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Nitrogen and phosphorus effects on winter maize in an irrigated agroecosystem in western Indo-Gangetic plains of India

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Abstract

Winter maize is an innovation in Indian cropping systems. It grows 50-60 days longer than rainy-season maize and is a heavy feeder cereal. It lacks proper management of nutrients, particularly nitrogen and phosphorous. N and P determine the photosynthetic and reproductive capacity of plants. The response of maize to these nutrients is season-dependent and location-specific, but has seldom been studied in winter maize areas in India. This study was designed to evaluate the impact of N and P independently and interactively on winter maize. Maize yield was highest at 240 kg N ha^{-1}, but the yield obtained at 160 kg N ha^{-1} was comparable. Every kg N applied produced 44.34 kg grain, and the N-use efficiency was reduced with increased N dose (67.4, 38.4, and 27.2 kg grain kg^{-1} N for 80, 160, and 240 kg N ha^{-1}, respectively). Phosphorus application increased yield up to 26.4 kg ha^{-1}. A combination of 240 kg N ha^{-1} and 26.4 kg P ha^{-1}, providing highest gross returns, net returns and net benefit: cost, was most profitable. The economic optimum dose for N and P was 196 kg N ha^{-1} and 23.4 kg P ha^{-1}, respectively. This study shows that winter maize is responsive to higher levels of N up to 240 kg ha^{-1} compared to 120 kg N ha^{-1} recommended for rainy-season maize, but P application at 26.4 kg ha^{-1} remains same for both the seasons. The study provides recommendation of N and P for winter maize based on economics. The data would be useful for fitting models and simulating yields across the doses of N and P.

Keywords: winter maize yield, nutrients, nitrogen, phosphorus, economics

Introduction

Maize (*Zea mays* L) has the highest genetic yield potential among cereals and is referred to as the 'queen of cereals' (Tollenaar and Lee, 2006). It is the third most important cereal crop and cultivated in 160 countries on almost 150 million ha and contributes to 36% (78.2 million tonnes) in the total grain production of the world (McCann, 2007; Parihar et al, 2011). India is ranked fifth among maize producing countries (FAO, 2010). In India, maize is predominantly used for industries, only 25% of its production is used as human food (Jat et al, 2009). It makes the crop more market-oriented and its cultivation requires more attention. This has prompted farmers to grow maize even in non-traditional seasons such as winter and spring, which were not traditionally known to be good for maize. Thus, winter maize cultivation is a new innovation in Indian cropping systems. Unlike rainy-season maize, grown during July to October for almost 120-130 days, winter maize (maize grown during winter) grows during November to April for 170-180 days. Although, rainy season maize contributes largely to the total production (71.6% in 2008-09), has less productivity owing to severe pest incidence and nutrient losses through heavy rains, including water logging. Hence, its winter cultivation has gained an increased attention.

Winter maize with longer duration (Kumar and Singh, 1999) and less pest problems has been found more productive than rainy-season maize as evidenced by the reported grain yields as high as 9 t/ha in the State of Bihar (Sinha et al, 1995). Its cultivation has become a common practice in Peninsular India and North-Eastern Plains where the winter season remains frost-free and mean temperatures do not fall below 13°C (Singh et al, 1997; Reddy et al,1999). However, information is meager on exploring the feasibility of growing winter maize in North India including Delhi, where cool weather conditions are accompanied by occasional frost and temperatures lower than 13°C (Mishra et al, 2001). This innovation in Indian cropping systems calls for more researches need to be undertaken on fertilizers management in order to give farmers appropriate recommendations for improving productivity of this crop. The effect of nutrient management is one of the most important variables that must be controlled to ensure that farm-

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ers get high yields of good quality (de Grazia et al, 2003). Maize is a cereal crop and heavy feeder, which requires higher amounts of nutrients to maintain higher production. Use of inadequate quantity of fertilizers coupled with declining native/original soil fertility often leads to nutrient deficiencies and reduced production of this crop. In India, numerous studies have been conducted on rainy season maize, but there is lack of such studies in winter maize. Among nutrients, N and P are the most limiting in Indian soils and drastically curtail maize productivity. This is more so, when we look at the fact that rainy-season maize removes 29.9 kg N and 5.94 kg P per tonne of grain produced (Shivay and Kumar, 2008). The response of winter maize to N and P up to 150-180 and 25.2-35.4 kg ha^{-1}, respectively has been reported in different states of northern and western India (Singh et al, 2000; Maurya et al, 2005; Kumar, 2010). However, the collective influence of N and P fertilization on winter maize is scanty and least investigated. Nitrogen and P determine the setting and maintenance of the photosynthetic potential of the canopy and the plant reproductive capacity. Both nutrients must be supplied in adequate amounts and timings to ensure an optimum physiological state at flowering, the stage around which the number of grains per unit surface area is established (Tollenaar and Dwyer, 1999; de Grazia et al, 2003). Nitrogen deficiencies reduce grain yield by affecting both grain number and weight. The number of ears per plant and the number of grains per cob are affected by N level (Uhart and Andrade, 1995a, 1995b; Tollenaar and Lee, 2002). The growth is also affected by the quantity and the time of application of N. The effect of P on performance of maize is not well studied as that of N. Though the interaction of these important nutrients has been studied by many workers, their effect on winter maize was least studied. It has also been reported that P deficiency reduces the number of ears per plant, the number of grain per ear and ultimately the grain yield (de Grazia et al, 2003).

