Research Findings

Photo 1. A field trip to a sugarcane demonstration plot at Kamta Maharajganj, Uttar Pradesh, India. Photo courtesy of Potash for Life, India.

The Impact of Potassium Fertilization on Sugarcane Yields: A Comprehensive Experiment of Pairwise Demonstration Plots in Uttar Pradesh, India

Bansal, S.K.[(1)*], **P. Imas**[(2)], **and J. Nachmansohn**[(3)]

Abstract

Degradation of soil fertility due to significant nutrient demands by crops and imbalanced fertilizer application is very common in the arable lands of Uttar Pradesh, India. While practices of nitrogen (N) and phosphorus (P) application have been established and disseminated, potassium (K) crop and soil requirements are almost ignored. Sugarcane (*Saccharum officinarum* L.) is among the most important cash crops grown in Uttar Pradesh, however, productivity is low compared to its well-demonstrated potential. This study aimed to evaluate and demonstrate the principal contribution of K application in increasing sugarcane yield and profitability and to raise the awareness of stakeholders and growers of the vital need to develop balanced, K-inclusive fertilization regimes for this crop. A comprehensive experiment was carried out during the seasons of 2014-2015 and 2015-2016 in seven districts of Uttar Pradesh, which included 161

[(1)]Indian Potash Research Institute, Gurgaon, Haryana, India
[(2)]International Potash Institute (IPI), Zug, Switzerland
[(3)]Fertilizer, Soil and Water Management Expert, Yeruham, Israel
*Corresponding author: surinkumar@yahoo.co.in

pairwise, control vs. K-applied, demonstration plot trials. The K-applied plots received a standard dose of 150 kg K_2O ha^{-1}, in addition to the common urea and di-ammonium phosphate (DAP) doses (175 and 80 kg ha^{-1} of N and P_2O_5, respectively). The additional K application resulted in a significant increase in sugarcane yield, from 62 to 71.4 Mg ha^{-1} the in control and K-applied plots, respectively. With an average yield increase of 9.35 Mg ha^{-1} (15.7%), and an average additional profit of 267,931 Rs ha^{-1}, the benefits arising from K application to the sugarcane grower are clear. However, significant differences in the control yields between eastern and western districts, and furthermore, considerable diversity in the yield response to K application in western districts highlights the significant impact that local conditions can have. While the K dose employed in the present study (150 kg K_2O ha^{-1}) can be recommended to sugarcane farmers in the short-term as a transient means to obtain higher yields and profits, further research is needed to determine appropriate K doses and application practices that ensure balanced crop nutrition, optimum fertilizer use, sufficient K availability, and sustainable soil fertility.

Keywords: K application; *Saccharum officinarum*; soil degradation; sugarcane yield.

Introduction

In India, agriculture forms the backbone of the economy, as it contributes a high proportion of the country's net domestic product (FAO, 2018). The ever-increasing demand for food, feed, and fibers, and the limitation of arable land necessitate not only novel practices of preserving, managing, and enriching natural resources, but also an up scaling of land-use-efficiency. Soil forms the basis for any crop production activity and is the most precious natural resource. Declining soil fertility is one of the primary factors that directly affects crop productivity (Prasad and Power, 1997; Pathak *et al.*, 2010; Singh *et al.*, 2012; Dey *et al.*, 2017). Therefore, soil fertility management is crucial to ensure productivity and nutritional security, while maintaining soil health and sustainability.

Fertilizer-use is a key factor in ensuring soil fertility and productivity (Ramamurthy *et al.*, 2017). Fertilizers are one of the costliest inputs in agriculture; and yet, if used correctly, they can be one of the most profitable. Imbalanced use of fertilizers not only afflicts nutrient use efficiency; it also deteriorates soil quality (Wallace, 2008). Therefore, balanced fertilizer use must be encouraged, as it is the only way to prevent soil fertility decline due to poor nutrient replenishment, or to repair soil quality deterioration caused by former excess or imbalanced nutrient application (Yadav, 2006).

India is the second largest producer of sugarcane (*Saccharum officinarum*) in the world (FAO, 2018). Thus, sugarcane is one of the most important cash crops in India, influencing the overall socio-economic development of the farming community (Nandhini and Padmavathy, 2017). Cultivation of sugarcane in India dates back to the Vedic period. The earliest mention of sugarcane cultivation is found in Indian writings dated to about 1400-1000 B.C. (Galloway, 2005). Currently, sugarcane makes up about 7% of the total agricultural output value and occupies about 2.6% of India's gross cropped area (FAO, 2005). Sugarcane also provides raw material for the second largest agro-based industry after textiles, supporting more than 500 sugar factories with a total annual sugar production capacity of about 24.2 million Mg (DSD, IMOA, 2013).

