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APPLICATION OF NITROGEN AND PHOSPHORUS IN DIFFERENT RATIOS TO AFFECT PADDY YIELD, NUTRIENT UPTAKE AND EFFICIENCY RELATIONS IN RICE

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ABSTRACT

Background Efficient and balanced fertilization is of paramount importance for both economic harvest and environmental aspects. Fertilizer use in Pakistan has been rising over the many years; however there is stagnation in crop yields due to imbalanced use of fertilizers. Generally, growers are applying high quantity of nitrogen (N) but only small or sub-optimal amounts of phosphorus (P). Moreover, inter and intra specific variations exist in crop plants for their nutritional requirements based on their genetic and agronomic characteristics. Therefore, it is essential to formulate balance fertilizer dose primarily for newly evolved crop genotypes to get higher yields and to fetch maximum economic return to the farmers.

Methodology A field trial was conducted at the experimental farm of Nuclear Institute of Agriculture (NIA) Tandojam, Pakistan to evaluate the effect of various N and P ratios on paddy yield and nutrient use efficiency of rice genotype (NIA-20/A). The study was planned in complete randomized block design (RCBD) with three replications. Three rates of N (90, 120, 150 kg ha^{-1}) and nine rates of P_2O_5 (23, 30, 40, 45, 60, 70, 75, 90, 110 kg ha^{-1}) were arranged into 4:1, 4:2 and 4:3 N: P_2O_5 ratios to formulate 10 treatments including control. All treatments were fertilized with same dose of 25 kg K_2O and 10 kg Zn ha^{-1}.

Results Analysis of variance revealed that addition of N and P_2O_5 in various ratios significantly ($p<0.05$) influenced the yield, yield attributes and nutrient efficiency related parameters. The highest number of tillers per hill (17), panicle length (25 cm), 100-grain weight (3.33 g), paddy yield (4785 kg ha^{-1}), total N uptake (103 kg ha^{-1}), N harvest index (66%), total N recovery (57.4%), N utilization efficiency (22.2 kg kg^{-1}) and maximum profit (Rs. 47318 ha^{-1}) were recorded at 120-90 kg N-P_2O_5 ha^{-1}. While maximum plant height (107.1 cm) and biological yield (14258 kg ha^{-1}) were produced at 150 kg N + 75 kg P_2O_5 ha^{-1}. Furthermore, total P recovery (29.7%), total P uptake (18.3 kg ha^{-1}) and P utilization efficiency (63.5 kg kg^{-1}) were noticed higher at 150-40 kg N-P_2O_5 ha^{-1}.

Conclusion Rice genotype 'NIA-20/A' performed efficiently at 120 kg N plus 90 kg P_2O_5 ha^{-1} (4:3 - N:P_2O_5) where highest paddy yield, net production value and profit were obtained. Hence, this combination could be suggested as the most balanced and economical fertilizer level for optimum paddy yield of rice.

INTRODUCTION

Rice (*Oryza sativa* L.) being an important cereal crop is known for cultivation under a wide range of agro ecological zones around the globe. In Pakistan, it is an exportable item holding second position as staple food crop. It was cultivated on area of 2.89 million hectares with total production of 7.01 million tons during 2014-15. Its share in value addition in agriculture and GDP was 3.2 and 0.7%, respectively (Anonymous 2014-15)

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Nitrogen (N) and phosphorus (P) are two essential plant macronutrients; nevertheless most of Pakistani soils are deficient in these elements (Ahmad et al. 1999). Nitrogen is involved in many plant compounds such as proteins, chlorophyll, enzymes, hormones, alkaloids and vitamins, but its excess delays maturity and unnecessarily prolongs vegetative growth duration (Brady and Weil 2008). Nitrogen is a key element for rice production and is generally applied under flooded conditions where its efficiency is seriously low. Its major losses in paddy fields occur due to NH_4^+ volatilization, besides other N escaping mechanisms i.e. nitrification, denitrification, leaching and immobilization (Zia et al. 1988). Therefore, judicious and timely application of nitrogenous fertilizers according to crop requirement is imperative for N utilization efficiency. Phosphorus is a vital constituent of major biomolecules such as DNA, RNA, ATPs, phosphate esters and phospholipids (Marschner 2012). More than 90% Pakistani soils hold moderate to severe P deficiency resulting in low crop harvests (Aslam et al. 2009). Phosphatic fertilizers used in agriculture to overcome native P deficiency are derived from non-renewable phosphate rock (Filippelli 2011). The role of P in increasing rice production is well recognized. For instance, addition of phosphorus in rice tends to increase number of tillers per hill, number of grains per panicle, grain weight and ultimately paddy yield (Khan and Imtiaz 2013).

