and 130 t/ha, respectively. The cane yield response to 0, 60, and 120 kg K_2O/ha appeared to be linear, suggesting that even greater productivity may be achieved under K application rates beyond 120 kg K_2O/ha. Singh et al. (2008) studied balanced fertilization for sugarcane and reported that application of 200 kg N, 100 kg P_2O_5, and 150 kg K_2O along with 60 kg S/ha and 30 kg Mg/ha together have produced cane yields of 112 t/ha in the Meerut district of western Uttar Pradesh.

Right Time

The timing of fertilizer application assumes great significance in maximizing the benefits. The nutrient application timing should match the nutrient demand throughout the season by high-yielding varieties. In Belguam district of Karnataka, a study was conducted to understand the effect of fertigation on yield and quality of sugarcane in a medium-black soil. The study showed that application of N and K at a recommended rate in six day intervals through drip irrigation, starting from 30 days after planting (DAP) to 240 DAP produced a 25% higher yield and saved 46% of the water applied. This was compared to the recommended fertilizer rate applied with surface irrigation. In this study, N and K were applied at recommended rates of 250 and 185 kg/ha, respectively (Rajanna and Patil, 2003). Another study conducted at Coimbatore, Tamil Nadu, found that an application of urea under a fertigation schedule starting from day 15 to day 180 in a fortnightly interval, reduced volatilization and leaching losses and increased N use efficiency (Hemalatha and Chellamuthu, 2013).

Ratoon crops follow a planted crop, or the preceding ratoons, on the same soil. Due to the impoverished physical soil conditions and relatively poor root system development, absorption of nutrients by the ratoon cane may be negatively affected. Therefore, it is necessary that ratoons are given adequate quantities of manures and fertilizers to result in high yields. Several experiments have proved the need for early fertilizer application to ratoon sugarcane (Gopalasundaram et al., 2012). For ratoon crop, N fertilizers may be applied in two or three splits. Even in cases of split application, a third to half of the N dose should be applied immediately at the time of ratoon initiation to ensure the adequate amount of available N in the soil to overcome the temporary immobilization of N due to microbial activity on the decomposing stubbles. A full dose of P should be applied at the same time as the first dose of N application at ratoon initiation. Compared to a planted crop, a ratoon crop requires more N to produce 1 t of cane.

Nutrient use efficiency (NUE) is also reported to be the highest in planted cane as it decreases with each successive ratoon. Reduced NUE in ratoons is a result of an imbalance in the shoot-to-root ratio at the juvenile stage, delayed shoot-to-root development, and relatively inefficient stubble roots. Response to a higher level of N application in the ratoon crop has been reported from all the sugarcane-growing states. It has been found that ratoon crops generally need 25 to 50% more

N than the planted cane. Application of 25% more N at five to seven days after the ratoon initiation operation produced the highest cane and sugar yields in Tamil Nadu (Mahendran et al., 1995). The yield response to applied N, at the recommended dose for ratoon sugarcane, was reported to be 254 kg of cane/kg N at Anakapalle, 215 kg at Kanpur, 160 kg at Shahjahanpur, 160 kg at Muzaffarnagar, 136 kg at Mandya, 120 kg at Lucknow, and 119 kg at Jalandhar (Verma, 2002).

Right Place

The adoption of the proper method of fertilizer application is essential to minimize the loss of nutrients from the soil and to increase fertilizer use efficiency. Besides increasing cane yield, proper placement also reduces volatilization loss of nitrogenous fertilizers and lowers fixation of phosphatic fertilizers. Placement can occur at 8 to 10 cm deep furrows on either side of the cane rows using implements, placing the fertilizers in the furrows, and then covering them.

Nitrogen flux pathways in the soil are beneficially influenced by management techniques such as mounding of the rows, subsurface banding in narrow fertilizer bands, reduced fertilizer rates, and trash retention along with the timing of fertilizer application. These techniques help to coincide with the optimum uptake by the plant (Reghenzani et al., 1996).