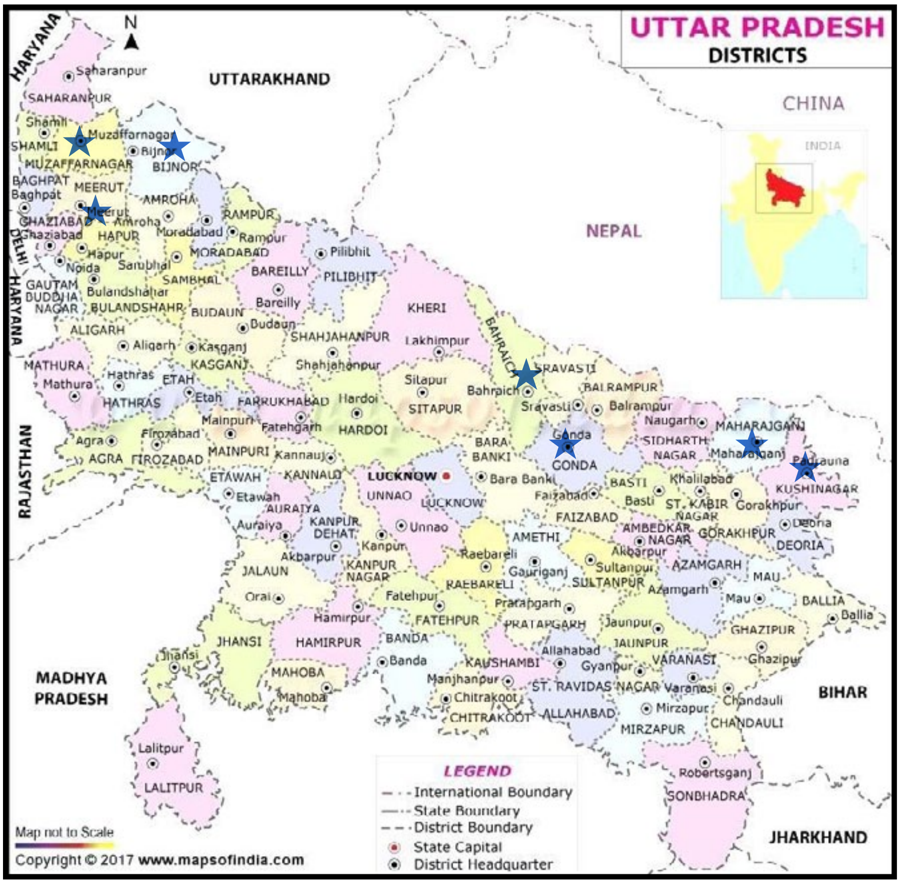
Saccharum is a monocotyledonous plant genus that belongs to the Gramineae family (Poaceae), order Glumaceae sub family Panicoidae, tribe Andripogoneae and sub tribe Saccharininea. The cultivated canes belong to two main groups: (a) thin, hardy north Indian types (*S. barberi* and *S. sinense*), and (b) thick, juicy noble canes (*S. officinarum*), which is the most economically viable. Sugarcane is a tall perennial plant growing erect up to 5-6 m and producing multiple stems. The plant is composed of four principal parts: root system, stalk, leaves and inflorescence. Sugarcane is a C_4 plant, which is highly efficient at converting and storing solar energy into sucrose. The crop's global distribution is restricted to the warm strip between 37ºN and 31ºS, extending from tropical to sub-tropical zones. Sugarcane is a long duration crop, which produces huge amounts of biomass, requiring large quantities of water, and is typically grown in loamy soils. It has essentially four phases of plant development: germination, tillering, growth, and maturation/ripening. Optimum temperature for sprouting of stem cuttings is 32° to 38°C. Higher temperatures reduce the rate of photosynthesis, increase plant respiration, and productivity sharply declines. Under 25ºC, cane growth declines significantly and sucrose accumulation is favored. Low temperatures, in the range of 12-14°C, are desirable for ripening, though the plant is susceptible to frost. Sugarcane is also vulnerable to water logging and drought.

In India, sugarcane is cultivated all over the country from latitude 8 to 33ºN, excluding cold hilly areas. Indian sugarcane production is roughly divided between tropical and sub-tropical regions, which significantly differ in crop environment, management, and consequently in yield levels. In the sub-tropical zone, Uttar Pradesh is the leading state in sugarcane production area but second for yield levels (DSD, IMOA, 2013). Sugarcane farmers in Uttar Pradesh have faced additional challenges in recent years as weather patterns, droughts, and flooding have been more extreme. For example, spring and early summer temperatures have increased high above normal thresholds, with extended drought periods. The pattern of the monsoon season has also changed, with more flooding events. In addition, frost events have become more frequent.

Despite the environmental obstacles to production, the factors that are within the farmers' control and yet limit sugarcane production seem more urgent, and furthermore, resolvable. Principles, recommendations and practices of balanced N and P fertilization have been successfully disseminated among sugarcane farmers in Uttar Pradesh. However, K is often ignored. Potassium is essential in many aspects of plant life and development (Mengel, 2016). It is particularly important in carbon assimilation, sugar production, translocation, and accumulation, as K facilitates many other biochemical and physiological processes (Geiger and Conti, 1983; Stephen, 1985; Cavalcante *et al.*, 2015).