The prime constraints for low rice yield include low responsive genotypes and imbalance use of fertilizers (Mondal 2011). Balanced fertilization through appropriate application techniques is a promising strategy to sustain crop yields, restore soil fertility and to improve fertilizer use efficiency (Khan and Imtiaz 2013). The importance of balanced fertilization (i.e. the nutrient concoction which gives the optimum cost-effective return) for sustainable productivity and maintaining soil fertility is highly evident (Anonymous 2000). Nitrogenous fertilizer addition is preferred by growers owing to their quick plant response, relatively low cost and wide spread availability. Response of N application to crops would be reduced when applied on soils deficient in P (Senigagliesi et al. 1983). However, wise management of both nutrients can cause marked increase in crop yield (Abbas et al. 2016a).

The response of a genotype depends on environment while rhizospheric environment depends on soil nature and nutrient addition. Currently, world is facing the shortage of major fertilizer especially N and P mainly due to finite phosphate reserves, geopolitics, energy crises, price hiking and non-accessibility at critical crop phase (Dawson and Hilton 2011). Moreover, genotypes behave differentially under variable fertilizer inputs. For that reason, their nutritional requirements must be investigated for obtaining higher production. The present experiment was therefore, planned to devise balanced and optimum fertilizer dose of N and P to exploit maximum yield potential and fertilizer use efficiency by the rice genotype 'NIA-20/A' under the agro-climatic condition of Sindh, Pakistan.

MATERIALS AND METHODS

Experimental set up and crop management

A field experiment was carried out during Kharif, 2015 at the experimental farm of NIA Tandojam [25.42557N/68.54060E] to evaluate the impact of different N and P_2O_5 doses on paddy yield, nutrient accumulation and nutrient use efficiency by the newly evolved rice genotype 'NIA-20/A'. Soil samples (0-15 cm layer) were randomly collected from experimental area and then a composite soil sample was subjected to analysis for various soil physical and chemical characteristics (Table 1). Three levels of N (90, 120 and 150 kg ha^{-1}) and nine levels of P (23, 30, 40, 45, 60, 70, 75, 90 and 110 kg ha^{-1}) were arranged into 4: 1, 4: 2 and 4: 3 N: P_2O_5 ratios to formulate 10 treatment combinations including control (unfertilized). The trial was laid out following randomized complete block design having three replications. All treatments were fertilized with a constant dose of 25 kg K_2O and 10 kg Zn ha^{-1}. The required quantities of P_2O_5 and K_2O were applied at the time of nursery transplanting, whilst the N was applied in three equal splits i.e. at transplanting, tillering and panicle initiation stages. Zinc was top dressed on soil surface after two weeks of transplanting in order to minimize antagonistic effect of Zn on P absorption. One month old rice nursery was transplanted into individual plots (4 m × 4 m) having two plants per hill with inter row and inter plant spacing of 20 cm. The required agronomic practices i.e. irrigation; weeding; spraying etc. were uniformly adopted to all treatments throughout the crop season. The crop was harvested at maturity, separated into paddy and straw and data was recorded regarding yield and yield related attributes.

Plant analysis and other nutrient efficiency relations

The plant material (paddy and straw) was oven dried at 70 ºC for 48 hours and then ground using Thomas Wiley's mill (3383L10, Thomas Scientific, USA). The ground samples (0.1 g) were digested according to the method of McGill and Figeiredo (1993) using sulfuric acid and hydrogen peroxide. The digested samples were analyzed for total N using fully automated distillation apparatus (2200 Kjeltic, FOSS, UK) following method of Jackson (1962), while total P concentration was determined at 470 nm using a

Table 1 Selected physico-chemical characteristics of experimental site (0-15 cm surface layer)

Soil characteristics	**Unit**	**Value**	**Reference**
Physical characteristics			
Sand	%	18.27	Bouyoucos (1962)
Silt	%	40.50	~
Clay	%	41.23	~
Textural class		Silty clay	~
Chemical characteristics			
pH $_{(1:2.5)}$		7.15	Mclean (1982)
EC $_{(1:2.5)}$	dS m^{-1}	0.99	Richards (1954)
Organic matter	%	0.72	Nelson and Sommers (1982)
Total Organic carbon	%	0.41	~
Oxidizable Organic Carbon	%	0.32	~
Kjeldahl's nitrogen	%	0.06	Jackson (1962)
AB-DTPA extractable P	mg kg^{-1}	3.11	Soltanpour and Workman (1979)
AB-DTPA extractable K	mg kg^{-1}	191.77	~

double beam spectrophotometer (U-2900UV/VIS, Hitachi, Japan) following protocol as described by Estefan et al. (2013).