Foliar feeding of N for sugarcane is a well-recognized technique. Foliar application is best used when there are adverse soil moisture conditions, such as waterlogging and limited water supply situations. The use efficiency of foliar applied N could be as high as 90 to 95% (Singh and Yadav, 1996). Foliar application of urea with potash during the formative phase (2.5% each of urea and KCl at 60, 90, and 120 DAP) was found to be beneficial when moisture was limiting. This method can increase cane yield by 19% over control. Soil application of 75% K and foliar application of the remaining 25% at 90 DAP was found beneficial in Kerala where soils are K deficient (Mathew et al., 2004).

Fertigation is another method of nutrient application, considered very effective for sugarcane. The efficiency of nutrient use can be improved when it is applied by fertigation to most of the crops. Fertigation enables adequate supplies of water and nutrients with precise timing and uniform distribution to meet the crop nutrient demand. Fertigation can be a more efficient means of applying crop nutrients, particularly N and K as compared to surface application (Bharadwaj et al., 2007; Hemalatha and Chellamuthu, 2013). Studies have reported that drip irrigation can increase the sugarcane yield from 111 to 150 t/ha in Tamil Nadu, while keeping the fertilizer application rates the same (Bharadwaj et al., 2007). Bangar and Chaudhuri (2004) also reported that application of fertilizers through drip irrigation resulted in significant increase in cane yield (28%) and water use efficiency (114%) over surface irrigation method. Pawar et al. (2013) reported that 100% drip fertigation showed 42% increase in yield. Yield increased up to 25% (about 166 t/ha) by applying only N through drip against the conventional method (133 t/ha). Fertigation also resulted in saving 40% of the fertilizer (Hemalatha and Chellamuthu, 2013).

Summary

This article provides general guidelines for 4R Nutrient Stewardship of sugarcane under varied agro-climatic situations. The review highlights that a general nutrient management recommendation may not be ideal for optimum return and the 4R concept needs to be adapted for different growing conditions to achieve higher productivity and increased profits from sugarcane growing. BC-SA

Fertilizer application in the furrow at planting is the right place for sugarcane compared to broadcasting.

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References

Bangar, A.R. and B.C. Chaudhuri. 2004. J. Indian Soc. Soil Sci. 52(2):164-171.
Bharadwaj, A., R. Tongia, and V.S. Arunachalan. 2007. Current Science. 92(8):1071-1077.
Devi, T.C., M. Bharathalakshmi, M.B.G.S. Kumari, and N.V. Naidu. 2012. Sugar Tech.14(2):195-198.
FAI, 2015. Fertiliser Statistics. The Fertiliser Association of India, New Delhi, India.
Gopalasundaram, P., A. Bhaskaran, and P. Rakkiyappan. 2012. Sugar Tech. 14(1):3-20.
Hemalatha, S. and S. Chellamuthu. 2013. Trends Biosciences 6(5):597-602.
Mahendran, S., J. Karamathullah, S. Porpavai, and A. Ayyamperumal. 1995. Bharatiya Sugar 22(1):123-127.
Mathew, T.M., B.G. Kurian, J. Sosamma, M. Kuriakose, K. Sreekumar, and G. Jayakumar. 2004. Sugar Tech. 6(1&2):81-83.
Pawar, D.D., S.K. Dingre, and U.S. Surve. 2013. Indian J. Agron. 58(3):396-401.
Phonde, D.B., Y.S. Nerkar, N.A. Zende, R.V. Chavan, and K.N. Tiwari. 2005. Better Crops, 3:21-23.
Rajanna, M.P. and V.C. Patil. 2003. Indian Sugar 52:1007-1011.
Reghenzani, J.R., J.D. Armour, B.G. Prove, P.W. Moody, and T.J. McShane. 1996. *In* Proceedings of sugar 2000 symposium: Sugarcane research towards efficient and sustainable production, pp.275-277.
Saini, S.K., D. Singh, and A. Bhatnagar. 2006. *In* Souvenir, 26th all India workshop of AICRP on sugarcane, Pantnagar, Uttaranchal: GBPUAT, pp.60-63.
Singh, G.B., and D.V. Yadav. 1996. *In* Proceedings of symposium on plant nutrient supply needs, efficiency and policy issues. New Delhi, India: pp.2000-2025.
Singh, V.K., A.K. Shukla, M.S. Gill, S.K. Sharma, and K.N. Tiwari. 2008. Better Crops-India:12-14.
Shukla, S.K., R.L. Yadav, P.N. Singh, and I. Singh. 2009. Eur. J. Agron. 30:27-33.
Verma, R.S. 2004. International Book Distributing Co: Lucknow, India.
Verma, R.S. 2002. International Book Distributing Co: Lucknow, India.