Sugarcane is special with regard to K requirements, as its main value comes from a quality aspect – sugar content. In order to ensure a high sugar content, K must be available whenever required during crop growth and development, preventing any physiological constraints that might inhibit sugar synthesis and storage (Orlando Filho, 1985; Kwong and Pasricha, 2002; Yadav, 2006; Shukla *et al.*, 2009; Medina *et al.*, 2013). Moreover, a high soil nutrient status should be preserved to maintain future sustainable use of the land. A balanced fertilizer input, which includes a considerable K dose, can therefore be a preliminary step in achieving these vital goals.

The objective of this study was to evaluate and demonstrate the principal advantage of K application in increasing sugarcane yield and profitability, despite the considerable native environmental heterogeneity of Uttar Pradesh state.



Map 1. District map of Uttar Pradesh. The districts where sugarcane trials took place are marked with stars. *Source:* http://parachinar.info/wp-content/uploads/2018/05/districts-of-uttar-pradesh-district-map-free-download.jpg

Materials and methods

Verification trials for sugarcane response to K application took place in seven districts of Uttar Pradesh: Muzaffarnagar, Bijnor, and Meerut (western districts), and Kushinagar, Maharajganj, Gonda, and Bahraich (eastern districts) (Map 1). The trials were conducted in the fields of different farmers in each district, totaling 161 demonstration plots throughout the state (Table 1). In each field, two similar plots of 0.4 ha each, laying side-by-side, were used as control and treatment, leaving a 1 m wide path between them.

Excluding K, each pair of plots received a similar fertilizer practice of urea and DAP. The N dose was 150 and 175 kg N ha^{-1}, and the P dose was 60 and 80 kg P_2O_5 ha^{-1}, in the western and eastern districts, respectively (Table 1). In addition, farmyard manure (FYM) was applied in eastern districts at doses ranging from 2-3.5 Mg ha^{-1}. While control plots received no K fertilizer, their corresponding neighbor plots were applied with 150 kg K_2O ha^{-1} as muriate of potash (MOP).

Different improved sugarcane cultivars were used in the trial according to local recommendations in each district or location. Pest management and other routine practices were also carried out following local recommendations. Meteorological information for the relevant districts and growing seasons was extracted from https://www.worldweatheronline.com/.

Due to the large scope of the study, sugarcane yield parameters included only processable cane biomass at harvest. Economic evaluations focused on the profit gained due to K application at each site; the cost of the additional K fertilizer was subtracted from the extra revenue obtained, using local current prices.

Statistical analysis was performed using pairwise t-tests, with a confidence level of 0.95. Data analysis was conducted in one block, comparing all 161 data points in the

Table 1. Detailed description of 161 sugarcane demonstration plot trials of K application vs. control in the 2014-2015 and 2015-2016 growing seasons in seven Uttar Pradesh districts.

District	Numbers of plots	Planting	Harvest	N dose	P_2O_5 dose	K_2O dose		FYM
						Trial	Control	
		Time		*kg ha⁻¹*				
Bahraich	6	Mar 2015	Mar 2016	175	80	150	0	+
Gonda	10	Mar 2015	Mar 2016	175	80	150	0	+
Kushinagar	35	Mar 2014	Mar 2015	175	80	150	0	+
Kushinagar	15	Mar 2015	Mar 2016	175	80	150	0	+
Maharajganj	35	Mar 2014	Mar 2015	175	80	150	0	+
Bijnor	20	Mar 2015	Mar 2016	150	60	150	0	-
Meerut	20	Mar 2015	Mar 2016	150	60	150	0	-
Muzaffarnagar	20	Mar 2015	Mar 2016	150	60	150	0	-

Note: FYM = farmyard manure.

whole state. In addition, the data set was dissected according to districts to elucidate some sources of variation.

Results and discussion

Potassium, applied as MOP (KCl) at 150 kg K_2O ha^{-1} - in addition to the common fertilization practices of urea, DAP, and manure - resulted in a significant increase in sugarcane yield. While the mean sugarcane control yield was 62 Mg ha^{-1}, the corresponding K-applied plots obtained 71.4 Mg ha^{-1}, on average (Fig. 1). With an average yield increase of 9.35 Mg ha^{-1} (15.7%), and an average additional profit of 267,931 Rs ha^{-1}, the benefits arising from K application to the sugarcane grower are clear. While, sugarcane yield levels of 72 Mg ha^{-1} correspond with the average in India, they are still far below those of many sugarcane-producing countries that reach 100-130 Mg ha^{-1} (FAOSTAT, 2016). Further analyses by this study elucidates some possible explanations to this gap.

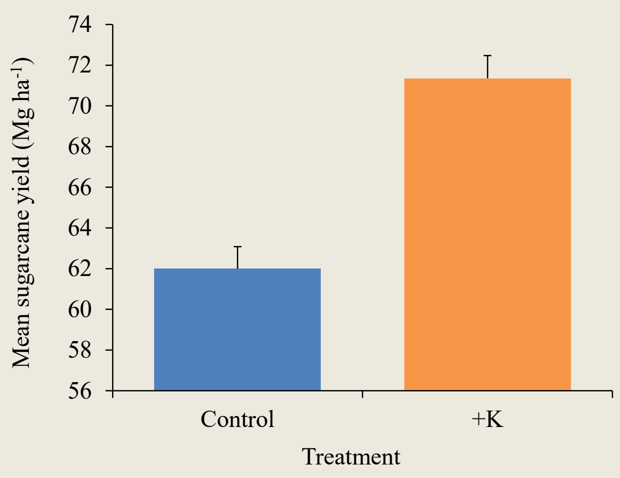


Fig. 1. Mean sugarcane control vs. K-applied yields. Values represent all 161 demonstration plots in seven districts of Uttar Pradesh. Bars indicate SE.

