Research Findings

Cabbages grown with (right) and without (left) potash fertilizer, from demonstration plots in Nasik, Maharashtra, India. Photo by Potash for Life.

Response of Cabbage to Potash Fertilization in Field Plot Trials Conducted in Jammu & Kashmir, West Bengal and Maharashtra

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Abstract

Potassium (K) in Indian agriculture operates at an annual deficit of nearly 10 million tonnes (Mt) and has increasingly become a limiting nutrient adversely affecting both yield and quality of agricultural and horticultural produce. Lower additions on the pretext of soils being rich in available potassium have further exacerbated the situation. For demonstrating the usefulness and criticality of potassium as a yield-limiting nutrient, Indian Potash Limited conducted field experiments as a part of the Potash for Life (PFL) project to evaluate the K response in cabbage, and to demonstrate to farmers the increased yield and profitability obtained with muriate of potash (MOP) on the K-depleted soils. A simple and straight forward methodology was applied; the yields of two identical plots positioned side by side were recorded with the only difference that one of them was fertilized with additional K. Results from all trial plot-pairs showed a significant yield increase response to the MOP addition; average yield increase was statistically significant and stable at 3,139 kg ha^{-1} (absolute) or 11.8% (relative).

Keywords: Cabbage, potash fertilization, field plot trials, relative yield, mean, median

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Introduction

Despite concerted efforts towards industrialization, particularly over the past three decades, the Indian economy still continues to be an agricultural one. Contribution of agriculture to the India's GDP is 14% against 7% of China (World Bank, 2019). Value of Indian agriculture to the domestic economy has increased by more than US$ 1 billion since 2010. The size and growth of the Indian economy is dependent on the quality and fertility of soils as it directly influences the sustainability and profitability of agriculture. Soil fertility management is, therefore, central to sustenance of productivity and nutritional security (Prasad and Power, 1997). Fertilizer use is essential in arresting the fertility decline and realizing the potential crop yields.

Fertilizer constitutes one of the highest running costs of agricultural systems. Yet, if used correctly it can also be one of the most profitable investments. Imbalanced and incorrect use of fertilizers is known not only to lower the nutrient use efficiency, but it can also cause deterioration of soil quality (Wallace, 2008). Promotion of balanced fertilizer is, therefore, a must for prevention of both soil fertility decline in case of insufficient use, or soil quality deterioration arising out of over-fertilization exacerbated by the imbalanced use. Depletion of soil potassium (K) is a major factor for decline in soil fertility. Loss of K is most significant in developing countries such as India, where K-deficit is around 11 Mt (Tan *et al.*, 2005); in the developed and least developed areas of the world it is only 900 t and 1 Mt, respectively.

A number of cabbage-specific field trials have been carried out by different researchers in India to examine the effect of different fertilization regimes on yields. These trials are designed to understand the combination of fertilizer inputs best suited to improving soil fertility and therefore yield levels. These have included NPK, farmyard manure and vermicompost in different ratios. However, to date no field trials have been carried out as a means to examine the specific effects of K on cabbage yield levels in the country.

Cabbage is a rich source of vitamins (A, B_1, B_2 and C) as well as vital minerals such as calcium (Ca), sodium (Na), potassium (K) and phosphorus (P) – important to human health. Additionally, edible cabbage leaves contain water, carbohydrates and fiber which serve to improve the human health. Originating in Europe, cabbage found its way to Asia through Egypt and Mesopotamia. It was brought to India by Portuguese settlers during the middle of the second millennium. The absence of Sanskrit words for cabbage suggests that it arrived later than other vegetables.

Today, India ranks among the world's top two cabbage producers by volume (8.8 Mt – Fig. 1) after China. Despite being among the top three producers worldwide, yield levels of cabbage are particularly low in India at just 22 t ha^{-1} compared to 30–35 t ha^{-1} in China and Russia (Fig. 1). Vulnerability of the Indian soils to depletion of nutrients through years of intensive and aggressive agricultural

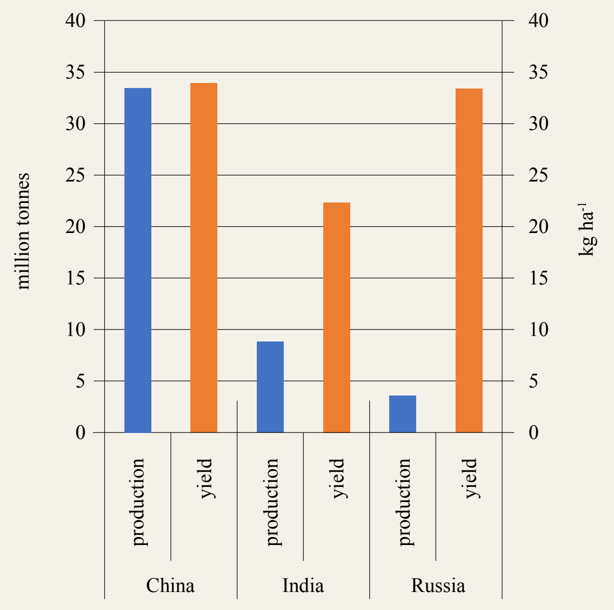

Fig. 1. Annual production and average yields of cabbage in top three countries.

