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Exploiting the Yield Potential of Wheat Genotype NIA-MB-2 under Different Rates of Nitrogen and Phosphorus

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Abstract

Extensive variations exist among crop species and even genotypes within species for their nutritional requirements. Therefore, formulating genotype-specific fertilizer recommendations is pivotal to achieve higher yields per unit area and sustain agricultural productivity. Field experiments were conducted at the Nuclear Institute of Agriculture (NIA), Tando Jam during two consecutive years (Rabi 2013-14 and 2014-15) in order to exploit the yield potential of wheat genotype NIA-MB-2 under different nitrogen (N) and phosphorus (P) regimes. The analysis of pooled data for both years revealed that the maximum plant height and straw yield were obtained in the treatment where N-P_2O_5 was applied at the rate of 150-110 kg ha^{-1}. The maximum spike length, no. of grains per spike, 100-grain weight, and grain yield was achieved in plots receiving 120 kg N and 90 kg P_2O_5 ha^{-1}. The highest total N and P uptake were recorded in treatment having 150-110 kg N-P_2O_5 ha^{-1}, which were statistically identical with that obtained at 120 kg N and 90 kg P_2O_5 ha^{-1}. Moreover, apparent recovery efficiency (ARE), agronomic efficiency (AE) and physiological efficiency (PE) of both nutrients were markedly affected under various N and P combinations. The economic analysis further revealed that maximum net income (USD 993 ha^{-1}) and profit (USD 798 ha^{-1}) was accrued when 120 kg N along with 90 kg P_2O_5 was applied per hectare. Hence, it may be concluded that N-P_2O_5 @ 120-90 kg ha^{-1} combined with 4:3 ratio can be the most balanced dose for the maximum economic harvest of wheat genotype NIA-MB-2.

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Introduction

Wheat (*Triticum aestivum* L.) earns a highly important spot among staple food crops and is the main source of nutrients for most of the world's population [1]. Its grain generally contains carbohydrates (60-90%), protein (10-18%), lipids (1.5-2%) and about 1% vitamins [2]. In Pakistan, wheat is a leading food grain crop and occupies the largest area under cultivation. It contributes 2.1% to GDP and 10% in value addition. During the year 2015-16, wheat was cultivated in an area of 9.26 million hectares and production stood at 25.48 million tons [3]. The average yield of wheat in developing countries like Pakistan is much below compared to the other developed countries of the world. Mineral nutrient deficiencies, especially of macronutrients nitrogen (N) and phosphorus (P) are among the leading causes that greatly limit wheat production in Pakistan.

Despite the green revolution, the food situation is precarious in most of the developing countries. About 40% additional demand of wheat at the global level is projected till 2020 [4]. Inorganic fertilizers are responsible for 40-60% of food production on most of the arable lands around the globe [5]. Imbalanced fertilization (inadequate or excessive/over fertilization) negatively affects crop quality and inhibits the expression of yield potential in many countries [6]. Generally, nutrient recovery efficiency is high where crop demand is high or if fertilizer use is relatively low. Nutrient recovery efficiency reduces substantially due to over-fertilization on soils where indigenous nutrient supply is high and having a good degree of synchrony between nutrient demand and supply [7]. Degradation of soil quality, particularly nutrient depletion is strongly related to declines in crop yields [8]. Imbalanced and insufficient use of fertilizers is the major reason for nutrient depletion [9]. Balanced fertilization has a key role in sustaining high yields and efficient use of costly fertilizers.

Both N and P influence source-sink relations directly or indirectly in cereals by influencing assimilate production and distribution [10]. Nitrogen has a central role in cell metabolism and determines plant growth by influencing leaf area development, photosynthetic efficiency and dry matter allocation to reproductive organs [11]. Phosphorus plays a pivotal role in biochemical reactions relating to carbohydrates and protein metabolism, energy transfer within cell organization, cell division, and transformation of heredity characteristics. Deficiency of P diminishes biomass accumulation in a fashion different to N and is reported to affect the number of grains and yield in wheat [12]. Because of the synergistic relationship between N and P, an adequate level of N leads to increased P absorption in plants by stimulating root growth, increasing P translocation, increasing the solubility of P fertilizers through lowering soil pH due to the absorption of NH_4^+ ion [13].

