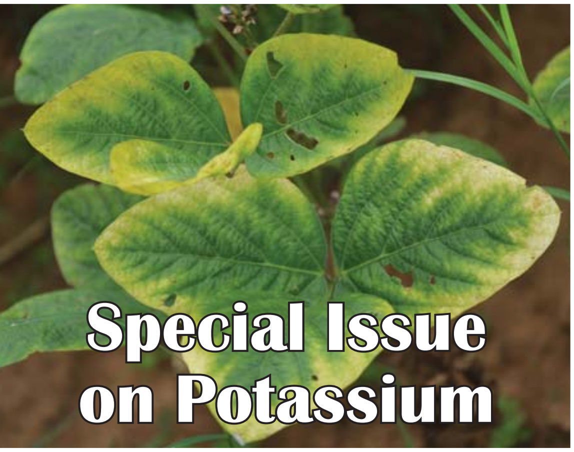
BETTER CROPS
SOUTH ASIA

A Publication of the International Plant Nutrition Institute (IPNI)
Volume 7, Number 1, 2013



Special Issue on Potassium

An Issue Dedicated to K Response and Economics in ...

Rice-Maize Systems

Rice-Wheat Systems

Oilseeds, Pulses and Staple Food Crops

Also:

Nutrient Expert® Launched in India

Mapping K Budgets

...and much more

IPNI
www.ipni.net

BETTER CROPS–SOUTH ASIA

Volume 7, Number 1, December 2013

Our cover: A collage of potassium deficiency symptoms in crops.

Photos by: IPNI South Asia Staff (clockwise from top left): K deficiency in soybean leaves, unfilled maize cob in K omission plot, K deficiency in potato leaves, K deficiency in young cucumber plant, reduced root development in K deficient maize plant, K deficiency in mature plum tree.

Editor: Gavin D. Sulewski
Assistant Editor: Danielle C. Edwards
Agronomic and Technical Support Specialist:
Dr. Harmandeep Singh Khurana
Design: Rob LeMaster

INTERNATIONAL PLANT NUTRITION INSTITUTE (IPNI)
S.R. Wilson, Chairman (CF Industries Holdings, Inc.)
J.T. Prokopanko, Finance Committee Chair (The Mosaic Company)

IPNI Administrators
Dr. Terry L. Roberts, President, Norcross, Georgia, USA
Dr. Adrian M. Johnston, Vice President, Asia and Africa Group, Saskatoon, Saskatchewan, Canada
Dr. Paul E. Fixen, Senior Vice President, Americas and Oceania Group, and Director of Research, Brookings, South Dakota, USA
Dr. Svetlana Ivanova, Vice President, Eastern Europe/Central Asia and Middle East, Moscow, Russia
S.J. Couch, Vice President, Administration, Norcross, Georgia, USA

South Asia Program—Director and Deputy Directors
Dr. Kaushik Majumdar, Gurgaon–North & West
Dr. T. Satyanarayana, Hyderabad–South
Dr. Sudarshan Dutta, Kolkata–East

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.

The Government of Saskatchewan, Canada, helps make this publication possible through its resource tax funding. We thank them for their support of this important project.

Inquiries related to this issue should be directed to:

IPNI South Asia Programme
Dr. Kaushik Majumdar, Director
354, Sector-21, Huda
Gurgaon 122016, India
Phone: 91-124-246-1694
Fax: 91-124-246-1709
E-mail: kmajumdar@ipni.net
Website: sasia.ipni.net

Headquarters information:
International Plant Nutrition Institute (IPNI)
3500 Parkway Lane, Suite 550
Norcross, Georgia 30092 USA
Phone: 770-447-0335 Fax: 770-448-0439
Website: www.ipni.net E-mail: info@ipni.net

Printed in India

CONTENTS

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

IPNI Members: Agrium Inc. • Arab Potash Company • Belarusian Potash Company • CF Industries Holdings, Inc. • Compass Minerals Specialty Fertilizers • OCP S.A. • Incitec Pivot • International Raw Materials LTD • Intrepid Potash, Inc. • K+S KALI GmbH • PotashCorp • QAFCO • Simplot • Sinofert Holdings Limited • SQM • The Mosaic Company • Uralchem • Uralkali

Affiliate Members: Arab Fertilizer Association (AFA) • Associação Nacional para Difusão de Adubos (ANDA) • Canadian Fertilizer Institute (CFI) • Fertiliser Association of India (FAI) • International Fertilizer Industry Association (IFA) • International Potash Institute (IPI) • The Fertilizer Institute (TFI)

Welcome...

You are reading the seventh issue of *Better Crops South Asia (formerly Better Crops-India)*, first introduced in 2007. This publication is released annually in the fourth quarter and follows a format similar to our quarterly publication known as *Better Crops with Plant Food*.

For 2013, the issue is focused on potassium (K). There is a marked variability in plant K availability in soils of South Asia, but concerns have been raised on severe mining of K in these soils. Fertiliser K recommendations in South Asia are generalized over large areas, while farmers neglect K application to crops and remove crop residues from fields. Evidence from several long-term fertiliser experiments in South Asia has indicated significant yield responses to K application and negative K balances, especially where K application is either omitted or applied sub-optimally.

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

2013 IPNI Scholar Award Recipients Announced

The winners of the 2013 Scholar Awards sponsored by the International Plant Nutrition Institute (IPNI) have been selected. The awards of US$2,000 are available to graduate students in sciences relevant to plant nutrition and management of crop nutrients.

"We had a higher number of applicants for the Scholar Awards this year, and from a wider array of universities and fields of study," said Dr. Terry L. Roberts, IPNI President. "And the qualifications of these students are impressive. The academic institutions these young people represent and their advisers and professors can be proud of their accomplishments. The selection committee adheres to rigorous guidelines in considering important aspects of each applicant's academic achievements."

The following 4 graduate students from the South Asia Region were named to receive the IPNI Scholar Award in 2013.


Anjani Kumar

Mr. Anjani Kumar is pursuing his Ph.D. in Agricultural System Management at Indian Institute of Technology in Kharagpur, India. The focus of his research is on nutrient and water management in aerobic rice systems, where he is evaluating nutrient management strategies and estimating the critical soil moisture potentials at the rice root zone depth for scheduling irrigation to sustain higher crop and water productivity. In the future, Mr. Kumar wants to pursue his research interests in crop modeling.


Mahesh Rajendran

Mr. Mahesh Rajendran is working toward his Ph.D. Agronomy degree at Tamil Nadu Agricultural University in Coimbatore, India. His research dissertation is titled "Best management practices to improve fertiliser and water use efficiency in sugarcane under subsurface drip fertigation system." The research aims to provide a list of best management practices based on 4R Nutrient Stewardship to enhance sugarcane productivity and achieve higher nutrient- and water-use efficiencies. Mr. Mahesh aims to join a postdoctoral fellowship program to hone his skills in soil fertility and plant nutrition further with the goal of becoming a distinguished agricultural scientist.


Sonalika Sahoo

Ms. Sonalika Sahoo is working toward a doctorate degree in Soil Science and Agricultural Chemistry at Indian Agricultural Research Institute in New Delhi, India. Her dissertation is titled "Effect of nanoclay polymer composites loaded with urea and nitrification inhibitor on nitrogen use efficiency, nitrogen dynamics and soil properties." The main objective of her study is to identify new slow release fertiliser products that will decrease nutrient losses and increase nutrient use efficiency to support the increasing food demand without deteriorating environment and ecosystem. For the future, Ms. Sahoo hopes to establish a career in agricultural research.


Naveen Gupta

Mr. Naveen Gupta is presently pursuing his doctorate program in Charles Sturt University, Australia on "Tillage and mulch effects on water balance and crop productivity of rice-wheat cropping system in northwest India." He has also worked on nutrient management in rice and wheat grown with resource conservation technologies in Indo-Gangetic plains of India. He aims to become a Research Scientist in an international organization of repute in near future and work on nutrient and water interactions in cereal crops especially under changing climatic scenarios.

Variability in Potassium Concentrations of Irrigation Waters in India

By T. Satyanarayana, V.K. Singh, S. Chaterjee, S. Dutta, V. Govil, and K. Majumdar

Potassium concentrations in irrigation waters varied greatly across different locations in India (spatial), different times of the year (temporal), and different sources of irrigation used. Therefore, local assessment of K contribution from irrigation water, including K leaching losses, is required in determining field-specific fertiliser K application rate.

Irrigation water contains beneficial constituents including essential plant nutrients, which upon addition to soil improve soil fertility (Singh and Bishnoi, 2001). Presence of K in irrigation water constitutes an important source of indigenous supply of K to plants. In addition to its nutritive value, the presence of K in irrigation water also mitigates the adverse effect of Na in the soil. Paliwal and Yadav (1976) reported that less Na is adsorbed on soil particles if sufficient K is present, possibly because of the higher bonding energy of K to soil clay surfaces than Na. Potassium, when present in amounts up to one-tenth of the total concentration of Na in irrigation water, greatly reduces Na hazard (Heimann, 1966).

The K input from irrigation water depends primarily on (a) K concentration in the added water and (b) the quantity of water added during the entire crop production cycle, i.e., from the onset of land preparation to harvest (Bijay-Singh et al., 2004). However, K concentration in irrigation water varies with different sources of irrigation (canals, bore wells, farm ponds, community tanks, open wells etc.) and also with its time of application at different stages of crop growth. This leads to uncertainty in quantifying the K input to a specified crop (Yadvinder-Singh et al., 2005). Nature of the parent material, presence of soluble minerals releasing K into water aquifers, and surface runoff of the top fertile soil with irrigation water increase the variability in K content in irrigation water from ground water sources. Singh and Kumar (2009) surveyed 500 irrigation water samples from Ferozepur district of Punjab and reported that K concentrations varied from 1.95 to 96.3 mg/L, with an average concentration of 10.14 mg/L. This average concentration supplied 31.2 kg of K per one ha foot of irrigation water. In another recent study (Buresh et al., 2010), K concentrations in irrigation water within a rice-growing area of the Cauvery Delta in Tamil Nadu varied from 1.0 to 9.5 mg/L, and K input through irrigation water to rice fields ranged from 10 to 95 kg/ha in the study area with 50% of the fields receiving 13 to 30 kg K/ha. Rajput and Polara (2013) surveyed 220 underground water samples in Bhavnagar district of Gujarat, and found that K concentrations in the collected irrigation water samples varied from 0.0 to 54.6 mg/L with an average concentration of 4.29 mg/L. They also reported a significant difference in K concentrations between well and tubewell sources of irrigation.

This paper examines the variability in K contents across different sources of irrigation water sampled in India and the extent of K addition through irrigation water that is useful in determining field-specific fertiliser K rates for crops.

Geo-referenced irrigation water samples were collected from 32 districts of Uttar Pradesh representing the upper Gangetic plain (UGP) region (Singh et al., 2013) and four blocks (Nalhati I, Rampurhat I, Muraroi I and Muraroi II) of Birbhum district of West Bengal in the lower Gangetic plain (LGP) region. Potassium concentrations in irrigation water samples (124 from Uttar Pradesh and 142 from West Bengal) were determined by flame emission spectrophotometer following standard procedure (APHA, 1998). For comparative studies, we also incuded K concentrations in 30 irrigation water samples from the semi-arid tropical region of India including watersheds of ICRISAT and Kothapalli in Andhra Pradesh, Kolar and Haveri in Karnataka, Semli and Shyamapura in Madhya Pradesh and Thana and Govardhanapura in Rajasthan (Srinivasarao et al. 2012) and 70 irrigation water samples from bore wells in Nanded district of Maharashtra (Juned and Arjun, 2011). Surface maps of irrigation water K contents were prepared with Inverse Distance Weighted (IDW) method using ArcGIS 10.1 (ESRI, 2012).

Table 1. Distribution (%) of K concentrations in irrigation water samples across different regions of India.

K Concentration (mg/L)	Distribution (%)
Upper Gangetic Plain region (n = 124)	
< 2	2.4
2.0 - 4.0	11.3
4.0 - 5.0	16.9
5.0 - 6.0	21.8
6.0 - 7.0	14.5
7.0 - 13	21.0
> 13	12.1
Birbhum, West Bengal (n = 142)	
> 0.5	4.9
0.5 - 1.0	43.0
1.0 - 1.5	26.8
1.5 - 2.0	11.3
2.0 - 2.5	2.8
> 2.5	11.3
Dry land region (n = 30)	
< 1	16.7
1.0 - 2.0	33.3
2.0 - 5.0	33.3
> 5	16.7
Nanded, Maharashtra (n = 70)	
≤ 0.1	20.0
0.2	21.4
0.3	11.4
0.4	20.0
0.5	17.1
≥ 0.6	10.0

Results

Distribution of K concentrations in irrigation water samples was highly variable across different regions in India. Of the total 124 samples analysed in UGP, 13% samples had K concentrations below 4 mg/L, about 40% of samples had K concentrations between 4 to 6 mg/L, and 47% samples had K concentrations above 6 mg/L (**Table 1**). In the Birbhum district of West Bengal (LGP region), 48, 38, and 14% samples had K concentrations of ≤ 1 mg/L, 1 to 2 mg/L, and ≥ 2 mg/L, respectively. Similar variations in the distribution of K con-

Abbreviations and notes: K = potassium; Na = sodium.

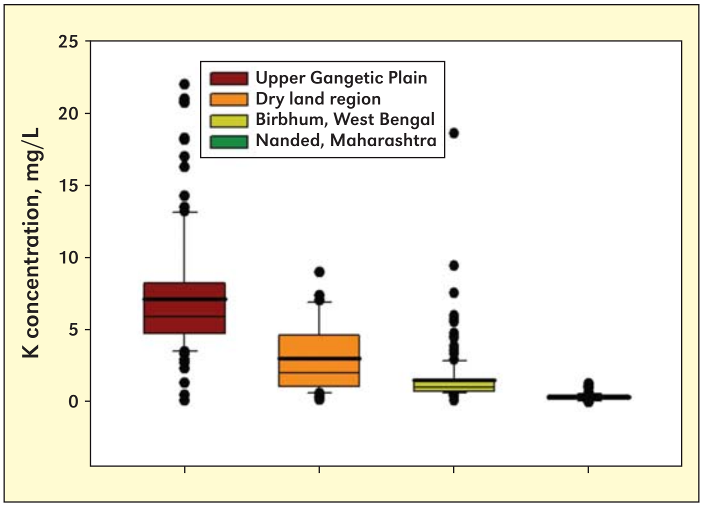


Figure 1. Irrigation water K concentrations (mg/L) in different regions of India. Boxes represent data within the first and third quartiles (interquartile range). The thin line denotes the second quartile or median, while the thick line represents the mean. Lines extending beyond the interquartile range denote the 10th to 90th percentile of the data. Statistical outliers are plotted as individual points outside these lines.

centrations was also observed in semi-arid tropical region and Nanded region of Maharashtra. In the semi-arid tropical region, K concentrations in irrigation water ranged from 0.14 to 9 mg/L, with an average concentration of 3.04 mg/L, while the Nanded region of Maharashtra indicated lower K concentrations (0.01 to 1.3 mg/L), with an average concentration of 0.35 mg/L (**Figure 1**). Some possible reasons for lower K contents in irrigation waters of Nanded could be intensive agricultural activities and slow release of K in the groundwater from silicate minerals that are abundant in this region (Juned and Arjun, 2011). Comparatively higher K concentrations were observed in the irrigation water samples of the UGP region, 0.1 to 22 mg/L with an average K concentration of 7.1 mg/L (**Figure 1**). These higher values could be attributed to the presence of illitic minerals and extremely fertile, deep layers of alluvium spread in this region, which could have deposited K rich sediments in the irrigation water through the slow-moving rivers of the Ganges system. Earlier studies also reported large variability in irrigation water K input under rice-based systems in the IGP (Bijay-Singh et al., 2004; Buresh et al., 2010).

Irrigation water K contents also varied significantly with time. Srinivasarao et al. (2012) reported that K content in ground water differed significantly from monsoon to post monsoon seasons and was higher in monsoon season. Ashraf et al. (2006) also reported that in the gravity fed tube well water, highest K concentration was observed in the last two fortnights of winter season, whereas it was the lowest during the second fortnight of winter season.

Among the surveyed watersheds in semi-arid tropical India, K concentration of irrigation water varied with the sources of irrigation. The highest average K content of 4.99 mg/L was recorded in farm ponds followed by open wells (2.49 mg/L), bore wells (1.73 mg/L) and finally, in community tanks (1.57 mg/L) (Srinivasarao et al., 2012). These results are in slight contrast to the findings of Ashraf et al. (2006) as they reported highest K concentrations in the tube well irrigation water.

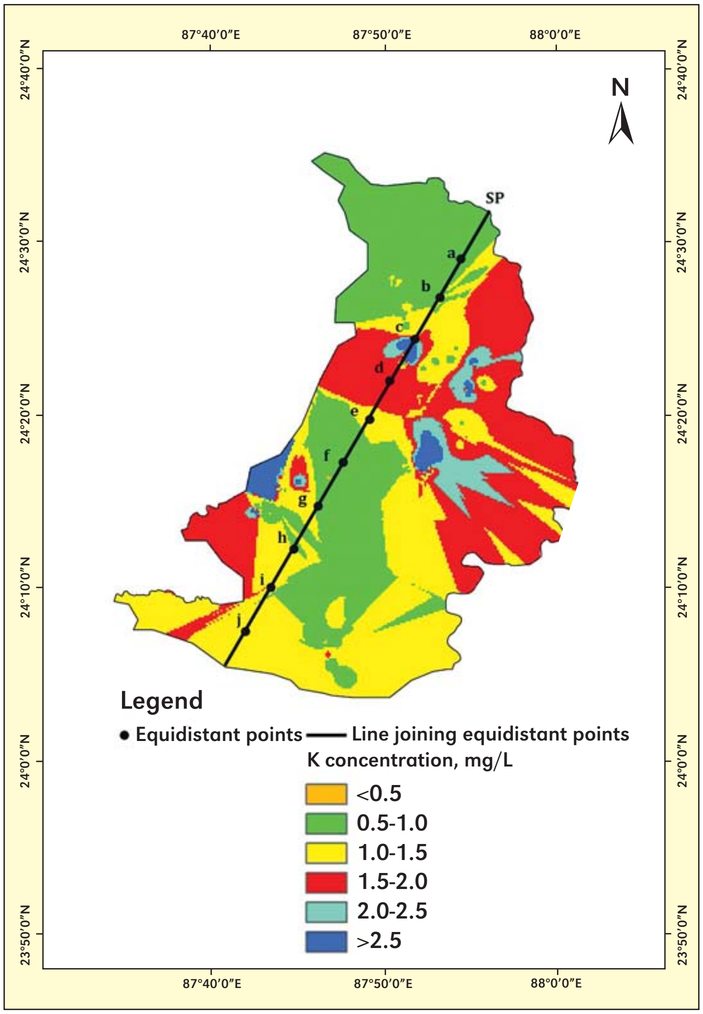


Figure 2. Spatial variability of irrigation water K contents in the lower Gangetic plain region.

The input of K in the studied watersheds of semi-arid tropical regions (Srinivasarao et al., 2012) was of the order of Govardhanapura (3.6 kg/ha) and Thana (3.0 kg/ha) in Rajasthan followed by ICRISAT (2.8 kg/ha) in Andhra Pradesh. Using these K contents, Srinivasarao et al (2012) reported that irrigation water in the region would supply 25 to 30% of the K requirement of cotton, 15 to 20% of sorghum and wheat, 10 to 15% of maize, and 5 to 10% of pulses (pigeon pea, chickpea and soybean). Buresh et al. (2010) reported a contribution of 18 kg K/ha from the irrigation water, having a median K concentration of 1.8 mg/L, collected from rice-rice cropping systems across Asia. However, the data from Uttar Pradesh and West Bengal showed that there is large variability in K content in irrigation water, both within and between regions. And it may not be prudent to assume a blanket K contribution value from irrigation water, particularly at regional or continental scale. Assuming an addition of 1000 mm of irrigation water to rice grown in UGP with a median K content of 5.9 mg/L, this would add 59 kg K/ha. However, a similar amount of irrigation water added to rice crop in West Bengal with a median K concentration of 1.02 mg/L would contribute 10.2 kg K/ha, which is only 17% of the K input received in Uttar Pradesh.