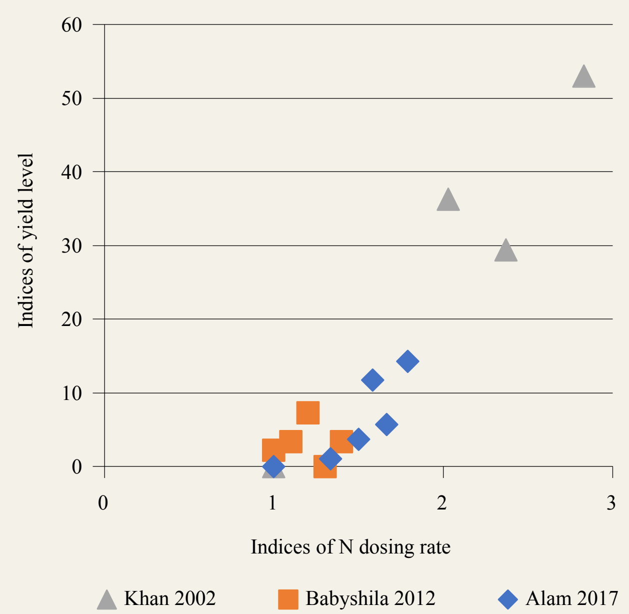

Fig. 2. Examples of results from literature on field trials on cabbage yield levels
Note: Compilation of results on cabbage field trials (nitrogen). Results on the effects of nitrogen in all papers are clear; however there is an absence of field trials on K in cabbage in India (author's own analysis).

Table 1. Fertilizer type and dose applied to the two treatments in both cabbage demo plot trial in Jammu and Kashmir in India.

Fertilizer source	Treatment (size of dosage)*			
	Control	+ K	Control	+ K
	----------kg ha^{-1}----------		----------kg $plot^{-1}$----------	
N (from urea + DAP)	75 or 45		30 or 18	
P_2O_5 (from DAP)	60		24	
K_2O (from MOP)	0	35 or 48	0	14 or 19.2
Manure (tonnes)	15-20		6-8	

* There were only two sites in Jammu and Kashmir. Different dosing sizes were used in the two plots as shown here.

Table 2. Fertilizer type and dose applied to the two treatments in both cabbage demo plot trials in Maharashtra in India.

Fertilizer source	Treatment (size of dosage)*			
	Control	+ K	Control	+ K
	----------kg ha^{-1}----------		----------kg $plot^{-1}$----------	
N (from urea + DAP)	150		60	
P_2O_5 (from DAP)	75		30	
K_2O (from MOP)	0	150	0	60
Manure (tonnes)	1 or 2		0.4 or 0.8	

* Of the two plots in Maharashtra, all dosing rates were the same except for manure (either 1 or 2 tonnes per hectare).

practices also makes it imperative to go in for the balanced fertilization in cabbage.

Cabbage is a heavy feeder of N and K and use of these nutrients has been made in its cultivation; rates of application depend on climatic conditions, local soil types and cropping intensity. Interestingly, it was found in a study where technology adoption behaviors by the Indian tomato and cabbage growers were compared that neither the fertilizer cost nor availability of fertilizer was a constraint on adoption of cabbage cultivation technology (Asati *et al.*, 2013).

Response of cabbage to different fertilization treatments in India has been studied (Khan *et al.*, 2002; Babyshila and Irabanta, 2014; Alam *et al.*, 2017; Islam *et al.*, 2017; Chaudhary *et al.*, 2018; Srivastava *et al.*, 2018) (Fig. 2). However only one of these fertilization treatments included specific isolation of K effects on cabbage yield levels (Srivastava, 2018). Recognizing the importance of K as one of the main limiting factors in crop production, a collaborative project between Indian Potash Limited (IPL) and International Chemical Limited (ICL) Fertilizers named "Potash for Life (PFL)" was launched to improve the understanding on effect of potash on economically-significant and heavy-feeding crops such as cabbage; and to demonstrate to farmers the increased yield and profitability through fertilizing with muriate of potash (MOP) on K-depleted soils. It was specifically launched to address the recent negative development in potash (KCl) use in India, and to support the farm sector profitability. Main objectives of the study included to i) demonstrate on the farmers' fields the increased yield and profitability through application of MOP in addition to conventional use of DAP, urea and manure, ii) evaluate cabbage response to MOP according to recommended fertilizer blends on K- deficient soils, and iii) study the influence of secondary factors, if any, on the cabbage yields.

Table 3. Fertilizer type and dose applied to the two treatments in all cabbage demo plot trials in West Bengal in India.

Fertilizer source	Treatment (size of dosage)*			
	Control	+ K	Control	+ K
	----------kg ha^{-1}----------		----------kg $plot^{-1}$----------	
N (from urea + DAP)	180		23.4	
P_2O_5 (from DAP)	50		6.5	
K_2O (from MOP)	0	50	0	6.5
Manure (tonnes)	2-22		0.8-2.9	

* All dosing rates were the same in West Bengal except for manure which varied significantly between plots as indicated.

Materials and Methods

Experimental Setup

Trials for K response in cabbage were conducted in the states of West Bengal, Maharashtra and Jammu and Kashmir. On each farm, a pair of equally-sized cabbage plots was laid side-by-side; one for the control to receive a standard fertilizer treatment containing N and P and other to include the same treatment plus MOP. Plot sizes within each pair were the same; however, the sizes of the plots were either 0.13 or 0.4 ha depending on farm location. Irrigation was either through a canal system or not reported. Plot soil types were either clay-loam, black or not reported. A total of eight cabbage varieties used in the trials were Real Ball, Snowball, Namdhari, Najmi, Green, Resist Crown, Snow Resist and Takiz Coral. All recommended growing practices were followed.