4R Nutrient Stewardship for Sustainable Pulse Production in India

By Ummed Singh, Sudarshan Kumar Dutta, and T. Satyanarayana

4R-based nutrient management is needed to increase productivity of pulse crops in India to meet growing demands.

Dr. Ummed Singh inspecting the standing crop during a field visit.

India is the world's largest producer of pulses. Pulses provide the cheapest source of vegetable protein for human and animal nutrition. Even though India produces 19.3 million (M) t of pulses with an average productivity of 764 kg/ha (FAI, 2015), the country still imports 2 to 3 M t of pulses every year to meet the growing demand. The projected pulse requirement for the year 2030 is 32 M t, which will require an annual production growth rate of 4.2% (Nadarajan et al., 2013). The diversified agro-climatic condition in India supports the growing of a variety of pulses; however, a large gap exists between attainable and actual yield. Bridging this gap would substantially increase the country's pulse production. Pulses are predominantly grown by resource poor farmers in the marginal lands. Low adoption of improved varieties coupled with inadequate agronomic and nutrient management by farmers, have resulted in static production of pulses in the country.

The United Nations declared 2016 as the International Year of Pulses, aimed at positioning pulses as a primary source of protein and other essential nutrients, especially for countries with a large vegetarian population. The FAO intends to make people more aware of the nutritional value of pulses and their contribution to sustainable food production to ensure food security and improved human nutrition. The general consensus is to promote better production of pulses worldwide through improved crop rotation and better crop management. In support of the International Year of Pulses, the authors have made an attempt to assemble the 4R nutrient management guidelines for increasing productivity and profitability of pulses in India.

Abbreviation and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulphur; Ca = calcium; Se = selenium.

4R Nutrient Stewardship for Macronutrients

Appropriate nutrient management is one of the important factors for increasing the production of pulses. Studies reported that in N deficient soils, application of N to pulse crops considerably increases productivity. Higher doses of N application is generally avoided as it decreases nodulation; however, lower doses of N at early growth stages often benefits the symbiosis. Biological N_2 fixation enables pulse crops to meet 80 to 90% of their N requirements, hence a small dose of 15 to 25 kg N/ha is sufficient to meet the requirement of most pulse crops (Thiyagarajan et al., 2003). In emerging cropping systems like rice-chickpea, a higher dose of N (30 to 40 kg/ha) has shown beneficial effect. Kaushik et al. (1993) studied the impact of different N sources, including urea, ammonium sulphate, and

Table 1. Yield response of phosphate fertilizer application in different pulses. (Source: Majumdar and Govil, 2015).

Crop	P_2O_5 applied, kg/ha	Yield increase due to P_2O_5, kg/ha (±SE)	Response per kg of P_2O_5 applied, kg/kg
Black gram (7)[1]	90	106 (±20)	1.7
Gram (5)	147	445 (±91)	3.3
Greengram (6)	58	221 (±19)	4.4
Pigeon pea (9)	111	460 (±41)	4.6
Urdbean (5)	72	129 (±33)	1.9
Cowpea (1)	20	139	7.0
Chickpea (26)	68	640 (±60)	11.5
Mung bean (3)	59	127 (±3)	3.4

[1]Number of studies

potassium nitrate at variable rates of application, and reported that application of N to pigeon pea at 20 kg/ha was optimum and all three sources were at par in terms of grain yield and N concentration enhancement. In chickpea, positive responses to a starter doses of N at 15 to 20 kg/ha have been observed particularly in soils of poor texture, but a similar response may or may not be found in soils with better texture (Thiyagarajan et al., 2003). In pulses, low levels of available soil N causes "N hunger" and may reduce yield, nodulation, and N_2 fixation. Therefore, applying starter doses of N fertilizer at the time of seeding could alleviate N deficiency during the early plant growth stage.

