Research Findings

Maize experimental plot in Punjab. Severe lodging affected the K=0 plot. Photo by M.S. Brar.

Nitrogen Use Efficiency (NUE), Growth, Yield Parameters and Yield of Maize (*Zea mays* L.) as Affected by K Application

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Introduction

Nitrogen Use Efficiency (NUE) which is expressed as grain yield in kg per kg of N applied as fertilizer hardly exceeds 50 percent in cereal crops. Under field conditions, NUE varies from 25 to 34 percent in rice and 40 to 60 percent in other crops, with a global average of about 50 percent (Mosier, 2002), maize being no exception. Global cereal NUE has been reported to be 33 percent and it has been estimated that an increase in NUE by one percent is worth as much as USD 234 million (Magen and Nosov, 2008). Cassman (2002), on the basis of number of field experiments, reported nitrogen recovery in rice in Asia as 31 percent under farmers' practices and 40 percent under field specific management. Cassman further reported that nitrogen recovery in wheat varied from as low as 18 percent under unfavorable weather to 49 percent under favorable weather conditions. In addition to weather, NUE is controlled by many other factors such as: crop demand for N, supply of N from soil and fertilizers, and losses of N from the soil-plant system. Imbalanced and inappropriate use, not only of N but other nutrients, such as potassium in agroecosystems, can also modify NUE.

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Table 1. Effect of fertilizer treatments on N and K uptake by maize grains.

Treatment[(1)]	Year					
	2003	2004	2005	2006	2007	Average
No. of fields	4	3	4	4	3	18
	---*N uptake (kg ha^{-1})*---					
K_0	23.2	39.5	37.7	50.7	49.8	40.2
K_{30}	27.4	48.9	38.8	51.4	54.4	44.2
K_{60}	30.4	55.4	37.7	51.6	52.6	45.5
K_{90}	29.0	57.9	45.7	62.9	59.1	50.9
CD (5%)	4.13	11.57	8.19	10.18	NS	
	---*K uptake (kg ha^{-1})*---					
K_0	8.4	10.3	11.9	22.2	44.1	19.4
K_{30}	12.4	13.0	13.1	20.1	45.9	20.9
K_{60}	15.7	14.9	13.7	23.3	48.4	23.2
K_{90}	15.7	16.5	15.6	34.6	51.8	26.8
CD (5%)	2.6	3.6	2.7	5.4	NS	

[(1)]N and P_2O_5 levels were 125 and 60 kg ha^{-1}

Table 2. NUE of fertilizer N (kg grain/kg N) and apparent N recovery (%) at different levels of applied potassium.

K level (kg K_2O ha^{-1})	2003	2004	2005	2006	2007	Average	% increase over K_0
	---*NUE (kg grain/kg applied N)*---						
0	21.1	32.0	26.8	38.2	45.4	32.7	-
30	24.2	37.9	27.3	39.5	47.6	35.3	7.9
60	27.0	41.8	27.4	41.3	53.3	38.0	16.2
90	26.4	40.9	30.9	48.2	48.8	39.0	19.3
	---*ANR (%)*---						
0	19	32	30	41	40	32	-
30	22	39	31	41	44	35	9.3
60	24	44	30	41	42	36	12.5
90	23	46	37	50	47	41	28.1

The NUE was calculated by dividing grain yield (kg) by the N applied (kg), and ANR (%) was calculated by dividing uptake of Nitrogen in kg by N applied in kg and multiplied by 100 (Ladha *et al*., 2005).

IPI on-farm experiments in Asia and Europe have indicated that besides yield, NUE on average can be increased by 15.5 percent in maize in Ukraine, 18 percent in maize in India, 19 percent in wheat in China and 26.3 percent in rice in Bangladesh, by application of appropriate amounts of K. Experiments conducted on pearl millet in Haryana, India showed the partial factor productivity of N was increased from 20.3 to 23.8 kg grain kg^{-1} N, with the application of 60 kg K_2O ha^{-1} (Yadav *et al*., 2007).

In India, maize is an important cereal crop. In Punjab, it is predominantly grown in the north-eastern region of the State on light textured soils of low fertility status. Balanced nutrition plays a key role in increasing crop production. Since farmers are not used to applying K to the maize crop, imbalanced nutrition seems to be one of the yield limiting factors, resulting in low productivity and low NUE in maize in the region.

Field experiments on farmers' fields were conducted in Hoshiarpur and Nawanshehar districts of Punjab for five years, using a total of 18 locations. At each location, treatments were replicated three times. The plot size of each treatment was 800 m^2. Four treatments viz. 125:60:0, 125:60:30, 125:60:60 and 125:60:90 kg ha^{-1} of N, P_2O_5 and K_2O were applied using urea, diammonium phosphate (DAP) and muriate of potash (MOP). DAP, MOP and one-third of the dose of urea were applied at sowing. The second one-third dose of urea was applied at the knee-high stage and the remaining one-third at the pre-tasseling stage. Maize was sown during the month of June and was harvested at maturity in September every year. Plant height, stem girth and leaf area were measured at maturity. Length of cob, girth of cob, cob weight and grain weight were also recorded at harvesting. Grain yield was recorded by threshing the crop after 10-15 days of air-drying the cobs. Plant samples were collected at the time of harvesting, washed in distilled water, oven dried at 65°C then ground in a stainless steel Willey mill. Plant samples were digested in a mixture of nitric and perchloric acids (ratio 3:1) then analyzed for N (Kjeldahl) and K (flame photometry).

