Research Findings

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Potassium Nutrition for Improving Yield and Quality of Onion

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Abstract

Field experiments were conducted at the Post Graduate Institute Farm of the Department of Soil Science and Agricultural Chemistry, Mahatma Phule Agricultural University, Rahuri (Maharashtra) during three consecutive Rabi seasons from 2007-2008 to 2009-2010 to study the effect of increasing rates of potassium (K) fertilizer application on yield, quality and nutrient uptake of onion (Cv. N-2-4-1). All treatments including a yield targeted treatment and one based on a soil test significantly increased bulb yield compared to the control without K. Application of 100 kg K_2O ha^{-1} recorded statistically superior bulb yield of (52 mt ha^{-1}); but further improvement on yield was not detected with the two higher rates of up to 150 kg K_2O ha^{-1}. Total sugar, reducing sugar and non-reducing sugar percentage contents of the

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bulbs increased significantly as a consequence of application of K_2O (100 kg ha^{-1}) along with the recommended dose of N and P fertilizers. The yield contributing characters viz., polar diameter and equatorial diameter were significantly increased by 100 kg K_2O ha^{-1}. Application of graded levels of K raised the quality of the crop by increasing the total soluble solids, non-reducing sugars and chlorophyll (45 days after transplanting) content up to 100 kg K_2O ha^{-1}. This beneficial influence of K most probably largely relates to its stimulating effect on photosynthesis and the translocation of photosynthetic products to the bulbs.

Nutrient balance (fertilizer input vs. crop offtake) was influenced by the various K treatments. Offtake of nutrients increased with increased yields but also with higher N and K tissue concentrations. At zero or low levels of applied K fertilizer, a positive nitrogen (N) balance (unused N fertilizer by the crop) was induced in accordance with the low yield. A zero N balance between crop offtake and fertilizer input was observed with an application of 75 kg K_2O ha^{-1}. With further increase in K fertilizer input, yield increased up to 100 kg K_2O ha^{-1}, but at higher levels of K fertilization a negative balance of N to the extent of 70-80 kg N ha^{-1} was evident. These results suggest that the stagnation in yield increase beyond the application of 100 kg K_2O ha^{-1} was largely due to a lack of N. The results obtained in the present investigation indicate that the economic analysis is not sensitive to the cost of K fertilizer, and on this particular site the application of 150 kg K_2O ha^{-1} resulted in the highest economic yield.

Introduction

Onion is one of the most widely grown vegetable crops on a commercial scale. It is extensively cultivated all over the world, especially in Australia, Bangladesh, China, India, The Netherlands and Pakistan. As the second largest onion growing country in the world, India accounts for about 16% of world production, but has an average yield of only 10.38 mt ha^{-1}, considerably lower than the global average of 18.08 mt ha^{-1} (www.fao.org, 2005). Imbalanced fertilization with excess N and too little phosphorus (P) and K, inducing low nutrient efficiency, is a common cause of low yield and poor quality in vegetables, including onion (Kanwar and Sekhon, 1998).

The essential role of K in numerous physiological and biochemical processes in the plant - including photosynthesis, enhancing the translocation of assimilates, protein synthesis, maintenance of water balance, and promoting enzyme activities - are well established (Marschner, 2012). In practical terms the importance of K in relation to onion yield and quality has been reported (Yadav *et al.*, 2002; Masalkar *et al.*, 2000). An adequate K content of the bulb is also important for storage quality of the crop. K deficiency in onion is expressed by the appearance of brown tips in older leaves and poor bulb formation. The application of an appropriate quantity and source of K to onion at critical growth stages is thus essential for maintenance of growth and quality (Subba Rao and Brar, 2002). The onion crop removes large quantities of nutrients from the soil, which must be replenished to maintain soil fertility. For a 40 mt ha^{-1} bulb yield this amounts to 120 kg N, 50 kg P and 160 kg K per ha^{-1} (Tandon and Tiwari, 2008), whereas lower nutrient rates of 100 kg N, 50 kg P_2O_5 (30 kg P) and 50 kg K_2O (41 kg K) per ha^{-1} are commonly applied, especially for K.