Data from West Bengal (**Figure 2**) and Uttar Pradesh (**Figure 3**) were used to develop irrigation water K content

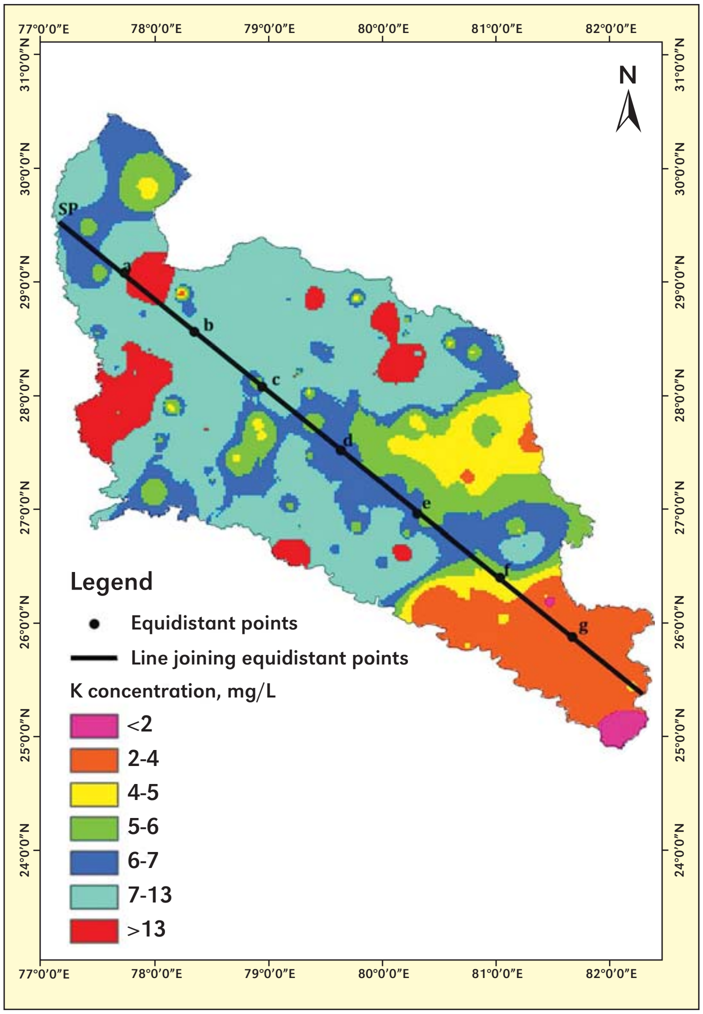


Figure 3. Spatial variability of irrigation water K contents in the upper Gangetic plain region.

surface maps of study areas. The surface maps showed that K concentration in irrigation water changed within short distances. Transects connecting equidistant points within the study areas were drawn across the maps. The transect length of the study area in West Bengal was about 55 km, while the length of transect in Uttar Pradesh was over 750 km. Potassium content of equidistant points on the transects were measured and reported in **Tables 2 and 3**, and this data also showed that K content of irrigation water varied within short distances. This suggests that assuming blanket K concentration in irrigation water, even within such small areas, may give incorrect information on K input from irrigation water.

Current data and the studies referred to here suggest that a portion of crop K requirement may be contributed by irrigation water, and this contribution varies spatially and temporally as well as with sources of irrigation. However, while discussing input of K from irrigation water, it must be understood that all the K input to the field *via* irrigation water may not be available to plants. A portion of the K and other basic cations added to the field through irrigation water may be lost *via* leaching from fields with adequate drainage. Leaching losses of K can be substantial in highly permeable soils with low cation-exchange capacities. Yadvinder-Singh et al. (2005) found that leaching losses of K were 22% and 16% of the applied K in sandy loam and loamy soils, respectively, maintained at submerged moisture regimes. Such losses in Bangladesh rice soils were as high as 0.1 to 0.2 kg K/ha/day (Timsina and Connor, 2001). Therefore, leaching losses of K from the effective root zone must also be taken into account while making field specific K recommendation for a crop.

Table 2. Potassium concentrations at equidistant points across a transect over the study area in West Bengal in the lower Gangetic plain zone.

Location on map	K concentration, mg/L
Starting Point (SP)	0.95
SP + 5.5 km (a)	0.98
a + 5.5 km (b)	0.98
b + 5.5 km (c)	1.82
c + 5.5 km (d)	1.83
d + 5.5 km (e)	1.18
e + 5.5 km (f)	0.675
f + 5.5 km (g)	0.97
g + 5.5 km (h)	1.16
h + 5.5 km (i)	1.07
i + 5.5 km (j)	1.05

Table 3. Potassium concentrations at equidistant points across a transect over the study area in Uttar Pradesh in the upper Gangetic plain zone.

Location on map	K concentration, mg/L
Starting Point (SP)	6.96
SP + 80 km (a)	10.68
a + 80 km (b)	8.87
b + 80 km (c)	6.57
c + 80 km (d)	6.50
d + 80 km (e)	6.24
e + 80 km (f)	4.8
f + 80 km (g)	3.22

Summary

Potassium concentrations in irrigation waters varied significantly among the surveyed regions. Such variations, both at spatial and temporal scales, lead to uncertainties in estimating the contribution of K from irrigation water for a specific crop in a given region. Studies have assumed blanket irrigation water K contents while estimating fertiliser K requirements of crops, which may lead to inadequate K application to crops. Potassium content of irrigation water from studied areas showed that the K contribution of irrigation water is far below the total crop K requirement and that external K application through fertiliser sources would be required to sustain and improve crop yields while also maintaining soil K fertility levels.

Drs. T. Satyanarayana, S. Dutta, K. Majumdar and Ms. V. Govil are with IPNI-South Asia Program; (e-mail: tsatya@ipni.net). Dr. V.K. Singh is National Fellow with the Project Directorate for Farming Systems Research, Modipuram, Meerut. Dr. S. Chatterjee is Assistant Agricultural Chemist, ZARS, Nalhati, Govt. of West Bengal.

References

APHA. 1998. Standard methods for the examination of water and wastewater. (S. Lenore, E. Arnold, D. Andrew, eds). 20th ed. Washington: American Public Health Association.

Ashraf, M., M.M. Saeed, and M.N. Asghar. 2006. J. Drainage & Water Mgt., 6:45-51.

Bijay-Singh, P. Imas, and X. Jing-chang. 2004. Adv. Agron. 81:203-259.

Buresh, R.J., M. Pampolino, and C. Witt. 2010. Plant and Soil 335:35-64.

ESRI. 2012. http://www.esri.com/software/arcgis/arcgis10. Last accessed on November 29, 2013.

Heimann, H. 1966. *In* Salinity and Aridity (H. Boyok and W. Junk eds), The Hague, pp. 201-213.

Juned, S. A. and B.B. Arjun. 2011. European J. Exptl. Biol. 1(1):74-82.

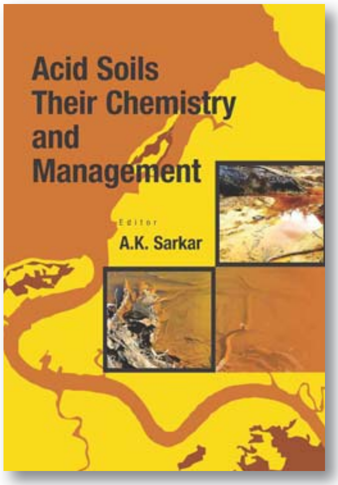
Paliwal, K.V. and B.R. Yadav. 1976. Irrigation water quality and crop management in the union Territory of Delhi. LA.R.L Res Bull. #9.

Rajput, S.G. and K.B. Polara. 2013. J. Indian Soc. Soil Sci. 61(1):34-37.
Singh, B. and S.R. Bishnoi. 2001. J. Indian Soc. Soil Sci. 49(1):188-190.
Singh, B. and B. Kumar. 2009. J. Res. Punjab Agric. Univ. 46(1&2):17-22.
Singh, V.K. 2013. Annual report 2012-13. Project Directorate for Farming Systems Research, Modipuram, pp. 71.
Srinivasarao, Ch., S.P. Wani, K.L. Sahrawat, J.V. Sandeep, S. Kundu, B.K.R. Rao, et al. 2012. Indian J. Dryland Agric. Res. & Dev. 27(1):58-69.
Timsina, J. and D.J. Connor. 2001. Field Crops Res. 69:93-132.
Yadvinder-Singh, R.P.S. Pannu, and Bijay-Singh. 2005. J. Ind. Soc. Soil Sci. 53:207-213.

BOOK REVIEWS

Acid Soils: Their Chemistry and Management

Edited by Dr. A.K. Sarkar, Former Dean & Professor & Head (Soil Science), Birsa Agricultural University, Ranchi and Published by New India Publishing Agency (NIPA), New Delhi.



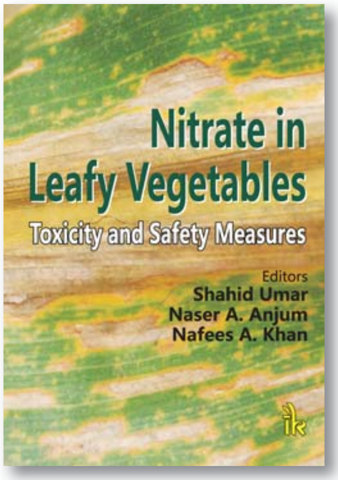
About 25 million ha of cultivated soils in India are affected by soil acidity (pH < 5.5), mainly in the Himalayan region and areas with red and lateritic soils. Crops grown on acid soils, such as maize, jute, pulses, oilseeds, wheat, millets and vegetables, generally produce less than 50% of the yields obtained in neutral soils (pH 6.5 to 7.0). Eastern and Northeastern parts of India are of greater concern in this regard.

The book outlines theoretical as well as practical aspects of soil acidity and it's management. It not only deals with the genesis of acid soils through the variety of chemical reactions involved, but also provides scientific support for the technique of lime application in furrows of direct seeded crops and the economic benefits farmers can derive from the implementation of this technique in their fields. The book emphasises on using locally available, low cost and efficient liming materials for ameliorating soil acidity and provides on-farm results from several states of India on the efficacy of lime and nutrient application in acid soils in different crops. It also attempts to draw a strategic framework for sustainable development of acid soil regions.

The book consists of 10 chapters, viz., Introduction, Concepts and Applications, Chemistry of Acid Soils, Genesis and Classification of Acid Soils, Field Studies on Acid Soils, Acid Soils of Northeastern states, Jharkhand, Odisha, Secondary and Micronutrients in Acid Soils, Paper Mill Sludge as an Acid Soil Ameliorant, and Way Forward. This multi-authored book from experienced scientists is a valuable contribution in the field of Soil Science.

Nitrate in Leafy Vegetables: Toxicity and Safety Measures

Edited by Shahid Umar, Naser A. Anjum and Nafees A. Khan and Published by I.K. International Publishing House Pvt. Ltd., New Delhi.



Vegetables, especially the green leafy vegetables, constitute a major dietary source of nitrate. Although nitrate itself is relatively non-toxic, and even beneficial within permissible limits for their role in vascular and immune functions, the possible harmful effects of nitrate-derived compounds on human health arouse public concern. The use of excessive nitrogenous fertilizers has been regarded as one of the major reasons leading to accumulation of nitrate in leafy vegetables, which is wrongly considered by farmers as reasonable insurance against yield loss. Therefore, vegetable nitrate content is of great interest to governments and regulators as well as to plant scientists and health professionals.

This book is a comprehensive compilation of the latest science on dietary nitrate sources and provides practical and scientific data-driven resources on the potential human health effects and sustainable remedial strategies for nitrate in plants and humans. The book attempts to provide a wealth of information and a common platform for plant scientists and health professionals working towards sustainable solutions to nitrate-led human and environmental health consequences. The 8 chapters in this book have been written by eminent researchers and scientists working in the field of nitrate in soils and plants. The book is sure to enlighten readers from various disciplines and at various levels, and should prove useful for advanced students, researchers, faculty of both plant and animal sciences, and environmentalists and policy makers.

Potassium, Sulphur and Zinc Application Improved Yield and Economics of Rice-Wheat Systems

By V.K. Singh, B.S. Dwivedi, R.J. Buresh, M.L. Jat, K. Majumdar, B. Gangwar, V. Govil and S.K. Singh

On-farm experiments conducted at 60 locations in northern India demonstrated that yields and profits for rice and wheat increased significantly with a combined application of K, S and Zn along with farmer fertilisation practice that primarily focuses on N and P application. Application of Zn improved grain Zn contents in rice and wheat, which is critical for nutritional security in the region. Soil exchangeable and non-exchangeable K decreased without K application and increased with K application within just one rice-wheat cropping cycle.

Caption: Zinc deficiency in rice (left) and **S deficiency in wheat** (right). Zinc deficiency is seen as yellow and brown necrotic patches gradually extending outwards towards the tip and base of the leaf; while S deficiency is seen as general leaf yellowing with young leaf tips eventually becoming necrotic.

Fertiliser use in the rice-wheat systems (RWS) of Indo-Gangetic Plains (IGP) is highly variable. Generally, the nutrient application rates do not match the nutrient removal rates from the soils, leading to declining crop yields and factor productivity in the RWS (Singh et al., 2005). On-farm farmers' participatory surveys showed that farmers typically applied ample N (78 to 150 kg N/ha) and P (13 to 25 kg P/ha) to rice, and 82 to 196 kg N/ha and 15 to 33 kg P/ha to wheat, while largely ignoring application of other nutrients, particularly K (Singh et al., 2013). This is because farmers are either unaware of the benefits of other nutrients or lack access to those fertilisers during periods of peak demand. All this is leading to increasing concerns on the productivity of RWS and soil fertility status in the IGP. For example, Bijay-Singh et al. (2003) and Yadvinder-Singh et al. (2005) observed that soil K reserves are being depleted to levels insufficient to sustain high yields. Similarly, Shukla and Behra (2011) indicated that S and micronutrient deficiencies are emerging as significant limitations to the productivity of RWS. We conducted on-farm experiments with rice and wheat crops in northern India to: 1) determine the responses of rice and wheat to fertiliser K, S and Zn applications, 2) assess financial returns associated with their application, and 3) evaluate soil K balances.

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

About 60 famers' fields were chosen in Punjab (Fatehgarh Sahib district), Uttar Pradesh (Meerut, Banda and Barabanki districts) and Bihar (Bhagalpur district) states to conduct the experiments in 2005-06. Fatehgarh Sahib, Meerut, Barabanki, and Bhagalpur districts are located in the IGP, while Banda district, which is located outside the IGP, has RWS as an emerging crop production system. All locations had four fertiliser treatments, viz., farmer's fertiliser practice (FFP), FFP + K (+K), FFP + K + S + Zn (+KM), and FFP + S + Zn (+M). In the +K and +KM plots, K was applied using muriate of potash at 63 kg K/ha to rice as well as wheat. In rice, K was applied as 50% basal and 50% at 50 days after transplanting, whereas in wheat, all K was applied as basal. Sulphur was applied as basal using elemental S powder (80% S) at 30 kg S/ha to both rice and wheat, while Zn was applied only to the rice crop as zinc sulfate (21% Zn) at 5 kg Zn/ha. The existing farmer's fertiliser practice that only includes the applications of fertiliser N and P was followed in all four treatments for rice and wheat. The +M treatment with applied S and Zn was treated as the equivalent of a K-omission plot allowing assessment of the K-limited yield because farmers typically apply sufficient fertiliser N and P but no fertiliser K to their fields (Singh et al., 2013). The treatment with applied K served as an omission plot for S plus Zn capable of assessing soil indigenous S and Zn supply based on the yields of rice and wheat. However, it was not possible to ascertain from this study whether the yield

Table 1. Effect of potassium and sulphur plus Zn (M) additions in rice and rice-wheat system (SREY) at five locations in northern India.

	-- Fatehgarh Sahib --			------ Meerut ------			------ Banda ------			----- Barabanki -----			----- Bhagalpur -----		
Parameter	No M	+M	Diff†	No M	+M	Diff	No M	+M	Diff	No M	+M	Diff	No M	+M	Diff
Rice grain yield (t/ha)															
No K	5.9	6.6	0.7**	4.9	5.5	0.6***	2.7	3.3	0.6***	5.0	5.4	0.4***	3.5	4.3	0.9***
+K	6.5	7.0	0.5*	5.7	6.1	0.4***	3.7	4.1	0.4***	5.6	5.9	0.3***	4.6	4.9	0.2***
Difference‡	0.6***	0.4*		0.9***	0.6***		1.0***	0.7***		0.6***	0.5***		1.2***	0.5***	
Rice grains per panicle (no.)															
No K	91	97	6ns	64	69	5***	97	105	8***	108	110	3**	81	86	5***
+K	98	104	6**	69	72	3***	118	128	10***	112	115	3***	88	90	1***
Difference	7**	7*		5**	3***		22***	23***		5***	5***		8***	4***	
Total K in rice (kg/ha)															
No K	108	122	14**	102	114	12***	56	66	11***	98	101	3ns	74	90	16***
+K	130	140	10**	130	137	7***	80	87	7***	119	127	8***	103	109	6***
Difference	23***	18***		27***	22***		24***	21***		21***	26***		29***	20***	
Wheat grains per spike (no.)															
No K	44	46	2.5***	40	44	4.4***	41	43	1.6***	38	39	1.6***	39	42	3.0***
+K	46	49	3.2***	46	48	2.2***	43	46	2.7***	40	41	1.4**	45	47	2.5***
Difference	1.7***	2.4***		6.0***	3.8***		2.0***	3.1***		2.2***	2.0***		5.3***	4.8***	
Rice equivalent yield for system (SREY) (t/ha)															
No K	11.7	12.6	0.9***	10.0	11.2	1.2***	5.7	6.8	1.0***	9.5	10.3	0.7***	6.4	7.7	1.3***
+K	12.5	13.2	0.7**	11.8	12.6	0.8***	7.2	8.0	0.8***	10.6	11.2	0.6***	8.4	9.1	0.7***
Difference	0.8***	0.6**		1.8***	1.4***		1.5***	1.3***		1.1***	0.9***		2.1***	1.4***	

† Diff = Difference between non-rounded treatment means for no added S + Zn (no M) and added S + Zn (+M).

‡ Difference = Difference between non-rounded treatment means for no added K (no K) and added K (+K).

ns = Not significant at $p \le 0.05$, * = Significant at $p \le 0.05$, ** = Significant at $p \le 0.01$, and *** = Significant at $p \le 0.001$.

The K×M×location interaction was significant at $p \le 0.05$ for all listed parameters.

gains from S + Zn arose from added S, Zn, or both S and Zn.

Twenty-five day old seedlings of rice (cv. PHB 71) were transplanted during June-August in farmers' fields. At maturity, rice was harvested manually, the land was tilled three to four times, and the succeeding wheat crop (cv. PBW 343) was sown on the same plots during November-December. Grain and straw yields of rice and wheat were determined from a 10 m^2 area in each plot, comprised of four predetermined 2.5 m^2 harvest areas. Rice and wheat grain yields were reported at 14% moisture content. Soil samples were collected at 0 to 15 cm depth before the start of the experiment and after wheat harvest. Soils were analysed for extractable N, extractable P, exchangeable K, non-exchangeable K, extractable S, and DTPA-extractable Zn using standard analytical procedures. Means for the initial soil properties for each district are reported elsewhere (Singh et al., 2013). Representative subsamples of grain and straw of rice and wheat crops were analysed for total K, S and Zn.

Added net return for fertilisation with K, S and Zn relative to FFP was determined using prices for rice grain (₹8.55/kg), rice straw (₹0.5/kg), wheat grain (₹10.35/kg), wheat straw (₹2.75/kg), fertiliser N (₹10.35/kg), fertiliser P (₹16.2/kg), fertiliser K (₹9.0/kg), fertiliser S (₹11.7/kg) and fertiliser Zn (₹30.15/kg). Comparisons of yield for the locations were made on rice equivalent yield for systems (SREY):

$$\text{SREY} = Y_R + [(YW \text{ x } PW) / PR]$$

where, Y_R = rice grain yield in kg/ha, Y_W = wheat grain yield in kg/ha, P_R = price of rice in ₹/kg, and P_W = price of wheat in ₹/kg. All data were analysed using SAS (version 9.1.2).

Crop Response to Potassium, Sulphur and Zinc Application

Rice yield in FFP plots ranged from 2.7 t/ha at Banda to 5.9 t/ha at Fatehgarh Sahib. Application of K increased rice grain yields ($p \le 0.001$) at all locations (**Table 1**) regardless of the large differences in soil textures as well as soil exchangeable and non-exchangeable K statuses among farms (Singh et al., 2013). For example, K application increased rice yields by 0.6 t/ha in Fatehgarh Sahib and Barabanki, 0.9 t/ha in Meerut, 1 t/ha in Banda, and 1.2 t/ha in Bhagalpur. Similarly, the yield increases from applied K in the presence of S and Zn (+M) ranged from 0.4 to 0.7 t/ha across all locations. The significant increase in rice yields due to K application is in stark contrast to the popular belief that K status of the IGP soils is sufficient to meet the K needs of crops (Bijay-Singh et al., 2003), but is consistent with recent scientific reports that clearly indicate that the application of K has become essential for sustaining high yields in the IGP (Regmi et al., 2002). This increase in rice yields due to K application was associated with increased number of grains per panicle (**Table 1**) and a reduced percentage of unfilled grains (**Table 2**). Application of K increased total plant K at maturity ($p \le 0.001$) by 21 to 29 kg/ha across the five locations (**Table 1**), while the increase in total plant S ranged from 1.3 to 2.8 kg/ha (**Table 2**).

