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Research Paper

Effect of cultivars and levels of nitrogen, phosphorus and potassium on growth, yield and nutrient uptake of maize (*Zea mays*) hybrids

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ABSTRACT

A field study was conducted during the winter season of 2013–14 and 2014–15 at farmer's field, Gayeshpur, Nadia, West Bengal, to evaluate the performance of maize (*Zea mays* L.) as influenced by cultivars and levels of NPK. The experimental soil was clay in texture and neutral in reaction, having low available N, high available P and medium available K. The experiment was laid out in a strip-plot design with 3 maize hybrids ('P 3522', 'P 3396' and 'Rajkumar') in vertical strip and 9 NPK levels [50% recommended dose of fertilizer (RDF), 75% RDF, RDF (200 kg N, 60 kg P and 60 kg K/ha), 125% RDF, 150% RDF, 100% PK, 100% NK, 100% NP and control (zero-NPK)] in horizontal strip, replicated thrice. Maize hybrid 'P 3396' recorded better cob characteristics (cob length, cob girth and cob weight) and test weight, while other yield attributes (number of cobs/plant, number of grain rows and grains/cob) were higher in 'P 3522'. Across cultivars, 125% RDF application resulted in significant increase in yield attributes over the control. The cultivar 'P 3396' recorded second best yield (grain and stover) after 'P 3522'. Application of 125% RDF resulted in the maximum grain and stover yield with 124.5 and 91.2% increase over the control respectively. Total P and K uptake increased up to 125% RDF; however, total N uptake increased till 150% RDF application. Grain yield reduction, in comparison with RDF plots, was estimated to be 43.90% due to N omission, 16.76% due to P omission, and 26.94% due to K omission. Net returns and benefit: cost ratio continued to increase till 125% NPK, and decreased further with addition of NPK (150%).

***Key words*:** Maize, Macro-nutrient, Nutrient omission, Nutrient-use efficiency, Yield

In India, maize is the third most important grain crop, after rice and wheat. The crop is having wider adaptability, and grown in diverse seasons and ecologies for various purposes. This wide variability of maize makes it particularly important to the poor people of India as a means of overcoming hunger and improving food security (Banerjee *et al.*, 2014). India holds 7th rank in terms of production (26.26 million tonnes) of the crop from an area of 10.20 million ha, having low average productivity of 2.57 t/ha (FAOSTAT, 2018). The introduction of hybrids in West Bengal has also increased the production potential of maize and its utilization for food and feed purpose. In West Bengal, maize is cultivated in 0.152 million ha during 2014–15, with an annual production of 0.663 million tonnes, and an average state productivity of 4.35 t/ha (Government of India, 2018).

Traditionally maize is grown in tribal parts of India as subsistence crop mostly under low input conditions and under poor management (imbalanced fertilization with unequal plant stand). Although recently released maize hybrids require high input, especially nutrients. The role of plant nutrients is of paramount importance, and balanced use of fertilizer is one of the options to increase nutrient-use efficiency (NUE) of maize (Banerjee *et al.*, 2014). Of all the nutrients, nitrogen (N), phosphorus (P) and potassium (K) remain the major ones for increased and sustained productivity. Synthetic fertilizer is the dominant source of nutrients and is required to enhance yield of maize, but should be applied in such a quantity that it becomes profitable and will have least adverse effect on environment (Timsina *et al.*, 2010).

On the other hand, continuous production of high-yielding maize may lead to the rapid depletion of mineral nutrients from soil unless appropriate nutrient inputs are supplied. Maize hybrids grown in winter (*rabi*) season in West Bengal have an attainable grain yield of about 10-12 t/ha,