Following formulae were used to calculate nutrient efficiency related parameters i.e. nutrient uptake (kg ha^{-1}), nutrient harvest index (%), total nutrient recovery (%) and nutrient utilization efficiency (kg kg^{-1}).

- *Nutrient Uptake (kg ha^{-1}):* [Yield (kg ha^{-1}) × Nutrient concentration in plant (%)] / 100
- *Total Nutrient Uptake (kg ha^{-1}):* Nutrient uptake by paddy + Nutrient uptake by straw
- *Nutrient Harvest Index (%):* (Nutrient uptake by paddy / Total nutrient uptake) × 100
- *Total Nutrient Recovery (TNR, %):* [(Nutrient $uptake_{treatment}$ - Nutrient $uptake_{control}$) / Nutrient applied (kg ha^{-1})] × 100
- *Nutrient Utilization Efficiency (kg kg^{-1}):* [($Yield_{treatment}$ - $Yield_{control}$) / Nutrient applied]

Statistical analysis

The collected data for each parameter was subjected to analysis of variance (ANOVA) and correlation coefficients were determined using computer based software STATISTIX 8.1® [Analytical Software, Inc., Tallahassee, FL, USA]. The differences among treatment means were separated employing least significant difference test (Steel et al. 1997).

RESULTS AND DISCUSSION

Yield and yield related attributes

Various levels of N and P combined into 4: 1, 4: 2 and 4:3 ratios greatly influenced the yield and yield related attributes i.e. number of tillers per hill, panicle length and 100-grains weight. Data presented in Table 2 revealed that plant height was increased significantly (p<0.05) with gradual increase in P at each N level. The tallest rice plants (107.1 cm) were produced in plots fertilized with 150-75 kg N-P_2O_5 ha^{-1} while in control plots, average plant height was 82.9 cm. Total number of tillers per hill was increased considerably at each N level with successive increment in P_2O_5 rates (Table 2). The maximum (17) number of tillers per hill was found in treatment having N-P_2O_5 at the rate of 120-90 kg ha^{-1}, which was 44% more than control. Almost similar increasing trend was noticed in case of panicle length. Fertilized plots produced significant higher panicle length as compared to unfertilized (control) plots. The treatment with 120-90 kg N-P_2O_5 ha^{-1} illustrated greater panicle length (25 cm) showing 37% increase over control. Moreover, 100-grains weight of rice genotype was also significantly (p<0.05) affected with varying rates of N and P fertilizers. 100-grains weight increased linearly up to 120-90 kg N-P_2O_5 ha^{-1}, showing value of 3.33 g which was statistically different from all other treatments. Control treatment produced 100-grains weight of 1.58 g, which was 53% less than 100-grains weight (3.33 g) of plot receiving 120 kg N and 90 kg P_2O_5 ha^{-1}. The positive correlation was observed between paddy yield and number of tillers per hill (r = 0.43, p<0.05), panicle length (r = 0.81, p<0.01) and 100-grain weight (r = 0.83, p<0.01). Adequate supply of N alters hormonal balances in plant body resulting in excessive shoot growth at the expense of roots (Lea and Miflin 2011). Similarly, increase in plant height with corresponding addition of N may be due to improved vegetative growth (Manzoor et al. 2006). According to Matsua et al. (1995) balance supply of N and P is indispensable to facilitate better nutrient absorption by rice plants for productive tillering. Abundance of N favored cell division and cell enlargement which consequently led to better panicle development and number of grains per panicle (Sahar and Burbey, 2003; Zaidi and Tripathy 2007). Increase in grain weight with subsequent N and P addition tended to augment

Table 2 Influence of various combinations of N and P fertilizers on plant height, number of tillers per hill, panicle length and 100-grain weight of rice genotype 'NIA-20/A' under field conditions