Highest yield of rice was obtained when K was applied with S + Zn (**Table 1**). Application of K, S and Zn with FFP increased rice grain yields by 1.1 t/ha at Fatehgarh Sahib, 1.2 t/ha at Meerut, 1.4 t/ha at Banda, 0.9 t/ha at Barabanki, and 1.4 t/ha at Bhagalpur vis-à-vis FFP alone. Singh et al. (2008)

Table 2. Effect of potassium and sulphur plus zinc (M) application on grain filling and uptake of nutrients by rice and grain yield and the uptake of nutrients for wheat at five locations in northern India.

Parameter	Fatehgarh Sahib	Meerut	Banda	Barabanki	Bhagalpur
Rice unfilled grain (%)					
No K	12	10	11	10	12
+K	10	6	5	8	10
Difference[†]	-1.8ns	-4.5***	-5.4***	-1.3*	-2.7***
No M	12	9	9	10	11
+M	9	7	7	9	11
Difference[‡]	-2.9***	-2.3***	-1.7**	-1.0ns	-1.0ns
Total S in rice (kg/ha)					
No K	24	23	12	20	15
+K	26	25	15	22	17
Difference	1.3***	2.2***	2.8***	1.7**	2.4***
No M	20	20	10	16	12
+M	30	28	17	25	21
Difference	10.8***	8.4***	7.4***	9.1***	9.3***
Rice grain zinc (mg/kg)					
No K	32	32	34	31	33
+K	32	32	34	32	34
Difference	0.2ns	0.2ns	0.0ns	0.7*	0.9**
No M	29	30	30	28	30
+M	35	35	38	34	37
Difference	6.3***	5.2***	7.3***	6.0***	6.3***
Wheat grain yield (t/ha)					
No K	4.6	4.3	2.5	3.7	2.5
+K	4.8	5.0	2.9	4.1	3.2
Difference	0.2***	0.7***	0.4***	0.3***	0.7***
No M	4.6	4.4	2.6	3.8	2.6
+M	4.8	4.8	2.9	4.0	3.0
Difference	0.2***	0.4***	0.3***	0.3***	0.4***
Total K in wheat (kg/ha)					
No K	101	80	51	74	50
+K	114	99	64	93	68
Difference	13.8***	18.7***	13.3***	19.8***	17.8***
No M	108	86	55	81	56
+M	107	93	60	86	62
Difference	-0.1ns	7.5***	5.8***	4.1**	6.4***
Total S in wheat (kg/ha)					
No K	25	23	13	18	13
+K	26	27	14	20	16
Difference	0.4*	3.7***	1.8***	1.9***	3.7***
No M	20	20	10	15	11
+M	31	29	17	24	18
Difference	11.4***	9.0***	6.9***	9.8***	6.7***
Wheat grain zinc (mg/kg)					
No K	30	31	33	30	32
+K	30	31	33	30	33
Difference	0.5ns	0.4ns	0.3ns	-0.1ns	0.3ns
No M	27	29	29	26	29
+M	33	34	37	34	36
Difference	5.7***	5.0***	7.8***	7.4***	6.8***

[†] Difference between non-rounded means for two no K treatments (no application of K, S or Zn and application of S + Zn) and two +K treatments (application of K only and application of K with S + Zn).

[‡] Difference between non-rounded means for two no M treatments (no application of K, S or Zn and application of K only) and two +M treatments (application of S + Zn only and application of K with S + Zn).

ns = Not significant at $p \leq 0.05$, * = Significant at $p \leq 0.05$, ** = Significant at $p \leq 0.01$, and *** = Significant at $p \leq 0.001$.

The K×M×location interaction was not significant at $p \leq 0.05$ for all the listed parameters.

observed K, S and Zn deficiencies for rice in on-station and researcher-managed trials in the IGP and also documented the benefits of K, S and Zn in farmers' fields across the IGP from Punjab to Bihar.

Application of S plus Zn (+M) with and without the application of K increased rice yields by 0.2 to 0.9 t/ha across the experimental locations (**Table 1**). Like with K application, the increase in rice yield due to S + Zn application was associated with increased number of grains per panicle and a reduced percentage of unfilled grains. Shukla and Behra (2001) indicated widespread deficiencies of S and Zn in Indian soils. Application of S + Zn significantly ($p \leq 0.001$) increased the total plant S content by 7.4 to 10.8 kg/ha and the total plant Zn content by 76 to 103 g/ha at maturity across the five locations. This increase in plant Zn corresponded to significant increases ($p \leq 0.001$) in Zn concentrations by 5.2 to 7.3 mg/kg in un-milled rice grain across the five locations. This indicated that a balanced application of Zn can help in increasing yields and the nutritional quality of rice.

Wheat yield with FFP ranged from 4.5 t/ha at Fatehgarh Sahib to 2.3 t/ha at Banda and Bhagalpur (Singh et al., 2013). Application of 63 kg K/ha to wheat following the similar application to rice significantly increased ($p \leq 0.001$) wheat yield by 0.2 t/ha at Fatehgarh Sahib, 0.7 t/ha at Meerut and Bhagalpur, 0.4 t/ha at Banda and 0.3 t/ha at Barabanki (**Table 2**). The increase in wheat yield due to K fertilisation was associated with increased number of wheat grains per spike (2 to 6) at all locations (**Table 1**).

Application of S + Zn to the preceding rice crop and then the application of 30 kg S/ha to wheat crop (+M) significantly increased ($p \leq 0.001$) wheat yields by 0.2 t/ha at Fatehgarh Sahib, 0.4 t/ha at Meerut and Bhagalpur and 0.3 t/ha at Banda and Barabanki (**Table 2**). Like with rice, the application of S to wheat significantly increased the total S content in the wheat plant at maturity by 6.7 to 11 kg/ha. However, the increase in plant Zn content in wheat crop at maturity corresponded to increases ($p \leq 0.001$) in Zn concentration of 5.0 to 7.8 mg/kg in un-milled wheat grain across the five locations despite no Zn application in wheat. This indicated that the residual effect of Zn applied to rice can be sufficient to increase Zn content in grains of the subsequent wheat crop.

System Performance and Financial Returns

The productivity of the RWS measured in terms of rice equivalent yield for the system (SREY) increased significantly with the application of either K or S+Zn at all locations (**Table**

Table 3. Effect of potassium and sulphur plus zinc (M) application on added net return for rice and wheat relative to the farmer's fertiliser practice without added K or M in a rice-wheat system at five locations in northern India.

		Added net return from added nutrients				
		Fatehgarh Sahib	Meerut	Banda	Barabanki	Bhagalpur
Crop	Treatment	₹/ha				
Rice	+K	5,355a	7,830b	8,595b	5,130b	10,485b
Rice	+KM	9,765a	11,160a	12,015a	7,875a	12,645a
Rice	+M	6,075a	5,670c	5,400c	3,240c	7,740c
Wheat	+K	1,305b	9,540b	5,175b	4,545b	9,630b
Wheat	+KM	2,655a	13,995a	9,630a	7,875a	14,400a
Wheat	+M	1,710ab	6,030c	4,500c	3,330c	4,950c

Means within a column for a crop followed by the same letter are not significantly different according to Tukey–Kramer test at $\alpha = 0.05$.

1). Application of K increased SREY by 0.6 to 2.1 t/ha, while the application of S+Zn increased SREY by 0.6 to 1.3 t/ha. Combined application of the three nutrients (K, S and Zn) increased SREY from 1.5 t/ha in Fatehgarh Sahib to 2.7 t/ha in Bhagalpur.

Added net return from applied K and S+Zn was positive for rice and wheat at all locations (**Table 3**). Added net return for rice was lowest with the application of only S+Zn (without K) and highest with the application of K+ S + Zn across all locations, except for Fatehgarh Sahib. Similarly, the added net return in wheat was highest with the application of K with S+Zn across all locations, except Fatehgarh Sahib. Added net return for wheat was greater from the application of only K than only S+Zn at all locations, except Fatehgarh Sahib and Banda. Although yields and yield gains from added nutrients tended to be lower for wheat than rice, the added net return remained high for wheat due to higher values of grain and straw for wheat than for rice and lower fertilisation costs in wheat because zinc was not applied to wheat.

Changes in Soil K Status

In the absence of added K, exchangeable K decreased by 6 to 9 mg/kg and non-exchangeable K decreased by 18 to 30 mg/kg during one rice-wheat cropping cycle (**Table 4**). With K application, exchangeable K increased by 6 to 9 mg/kg and non-exchangeable K increased by 7 to 14 mg/kg. The differences between application of K with FFP and FFP after one rice-wheat cropping cycle ranged from 13 to 18 mg/kg for exchangeable K and 26 to 41 mg/kg for non-exchangeable K across all locations. The decline in soil K without added K highlights the risk of rapid short-term mining of soil K with the farmer's current fertilisation practice of using relatively high rates of N and P with little or no use of K. Long-term cropping with negative K balances has been associated with yield declines in the RWS in South Asia (Bijay-Singh et al., 2003). Although the K-supplying capacity of illite-dominated alluvial soils of the IGP is relatively high, long-term intensive cropping with inadequate application of K can result in K mining leading to large negative balances and depletion of native K reserves (Yadvinder-Singh et al., 2005).

Table 4. Change in soil potassium during one cycle of rice-wheat cropping at five locations in northern India.

Parameter	Fatehgarh Sahib	Meerut	Banda	Barabanki	Bhagalpur
Change in exchangeable K (mg/kg)					
No K	-6	-6	-7	-8	-9
+K	6	7	7	8	9
Difference[†]	13***	13***	14***	17***	18***
Change in non-exchangeable K (mg/kg)					
No K	-30	-22	-19	-26	-18
+K	11	9	7**	14	14
Difference	41***	31***	26***	40***	33**

[†] Difference between non-rounded means for two no K treatments (no application of K, S or Zn and application of S + Zn) and two +K treatments (application of K only and application of K with S + Zn).
ns = Not significant at $p \le 0.05$, * = Significant at $p \le 0.05$, ** = Significant at $p \le 0.01$, and *** = Significant at $p \le 0.001$.
The K×M×location interaction was not significant at $p \le 0.05$ for all the listed parameters.

Summary

Widespread deficiencies of K, S and Zn in the soils of the IGP due to imbalanced and inadequate application of these nutrients have become major constraints for sustained productivity of the RWS. The results of our on-farm experiments distributed across contrasting locations and fields in the IGP established the importance of sufficient use of K, S and Zn along with N and P to match crop needs. Our study clearly showed that the use of K with S+Zn can increase crop yields and productivity of the RWS and provide attractive net economic benefits to farmers. Application of Zn improved grain Zn contents in rice and wheat, which is critical for nutritional security in the region.

Drs. V.K. Singh (e-mail: vkumarsingh_01@yahoo.com), B. Gangwar, V. Govil and S.K. Singh are with the Project Directorate for Farming Systems Research, Modipuram, Meerut, India; Dr. B.S. Dwivedi is with the Division of Soil Science and Agricultural Chemistry, IARI, New Delhi, India; Dr. R.J. Buresh is with IRRI, Metro Manila, Philippines; Dr. M.L. Jat is with CIMMYT, NASC Complex, Pusa, New Delhi, India; and Dr. K. Majumdar is Director, IPNI-South Asia Program, Gurgaon, Haryana, India.

This article is a summary of the paper titled "Potassium Fertilisation in Rice-Wheat System across Northern India: Crop Performance and Soil Nutrients" published in Agron. J. 105:471–481 (2013).

References

Bijay-Singh, Yadvinder-Singh, P. Imas, and J.C. Xie. 2003. Adv. Agron.81:203-259.
Regmi, A.P., J.K. Ladha, E. Pasuquin, H. Pathak, P.R. Hobbs, L.L. Shrestha, D.B. Gharti, and E. Duveiller. 2002. Biol. Fertil. Soils 36:240-247.
Shukla, A.K., and S.K. Behra. 2011. Indian J. Fert. 7(10):14-33.
Singh, V.K., B.S. Dwivedi, A.K. Shukla, Y.S. Chauhan, and R.L. Yadav. 2005. Field Crops Res. 92: 85-105.
Singh V.K., R. Tiwari, M.S. Gill, S.K. Sharma, K.N. Tiwari, A.K. Shukla, and P.P. Mishra. 2008. Better Crops-India 2(1):16-19.
Singh, VK, B.S. Dwivedi, R.J. Buresh, M.L. Jat, K. Majumdar, B. Gangwar, V. Govil, and S.K. Singh. 2013. Agron. J. 105:471-481.
Yadvinder-Singh, Bijay-Singh, and J. Timsina. 2005. Adv. Agron. 85:269-407.

Response of Groundnut to Balanced Fertilisation and Omission of Potassium

By A.K. Mohapatra, Priyambada Parida, S.K. Pattanayak and T. Satyanarayana

On-farm and on-station trials showed that balanced fertilisation (i.e., applying the right rates of N, P, K, S, Zn, B, and Ca) helped in maximising groundnut yield, nutrient uptake, and farmer profitability. Skipping of K application to groundnut for one-season results in a yield loss of 335 kg/ha, in addition to the depletion of about 34 kg/ha of soil K reserves.

Odisha grows oilseed crops covering 0.77 million (M) ha area or 8.7% of the total cultivated area in the state (FAI, 2012). Of the major oilseeds grown in the state, groundnut is the predominant crop covering an area of 0.25 M ha with a production and productivity of 0.42 M t and 1,680 kg/ha, respectively. The state requires an additional oilseed production of 1.4 M t to meet the demand of the projected population increase (45 M by 2020) (Orissa Agriculture Statistics, 2009-10).

The majority of the soils on which groundnut is grown in the state are light-textured, red and acidic soils. These soils are devoid of organic C and exhibit deficiencies of not only NPK, but also of secondary and micronutrients such as S, Zn and B. Groundnut crop with an economic yield of 2.0 to 2.5 t/ha requires about 160 to 180 kg N, 20 to 25 kg P, 80 to 100 kg K, 60 to 80 kg Ca, 15 to 20 kg S, 30 to 45 kg Mg, 300 to 400 g Mn, 150 to 200 g Zn, 140 to 180 g B, and 8 to 10 g Mo (Singh, 1999). Similarly, Mishra (2004) reported that groundnut crop with a yield of 1.8 t/ha removed 212 kg N, 30 kg P, 115 kg K, 75 kg Ca and 15 kg S/ha in the Inceptisols of Bhubaneswar. Unfortunately, the intensity of fertiliser use ($N+P_2O_5+K_2O$) in Odisha is very low at 56.5 kg/ha (i.e., 35.5, 14.9 and 6.1 kg/ha N, P_2O_5 and K_2O, respectively). Satyanarayana and Tewatia (2009) reported that total nutrients added through fertilisers in Odisha account for only 58% of the crop nutrient removal, while fertiliser K added accounts for only about 16% of the K removed by crops. This results in severe mining of nutrients from soils and, especially, a net negative K balance in the state. For example, Motsara (2002) reported that almost one-third of Odisha soils are low in available K. Both under and imbalanced application of fertilisers are probably the reason why researchers have not been able to break the stagnant yield barrier in groundnut (Singh, 1999). It is, therefore, important to understand the response of balanced fertilisation (and especially K responses) in different groundnut-growing regions of Odisha.

Table 1. Details of fertiliser treatments used at different experimental sites.

S. No.	Treatment details	Location	BFT* details for different locations, kg/ha
T_1	BFT*	Bhubaneswar (kharif)	$N_{30}P_{40}K_{60}S_{56}B_{1.5}Zn_{3.3}Ca_{1300}$****
T_2	N omission (T_1 – N)	Jajpur Deoda (kharif)	$N_{30}P_{40}K_{60}S_{56}B_{1.5}Zn_{3.3}Ca_{1300}$
T_3	P omission (T_1 – P)	Bhubaneswar (rabi)	$N_{30}P_{50}K_{60}S_{56}B_{1.5}Zn_{3.3}Ca_{500}$
T_4	K omission (T_1 – K)	Sankaradiha (rabi)	$N_{30}P_{50}K_{60}S_{56}B_{1.5}Zn_{3.3}Ca_{1120}$
T_5	S omission (T_1 – S)	Sankaradiha (rabi)	$N_{30}P_{40}K_{60}S_{56}B_{1.5}Zn_{3.3}Ca_{1200}$
T_6	B omission (T_1 – B)	Bhuban (rabi)	$N_{30}P_{50}K_{60}S_{56}B_{1.5}Zn_{3.3}Ca_{1000}$
T_7	Zn omission (T_1 – Zn)	Bhuban (rabi)	$N_{30}P_{60}K_{60}S_{56}B_{1.5}Zn_{3.3}Ca_{1540}$
T_8	Ca omission (T_1 – Ca)	Sankaradiha (rabi)	$N_{30}P_{60}K_{60}S_{56}B_{1.5}Zn3.3Ca_{1680}$
T_9	RDF** ($N_{20}P_{40}K_{40}S_{45}B_{1.0}Zn_{2.5}Ca_{500}$)	Sankaradiha (rabi)	$N_{30}P_{50}K_{60}S_{56}B_{1.5}Zn_{3.3}Ca_{1000}$
T_{10}	FFP*** ($N_{22.5}P_{72.5}K_{57}$)	Bhuban (rabi)	$N_{30}P_{50}K_{60}S_{56}B_{1.5}Zn_{3.3}Ca_{1000}$

*BFT denotes balanced fertiliser treatment, which varied for each location; **RDF = state-recommended fertiliser rate, which remained constant for all experimental sites; ***FFP = farmers' fertiliser practice, which again remained constant for all experimental sites; ****Calcium (Ca) applied through Paper Mill Sludge (PMS) as the liming material.

Experiments were conducted at the Central Research Station of Orissa University of Agriculture and Technology (OUAT), Bhubaneswar and in the farmers' fields in Dharmasala block of district Jajpur. The replicated station trial was conducted during both kharif and rabi seasons of 2011-12, while one, non-replicated on-farm trial was conducted in village Achutapur during kharif 2011 and seven, non-replicated on-farm trials were conducted in Sankaradiha and Bhuban villages during rabi 2011-12. All experimental soils were analysed for physical and chemical properties before conducting the experiments. All soils were acidic (pH range 4.7 to 6.2) with low OC (range 3.1 to 6.5 g/kg), low N (140 to 180 kg/ha), low to high P (6.7 to 66.8 kg/ha), low to medium K (71 to 208 kg/ha), low S (6 to 10.5 kg/ha), B (0.28 to 0.35 kg/ha), and Zn (0.15 to 0.48 kg/ha). Lime requirement for the different experimental sites varied from 0.48 in Bhubaneshwar to 1.9 t/ha in Bhuban. The experimental treatments were formulated based on the results of this initial soil analysis (**Table 1**). A total of 10 treatments (i.e., one balanced fertilisation treatment (BFT), omission of N, P, K, S, Zn, B and Ca from BFT, one state recommended dose of fertiliser (RDF) and one farmers' fertiliser practice (FFP)) were used at each location. BFT varied across different locations, while RDF and FFP treatments were the same at all the experimental sites. During kharif 2011, groundnut variety Smruti (OG 52-1) was sown during July 16 to 25 at both the locations at a spacing of 30 x 10 cm. During the rabi season, sowing in 8 different locations was completed between November 12 to 16 and the variety TMV-2 was sown at a seed rate of 125 kg/ha. All nutrients were applied at sowing, while 50% Zn as Zn-EDTA was applied at sowing and the remaining 50% was topdressed in 2 equal splits at 45 and 60 days after sowing (DAS). The sources of nutrients used were urea,

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulphur; Mg = magnesium; Mn = manganese; Mo = molybdenum; Zn = zinc; B = boron; Ca = calcium; C = carbon; EDTA = ethylenediamine-tetraacetic acid.

Table 2. Effect of balanced fertilisation and K omission on yield, quality attributes and economics of groundnut.