Currently, the world is facing the shortage of mineral fertilizers and this situation is worst in developing countries. Moreover, the importance of improved fertilizer use efficiency might not be underestimated, even when fertilizer supply is satisfactory. Various crop genotypes may respond differently to applied nutrients based on their genetic and agronomic traits [14, 15]. Plant growth and yield are manifestly affected when crops are fertilized with N and P either below or in excess than optimum level. Therefore, it is necessary to investigate the adequate requirements of N and P for newly evolved genotypes to realize the maximum economic harvest and increase nutrient use efficiency. Hence, the present study was proposed to exploit the yield potential of a candidate wheat genotype NIA-MB-2 under varying levels of N and P.

Materials and methods

Experiment location and soil properties

Field experiments were carried out for two consecutive years during Rabi 2013-14 and 2014-15 in the research area of the Nuclear Institute of Agriculture (NIA), Tando Jam, Pakistan (25.42557N/68.54060E). Soil samples were collected from upper 20 cm soil layer prior to the sowing of wheat and were subjected to the analysis o different physicochemical characteristics like soil texture [16], pH [17], EC [18], organic matter [19], Kjeldahl nitrogen [20] and extractable P and K [21]. Soil of experimental site was clay loam in texture (according to the USDA classification system, 21.7% sand, 42.2% silt and 36.1% clay), alkaline in reaction (pH = 7.8), and non-saline (EC_e = 2.3 dS m^{-1}), with 0.91% organic matter, 0.077% Kjeldahl N and 5.51 and 178 mg kg^{-1} AB-DTPA extractable P and K, respectively.

Experimental design and crop establishment

The experiment was carried out during both years on a fixed layout following randomized complete block design (RCBD). Three rates of nitrogen (90, 120 and 150 kg N ha^{-1}) and nine rates of phosphorus (23, 30, 40, 45, 60, 70, 75, 90 and 110 kg P_2O_5 ha^{-1}) were applied in 4:1, 4:2 and 4:3 N: P_2O_5 ratios. Ten combinations of N and P_2O_5 (90-23, 90-45, 90-70, 120-30, 120-60, 120-90, 150-40, 150-75 and 150-110 kg N-P_2O_5 ha^{-1}) along with control (without N and P) were replicated thrice. A constant dose of 60 kg K_2O per hectare was applied in all treatments. The entire required amount of K_2O and P_2O_5 was applied at sowing, while N was used in three equal splits, i.e., 1/3rd at sowing, 1/3rd after 25 days of sowing (crown root initiation stage) and 1/3rd after 60 days of sowing (jointing stage). Wheat was sown in individual plots of size 4m × 4m using single row hand drill and at an inter-row spacing of 30 cm with the seed rate of 150 kg ha^{-1}. Five irrigations viz., after 25, 60, 90, 110 and 125 days of sowing were applied to the crop. The crop was harvested at maturity, and data regarding biological and grain yield were recorded. Five plants were randomly collected from each experimental unit and were subjected to observation for various agronomic traits.

Plant analysis and nutrient relations

The straw and grain samples were oven dried at 70°C for 48 hours and subsequently ground using Thomas Wiley's mill (3383L10, Thomas Scientific, USA). About 0.5 g of ground plant material was digested in H_2SO_4 to determine the total N following modified Kjeldahl method [20]. For total P determination, samples were digested in a di-acid mixture of HNO_3: $HClO_4$ prepared in 5:1 ratio [22]. Total P in the digested material was determined following metavanadate yellow color method [23] using a double beam Spectrophotometer (U-2900UV/VIS, Hitachi, Japan).

The nutrient relations, i.e. apparent recovery efficiency, agronomic efficiency and physiological efficiency of N and P were calculated by the formulae of Fageria et al. [24].