Yields from the control sugarcane plots that were not applied with K were clustered into two distinct groups; northeastern districts had significantly lower yields than in the northwestern districts (Table 2). This clustering pattern was less obvious in corresponding official yield averages (Table 2). The annual pattern of the daily average and extremum temperatures does not differ significantly between the western and eastern districts, where the active

Table 2. Sugarcane yields, dissected according to the Uttar Pradesh districts included in the study, and the effects of K application on the yield increase and the consequent profits.

District	Trial data				District means of annual yields*		FYM
	Control yield	Yield increase		Net profit	2013-2014	2014-2015	
	Mg ha⁻¹	*Mg ha⁻¹*	*%*	*KRs ha⁻¹*	*Mg ha⁻¹*		
Bahraich	51.9 ± 0.8	10.00 ± 0.56	19.3 ± 1.2	299.0 ± 16.8	56.0	57.7	+
Gonda	52.2 ± 1.4	8.71 ± 0.21	16.8 ± 0.5	260.3 ± 6.3	57.7	51.5	+
Kushinagar	53.3 ± 0.5	9.44 ± 0.32	18.5 ± 0.6	276.6 ± 9.3	59.8	60.2	+
Maharajganj	52.1 ± 0.9	8.65 ± 0.16	16.8 ± 0.5	253.5 ± 4.8	61.0	59.8	+
Bijnor	75.2 ± 1.2	7.90 ± 0.52	10.6 ± 0.7	221.2 ± 14.7	59.9	65.7	-
Meerut	79.6 ± 2.8	11.40 ± 1.14	14.4 ± 1.3	319.1 ± 31.8	71.2	78.5	-
Muzaffarnagar	76.2 ± 2.1	8.53 ± 0.72	11.3 ± 0.9	238.8 ± 20.1	72.9	71.9	-
Average	62.0 ± 1.1	9.35 ± 0.23	15.7 ± 0.4	267.9 ± 6.5	62.6	63.6	

Note: Values are means ± SE. FYM = farmyard manure. **Source:* http://upenvis.nic.in/Database/Sugarcane_Yield_1103.aspx.

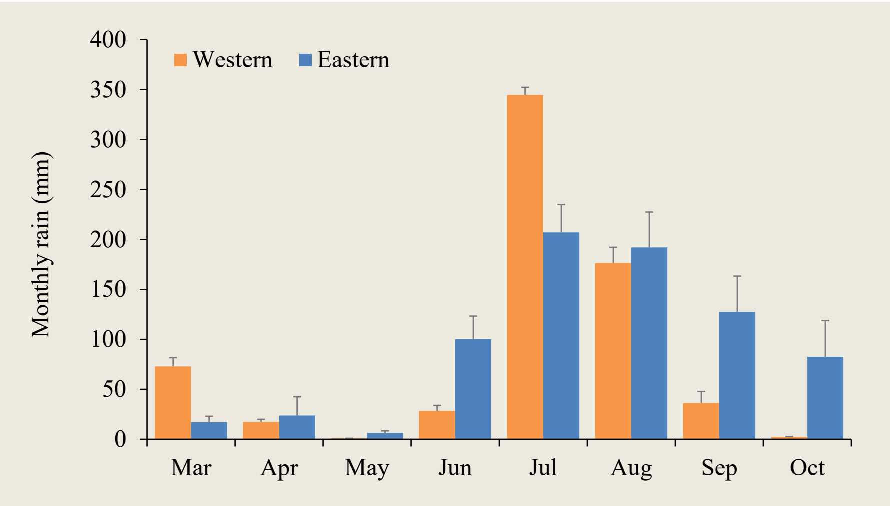


Fig. 2. Monthly rainfall in western and eastern Uttar Pradesh districts during the trial. Data extracted from https://www.worldweatheronline.com/.

sugarcane-growing season is restricted to 4-5 months only (July - November). In both regions, extremely high temperatures from April to June, significantly exceeding the optimum range of 32-38°C for sugarcane photosynthesis and growth, probably interrupt early sugarcane developmental stages (germination, tillering, and growth). During December and January, temperatures then drop too low, quite often touching sub-zero levels (DSD, IMOA, 2013). In eastern districts, however, the monsoon period during the trial lasted two months longer than in western districts (Fig. 2). In the eastern lowlands (0-150 m above sea level), floods and water logging occur frequently during monsoon and restrict sugarcane growth (DSD, IMOA, 2013). This may provide an explanation for the lower sugarcane yields in eastern districts. Beyond this difference, it appears that sugarcane yields tend to fluctuate significantly from one year to another on a local basis, probably due to transient extreme environmental conditions during sensitive stages of crop development.