Weather parameters in India are highly variable from season to season and region to region, which urges upon location-specific recommendation for higher maize production. This study was designed to assess the impact of N and P fertilization independently and interactively on the productivity, nutrient uptake and economics of maize that was grown in untraditional winter season.

Materials and Methods

Experimental site

The field experiment was carried out at the Division of Agronomy, Indian Agricultural Research Institute, New Delhi (situated at latitude 28.4°N and longitude 77.11°E) during the winter of 2010-11. The soil was sandy loam in texture, medium in organic carbon (0.62%), total N (0.048%), and available P (19.6 kg ha^{-1}) and available K (269.9 kg ha^{-1}) with pH 7.2. The available N in the form of NH_4^+-N was 3.4 mg kg^{-1} soil and in the form of NO_3^--N was 3.2 mg kg^{-1} soil. The field capacity, permanent wilting point, and bulk density of the soil were 13.6%, 5.3%, and 1.57 Mg m^{-3}, respectively with a soil surface albedo of 1.13.

Treatments

The treatments comprising of four levels of N (0, 80, 160, and 240 kg N ha^{-1}) in the main plot and four levels of P (0, 13.2, 26.4, and 39.6 kg P ha^{-1}) in the sub-plots were laid out in a split plot design with three replications. Nitrogen was applied in the form of prilled urea as per the treatments in three equal splits. The 1/3 amount of N as per the treatments, was applied as basal, 1/3 at knee high stage and the remaining quantity of N was applied at tasseling stage. The total P was applied through single superphosphate as basal as per treatment. Potassium was applied as basal at the rate of 60 kg K_2O ha^{-1} and zinc sulphate at 25 kg ha^{-1} uniformly to all the plots. Sulphur, added through single superphosphate was balanced through elemental sulphur in the P-applied plots. The sizes of the main plot, sub-plot and net plots (~ area actually harvested for grain and stover yield) were 11.8 m x 9.5 m, 5.4 m x 4.4 m and 4.4 m x 2.0 m, respectively.

Crop variety and agro-practices

Maize cv. HQPM1 is a single cross hybrid (HKI 193-1 x HKI 163), released in 2006 by Choudhary Charan Singh Haryana Agricultural University, Hisar, India. It is adapted to all agro-ecological regions in India and tolerant to frost/cold and resistant to Maydis leaf blight (MLB) and common rust. It can be grown under both rainfed and irrigated conditions. It is late maturing and can take up to 180 days to mature and its potential grain yield is 6.2 t ha^{-1}. Maize seed was dibbled along the rows spaced at 60 cm, using 20 kg seed/ha. Atrazine at 1.0 kg ha^{-1} was applied two days after sowing as pre-emergence to control the initial flushes of weeds. In addition to this, three manual weeding at 49, 82, and 103 days after sowing (DAS), ensuring adequate weed control, and shallow hoeing to provide aeration and facilitate better root growth were provided to maize. A pre-sowing irrigation to the entire field for ensuring optimum moisture for germination and eight post-sowing irrigation were applied. There were no or low incidences of insect pests and diseases in maize, nevertheless, phorate @ 25 kg ha^{-1} was applied to control insect pests. Maize crop matured on 168 DAS.