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with similar amount of non-grain biomass (Ray *et al.*, 2018). For decades, researchers have attempted to optimize N, P and K application rates in order to solve the economic and environmental problems associated with over-fertilization. But existing fertilizer recommendations for maize crop consists of one predetermined rate of nutrients for vast maize-growing areas of Bengal. It has been proved beyond doubt that the needs of supplemental nutrients of any crop can vary greatly among fields, seasons and years as a result of differences in crop-growing seasons, crop and soil management, and climate (Timsina *et al.*, 2010). Moreover, farmers have resorted to use of greater than the recommended dose of fertilizer in many intensively cultivated areas (Mozumder *et al.*, 2014). Hence, managing the location- and season-specific variability in nutrient supply is the key strategy to overcome the current mismatch of fertilizer rates and crop nutrient demand. On the other hand, there is a growing deficiency of secondary and micronutrients due to intensive cropping with the use of high-analysis fertilizers. The glaring non-responsiveness to application of recommended or elevated levels of NPK is due to the growing hidden hunger for secondary and micronutrients (Alipatra *et al.*, 2019). Therefore, site-specific nutrient management (SSNM) approach is used to address nutrient differences that exist within/between fields by making adjustments in nutrient application (Dobermann *et al.*, 2002). In recent times, attempts were made through nutrient omission approaches to evaluate soil and fertilizer nutrient contributions to the crop performance and ultimately to develop SSNM recommendations for sustainable yield of cereals. This new SSNM approach has been evaluated at numerous locations in India but only in rice, and remains unexploited for other cereals.

Hence, present experiment was structured with precise objectives to (i) evaluate the growth and yield of modern maize hybrids under varied levels of NPK, (ii) estimate the nutrient-use efficiency (NUE) of maize hybrids under different levels of NPK and (iii) find out the profitability under different fertilizer-management options.

MATERIALS AND METHODS

The present investigation was carried out during the winter of 2013–14 and 2014–15 at farmer's field, Madandanga, Gayeshpur, Nadia, West Bengal (23°26.010ˆ N, 88°22.221ˆ E and 12 m above mean sea level). Maximum and minimum temperature fluctuated between 21.2 and 39.8°C and 6.9 and 25.2°C during winter 2013–14, while 23.1 and 41.3°C and 9.2 and 26.6°C during winter 2014–15. The maximum and minimum relative humidity prevailed between 83 and 98% and 25 and 68% during winter 2013–14, while 80 and 95% and 35 and 62% during winter 2014–15. The rainfall during the experimental period (November to March) was 91.4 and 54.7 mm during winter season of 2013–14 and 2014–15 respectively. The soil of the experimental field was clay in texture, having *p*H 7.31, organic carbon 0.66%, available N 215.2 kg/ha, available P 41.6 kg/ha and available K 186.4 kg/ha.

The experiment was laid out in a strip-plot design with 3 hybrid maize cultivars 'P3522', 'P 3396' and 'Rajkumar' in the vertical strip and 9 levels of NPK [50% recommended dose of fertilizer (RDF, $N_{100}P_{30}K_{30}$), 75% RDF ($N_{150}P_{45}K_{45}$), 100% RDF ($N_{200}P_{60}K_{60}$), 125% RDF ($N_{250}P_{75}K_{75}$), 150% RDF ($N_{300}P_{90}K_{90}$), 100% P and K ($P_{60}K_{60}$, N omission), 100% N and K ($N_{200}K_{60}$, P omission), 100% N and P ($N_{200}P_{60}$, K omission) and the control (zero-NPK)] in the horizontal strip, replicated thrice. Seeds were sown @ 25 kg/ha on 20th November in both cropping seasons at a spacing of 60 cm × 30 cm (55,555 plants/ha). The plot size was 4 m × 3 m. Forty per cent of N (urea) with full dose of P (single super phosphate) and K (muriate of potash) was surface broadcast by hand-during final land preparation (as basal). Rest of the N was top-dressed in 2 equal splits, at 45 (knee-height stage) and 80 days after sowing (DAS pre-tasseling stage). All typical cultivation practices were followed by local best management practices (Ray *et al*., 2018).

In each plot, 5 randomly selected plants from destructive sampling (1 m long row) were used to record plant height and total dry-matter accumulation (DMA) at 120 DAS. For estimating DMA, the samples were dried in a hot-air oven at a temperature of 80°C for 10 hours, till constant weights were obtained. The leaf-area index (LAI) was calculated from the leaf area-weight relationship at the time of harvesting. Days from planting to 50% tasseling or silking was recorded when 50% plants in each plot had produced tassel or silk. The date of physiological maturity was recorded when 50% of the spikes in a plot had lost their green colouration. At harvesting, 5 plants from each plot were selected for recording yield components. Total number of matured cobs (from 5 plants) were recorded, and averaged to get the number of cobs/plant. Length and girth of the matured cobs (from 5 plants) were recorded using a measuring tape, weighed using an electronic weighing machine, and then averaged to get mean cob weight. Other yield component, i.e. number of grain rows/cob, was counted from each of 5 cobs separately, and averaged to get mean value. After proper sun-drying, grains were de-shelled, and the number of grains/cob and 1,000-grain weight (test weight) were recorded. Plants from the demarked net plot area were harvested and tied in bundles after removing all the matured cobs from them. Grains were deshelled from the cob (dehusked) and then dried properly to reduce the moisture content at 14.0%. Weight of grains was recorded as kg/plot and then converted into t/ha. The plants (without grain) were dried in the Sun and finally weighed to get stover yield in kg/ha and converted into t/ha. The harvest index was calculated from the ratio of grain weight (t/ha) and total above-ground biomass yield (t/ha), multiplied by 100. The shelling percentage was calculated from the ratio of grain weight (g) and cob weight (g), multiplied by 100. For both soil (initial and post-harvest) and plant nutrient (N, P and K) content (%), methodologies mentioned in Ray *et al.* (2018) was followed. Total uptake of nutrients (NPK) was calculated by multiplying their concentration (%) with the plant dry-matter (kg/ha) at harvest, divided by 100.