Treatments

The two treatments used consisted of: a) control, where a standard fertilizer treatment of N and P was applied, and: b) '+K treatment', where muriate of potash (MOP) was applied in addition to the other standard treatments. The control and the treatment were, therefore, identical between each plot-pair except for the MOP input in the '+K treatment'. Doses of all three nutrient inputs varied from states to states (Tables 1, 2 and 3).

Statistical Analysis

Outlier test used was 1.5 and 3 times the inter-quartile range for inner and outer fences, respectively. Pairwiset-test was applied to determine the probability whether the differences in the average yield levels between the control and K-treated data sets were due to application of MOP or due to chance. Analysis by pairwise t-test was conducted in one block, comparing all 23 data points in all the three states, with a pairwise t-test (paired two sample for mean), in order to compare control plots with '+K treatment' plots.

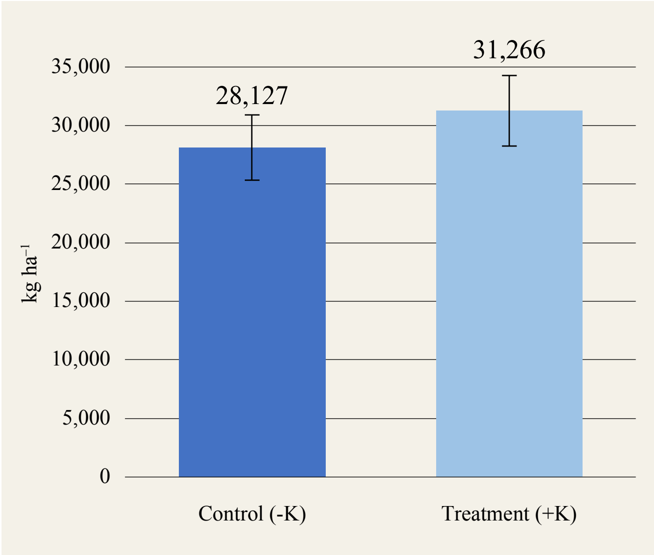

Fig. 3. Average control and +K yield levels. Error bars show one standard error. Results were statistically different despite errors overlapping.

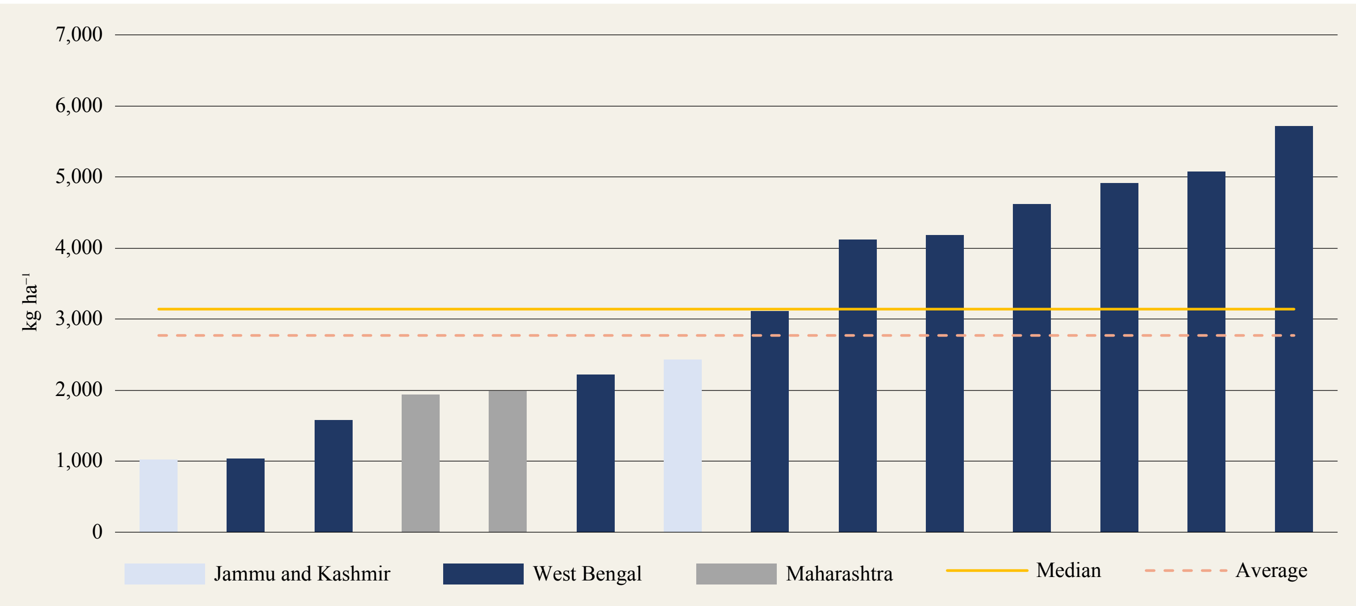

Fig. 4. Absolute yield increases across all sites in order.

Note: Absolute yield increases in all plot-pairs through adding MOP ordered by size. Bar colours represent each state. Solid and orange dotted lines represent average and median values, respectively.