Apparent recovery efficiency (ARE)

$$\text{ARE (\%)} = \frac{\text{Nuf} - \text{Nuc}}{\text{Na}} \times 100$$

Where N_{uf} is nutrient uptake (grain plus straw) in fertilized treatment (kg), N_{uc} is nutrient uptake (grain plus straw) in the control treatment (kg), while N_a is the amount of applied nutrients (kg), i.e. N or P_2O_5.

Agronomic efficiency (AE)

$$\text{AE (kg yield/kg nutrient applied)} = \frac{\text{GYf} - \text{GYc}}{\text{Na}}$$

Where GY_f is grain yield from fertilized treatment (kg), GY_c is grain yield from the control treatment (kg), while N_a is the amount of applied nutrients (kg), i.e. N or P_2O_5.

Physiological efficiency (PE)

$$\text{PE (kg biological yield / kg nutrient absorbed)} = \frac{\text{BYf} - \text{BYc}}{\text{Nuf} - \text{Nuc}}$$

Where BY_f is biological yield from fertilized treatment (kg), BY_c is biological yield from the control treatment (kg), N_{uf} is nutrient uptake (grain plus straw) in fertilized treatment (kg), while N_{uc} is nutrient uptake (grain plus straw) in the control treatment (kg).

Statistical analysis

The data were statistically analyzed using software STATISTIX 8.1® (Analytical Software, Inc., Tallahassee, FL, USA). Significant differences among treatment means were obtained using the Least Significant Difference (LSD) test at 5% probability level [25].

Results and discussion

As there was no significant year × treatment interaction for almost all parameters, therefore, the results in the present article were reported as an average of two years.

Plant height (cm)

The data pertaining to plant height (Table 1) indicates that application of nitrogenous and phosphatic fertilizers in different combinations significantly ($P \leq 0.05$) influenced the plant height. The magnitude of plant height varied from 80.6 cm in the control treatment to 101.2 cm in treatment fertilized with 150 kg N and 110 kg P_2O_5 ha^{-1}. According to Khan et al. [26], plant height increases significantly with the increasing rates of N and P_2O_5. Nitrogen is the constituent of multiple plant components, including chlorophyll, which is known as the heart of photosynthesis. Plant growth is markedly affected by the increased level of N that may influence the rate of photosynthesis. Generally, a significant positive interaction between nitrogen and phosphorous on plant growth has been reported [27]. The increase in plant height with the application of phosphorus and nitrogen might be due to balanced mineral nutrition. It is commonly inferred that a synergistic effect among both N and P results in stimulatig plant growth and increased absorption of these nutrients [13]. Similar results were also reported by Ahmad et al. [28], which signify a linearly increasing trend in plant height of wheat with a corresponding increase in N and P rates.

Number of productive tillers plant^{-1}

Improved yield and better crop stand might be ensured through increased number of productive tillers. The highest tiller count per plant (4.6) was recorded in case of 150-75 kg N-P_2O_5 ha^{-1}, which was statistically identical to the treatment receiving N-P_2O_5 @ 120-90 kg ha^{-1}. Whereas, least number of tillers $plant^{-1}$ (2.63) were observed in control plots. Enhanced crop growth results from better development of the root system when sufficient nutrients in a balanced proportion are available to crop [13]. Our results regarding the number of tillers per plant are the confirmation of the fact that balanced and adequate availability of nutrients leads the crops to produce more fertile tillers. These findings are same as reported by Khan et al. [26].

Spike length (cm)

Spike length is another important yield contributing parameter because longer spikes contain more number of grains in comparison to shorter spikes which affect crop yield considerably [29]. In the present study, spike length varied significantly ($P \leq 0.05$) by the application of various fertilizer combinations (Table 1). Numerically the highest average spike length (13.4 cm) was observed in treatment receiving N and P_2O_5 at the rate of 120 and 90 kg per hectare which was statistically at par with the values of 13.22 and 13.02 cm recorded in treatments having 150-110 and 150-75 kg N-P_2O_5 ha^{-1}, respectively, while, control plots produced shorter spikes (9.72 cm). Improved spike length at 120-90 kg N-P_2O_5 ha^{-1} might be due to the appropriate and adequate availability of nutrients to plants at this combination. A number of scientists have reported substantial variations in spike length of wheat grown under different combinations of N and P levels [26, 30, 31].