The present work was therefore undertaken to study the effect of soil applied graded levels of K as muriate of potash (MOP) on yield, quality and nutrient uptake by onion (Cv. N-2-4-1).

Materials and methods

Field experiments using onion (Cv. N-2-4-1) were conducted during three consecutive Rabi seasons from 2007-2008 to 2009-2010 at the same site of the Post Graduate Institute Farm of the Department of Soil Science and Agricultural Chemistry, Mahatma Phule Agricultural University, Rahuri (Maharashtra). Experiments were laid out in a randomized block design comprising eight potash treatments, each replicated four times. These included five increasing potash rates (50, 75, 100, 125, 150 kg K_2O ha^{-1}) and three other treatments viz. an absolute control, a treatment as per soil test and a treatment as per yield targeted 40 mt ha^{-1} (Table 1). A fertilizer dose of 100 kg N as urea and 50 kg P_2O_5 as single super phosphate was uniformly given to all treatments, except T_2 and T_5, in accordance with the soil test (higher N) and yield target calculation (higher N and P). K_2O was applied in the form of muriate of potash (KCl). The gross plot size was 5 m x 3 m while the net plot size was 4.40 m x 2.60 m using the recommended spacing of onion at 15 x 10 cm. The soil used in the experiment was an Inceptisol (Vertic Haplustepts) with the following chemical properties: pH 8.5, electrical conductivity (EC) 0.16 dS m^{-1}, organic carbon (6.2 g kg^{-1}), calcium carbonate (106.2 g kg^{-1}), available N (75 ppm), available (Olsen-P) P (8.5 ppm) and available (NH_4OAc-K) K (130 ppm). Farmyard manure (FYM) @ 10 mt ha^{-1} was applied to all the treatments every year.

Table 1. Treatments with applied nutrients.

Treatment		Applied nutrients		
		N	P_2O_5	K_2O
			kg ha⁻¹	
T_1	NP	100	50	0
T_2	NPK(1)	125	50	33
T_3	NPK_{50}	100	50	50
T_4	NPK_{75}	100	50	75
T_5	NPK(2)	125	78	86
T_6	NPK_{100}	100	50	100
T_7	NPK_{125}	100	50	125
T_8	NPK_{150}	100	50	150

(1)According to soil test; (2)yield target 40 mt ha^{-1}

Note: Values of P and K are for P_2O and K_2O.

Size of onion plants with increasing levels of K application. Photo by S.K. Bansal.

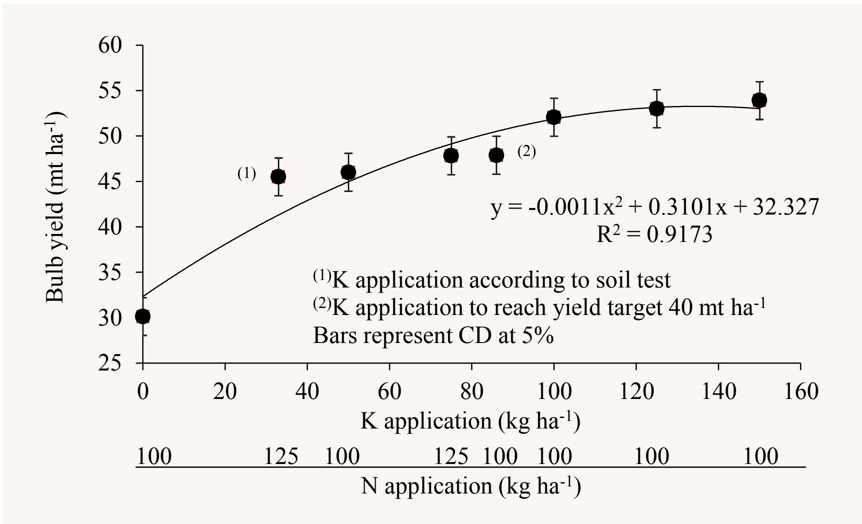


Fig. 1. Response of onion (bulb yield) to K and N application.