Photo 2. A visit to the sugarcane demonstration plot at Muzaffarnagar, Uttar Pradesh, India, 2017. Photo courtesy of Potash for Life, India.

A more detailed analysis of the trial results (Fig. 3) provides interesting information regarding the effect of K application on the yield increase. The absolute yield increase was always positive, ranging from 5-25 Mg ha^{-1} (Fig. 3A) but was very stable, as indicated by the proximity of the mean and the median, 9.35 and 9.04 Mg ha^{-1}, respectively (Fig. 3C). The absolute yield increase extremes were associated most strongly with the high control yields, while the main bulk around the median was distributed more evenly between the high and low control yielding plots (Fig. 3A). On the other hand, the relative yield increase displayed a much wider distribution, from 6-35%, with 15.7 and 15.8% as the mean and median, respectively (Fig. 3B and D). As may be expected, the majority of the lower edge of the yield increase distribution was associated with the high control yields, while plots with low control yields were characterized by higher relative yield increases.

Figure 4 demonstrates the clear-cut split between the low-yielding eastern districts, and the high-yielding western districts. The control sugarcane yields ranged from 40 to 65 Mg ha^{-1} and from 65 to 110 Mg ha^{-1}, in eastern and western districts, respectively. In eastern districts, excluding very few exceptions, the yield increase in response to K application was very stable and close to the mean of 9.35 Mg ha^{-1} (Fig. 4A). Consequently, the relative yield increase dropped steadily from 25% to about 12% of the control yield as a function of the latter (Fig. 4B). In western districts, however, the yield increase scattered quite differently,