Phosphorus nutrition in pulses assumes primary importance due to its role in root proliferation and atmospheric N_2 assimilation. Phosphorus is involved in metabolic and enzymatic reactions and is a constituent of ATP and ADP. Chesti and Ali (2012) evaluated the right source and rate of P application to green gram and suggested a combined application of farm yard manure (FYM) at 10 t/ha and P_2O_5 at 30 kg/ha through diammonium phosphate (DAP), which significantly improved the rhizosphere microflora, nutrient availability, and yield of green gram. Differences among sources of phosphatic fertilizers for legume production were reported, where application of single superphosphate (SSP) recorded higher nodulation, yield, N and P uptake, and available soil P than DAP. Moreover, SSP was found to be a superior source of P in terms of higher agronomic and recovery efficiency (Singh et al., 2012).

While determining the right rate, Thiyagarajan et al. (2003) found that P deficiency is widespread in Indian soils. Most of the grain legumes have shown good response to application of 20 to 80 kg P_2O_5/ha depending upon nutrient status of soil, cropping system, and moisture availability. The addition of the optimum amount of P had a positive influence on apparent P fertilizer utilization (APU) and native P use. Across India, pulses responded to P application—between 1.7 to 11.5 kg grain/kg P_2O_5 application (Majumdar and Govil, 2015; **Table 1**). Responses to applied P of 17 to 26 kg P_2O_5/ha have been observed in most of the pulse crops on soils of low to medium P availability. The response to applied P also varies considerably in pigeon pea (17 to 43 kg) depending upon the P status of soil. Chickpea was found to be more efficient than other pulses in taking up P from soil, as it secretes more acid, which helps in solubilizing Ca-P secondary minerals in the soil (Thiyagarajan et al., 2003). Majumdar and Govil (2015), while reviewing P response of pulses over a 10-year period across India, suggested that response quartiles of large data sets could be effectively used to determine the right rate of P application to pulses.

Since P is less mobile in soil, its uptake and the utilization can be increased by its placement at the proper soil depth. Singh and Singh (1992) studied the rate of application and placement of P and indicated that P application significantly improved the yield attributes and grain yield up to 80 kg P_2O_5/ha in pigeon pea, and up to 40 kg P_2O_5/ha in green gram and cowpea. The study above also reported that the placement of P at 15 cm depth significantly increased the yield in pigeon pea; whereas, placement at 7.5 cm was better in green gram and cowpea. Shallow placement of P in green gram was beneficial due to its shorter root length, whereas, pigeon pea benefited by deep placement of P because of deeper root geometry and long crop duration. In another study, Singh et al. (2015) reported that the application of full basal rate of P enhanced nodulation due to increased availability of P at the initial stage of root development and also helped in nodule initiation, multiplication, and proliferation. Split application of P (50% P as basal + 50% P as top dressing at branch initiation) reduced P fixation and improved P use efficiency. However, delayed application of P had little effect on plant growth and development.

Potassium is the key nutrient element in the biosynthesis of protein in pulse crops. In general, pulses require 16 kg K_2O (e.g., for pigeon pea grain) to as high as 73 kg K_2O (e.g., for green gram grain) from the soil to produce 1 t of grain (Majumdar and Govil, 2013). However, K fertilizer use is limited in pulse crops and a recent estimate suggests that only 41% of the cropped area under pulses receive about 6.3 kg K_2O/ha, indicating that lack of adequate K use in pulses is one of the major reasons for their low yields and poor crop quality in India (Majumdar and Govil, 2013). Majumdar and Govil (2013) also conducted a review on K response in pulses and found that responses varied between 1 to 22 kg grain per kg of applied K (**Table 2**).

Table 2. Yield response of potassium fertilizer application in different pulses. (Source: Majumdar and Govil, 2013).