Sampling and observations

The total number of matured cobs obtained from the plants per net plot area was counted and expressed per one square meter. Matured and dried cobs and stover were harvested from the net plots manually and sun-dried for few days. Then, the dried cobs were dehusked and shelled using mechanical shelling machine and grain yield was recorded at 15% moisture content and expressed in t ha^{-1}. The number of grains or kernels per cob was counted from nine randomly selected cobs in each sub-plot and 1000-grain weight was recorded from randomly sampled 1000 grains from the bulk grain across treatments. After harvesting, cobs from each plot were weighed after removing husks and silks. Grain weight was taken after shelling separately and shelling percentage was calculated as follows:

$$\text{Shelling percentage}(\%) = \frac{\text{Grain weight}(\text{kg ha}^{-1})}{\text{Cob weight}(\text{kg ha}^{-1})} x100 \quad \text{[Eq 1]}$$

The harvest index (HI) was calculated using:

$$\text{Harvest index}=\frac{\text{Grain yield (kg ha}^{-1})}{\text{Grain+stover yield (kg ha}^{-1})} x100 \quad \text{[Eq 2]}$$

Economics of winter maize

To assess the costs and benefits associated with different treatments, the partial budget technique as described by CIMMYT (1988) was applied on the yield results. The cost of cultivation, gross and net returns and net benefit:cost were worked out, using the prevailing market prices for inputs and outputs on hectare basis in Indian Rupees (₹). The minimum support price for maize as declared by the Government of India, New Delhi was used. The gross returns/ha (GR) is the sum of products of the price for maize grain and stover and the respective yields of grain and stover for each treatment. The price of N or P per kg is the nutrient retail cost per kg, prevailing in the market at the time of sowing. The cost of fertilizer application is the product of man-days used in applying the fertilizer and wage rate. The total variable cost (TVC) is the sum of cost of fertilizer and the cost of cultivation, including the costs of irrigation, plant protection, etc. The net benefit ha^{-1} for each treatment is the difference between the GR and TVC. Net benefit:cost ratio (Net B:C) or net benefit per rupee invested was calculated as:

$$\text{Net B:C}=\frac{\text{Net return (Rs/ha)}}{\text{Total cost (Rs/ha)}} \quad \text{[Eq 3]}$$

The economic optimum doses for both N and P were calculated from the response curves using:

$$\text{Economic optimum dose= (q/p-b)/2c} \quad \text{[Eq 4]}$$

Where, q is the cost of input (₹/kg); p, the price of output (₹/kg); b and c, coefficients of the quadratic response equation.

Concentration and uptake of N and P

Maize grain and oven-dried stover were ground in a Wiley Mill (Thomas Scientific, New Jersy, USA), and passed through a 40-mesh sieve. Separate samples of 0.5 g each of grain and stover of maize were taken for the estimation of N and P concentration of the grain and stover. The N concentration was determined by modified Kjeldahl method and the P concentration was estimated by vanadomolybdo phosphoric acid yellow colour method using Spectrophotometer (GS 5702, Electronic Ltd) at 470 nm wave length (Jackson, 1973). The P concentration of the samples was calculated by plotting the per cent transmittance value on ruled sheet against standard curve. The uptake of N and P by grains and stover of maize was worked out separately by multiplying the respective per cent concentration with the dry weight of maize grain and stover in each treatment and was expressed in kg ha^{-1}.

Statistical analysis

The data on yield variables and grain, stover and total biological yield of maize were analyzed by applying the technique of ‘analysis of variance (ANOVA)’ for split plot design (Gomez and Gomez, 1984) using Microsoft Excel software. The values of standard error of mean (SE) and least significant difference (LSD) were calculated at 5% level of significance for comparing the treatment means. Where the differences are significant, LSD values have been indicated, oth-

Table 1 - Effect of N and P on yield components of winter maize.

Treatment	1,000-grain weight (g)	Cobs m^{-2} (No)	Cobs plant^{-1} (No)	Seeds cob^{-1} (No)	Shelling (%)
Nitrogen (kg ha^{-1})					
N_0	204	8.4	1.0	285	63.0
N_{80}	259	10.7	1.3	365	69.9
N_{160}	271	12.6	1.5	387	70.0
N_{240}	282	13.2	1.6	401	68.1
SE	11.3	0.54	0.06	10.0	2.36
LSD ($P \leq 0.05$)	39.3	1.86	0.22	34.6	NS†
Phosphorus (kg ha^{-1})					
P_0	235	10.5	1.3	342	71.6
$P_{13.2}$	258	11.0	1.3	368	67.5
$P_{26.4}$	272	11.7	1.4	368	63.4
$P_{39.6}$	250	11.7	1.4	359	68.7
SE	6.0	0.42	0.05	12.5	2.03
LSD ($P \leq 0.05$)	17.5	NS	NS	NS	NS
N x P interaction					
SE	8.56	0.84	0.10	25.10	4.06
LSD ($P \leq 0.05$)	25.00	NS	NS	73.28	NS

†NS, non-significant

Table 2 - Effect of N and P levels on grain, stover and total biomass yield (kg ha^{-1}) of winter maize.