Nitrogen uptake

Increase in NUE is the consequence of enhanced uptake and improved utilization of N by the crop. The significant increase in N uptake by maize seeds was observed with the increase in levels of applied K (Table 1). The N uptake into the grain, which on average was 40.2 kg ha^{-1} with the application of N and P, increased to 50.9 kg ha^{-1} with the application of 90 kg K_2O ha^{-1} together with the N and P. Potassium uptake also increased with the progressive increase in levels of K application.

Nitrogen use efficiency (NUE)

Application of K greatly influenced NUE (kg grain/kg applied N) in maize. At different locations/years, and with the application of K, NUE varied from 21.1 to 53.3 kg grain kg^{-1} applied N (Table 2). Averaged over the years and sites, the NUE was 32.7, 35.3, 38.0, and 39.0 kg grain kg^{-1} applied N at 0, 30, 60, and 90 kg of applied K_2O ha^{-1} respectively. The graded levels of applied K increased NUE by 7.9, 16.2 and 19.3 percent, over K_0 (No K) application. The Apparent Nitrogen Recovery (ANR, kg N uptake/kg applied N) varied from 19 to 50 percent at different locations/years and, on average, increased from 32 percent (K_0) to 41 percent (K_{90}) with the application of K indicating the beneficial effect of applied K on N utilization. The practical implication of this is the improved utilization and lower loss of applied N to cause environmental pollution.

Experimental plot with 30 kg K_2O ha^{-1}. Photo by M.S. Brar.

Table 3. Effect of fertilizer treatments on growth parameters of maize.

	Plant girth	Plant height	Leaf area
	--------------------*cm*--------------------		cm^2
$N_{125}P_{60}K_0$	6.34	229.6	5,669
$N_{125}P_{60}K_{30}$	6.71	234.1	5,966
$N_{125}P_{60}K_{60}$	7.00	240.1	6,091
$N_{125}P_{60}K_{90}$	6.95	242.3	6,334

Growth parameters

The girth of the plant is an important criterion, which determines its strength and ability to resist lodging. K application favorably influenced the girth of maize plants, which increased with level of K application, the greatest girth being observed with the application of 125:60:60 kg ha^{-1} of N, P_2O_5 and K_2O (Table 3). The increase in stem girth of maize under balanced fertilization, and especially at higher levels of K application, may be due to cell expansion, which induces sturdiness and healthiness of plants, including better root development (Walker and Parks, 1969; Singh and Tripathi, 1979; Ahmed, 1992). In plots without K application, strong winds caused the crop to lodge but no lodging took place in the NPK treated plots because of the increased stem strength and root development enhanced by balanced nutrition with potassium.

Averaged over the five years, plant height varied from 223.5 to 242.3 cm and increased with the application of K, although the effect was non-significant for most of the years (Table 3). The production of photosynthates via photosynthetic activity in the leaf is ultimately the driver of crop yield and is dependent on leaf area. Any treatment increasing leaf area is thus likely to contribute towards raising crop yield. In this respect, leaf area was found to increase with the addition of graded doses of K (Table 3). On average, maximum leaf area was observed when K was applied at 90 kg ha^{-1}. As well as its effect in promoting photosynthetic activity, potassium also increases cell expansion by regulating solute potential that may increase the rate of leaf expansion and the leaf area (Rao and Madhava, 1983; Yahiya *et al.*, 1996).

Yield parameters

Cob length and girth were measured at harvesting. Data revealed that application of K at the rates of 60 and 90 kg K_2O ha^{-1} resulted in significantly bigger cobs with

Table 4. Effect of K application on yield parameters and grain yield (average of five years at 18 locations) of maize.

Treatments	Cob length	Cob girth	Grain weight of 100 cobs	Thousand grain weight	Grain yield
	-----------*cm*----------		*kg*	*g*	*mt ha^{-1}*
$N_{125}P_{60}K_0$	20.0	14.4	9.1	235	5.69
$N_{125}P_{60}K_{30}$	20.6	14.6	9.5	238	5.95
$N_{125}P_{60}K_{60}$	21.1	14.8	10.5	249	6.54
$N_{125}P_{60}K_{90}$	21.4	14.9	11.1	254	6.10

more length and girth over the NP treatment without K (Table 4). Larger cob size may be the result of enhanced photosynthetic activity followed by efficient utilization of applied N, efficient transfer of metabolites and subsequent accumulation of these metabolites in the cob.

Potassium application significantly increased the thousand-grain weight and grain weight of 100 cobs during all five years of the study (Table 4). Average grain weight of 100 cobs increased by 37 percent, and thousand grain weight by 15 percent, with the application of 90 kg K_2O ha^{-1} over the control treatment, where N alone was applied to the maize crop (data not presented in table). Similarly, there was a substantial increase in these parameters over the NP treatments as the rate of K fertilization was increased.

Grain yield

The data of five years of study (Table 3) indicate that it is not possible to obtain optimum yield of maize with the application of only N and P. The application of K is essential to obtain higher yields. With the application of 60 kg K_2O ha^{-1} the grain yield increased by 15 percent over the NP treatment. Grain yield of maize increased with application of K due to the cumulative effect on both growth and yield parameters, which were increased substantially by the application of K, along with N and P, and greater uptake and utilization of N in the presence of applied K.

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