A yield targeted treatment of 40 mt ha^{-1} was established using the equations below:

$FN = 5.40 \times T - 0.54 \times SN$
$FP_2O_5 = 4.0 \times T - 4.32 \times SP$
$FK_2O = 3.10 \times T - 0.13 \times SK$

where FN, FP_2O_5 and FK_2O represent fertilizer N, P_2O_5 and K_2O (kg ha^{-1}), and T the targeted yield finalized on the basis of maximum achievable yield by progressive onion growers for the productive capacity of the variety (mt ha^{-1}). SN, SP and SK indicate soil available N, P and K (kg ha^{-1}), respectively (Kadam and Sonar, 2006). The treatment of the soil test was based on measurement of available K.

Farmers currently use a fertilizer dose of $N_{100}P_{50}K_{50}$. However, the introduction of high yielding onion varieties, with assured irrigation facilities, while increasing productivity and helping to enhance farmers' income has placed a higher nutrient demand that cannot be met by current rates of fertilizer application, especially of K.

Soil samples were collected before planting and after harvesting the crop. Dry and processed soil samples (<2 mm) were used to determine chemical properties using standard procedures. Measurements were made as follows: pH and electrical conductivity in 1:2 soil suspension (Jackson, 1973), organic carbon (C) by the methods of Nelson and Sommer (1982); available N by the alkaline permanganate method (Subbiah and Asija, 1956); available P by extracting the soil with $NaHCO_3$ at pH 8 followed by spectrophotometeric determination (Olsen *et al.*, 1954) and available K by soil extraction with 1N neutral NH_4OAc followed by estimation using a flame photometer (Knudsen *et al.*, 1982).

Plant samples were dried to a constant weight, then ground and analyzed. Total N was determined using the micro-kjeldahl digestion method with H_2SO_4:H_2O_2 (1:1) followed by ammonia estimation. Total P and K were both determined following wet digestion of the dried plant material with H_2SO_4:$HClO_4$:HNO_3 (1:4:10) as described above. Total soluble solids (TSS) were determined using a hand refractometer. Reducing and non-reducing sugars were estimated by the Fehling reagent method as per procedures given by A.O.A.C. (1990). Chlorophyll content of the fresh leaves was determined at 45 days after transplanting. Fresh leaf tissue was crushed in acetone by use of a pestle and mortar then filtered. The color intensity of the filtrate was then measured spectrophotometrically at 645 and 663 nm wavelengths as per the method outlined by Arnon (1949).

Results and discussion

Yield of onion

Yield data is presented in Fig. 1 and yield contributing characters are given in Table 2. As evident from Fig. 1, application of KCl at various levels and treatments all significantly increased bulb yield over the control without K (NP, T_1). Application of K_2O of 150 kg ha^{-1} (T_8) recorded the highest bulb yield of 53.90 mt ha^{-1}, however, there was no statistical difference between this treatment and the maximum achieved with the application of 100 kg K_2O ha^{-1} (T_6) (52.06 mt ha^{-1}). The yields of all three treatments (T_6, T_7, T_8) were significantly higher than the yield of T_1 - the absolute control with no K (30.11 mt ha^{-1}) - and the yields of the four other treatments with K levels lower than 100 kg K_2O ha^{-1}, including the dose calculated from soil test (T_2) and that calculated for yield target (T_5).

These findings show that the treatment as per soil test (T_2; point 1 in Fig. 1) overestimated N requirement and underestimated K_2O requirement, clearly indicating the need for a complete reappraisal of the interpretation of this soil testing method in relation to K fertilizer recommendations for the onion crop. In the targeted yield treatment (T_5; point 2 in Fig. 1), it appears that despite the 25% additional N and 56% additional P_2O_5 applications (Table 1), the yield was restricted by sub-optimal K_2O application. The addition of more K than the recommended dose, at levels greater than 100 kg K_2O ha^{-1}, resulted in vigorous plant growth and higher bulb yield. This may possibly be due to higher concentrations of K in promoting photosynthesis, enhancing the translocation of assimilates as well as enzyme activity, and protein synthesis (Shaheen *et al.*, 2011; Shusheel Kumar *et al.*, 2006).