Treatment	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Total biomass yield (kg ha^{-1})	Harvest index
Nitrogen (kg ha^{-1})				
N_0	2,457	4,067	6,524	0.38
N_{80}	5,390	8,310	13,700	0.41
N_{160}	6,144	9,657	15,801	0.40
N_{240}	6,541	9,894	16,435	0.41
SE	201.0	508.6	242.6	0.01
LSD (P≤0.05)	695.7	1,759.9	839.5	NS†
Phosphorus (kg ha^{-1})				
P_0	4,541	5,686	10,227	0.44
$P_{13.2}$	5,194	7,967	13,161	0.39
$P_{26.4}$	5,503	10,285	15,988	0.37
$P_{39.6}$	5,294	7,989	13,084	0.40
SE	156.7	635.9	706.9	0.02
LSD (P≤0.05)	457.5	1,856.1	2,063.5	NS
N x P interaction				
SE	313.5	1,271.7	1,413.9	0.04
LSD (P≤0.05)	915.1	NS	NS	NS

†NS, non-significant

erwise, only the values of SE have been given. The significant interactions obtained between N and P levels have been indicated in the respective table of data and discussed (data not shown). Regression analysis was performed to find out the relationship between the levels of N and P separately with the grain, stover, and total biomass yield, and gross and net returns of maize cultivation.

Results

Winter Maize Yield Attributes

The yield attributes of maize such as number of grains per cob, cobs per plant, test weight (~1,000-grain weight) differed significantly (P≤0.05) due to N levels with the highest values observed at 240 kg N ha^{-1} (Table 1). There was no significant effect of P application on these yield attributes except on test weight, which was significantly (P≤0.05) higher at 26.4 kg P ha^{-1}. Conversely, shelling percentage (Table 1) and harvest index (Table 2) were not significantly affected due to application of N and P, and no interaction effect between these two nutrients was observed. Maize test weight was increased markedly due to N as well as P levels over control with lower variability due to P levels compared to that in N levels. A significant interaction between N and P was observed for test weight and seeds/cob of winter maize.

Winter maize grain and stover yield

The grain and stover yield with each increase of N levels were significant (P≤0.5) (Table 2; Figure 1a). The N levels at 80, 160 and 240 kg N ha^{-1} resulted in 54.1, 60.0, and 62.4% increase in grain yield, respectively over control. In contrast, stover yield was in-

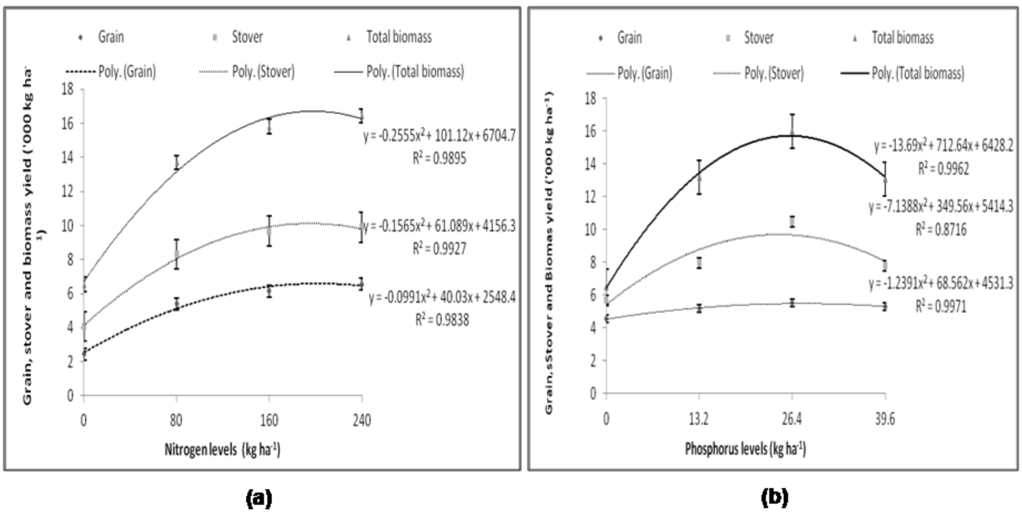

Figure 1 - Maize grain yield as affected by N (a) and P(b).

Table 3 - Effect of N and P levels on N and P concentration in maize plants (%) at different growth stages.