Treatments (N: P_2O_5 kg ha^{-1})	Plant height (cm)	Number of tillers $hill^{-1}$	Panicle length (cm)	100-grains weight (g)
Control	82.9 (-)*e	09 (-) e	15.7 (-) d	1.58 (-) g
90-23 (4:1)	92.8 (11) d	12 (25) d	16.5 (05) d	2.47 (36) f
90-45 (4:2)	92.7 (11) d	13 (31) cd	20.5 (24) c	2.70 (41) e
90-70 (4:3)	95.9 (14) cd	15 (40) bc	22.1 (29) bc	2.78 (43) de
120-30 (4:1)	93.1 (11) d	14 (35) c	23.9 (35) ab	2.89 (45) c
120-60 (4:2)	99.9 (17) bc	15 (40) bc	22.9 (32) abc	2.92 (46) c
120-90 (4:3)	104.2 (20) ab	17 (44) a	25.0 (37) a	3.33 (53) a
150-40 (4:1)	103.5 (20) ab	14 (35) c	23.4 (33) ab	2.87 (45) cd
150-75 (4:2)	107.1 (23) a	15 (40) bc	24.5 (36) ab	2.90 (46) c
150-110 (4:3)	105.4 (21) ab	16 (41) ab	24.6 (36) ab	3.07 (49) b
$LSD_{0.05}$	6.2704	1.1651	2.7421	0.0992

Treatment means sharing same letter(s) in the same column indicates non-significant differences
*Values in parenthesis indicate % increase over control

photosynthetic activity ensuring plenty of assimilates during grain filling (Abbas et al. 2016b).

An overview of data presented in Table 3 revealed that paddy yield, straw yield and biological yield of rice genotype were influenced significantly ($p<0.05$) under various combinations of N and P levels. Paddy yield increased linearly up to the level of 90 kg N ha^{-1}, however further addition of N beyond this level did not showed any positive response. Control treatment produced least paddy yield of 2122 kg ha^{-1}. The treatment where N and P were integrated at the rate of 120 and 90 kg ha^{-1} exhibited the highest paddy yield (4785 kg ha^{-1}) which was 56% more over control. Addition of 40, 75 and 110 kg P_2O_5 ha^{-1} along with constant level of 150 kg N ha^{-1}, produced paddy yield of 4664, 4535 and 4606 kg ha^{-1}, respectively which were statistically identical to paddy yield produced at 120-90 kg N-P_2O_5 ha^{-1}. The straw yield was strongly influenced with the addition of N and P into various ratios (Table 3). Straw yield increased with the successive addition of P at each N level. Numerically, the least straw yield (4265 kg ha^{-1}) was observed in control plots, while the highest straw yield (9723 kg ha^{-1}) was recorded in plots receiving 150 kg N + 75 kg P_2O_5 ha^{-1}, showing an increase of 56% over control. Likewise, an identical trend to straw yield was also illustrated in case of biological yield with minimum (6387 kg ha^{-1}) in control and maximum (14258 kg ha^{-1}) in treatment receiving 150-75 kg N-P_2O_5 ha^{-1}. The significant and highly positive correlation between paddy yield and total N uptake ($r = 0.90$, $p<0.01$) and total P uptake ($r = 0.93$, $p<0.01$) suggested a direct relationship between nutrient acquisition and their internal utilization. Sufficient P nutrition substantially contributes in better development of plant root system tailoring more nutrients and water absorption which ultimately influenced the crop yield. At elevated N and P levels, the higher paddy yield is reported by Khan *et al.* (2008). Enhancing straw yield with corresponding addition of N was due to the increased vegetative growth which was the most important function attributed to N (Ma et al. 2004). Brink et al. (2001) has also reported an additive effect of P on plant growth when combined with N in balance proportion.