Chlorophyll content and yield contributing characters

The application of potash significantly increased the chlorophyll content of onion leaves (Table 2). The chlorophyll leaf content at 45 days after transplanting (DAT) was significantly higher with 100 kg K_2O ha^{-1} (0.627 mg g^{-1} of fresh weight) than all other treatments tested. To our knowledge there is no evidence that K plays a direct role in chlorophyll synthesis. However, it seems very plausible that a high K status should facilitate essential processes of growth and development, thereby, inducing an indirect effect to increase chlorophyll concentration. Evidence in support of this concept comes from the findings of Varpe (2005) who reported an increased chlorophyll content in onion leaves at 45 days after transplanting in response to raised supply of all three nutrients N, P and K, presented individually compared to the control.

Table 2. Effect of potash levels on chlorophyll content (45 DAT) and yield contributing characters of onion.

Treatment	Chlorophyll content in leaves	Polar diameter	Equatorial diameter	Neck thickness
	mg g^{-1} fresh wt	-----------------------*cm*-----------------------		
$N_{100}P_{50}$	0.542	4.43	4.83	0.28
$N_{125}P_{50}K_{33}$ (1)	0.596	5.48	5.63	0.61
$N_{100}P_{50}K_{50}$	0.547	5.40	5.63	0.63
$N_{100}P_{50}K_{75}$	0.595	5.75	5.73	0.62
$N_{125}P_{78}K_{86}$ (2)	0.549	5.70	5.74	0.55
$N_{100}P_{50}K_{100}$	0.627	6.88	7.00	0.56
$N_{100}P_{50}K_{125}$	0.583	5.54	5.78	0.56
$N_{100}P_{50}K_{150}$	0.558	5.53	5.73	0.57
SE $\pm$	0.003	0.149	0.164	0.026
CD at 5%	0.009	0.439	0.482	0.077

(1) According to soil test; (2) yield target 40 mt ha^{-1}

Significant effects of treatment combinations on the size of the onion bulb (viz. polar diameter, equatorial diameter and neck thickness) were recorded (Table 2). The highest polar diameter and equatorial diameters were found in treatment T_6 i.e. application of 100 kg K_2O ha^{-1} (6.88 and 7.00 cm, respectively). Neck thickness was also affected by K application, ranging between 0.55 to 0.61 cm, compared to the control (only 0.28 cm). Similar results have been reported by others (Mohanty and Das, 2001; Yadav *et al.*, 2003; Kumar *et al.*, 2001; Nandi *et al.*, 2002).

Quality parameters of onions

Potash levels significantly increased bulb contents of total soluble solids (TSS),

Table 3. Effect of potash levels on quality parameters of onion.

Treatment	TSS	Reducing sugar	Non-reducing sugar	Total sugar
	°brix	---------------------%---------------------		
$N_{100}P_{50}$	7.19	2.01	3.88	5.89
$N_{125}P_{50}K_{33}$ (1)	7.94	2.16	4.43	6.59
$N_{100}P_{50}K_{50}$	7.56	2.18	4.25	6.43
$N_{100}P_{50}K_{75}$	7.83	2.66	4.44	7.10
$N_{125}P_{78}K_{86}$ (2)	7.87	2.68	3.92	6.60
$N_{100}P_{50}K_{100}$	8.34	2.56	4.76	7.32
$N_{100}P_{50}K_{125}$	8.25	2.74	3.77	6.51
$N_{100}P_{50}K_{150}$	7.87	2.60	4.45	7.05
SE $\pm$	0.030	0.026	0.108	0.097
CD at 5%	0.088	0.075	0.319	0.286

(1) According to soil test; (2) yield target 40 mt ha^{-1}

reducing and non-reducing sugars and thereby total sugar (Table 3). The highest TSS (8.34° brix) was achieved with the application of 100 kg K_2O ha^{-1}, significantly higher than 7.19° brix obtained with K=0 (absolute control). Many workers have reported increased TSS content in onion in response to raised K status which has been ascribed to enhanced carbohydrate production during photosynthesis (Singh and Singh, 2000; Vacchani and Patel, 1993). Additionally from evidence of other crops, such as sugar cane, higher concentrations of K in the phloem enables more rapid translocation of photosynthates including both sucrose and amino N compounds from leaves to other plant parts i.e. source to sink (Hartt, 1969).