N treatment	30 DAS†	60 DAS	90 DAS	121 DAS (Tasseling)	136 DAS (Silking)	P treatment	30 DAS	60 DAS	90 DAS	121 DAS (Tasseling)	136 DAS (Silking)
					N concentration in maize plants (%)						
N_0	3.91	3.77	3.55	2.97	2.10	P0	4.04	3.89	3.67	3.23	2.19
N_{80}	4.04	3.97	3.75	3.20	2.20	P13.2	4.10	4.00	3.77	3.32	2.28
N_{160}	4.21	4.16	3.92	3.52	2.38	P26.4	4.15	4.19	3.95	3.38	2.30
N_{240}	4.25	4.25	4.01	3.58	2.47	P39.6	4.12	4.06	3.83	3.35	2.27
LSD ($P \leq 0.05$)	0.055	0.190	0.179	0.118	0.264		0.046	0.167	0.158	0.083	0.163
					P concentration in maize plants (%)						
N_0	0.42	0.38	0.35	0.33	0.30	P0	0.43	0.41	0.37	0.35	0.35
N_{80}	0.45	0.40	0.37	0.35	0.33	P13.2	0.46	0.43	0.40	0.37	0.37
N_{160}	0.50	0.46	0.43	0.40	0.38	P26.4	0.49	0.44	0.41	0.38	0.36
N_{240}	0.52	0.47	0.43	0.41	0.40	P39.6	0.51	0.44	0.41	0.38	0.37
LSD ($P \leq 0.05$)	0.037	0.042	0.039	0.036	0.023		0.056	0.029	0.027	0.025	0.021

† DAS, days after sowing of maize

creased with 80, 160 and 240 kg N ha^{-1} by 51.1, 57.9 and 58.9%, respectively over control. The effect of P on grain and stover yield was also significant (P≤0.05) and the highest was reached at 26.4 kg P ha^{-1} after which further increase declined the yield (Table 2; Figure 1b). There was an increase in grain yield, amounting to 12.6, 17.5, and 14.3% with 13.2, 26.4, and 39.6 kg P ha^{-1} over control. In the case of stover yield, the corresponding increases were 28.6, 45.8, and 27.0%. Increase beyond 26.4 kg P ha^{-1} caused a reduction in stover yield by 28.7% (Table 2; Figure 1b). The interaction between N and P was significant only for grain yield.

Concentration and uptake of N and P by winter maize

As the crop growth stages advanced from seedling (30 DAS) to silking (136 DAS), the N and P concentration (Table 3) in maize plants decreased gradually, reaching their lowest at maturity. The applications of N up to 240 kg ha^{-1} and P up to 26.4 kg ha^{-1} continued to consistently maintain higher levels of N in maize plants over the control at almost all growth stages. The P application at higher 39.6 kg ha^{-1} reduced N content than that observed at 26.4 kg P ha^{-1} at all growth stages. The P concentration in maize plants increased due to N application at all the doses up to 240 kg N ha^{-1}, and due to P application up to 26.4 kg P ha^{-1} (Table 3). The concentration of N and P either declined or remained unchanged due to P application beyond 26.4 k ha^{-1}.

In general, the successive increase of N at each level of 80, 160 and 240 kg N ha^{-1} resulted in higher uptake of total N by 129.7, 181.2 and 203.2%, respectively over control (Table 4). The N uptake by grain, stover as well as total uptake was significantly higher at 240 kg N ha^{-1} than those in other levels, except 160 kg N ha^{-1}. In contrast, P uptake was increased by 20.9, 51.1, and 55.1% at 80, 160, and 240 kg N ha^{-1} over control. Phosphorus application also caused an increase in N uptake, but not at the same magnitude as the N application did (Table 4). It led to an increase in N uptake in maize by 22.7, 40.2, and 24.4% due to 13.2, 26.4, and 39.6 kg P ha^{-1}, respectively over control. It also resulted in an increase in P uptake by 20.6, 34.0, and 22.7%, respectively with 13.2, 26.4, and 39.6 kg P ha^{-1} over control. The

Table 4 - Effect of N and P levels on N and P uptake (kg ha^{-1}) by maize plants.