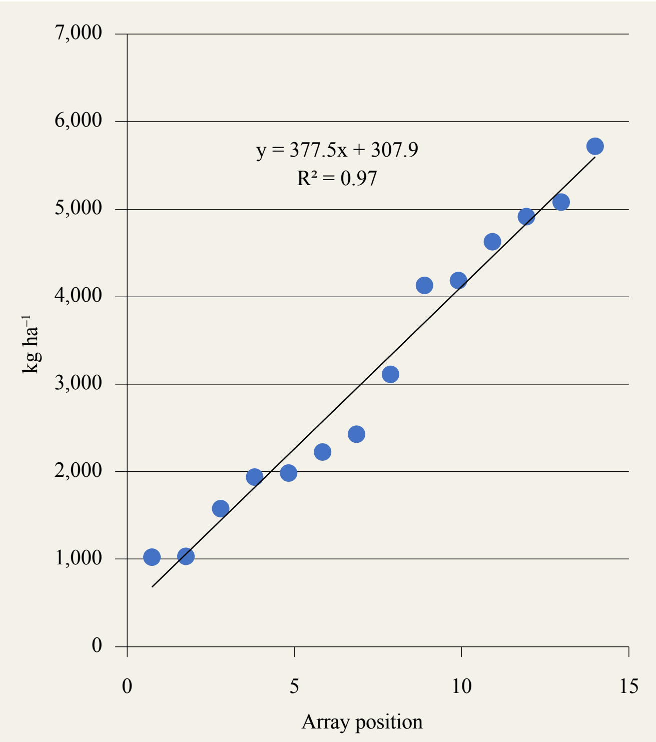

Fig. 5. Actual absolute yield increases (circles) against a linear fit. Data followed the linear distribution closely with an R^2 value of 0.97. The plot annotation indicates the fit of the curve.

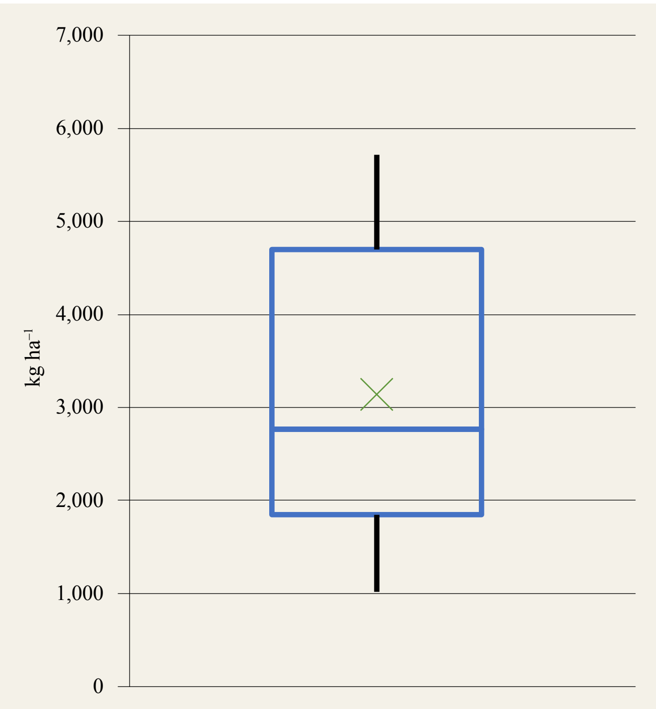

Fig. 6. Spread of absolute yield increases. The median is represented by the middle line, 25th and the 75th percentiles by the upper and lower box edges, the average by the x and maximum and minimum by bar lengths.

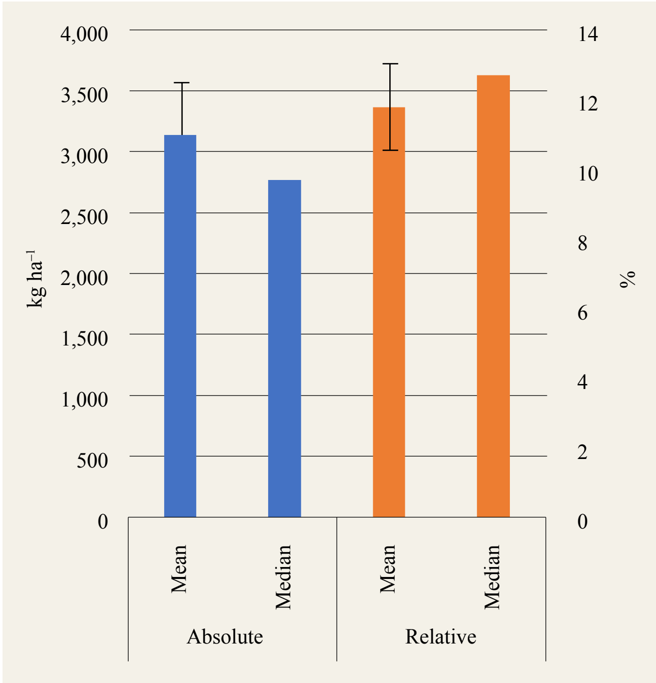

Fig. 7. Average and medians of the yield level increase data. Error bars indicate 1 standard error. The low standard errors indicate stability in the data and the proximities of the average and median values their accurate representation of the data.

ANOVA tests were used to determine which if any independent variables influenced yield metrics. Variables deemed to have influenced results were examined further through post-hoc tests to determine significance between variables. The post-hoc correction type used was Bonferroni with results ranked according to the Holm principle; linear regressions on continuous dependent variables (i.e., fertilizer dosing rates).