Similarly, for total sugar percentage content, increase in potash levels from the absolute control to 100 kg K_2O ha^{-1} significantly increased values from 5.89% (T_1) to 7.32% (T_6). With a further increase in potash levels, for the two higher treatments, T_7 and T_8, a decrease in content of total sugar in the bulb was observed at 6.51 and 7.05%, respectively. The maximum non-reducing sugar content of bulbs was 4.76% in T_6 (100 kg K_2O ha^{-1}). The maximum reducing sugars content of bulbs was recorded at 2.74% in T_7 (125 kg K_2O ha^{-1}) and an increasing trend was found from T_1 to T_5 treatments. The higher sugar contents of the onion bulbs with increasing K application may be explained by the direct stimulating effect of K on photosynthesis in the onion leaves and enhancing transport of the resulting photosynthates to the bulbs which act as a very strong sink.

Nutrient offtake and input/output balance

Offtakes of N, P and K by bulbs and leaves of onion (kg ha^{-1}) are presented in Fig. 2, and as a function of the yield in Fig. 3A and 3B. We found that offtake of nutrients in bulbs is more than three times higher than that of leaves, and hence, bulb yield and offtake are the critical components for nutrient balance calculations. A good yielding onion field with yields of 50-55 mt ha^{-1} removes 300-350 kg of nutrients (Fig. 2) per season.

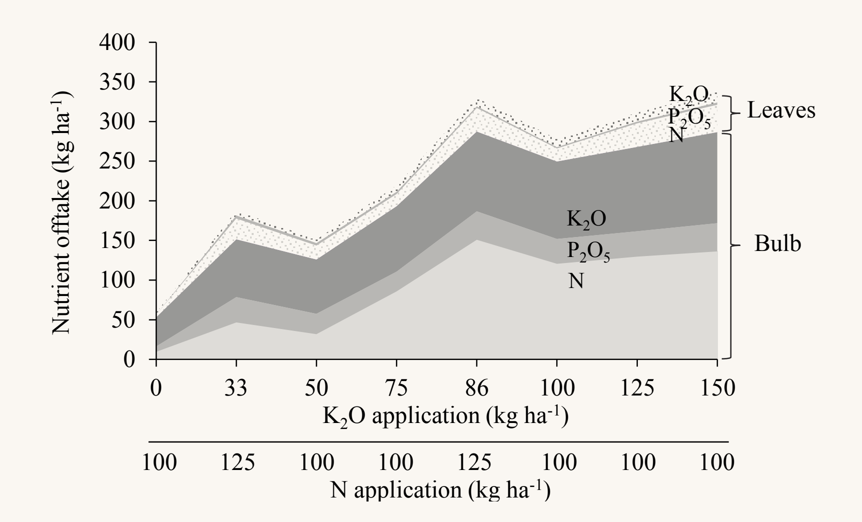


Fig. 2. Nutrient offtake in bulbs and leaves of onion.