Number of grains spike^{-1}

It is evident from the data that different combinations of N and P fertilizer influenced significantly ($P \leq 0.05$) the no. of grains per spike (Table 1). The highest no. of grains per spike (65.27) were recorded in plots where fertilizer was applied at the rate of 120 kg N and 90 kg P_2O_5 ha^{-1}, while control plots produced the least no. of grains $spike^{-1}$ (45.93). The application of nutrients in balanced proportion is known to enhance spikelet count per spike and eventually no. of grains $spike^{-1}$, leading to improved crop yield [32, 33].

100-grain weight (g)

The 100-grain weight is a decisive agronomic trait related positively to grain yield, i.e. higher the 100-grain weight, more will be grain yield. Data revealed that various combinations of N and P influenced significantly ($P \leq 0.05$) the 100-grain weight (Table 2). The highest 100-grain weight (4.03 g) was noticed in plots supplied with 120 kg N + 90 kg P_2O_5 ha^{-1}, followed by 3.84 g at 150-75 kg N-P_2O_5 ha^{-1}. The plots without external addition of either N or P_2O_5 (control) yielded minimum 100-grain weight (3.17 g) which was significantly lower than all other fertilizer treatments. Imtiaz et al. [34] has also observed a distinct increase in 100-grain weight of wheat genotype SI-91195 with the successive increment of N and P_2O_5 rates that might be due to their influence on plant growth, seed formation, and development.

Table 1 Mean values (average of 2 years) of various agronomic parameters for wheat genotype NIA-MB-2 under fertilization with different N and P combinations.

Treatments (N-P_2O_5 kg ha^{-1})		Plant height (cm)	No. of tillers $plant^{-1}$	Spike length (cm)	No. of grains $spike^{-1}$
Control		80.60 d	2.63 e	9.72 e	45.93 c
90-23	(4:1)	89.57 c	3.25 de	12.17 d	49.60 c
90-45	(4:2)	90.13 c	3.52 cd	12.45 cd	51.50 bc
90-70	(4:3)	90.30 c	4.20 abc	12.53 cd	56.63 abc
120-30	(4:1)	92.00 c	3.68 cd	12.78 bcd	59.02 ab
120-60	(4:2)	96.53 b	3.87 bcd	13.00 abc	60.67 a
120-90	(4:3)	97.43 b	4.60 ab	13.47 a	65.27 a
150-40	(4:1)	98.40 ab	4.52 ab	12.80 bcd	62.50 a
150-75	(4:2)	99.83 ab	4.63 a	13.02 abc	60.67 a
150-110	(4:3)	101.23 a	4.10 abc	13.22 ab	61.23 a
$LSD_{0.05}$		3.73	0.76	0.67	8.80

Treatment means sharing same letter (s) in the same column indicate non-significant difference from each other at 5% level of significance.

Table 2 Influence of different levels of N and P fertilizers on the mean values (average of 2 years) of yield parameters for wheat genotype NIA-MB-2.

Treatments (N-P_2O_5 kg ha^{-1})		100-grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Biological yield (kg ha^{-1})
Control		3.17 g	2187.3 d	3229.3 d	5417 f
90-23	(4:1)	3.43 f	2858.3 c	5479.3 c	8338 e
90-45	(4:2)	3.57 ef	3001.7 c	5679.7 c	8681 e
90-70	(4:3)	3.61 de	3102.3 c	6524.3 b	9627 d
120-30	(4:1)	3.64 cde	3400.3 c	7137.0 ab	10538 c
120-60	(4:2)	3.79 bc	4109.0 b	7022.7 ab	11131 bc
120-90	(4:3)	4.03 a	4776.3 a	7482.7 a	12259 a
150-40	(4:1)	3.76 bcd	4493.7 ab	7358.3 a	11852 ab
150-75	(4:2)	3.84 b	4744.3 a	7269.7 a	12014 a
150-110	(4:3)	3.82 b	4352.3 ab	7529.0 a	11881 ab
$LSD_{0.05}$		0.18	581.44	710.52	807.91

Treatment means sharing same letter (s) in the same column indicate non-significant difference from each other at 5% level of significance.