On account of flooding, nine out of the 23 plot-pairs had to be abandoned. These data were, therefore, precluded from the analysis leaving a total of fourteen sites of interest. The outlier test indicated no outliers in the remaining datasets.

Results and Discussion

Effect of MOP on Cabbage Yield

The average cabbage yield level in the control plots carried out across the three states was 28,127 kg ha^{-1}; across the +K plots, this increased to 31,266 kg ha^{-1} (Fig. 3). Statistical testing indicated that the increase was significant, and that potassium applied as MOP (KCl) had a positive effect on yield over the standard treatment of N and P. Clear benefits of MOP application were registered through an average yield increase of 3,139 kg ha^{-1} (Fig. 4). Increases were observed across all fourteen plots under study varying from 1,019 kg ha^{-1} to 5,715 kg ha^{-1}. The median increase was 2,770 kg ha^{-1}.

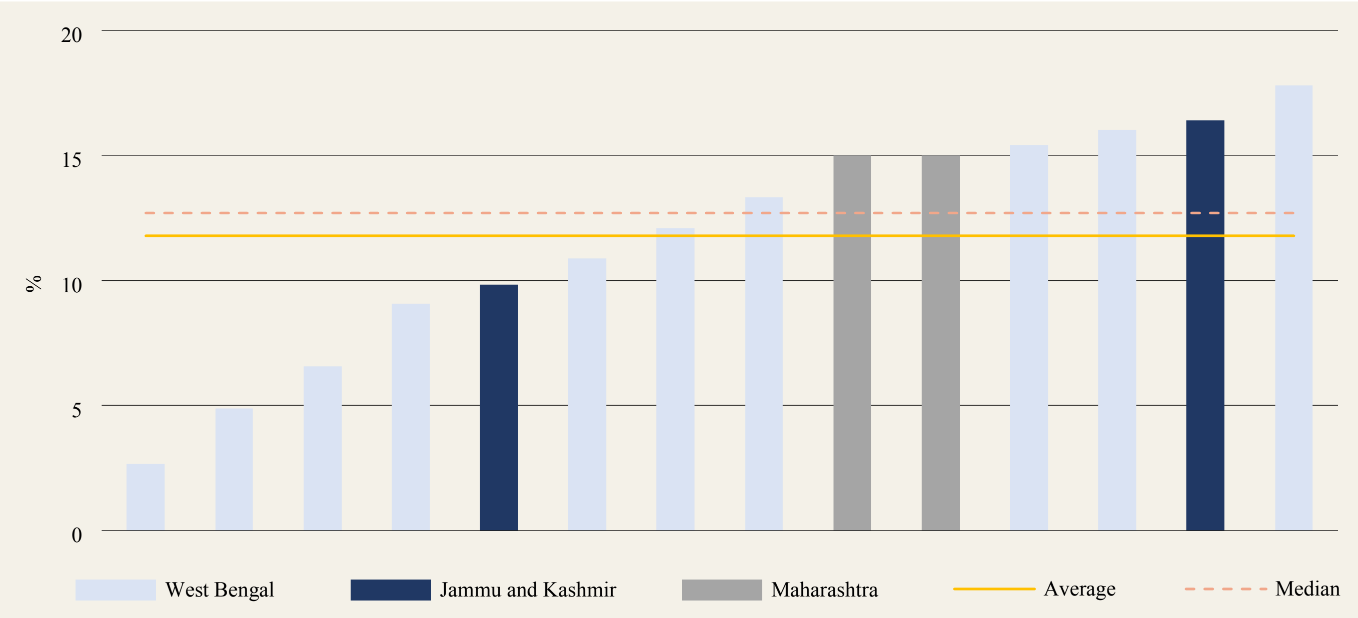

Fig. 8. Relative yield increases across all sites in order.
Note: Relative yield increases in all plot-pairs through adding MOP ordered by size. Bar colors represent each state. Solid and orange dotted lines represent average and median values, respectively.

Verification and Distribution of the Absolute Yield Increase Data

Differences between the control and MOP-treated yield levels were explored through regression analysis (Fig. 5). Absolute yield increase data recorded through the trials demonstrated clear proximity to a linear curve with an R^2 value of 0.97; R^2 value of 1 indicates an exact correlation. The box plot (Fig. 6) illustrates the distribution of the absolute yield increase data. As indicated, the response to MOP application ranged from 1,019 to 5,715 kg ha^{-1}, and the 25th and 75th percentiles were 1,846 and 4,698 kg ha^{-1}, respectively. Plot shows the unequal spread of the data across the range due to a considerable skew towards higher yield increase effects as indicated by the median splitting the data in the lower half of the box. This means that the yield increases at the lower levels were closer together than those at the higher levels. This shape of the data was also confirmed by the median absolute yield increase (box line) being slightly lower than the average ("X" in the box).

Quality of the Yield Increase Data

As in the case of the absolute yield increase data, the average value of the relative yield increase showed stability on account of the standard error (1.2%) being a low proportion of the mean (11.8%) (Fig. 7). Again, as in the absolute yield increase data case, the proximity of the median (12.7%) to the mean (11.8%) indicated their accurate representation of the datasets.