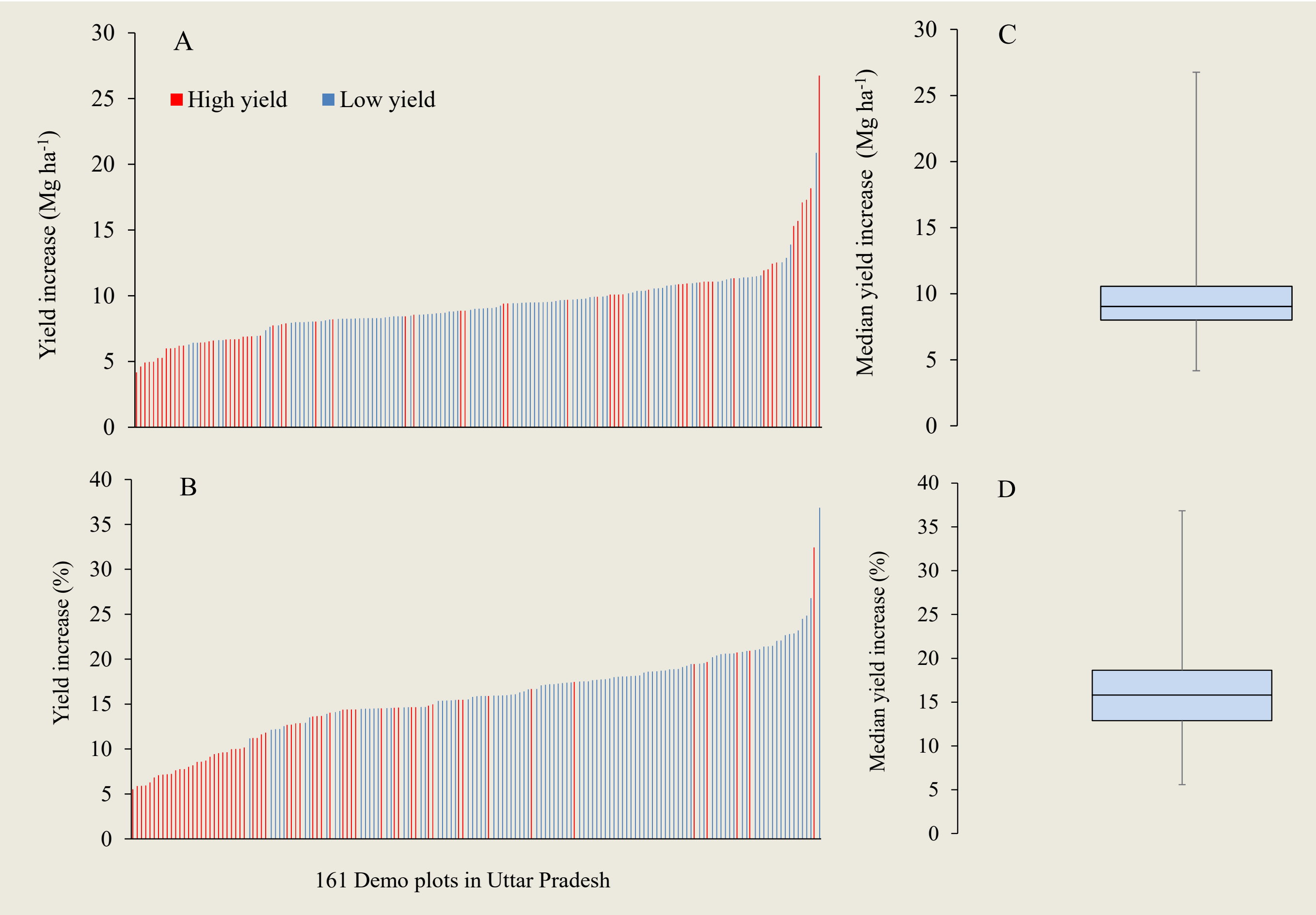


Fig. 3. Absolute (A) and relative (B) yield increase due to K application, presented in an ascending distribution among 161 demonstration trial plots in Uttar Pradesh, dissected according to high and low control yields. The corresponding statistical analyses (C and D) are presented as box plot diagrams, where the middle line represents the median, the upper and lower box edges represent the 25th and the 75th percentiles respectively, and the bars reach the maximum and minimum values.

displaying district-specific patterns (Fig. 4C). Both absolute and relative yield increases in Bijnor were the lowest (Table 2), showing a declining pattern as a function of the control yield (Fig. 4C and D). In Muzaffanagar, the yield increases split between a normal level of about 8-12 Mg ha^{-1}, which corresponded with those in eastern districts, and a lower level of about 4-7 Mg ha^{-1} that corresponded with yields in Bijnor. Meerut obtained the highest mean yield increase (Table 2), nevertheless, it resulted from extremely dispersed data, ranging from 7-27 Mg ha^{-1}, indicating the predominance of local conditions on sugarcane response to K application in this district.

The significant and straightforward effect of K application at every single site throughout the state, and in spite of considerable environmental differences, strongly demonstrates the pivotal role of this nutrient in sugarcane production. These results agree with many studies that demonstrated the significant contribution of K application to sugarcane yield and quality (Orlando Filho, 1985; Kwong and Pasricha, 2002; Yadav, 2006; Shukla *et al.*, 2009; Medina *et al.*, 2013; Kumawat *et al.*, 2016; Tran *et al.*, 2016; Ali *et al.*, 2018). The results also strongly confirm recent research highlighting the poor nutrient status of Uttar Pradesh soils, particularly regarding K availability (Singh *et al.*, 2012; Dey *et al.*, 2017; Patra *et al.*, 2017; Ramamurthy *et al.*, 2017). It is hoped that these results will lead to changes in the approach of the sugarcane industry regarding the vital need of K fertilization.

The diversity in control yields is not surprising. Considering the large scope of the study, including the geographic heterogeneity across Uttar Pradesh, different cultivars, local farmer practices, soils, seasons and year of harvest, control yield variation from 42 to 110 Mg ha^{-1} is quite normal. In contrast, the variation in the yield increase response was moderate and quite stable (Fig. 3). The relatively stable yield increase in response to fixed K application across a wide range of control yield, which occurred particularly in eastern districts (Fig. 4A), may suggest that K