To measure the re-translocation efficiency of absorbed nutrients (NPK) from vegetative plant parts to grain and also to measure nutrient (NPK) partitioning in maize plant, nutrient harvest index was estimated as per Fageria (2014).

$$\text{N/P/K harvest index (\%)} = \frac{\text{Uptake of N/P/K in grain (kg/ha)}}{\text{Uptake of N/P/K in total above ground biomass (kg/ha)}}$$

For economic analysis, cost of cultivation, gross return, net return and benefit: cost ratio (B : C ratio) were determined using the formula given by Banerjee *et al.* (2014).

Data were subjected to analysis of variance (ANOVA) as strip-plot design (Gomez and Gomez, 1984). The significance of difference for sources of variance was tested by error mean square by Fisher Snedecor's 'F' test at probability level of 0.05. For comparison of 'F' values and computation of critical difference (CD) at 5% level of significance, Fisher and Yates' tables were consulted. The variance over years was estimated homogeneously by performing Bartlett's chi-square test and pooled analyses of observations are presented to draw logical conclusions.

RESULTS AND DISCUSSION

Growth attributes of hybrid maize

Hybrid maize cultivar 'P 3522' produced significantly taller plants than the tested cultivars (Table 1). Across cultivars, the NPK fertilization brought about significant increase in plant height. The highest plant height was observed with 150% RDF application, being statistically at par with 125% RDF. Interaction effect (cultivar × NPK) exerted significant variation in plant height at 120 DAS. The cultivar 'P 3522' attained the maximum height when fertilized with 150% RDF followed by the cultivar 'P 3396' with 125% RDF and 'Rajkumar' with 150% RDF. Nutrient-omission treatments caused serious reduction in plant height of all the maize hybrids, and the lowest plant height was observed in the control plots. Significant difference in dry-matter (DM) accumulation among the cultivars was observed (Table 2), and the cultivar 'P 3522' accumulated higher DM than 'P 3396' and 'Rajkumar'. Application of 125% RDF resulted in the highest DMA in the plants. Further increase in NPK level reduced the DMA across the cultivars. As shown in Table 2, interaction effect (cultivar × NPK) exhibited non-significant variation in DMA in the tested cultivars at 120 DAS. Cultivars showed non-significant difference in leaf-area index (LAI) at physiological maturity (120 DAS) (Table 2). Significant effect of NPK fertilization on LAI was recorded up to 125% RDF. But the plants raised in the nutrient-omission plots and the control plots showed lower LAI than the combined application of NPK. Moreover, under conditions with high photosynthetic activity of winter maize (high light intensity, optimum temperature and absence of water stress), the level of NPK must also be high (Mengel and Kirkby, 2006).

Table 1. Plant height (cm) of maize at harvesting as influenced by cultivar and levels of NPK (pooled data of 2 years)

Levels of NPK	Hybrid cultivars			Mean
	'P 3522'	'P 3396'	'Rajkumar'	
50% RDF	308.1	267.2	267.2	271.5
75% RDF	309.2	268.1	268.1	273.2
100% RDF	317.3	271.3	271.3	277.0
125% RDF	326.7	273.0	273.0	281.3
150% RDF	337.6	270.3	270.3	285.7
100% PK	270.9	245.3	245.3	240.5
100% NK	300.7	262.5	262.5	267.4
100% NP	293.1	258.4	258.4	262.8
Control (-NPK)	269.0	244.0	244.0	233.0
Mean	303.6	262.2	231.6	-
	SEm±	CD (P=0.05)		
Cultivar	1.17	3.83		
Fertilizer	1.97	5.66		
Cultivar × Fertilizer	5.00	14.37		
Fertilizer × Cultivar	4.94	14.04		