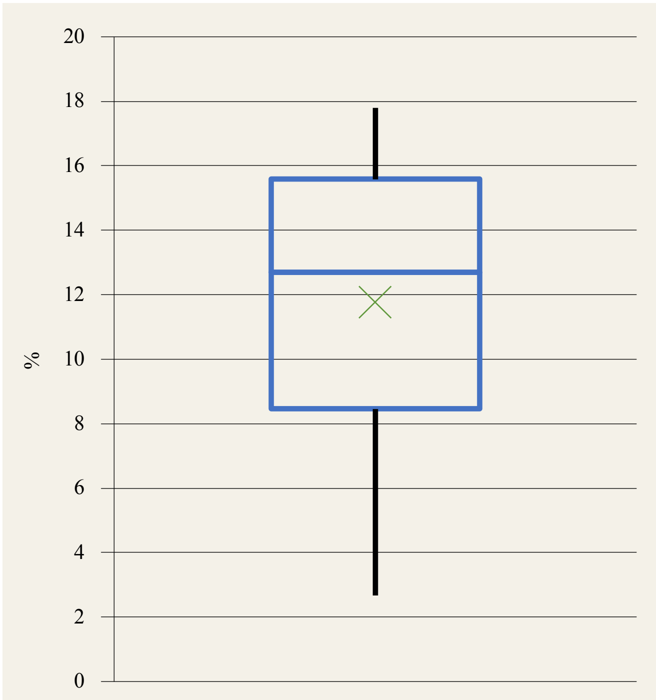

Fig. 9. Spread of the relative yield increases. The median is represented by the middle line, 25th and the 75th percentiles by the upper and lower box edges, the average by the x and maximum and minimum by bar lengths.

Table 4. Determining extraneous variables.

		Variable		
		State	Variety	Dosing rate
Metric	Control (-K) yield level			
	Treatment (+K) yield level			
	Absolute yield difference			
	Relative yield difference			

Indicates differences in yield metric as a function of variable

Indicates extraneous variables

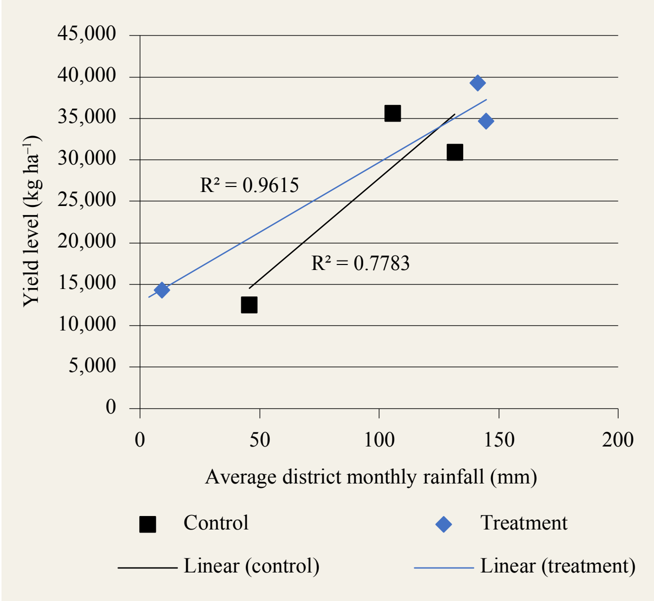

Fig. 11. Possible relationship between average district monthly rainfall and yield levels by district, 2014.

Relative Yield Increase Data and its Relative Distribution

In relative terms, the inclusion of MOP into the standard fertilizer treatment of urea, DAP and manure resulted in an average cabbage relative yield increase of 11.8% with a range of 2.7 to 17.8% and a median value of 12.7% (Fig. 8).

Box plot in Fig. 9 shows the distribution of the relative yield increase data. As indicated, the relative response to MOP application ranged from 2.7 to 17.8%. The median value was 12.7% versus an average of 11.8% and the 25th and 75th percentile values were 9.1 and 15.4%, respectively. Shape of the relative yield increase data spread differed from that of the absolute yield increase data in that it was skewed towards lower yield levels. This means that the yield increases of the higher yield increases were closer together than those of the lower yield increases. This shape of the data was also confirmed by the median relative yield increase (box line), which was higher than that of the mean ("X" in the box); the positions of the relative yield increase average and median were also, therefore, reversed when compared to that of absolute yield increase data (wherein the average was higher than the median).

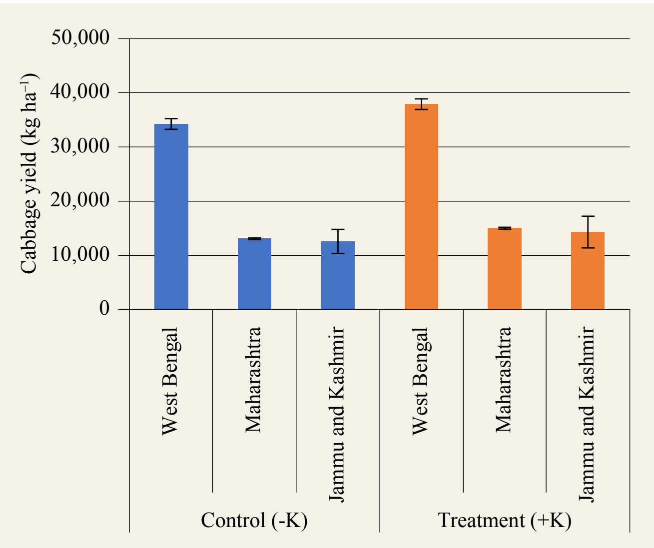

Fig. 10. Effect of state on yield metrics. Control and +K treated yield levels by state. Yield levels were highest in West Bengal compared to Maharashtra and Jammu and Kashmir.