Treatments	Pod yield, kg/ha	Haulm yield, kg/ha	Yield difference, kg/ha	Oil content, %	Oil yield, kg/ha	Gross return, ₹/ha	Net return, ₹/ha	Benefit:Cost ratio
Kharif groundnut, Bhubaneswar Site 1 (Replicated trial)								
BFT	1,565	756	-	48.6	761	62,600	26,780	1.75
-K	1,246	574	319 (20.4)	47.7	594	49,840	15,142	1.44
RDF	1,068	750	497 (31.7)	46.8	500	42,720	8,928	1.26
FFP	1,060	780	505 (32.3)	45.0	477	42,400	12,719	1.40
C.D. (p = 0.05)	187	135	-	0.89	113			
Kharif groundnut, Deoda, Dharmasala Site 2 (Non-Replicated trial, n = 1)								
BFT	1,355	534	-	44.6	604	54,200	18,380	1.51
-K	1,254	556	101 (7.5)	41.8	524	50,160	15,462	1.45
RDF	1,058	514	297 (21.9)	43.8	463	42,320	8,528	1.25
FFP	1,040	450	315 (23.2)	38.7	402	41,600	11,397	1.38
Rabi groundnut, Bhubaneswar Site 3 (Replicated trial)								
BFT	1,850	1782	-	47.5	879	74,000	38,180	2.07
-K	1,456	2110	394 (21.3)	44.8	652	58,240	23,542	1.68
RDF	1,530	1614	320 (17.3)	45.3	693	51,200	17,408	1.52
FFP	1,466	1830	384 (20.8)	43.1	632	58,640	28,437	1.94
C.D. (p = 0.05)	185	243	-	-	-			
Rabi groundnut, Sankaradiha and Bhuban, Dharmasala Site 4 (Non-Replicated trial, n = 7)								
BFT	2,800	770	-	45.3	-	112,000	76,180	3.13
-K	2,450	750	350 (12.5)	41.1	-	98,000	63,302	2.82
RDF	2,500	740	300 (10.7)	44.0	-	100,000	66,208	2.96
FFP	1,990	660	810 (28.9)	37.8	-	79,600	49,397	2.64
C.D. (p = 0.05)	280	120	-	1.34				

n = number of farmer fields in each site. Values in parentheses are percent decline in yield relative to the balanced fertilisation treatment.
Prices: groundnut = ₹40/kg, N = ₹12/kg, P = ₹30/kg, K = ₹16.7/kg.

DAP and SSP, MOP, Elemental sulphur (S-80) and SSP, Borax, Zn-EDTA and paper mill sludge (PMS) for N, P, K, S, B, Zn and Ca, respectively. During the rabi season, prior to sowing, one pre-sowing irrigation was given for uniform germination. Intercultural operations (hoeing and weeding) were taken up at 15 and 25 DAS. For this paper, only the BFT and K Omission treatment data is presented and compared with RDF and FFP treatments.

Results

Among the treatments used, the average groundnut pod yield decreased in the following order: BFT (2,226 kg/ha) > K omission (1,891 kg/ha) > RDF (1,885 kg/ha) > FFP (1611 kg/ha) (**Table 2, Figure 1**). The BFT recorded significantly higher pod yield of groundnut than any of the other treatments used across all locations and seasons. The mean pod yield of groundnut was higher in the rabi season than in the kharif season. Omission of K led to significant decreases of 319, 101, 394, and 350 kg/ha at Bhubaneswar (Kharif), Deoda (Kharif), Bhubaneswar (Rabi) and Sankaradiha & Bhuban (Rabi), respectively, as compared to the BFT treatment. The corresponding mean reductions in pod yield in the RDF were 32, 22, 17 and 11% of the BFT, while for FFP, these values ranged between 21 to 32% of the BFT. No significant difference in pod yield between RDF and FFP was evident, except for Rabi groundnut grown in farmer fields, and all yield attributes also followed a similar trend (data not shown). The mean pod yield of groundnut was reduced by 15.4, 20.4, and 26.3% due to K omission, RDF and FFP, respectively, across locations. These results indicate the importance of potash nutrition and

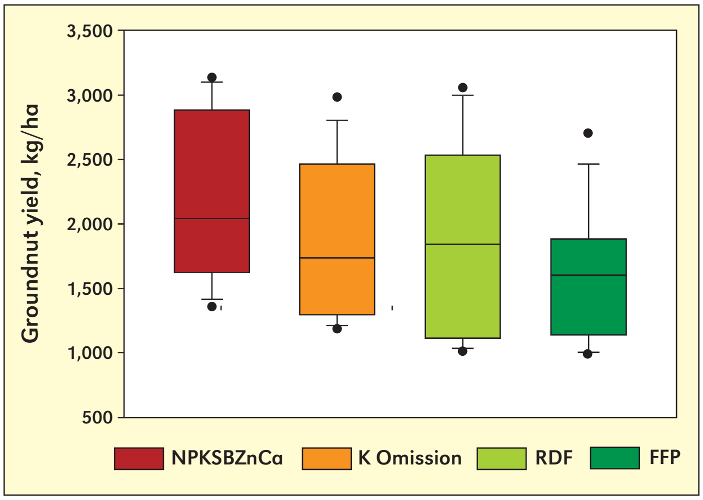


Figure 1. Pod yield of groundnut as influenced by balanced fertilisation and omission of potassium. Boxes represent data within the first and third quartiles (interquartile range). The thin line denotes the second quartile or median. Lines extending beyond the interquartile range denote the 10th to 90th percentile of the data. Statistical outliers are plotted as individual points outside these lines.

Visiting on-station experiment in Bhubaneswar.

Table 3. Total uptake of nutrients (kg/ha) by groundnut as influenced by balanced fertilisation and K omission.

Treatments	N	P	K	S
Kharif groundnut, Bhubaneswar Site 1 (Replicated trial)				
BFT	146.4	7.6	28.3	2.26
-K	137.5	6.2	22.6	1.80
RDF	124.8	6.9	27.4	1.89
FFP	122.0	6.4	26.2	1.97
C.D. (p = 0.05)	5.6	1.6	5.9	0.48
Kharif groundnut, Deoda, Dharmasala Site 2 (Non-Replicated trial, n = 1)				
BFT	139.4	5.8	19.0	1.7
-K	131.0	5.0	15.8	1.2
RDF	130.4	4.4	18.4	1.2
FFP	116.5	4.5	15.4	1.1
Rabi groundnut, Bhubaneswar Site 3 (Replicated trial)				
BFT	144.8	9.7	46.1	8.3
-K	137.7	9.0	31.5	8.3
RDF	135.5	8.3	34.4	8.3
FFP	120.7	9.1	38.6	7.6
C.D. (p = 0.05)	5.6	0.7	3.4	1.0
Rabi groundnut, Sankaradiha and Bhuban, Dharmasala Site 4 (Non-Replicated trial, n = 7)				
BFT	143.6	12.7	49.1	8.7
-K	131.5	9.9	38.1	5.9
RDF	134.6	10.5	41.6	6.5
FFP	114.1	7.0	30.0	5.2
C.D. (p = 0.05)	N.S.	2.0	7.4	1.5

highlight the scope for increasing the production of groundnut through improving the existing nutrient management in RDF and FFP. The authors believe that the nutrient rates in RDF, especially Ca, were not enough to effectively mitigate soil acidity. This is because the Ca applied through PMS in RDF was 500 kg/ha vis-à-vis an average application of 1,164 kg/ha of Ca applied in BFT based on soil testing.

Similar to yields, the BFT recorded higher mean oil content (46.5%) and mean oil yield (748 kg/ha) over the other treatments (**Table 2**). The corresponding values for K omission, RDF and FFP treatments were 44, 45 and 41 % and 590, 552 and 504 kg/ha, respectively. In general, the pod yield, haulm yield, oil content, oil yield and other yield attributing parameters were higher in the rabi season than in the kharif season. This is because the cultivation of groundnut during kharif season is dependent on monsoon rainfall and is often subjected to adverse weather conditions, where there is continuous withdrawal and inadequate supply of nutrients, enhanced leaching and runoff and decreased N_2 fixation in soil.

Economic analysis closely followed the groundnut yield and quality parameters with respect to the treatments used in the study. The BFT gave higher mean gross return of ₹75,700 and a mean net profit of ₹39,880 than all other treatments (**Table 2**). Omission of K from the BFT reduced the net profit by 43, 16, 38 and 17% at Bhubaneswar (kharif), Deoda (kharif), Bhubaneswar (rabi) and Sankaradiha & Bhuban (rabi), respectively. RDF and FFP exhibited the lowest values of economic parameters among all the treatments used.

Table 4. Initial soil K status, K addition, K removal and K balance values as influenced by balanced fertilisation and K omission.

Treatments	Initial soil K, kg/ha	K added through fertiliser, kg/ha	Total K removal, kg/ha	K balance, kg/ha	Post harvest soil K, kg/ha
Kharif groundnut, Bhubaneswar Site 1 (Replicated trial)					
BFT	113	60	28.3	145	98.5
-K	113	0	22.6	90.4	69.4
RDF	113	40	27.4	126	74.6
FFP	113	57	26.2	144	70.5
Kharif groundnut, Deoda, Dharmasala Site 2 (Non-Replicated trial, n = 1)					
BFT	147	60	19.0	188	103
-K	147	0	15.8	131	65.3
RDF	147	40	18.4	169	80.2
FFP	147	57	15.4	189	119
Rabi groundnut, Bhubaneswar Site 3 (Replicated trial)					
BFT	127	60	46.1	141	110
-K	127	0	31.5	96	72.3
RDF	127	40	34.4	133	111
FFP	127	57	38.6	145	80.6
Rabi groundnut, Sankaradiha and Bhuban, Dharmasala Site 4 (Non-Replicated trial, n = 7)					
BFT	104	60	49.1	115	159
-K	104	0	38.1	66	128
RDF	104	40	41.6	103	143
FFP	104	57	30.0	131	105

Total nutrient uptake was significantly influenced by the balanced application of nutrients. The highest total uptake of N (139 to 146 kg/ha), P (6 to 12 kg/ha), K (19 to 49 kg/ha) and S (1.7 to 8.7 kg/ha) were recorded with BFT (**Table 3**). This could have resulted in higher yields with BFT vis-à-vis the other treatments. The highest average yield of 1,893 kg/ha was obtained with removal of 76 kg N, 4.7 kg P, 18.8 kg K, and 2.7 kg S per tonne of groundnut pod yield. A significantly lower total uptake of nutrients under K omission, RDF and FFP as compared to BFT suggests that limitation of one nutrient in the soil affects the uptake of other nutrients. Total N, P, K, and S uptakes in the K omission treatment were 7, 16, 24 and 18% lesser, respectively, than the corresponding total uptakes observed in BFT.

With an average initial soil K status of 123 kg/ha, the average K balances after harvest of groundnut in BFT, K omission, RDF and FFP treatments were 147.2, 95.6, 132.4 and 152.3 kg/ha, respectively (**Table 4**). However, the average post harvest soil K status in BFT, K omission, RDF and FFP treatments were 117.7, 83.8, 102.1 and 93.9 kg/ha, respectively. This indicated a corresponding K mining of 5.3, 39.2, 20.9 and 29.1 kg/ha, respectively.

Summary

Results from our experiments clearly showed that practicing balanced fertilisation significantly improved groundnut yield and economics over the existing state recommendations and farmers' fertiliser practice. Balanced application of nutrients could increase the groundnut yield by almost 30% from the current yield levels in farmer fields with consequent increase in farmer profits. Skipping of K application to groundnut for one-season results in a yield loss of 335 kg/ha, in addition to the depletion of about 34 kg/ha of soil K reserves. Thus, balanced fertilisation offers hope to break the stagnating yield barrier of groundnut in Odisha.

Dr. Ashok Kumar Mohapatra is Professor, Department of Agronomy, Ms. Priyambada Parida is Research Scholar, Dept. of Agronomy, Dr. Sushanta Kumar Pattanayak is Professor, Dept. of Soil Science and Agricultural Chemistry, Orissa University of Agriculture and Technology (OUAT). Dr. Satyanarayana is Deputy Director, IPNI South Asia Program; e-mail: tsatya@ipni.net.

References

FAI. 2012. Fertiliser Statistics, Fertiliser Association of India, FAI House. New Delhi.

Mishra, M. 2004. Response of crops to graded doses of lime added with or without FYM. M. Sc. Thesis submitted to OUAT.

Motsara, M.R. 2002. Fert. News. 47(8):15-21.

Orissa Agriculture Statistics 2009-10. Published by Department of Agriculture and Food Production. Government of Orissa, Bhubaneswar.

Satyanarayana, T. and R.K. Tewatia. 2009. *In*, The proceedings IPI-OUAT-IPNI International symposium on "Potassium role and benefits in improving nutrient management for food production, quality and reduced environmental damages", OUAT, Bhubaneshwar, Orissa. pp. 467- 485.

Singh, A.L. 1999. *In* Mineral nutrition of groundnut In Advances in plant physiology (ed. A Hemantranjan), vol. II. Scientific publishers (India), Jodhpur, India. pp.161-200.

Potassium Response in Rice-Maize Systems

By J. Timsina, V.K. Singh and K. Majumdar

Emerging data from on-farm and on-station experiments in the rice-maize systems in India and Bangladesh have revealed very high system productivity and high responses of maize and rice to applied K. These results suggest that higher K deficits and higher fertiliser K requirement are to be anticipated in the region's R-M systems.

Rice-maize (R-M) systems are vital to meet food requirements and improve food security for a large number of urban and rural poor in South Asia. Rice-maize systems are distributed all over South Asia and currently occupy more than 3 million (M) ha in Asia (Timsina et al., 2010). The spread of the R-M system in South Asia has been driven by the rising demand for maize, especially by the poultry sector, and the tightening of world export-import markets. The more recent development of short-duration rice varieties and maize hybrids with improved drought tolerance is also giving rise to opportunities for the expansion of R-M systems into areas of South Asia with insufficient irrigation or rain for continuous rice cultivation.

Table 1. On-farm productivity of rice, maize and R-M system (t/ha) as influenced by SSNM under R-M system at Sabour, Bhagalpur, Bihar.

Treatment	Rice yield	% Increase over FFP	Maize yield	% Increase over FFP	System-level maize equivalent yield, SMEY
FFP*	5.21	-	6.75	-	12.49
FFP+K_{62}	7.01	35	7.58	12	15.31
FFP+K_{62}+S_{40}+Zn_5	8.23	58	8.06	19	17.13
FFP+S_{40}+Zn_5	6.07	17	7.26	8	13.95
C.D. ($p \leq 0.05$)	0.83	-	0.54	-	1.23

*FFP=80 kg N/ha and 23 kg P/ha in rice and 100 kg N/ha and 23 kg P/ha in maize; data are means of 12 farmers fields. Source: AICRP-CS Report (2007-10).

Table 2. Changes in soil K content (mg/kg) due to K application after one R-M cycle at Sabour, Bhagalpur, Bihar.

	FFP*	FFP+K_{62}	FFP+ K_{62}+S_{40}+Zn_5	FFP+ S_{40}+Zn_5
Initial	102.3	102.3	102.3	102.3
After 1 R-M Cycle	97.3	111.2	107.3	96.1
Change over initial	-5.0	8.9	5.0	-6.2

*FFP = farmer fertiliser practice; Source: AICRP-CS Report (2007-10).

The high yielding cultivars and the growing environments of rice (anaerobic) and maize (aerobic) crops have a profound effect, particularly, on K nutrition in R-M systems. Soil solution K is kept at relatively high levels in flooded rice soils. This is because large amounts of soluble Fe^{++}, Mn^{++} and NH_4^+ ions brought into solution displace cations from the clay complex and release exchangeable K into the soil solution. The displacement of K from the exchange complex, however, ceases on the return to aerobic conditions prevalent during maize planting. In fields with adequate drainage, K and other basic cations are lost via leaching. Leaching losses of K can be substantial in highly permeable soils with low cation exchange capacities. Yadvinder-Singh et al. (2005) found that leaching losses of K were 22 and 16% of the applied K in sandy loam and loamy soils, respectively, that were maintained at submerged moisture regimes. For Bangladesh, such losses can be as high as 0.1 to 0.2 kg K/ha/d (Timsina and Connor, 2001). Despite often having a relatively large total K content, the K nutrition of R-M systems grown on the soils of South Asia is not assured, because many heavy textured alluvial floodplain Terai soils of Nepal and northern and eastern India, and soils of Bangladesh contain vermiculite, illite, or other K-fixing minerals (Dobermann et al., 1996, 1998).

Three on-farm experiments in India and Bangladesh and one on-station experiment in India were carried out to elucidate the critical role of K in the sustainability of R-M systems in South Asia.

On-farm Trials at Bhagalpur, Bihar

Twelve on-farm trials were conducted during 2006-07 in Sabour, District Bhagalpur (25°15'N, 87°1'E) of Bihar state. Four treatments were compared: i) farmers' fertiliser practice (FFP), ii) FFP+ 62 kg K/ha (FFP+K_{62}), iii) FFP+K_{62}+40 kg S/ha+5 kg Zn/ha (FFP+K_{62}+S_{40}+Zn_5), and iv) FFP+S_{40}+Zn_5. The same rate of K was applied to both crops, while S and Zn were applied to rice only. The average use of fertiliser by farmers of the locality was 80 kg/ha N and 23 kg/ha P in rice and 100 kg/ha N and 23 kg/ha P in maize, while K application was negligible.

Inclusion of K in the FFP significantly ($p \leq 0.05$) increased rice yield by 1.8 t/ha and in the FFP+S+Zn treatment by 3.02 t/ha (**Table 1**). Application of 62 kg/ha K increased ($p \leq 0.05$) maize yield over FFP by 0.83 t/ha and over FFP+S+Zn by 1.31 t/ha. The productivity of R-M, measured in terms of maize equivalent yield for the system (SMEY), increased significantly with K or with the combined use of K+S+Zn. Use of 62 kg K/ha over FFP produced additional SMEY of 2.82 t/ha ($p \leq 0.05$). With K+ S+Zn, on the other hand, the SMEY increased by 4.64 t/ha compared to the applications of individual nutrients.

Soil exchangeable K (K_{ex}) content improved with K fertilisation alone (13.9 mg/kg) or in combination with S and Zn (10 mg/kg), whereas a moderate decline in K_{ex} (1.2 mg/kg) was noticed with S+Zn application over FFP. Application of K or K+S+Zn in R-M enhanced K_{ex} (8.9 mg/kg) as compared to the initial content (5.0 mg/kg) (**Table 2**). On the other hand, omission of K from the fertiliser schedule resulted in a decline of K_{ex} (-5.0 to -6.2 mg/kg). The decline in K content under K omission revealed that higher rates of N (>180 kg/ha) and optimal to sub optimal rates of P (46 to 64 kg P_2O_5) used by farmers encouraged K mining from soil. Thus, adequate K input was essential to prevent or at least mitigate this adverse effect of

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Fe = iron; Mn = manganese; Zn = zinc; NH_4^+ = ammonium; K_{ex} = soil exchangeable K; AE_N, AE_P, AE_K = Agronomic efficiency of N, P, or K.

Table 3. On-farm yield (t/ha) and agronomic efficiency (kg grain/kg nutrient) with N, P and K applications in rice and maize under R-M system in Bangalore, Karnataka, India.

Treatment	2008-09	2009-10	Treatment	2008-09	2009-10
	- - Rice yield - -			- - Maize yield - -	
Control	2.23	2.50	Control	1.98	2.45
N_{100}	2.94	3.69	N_{150}	2.87	3.49
$N_{100}\ P_{22}$*	3.36	5.22	$N_{150}\ P_{33}$	4.29	5.27
$N_{100}\ K_{42}$*	3.26	4.78	$N_{150}\ K_{33}$	3.87	4.67
$N_{100}\ P_{22}\ K_{42}$	4.26	5.80	$N_{150}\ P_{33}\ K_{33}$	6.22	7.09
C.D. ($p \leq 0.05$)	0.22	0.24	C.D. ($p \leq 0.05$)	0.28	0.2
Agronomic efficiency			Agronomic efficiency		
N over control	7.1	11.9	N over control	7.9	6.9
P over N	19.1	69.5	P over N	43.0	53.9
K over N	7.6	26.0	K over N	30.3	35.8
P over NK	45.5	46.4	P over NK	71.2	73.3
K over NP	21.4	13.8	K over NP	58.5	55.2

*Indicated rates of P and K were P_2O_5 (22) and K_2O (42) applied to both crops. Source: AICRP-IFS report (2009-11); data are means of 24 farmers fields in each year.

imbalanced fertiliser use.