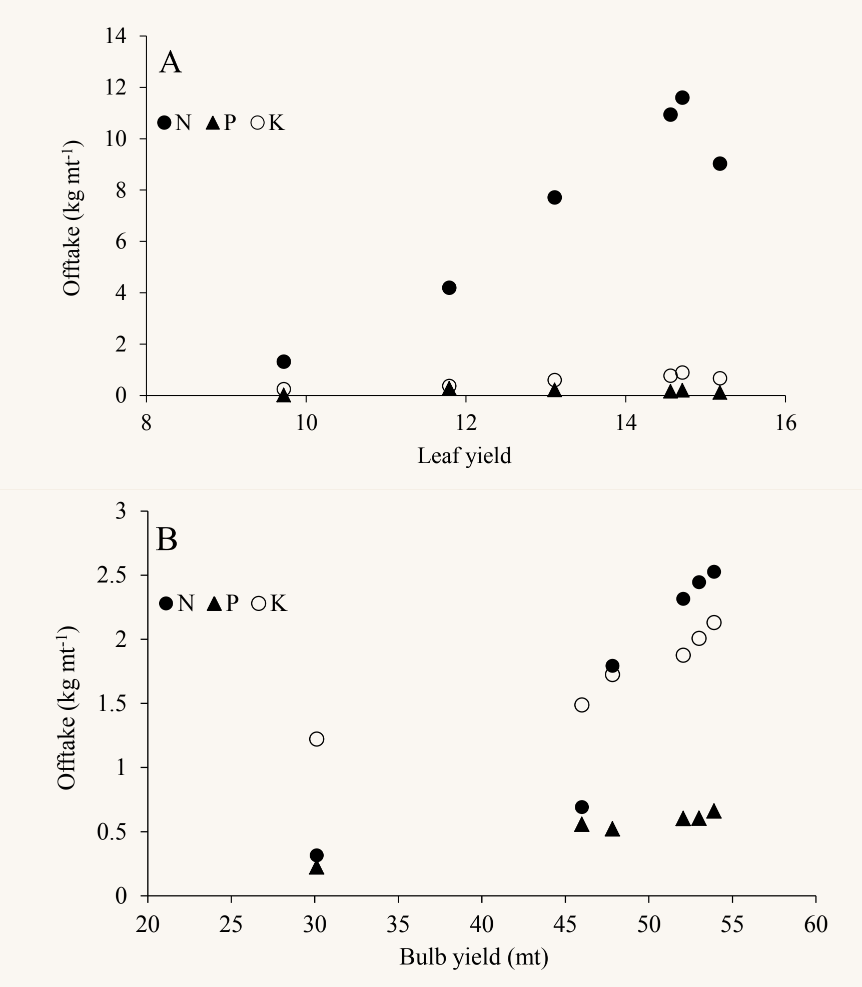


Fig. 3. Concentration of N, P and K in leaves (A) and bulbs (B) of onion, at harvest in relation to bulb yield levels obtained in the experiment.

N offtake in bulbs increased tenfold as K application increased, from approximately 10 kg ha^{-1} with K=0 to 136 kg N when K=150 kg ha^{-1} (Fig. 2). At the same time, yield doubled (Fig. 1 and 3A), so that N concentration in bulb tissue increased as yield increased from 0.3 to 2.5 kg N mt^{-1} of bulbs (Fig. 3B). The N concentration in leaves also increased markedly (10 fold) as leaf yield of onion increased (Fig. 3A). K offtake in bulbs increased from 37 to 115 kg K_2O ha^{-1}, as K increased from zero to 150 kg K_2O ha^{-1}, or three times more, and its concentration in the bulbs doubled as yield doubled, from 1.2 to 2.1 kg K_2O mt of bulbs (Fig. 3B). K offtake in leaves, however, hardly changed as yield increased (Fig. 3A). These findings thus show that the application of K greatly influence N and K offtake in bulbs and leaves, by both increasing the yield, and, no less significantly, by increasing N and K levels in the bulbs, and leading to higher N in the leaf tissue with increasing yield. P offtake in bulbs increased from 7 to 36 kg P_2O_5 ha^{-1}, mostly accountable by increased yield (Fig. 1) and to a small extent by increased P levels in bulb tissue as yields increased (Fig. 3B).

The peak nutrient offtake at T_5, associated with higher N offtake in bulbs, was probably due to the higher N application rate (125 kg ha^{-1}), although it did not induce a yield increase. In T_8, N offtake was lower than that of T_5, probably due to lower N application (100 kg ha^{-1}), but had a higher K offtake, potentially due to higher rates of K application (150 kg K_2O ha^{-1}). Hence, increased K application can induce higher N offtake in both bulbs and leaves (Fig. 2).