Nutrient uptake and efficiency relations

Both N and P uptakes by rice genotype 'NIA-20/A' was markedly affected under varying ratios of N: P_2O_5 as revealed by data in Table 4. Total N uptake showed positive response up to 120 kg N ha^{-1} with non-significant effects by the addition of further N beyond the former level. The highest mean total N uptake (103 kg ha^{-1}) was recorded at 120-90 kg N-P_2O_5 ha^{-1}, which was statistically at par with N uptake of 95.8, 101.8 and 97.5 kg ha^{-1} recorded at 150 kg N ha^{-1} along with 40, 75 and 110 kg P_2O_5 ha^{-1}, respectively. The unfertilized treatment unveiled minimum value of total N uptake (34.1 kg ha^{-1}) showing 67% decrease as compared to treatment with maximum N uptake. Total P uptake (paddy + straw) by the rice plants varied significantly ($p<0.05$) as P_2O_5 rates were increased from 0-110 kg ha^{-1} (Table 4). The magnitude of difference with respect to total P uptake changed from 6.8 kg ha^{-1} in control to 18.7 kg ha^{-1} (64% more over control) in treatment fertilized with 150-40 kg N-P_2O_5 ha^{-1}. Nitrogen uptake in paddy and straw is greatly coincided i.e. increase with increase in N addition. Nutrients applied in appropriate proportion facilitated their absorption by the plants (Mandal et al. 1999). Hossain et al. (2005) reported that subsequent addition of N at each level assisted plants to tailor N uptake. Moreover, Khan et al. (2010) concluded that total N uptake escalated from 23.3-114.7 kg ha^{-1} as N

Table 3 Paddy, straw and biological yield of rice genotype 'NIA-20/A' as affected by N and P rates combined in different ratios

Treatments ($N-P_2O_5$ kg ha^{-1})	**Yield (kg ha^{-1})**		
	Paddy	**Straw**	**Biological**
Control	2122 (-)*e	4265 (-) i	6387 (-) h
90-23 (4:1)	2816 (25) d	4960 (14) h	7943 (20) g
90-45 (4:2)	2983 (29) d	5882 (27) g	8698 (27) f
90-70 (4:3)	3401 (38) c	6124 (30) g	9525 (33) e
120-30 (4:1)	3462 (39) c	6490 (34) f	9952 (36) e
120-60 (4:2)	4515 (53) b	6899 (38) e	11414 (44) d
120-90 (4:3)	4785 (56) a	8489 (50) d	13274 (52) c
150-40 (4:1)	4664 (54) ab	8801 (52) c	13465 (53) bc
150-75 (4:2)	4535 (53) b	9723 (56) a	14258 (55) a
150-110 (4:3)	4606 (54) ab	9245 (54) b	13851 (54) ab
$LSD_{0.05}$	218.27	283.39	447.54

Treatment means sharing same letter (s) in the same column indicates non-significant differences
*Values in parenthesis indicate % increase over control

Table 4 Nitrogen and phosphorus uptake by paddy and straw of rice genotype 'NIA-20/A' under fertilization with different combinations of N and P fertilizers

Treatments ($N-P_2O_5$ kg ha^{-1})	**Nitrogen uptake (kg ha^{-1})**			**Phosphorus uptake (kg ha^{-1})**		
	Paddy	**Straw**	**Total**	**Paddy**	**Straw**	**Total**
Control	14.2 (-)*e	19.9 (-) e	34.1 (-) d	4.4 (-) f	2.4 (-) d	6.8 (-) g
90-23 (4:1)	28.0 (49) d	29.8 (33) bcd	57.8 (41) c	7.2 (39)de	3.2 (25) d	10.5 (35) ef
90-45 (4:2)	41.9 (66) c	23.7 (16) de	65.6 (48) bc	6.7 (34) e	3.3 (26) d	10.0 (32) f
90-70 (4:3)	42.5 (67) c	23.8 (17) de	66.3 (49) bc	6.9 (36)de	4.4 (45) c	11.3 (40) de
120-30 (4:1)	40.4 (65) c	25.9 (23) cde	66.3 (49) bc	7.7 (43) d	4.5 (46) c	12.2 (44) d
120-60 (4:2)	40.8 (65) c	36.4 (45) ab	77.2 (56) b	10.9 (60) b	4.6 (48) c	15.5 (56) c
120-90 (4:3)	67.8 (79) a	35.2 (44) abc	103.0 (67) a	10.5 (58) b	5.8 (58) ab	16.3 (58) bc
150-40 (4:1)	54.7 (74) b	41.1 (52) a	95.8 (64) a	12.9 (66) a	5.8 (58) ab	18.7 (64) a
150-75 (4:2)	61.1 (77) ab	40.7 (51) a	101.8 (67) a	9.3 (53) c	6.7 (64) a	16.0 (57) bc
150-110 (4:3)	53.3 (73) b	44.2 (55) a	97.5 (65) a	11.1 (61) b	5.7 (58) b	16.8 (60) b
$LSD_{0.05}$	10.01	9.47	13.24	0.889	0.929	1.167

Treatment means sharing same letter(s) in the same column indicates non-significant differences
*Values in parenthesis indicate % increase over control

was increased from 0-150 kg N ha^{-1}.