On-farm Trials at Bangalore, Karnataka

Twenty-four on-farm trials (each in 2008-09 and 2009-10) were conducted in Bangalore (12°8'N, 77°37'E), Karnataka with five treatments (control; 100 kg/ha N; 100 kg/ha N and 22 kg/ha P_2O_5; 100 kg/ha N and 42 kg/ha K_2O; 100 kg/ha N, 22 kg/ha P_2O_5 and 42 kg/ha K_2O). Results showed that the application of recommended doses of NPK (100, 22, 42 kg N, P_2O_5 and K_2O, respectively) to rice produced grain yields of 4.26 and 5.80 t/ha during 2008-09 and 2009-10, respectively (**Table 3**). Omission of P and K fertilisers caused yield losses of 0.6 to 0.9 t/ha and 1.0 to 1.02 t/ha, respectively. AE_K was between 13.8 to 21.4 kg grain/kg of K. Similar response to K over N alone was 7.6 to 26 kg/kg for K.

Like rice, the maize grain productivity was maximum in plots treated with the recommended doses of NPK (6.22 to 7.09 t/ha). Omission of K resulted in significant ($p \leq 0.05$) yield losses of 1.82 to 1.93 t/ha over the two years (**Table 3**). At these response levels, AE_K was 55.2 to 58.5 kg/kg, respectively. These results agreed closely with another on-farm study by Majumdar et al. (2012) in which yield losses due to the omission of K application to rice and maize were 90 to 1,806 kg/ha (mean = 622 kg/ha) and 140 to 1,320 kg/ha (mean = 700 kg/ha), respectively. Considerable increases in AE_N and AE_P due to K application were observed in this experiment. Synergistic effects of balanced fertilization were earlier reported by Tiwari (2002), which revealed that efficiency of applied N and P increased with increasing initial available K status of soils. Thus, to obtain full benefit from P fertilisation and to maintain high soil K status, adequate K supply should be ensured.

On-station Experiment at Bhagalpur, Bihar

Nutrient management in the R-M system was investigated under on-station situation at Sabour, Bhagalpur (25°15'N, 87°1'E), Bihar from 2006-07 to 2008-09. Eight treatments were compared: 3 levels of P_2O_5 (0, 30 and 60 kg/ha) and 3 levels of K_2O (0, 50 and 100 kg/ha) to both crops; 4 levels of S (0, 20, 40 and 60 kg/ha) to rice only; and 150 kg N/ha to both crops. The results revealed that the application of 150 kg N, 30 or 60 kg P_2O_5, and 100 K_2O to each crop along with 40 kg/ha S application in rice gave highest productivity of the individual crops and of the system. Gradient rates of K application brought significant yield gains over K omission in both crops as well as for the total system (**Table 4**). Total N, P and K uptake increased with increasing K application rate in rice crop, maize crop, and in the R-M system in this experiment (Timsina et al., 2013). Application of 50 kg K_2O/ha led to a significant ($p \leq 0.05$) increase in total uptake of N and K over K omission. The magnitude of these increases were 15.1, 21.6 and 18.6% for N and 31.2, 20.1, and 25.2% for K in rice, maize, and the R-M system, respectively (Timsina et al., 2013). On the other hand, increase in total P uptake was significant ($p \leq 0.05$) only at 100 kg/ha K_2O application compared with K omission. Thus, balanced fertilization with K not only increased rice and maize productivities, but also helped to mitigate N and P stresses by increasing uptake of these nutrients.

Table 4. Productivity of rice, maize and R-M system (t/ha) as influenced by different site-specific nutrient management (SSNM) options at Sabour, Bhagalpur, Bihar (mean of 3 years).

Nutrient rates, kg/ha	Rice	Maize	System-level maize equivalent yield (SMEY)
$N_{150}\ P_{30}\ K_{100}\ S_{40}$	7.42	7.99	16.16
$N_{150}\ P_{60}\ K_{100}\ S_{40}$	7.78	8.55	17.13
$N_{150}\ P_{0}\ K_{100}\ S_{40}$	6.38	6.91	13.94
$N_{150}\ P_{30}\ K_{50}\ S_{40}$	7.19	7.72	15.65
$N_{150}\ P_{30}\ K_{0}\ S_{40}$	6.16	6.71	13.49
$N_{150}\ P_{30}\ K_{100}\ S_{60}$	7.46	8.18	16.39
$N_{150}\ P_{30}\ K_{100}\ S_{20}$	6.96	7.65	15.33
$N_{150}\ P_{30}\ K_{100}\ S_{0}$	6.66	7.49	14.83
SR*	6.32	7.40	14.37
FFP**	5.03	6.55	12.10
C.D. ($p \leq 0.05$)	0.61	0.67	1.54

*SR=state-recommend rates of nutrient application; **FFP = farmer fertiliser practice; Indicated rates of P and K were as P_2O_5 and K_2O and S was applied to rice crop only. SR = 100 kg N, 40 kg P_2O_5 and 20 kg K_2O/ha in rice and 120 kg N, 75 kg ha P_2O_5 and 50 kg K_2O/ha in maize; FFP = 70 kg N, 35 kg P_2O_5 and 10 kg K_2O/ha in rice and 100 kg N, 30 kg P_2O_5 and 20 kg K_2O/ha in maize. Source: AICRP-CS Report (2007-10).

Agronomic and recovery efficiencies of P were greater when 100 kg K_2O was applied along with N, P and S. This indicates that balancing K supply in the fertilisation schedule improves the efficiency of other nutrients (Timsina et al., 2013). These results are consistent with the findings of other workers (Dwivedi et al., 2011; Tiwari et al., 2006). Application of gradient rates of K improved the exchangeable K content in the soil after three cycles of rice-maize cropping, with more than 12% increase in exchangeable K content at 100 kg K_2O per ha application rate (data not shown). However, the highest contents of available N,

Table 5. Grain yield (t/ha) of winter maize grown after rice in omission plot trials, ACIAR R-M and IPNI project sites, Bangladesh.*

	------ 2009-10 ------			------ 2010-11 ------		
Treatment	Comilla (n=18)	Rajshahi (n=9)	Rangpur (n=5)	Comilla (n=17)	Rajshahi (n=17)	Rangpur (n=8)
-K	5.3	7.8	7.5	3.4	6.7	6.0
NPK	8.3	9.3	8.3	9.0	8.8	8.1
NK Low P	8.0	8.2	7.7	8.7	8.0	6.0
NP Low K	7.9	8.5	7.3	9.0	7.7	5.8
N Low PK	7.9	8.8	6.8	8.8	7.7	5.7
C.D. ($p \le 0.05$)	0.8	0.6	1.2	0.7	0.5	0.9

*N, P_2O_5, and K_2O rates for the full NPK treatment were 240, 170 and 240 kg/ha, respectively. Low P and low K rates were 100 and 170 kg/ha P_2O_5 and K_2O, respectively.

Olsen-P and extractable S were recorded in the no-K treatment, where the K_{ex} content was lowest. Greater mining of soil N, P and S due to increased biomass production and higher uptake of N, P and S content with +K compared with no-K could be the reason for the decline in soil N, P and S contents.

On-farm Trials in Bangladesh

Site-specific nutrient management (SSNM) studies in R-M systems were conducted from 2008 to 2011 in several farmers' fields in three districts of Bangladesh, viz., Comilla, Rajshahi and Rangpur. At all these sites, winter maize was planted after monsoon rice. Exchangeable K contents in soils at Comilla and Rajshahi were 0.15 and 0.19 cmol/kg (more than the critical level of 0.1 cmol/kg for lowland rice and less than 0.2 cmol/kg for upland crops), while soils at Rangpur contained a very high level of K (0.32 cmol/kg).

On-farm omission plot trials with winter maize after rice showed that omission of K decreased maize yields significantly at all sites in both years, with the highest reduction observed at Comilla (**Table 5**). The yields were maintained or just slightly reduced with the application of a low level of K (~70% of the full rate). Interestingly, for both years of the experiment, the soil test available K poorly explained the yield of maize in –K treatments (Timsina, unpublished data).

The response of maize to applied N, P and K varied for both years, and was variable among farmers' fields within a district in each year. In 2009-10, there was more than 3 t/ha response to K in more than 60% of the farms at Comilla, while, in the other two districts, a similar response was only observed in about 20% of the farms. In 2010-11, all fields at Comilla and 50 to 60% fields in the other two districts showed >3 t/ha response (data not shown). Comilla had the lowest level of soil K_{ex}, and therefore, the response to K application was highest. In both years, the AE_K varied widely across districts as well as across farmers' fields within a district. In individual fields, AE_K ranged from 0.2 to 29.4 kg grain/kg K applied in the first year of the experiment and from 0 to 38.3 kg grain/kg K applied in the second year. The mean AE_K in the three districts ranged from 4.1 (Rangpur) to 15.4 kg grain/kg K applied (Comilla) in the first year and from 10.1 (Rangpur) to 28.2 kg grain/kg K applied (Comilla) in the second year (data not shown). These results demonstrate high variability in grain yield of winter maize grown after rice across farmers' fields in Bangladesh and also remarkably high yield response to K in all districts, especially in Comilla. Comilla is also the district with the lowest level of soil exchangeable K and the highest AE_K. Under these conditions, if K fertiliser is not applied to winter maize as per crop demand, a tremendous yield loss accompanied by a decline in soil K supplying capacity will occur causing loss of sustainability of R-M systems.

Summary

The emerging R-M system in South Asia offers a major challenge to maintaining K balance in the soil for two main reasons: a) the ecosystems in which the R-M systems thrive (eastern and southern India, Bangladesh, Nepal, and parts of Pakistan) do not have high K content in irrigation water and b) the retention of residues of rice and maize in the field is not a common practice. Additionally, the dry matter yield of the R-M system is usually much higher than that of Rice-Rice and Rice-Wheat that leads to higher extraction of nutrients from the soil. In the absence of residue retention practices, large amounts of K are exported out of the field with harvested product and the residues. This suggests that higher K deficits and fertiliser K requirement are to be anticipated in the R-M system, and that field-specific application of K and retaining some amount of crop residues will be required to maintain and improve crop yield and soil K fertility. BC-SA

Dr. Timsina was with International Rice Research Institute, Bangladesh Office, Dhaka, Bangladesh. Dr. Singh is National Fellow at the Project Directorate for Farming Systems Research, Modipuram, Meerut; e-mail: vkumarsingh_01@yahoo.com. Dr. Majumdar is Director, International Plant Nutrition Institute, South Asia Program, Gurgaon, Haryana; e-mail: kmajumdar@ipni.net.

This article is a summary of the paper titled "Potassium Management in Rice-Maize Systems in South Asia" published in J. Plant Nutr. Soil Sci.176:317-330 (2013).

References

AICRP-CS Reports. 2007-10 & 2009-11: All India Coordinated Research Project on Cropping Systems Annual Report (2007-11), Project Directorate for Cropping Systems Research Modipuram, Meerut, India.

Dobermann, A., K.G. Cassman, C.P. Mamaril, and J.E. Sheehy. 1998. Field Crops Res. 56:113-138.

Dobermann, A., K.G. Cassman, P.C. Sta Cruz, M.A. Adviento, and M.F. Pampolino. 1996. Nutr. Cycling Agroecosyst. 46:11-21.

Dwivedi, B.S., V.K. Singh, and V. Kumar. 2011. J. Farming Systems Res. Dev. 17(1&2):1-14.

Majumdar, K.A. Kumar, V. Shahi, T. Satyanarayana, M.L. Jat, D. Kumar, et al. 2012. Indian J. Fert. 8 (5):44-53.

Timsina, J. and D.J. Connor. 2001. Field Crops Res. 69:93-132.

Timsina, J., M.L. Jat, and K. Majumdar. 2010. Plant Soil 335:65-82.

Timsina, J., V.K. Singh, and K. Majumdar. 2013. J. Plant Nutr. Soil Sci. 176:317-330.

Tiwari, K.N. 2002. Fert. News 47(8):23-49.

Tiwari, K.N., S.K. Sharma, V.K. Singh, B.S. Dwivedi, and A.K. Shukla. 2006. PDCSR, Modipuram and PPIC-India Programme, Gurgaon, India, pp. 92.

Yadvinder-Singh, R.P.S. Pannu, Bijay-Singh. 2005. J. Ind.Soc. Soil Sci. 53:207-213.

Response to Potassium in the Rice-Wheat Cropping System of Red and Lateritic Soils

By Sourov Chatterjee, Sudarshan K. Dutta, Kaushik Majumdar, Probir Kr. Saha

West Bengal soils, thought to be rich in K, showed a significant increase in grain yield of rice and wheat with K addition over the existing fertilisation practice. Improved K fertilisation is required to reduce the current rice and wheat yield gap that exists between West Bengal and other parts of the Indo-Gangetic Plain.

In India, the rice-wheat crop rotation is the dominant cropping sequence in the Indo-Gangetic plain (IGP) and is important for the food security of the region (Ladha et al., 2003; Yadav et al., 2000). Approximately 9.8 million hectare (M ha) is under this cropping system and contributes about 23% of the total food grain production in the country. However, yield stagnation, and in some cases, decline in the productivity and sustainability of this system has become a major concern (Singh et al., 2013). Compared to the average rice and wheat yield from other parts of the IGP, the productivity is less in the case of West Bengal. For example, average productivity of rice and wheat could reach up to 6.8 t/ha and 5.4 t/ha, respectively, in the northwestern part of the IGP (Ladha et al., 2000; Timsina and Connor, 2001). However, the average rice and wheat yield at Birbhum district of West Bengal are 2.8 t/ha and 2.5 t/ha, respectively (http://drd.dacnet.nic.in). Therefore, there is a potential to increase the rice and wheat yield by 1.5 to two-fold in the rice- wheat cropping system of West Bengal.

A number of experiments conducted by the Agricultural universities and state-government research organisations in West Bengal have shown that there is a major depletion of K under different cropping sequences due to inadequate or no application of this nutrient. It has been shown earlier that the K balance ranged from -123 kg/ha in rice-rice cropping sequence to -310 kg/ha in rice-potato-sesame cropping sequence (Chatterjee and Sanyal, 2007) in West Bengal. This highlights the mining of the native soil K reserve at present farmers' fertilisation practices (FFP). In particular about 70% of the soil of Birbhum District is K deficient (Government of West Bengal in 2009).

The present study was undertaken to evaluate the variability in indigenous K supply capacity of soils in the wheat-rice system under red and lateritic soils in some selected farm sites of West Bengal. Specific objectives of the study were:

i) comparing grain yield achieved by FFP with recommendations provided by State government.
ii) assessing agronomic parameters of limiting nutrients using comparative omission plot study.
iii) determining plant uptake of K across different treatments for three consecutive years.

The experiment was set up at the Zonal Adaptive Research Station, Nalhati, West Bengal. The site is located in the lower Gangetic Plain at 24.29° N latitude and 87.84° E longitude. The area falls under the hot, dry sub-humid zone, 60 m above mean sea level. The soil of the experimental location is very deep, well-drained, clay loam, generally mixed Hyperthermic Typic Haplustalfs to Haplustepts, having moderate water holding capacity, acidic pH, and low fertility status. Wheat (var. K–9107) and rice (var. MTU–7029) were grown in a sequence starting from rabi 2009 with wheat cultivation followed by rice in kharif 2010; the experiment was continued for three consecutive years (2009-2012). The treatment plots included: a) 100% application of state-recommended (SR) fertiliser NPK rates (120-60-60 kg N-P_2O_5-K_2O/ha for wheat and 80-40-40 kg/ha for rice), b) omission of K from the SR (-K), and c) FFP (70-48-48 kg/ha for wheat and 90-39-39 kg/ha for rice) (**Table 1**). The treatments were replicated three times.

Dr. Dutta (center) and Dr. Chatterjee (right) investigating a wheat field for any potential nutrient deficiencies.

Spatial Variation in Grain Yields

Rice and wheat grain yields were significantly ($p \leq 0.05$) higher in the SR plots compared to the FFP plots as well as the

Table 1. Details of the experimental trial conducted

Location: Z.A.R.S., Nalhati. Plot size: 5 m x 5 m		
	Wheat	Rice
Variety	K-9107	MTU-7029
Seed rate, kg/ha	100	50
Spacing, cm x cm	20 x continuous	20 x continuous
Time of sowing	Within December	Within June
Yield target	5 t/ha	7 t/ha
Plant Protection	Need based	Need based
Water management	Continuous submergence up to 5-8 cm depth for rice and for wheat irrigation was provided as per recommendations.	
Fertiliser recommendation, kg N-P_2O_5-K_2O/ha		
State Recommendation	120-60-60	80-40-40
Farmer's practice	70-48-48	90-39-39

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

Table 2. Different agronomic parameters of wheat crop in different treatment plots.

Treatments	No. of earhead/m^2	No. of grains/ earhead	1000 grain weight, g	AE$_K$
		2009		
-K	240	33	28.6	12.8
SR	241	35	32.3	–
FFP	238	35	31.4	–
C.D. (p = 0.05)	7.4	3.1	NS	–
CV (%)	1.9	6.0	–	–
		2010		
-K	219	34	28.8	12.7
SR	225	36	31.6	–
FFP	223	34	31.3	–
C.D. (p = 0.05)	5.8	2.7	NS	–
CV (%)	1.7	4.9	–	–
		2011		
-K	210	32	29.8	18.2
SR	242	39	31.2	–
FFP	237	36	30.9	–
C.D. (p = 0.05)	6.4	2.1	NS	–
CV (%)	1.4	6.3	–	–

-K indicates potassium omission plot; SR indicates state-recommended fertiliser recommendation; FFP indicates farmer fertilisation practice; C.D. (p = 0.05) indicates critical difference at 5% level of significance, and CV (%) is the coefficient of variation.

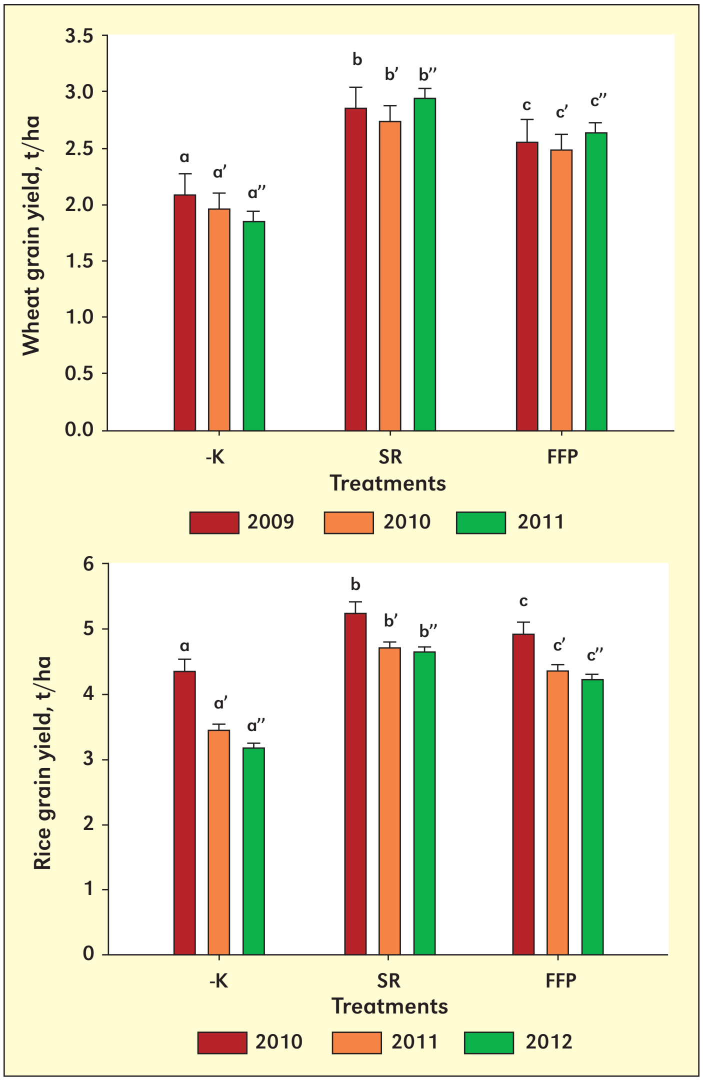


Figure 1. Average grain yields of wheat (top) and rice (bottom) in three years in the different treatment plots of the study. (–K indicates potassium omission plot, SR indicates state-recommended fertiliser recommendation, and FFP indicates farmer fertilisation practice.)

K omission plots (-K) across three consecutive years (**Figure 1**). The increased rice grain yields in SR vis-à-vis FFP (with almost similar nutrient application rates) were probably due to the residual effect of higher nutrient application in previous wheat. Omission of K significantly reduced grain yield of rice and wheat by about 1.5 to 2 t/ha compared to the NPK and FFP plots. This is an interesting observation considering the common belief that West Bengal soils are rich in K and may not require external K application.