Pulses	K_2O applied, kg/ha	Mean yield increase due to fertilizer K application, kg/ha (±SE)	Response per kg of K applied, kg/kg
Chickpea	50	385 (±128)	7.8
Urdbean	36	46 (±17)	1.5
Lentil	32	89 (±8)	3.2
Pigeon pea	38	115 (±32)	3.6
Pea	36	105 (±21)	3.4
Mung bean	30	30 (±0.5)	1.0
Green gram	25	265 (±44)	11.5
Black gram	85	302 (±10)	4.0
Cluster bean	40	160	4.0
Cowpea	50	1,100	22.0
Guar bean	30	170	5.7

Table 3. Response of grain legumes to different rates of sulphur applications (Ali and Singh, 1995).

Crop	Fertilizer, kg/ha	Mode of application	% Yield increase over control
Lentil	20 kg S	Basal	50
Pigeonpea	20 kg S	Basal	16
Urdbean	20 kg S	Basal	25
Mungbean	40 kg S	Basal	20

Stewardship of Secondary and Micronutrients

Sulphur is now recognized as the fourth most important plant nutrient in India after N, P, and K. Oilseeds require high amounts of S, followed by pulses, forages, tuber crops, and cereals. Optimized S application is required to enhance uptake and use efficiency of other plant nutrients through synergism, and suppress the uptake of undesirable and toxic elements (e.g., Se through antagonism; Singh et al., 2015). In different studies, the right rate and right source of S fertilization increased mean grain yield by 18% in chickpea, 28% in lentil, 20% in mung bean, 20% in urd bean, 22% in pigeon pea, 32% in field pea, and 33% in cowpea over S omitted treatments (Singh et al., 2015). The rate of applied S to the grain legumes depended on type of crop, genotype, soil S status, soil status of N and P, crop yield potential, cropping intensity, management and environmental factors, etc. (Singh et al., 2015). An analysis of experiments revealed that the optimum rate for sulphate-S sources varies from 10 to 100 kg/ha across the crops under variable environmental conditions.

A wide range of S containing or straight S fertilizers are available in the market. Gypsum, pyrite, and elemental S are used as different sources of S fertilizers. Some of the fertilizers containing primary nutrients, such as SSP, potassium sulphate, ammonium sulphate, and sodium sulphate, etc. are also good sources of S. In neutral to slightly alkaline soils, easily soluble ammonium sulphate, potassium sulphate, and sodium sulphate are considered more suitable sources of S for easier uptake by plants. Granular form of modified pyrite and elemental S (e.g., S-Bentonite) are quickly dispersible upon wetting and readily available to the plants (Tiwari et al., 2002). In S deficient soils (e.g., calcareous soils), easily soluble sources such as ammonium sulphate, are more suitable to correct the deficiency rather than gypsum which is less soluble.

The source and rate of S fertilizer produces significant yield improvement in chickpea. Supplying S through ammonium sulphate proved better over gypsum and enhanced the grain yield of chickpea by 5% averaged over locations and years under sandy loam and loamy sand soils. Application of S at 20 kg/ha to lentil, enhanced grain yield by 50% over no S application (**Table 3**; Ali and Singh, 1995). Based on crop response analysis, application of 20 to 40 kg S/ha, in the form of sulphate-S, is necessary to supply an adequate amount of S to the pulses. A study on the different rates of application for S on yield, quality, and nutrient uptake of mung bean revealed a significant increase of grain yield from 1.7 to 16% with increasing levels of S application from 0 to 20 kg/ha (Singh et al., 2014). The study also indicated a significant increase in N uptake and protein content in grain. Sulphur application indirectly influenced N_2 fixation by increasing the number and size of nodules and helped in increasing the N uptake in mung bean through increased fixation of atmospheric N.

Sulphur is commonly applied to the main crop within a cropping system and the residual effect of the applied S shows a detrimental effect to the succeeding crop, unless the right source and rate of S was applied to the main crop. Kumar et al. (2014) studied the effect of different sources and rates of S application on yield, S uptake, and protein content in rice-pea cropping system. The study revealed that application of 30 kg S/ha as phosphogypsum or SSP proved to be sufficient for substantial increases in yield, S uptake, and protein content for rice grown on the S deficient acid soil. However, to ensure a better residual effect of S to the succeeding pea crop, the study suggested applying 40 kg S/ha through a pyrite source at 3 weeks before sowing of rice (Kumar et al., 2014).