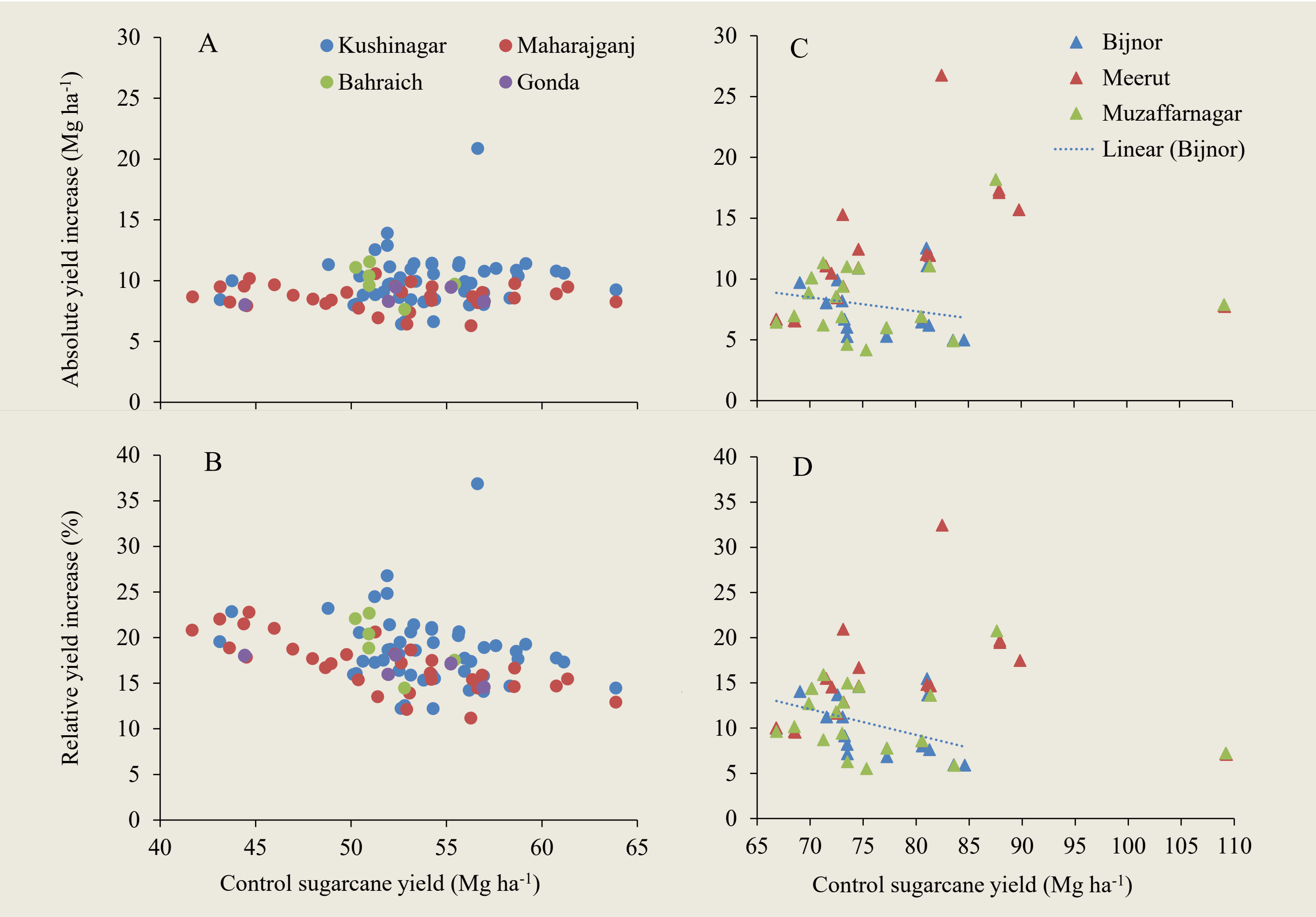


Fig. 4. The absolute (A and C) and the relative (B and D) sugarcane yield increase resulting from K application, as a function of the control yield in eastern (A and B) and western (C and D) districts of Uttar Pradesh that were included in the demonstration plot trials. The dotted line indicates the trend in Bijnor.

requirements were only partially met. A larger basal application might satisfy crop needs at earlier stages of development but completely disappear by the beginning of the monsoon season, leaving insufficient nutrient availability during the rest of the season, which is critical to sugar accumulation (Geiger and Conti, 1983; Stephen, 1985; Cavalcante *et al.*, 2015; Mengel, 2016). Therefore, further research is needed to optimize K application dose and timing, fitting it to crop requirements during the season and according to its developmental phases. The diversity in western districts was much greater (Fig. 4B), indicating significant differences between locations. In this case, the soil test yield-targeted approach (Velayutham *et al.*, 2016) could be useful in optimizing the procedure.

Conclusions

Potassium application, in addition to commonly applied N and P fertilizer, had an unequivocal effect, significantly increasing sugarcane yield over a broad scale of environmental heterogeneity throughout Uttar Pradesh. These results strongly indicate a critical need for the development of K fertilization practices aimed to increase sugarcane yield and profit in the state, as well as in neighboring sugarcane producing states. In the short-term, the K dose successfully employed in this study (150 kg K_2O ha^{-1}) can be recommended to sugarcane farmers as a transient means to obtain higher yields and profits. Nevertheless, further research is needed in order to determine appropriate K doses and application practices to ensure balanced crop nutrition, optimum fertilizer use, sufficient K availability whenever needed, and sustainable soil fertility.

Acknowledgements

This project is supported by 'Potash For Life (PFL)', which is a consortium between Indian Potash Limited (IPL) and Israel Chemicals Ltd. (ICL) founded in response to recent regression in potash use in India. The PFL project is raising awareness of the importance of potash fertilization in sugarcane, one of the key cash crops in India, mainly through demonstration plot trials in collaboration with local farmers, where the results are clear and demonstrative.

References

Ali, H., I. Ahmad, S. Hussain, M. Irfan, A. Areeb, and R.N. Shabir. 2018. Basal Application of Potassium Nutrition Enhances Cane Yield, Juice Quality and Net Returns of Sugarcane (*Saccharum Officinarum* L.). Pakistan Journal of Agricultural Sciences 55(2).

Cavalcante, V.S., R. de Mello Prado, H.J. de Almeida, F.J.R. Cruz, and D.M.M. dos Santos. 2015. Gaseous Exchanges, Growth and Foliar Anatomy of Sugarcane Plants Grown in Potassium (K) Deprived Nutrient Solution. Australian Journal of Crop Science 9(7):577.

Dey, P., R. Santhi, S. Maragatham, and K.M. Sellamuthu. 2017. Status of Phosphorus and Potassium in the Indian Soils Vis-à-Vis World Soils. Indian J. Fertilisers 13(4):44-59.

DSD (Directorate of Sugarcane Development). IMOA (India Ministry of Agriculture). 2013. Status Paper on Sugarcane. https://farmer.gov.in/imagedefault/pestanddiseasescrops/sugarcane.pdf.

FAOSTAT. 2016. http://www.fao.org/faostat/en/#data.

Food and Agriculture Organization of the United Nations (FAO). 2005. Fertilizer Use by Crops in India. Available at: http://www.fao.org/tempref/docrep/fao/009/a0257e/a0257e07.pdf [Accessed 18/09/2018].