Treatment	N uptake (kg ha^{-1})			P uptake (kg ha^{-1})		
	Grain	Stover	Total	Grain	Stover	Total
Nitrogen (kg ha^{-1})						
N0	40.2	15.1	55.3	20.3	3.8	24.1
N80	94.5	32.5	126.9	21.5	8.1	29.6
N160	117.4	38.5	155.9	25.3	11.2	36.5
N240	127.0	41.0	168.0	25.8	11.6	37.3
SE	3.32	2.08	5.14	0.68	0.66	0.98
LSD ($P \leq 0.05$)	11.51	7.20	17.78	2.35	2.28	3.40
Phosphorus (kg ha^{-1})						
P0	81.9	21.8	103.7	21.0	5.7	26.7
P13.2	96.1	31.3	127.5	23.4	8.8	32.2
P26.4	102.8	42.1	145.7	24.1	11.5	35.6
P39.6	98.2	31.8	129.2	24.3	8.7	33.0
SE	3.23	2.54	3.76	0.55	0.62	0.84
LSD ($P \leq 0.05$)	9.42	7.40	10.97	1.61	1.81	2.44
N x P interaction						
SE	6.46	5.07	7.53	1.10	1.24	1.67
LSD ($P \leq 0.05$)	NS†	NS	21.98	3.21	3.63	4.89

†NS, non-significant

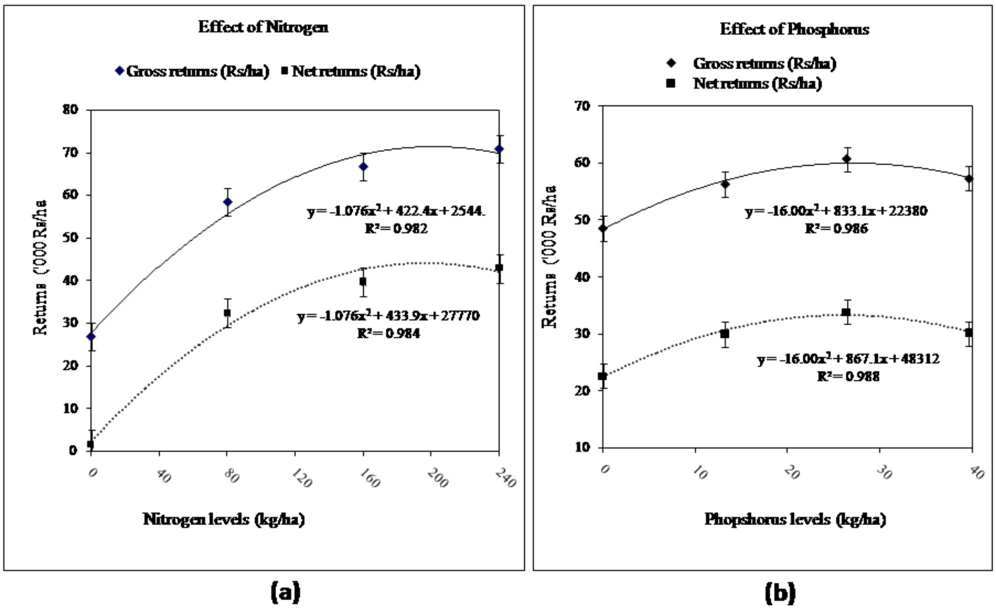

Figure 2 - Gross and net return of winter maize as affected by N (a) and P (b)fertilization. * 1.0 Indian Rupee (INR) = approximately 0.02 US$.

observed nutrient uptake was in the range of 24.7 kg N and 6.2 kg P per tonne of grain produced.

Economics of winter maize

In general, the cost of cultivation of maize increased with the increase in levels of inputs used and ranged from 14,207 ha^{-1} to 18,313 ha^{-1} (data not shown). Among N levels, the highest level at 240 kg N ha^{-1} resulted in the highest values of gross and net returns, but 160 kg N ha^{-1} was comparable with it (Table 5; Figure 2a). The net benefit per rupee invested was also higher at 240 kg N ha^{-1} and 160 kg N ha^{-1} was at par. On the other hand, gross returns, net returns and net benefit per rupee invested increased with each increasing levels of P till 26.4 kg P ha^{-1} after which all these parameters declined (Table 5; Figure 2b). The interaction between N and P significantly influenced gross and net returns and net B:C with 240 kg N ha^{-1} and 26.4 kg P ha^{-1}. The optimum economic doses (Figure 1) were found to be 196.4 kg and 23.4 kg for N and P, respectively.

Discussion

Effects on yield attributes and yield

The source-sink relationship and the rate at which translocation takes place from source to sink during the reproductive stage largely determine grain yield. Maize yield is a function of different yield components such as the number of cobs per ha, length and girth of cob, number of grain rows per cob, number of grains per grain row, 1,000-grain weight and shelling percentage. Source components such as leaf area index and dry matter accumulation before flowering (data not shown) play an important role in determining the final grain yield (Tollenar and Dwyer, 1999). The higher values of yield attributes such as number of grains per cob and 1000-grain weight were recorded with 240 kg N ha^{-1} than other N levels (Table 1). This is explained by the fact that the sink capacity of the plant is dependent, mainly on vegetative growth, and vigorous vegetative growth increased leaf area index with the application of higher doses of N, leading to greater quantity of active radiation intercepted by the plants; consequently supply of photosynthates for the formation of yield components was also enhanced. Similar findings as reported by Chela et al (1993) and de Grazia et al (2003) corroborate our results. With N deficiency leading to reduced LAI, the crop with lower levels of N have lower values of intercepted radiation and conversion efficiency, which reduce the growth rate. This is more severe during flowering stage during which the number of grains per cob is determined, hence low yields (Cox et al, 1993; Cirilo and Andrade, 1994; Andrade et al, 1999; de Grazia et al, 2003).