Nutrient fertilization in the balanced ratio may result in the production of heavier wheat grains [35].

Grain and straw yield (kg ha^{-1})

Both grain and straw yield were significantly ($P \leq 0.05$) influenced by subsequent increasing levels of N and P_2O_5 in different combinations (Table 2). The highest grain yield (4776 kg ha^{-1}) was produced by the plots fertilized with 120 kg N + 90 kg P_2O_5 ha^{-1}, which was statistically at par with grain yield (4744 kg ha^{-1}) recorded at 150-75 kg N-P_2O_5 ha^{-1}, while minimum grain yield (2187 kg ha^{-1}) was observed in control plots (Table 2). The increase in grain yield with the application of 120 kg N in combination with 90 kg P_2O_5 ha^{-1} might be due to the elevated performance of yield driving attributes, i.e. number of spikelets per spike, spike length, 100-grain weight etc. which were highest at this level in comparison to other treatments [36]. The balanced addition of N and P has a stimulatory effect on the expansion of better root system and grain formation [37]. On the other hand, adequate supply of N enhances protein contents in both foliage and grains of cereals [38]. Similar increasing trend in wheat grain yield by the addition of N and P_2O_5 in the ratio of 4:3 was reported by Khan et al. [26, 39].

Different ratios of N and P_2O_5 significantly ($P \leq 0.05$) affected the production of straw yield (Table 2). Straw yield increased linearly with the addition of nitrogen and phosphorus levels. Numerically the highest straw yield of 7529 kg per hectare was obtained in plots supplemented with N-P_2O_5 at the the rate of 150-110 kg ha^{-1}, while least straw yield was produced by the control plots (3229 kg ha^{-1}). Total biomass produced (biological yield) was also influenced significantly ($P \leq 0.05$) with the addition of various ratios of nitrogen and phosphorus. The treatment with 120-90 kg N-P2O5 per hectare

Table 3 Nitrogen and phosphorus uptake in the grain and straw of wheat genotype NIA-MB-2 at different combinations of N and P fertilizers (means are averaged over 2 years).

Treatments		Nitrogen uptake (kg ha^{-1})			Phosphorus uptake (kg ha^{-1})		
(N-P_2O_5 kg ha^{-1})		Grain	Straw	Total	Grain	Straw	Total
Control		43.95 d	6.71 f	50.65 e	3.01 g	1.49 f	4.51 f
90-23	(4:1)	66.85 c	13.99 e	80.84 d	5.61 f	2.90 e	8.51 e
90-45	(4:2)	70.13 c	15.49 de	85.62 d	8.03 de	3.75 de	11.77 d
90-70	(4:3)	72.62 c	18.16 d	90.78 d	11.16 c	5.30 b	16.46 c
120-30	(4:1)	76.20 c	25.62 c	101.82 c	6.92 e	3.88 cd	10.80 d
120-60	(4:2)	88.42 b	29.93 b	118.35 b	11.38 c	4.69 bc	16.07 c
120-90	(4:3)	102.03 a	31.42 ab	133.45 a	14.45 ab	7.37 a	21.82 a
150-40	(4:1)	102.76 a	32.75 a	135.50 a	8.67 d	3.14 de	11.81 d
150-75	(4:2)	99.59 a	31.67 ab	131.26 a	13.23 b	5.32 b	18.55 b
150-110	(4:3)	101.26 a	32.28 ab	133.54 a	15.73 a	7.57 a	23.31 a
$LSD_{0.05}$		9.71	2.73	10.39	1.31	0.94	1.64

Treatment means sharing same letter (s) in the same column indicate non-significant difference from each other at 5% level of significance.

Table 4 Various nutrient relations (values are an average of 2 years) for wheat genotype NIA-MB-2 as influenced by different combinations of N and P fertilizers.