RDF, Recommended dose of fertilizer = 200 kg N, 60 kg P and 60 kg K/ha

In the present study, omission of N, P or K significantly reduced the plant growth. Reduction of plant height and DMA was greater with N omission, followed by K and P omission respectively. At physiological maturity, reduction of DMA was accounted for 36.51, 8.11 and 11.23% due to N, P and K omission respectively. But effect of nutrient omission on reduction of LAI was in the order of –N > –P > –K. Such observations indicate the essentiality of these macronutrients and probable interactions among them for better growth of maize hybrids. Adequate supply of N might have helped the maize plants to increase their growth, which in turn put forth more photosynthetic surface and leaf-area index (LAI), thus contributing more dry matter (Abubakar *et al.*, 2019). Ray *et al.* (2018) reported limited rate of dry-matter accumulation of maize under inadequate N supply. On the other hand, insufficient K and P supply may retard vegetative growth associated with an accumulation of carbohydrates in leaves (Mengel and Kirkby, 2006).

Phenophases of hybrid maize

Days required by the tested cultivars to attain 50% tasseling differed significantly; however, all the cultivars took almost the same time for 50% silking and maturity (Table 2). The time intervals between tasseling and silking, and silking and maturity were the lowest in 'P 3522' (8 and 32 days respectively) and the highest in 'P 3396' (10 and 34 days respectively), which indicates the characteristic longer vegetative and shorter reproductive growth of 'P 3522' while shorter vegetative and longer reproductive growth of 'P 3396'. The NPK fertilization exerted significant variation in days to achieve 50% tasseling, silking and maturity, but no definite trend was noticed. Om *et al.* (2014) demonstrated non-significant response of winter-grown maize hybrids towards N application with respect to days to 50% tasseling and silking. In the present study, phenophases (tasseling, silking and maturity) of the tested hybrids were delayed significantly in the N-omission (100% PK) and the control plots. Nitrogen stress prolonged the period between anthesis and silking, causing an increase in the number of days required for 50% tasseling and silking. These results are in good line with that of Nsanzabaganwa *et al.* (2014), who also reported delayed tasseling and silking in maize hybrids from zero-N plots. However, in the present study, such direct effect of N on the phenophases of maize hybrids was not manifested for P and K. Nsanzabaganwa *et*

Table 2. Effect of cultivars and levels of nitrogen, phosphorus and potassium on total dry-matter accumulation (DMA) and leaf-area index (LAI) at harvesting and phenophases of maize (pooled data of 2 years)

Treatment	Total DMA (g/plant)	LAI	Days to 50% tasseling	Days to 50% silking	Days to maturity
Hybrid cultivars					
'P 3522'	428.7	2.45	99	107	139
'P3396'	401.4	2.85	94	104	138
'Rajkumar'	385.4	2.01	95	105	138
SEm±	9.77	0.27	0.34	0.64	0.35
CD (P=0.05)	31.86	NS	1.12	NS	NS
Levels of NPK					
50% RDF	371.6	2.47	96	105	137
75% RDF	420.1	2.54	96	105	137
100% RDF	471.1	2.64	95	104	137
125% RDF	488.1	2.99	94	103	139
150% RDF	473.5	2.83	94	105	140
100% PK	299.1	2.04	100	108	141
100% NK	432.9	2.21	94	104	136
100% NP	418.2	2.39	95	105	137
Control (-NPK)	272.0	1.81	100	108	140
SEm±	9.88	0.10	0.72	0.72	1.09
CD (P=0.05)	28.47	0.29	2.07	2.08	3.14
Interaction					
Cultivar × Fertilizer					
SEm±	25.83	0.47	1.69	1.90	2.11
CD (P=0.05)	NS	NS	4.83	NS	NS
Fertilizer × Cultivar					
SEm±	23.50	0.27	1.73	1.77	2.35
CD (P=0.05)	NS	NS	4.92	NS	NS

RDF, Recommended dose of fertilizer = 200 kg N, 60 kg P and 60 kg K/ha; NS, non-significant *al*. (2014) also pointed out that, the effect of P on phenophases was absent for winter maize. The present study clearly indicates maturity date was delayed due to firstly the indigenous nature of the cultivars (stay-green) and secondly the nitrogen stress. Even interaction effect (cultivar × NPK) did not exhibit any significant variation in maturity date of the tested cultivars (Table 2).