Physiological functions such as photosynthesis and enzyme activities, etc. are severely affected by S deficiency, especially in the initial growth stage of the plants. Therefore, application of S at early growth stages of pulses produces better yield and use efficiency (Aulakh, 2003). Studies have reported both the synergistic and antagonistic relationship between S and P depending upon the crops grown and the rate of application of both the nutrients. For example, a synergistic effect was observed between P and S for yield enhancement of rice while the effect was antagonistic in case of mung bean (Singh et al., 2014).

Summary

The present article highlights the large potential for productivity improvement of pulses through 4R Nutrient Stewardship to achieve future production goals. However, limited number of farmers follow the 4R-based nutrient management for pulses and the focused extension efforts are needed for large-scale adoption. BC-SA

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References

Ali, M. and K.K. Singh. 1995. Technical Bulletin, IIPR, Kanpur, pp.17.
Aulakh, M.S. 2003. *In* Y.P. Abrol and A. Ahmad (eds) Sulphur in Plants. Kluwer Academic Publishers, pp.341-358.
Chesti, M.H. and T. Ali. 2012. J. Indian Soc. Soil Sci. 60(1):26-29.
FAI, 2015. The Fertilizer Association of India, New Delhi, India.
Kaushik, U.K., R.C. Dogra, and S.S. Dudeja. 1993. Int. J. Trop. Agric. 11(2):102-108.
Kumar, R., J.K. Lal, A. Kumar, B.K. Agrawal, and S. Karmakar. 2014. J. Indian Soc. Soil. Sci. 62(2):140-143.
Majumdar, K. and V. Govil. 2015. Better Crops-South Asia 9(1):15-18.
Majumdar, K. and V. Govil. 2013. Better Crops-South Asia 7(1):23-25.
Nadarajan, N., N. Kumar, and M.S. Venkatesh. 2013. Indian J. Fert. 9(4):122-136.
Singh, D. and R.K. Singh. 1992. Indian J. Agron. 37(1):130-134.
Singh, S.R., G.R. Najar, and U. Singh. 2012. Indian J. Agr. Sci. 82(6):494-99.
Singh, U., N. Kumar, C.S. Praharaj, S.S. Singh, and L. Kumar. 2015. The Ecoscan 9(3&4):731-736.
Singh, Y.V., D.K Singh, P.K. Sharma, R.K. Singh, and P. Singh. 2014. J. Indian Soc. Soil Sci. 62(2):179-183.
Thiyagarajan, T.M., M.R. Backiyavathy, and P. Savithri. 2003. Agric. Reviews 24(1):40-48.
Tiwari, T.N., D. Kamal, R.K. Singh, and R.S. Prasad. 2014. Annals of Agric. Res. New Series 35(2):164-170.

IPNI at the 4th International Agronomy Congress, New Delhi

The 4th International Agronomy Congress was held in New Delhi on November 22 to 26, 2016. Organized every four years, the theme of this year's Congress focused on "Agronomy for Sustainable Management of Natural Resources, Environment, Energy and Livelihood Security to Achieve Zero Hunger Challenge." The International Plant Nutrition Institute (IPNI) is engaged in sustainable plant nutrient management research and education for meeting food security goals across the world and led leading two important sessions to support the theme of the Congress.

The Symposium VII on **"Precision Nutrient Management,"** chaired by Dr. Paul E. Fixen (IPNI Senior Vice President and President American Society of Agronomy), highlighted the recent developments in precision nutrient management strategies in smallholder and large acreage farms across the globe. Precise management of nutrients and other inputs are critical to achieve food security goals in a sustainable manner. Dr. Kaushik Majumdar, IPNI Vice President and Convener of the Symposium, said "Symposium VII will see global experts discussing their experiences to support the objectives." Selected young scientists, working in the area of precision nutrient management, were provided the opportunity to make 'Rapid Fire' presentations to further enrich the discussions. Carefully planned experiments, cautious data collection, archiving precise and accurate data, and access to data for analysis are all critical to advance the science of agronomy.