Nutrient efficiency relations i.e. nutrient harvest index (%), recovery efficiency (%) and utilization efficiency (kg kg^{-1} of applied nutrient) were calculated in order to test out the efficacy of applied nutrients under the respective biogeochemical system. The data pertaining to nutrient efficiency relations showed significant ($p<0.05$) disparities under different N: P_2O_5 ratios (Table 5). The average harvest index was more at lower levels of N and decreased or marginally increased at higher levels of N in combination with P_2O_5. The highest N harvest index (66%) was observed at 120-90 kg $N-P_2O_5$ ha^{-1}, which was statistically at par with 63.9, 64.0, 61.4, 57.2 and 60.2% recorded at 90-45, 90-70, 120-30, 150-40 and 150-75 kg $N-P_2O_5$ ha^{-1}, respectively. The greater P harvest index (69.9%) was recorded in plots having 120 kg N + 60 kg P_2O_5 ha^{-1}, showing statistical identity with 69.1, 67.1, 68.7 and 66.1% noticed at 90-23, 90-45, 150-40 and 150-110 kg $N-P_2O_5$ ha^{-1}, respectively. Positive correlation was observed between total N uptake and N harvest index (r = 0.47, $p<0.01$). Hasanuzzaman et al. (2012) reported the maximum harvest index (51.75%) at 160 kg N ha^{-1} followed by 46% at 120 kg N ha^{-1}. Rice genotypes having higher values of nutrient harvest index explained their ability to accumulate more N or P in paddy as compared to straw.

Total (paddy + straw) recoveries of both N and P were significantly ($p<0.05$) influenced when P_2O_5 rates were increased at each N level (Table 5). The overall magnitude of N recovery improved with corresponding increase in N rates. The plots fertilized with 120-90 kg $N-P_2O_5$ ha^{-1} exhibited higher value of N recovery (57.4%), while minimum (26.3%) was noticed in treatment with 90-23 kg $N-P_2O_5$ ha^{-1}.

Table 5 Effect of various combinations of N and P fertilizers on harvest index, nutrient recovery and utilization efficiency of rice genotype 'NIA-20/A' under field conditions

Treatments (N-P_2O_5 kg ha^{-1})	Harvest index (%)		Nutrient recovery (%)		Utilization efficiency (kg kg^{-1})	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Control	41.8 e	64.3 bcd	00.0 d	00.0 i	0.0 g	0.0 f
90-23 (4:1)	47.9 de	69.1 ab	26.3 c	15.9 bc	7.7 f	30.2 d
90-45 (4:2)	63.9 ab	67.1 abc	35.0 bc	7.0 gh	9.6 e	19.1 e
90-70 (4:3)	64.0 ab	61.6 de	35.8 bc	6.4 h	14.2 d	18.3 e
120-30 (4:1)	61.4 abc	63.3 cde	26.9 c	18.0 b	11.2 e	44.7 b
120-60 (4:2)	52.4 cd	69.9 a	35.9 bc	14.5 cd	19.9 b	39.9 c
120-90 (4:3)	66.0 a	64.4 bcd	57.4 a	10.6 ef	22.2 a	29.6 d
150-40 (4:1)	57.2 abcd	68.7 ab	41.1 b	29.7 a	16.9 c	63.5 a
150-75 (4:2)	60.2 abc	58.2 e	45.1 ab	12.3 de	16.1 c	32.2 d
150-110 (4:3)	54.6 bcd	66.1 abcd	42.3 b	9.1 f g	16.6 c	22.6 e
$LSD_{0.05}$	9.76	5.08	12.46	2.61	1.69	4.69

Treatment means sharing same letter(s) in the same column indicates non-significant differences

Phosphorus recovery showed decreasing trend with successive increase in P rates at each N level. The higher P recovery (29.7%) was achieved at 40 kg P_2O_5 along with 150 kg N ha^{-1} followed by 18.0 and 15.9 % recorded at 30 kg P_2O_5 + 120 kg N and 23 kg P_2O_5 + 90 kg N ha^{-1}, respectively. Positive correlation was found between total N recovery and N use efficiency (r = 0.83, $p<0.01$) and total P recovery and P use efficiency (r = 0.93, $p< 0.01$). Higher level of P application resulted in excess of the requirement of plants thereby reducing P recovery (Awan et al. 2007). Recoveries of N and P can be improved employing their appropriate ratios according to crop requirements (Abbas et al. 2016b).