Temporal Variation in Grain Yields

The grain yield of wheat and rice decreased significantly ($p \leq 0.05$) in the omission plots from first year of study to the third year of study (**Figure 1**). This decrease could be attributed to the depletion in soil K supply capacity in the treatment plots. It is obvious that the indigenous K supplying capacity of the soil depleted under continuous rice-wheat cropping with no external supply of K. Moreover, similar rates of N, P_2O_5 and K_2O applications in the SR and FFP plots decreased rice grain yield over three years; however, the same temporal effect was not observed in wheat, probably because wheat plots received more nutrient application compared to rice (**Table 1**).

Agronomic Parameters

There were temporal differences in various agronomic parameters (e.g., number of earheads/m^2, number of grains/earhead, 1000 grain weight (g) etc.) within SR, FFP and K omission plots that led to the differences in final grain yield (**Table 2**). In the case of rice, the agronomic parameters such as plant height, number of tillers per plant, number of panicles/m^2, and grains per panicle were higher in the SR plots compared to that in FFP and K omission treatments (**Table 3**). The agronomic efficiency of K (AE$_K$) for both wheat and rice were calculated based on the following equation (Cassman et al., 1996):

AE$_K$ = (Grain yield in 100% NPK Plot – Grain Yield in K Omission Plot) / Amount of K applied in 100% NPK plot.

AE$_K$ increased over time (i.e., from the first year to the third year) for both wheat and rice (**Table 2** and **3**), suggesting increased yield differences between the SR and the -K treatment over time. This again highlights the concern for depletion of native K resources under intensive rice-wheat cropping system. The AE$_K$ values for wheat in the current experiment were low, which could be due to a low yield of wheat. Wheat is usually sown late in the lower IGP due to late harvesting of rice. Such late sown wheat often face terminal heat stress due to high ambient temperature during flowering that causes yield loss. So besides efficient nutrient management, optimising planting time of component crops is also essential to achieve high rice-wheat system yield in West Bengal.

Potassium uptake by rice and wheat grain was highest in the SR plots followed by FFP, and then the -K plots (**Table 4**). It was also observed that the K uptake in K omission plots decreased over time for both grain and straw of rice and wheat (**Table 4**).

Summary

Our study highlighted that K application in rice and wheat is essential in the red and lateritic soil of West Bengal and that judicious application of K could significantly ($p \leq 0.05$) increase grain yield of rice and wheat. Application of K at state recommended levels can significantly increase rice and wheat grain yields in farmers' fields. The study also highlights that current state recommended level of K application may not be adequate to maintain or improve rice-wheat system yield as rice yield in the SR treatment showed yield decline over three years of study. Lower than expected AE_K values in wheat highlights that better crop and nutrient management is necessary to improve yield and agronomic efficiency.

Dr. Sourov Chatterjee is Assistant Agricultural Chemist, ZARS, Nalhati, Government of West Bengal; e-mail: chatterjee_sourov@yahoo.co.in. Dr. Dutta is Deputy Director, IPNI South Asia Program, Kolkata, India. Dr. Majumdar is Director, IPNI South Asia Program, Gurgaon, India. Mr. P.K. Saha is the Agronomist, ZARS, Nalhati, Birbhum.

Table 3. Different agronomic parameters of rice crop in different treatment plots.

Treatments	Plant height, cm	Tiller no./ plant	Panicle no./m^2	Grain/ panicle	1000 grain weight, g	AE_K
2010						
-K	103	10	143	133	22.4	22.3
SR	108	13	158	149	22.8	–
FFP	105	11	155	141	22.6	–
C.D. (p = 0.05)	3.6	1.2	6.8	10.9	NS	–
CV (%)	1.9	6.7	3.9	4.7	–	–
2011						
-K	109	12	166	121	21.7	31.8
SR	113	14	183	154	23.2	–
FFP	111	13	180	146	22.6	–
C.D. (p = 0.05)	4.8	1.0	8.9	7.0	NS	–
CV (%)	2.5	4.9	4.4	5.2	–	–
2012						
-K	105	12	146	118	20.4	36.8
SR	109	14	178	148	22.8	–
FFP	107	13	173	142	21.5	–
C.D. (p = 0.05)	4.4	1.1	7.7	6.0	NS	–
CV (%)	2.3	4.6	4.2	4.4	–	–

-K indicates potassium omission plot; SR indicates state-recommended fertiliser recommendation; FFP indicates farmer fertilisation practice; C.D. (p = 0.05) indicates critical difference at 5% level of significance, and CV (%) is the coefficient of variation.

Table 4. Uptake of K (kg K_2O/ha) by wheat and rice crops in different treatment plots.

	Uptake by wheat grain			Uptake by rice grain		
Treatments	2009	2010	2011	2010	2011	2012
-K	13	8	8	7	4	3
SR	25	16	17	15	14	14
FFP	20	12	13	12	11	11
C.D. (p = 0.05)	1.7	0.8	1.6	1.0	1.1	1.3
CV (%)	6.4	4.9	9.2	5.0	7.0	8.6

-K indicates potassium omission plot; SR indicates state-recommended fertiliser recommendation; FFP indicates farmer fertilisation practice; C.D. (p = 0.05) indicates critical difference at 5% level of significance, and CV (%) is the coefficient of variation.

References

Cassman, K.G., A. Dobermann, and D.T. Walters. 1996. Ambio Vol. 31, No. 2, 132-140.

Chatterjee, S., and S.K. Sanyal. 2007. Better Crops India. Pp: 22-25. Directorate of Rice Development. http://drd.dacnet.nic.in. Accessed on Oct. 20, 2013.

Directorate of Rice Development. 2013. http://drd.dacnet.nic.in. Accessed on Oct. 20, 2013.

Ladha, J.K., K.S. Fischer, M. Hossain, P.R. Hobbs, and B. Hardy. 2000. Discussion Paper No. 40. IRRI.

Ladha, J.K., H. Pathak, A.T. Padre, D. Dawe, and R.K. Gupta. 2003. *In* J.K. Ladha et al. (eds.). ASA Spec. Pub: 65. ASA, CSSA, SSSA, Madison, WI. p. 45-76.

Singh V.K., B.S. Dwivedi, R.J. Buresh, M.L. Jat, K. Majumdar, B. Gangwar, V. Govil and S.K. Singh, 2013. Agron. J. 105: 471-481.

Timsina, J. and D.J. Connor. 2001. Field Crops Research 69: 93-132.

Yadav, R.L. B.S. Dwivedi, and P.S. Pandey. 2000. Field Crops Research 65: 15-30.

Nutrient Expert® Decision Support Tools for Maize and Wheat Launched in India

The International Plant Nutrition Institute (IPNI) is pleased to announce that the Nutrient Expert® decision support tools for maize and wheat crops were officially launched for public use in India on June 20, 2013 at the National Agricultural Science Center (NASC) Complex in New Delhi during a meeting organized jointly by IPNI and International Maize and Wheat Improvement Center (CIMMYT).

Nutrient Expert is an easy-to-use, interactive, and computer-based decision support tool that can rapidly provide nutrient recommendations for individual farmers' field in the presence or absence of soil testing data. "Beginning in 2009, under the umbrella of Cereal Systems Initiative for South Asia (CSISA), Nutrient Expert for maize and wheat were developed and extensively tested in real farm conditions with the objective of easy implementation of improved nutrient management practices in smallholder maize and wheat systems of India," said Dr. Adrian Johnston, Vice-President, IPNI Asia & Africa Programs.

The development of Nutrient Expert for a specific crop and geography was done in collaboration with target users and local stakeholders from both public and private sectors through a series of dialogues and consultations. The approach integrated Site-specific Nutrient Management (SSNM) principles, developed over the last two decades, into a user-friendly nutrient decision support tool to help Indian wheat and maize farmers achieve higher yield and profitability. "Resource constraints of the smallholder farmers, lack of access to soil testing, and absence of tillage-specific nutrient management strategies in India were adequately taken care of in these tools, making them truly location-specific tools capable of spatial and temporal management of nutrients. The tools have been validated for three consecutive years across large number of locations, in collaboration with Indian Council of Agricultural Research (ICAR), State Agricultural Universities, State Agriculture Departments, Fertiliser and Seed Industry, to assess their efficacy under contrasting management scenarios and have shown improved productivity, profitability, efficiency and reduced environmental footprints over existing fertiliser management practices," said Dr. Kaushik Majumdar, Director, IPNI South Asia Program.

The tools were released in the presence of Dr. Tom Lumpkin, Director General, CIMMYT, Dr. Swapan K. Datta, Deputy Director General (Crop Sciences), Dr. J. S. Sandhu, Agricultural Commissioner, Govt. of India, Dr. Adrian M. Johnston, Vice President, IPNI, Dr. Bruno Gerard, Director, Global Conservation Agriculture Program (GCAP), CIMMYT, and Dr. B. Mohankumar, Additional Director General (Natural Resource Management), ICAR. Directors and scientists of several ICAR Institutes namely, Directorate of Wheat Research (DWR), Karnal, Directorate of Maize Research (DMR), New Delhi, Project Directorate of Farming Systems Research (PDFSR), Modipuram, Indian Institute of Soil Science (IISS), Bhopal, Indian Agricultural Research Institute (IARI), New Delhi, and National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Nagpur, attended the launch meeting. A large number of development and validation partners of the Nutrient Expert tools, representing State Agricultural Universities, State Agriculture Departments, Fertiliser and Seed Industry, and NGOs participated in the inaugural session as well as in the following panel discussions to chart out the future course of action for large scale dissemination of these tools for public good. As India faces many challenges to feed its growing population with changing food habits, Dr. Lumpkin emphasized the need for new tools: "We need to apply precision agriculture on each square meter; we need tools like the Nutrient Expert and remote-sensing technology to be able to do so."

Dignitaries formally launching the Nutrient Expert Tool for free public use.

Participants at the Nutrient Expert Launch Meeting.

The concluding session was chaired by Dr. K.D. Kokate, Deputy Director General (Extension), ICAR, and provided necessary guidance for extension of these tools through different stakeholder bodies. The meeting was coordinated by Drs. Kaushik Majumdar and M.L. Jat, CIMMYT Senior Cropping Systems Agronomist. According to Dr. Bruno Gerard, "the excellent outputs of the IPNI-CIMMYT partnership will benefit not only South Asia but also other regions." BC-SA

Potassium Response and Fertiliser Application Economics in Oilseeds and Pulses in India

By Kaushik Majumdar and Vidhi Govil

A review of the published literature showed variable K response in oilseeds and pulses across India. Economic calculations, using current prices of crop commodities and potash fertiliser, revealed significant return on investment to fertiliser K application in these crops. An approach based on yield response to K fertiliser application has been proposed to improve the yield of oilseeds and pulses and maintain K fertility levels of soils.

India is the largest producer of pulses and second largest producer of oilseeds in the world. The majority of the Indian population is vegetarian, and pulses provide a major source of protein while oilseeds provide a major source of fat and oil supplement for carbohydrate intake through cereals, millets and tuber crops (Tiwari et al., 2012). As principal sources of dietary lipid and protein, pulses and oilseeds assume great importance for food, nutrition and agricultural sustainability in the country.

In order to meet the growing demand, India has to import 2 to 3 million tonnes (Mt) of pulses every year. The projected pulse requirement for the year 2030 is 32 Mt, which necessitates an annual growth rate of 4.2% in pulse production (Nadarajan et al., 2013). The edible oilseeds demand is projected to grow at 12.6% per year during the 12th Five-year Plan on account of the increase in population and economic growth. This projected growth rate is 2.5 times higher than that experienced in domestic production of oilseeds during the previous decade. This clearly indicates that the production of pulses and oilseeds in the country has to be improved considerably to meet the growing demand (Jha et al., 2012).

Potassium requirement of pulses and oilseeds is quite high. Apart from fulfilling other major physiological and biochemical requirements for plant growth, K is a key nutrient element in the biosynthesis of oil in oilseeds and 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 greengram grain) from the soil to produce 1 t of grain. For oilseeds, uptake ranges from 16 kg K_2O (e.g., for castor seed) to 126 kg K_2O (e.g., for sunflower seed) per t of seed. However, fertiliser use, particularly K fertiliser use, is limited in pulse and oilseed crops. In general, farmers apply low rates of N and P, but K is frequently absent from their fertiliser schedule. Recent estimates suggest that only 41% of the cropped area under pulses and 77% under oilseeds receive about 6.3 and 9.3 kg K_2O/ha, respectively. Lack of K use in oilseeds and pulses is one of the major reasons for their low yields and poor crop quality in India (Tiwari et al., 2012).

It is generally perceived that Indian soils have high soil K status and that K application in pulses and oilseeds may not be economic at the current K fertiliser cost due to low response levels. The present review was initiated to assess the reported K responses in pulses and oilseeds. Four major scientific journals, viz., Journal of the Indian Society of Soil Science, Indian Journal of Agronomy, Indian Journal of Agricultural Sciences and Indian Journal of Fertilisers were used for this effort for a decadal period between 2003 and 2012. There were 72 studies reported on K responses in oilseeds, while 32 studies reported on K responses in pulses. Besides this, 23 and 14 K response studies in oilseeds and pulses, respectively, conducted by the International Plant Nutrition Institute (IPNI) were included in this review. The studies that reported grain yield responses due to K were chosen for analysis, while the ones that reported the effect of K application on quality parameters like oil content and protein percentages were ignored for this paper.

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

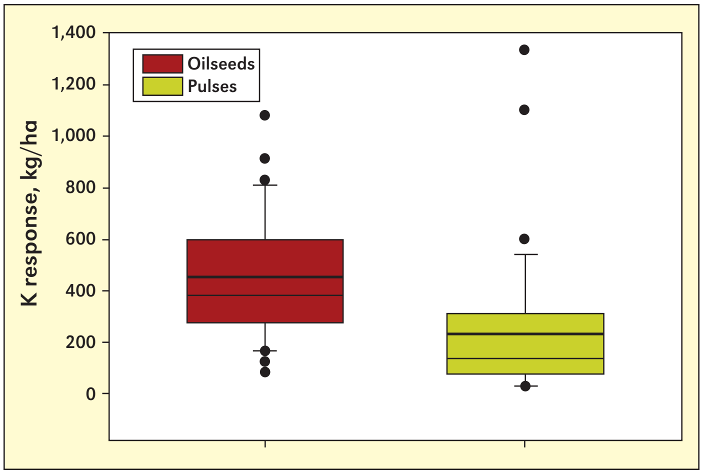


Figure 1. Range of grain yield response to potassium application in oilseeds and pulses. Boxes represent data within the first and third quartiles (interquartile range). The thin line denotes the second quartile or median, and the thick line denotes the mean. Lines extending beyond the interquartile range denote the 10th to 90th percentile of the data. Statistical outliers are plotted as individual points outside these lines.

The studies were well-distributed across major pulse and oilseeds growing areas of the country and covered major soil types. The reported studies were from Assam, Andhra Pradesh, Bihar, Jharkhand, Orissa, West Bengal, Uttar Pradesh, Punjab, Himachal Pradesh, Haryana, Madhya Pradesh, Gujarat, Rajasthan and Maharashtra states. However, it was not possible to show a spatial distribution of the study locations on a map due to the absence of geographic coordinates in most of the reported studies.

Information on crop yield responses to applied K levels were collated from the reviewed papers to estimate potassium yield response as follows:

K response = Yield of the crop at the applied K level - Yield of the crop at no K application

Current value of the crop commodities, cost of K fertiliser, and minimum support price (MSP) (Majumdar et al., 2012) were used to estimate the return on investment (ROI) in K application to oilseeds and pulses as follows:

Table 1. Distribution of reviewed data in yield response classes.

	Oilseeds		Pulses	
Yield Response for K, kg/ha	Number of samples (total = 59)	% samples	Number of samples (total = 38)	% samples
<300	17	29	27	71
300-600	26	44	7	19
>600	16	27	4	10

ROI on K fertiliser = [Yield increase due to K fertiliser (kg/ha) X MSP of crop (₹/kg)]/[K fertiliser application (kg/ha) X cost of K fertiliser (₹/kg)]

K Response in Oilseeds and Pulses

Figure 1 shows the extent of K response in oilseeds and pulses across the reviewed studies. Potassium response in oilseeds was higher than pulses. Average grain yield response of oilseeds was approximately 500 kg/ha, while average K response in pulses was about 250 kg/ha. The response range of the reviewed data was classified in three yield response classes (**Table 1**). In oilseeds, 29% of the studies showed K response of < 300 kg/ha, 44% showed a response of 300 to 600 kg/ha, while 27% of the studies showed greater than 600 kg/ha of grain response to fertiliser K application. In pulses, majority of the studies (71%) showed K response of < 300 kg/ha, while 19% and 10% studies showed 300 to 600 kg/ha and > 600 kg/ha of yield response to fertiliser K application, respectively.

We also estimated the average yield response and the ROI to fertiliser K application for each crop using MSP for each crop and the current cost of K fertiliser. **Table 2** showed that K response in oilseeds ranged from 3.7 to 10.4 kg of grain per kg of applied potash. The ROI on fertiliser K in oilseeds was 3.5 to 9.8 rupees per rupee invested on K. The results showed that ROI was reasonably high even at the perceived high cost of K fertiliser and generally low K response of oilseeds. In other words, farmers can make a significant profit from fertiliser K application in oilseeds. Potassium response of pulses was lower than oilseeds with a range of 1 to 11.5 kg per kg of K_2O application (rejecting the high K response in one experiment in cowpea as an outlier) (**Table 3**). The ROI on fertiliser K application in pulses was between 1.2 to 13.8 rupees per rupee invested on potash.

Potassium application rates varied widely within and between crops in the reviewed literature. While calculating the ROIs (**Tables 2 and 3**), the application rates in different experiments for an individual crop were averaged to reach at a common application rate. This has an inherent weakness of data redundancy, which might lead to inappropriate representation of ROI. Besides, such average application rates, combining different experimental data from varied locations, may not provide guidance to the user to achieve a particular yield response or ROI.

To avoid data redundancy, the K response data were classified in quartiles within the observed range of K response data in the reviewed literature. This is expected to help guide K application based on yield response and crop uptake. The first, median and third quartile of K responses in oilseeds and pulses were estimated and are given in **Table 4**.

Return on investment was re-calculated based on the response levels in **Table 4** and at three chosen K application rates. The three K application rates were selected on the basis of current state-recommended K application rates in pulses and oilseeds in different states of India (Tandon, 2002). In the case of oilseeds, the application rates used were 25, 50 and 75 kg K_2O/ha for determining ROI values, while for pulses, the rates used were 20, 40 and 60 kg K_2O/ha (**Table 5**). The data showed that in all cases, except for 60 kg K_2O/ha application rate at 275 kg/ha response in pulses, the application of K_2O provides reasonable to high return when application rate is

Table 2. Economics of K application in oilseed crops.

Oilseeds (No. of locations)	K_2O applied, kg/ha	Mean yield increase due to fertiliser K application, kg/ha	Net return due to fertiliser K application**, ₹/ha	ROI for K fertiliser#	Response per kg of K applied, kg/kg
Mustard (27)	78	479 (±43.22)*	13,408	6.8	7.3
Linseed (2)	66	436 (±54.5)	12,194	6.1	6.6
Sesame (9)	100	363 (±66.8)	10,172	3.5	3.7
Sunflower (7)	96	567 (±122.78)	15,880	5.3	5.7
Soybean (8)	54	416 (±99.31)	11,648	9.0	9.7
Groundnut (5)	43	419 (±52.07)	11,732	9.8	10.4
Castor (1)	50	214	5,992	4.0	4.3

*± Standard Error in parentheses; **Price of Potash = ₹30/kg K_2O; #Average MSP of oilseeds used for calculating ROI = ₹28/kg of grain.

Table 3. Economics of K application in pulse crops.

Pulses (No. of locations)	K_2O applied, kg/ha	Mean yield increase due to fertiliser K application, kg/ha	Net return due to fertiliser K application**, ₹/ha	ROI for K fertiliser#	Response per kg of K applied, kg/kg
Chickpea (10)	50	385 (±127.6)*	13,849	9.3	7.8
Urdbean (3)	36	46 (±16.6)	1,668	1.9	1.5
Lentil (4)	32	89 (±8.3)	3,186	3.8	3.2
Pigeonpea (5)	38	115 (±32.2)	4,140	4.4	3.6
Pea (3)	36	105 (±21.4)	3,792	4.1	3.4
Mungbean (2)	30	30 (±0.50)	1,062	1.2	1.0
Green gram (4)	25	265 (±44.2)	9,549	13.8	11.5
Black gram (4)	85	302 (±10.3)	10,863	4.8	4.0
Cluster-Bean (1)	40	160	5,760	4.8	4.0
Cowpea (1)	50	1,100	39,600	26.4	22.0
Guar bean (1)	30	170	6,120	6.8	5.7

*± Standard Error in parentheses; **Price of Potash = ₹30/kg K_2O; #Average MSP of pulses used for calculating ROI = ₹36/kg of grain.