Both N and P had a significant effect (P≤0.05) on maize grain yield (Table 2; Figure 1). There was also a significant N x P interaction (P≤0.05) within and between the two nutrients. Phosphorus application had lower effect on yield compared to the effect of N. This can be explained by the role that N plays in dry matter built-up by intervening in the assimilate synthesis, which is different from the role of P, which is mainly a structural component of the plant materials (Amtmann and Armengaud, 2009). Though the effect of different levels of P was not highly manifested or significant as that of N, the effect of P fertilization was not negligible for both grain and stover. The overall

Table 5 - Effect of N and P combination on economics of winter maize cultivation.

N & P treatment	Gross returns (x1000 ₹ ha^{-1})					Net returns (x1000 ₹ ha^{-1})					Net B:C				
	P_0	$P_{13.2}$	$P_{26.4}$	$P_{39.6}$	Mean	P_0	$P_{13.2}$	$P_{26.4}$	$P_{39.6}$	Mean	P_0	$P_{13.2}$	$P_{26.4}$	$P_{39.6}$	Mean
N0	22.28	26.86	29.21	28.89	26.81	80.72	12.20	14.10	13.34	11.93	0.57	0.83	0.93	0.86	0.80
N80	58.30	55.78	63.92	55.90	58.47	43.17	40.20	47.89	39.43	42.67	2.85	2.58	2.99	2.39	2.70
N160	56.32	69.54	71.09	70.06	66.75	40.27	53.05	54.14	52.66	50.03	2.51	3.22	3.2	3.03	2.99
N240	57.21	73.15	78.58	74.51	70.85	40.24	55.70	60.71	56.19	53.21	2.37	3.2	3.4	3.07	3.01
Mean	48.53	56.32	60.69	57.34		32.94	40.29	44.21	40.41		2.1	2.5	2.6	2.3	
	N (N_0-N_{240})		P (P_0-$P_{39.6}$)	N x P		N (N_0-N_{240})		P (P_0-$P_{39.6}$)	N x P		N (N_0-N_{240})		P (P_0-$P_{39.6}$)	N x P	
SE	1.900		1.507	2.695		1.957		1.489	2.720		0.13		0.09	0.16	
LSD ($P \leq 0.05$)	6.576		4.399	7.868		6.772		4.347	7.939		0.44		0.26	NS†	

* ₹, Indian Rupee (INR); 1.0 ₹ = approximately USD 0.02 (in June 2011); Sale price of maize straw ₹ 0.55 kg^{-1}; Sale price of maize grain ₹ 10.00 kg^{-1}; †NS - non-significant

performance of P fertilization was due to the fact that the smaller number of grains per cob was compensated by heavier grains observed in crops fertilized with P. Similar trends were observed by de Grazia et al (2003) and Nour et al (2006). In fact, the interaction between N and P was significant and increased with increasing levels of N. The greatest yield was observed in 240 kg N ha^{-1} and 26.4 kg P ha^{-1} treatment and the lowest was observed in control. For treatments fertilized with higher level of N, all P application levels resulted in a significant increase in yield. It appears that response to P is less at the lower levels of N. Lower N fertilization decreased the grain and stover yield as well as the test weight because it affects the number of endospermatic cells and starch granules in the early post flowering period (Uhart and Andrade, 1995b; de Grazia et al, 2003). It also causes the reduction of the source assimilation during grain filling period.