These findings indicate that nutrient removal calculations for onion bulbs must take into account the bulb yield, as uptake levels per mt of bulbs can double when yields increase. The higher uptake of nutrients may possibly be attributed to a more expansive root system resulting from increased supply of photosynthetic productions as observed by Watson (1963) in the potato crop.

Partial nutrient balance (PNB; fertilizer input minus crop offtake) in the various treatments is presented in Fig. 4. Zero or low levels of applied K fertilizer (0, 33 and 50 kg K_2O ha^{-1}) induced a positive N balance of at least 50 kg N ha^{-1}, due to low yield and offtake. N was balanced when 75 kg K_2O ha^{-1} was applied (bulb yield of 48 mt ha^{-1}), but with increased K input and yields N became deficient to the extent of 70-80 kg N ha^{-1} (Fig. 4). With PNB calculations, P was slightly to medium over fertilized, and a surplus of 11-43 kg P_2O_5 prevailed through all treatments.

In contrast to N and P, K PNB was negative in almost all treatments, and became positive only with application of at least 125 kg K_2O ha^{-1} (Fig. 4). These results suggest that the stagnation in yield increase beyond the application of 100 kg K_2O ha^{-1} (Fig. 1) is due to the lack of N, as presented by the severe deficits of N in T_7 and T_8.

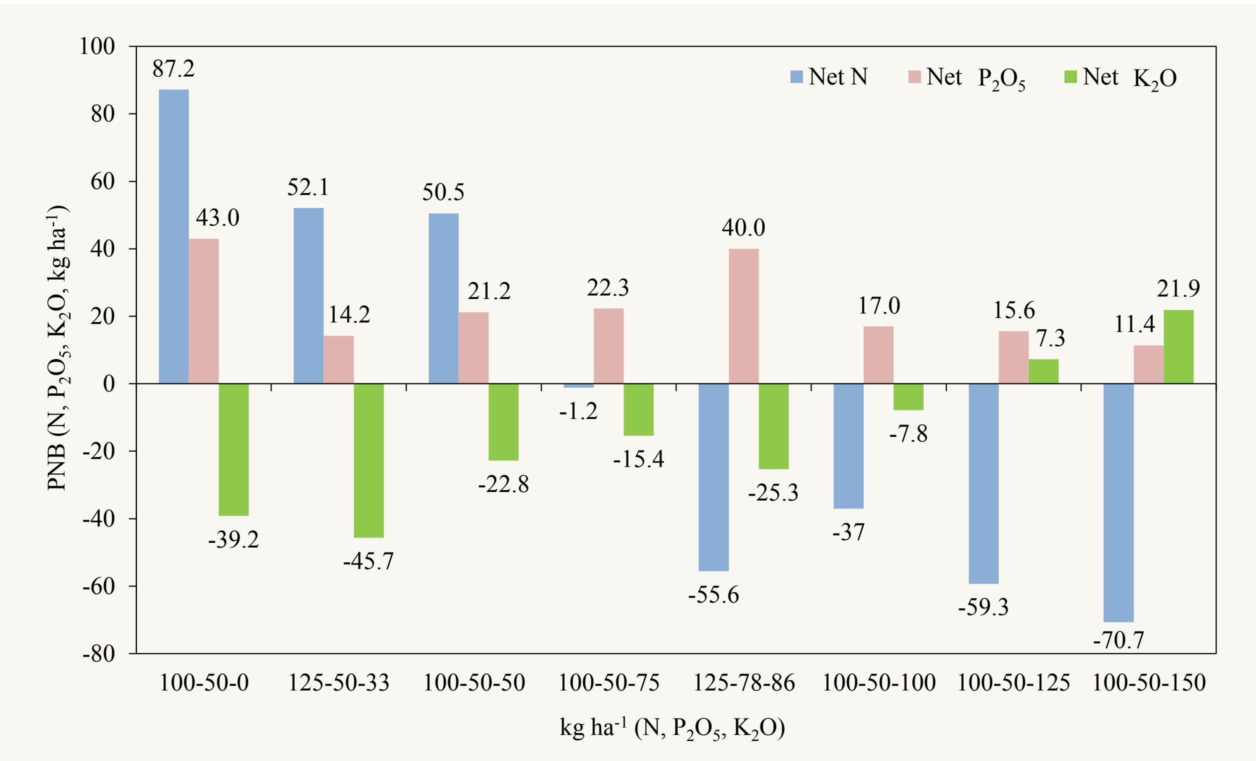
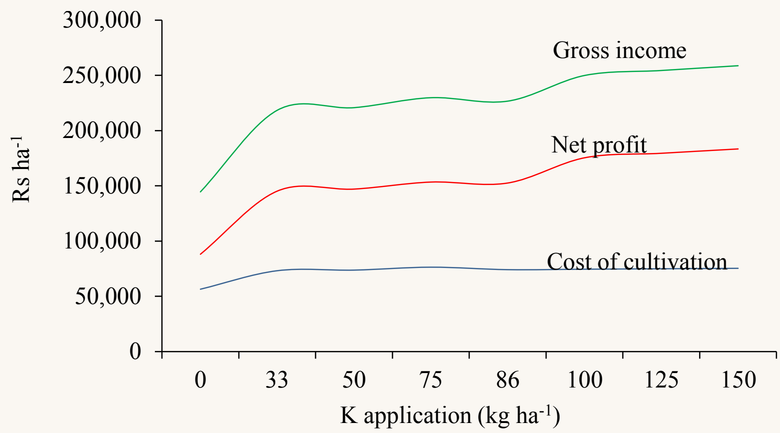