Yield attributes of hybrid maize

The cultivars showed significant variation with respect to all yield attributes (Table 3). Among the hybrids, 'P 3396' recorded higher values for all cob characteristics (length, girth and weight of cob) and test weight, while 'P 3522' for other yield attributes (number of cobs/plant, number of grain rows/cob and number of grains/cob). The cultivar 'Rajkumar' exhibited the lowest values for all yield attributes. Plants with better growth were expected to have better yield attributes, and hence the response. Ray *et al.* (2018) also observed significant relation among maize growth and yield attributes. The cultivar 'P 3396' used in this study might have the genetic make-up to make a better partitioning of dry matter in sink (cob) which has been reflected in higher yield attributes (Alias *et al.*, 2003). Results also revealed that all above yield attributes of the tested maize hybrids were significantly influenced by the NPK levels. Across the cultivars, application of 125% RDF resulted significant increase in all yield attributes over the control (-NPK) treatment, and further increase in NPK level failed to exert significant effect on those traits (Table 3).

Nutrient-omission treatment significantly reduced all yield attributes of tested cultivars. Greater reduction in yield attributes was observed with N-omission followed by K- and P- omission treatments. Yield attributes of maize hybrid under the control treatment was significantly lower than other NPK levels. Interaction effect of cultivar × NPK failed to exhibit any significant variation in yield attributes of tested maize hybrids (Table 3).

Yield of hybrid maize

Cultivars exhibited non-significant difference in respect of grain yield, stover yield and harvest index (Table 3). The cultivar 'P 3396' gave second best yield (both grain and stover) after 'P 3522'. In the present study, except potassium-harvest index (KHI), both the values of nitrogen-harvest index (NHI) and phosphorus-harvest index (PHI) were

Table 3. Influenced of cultivars and levels of nitrogen, phosphorus and potassium on yield attributes and yields of maize (pooled data of 2 years)

Treatments	Cob length (cm)	Cob girth (cm)	Cob weight (g)	Cobs/ plant	Grain rows/ cob	Grains/ cob	Test weight (g)	Grain yield (t/ha)	Stover yield (t/ha)	Harvest index (%)	Shelling %
Hybrid cultivars											
'P 3522'	18.9	15.54	271.7	1.60	14.77	375.4	309.6	8.34	6.71	54.44	62.6
'P 3396'	20.0	15.81	287.4	1.36	14.06	359.6	310.2	7.78	5.89	55.82	60.1
'Rajkumar'	18.5	15.17	236.9	1.46	13.30	330.3	290.1	7.54	5.24	58.64	66.4
SEm±	0.15	0.07	4.54	0.02	0.12	5.11	4.87	0.22	0.37	1.87	0.84
CD (P=0.05)	0.49	0.23	14.79	0.06	0.38	16.68	15.89	NS	NS	NS	2.73
Levels of NPK											
50% RDF	19.8	15.68	277.4	1.54	14.11	353.3	308.9	8.39	6.13	57.97	62.9
75% RDF	19.9	15.73	280.3	1.61	14.22	361.6	313.0	8.97	6.57	55.90	63.5
100% RDF	20.1	15.82	287.6	1.72	14.31	387.7	322.0	9.43	7.25	55.89	62.9
125% RDF	20.4	16.00	305.7	1.87	14.64	412.0	331.5	10.37	7.61	57.31	65.1
150% RDF	20.4	15.88	290.8	1.78	14.50	380.9	326.4	9.17	6.80	56.76	65.8
100% PK	16.9	14.87	212.1	1.09	13.61	312.6	282.1	5.29	4.53	54.53	59.3
100% NK	19.4	15.51	269.9	1.39	13.92	345.6	303.5	7.85	5.54	57.98	64.6
100% NP	19.0	15.40	260.4	1.26	13.78	331.8	285.2	6.89	5.11	56.78	63.2
Control (-NPK)	16.3	14.68	203.8	1.02	13.31	310.6	256.9	4.62	3.98	53.61	60.1
SEm±	0.49	0.15	7.91	0.08	0.21	15.31	7.34	0.44	0.41	2.38	2.02
CD (P=0.05)	0.97	0.42	22.80	0.22	0.60	44.10	21.14	1.28	1.17	NS	NS
Interaction											
Cultivar × Fertilizer											
SEm±	0.62	0.24	17.15	0.12	0.58	30.31	12.06	0.84	1.01	5.49	3.52
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Fertilizer × Cultivar											
SEm±	0.69	0.28	17.75	0.15	0.57	33.44	13.46	0.92	0.95	5.36	4.05
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