Understanding the necessity to highlight the importance of the careful acquisition of agronomic data, proper recording and archiving, data access, and analytical tools for interpreting large data sets for supporting evidence based agronomy inspired a session for the conference. IPNI, the International Maize and Wheat Improvement Center (CIMMYT), Agronomy, Crop and Soil Science Societies of America and International Rice Research Institute (IRRI) organized a special session on **"BIG Data and Evidence-based Agronomy for Future Food Security"** during the Congress. The objective of this special session was to have global expertise deliberate on standard protocols of data management, repository of data for archiving and access, and access of local knowledge to global community for making broader conclusions out of regional data. As outcomes, "we expect greater cooperation and sharing of quality agronomic data between research groups that not only takes the science of agronomy forward but also helps answer food security concerns at short, medium, and long-term," said Dr. Kaushik Majumdar, IPNI, and Dr. M. L. Jat, CIMMYT, the Co-conveners of the special session.

Special Session on "Myths and Realities of K Fertilizer Use in India: An Introspection" at 81st Annual Convention of the Indian Society of Soil Science

The International Plant Nutrition Institute (IPNI), in collaboration with the Indian Society of Soil Science (ISSS), organized a special session on **"Myths and Realities of K Fertilizer Use in India: An Introspection"**, at the 81st Annual Convention of the Indian Society of Soil Science held at Rajmata Vijayaraje Scindia Krishi Vishwavidyalaya (RSKVVV), Gwalior, Madhya Pradesh in October 2016. The session was chaired by Professor S.K. Sanyal, Former Vice Chancellor Bidhan Chandra Krishi Viswavidyalaya, and Dr. S.K. Chaudhury the President (Elect) of ISSS, and Assistant Director General for Soil and Water Management, ICAR, co-chaired the session.

The session was organized to re-focus on issues related to the imbalanced use of potassium (K) in Indian agriculture. At present, K contributes to less than 10% of the total nitrogen, phosphorus, and K consumption in the country. It is alarming that K application in cereal crops, which cover almost 80% of the gross cropped area in the country, is negligible. At the special session, speakers from the fertilizer industry highlighted how farmers perceive K as a nutrient that influences quality rather than yield-building. Surveys have revealed that the awareness level of farmers is higher for zinc as a plant nutrient, not K.

Participants from universities and research institutes provided strong arguments against the misconception that Indian soils are rich in K. This was through Pan-Indian studies that showed significant crop response to K application and high return on investment. Several studies in recent months found that low application of K on crops is continuously depleting the soil K levels, which could adversely affect the long-term food security goals of the country. It was encouraging to see the broad consensus between industry and the scientific group on the K requirement and use in the country. At the same time, the discussions highlighted the urgent need for extensive and sustained research and extension efforts to optimize K use in crops because it is essential for future food security and soil health.

Frontiers of Potassium Science Conference | kfrontiers.org

The International Plant Nutrition Institute (IPNI) has designed this unique international conference being held in Rome, Italy on January 25-27, 2017, as a forum to exchange information on how to improve potassium plant nutrition and soil management to better the health of soils, plants, animals, and humans. The 4R Nutrient Stewardship framework is integrated into the conference structure to keep the discussions anchored to the information needs of farmers and those who provide nutrient management guidance.

Please visit http://KFrontiers.org to obtain all program and registration details, and to sign up for all pre- and post-conference updates.

Speakers (Selected list)

Marta Alfaro, Instituto de Investigaciones Agropecuárias (INIA), Chile.
Michael Bell, University of Queensland, Australia.
Sylvie Brouder, Purdue University, USA.
Ismail Cakmak, Sabanci University, Turkey.
Heitor Cantarella, Agronomic Institute of Campinas, Brazil.
Paul Fixen, International Plant Nutrition Institute, USA.
David Franzen, North Dakota State University, USA.
Keith Goulding, Rothamsted Research, UK.
Philippe Hinsinger, UMR Eco&Soils, INRA-Montpellier SupAgro, France.
John Kovar, USDA ARS, USA.
Kaushik Majumdar, International Plant Nutrition Institute, India.
Robert Mikkelsen, International Plant Nutrition Institute, USA.
Scott Murrell, International Plant Nutrition Institute, USA.
Robert Mikkelsen, International Plant Nutrition Institute, USA.
Scott Murrell, International Plant Nutrition Institute, USA.
Steven Oosthuyse, HortResearch SA, SQM, South Africa.
Mike Rahm, The Mosaic Company, USA.
Michel Ransom, Kansas State University, USA.
Zed Rengel, The University of Western Australia, Australia.
Vinod Kumar Singh, Indian Agricultural Research Institute, India.
Michael Stone, Purdue University, USA.
Jeff Volenec, Purdue University, USA.
Connie Weaver, Purdue University, USA.
Philip White, James Hutton Institute, Scotland.