Effects on concentration and uptake of N and P

We observed a reduction in the concentration of N and P at the successive growth stages of maize, could be due to the dilution effect (Kogbe and Adediran, 2003), arising from substantial increase in biomass weight (Table 3). But, this effect was counteracted to a small extent by the application of N and P, due to which the concentration of N or P was maintained at higher levels in the plots fertilized with higher levels of these nutrients compared to that in control. Nitrogen uptake in both grain and stover enhanced significantly with the application of higher levels of N compared with lower doses of N (Table 4), but N content in grain remained comparable between 160 and 240 kg N ha^{-1}. P uptake was highest at 26.4 kg P ha^{-1} after which it declined. Plant tissue analysis has been used to reveal the deficiency, adequacy or excessiveness status of various nutrient elements in a soil-plant system since time immemorial. Unfortunately, a serious limitation to its utility is the dynamic nature of nutrient concentration in plants in relation to their availability in soil, either in the native state or through their addition to the soil in fertilizer form (Hussaini et al, 2008). Moreover, simple input-output nutrient budgets are inadequate to account for the dynamic nutrient fluxes such as mineralization of organic matter, which may be a significant source of nutrient uptake during crop growth (Panitpaitoon and Suwanarit, 2011). Therefore, in our experiment we could not match the removal of nutrients in the form of uptake and nutrients availability before sowing and after harvest to enable us draw informed conclusions on nutrient balances. The N and P uptake by maize stover in response to N and P application was in close concert with the response of the total dry matter to these two nutrients as had been reported by Hussaini et al (2001). In our study we found that with the application of fertilizer N, yield, percentage N content and the uptake of P were increased. Nutrient accumulation in the maize grain was greater than in the stover. This can be attributed to the mobilization of large proportion of nutrients from other parts of the plant to the grains as the grains develop. The same was observed by Derby et al (2004) and Hussaini et al (2008) in maize and Dordas (2009) in wheat. Generally, the N use efficiency values decreased with an increase in N rates. The values were 67.38, 38.40, and 27.25 kg grain per kg N at 80, 160, and 240 kg N ha^{-1}, respectively. Additional use of P also reduced the grain weight produced from every kilogram of P; the values were 393.50, 216.02, and 128.65 kg grain per kg P at 13.2, 26.4, and 39.6 kg P ha^{-1}, respectively. In general, the crop removed 24.7 kg N and 6.2 kg P per tonne grain produced.

A significant ($P \leq 0.05$) N x P interaction was observed at 240 kg N ha^{-1} and 26.4 kg P ha^{-1}, which resulted in the highest total uptake of N and P by maize plants (Table 4). Applications of 80, 160, and 240 kg N ha^{-1} caused an increase by 6.6, 14.5, and 15.9%, respectively in grain N concentration over that in control (data not shown). Grain P concentration was increased by 2.5, 4.0, and 3.2% over that in control due to applications of 13.2, 26.4, and 39.6 kg P ha^{-1}, respectively, but the increase in P concentration was recorded up to 26.4 kg P ha^{-1} after which it declined (data not shown). Similarly, maize stover N increased over control due to increased N application, but stover P did not increase until the highest, 240 kg N ha^{-1} was applied. A certain degree of synergy between N and P has been reported for many field crops (Hussaini et al, 2008). The addition/supply of N enhances the production of small roots and root hairs, which in turn facilitates the high absorbing capacity per unit of dry matter, and influence the uptake by the plant of soil and fertilizer P sources.

Effect on economics of winter maize

Higher levels of N fertilization resulted in higher values of gross and net returns and net returns per rupee invested, which were significantly higher than those in control (Table 5; Figure 2). Higher grain and stover yield of maize with increasing levels on N application (discussed above) led to higher net returns and net B:C. An increase in the cost of cultivation was realized due to adoption of the levels of N and P. However, the cost was comparatively lower than the price received from the extra yields of grain and stover obtained due to adoption of N and P levels. The increase in these economic parameters due to P application was only up to 26.4 kg P ha^{-1} and any additional P input beyond this dose was less economical. The economic analysis on the interaction showed that the combination of 240 kg N ha^{-1} and 26.4 kg P ha^{-1} was most superior. The economic optimum dose was found to be 196.4 kg N ha^{-1} and 23.4 kg P ha^{-1}. These results are in close conformity with those of Shilluli et al (2003) and Nour et al (2006).

Conclusion

Our results show that a dose of 240 kg N ha^{-1} can provide significantly higher grain and stover yield of winter maize, albeit 160 kg N ha^{-1} was comparable with it. Application of P up to 26.4 kg P ha^{-1} is remunerative; further increase after this dose would cause reductions in yields and economic returns. A combination of 240 kg N ha^{-1} and 26.4 kg P ha^{-1} results in significantly higher values of yield attributes, yield, nutrient uptake and economic returns. This may be worth-recommending. But, it would be better, if recommendation is made based on the economic optimum doses, which were worked out to be 196.4 kg N ha^{-1} and 23.4 kg P ha^{-1} for winter maize. The study provides recommendation of N and P for winter maize based on economics. The data would be useful for fitting models and simulating yields across the doses of N and P.

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