higher than grain-harvest index. Nutrient-harvest index always has a higher value than the yield harvest index, caused by a higher percentage of nutrient content in the maize grain than in stover (Fageria, 2014). However, shelling per cent of the tested cultivars varied significantly, and the cultivar 'Rajkumar' showed higher values. Both grain and stover yields were significantly influenced by NPK levels. Application of 125% RDF resulted in the maximum grain and stover yield with 124.46 and 91.21% increase over the control (-NPK) treatment. But further increase in NPK level up to 150% RDF failed to achieve higher yield by the law of diminishing return. For grain crops including maize, grain yield depends on 3 main yield components: number of ears/plant, number grains/ear and the single grain weight (Mengel and Kirkby, 2006). In the present study, all these yield traits were improved with NPK levels, and thus NPK fertilization exerted significant impact on maize yield. Nsanzabaganwa *et al.*, (2014) reported increase in maize yield, accompanied with increased yield traits, has been reported with nutrient application.

Significant yield reduction was observed in nutrient-omission plots, while the lowest yield was recorded in the control plot (Table 3). Omission of N caused greater reduction in grain and stover yield, followed by K omission and P omission. The N, P and K-limited grain yields were estimated 5.29, 7.85 and 6.89 t/ha, respectively, which confirm the prevailing P × K, N × K and N × P interactions in soil. When compared with 100% RDF, grain yield reduction with nutrient omission was 43.90% for N omission, 16.76% for P omission and 26.94% for K omission. Nutrient omission also caused reduction in stover yield, and it was to the tune of 37.52% for N omission, 23.59% for P omission and 29.52% for K omission. As shown in Table 3, interaction (cultivar × NPK) effect did not exhibit any significant variation with respect to grain yield, straw yield, harvest index and shelling per cent of tested maize hybrids.

Nutrient uptake and nutrient harvest indices

The maize cultivars showed significant difference in total P uptake, and difference in N and K uptake was non-significant (Table 4). The cultivar 'P 3396' recorded the highest total P uptake, followed by 'P 3522' and 'Rajkumar'.Among the cultivars, the NPK uptake of maize plants varied significantly due to changes in NPK levels.

Table 4. Effect of cultivars and levels of nitrogen, phosphorus and potassium on total nutrient uptake and nutrient harvest indices of maize (pooled data of 2 years)

Treatment	Total nutrient uptake (kg/ha)			Nutrient harvest index (%)			Soil-available nutrients (kg/ha)		
	N	P	K	N	P	K	N	P	K
Hybrid cultivars									
'P 3522'	193.7	45.0	131.6	63.3	74.1	31.4	135.4	28.7	150.0
'P 3396'	195.4	47.1	128.3	60.6	62.3	30.2	127.6	28.6	147.0
'Rajkumar'	189.4	42.6	122.6	58.2	66.0	29.9	151.1	28.1	155.0
SEm±	4.65	0.93	5.88	1.79	1.30	1.75	3.94	0.73	2.32
CD (P=0.05)	NS	3.03	NS	NS	4.25	NS	12.86	NS	NS
Levels of NPK									
50% RDF	191.8	42.9	124.3	61.1	67.5	30.9	142.9	28.4	151.3
75% RDF	211.9	48.9	141.0	60.9	67.8	31.8	149.3	29.0	154.2
100% RDF	239.1	53.7	149.9	60.0	66.5	30.0	153.4	30.6	157.3
125% RDF	259.2	66.7	175.4	57.9	58.6	27.5	171.2	32.1	159.9
150% RDF	279.2	57.3	159.5	54.7	64.6	29.6	167.5	35.1	164.1
100% PK	107.2	29.4	90.8	58.6	69.0	29.8	113.1	24.6	140.6
100% NK	197.4	37.6	120.4	65.7	69.5	32.0	131.9	26.2	147.1
100% NP	161.9	43.3	107.7	65.7	70.6	32.2	124.8	27.1	143.8
Control (-NPK)	87.5	24.2	78.4	61.6	73.2	30.3	88.3	23.2	137.7
SEm±	5.33	1.34	6.22	1.75	1.63	1.65	5.84	0.98	2.37
CD (P=0.05)	15.35	3.85	17.92	5.05	4.70	NS	16.83	2.83	6.82
Interaction									
Cultivar × Fertilizer									
SEm±	16.54	3.64	15.49	4.63	3.96	5.03	23.09	2.05	7.05
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Fertilizer × Cultivar									
SEm±	15.15	3.50	14.33	4.17	3.81	4.45	21.09	2.07	6.35
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