Food and Agriculture Organization of the United Nations (FAO). 2018. FAO in India/India at a Glance. Available at: http://www.fao.org/india/fao-in-india/india-at-a-glance/en/ [Accessed 15/04/2018].

Galloway, J.H. 2005. The Eastern Origins. *In:* The Sugar Cane Industry: A Historical Geography from its Origins to 1914 (Vol. 12). Cambridge University Press. p. 19-30.

Geiger, D.R., and T.R. Conti. 1983. Relation of Increased Potassium Nutrition to Photosynthesis and Translocation of Carbon. Plant Physiol. 71(1):141-144.

Kumawat, P.D., B.S. Rajawat, and A.D. Rathod. 2016. Role of Potassium Nutrition in Improving Growth, Yield and Quality of Sugarcane - A Review. Asian Journal of Science and Technology 7(9):3609-3613.

Kwong, K.F., and B. Pasricha. 2002. The Effects of Potassium on Growth, Development, Yield and Quality of Sugarcane. *In:* Potassium for Sustainable Crop Production. Proceedings International Symposium on the Role of Potassium in Nutrient Management for Sustainable Crop Production in India. p. 430-444.

Medina, N.H., M.L. Branco, M.A.G. da Silveira, and R.B.B. Santos. 2013. Dynamic Distribution of Potassium in Sugarcane. Journal of Environmental Radioactivity 126:172-175.

Mengel, K. 2016. Potassium. *In:* Handbook of Plant Nutrition. p. 107-136. CRC Press.

Nandhini, T.S.K.D., and V. Padmavathy. 2017. A Study on Sugarcane Production in India. International Journal of Advanced Research in Botany 3(2):13-17.

Orlando Filho, J. 1985. Potassium Nutrition of Sugarcane. *In:* Potassium in Agriculture (potassiuminagri), 1045-1062.

Pathak, H., S. Mohanty, N. Jain, and A. Bhatia. 2010. Nitrogen, Phosphorus, and Potassium Budgets in Indian Agriculture. Nutrient Cycling in Agroecosystems 86(3):287-299.

Patra, A.K., S.K. Dutta, P. Dey, K. Majumdar, and S.K. Sanyal. 2017. Potassium Fertility Status of Indian Soils: National Soil Health Card Database Highlights the Increasing Potassium Deficit in Soils. Indian Journal of Fertilisers 28.

Prasad, R., and J.F. Power. 1997. Soil Fertility Management for Sustainable Agriculture. Boca Raton, Florida. CRC Press LLC.

Ramamurthy, V., L.G.K. Naidu, G. Ravindra Chary, D. Mamatha and S.K. Singh. 2017. Potassium Status of Indian Soils: Need for Rethinking in Research, Recommendation and Policy. Int. J. Curr. Microbiol. App. Sci. 6(12):1529-1540. doi: https://doi.org/10.20546/ijcmas.2017.612.171.

Singh, V.K., V. Govil, S.K. Singh, B.S. Dwivedi, M.C. Meena, V.K. Gupta, and B. Gangwar. 2012. Precision Nutrient Management Strategies using GIS-Based Mapping in Western Uttar Pradesh. Better Crops 6(1):15-18.

Shukla, S.K., R.L. Yadav, P.N. Singh, and I. Singh. 2009. Potassium Nutrition for Improving Stubble Bud Sprouting, Dry Matter Partitioning, Nutrient Uptake and Winter Initiated Sugarcane (*Saccharum* spp. hybrid complex) Ratoon Yield. Eur. J. Agron. 30(1):27-33.

Stephen, H.C. 1985. Role of Potassium in Photosynthesis and Respiration. *In:* Munson, R.D. (ed). Potassium in Agriculture. ASA-CSSA-SSSA.

Tran, D.T., D.P. Nguyen, D.D. Nguyen, D.H. Vu, D.T. Nguyen, A. Shcherbakov. 2016. Potassium effects on the productivity and quality of sugarcane in Vietnam. International Potash Institute *e-ifc* IPI Electronic International Fertilizer Correspondent (*e-ifc*) 44:3-11.

Velayutham, M., R. Santhi, A. Subba Rao, Y. Muralidharudu, and P. Dey. 2016. The "Law of Optimum" and its Application for Realizing Targeted Yields in India - A Mini-Review. IPI Electronic International Fertilizer Correspondent (*e-ifc*) 44:12-20.

Wallace, A. 2008. Soil Acidification from Use of too Much Fertilizer. Communications in Soil Science and Plant Analysis 25(1-2):87-92.

Yadav, D.V. 2006. Potassium Nutrition of Sugarcane. *In:* D.K. Benbi, M.S. Brar, and S.K. Bansal (eds.). Balanced Fertilization for Sustainable Crop Productivity. Proceedings of the International Symposium held at Punjab Agricultural University, Ludhiana, India, 22-25 November 2006. p. 275-288.

The paper "The Impact of Potassium Fertilization on Sugarcane Yields: A Comprehensive Experiment of Pairwise Demo Plots in Uttar Pradesh, India " also appears on the IPI website at:

Regional activities/India