Fig. 4. Net PNB (fertilizer input minus crop offtake) of N, P_2O_5 and K_2O in onion (bulbs and leaves) in the different experimental treatments.

Economics

The highest gross income and net profit of Rs. 258,720 and Rs. 183,386 ha^{-1}, respectively, was obtained with the highest K application (T_8; 150 kg K_2O ha^{-1}; Fig. 5). With the cost of cultivation insensitive to the cost of additional K application, the higher the yield, the higher the net profit. Profits increased substantially (+50%) over the control for the first K application (T_2; 33 kg K_2O ha^{-1}), but made a further increase when applied K was greater than 86 kg K_2O ha^{-1}. From this data, it can be concluded that K application proved profitable up to the highest level of applied K (150 kg K_2O ha^{-1}). While yield increase over 100 kg K_2O ha^{-1} was not statistically different, the increase in income and net profit suggests that farmers can be generous with K application, as financial return is stable.



Note: Selling price of onion bulb (Av. of 3 years): Rs. 4'800 per mt

Fig. 5. Economics of applied K to onion crop (cost of MOP Rs. 11.80 kg^{-1}).

Conclusions

Application of all levels of K significantly increased bulb yield and quality of onion over no K treatment. The application of 100 kg K_2O ha^{-1} was found to be significantly greater than the recommended dose calculated from the soil test (33 kg K_2O ha^{-1} in soil with 130 ppm exchangeable K) and the calculated dose from target yield (86 kg K_2O ha^{-1}). These results suggest that both indicators (soil test and target yield calculation) need additional improvements.

The nutrient balance of onion is sensitive to bulb yield, and the application of at least 300 kg N, P and K is required to compensate for the removal of 55 mt onion bulbs per ha. Positive K PNB is achieved only when K application levels exceed 125 kg K_2O ha^{-1}.

The application of high levels of K fertilizer improves yield, but our findings point to the fact that at such high yield levels, N becomes the limiting nutrient. We propose to further investigate the response of onion (Cv. N-2-4-1) with NPK formulas ranging from 100-200 kg ha^{-1} for N and K_2O, while retaining the P level at 50 kg P_2O_5 ha^{-1}.

From the present study, it can be concluded that K application proved profitable up to the highest level of applied K (150 kg K_2O ha^{-1}). Moreover, with current income from onion, additional yield more than compensates for any incremental expenditure of nutrients. Our profit results also support the assumption that higher N and K application levels should be further investigated.

Acknowledgement

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The paper "Potassium Nutrition for Improving Yield and Quality of Onion" also appears on the IPI website at:

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