Nutrient utilization efficiency is the economical production of crops per unit of applied nutrient. The data regarding utilization efficiencies of both N and P at various ratios of applied N and P_2O_5 is depicted in Table 5. The N utilization efficiency increased up to certain level of N and tended to decrease at higher N levels. The highest N use efficiency (22.2 kg kg^{-1} N) was achieved at 120-90 kg N-P_2O_5 ha^{-1} in the ratio of 4: 3. Phosphorus utilization efficiency illustrated a decreasing trend with corresponding increase in P_2O_5 rates at each N level. The maximum (63.5 kg kg^{-1} P) and minimum (19.1 kg kg^{-1} P) values of P use efficiency were recorded at N-P_2O_5 combinations of 150-40 and 90-45 kg ha^{-1}, respectively (Table 5). The positive correlation between paddy yield and N use efficiency (r = 0.94, $p<0.01$) and P use efficiency (r = 0.61, $p<0.01$) explained the ability of genotype to produce higher yield per unit of applied nutrients. Nitrogen use efficiency could be improved significantly by corresponding increase in P rates at each N level reflecting strong synergistic relationship between both elements (Khan et al. 2010). In contrast, Yaseen and Malhi (2009) documented that nutrient use efficiency reduced substantially with additional increment in respective element.

Economic analysis

Economic feasibility of fertilizers is an excellent criterion to estimate the value of commodity produced and net profit generated (Abbas et al. 2016a). Moreover, there is lack of guidance and production policies for farmers to make decision about their production plans with the exception of price index. The economic analysis i.e. net production value, fertilizer cost, profit and value cost ratio (VCR) at every treatment is presented in Table 6. The maximum production value (Rs. 67835 ha^{-1}) as well as profit (Rs. 47318 ha^{-1}) were obtained from treatment having N-P_2O_5 combination of 120-90 kg ha^{-1} while treatment with 90 kg N + 23 kg P_2O_5 ha^{-1} produced minimum production value and profit of Rs. 17340 and Rs. 7719 ha^{-1}. Numerically, the higher value of VCR (3.74) was calculated from treatment where 150 kg N + 40 kg P_2O_5 ha^{-1} was applied followed by 3.52 and 3.31 gained at 120-60 and 120-90 kg N-P_2O_5 ha^{-1}, respectively (Table 6). The VCR at different N-P_2O_5 combinations increased up to certain level of nutrients beyond that rate it tended to decrease or show marginal increase indicating that addition of nutrients either below or above the optimum level was neither economical nor cost effective.

CONCLUSION

Rice genotype 'NIA-20/A' performed efficiently at P_2O_5 of 120-90 kg ha^{-1} with highest paddy yield, number of tillers per hill, panicle length, 100-grain weight, total N uptake, total N recovery, N utilization efficiency, net production value and profit. Hence, 120–90 kg N–P_2O_5 ha^{-1} (4: 3 N–P_2O_5 ratio) is

Table 6 Value cost ratios (VCR) and net income (Rs) generated by rice genotype 'NIA-20/A' under various combinations of soil applied N and P fertilizers under field conditions

Treatments (N-P_2O_5 kg ha^{-1})	Net production value (Rs) (Paddy)*	Fertilizer cost Rs)**	Profit (Rs)	VCR
Control	(–)	(–)	(–)	(–)
90-23 (4:1)	17340	9621	7719	1.80
90-45 (4:2)	21523	12472	9051	1.73
90-70 (4:3)	31953	15712	16241	2.03
120-30 (4:1)	33490	12741	20749	2.63
120-60 (4:2)	58555	16629	41926	3.52
120-90 (4:3)	67835	20517	47318	3.31
150-40 (4:1)	60703	16251	44452	3.74
150-75 (4:2)	60325	20786	39539	2.90
150-110 (4:3)	62090	25322	36768	2.45

*Paddy @ Rs 1000 40 kg^{-1}, **Urea @ Rs 1700 bag^{-1}, DAP @ Rs 3650 bag^{-1}

recommended as the most balanced and economical fertilizer dose for rice genotype 'NIA-20/A' under the agro-climatic conditions of Sindh, Pakistan.

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