Treatments (N-P_2O_5 kg ha^{-1})		ANRE (%)	APRE (%)	ANE (kg kg^{-1} N)	APE (kg kg^{-1} P)	PNE (kg kg^{-1} N)	PPE (kg kg^{-1} P)
Control		-	-	-	-	-	-
90-23	(4:1)	33.54 e	17.39 bc	7.45 d	29.17 bcd	109.68 ab	773.31 b
90-45	(4:2)	38.86 de	16.14 c	9.05 d	18.09 de	100.31 b	466.09 cd
90-70	(4:3)	44.58 cd	17.07 bc	10.15 cd	13.07 ef	110.83 a	356.81 d
120-30	(4:1)	42.64 de	20.97 a	10.11 cd	40.43 b	104.99 ab	822.05 a
120-60	(4:2)	56.41 b	19.27 ab	16.01 b	32.02 bc	84.32 c	500.54 c
120-90	(4:3)	69.33 a	19.23 ab	21.58 a	28.77 bcd	82.72 c	398.12 d
150-40	(4:1)	56.56 b	18.3 abc	15.38 b	57.66 a	76.01 cd	893.31 a
150-75	(4:2)	53.74 bc	18.7 abc	17.04 ab	34.09 b	82.29 c	474.21 cd
150-110	(4:3)	55.25 b	17.09 bc	14.43 bc	19.68 cde	78.03 cd	344.10 d
$LSD_{0.05}$		9.73	3.02	4.89	13.69	8.91	100.60

ANRE, apparent nitrogen recovery efficiency; APRE, apparent phosphorus recovery efficiency; ANE, agronomic nitrogen efficiency; APE, agronomic phosphorus efficiency; PNE, physiological nitrogen efficiency; PPE, physiological phosphorus efficiency

Treatment means sharing same letter (s) in the same column indicate non-significant difference from each other at 5% level of significance.

produced the highest biological yield (12259 kg ha^{-1}) which was statistically identical with 12014 kg ha^{-1} recorded at 150-75 kg N-P2O5 ha^{-1}. However, control treatment showed minimum biological yield of 5417 kg ha^{-1}. The pronounced effect of nitrogen in enhancing vegetative growth might be the reason behind better plant growth and straw yield with the subsequent increase in N rates [40]. Beside this, additive effect of N with P when supplied in balanced proportion also results in improved crop growth [41]. Khan et al. [39] has also reported the similar results as revealed in the present study.

Nutrients uptake (kg ha^{-1})

Total nitrogen and phosphorus uptake by the tested wheat genotype was significantly ($P \leq 0.05$) affected by the application of N and P in varying ratios. The magnitude of difference for total N uptake ranged from 50.65 to 133.54 kg ha^{-1} as N levels were increased from 0 to 150 kg ha^{-1} (Table 3). Moreover, successive increase in P_2O_5 rates at each N level considerably enhanced N-use efficiency suggesting a synergistic relationship between both nutrients. Identical findings were also reported by Van Keulen and Stol [42]. A linear increasing trend for phosphorus uptake was noticed with the corresponding application of P rates at each N level (Table 3). The highest value of total P uptake (23.3 kg ha^{-1}) was observed at 150-110 kg N-P_2O_5 ha^{-1}, which was statistically at par with 21.82 kg ha^{-1} obtained at 120 kg N + 90 kg P_2O_5 ha^{-1}. However, control treatment showed a lower value of total P uptake (4.51 kg ha^{-1}). These results are in close agreement with the results of Brink et al. [43] who stated that nutrients uptake by plants from rooting medium can be facilitated if nutrients are used in an

Table 5 Value cost ratios (VCR) and net income (USD) generated under various combinations of N and P fertilizers.

Treatments ($N-P_2O_5$ kg ha^{-1})		Net production value (USD) (wheat grain + straw)	Fertilizer cost (USD)	Profit (USD)	VCR
Control		---	---	---	---
90-23	(4:1)	326	92	234	3.55
90-45	(4:2)	379	119	260	3.19
90-70	(4:3)	458	150	308	3.06
120-30	(4:1)	579	121	458	4.77
120-60	(4:2)	775	158	616	4.89
120-90	(4:3)	993	195	798	5.08
150-40	(4:1)	905	155	750	5.85
150-75	(4:2)	971	198	773	4.90
150-110	(4:3)	874	241	633	3.63

United States Dollar (USD) @ 105 Pakistani Rupee (PKR), Wheat grain @ Rs 1200 per 40 kg, straw @ Rs 250 per 40 kg

appropriate fraction.