Extraneous Variables

Statistical tests were used to determine whether external variables (namely state, variety of cabbage and dosing rate) had any impact on the yield metric values recorded (Table 4). None of these variables had effect on yield increases; absolute or relative. However, both control yield levels and +K treatment yield levels differed as a function of state and variety of cabbage.

Yield Levels by State

Yield levels were higher in West Bengal than in Maharashtra or Jammu and Kashmir (Fig. 10). The statistical test showed that the average yield levels between Maharashtra and Jammu and Kashmir were effectively the same despite the significant geographic distance between these trials. Errors were markedly higher in the state of Jammu and Kashmir.

It is interesting to note that there may be some correlation between location (district), extent of rainfall and yield levels. A simple regression analysis comparing rainfall in the trial location districts and

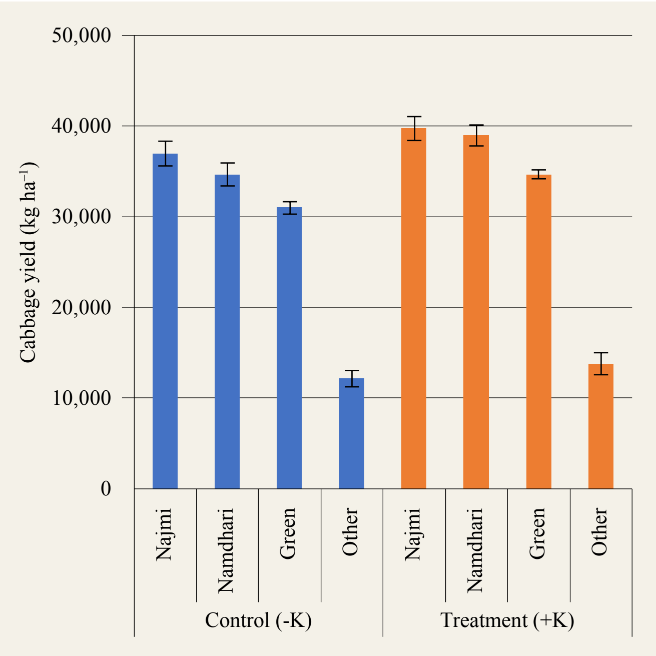

Fig. 12. Effect of variety on yield metrics.

yield levels pointed towards higher rainfall resulting in higher yields in both control and treatment levels (Fig. 11) with R^2 values being 0.78 and 0.96, respectively. No relationship between rainfall and absolute yield levels or relative yield levels was observed. Before any firm conclusions are drawn from the possible relationship between rainfall in trial locations and yield levels, it should be kept in mind that this possible observation is based on only three available data points.

Yield Levels by Variety

Yield levels also differed as a function of cabbage variety. As shown in Fig. 12, yield levels were highest in Najmi and were followed by Namdhari, Green and "Others" (Real ball, Snowball and Takiz Coral – grouped together for brevity). Averages as a function of cabbage variety were shown to be different in all the pairs except for Najmi-Namdhari which indicated no significant difference either in the control yield levels or the +K treated yield levels.

Profitability

Market price of cabbage in this work went largely unreported. Only three sites reported the market price of cabbage; two reported a price of Rs. 35 kg^{-1} and one reported Rs. 20 kg^{-1}. Likewise, cost of MOP was reported in just these three sites alone at a cost of Rs. 16 kg^{-1}. Average benefit to cost ratio of including MOP in the treatment was 82.00 based on average sale price of Rs. 27.5 kg^{-1}, MOP cost of Rs. 16 kg^{-1} and average absolute yield increase of 3,139 kg ha^{-1} (Fig. 13).

Based on a theoretical ±60% – a percentage range chosen based on the spread of yield increases, cabbage price and cost of MOP – the spread of benefit to cost ratios extended from 32.20 to 206.51. Relationship between cabbage price and profitability was linear though the relationship between MOP cost and profitability was non-linear and strongly inversely proportional.

Sensitivity analysis (Fig. 13) depicts the dynamics between cabbage price and cost of MOP on profitability. Analysis indicates that the benefit to cost ratio increases linearly with market price at about 0.8 (i.e. a price increase of 1% from current market price results in an increase in the benefit to cost ratio of about 0.8%). As would be expected, an increase in potash price results in a decrease in benefit to cost ratio. However, this relationship was not linear. It is also worth noting that on account of its non-linearity, rate in the drop of the benefit to cost ratio as a function of MOP cost falls as MOP cost increases; that is to say that at higher MOP costs, its effect on reducing farmer benefit to cost ratios becomes less significant and vice-versa.

It is also noteworthy that the range of MOP prices used in the sensitivity analysis (Fig. 13) includes the range of MOP prices reported across India since 2011 (Rs 8.43 – 28.33 kg^{-1}) (Chanda *et al.*, 2016).