Example Discussion Topics

Potassium in Sustainable Intensification of Cropping Systems
How do potassium inputs and outputs compare for different cropping systems and geopolitical boundaries?

4R Source: Improving Decisions About the Source of Potassium to Apply
How does the source of potassium fertilizer affect its proper placement in the soil?

4R Rate: Improving the Accuracy of Potassium Rate Recommendations
Why and to what extent do various crops differ in their recovery efficiency of potassium?

4R Time: Improving Decisions About When to Apply Potassium
What are the genetic effects on potassium accumulation rates, partitioning, and plant metabolism?

4R Place: Improving Potassium Placement Decisions
What plant characteristics (rhizosphere biology and chemistry, root architecture, etc.) most influence potassium placement decisions?

Connecting Frontier Science to Frontier Practice
How do we increase the impact of scientific findings on soil and crop management of potassium in the field?

2016 was the year of change in the IPNI South Asia Program. Dr. Adrian M. Johnston, Vice President, Asia, Africa and Middle East, retired from IPNI after mentoring the South Asia Program for over ten years. There was also a change of guard as I moved into Dr. Johnston's position while Dr. Satyanarayana took over as the new Director of the Program. In the backdrop of these changes, IPNI remains steadfast in its commitment to the development process of South Asia through research and education on appropriate management of plant nutrients for food security and economic development of millions of smallholder farmers in an environmentally sustainable manner.

This year, **4R Nutrient Stewardship** for crops has been chosen as the theme of *Better Crops-South Asia*. The 4R concept, developed by the fertilizer industry, provides guidelines for the sustainable management of plant nutrients for improved crop productivity and farm profitability while minimizing the environmental footprint of nutrient use in agriculture. The concept uniquely connects plant nutrient management to broader social, economic, and environmental benefits and has been embraced by stakeholders in the fertilizer nutrient production-use-outcome chain. The dichotomy of the concept's apparent simplicity and the depth of details required to successfully implement it on-farm is fascinating to say the least. And its interpretation in space and time also needs to be unique to achieve the desired goals. Before they reach a final decision, every single farmer, whether smallholders in South Asia or large acreage farmers in North America or Australia, thinks about what fertilizer to apply, at what rate, at what time, and how best to apply them. It is how to connect those farm-level decisions to rigorous scientific principles so that the outcomes benefit the farmer, as well as society at large, that the principles of 4R Nutrient Stewardship aim at.

I strongly believe that the **role of fertilizer** has changed radically from a mere input to a critical component of several Sustainable Development Goals as we grapple with managing increased population demand in our changing climate. Food security, improving livelihood of farmers and ensuring a better environment for future generations has a common denominator in fertilizer, and its precise use is a win-win scenario for all stakeholders. IPNI has invested strongly on research, education, and extension of the 4R concept and has engaged with multiple stakeholders to ensure the right traction. Bringing conceptual clarity through peer-reviewed publications and book chapters for future agronomists, developing training materials and on-line support to ensure continued learning, and finally developing an easy-to-use tool that helps implement the 4R concept on-farm are some of the examples we are most proud of. This Issue of *Better Crops-South Asia* is an extension of that effort as local experts imbibe the subtle nuances of the 4R Nutrient Stewardship principles and articulate them for important crops and soils of the region. One thing, however, that is clear is the large knowledge gaps still exist as we deal with 4R for myriads of crops, cropping systems, and growing environments. Future investments in research, development, and extension will be critical to achieve the future goals and aspirations of the region.

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