RDF, Recommended dose of fertilizer = 200 kg N, 60 kg P and 60 kg K/ha; NS, non-significant

Application of 150% RDF resulted in significantly higher N uptake (16.77% more than that of 100% RDF). Total P and K uptake increased significantly with the increasing level of NPK up to 125% RDF, but it was declined with further increase in NPK level up to 150% RDF.

In our study, nutrient-omission treatments resulted in significant reduction in NPK uptake, while plant with zero NPK (control) recorded the lowest uptake with respect to N, P and K. Maximum reduction in NPK uptake was noticed for N omission, while K omission reduced both N and K uptake. Maize can absorb N either in NH_4^+ or NO_3^- form. There is a unique possibility of anion–cation as well as cation-cation interactions with K^+. Most of the findings have illustrated that K^+ does not compete with NH_4^+ for uptake; rather it increases NH_4^+ assimilation in the plants and avoids possible NH_4^+ toxicity (Aulakh and Malhi, 2004).

Maize hybrids exhibited more P uptake in K-omitted plots, when compared with plants in N- and P-omitted plots (Table 4). Pasley *et al.* (2019) reported that, N can increase P uptake in maize plants by increasing root growth, ability of roots to absorb and translocate P. As shown in Table 4, the interaction (cultivar × NPK) effect was non-significant for total N and K uptake but significant for P uptake. The cultivar 'P 3396' showed higher P uptake with 125% RDF followed by 'Rajkumar' and 'P 3522' with same NPK level.

The maize cultivars did not show significant variation with respect to NHI and KHI and the variation was significant for PHI (Table 4). The cultivar 'P 3522' showed higher PHI followed by 'Rajkumar' and 'P 3396'. Levels of NPK exerted significant effect on NHI and PHI but not on KHI (Table 4); however, no definite trend was noticed. The NHI was higher for plant with N-and P-omission treatments, while the control (-NPK) treatment recorded higher values of PHI. Interaction of cultivar × NPK effect failed to exert significant effect on nutrient-harvest index (Table 4). Under low supply of NPK, most of the nutrients assimilated before and after silking stage were allocated to grain, thus increasing nutrient-use efficiency for grain filling, while decreasing the amount of NPK lost in the dry remains, thereby increasing the NHI (Masclaux-Daubresse and Chardon, 2011). In contrary, under high supply of NPK, a large portion of nutrient accumulated during pre-and post-silking stage is stored in stalk rather than being transported to grains, thereby lowering the nutrient harvest index (Ray *et al.,* 2018). The KHI was lower than N and P because post-silking K accumulation was negligible and thereby contributing less to grain K. And most of the grain K was contributed by vegetative K remobilization. The lower value of grain K with corresponding higher values of stover K determined the lower KHI in the present study.

Post-harvest soil nitrogen, phosphorus and potassium

The variation in available N and K content was significant among the plots having the 3 tested cultivars (Table 4); however, the variation in available P status was non-significant. The plots with 'Rajkumar' cultivar recorded the highest amount of available N and K. Plants grown in those plots showed lower uptake of N and K (Table 4), as a result higher residue N and K was found. This clearly indicates that better utilization of nutrient by any cultivar resulted in lesser amount of residue in soil. On the other hand, the NPK fertilization exerted significant influence on available N, P, and K status in post-harvest soil (Table 4). Results also showed that the available soil N content in the post-harvest soil was increased with 125% RDF; however, available P and K were increased with NPK fertilization up to 150% RDF. Plots receiving zero N/P/K fertilizer revealed lower nutrient (N/P/K) status in post-harvest soil, while poor NPK status was recorded in post-harvest soil of the control (-NPK) plots. Interaction of cultivar × NPK did not influence available N, P and K status in the post-harvest soil significantly (Table 4).