Table 4. Classes of K response in oilseeds and pulses.

	Yield response, kg/ha	
	Oilseeds	Pulses
1st Quartile	275	76
Median	381	137
3rd Quartile	600	312

guided by yield response. For example, the application of 25 kg K_2O/ha in oilseeds gave ROI values of 10.3, 14.2 and 22.4 rupees per rupee invested in potash at 275, 381 and 600 kg/ha K responses, respectively. Increasing application rates to 50 and 75 kg/ha in oilseeds decreased the ROI, and the lowest ROI of 3.4 was observed at 275 kg/ha response level and at 75 kg application rate. Similarly for pulses, ROIs of 4.6, 8.2 and 18.7 were achieved at 76, 137 and 312 kg/ha K_2O response levels with an application rate of 20 kg K_2O/ha. The economic return from K application in pulses was lower than oilseeds due to lower K responses as evident from the reviewed literature.

Table 5. Return on Investment (ROI) in K fertiliser in oilseeds and pulses at different crop response levels and application rates.

Yield response classes of Oilseeds, kg/ha	275	381	600
ROI (Oilseeds)			
25 kg K_2O/ha application rate	10.3	14.2	22.4
50 kg K_2O/ha application rate	5.1	7.1	11.2
75 kg K_2O/ha application rate	3.4	4.7	7.5
Yield response classes of Pulses, kg/ha	76	137	312
ROI (Pulses)			
20 kg K_2O/ha application rate	4.6	8.2	18.7
40 kg K_2O/ha application rate	2.3	4.1	9.4
60 kg K_2O/ha application rate	1.5	2.7	6.2

*Prices: Potash = ₹30/kg K_2O, Average MSP of oilseeds = ₹28/kg of grain, Average MSP of pulses = ₹36/kg of grain.

Table 5 clearly showed that applying fertiliser K based on K response of oilseeds and pulses is economically viable at current prices of fertiliser K. The generally low K response of oilseeds and pulses, because of low yields in these crops and high cost of potash, makes it important that K fertiliser is applied based on critical assessment of yield response.

Table 5 also poses an important question that, at 600 kg/ha K response in oilseeds, how would a farmer decide the appropriate application rate? All the three K application rates, at 600 kg/ha K response, gave significant ROI in fertiliser K. The highest return is always the most attractive for a farmer, but are there other considerations that needs to be taken into account before choosing the appropriate rate. It seems that while deciding about the right K applicaton rate, one has to consider plant biomass production. Potassium is usually accumulated in the aboveground parts of a crop, with very little amount of K stored in the grains. This is reflected in the uptake of K in oilseed or pulse crops (e.g., 16 kg K_2O is needed for a tonne of castor seed, while 126 kg K_2O is required to produce a tonne of sunflower seed). This is because sunflower requires more K_2O to support higher biomass production than castor. This suggests that K application rates should also be based on biomass production besides the expected response to K application. A crop producing relatively higher biomass than other crops would require a higher application rate to limit K mining from the soil. Soils showing higher K response suggest low availability of K, and a higher K application rate in a high biomass producing crop in such a soil would ensure reasonably high return and maintainence of K fertility levels of the soil. Similar logic could be extended to other K response levels in **Table 5**, where more K should be applied to high biomass producing oilseeds or pulses than crops producing less biomass, even if the response levels are similar.

Summary

Improving the production of oilseeds and pulses in India is required to meet their growing demand. Area expansion is possible in these crops as relative prices with competing crops are favourable and relative profitability is higher. Crop intensification in underutilized farming situations like rice fallows can contribute to an increase in area under oilseeds and pulses. However, there are ample opportunities to improve productivity of these crops in existing areas through proper nutrient management. This will lead to sustainable intensification, without sacrificing the area under other crops, while meeting the national requirement.

Dr. Majumdar (E-mail: kmajumdar@ipni.net) is Director and Ms. Govil is Consultant at IPNI-South Asia Program.

References

Jha, G.K. et al. 2012. Indian Agril. Res. Inst., New Delhi.

Majumdar, K. et al. 2012. Indian J. Fert. 8(5):44-53.

Nadarajan, N., N. Kumar and M.S. Venkatesh. 2013. Indian J. Fert. 9(4):122-136.

Tandon, H.L.S. (ed.). 2002. Nutrient Management Recommendations for Pulses and Oilseeds. Fert. Dev. Consul. Org., New Delhi. pp. 154 +vi.

Tiwari, D.D., S.B. Pandey, and M.K. Dubey. 2012. e-ifc, No. 31, June 2012, Intl. Potash Inst., Switzerland, pp. 16-20.

Potassium: A Key Nutrient for High Tuber Yield and Better Tuber Quality in Cassava

By K. Susan John, C.S. Ravindran, James George, M. Manikantan Nair and G. Suja

Potassium application led to increases in tuber yield, plant growth characteristics, tuber quality, K uptake and maintenance of available K in soil under cassava. In the absence of adequate K, poor yield and poor quality benefits were obtained even with application of high levels of N and P.

Tuber crops are considered as the third most important food crop for humans after cereals and grain legumes, and a potential source of energy at par with rice and wheat. Tropical tuber crops like cassava, sweet potato, yams, aroids and minor tuber crops like coleus and arrow root, are well adapted to the hot and humid conditions in many continents like Asia, Africa, South America etc. They play a crucial role in the food, nutritional, employment and economic security of more than 500 million people globally. Tuber crops, which have high K requirements, are grown mostly in lateritic (Ultisols and Oxisols), red (Alfisols) and sandy loam soils (Entisols), which are poor in native fertility, nutrient retention, and ironically, in K supplying power as well. Experiments conducted during the last 50 years by Central Tuber Crops Research Institute (CTCRI) in Thiruvananthapuram, Kerala, have clearly established strong and positive responses of these crops to manures and fertilisers.

Among the tuber crops, cassava (*Manihot esculenta* Crantz) is the most important crop for its yield potential, good tolerance to adverse weather, especially drought, less incidence of pests and diseases, substantially high tuber starch content, and use in the preparation of several value added industrial products including ethanol and biodegradable plastics.

Role of Potassium in Cassava

Tuber crops, in general and cassava in particular, are mainly grown for their starch. It is well known that K plays a significant role in the synthesis and translocation of carbohydrates, and as a catalyst for activating a number of enzymes involved in the synthesis of starch, protein and glycosides. Potassium has a moderating effect on improving the tuber quality by increasing the starch content and reducing the cyanogenic glucoside responsible for bitterness in cassava.

Potassium Uptake by Cassava

Nutrient, and especially K, uptake by tuber crops relative to other major crops is fairly high due to their high yields (15 to 50 t/ha) and dry matter production (10 to 25 t/ha). Compared to local cultivars, high yielding varieties (HYV) of cassava extracted more K under both irrigated and rainfed conditions (**Table 1**). The total uptake of K_2O in a rice-cassava cropping system common in the upland paddy regions of Kerala, was as high as 340 kg K_2O/ha – with 54 kg/ha and 286 kg/ha taken up by rice and cassava, respectively (Nayar et al., 1986).

Table 1. Uptake of K (kg/ha) by rainfed and irrigated Cassava.

	1981-82			1982-83		
Variety	Rainfed	Irrigated	Mean	Rainfed	Irrigated	Mean
M4 (local)	92	90	91	90	127	109
Sree Sahya (HY*)	105	116	111	112	153	132
Sree Visakham (HY)	109	134	122	112	161	136

*HY indicates high yielding (variety). Source: Nayar et al. (1986).

Effect of Potassium on Plant Growth Characteristics

Ramanujam and Indira (1987) reported an increase in plant growth characteristics at higher levels of K application in cassava. They observed that no K application resulted in stunted plant growth, elongated stems with more number of leaves, lower plant biomass, and lower crop growth rate (CGR) compared to K application.

The effect of different N and K application rates on three varieties of cassava under irrigated and rainfed conditions revealed that increasing both N and K rates enhanced CGR, total dry matter production, tuber yield and root:shoot ratio up to an application of 150 kg K_2O/ha (**Table 2**). These effects were more pronounced under irrigated conditions.

Table 2. Effect of N and K applications on dry matter production, crop growth rate (CGR), root shoot ratio and tuber yield of cassava under irrigated and rainfed conditions.

Levels of N and K_2O, kg/ha	Total dry matter production, t/ha		CGR, g/m²/day		Root:shoot ratio		Tuber yield, t/ha	
	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated
50:50	8.47	10.68	2.84	3.64	1.41	1.74	19.06	26.15
100:100	10.33	14.96	3.49	4.97	1.45	2.10	20.30	32.57
150:150	11.96	16.72	4.01	5.56	1.53	2.08	23.61	36.10
200:200	12.88	17.95	4.33	5.96	1.54	2.02	23.74	38.13

Source: Nayar et al. (1985).

Effect of Potassium on Cassava Tuber Yield

Nair and Sadanandan (1987) studied the effect of graded levels of K application and observed that K nutrition profoundly influences the number of storage roots and mean tuber weight per plant. An increase in the number of tubers per plant and tuber size was observed with an increase in K_2O application rates up to 200 kg/ha.

A long-term fertiliser experiment showed that continuous cultivation of cassava with only N or P fertilisers reduced the tuber yield (**Table 3**) (Susan John et al., 2005a). On average, the yield declines were up to 71% in the N only treatment and 83% (highest) in the P only treatment. Phosphorus application in the absence of K application has a negative

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

Table 3. Long-term effect of different nutrient combinations on tuber yield (t/ha) of cassava.

	Years													
Treatment	1	2	3	4	5	6	7	8	9	10	11	12	13	Mean
N only	12.53	18.85	11.70	7.61	13.81	3.36	7.20	7.09	3.79	5.26	7.10	3.29	3.60	8.09
P only	11.18	9.30	6.30	5.10	8.06	5.23	2.27	0.91	4.18	3.00	4.67	1.46	1.32	4.84
K only	17.02	15.54	10.00	10.41	9.23	12.02	16.87	5.90	8.89	9.38	10.90	2.31	3.35	10.14
NP	22.44	18.18	13.70	12.22	15.72	7.64	9.67	3.08	4.94	6.27	4.12	4.06	1.61	9.51
NK	17.19	22.99	18.00	15.56	16.27	15.74	29.83	13.11	16.40	19.67	25.72	12.03	9.44	17.84
PK	13.69	12.36	8.70	6.42	9.93	9.76	9.77	2.11	9.85	9.46	10.39	3.88	5.41	8.59
NPK	20.03	22.06	18.50	21.77	25.99	25.63	27.98	14.59	18.68	28.99	33.95	18.65	22.26	23.01
C.D.(0.05)	6.35	8.53	6.35	4.96	5.69	6.12	11.18	4.55	4.47	4.00	6.13	3.29	6.73	-

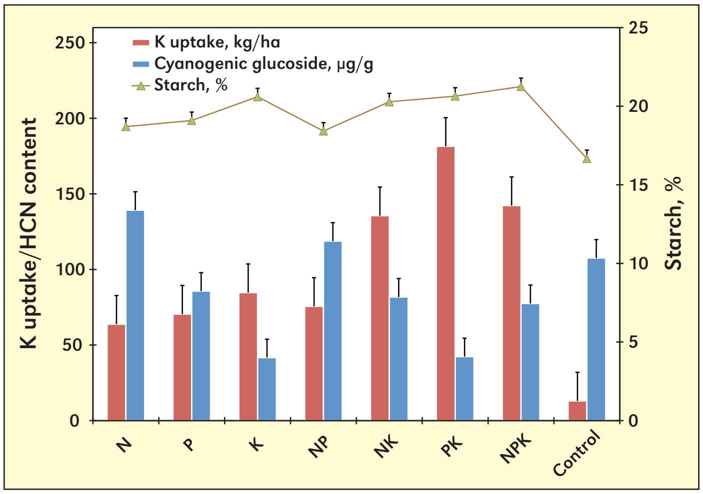


Figure 1. Mean K uptake and quality parameters of cassava over 13 years.

effect on the crop because high yields in the first crop might have exhausted the available soil K supply. However, the yield reduction (63%) was comparatively less in the K only treatment. This might be because a major portion of the K uptake (about two-thirds) gets exported to tuberous roots (Susan John et al., 2005a).

Effect of Potassium on Tuber Quality

The beneficial effect of K nutrition on cassava quality was observed in the reduction of cyanogenic glucoside (responsible for bitterness in cassava) and increase of starch content (**Figure 1**). Additionally, other starch quality parameters like amylose content, granule size, pasting temperature, viscosity and swelling volume also increased with increase in K application rates.

N:K Interaction in Cassava

The effect of N:K interactions in cassava nutrition varies according to soil type and variety. Studies have indicated that, in general, the N:K ratio ranges from 1:1 to 1:1.3 for optimum cassava production. For example, the optimum N:K ratio for cassava in the laterite soils of Kerala was 1:1 with 100 kg each of N and K_2O, while N:K ratios of 1:1.3, 1:1.25 and 1:2 were found ideal for cassava grown in the red loam, red and sandy loam soils of Kerala, respectively (Nair, 1982).

Maximum Yield Research and K in Cassava

Higher levels of applied K enhanced K uptake, tuber yield, tuber quality (i.e., reduced cyanogenic glucoside and increased starch content) as well as maintained the available K status of the soil (**Table 4**). Inadequate supply of K can lead to excessive vegetative growth at the expense of tuber production, including reduced tuber growth and production of poor quality tubers.

Table 4. Effect of high rates of K application on tuber yield, quality, K uptake, and available K in soil under cassava under a maximum yield research trial (mean of two years).

Levels of K, kg/ha	Tuber yield, t/ha	Starch, %	Cyanogenic glucoside, µg/g	K uptake, kg/ha	Available K in soil, kg/ha
0	22.85	30.49	80.51	108.61	82.26
150	26.83	30.50	49.33	137.32	168.76
300	29.93	30.11	57.52	188.77	251.80
450	31.44	35.06	22.58	192.29	444.40
C.D. (0.05)	4.432	4.98	16.09	31.14	114.21

Source: Susan John et al. (2005b, 2007).

Conclusion and Future Strategies

Potassium nutrition of cassava is very important to increase tuber yield and quality, and maintain soil available K status. For the future, site-specific nutrient management studies involving K are needed to standardize location-specific K needs of cassava. BC-SA

All authors are from the Central Tuber Crops Research Institute, Indian Council of Agricultural Research, Thiruvananthapuram, Kerala, India; E-mail: susanctcri@gmail.com

References

Nair, V.M. 1982. Ph.D. Thesis, Kerala Agricultural University, Trichur, Kerala.

Nair, V.M. and N. Sadanandan. 1987. *In*: Proc. National Symp. Production and Utilisation of Tropical Tuber Crops, CTCRI, Thiruvananthapuram. pp. 89-92.

Nayar, T.V.R., B. Mohankumar, and N.G. Pillai. 1985. J. Root Crops. 11(1&2):37-44.

Nayar, T.V.R., B. Mohankumar, and N.G. Pillai. 1986. J. Root Crops. 12(2):67-75.

Ramanujam, T. and P. Indira. 1987. *In*: Proc. National Symp. Production and Utilization of Tropical Tuber Crops, CTCRI, Thiruvananthapuram, pp. 119-122.

Susan John, K., C.S. Ravindran, and G. James. 2005a. Tech. Bull. Series No. 45, Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, pp. 89.

Susan John, K., V.K. Venugopal, and M. Nair. 2005b. J. Root Crops. 31(1):14-17.

Susan John, K., V.K. Venugopal, and P. Saraswati. 2007. Commun. Soil Sci. Pl. Anal., 38(5&6):779-794.

Mapping Potassium Budgets Across Different States of India

By Sudarshan Dutta, Kaushik Majumdar, H.S. Khurana, Gavin Sulewski, Vidhi Govil, T. Satyanarayana, and Adrian Johnston

Potassium input-output balances in different states of India were estimated and mapped using the IPNI NuGIS approach. Results showed negative K balances in most of the states suggesting deficit K application as compared to crop K uptake. Deficit application of K contributes to nutrient mining from soil, results in the depletion of soil fertility, and may significantly limit future crop yields.

Agricultural systems in India intensified significantly after independence. Although the net cultivated area remained stable around 140 million (M) ha, the area sown more than once increased from about 14 M ha in 1951-52 to 52 M ha in 2009-10 (FAI, 2012). This was largely made possible through the increase in irrigation facilities as the share of gross irrigated to gross sown area increased from 17 to 45% during the same period. This period also witnessed the introduction and large-scale adoption of high-yielding (HYV) and hybrid crop varieties with far higher yield potentials than the local varieties, and a concomitant increase in fertiliser nutrient use in crops. Food grain production increased five-fold, from 51 M t in 1950-51 to over 250 M t at present, while fertiliser nutrient ($N+P_2O_5+K_2O$) consumption increased by nearly 400 times during the same period. Such relatively rapid growth in crop production and fertiliser consumption may cause a mismatch between nutrient application and nutrient off-take from agricultural soils supporting such high crop production growth. This is especially true for K_2O as, historically, K application to crops in India has remained inadequate and the fact that K requirements of most crops are equal to or more than their N requirements.

Several studies have highlighted the disparity between nutrient input-output balances in Indian soils (Biswas, and Sharma, 2008), and widespread deficiency of plant nutrients in soils (Samra and Sharma, 2009). The All India Coordinated Research Project on Long Term Fertiliser Experiments by the Indian Council of Agricultural Research have shown negative K balances even at the optimum NPK application rates across India (Sanyal et al., 2009). Tandon (2004) estimated an annual depletion of 10.2 and 5.97 M t K_2O from Indian soils on a gross and net basis, respectively. He suggested that out of the net negative NPK balance or annual depletion of 9.7 M t, N and P depletion was 19 and 12% respectively, while a 69% depletion was shown for K. Later, Satyanarayana and Tewatia (2009) calculated state-wise nutrient balances in India and showed negative K balances in different states ranging from -0.1 to -1.1 M t.

The above studies highlighted that K application in Indian soils is much less than K off-take by crops, thereby leading to mining of native soil K. The general assumption that most Indian soils are well supplied with K and do not require any K application may not hold true for intensive cropping systems now practiced in the country. A soil well supplied with K for a yield level of 1 to 2 t/ha may turn out to be deficient in K as the yield target moves up due to the availability of better seeds, management options etc. This clearly indicates the necessity of assessing K balance periodically in intensively cropped areas to avoid unwanted decline in soil fertility levels. Earlier studies that assessed the yearly K balances in soils of India, used different methodologies, which do not allow an assessment of change in K status with time. The present study utilised standard data sources and methodologies to assess the changes in K balance across different states of India over a four-year interval (i.e., 2007 to 2011).

Abbreviations and Notes: N = nitrogen, P = phosphorus, K = potassium.

Determination of K Budget

The study analyzed the amount of potash fertiliser received by the agricultural soils through inorganic and organic sources, the removal of K by different agricultural crops, and estimated the K budget that determines the K accumulation or removal from the soil. Data on fertiliser use and the total amount of recoverable manure used in different states were obtained from the Agriculture Census Division, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India website (http://inputsurvey.dacnet.nic.in/districttables.aspx) as well as from the publications of the Fertiliser Association of India (FAI, 2007 and 2011). Information on district-wise K_2O consumption, through inorganic sources and recoverable manure, were accessed from the above two sources. The amount of manure consumed in each district was multiplied by a suitable factor, based on average K content in recoverable manure, to estimate K_2O contribution from organic sources.

The K_2O removal by the crops was calculated by multiplying the production with the removal per unit production. For example, if the rice production for a state in 2007 was 10 t and in 2011 was 12 t, then the K_2O removal in 2007 was 190 kg and 2011 was 228 kg considering the fact that the K_2O removal for production of 1 t of rice is 19.08 kg (Buresh et al., 2010). **Table 1** describes the K_2O removal per unit production for different crops used for calculation of State-wise K_2O removal in this study. The data source was Special Data Dissemination Standard Division, Director-

Table 1. Crop K_2O removal per unit of crop yield.