Results of these trail plots clearly show that the inclusion of MOP into fertilization regimes in cabbage in these trials increased the yield levels which were both quantifiable and verifiable through statistical tests. Based on this work, it can be inferred that the cabbage plantation in India can be expected to produce around additional three tonnes per hectare through MOP application. Responses to MOP were positive regardless of location, soil type, fertilizer dosing rates or cabbage

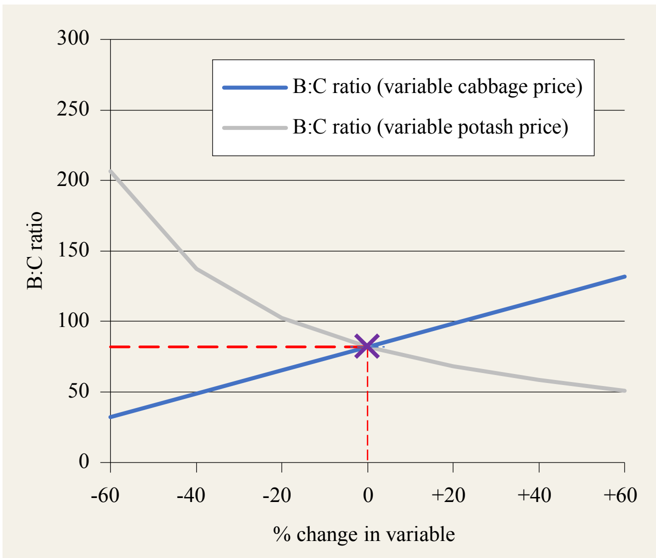

Fig. 13. Benefit:cost ratio sensitivity analysis showing range of benefit:cost ratios for different cabbage prices and potash costs. The red-dotted lines and purple slanted cross indicate the average benefit:cost ratio of 82.00.

variety, and average yield increase values were both high and stable. Even the lowest MOP responses were significant whether considered in relative or absolute terms.

This clear linear distribution trend of the yield increase response from MOP suggests a moderate average natural variability of K depletion within the response range. However, as indicated earlier there is a distinction in yield responses between the states. This indicates differences in the yield levels achievable between states which could be caused by many factors and but these are not simply because of the absence of sufficient K for healthy growth.

Differences in yield levels between the districts can be attributed to differences in geography, practices and levels of K depletion. Climate and topography which are very similar between the states showed different yield levels, e.g. Maharashtra and West Bengal. Therefore, the most likely explanation is the difference in fertilizer dosage (Tables 1, 2 and 3) and management between the districts.

Observations on the possible links between rainfall in district and yield levels are also worthy of discussion. A positive linear correlation between extent of rainfall and yield levels is always expected as the availability of water is inherent to agricultural productivity. However, the fact that correlations between rainfall and yield differences were not found to be significant indicates that the extent of rainfall need not be factored into fine-tuning of guidance with respect to MOP rates. This further confirms that the yield differences reported here are due to MOP and not due to other external factors.

Range in both the control and +K-treated yield levels indicates that demand for K in cultivated soils of India varies significantly. There are currently no means of predicting cabbage response to MOP application at a given location with certainty, other than by conducting comprehensive soil and K crop response tests. A relevant approach could be tailored to include a whole package of solutions.

It is evident that the yield increases reported through this work are of a magnitude comparable to similar work reported elsewhere. Srivastava *et al.* (2018) indicated a relative yield increase of 16% in a cabbage plot trial where rate of K was the only variable (from 5 to 30 kg ha^{-1}). Though the K-response in this work is not identical to the literature results, comparability between the two experiments in terms of order of magnitude provides some confirmation of the results here.

Finalizing nutrient balances at field scale through comprehensive soil testing is not feasible for local smallholder farmers. Rather, raising awareness of balanced fertilizer use with appropriate suggestions for MOP application rates based on empirically verified large scale trials could gradually improve the existing practices of the local smallholders farming systems. Fine-tuning of dosage and nutrient balancing on local field level would then become an inherently cost- and resource-effective trend towards the development of a clear, simple and straight-forward path to productivity, profitability and sustainability on a regional scale.

The Tangible Benefits to Farmers

Dissemination of MOP-fertilization practices has shown considerable potential for increasing cabbage productivity in the states of Jammu and Kashmir, Maharashtra and West Bengal. As indicated in this study and based on the current country production statistics (Fig. 1), it can be inferred that the MOP-fertilizer treatments would increase cabbage yields and push the sector's yields to the levels obtained in China and Russia. Current cabbage yield levels in India are lower than many of the cabbage growing countries of the world.

Assuming that the farmers use the same MOP rates as those used in this study, increases in output levels would provide a rough benefit:cost ratio of 82:1. Such results are likely to interest the country's cabbage farmers. The price sensitivity analysis shown in the results and the high benefit:cost ratios indicate that farmers are likely to experience net profit despite any fluctuations in cabbage prices or cost of MOP.

Conclusions

MOP application, in addition to commonly applied N and P fertilizers, had an unequivocal effect in significantly increasing the cabbage yields in the states of Jammu and Kashmir, Maharashtra and West Bengal. The soil status of plant available K was inadequate in meeting the K requirements of cabbage. Hence, MOP inclusive fertilizer regimes became necessary to improve and optimize yields of this important vegetable crop. These results strongly advocate the recommendation of K depending on the states (35, 48, 50 or 150 kg K_2O ha^{-1}) to obtain higher yields and profits.

Variations in MOP response give enough reasons to investigate further experiment having higher MOP dose, as well as ways to fine-tune the recommendations on a local field scale. Further research is recommended to determine the appropriate MOP doses and application practices to ensure balanced crop nutrition, optimal fertilizer use, sufficient K availability whenever needed, and sustainable soil fertility.

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The paper "Response of Cabbage to Potash Fertilization in Field Plot Trials Conducted in Jammu & Kashmir, West Bengal and Maharashtra" also appears on the IPI website.