Economics

Fertilization with NPK exerted positive effect on gross return, net return and benefit: cost (B : C) ratio in hybrid maize cultivation (Table 5). Net return and B : C ratio continued to increase till 125% NPK, and further addition of NPK (150%) resulted in decrease on net return and B : C ratio. Higher cost of cultivation in association with comparatively lower grain yield in 150% RDF was responsible for such an outcome. On the other hand, higher economic returns and B : C ratio were obtained at 125% NPK because of increased total grain yield realized at this application rate. These results confirm the findings of Kaledhonkar *et al.* (2011), who reported an increase in B : C ratio with increasing levels of NPK. With 125% RDF application, the cultivar 'P 3396' recorded highest net return and B : C ratio, followed by 'P 3522' and 'Rajkumar'. Despite of giving lower grain yield than 'P 3522' (however, statistically at par), cultivation of 'P 3396' fetched higher benefit (than that of 'P 3522') owing to lesser cost of cultivation (owing to lesser seed cost). Maize profitability was considerably affected by nutrient omissions (Table 5). Cost of cultivation differed marginally on account of nutrient omissions but resulted in large differences in the yield and net profit. The negative response in net return was recorded in plots treated with the control and N-omission treatments. This might be due to poor growth and low productivity of the crop. Omission of N reduced the net returns greatly and K proved to be the second most limiting nutrient in maize production.

Thus, it may be concluded that 125% RDF (250 kg N,

Table 5. Profitability of maize cultivation under different treatment combinations (mean data of 2 years)

Treatment combinations	Common cost (× 10^3 ₹/ha)	Treatment cost (× 10^3 ₹/ha)	Total cost (× 10^3 ₹/ha)	Gross returns (× 10^3 ₹/ha)	Net returns (× 10^3 ₹/ha)	Benefit: cost ratio
'P 3522' × 50% RDF	68.6	16.3	85.0	127.7	42.7	1.50
× 75% RDF	68.6	18.3	87.0	132.8	45.8	1.53
× 100% RDF	68.6	20.2	88.9	136.7	47.7	1.54
× 125% RDF	68.6	22.2	90.9	152.2	61.3	1.67
× 150% RDF	68.6	24.1	92.8	134.0	41.1	1.44
× 100% PK	68.6	16.1	84.7	79.3	-5.4	0.94
× 100% NK	68.6	17.0	85.7	112.6	26.8	1.31
× 100% NP	68.6	18.4	87.1	111.0	23.8	1.27
× Control (-NPK)	68.6	10.7	79.4	64.6	-14.8	0.81
'P 3396' × 50% RDF	68.6	13.8	82.5	118.5	36.0	1.44
× 75% RDF	68.6	15.8	84.5	123.1	38.6	1.46
× 100% RDF	68.6	17.7	86.4	130.5	44.0	1.51
× 125% RDF	68.6	19.7	88.4	150.6	62.2	1.70
× 150% RDF	68.6	21.6	90.3	125.8	35.4	1.39
× 100% PK	68.6	13.6	82.2	71.4	-10.8	0.87
× 100% NK	68.6	14.5	83.2	109.0	25.7	1.31
× 100% NP	68.6	15.9	84.6	82.3	-2.3	0.97
× Control (-NPK)	68.6	8.2	76.9	68.7	-8.2	0.89
'Rajkumar' × 50% RDF	68.6	12.6	81.3	106.0	24.7	1.30
× 75% RDF	68.6	14.5	83.2	120.7	37.4	1.45
× 100% RDF	68.6	16.5	85.2	128.6	43.4	1.51
× 125% RDF	68.6	18.4	87.1	132.5	45.3	1.52
× 150% RDF	68.6	20.4	89.1	125.5	36.4	1.41
× 100% PK	68.6	12.3	81.0	71.3	-9.7	0.88
× 100% NK	68.6	13.3	82.0	107.8	25.8	1.32
× 100% NP	68.6	14.7	83.4	96.0	12.6	1.15
× Control (-NPK)	68.6	7.0	75.7	60.7	-15.0	0.80

RDF, Recommended dose of fertilizer, 200 kg N, 60 kg P and 60 kg K/ha

75 kg P and 75 kg K/ha) was proved to be giving the highest growth, yield, nutrient uptake and economics when supplied for cultivar 'P 3396'. Thus, hybrid cultivar 'P 3396' with 125% RDF may be recommended in alluvial soil of West Bengal for maintaining sustainability and profitability in maize production systems.

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