Crop	K_2O removal, kg/t
Wheat	24.00
Rice	19.08
Maize	20.88
Barley (grain)	7.30
Gram	25.81
Arhar (Tur)	62.50
Moong	25.81
Masoor	18.35
Moth	25.81
Groundnut (nuts)	8.51
Sesame (seed)	2.54
Rapeseed (seed)	9.21
Linseed (seed)	11.62
Cotton	14.80
Sugarcane	1.44

Sources for the removal values for different crops are listed here: http://nugis-india.paqinteractive.com/About%20NuGIS/

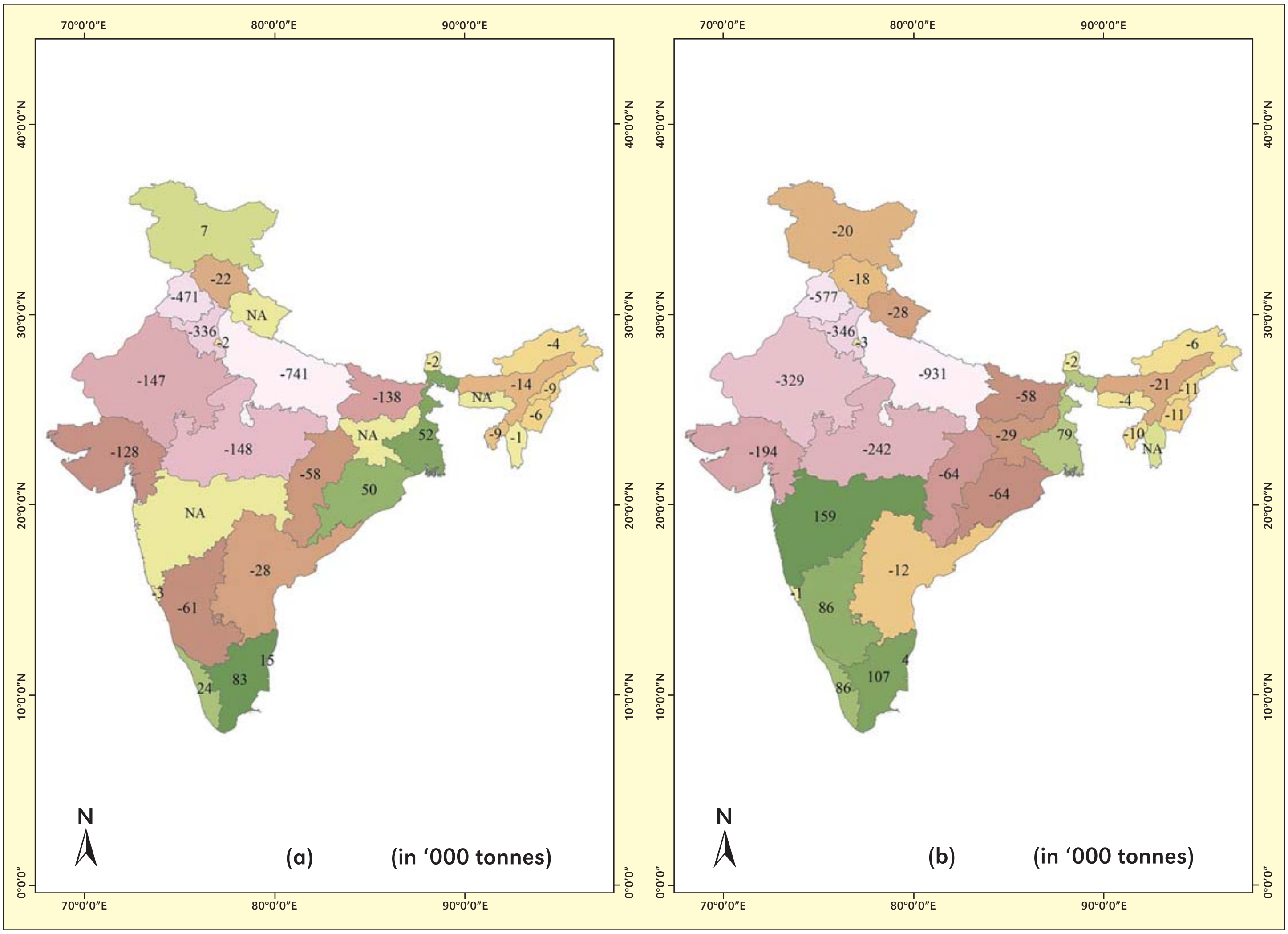


Figure 1. The K_2O balances (applied fertiliser – crop removal) for (a) 2007 and (b) 2011 across different states of India.

ate of Economics & Statistics Ministry of Agriculture Govt. of India, (http://apy.dacnet.nic.in/crop_fryr_toyr.aspx) and the publication of The Fertiliser Association of India (FAI, 2007 and 2011). The major crops considered in this study were rice, wheat, maize, barley, gram, arhar (tur), moong, masoor, moth, groundnut, sesame, rapeseed, linseed, cotton, and sugarcane. Potassium removal by horticultural crops was not considered in the K balance estimations.

The K_2O balances were calculated for different sates for the years 2007 and 2011 by calculating the difference between the amount of K_2O applied to soil in the form of fertiliser (with and without considering the manure application) and the crop removal values across different states. These values were then represented on the map of India using Arc-GIS 10.1 (ESRI, 2012).

Potassium Balance Comparison across Different States

The K_2O balances without manure across different states for 2007 and 2011 are shown in **Figure 1** where negative balance indicates K mining or depletion from soil while positive balance means "build up" of K_2O in the soil. It is evident from the figure that the K_2O depletion was more in 2011 compared to 2007 in most of the northern (such as Punjab, Haryana, Uttar Pradesh), eastern (Assam, Odisha, Tripura) and western (such as Gujarat, Rajasthan) states of India. This indicated that the soils of these states typically received less than the required amount of K_2O. Interestingly, the K_2O balances were negative in Bihar in the year 2007 as well as for Bihar + Jharkhand (Jharkhand was part of Bihar in 2007) in 2011, but the negative K_2O balance has decreased from 2007 to 2011. This decrease in negative value indicates that there was increase in the K_2O consumption and/or fertilisation practices. A similar trend was also observed in the case of Andhra Pradesh. The states of West Bengal and Tamil Nadu have shown positive K_2O balance in both 2007 and 2011, suggesting that no K mining has occurred in these two states. Surprisingly, a huge change in K_2O balances was observed in Karnataka and Odisha; while Karnataka showed positive balance, and a large change towards negative balance was observed in the case of Odisha. Review of available data showed that Uttar Pradesh produced 41 M t of foodgrain using 0.17 M t K_2O in 2007; whereas, in the year 2011 the total foodgrain production was 51 M t with total K_2O consumption of 0.27 M t. Therefore, on average, 4 to 4.5 kg of K_2O was applied per t of food grain production, which is much less than the required amount. This might be the reason for the increasingly negative K_2O balance in Uttar Pradesh (**Figure 1 and 2**). On the other hand, Andhra Pradesh produced 19.3 M t of foodgrain in 2007 using 0.34 M t K_2O; whereas, in the year 2011 the total foodgrain production was 20.1 M t with total K_2O consumption of 0.35 M t. Therefore, on average, 17

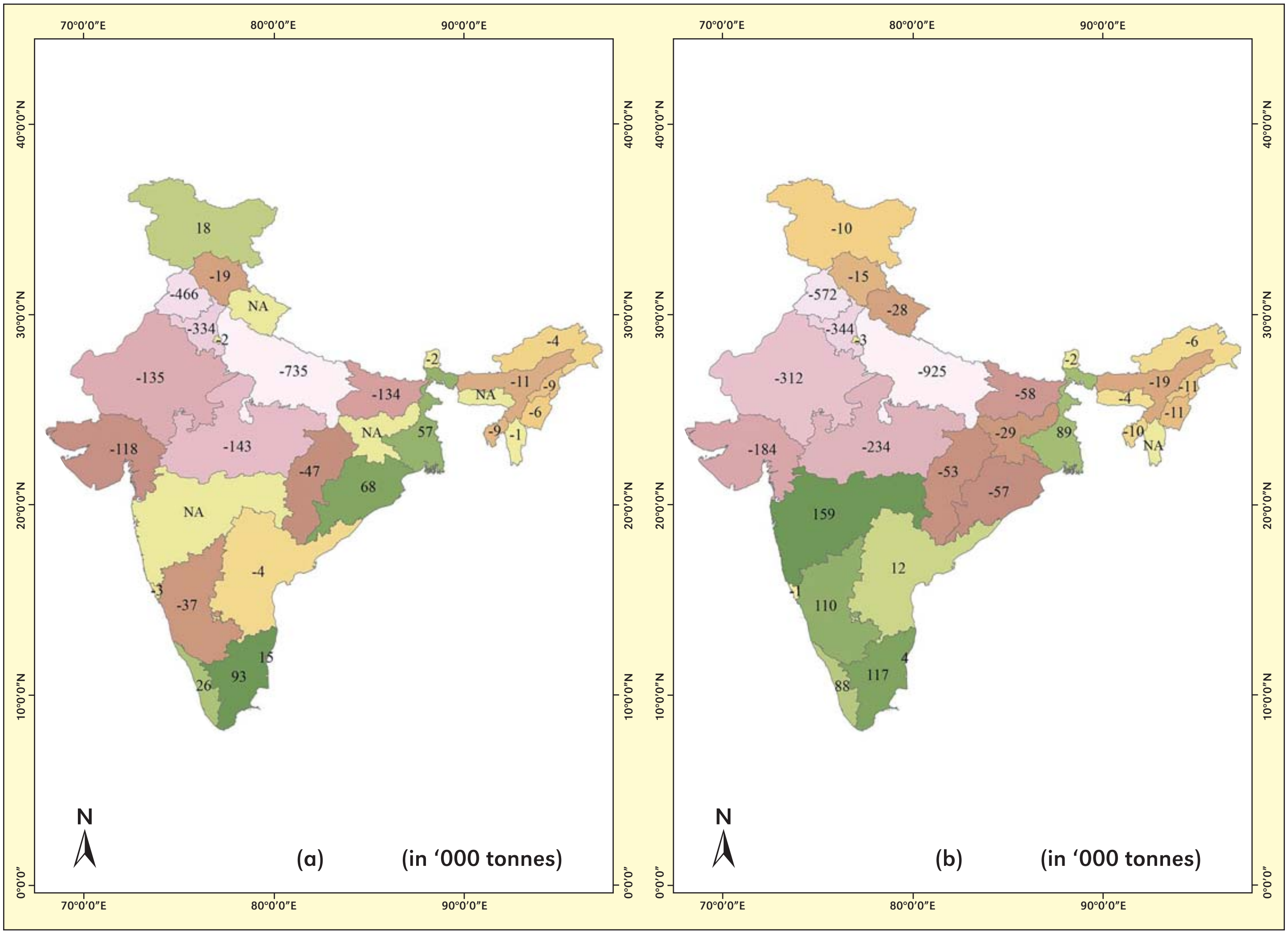


Figure 2. The K_2O balances (applied fertiliser + manure – crop removal) for (a) 2007 and (b) 2011 across different states of India.

kg K_2O was applied per t of food grain production. This might have lead towards more balanced K_2O application for the state and a lesser negative balance in 2011 as compared to 2007.

Figure 2 illustrates the K_2O balance by including the manure application across different states of India. As expected, our result highlights that inclusion of manure input reduces the negative balance and increase the positive balance for all the states; however, this does not cause much change in the K_2O balance values for most of the states except Andhra Pradesh, where the positive K_2O balance was observed in 2011 after inclusion of manure application while K_2O balance by considering only inorganic fertiliser and crop removal has given negative values. This is due to the fact that availability of organic manure for field application is limited in India because of competitive use of organic resources for fodder, fuel and other domestic purposes.

Our study highlighted that the K_2O balance (i.e., difference between K_2O applied through the application of fertiliser and manure and the removal of K_2O by the major crops) was negative for most of the states across India in the year 2007. These negative values increased in the year 2011 probably due to lesser fertiliser application and/or higher crop production. The K_2O balance data highlights negative values that indicate depletion of K_2O from soil and therefore mining of K after harvesting. Such depletion may not be immediately apparent through assessment of available K in soils as such depletion may occur from the non-exchangeable pool of soil K that is usually not measured during soil testing. Indeed, such unnoticed depletion of K from the soil may seriously deplete the K fertility status of the soil that will require much higher investment in future to restore the fertility levels. Studies have shown that excessive depletion of interlayer K may cause irreversible structural collapse of illitic minerals, thereby severely restricting the release of K from such micaceous minerals (Sarkar et al., 2013). Indian soils in general, and the alluvial soils in particular, are rich in micaceous minerals that attribute high K supplying capacity to these soils. However, there is a threshold value of K depletion a soil could support, beyond which any further depletion would cause irreversible loss of K fertility levels, a major soil quality parameter. This may adversely affect the productivity of these soils.

Summary

Our study highlighted negative K_2O balances in many Indian states, which increased in 2011 vis-à-vis 2007. Therefore, adequate and balanced application of K is required to reverse the trend of K depletion in Indian soils. Potassium application needs to be based on assessed indigenous K supplying capacity, that varies spatially and temporally, and the K requirement for achieving specific yield targets of a particular crop. This will ensure sustained crop productivity and maintenance of soil health. BC-SA

Dr. Dutta is IPNI Deputy Director, South Asia Program; e-mail: sdutta@ipni.net. Dr. Majumdar is Director, South Asia Program, Dr. Khurana is IPNI Agronomic and Technical Support Specialist, Mr. Sulewski is IPNI Editor, Ms. Govil is a Consultant at IPNI-South Asia Program, Dr. Satyanarayana is IPNI Deputy Director, South Asia Program, and Dr. Johnston is IPNI Vice President and Africa and Asia Group Coordinator.

References

Agriculture Census Division, Dept. Agric. and Coop., Ministry of Agric., Govt. of India website (http://inputsurvey.dacnet.nic.in/districttables.aspx). Last accessed on November 9, 2013.

Biswas, P.P. and P.D. Sharma. 2008. Indian J. Fert., 4(7): 59-62.

Buresh, R.J., M.F. Pampolino, and C. Witt. 2010. Plant and Soil. 335:35-64.

ESRI, 2012. http://www.esri.com/software/arcgis/arcgis10. Last accessed on November 29, 2013.

Fertilizer Statistics. 2007. Fertilizer Association of India. FAI House, New Delhi.

Fertilizer Statistics. 2012. Fertilizer Association of India. FAI House, New Delhi.

Special Data Dissemination Standard Division, Directorate of Economics & Statistics Ministry of Agriculture Govt. of India, (http://apy.dacnet.nic.in/crop_fryr_toyr.aspx). Accessed on October 24, 2013.

Samra, J.S. and P.D. Sharma. 2009. Proceedings of the IPI-OUAT-IPNI International Symposium Bhubaneswar, Orissa, India, 5-7 November, 2009, pp. 15-43.

Sanyal, S.K., M.S. Gill, and K. Majumdar. 2009. Proceedings of the IPI-OUAT-IPNI International Symposium Bhubaneswar, Orissa, India, 5-7 November, 2009, pp. 389-405.

Sarkar, G.K., A.P. Chattopadhyay, and S.K. Sanyal. 2013. Geoderma. 207-208: 8-14.

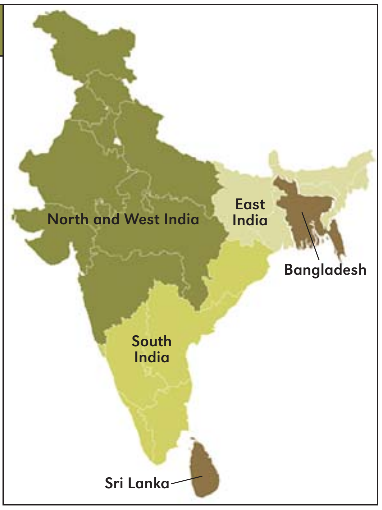
Satyanarayana, T. and R.K. Tewatia. 2009. Proceedings of the IPI-OUAT-IPNI International Symposium Bhubaneswar, Orissa, India, 5-7 November, 2009, pp. 467-485.

Tandon, H.L.S. 2004. Fertilizers in Indian Agriculture from 20th to 21st Century, FDCO New Delhi, pp. 240.

Current Research Supported by IPNI South Asia Programme

At the heart of IPNI's regional educational programmes is its support of local research. Below is a listing of the current research being funded throughout the IPNI South Asia Region. More details on these projects, and others conducted in field throughout the world, can be obtained from IPNI Staff or from our on-line research database found at: http://www.ipni.net/research.

North and West India



Site-specific nutrient management for rice-wheat system in Punjab

Site-specific nutrient management for rice-wheat system in Haryana

Assessment of soil K supplying capacity from soil nutrient reserves and dissemination of nutrient management technologies through Nutrient Manager

Development of soil fertility map as a decision support tool for fertiliser recommendation in citrus

Fertility mapping and balanced fertilisation for sustaining higher productivity of pearl millet-wheat cropping system in Agra district

Comparative evaluation of nutrient dynamics under conventional and no-till systems of crop establishment in rice-wheat and rice-maize cropping systems

Balanced fertilisation for enhancing the productivity of pearl millet-wheat-green gram crop sequence in Agra region of Uttar Pradesh

Climate change mitigation and adaptation through conservation agriculture and precise nutrient management in current and future cereal-based cropping systems of IGP

East India and Bangladesh

Assessment of agronomic and economic benefits of fertiliser use in maize production systems under variable farm size, climate and soil fertility conditions in eastern India

Global Maize Project in India: Ranchi, Jharkhand

Site-specific nutrient management for rice-wheat system in Bihar

GIS-based spatial variability mapping of agricultural holdings for precision nutrient management in red and lateritic soil zone

Development and validation of Nutrient Expert for Maize in Bangladesh

South India and Sri Lanka

Global Maize Project in India: Dharwad, Karnataka

Improving nutrient use efficiency and profitability in rainfed production systems

Maximising yield of groundnut (Arachis hypogaea) through improved nutrient management practices in acid soils of Odisha

Site-specific nutrient management in maize growing districts of Tamil Nadu

IPNI South Asia Programme regions are staffed by Dr. Kaushik Majumdar, Director, South Asia with regional responsibility in North and West India, Dr. Sudarshan Dutta, Deputy Director (East India & Bangladesh), and Dr. T. Satyanarayana, Deputy Director (South India & Sri Lanka).

ROLE OF K IN BALANCED FERTILISATION

There is growing interest in the concept of balanced fertilisation to increase food production, with the role of K taking center stage in this discussion. How many of you have been involved in field research and demonstration trials that clearly show the benefits of K? I would dare to say that in South Asia the number is large, and research conducted by IPNI over the last 2 decades certainly supports the use of K in most effective fertiliser management programmes. This issue of BCSA covers a series of issues related to K and balanced fertilisation from IPNI research activities in South Asia.

It is so evident that South Asia is going to have to work hard to restore the impact of whole crop removal over millennia of production. As someone who has visited and crossed South Asia over the last 8 years it has always amazed me how productive many of the soils are given the past management practices. Total crop removal, that is grain and all above ground biomass, has been part of the South Asian farming system. However, the impact on declining soil quality, fertility and productivity are becoming very obvious.

Field research conducted in farmers' fields clearly shows the impact of bringing balance to the traditional use of N and P. Recent field research by IPNI across the Indo-Gangetic Plains, as well as Eastern and Southern India has resulted in a clearer picture of how severe this nutrient imbalance is. While the impact of added macro, secondary and micronutrients varies considerably from state to state, and regions within states, the results are undeniable. Large yield responses can be achieved with the addition of K, while in many cases the rates of N and P remain unchanged, or even decrease.

Positive crop responses to K addition in field research is encouraging, and provides some link to ensuring future food security in the region. While the use of K in India is limited by awareness, cost and availability, farmers currently optimising their crop production with balanced fertilisation are convinced. Future increases in both crop production and profit for farmers will only be achieved when access to all required nutrients is ensured. Let's not forget, it is supporting farmers with the basic technology that is critical to keeping all of us fed.

It is time to take a second look at how effective we have been in educating farmers and their advisors on balanced fertilisation. It would be easy to present the overwhelming accumulated evidence on the impact of balanced fertilisation in addressing the 'yield stagnation' so often cited in India. However, history indicates that this has had limited impact on both understanding and impact at the farm level in the country. Let us take the time to reconsider how we both deliver basic information in our development and extension efforts to ensure we prevent further neglect in building awareness on the farm.

Numbers alone cannot define food security and a better livelihood. It entails the aspirations of millions of families to have adequate nutritious food on their plates, sending their children to school and having modern amenities at home. In South Asian countries, where nearly 60% of the population is dependent one way or other on agriculture, balanced fertilisation will always play a critical role in meeting these aspirations.

Adrian Johnston
IPNI Vice President, Asia and Africa Group
E-mail: ajohnston@ipni.net

BETTER
CROPS
International Plant Nutrition Institute
3500 Parkway Lane, Suite 550
Norcross, Georgia 30092-2844
www.ipni.net