Apparent recovery efficiency

Apparent recovery efficiency of any nutrient can be defined as the amount of a particular nutrient taken up by the plants per unit of applied nutrient [24]. Nitrogen and phosphorus recovery efficiencies were affected significantly ($P \leq 0.05$) by the application of N and P rates. The highest N recovery (69.33%) was achieved in plots supplied with $N-P_2O_5$ at 120-90 kg ha^{-1}, which was notably different from all other treatments (Table 4). However, N recovery efficiency was stagnant with subsequent increment in N levels. Recovery efficiency of N can be improved by the addition of P at a particular N level [44]. Hossain et al. [45] have also disclosed the identical findings. Various combinations of N and P rates influence markedly on the efficiency of P recovery. The maximum P recovery (20.97 %) was recorded where P_2O_5 was applied @ 30 kg per hectare along with 120 kg N per hectare, while least value of P recovery efficiency (16.14 %) was observed in treatment fertilized with 45 kg P_2O_5 + 90 kg N ha^{-1} (Table 4). Similar findings were revealed by Brink et al. [43] while studying P-uptake by temperate grasses like wheat, oat and rye, and legumes. Apparent recovery efficiencies of both nutrients can be enhanced using appropriate combinations and keeping in view the crop requirement of the said nutrients. Recoveries of both nutrients can be improved by tightening the ratio between N and P signifying that a reasonable amalgamation of elements is crucial to enhance their use efficiency [15].

Agronomic and physiological efficiency

Agronomic efficiency (AE) can be described as the economic produce obtained per unit of nutrient applied. The data presented in Table 4 clearly indicates that combinations of N and P applied in various ratios significantly ($P \leq 0.05$) affected the agronomic efficiency of both nutrients. The maximum AE of nitrogen (21.58 kg yield per kg of N applied) was achieved at 120 kg N plus 90 kg P_2O_5 per hectare applied in 4:3 ratio. Moreover, further addition of N resulted in the decline of AE. The highest AE of phosphorus (57 kg yield per kg of P applied) was achieved at 150-40 kg $N-P_2O_5$ per hectare, which was statistically different from all other treatments. At each N level, AE of phosphorus was decreased with the successive addition of P_2O_5. Fageria and Baligar [46] disclosed the similar type of findings which indicated that genotypes having a higher value of AE also produce higher yields.

The data regarding physiological efficiency (PE) of both N and P is presented in Table 4 showing that the values of PE varied significantly ($P \leq 0.05$) under various combinations of N and P_2O_5. The PE is generally defined as the biological yield (total biomass) produced per unit of absorbed nutrient. Numerically, the maximum value of PE for nitrogen was observed at the lowest level of N and it reduced with corresponding higher N rates. The higher PE for N (110.83 kg biomass per kg of N absorbed) was obtained where 90 kg N was integrated with 70 kg P_2O_5 ha^{-1}. The PE of phosphorus was highest in those treatments where N and P_2O_5 were used in 4:1 ratio as compared to the ratios of 4:2 and 4:3. The highest PE of phosphorus (893.31 kg biomass per kg of P absorbed) was recorded at 150-40 kg N-P_2O_5 ha^{-1}, while minimum (344.10 kg biomass per kg of P absorbed) was noticed in treatment receiving 150 kg N plus 110 kg P_2O_5 ha^{-1} (Table 4). The PE of nitrogen and phosphorus decreases substantially by the additional inputs of the respective element [47].

Value cost ratio (VCR) and net income

Economics of any commodity produced can be described better using the criteria of VCR that ultimately determine the net profit [26]. The calculations presented in Table 5 indicate the net income generated and VCR at different combinations of N and P_2O_5 rates. The data clearly shows that maximum net income (USD 993 ha^{-1}) and profit (USD 798 ha^{-1}) was achieved where N-P_2O_5 were added at the rate of 120-90 kg ha^{-1}. The treatment receiving 90 kg N + 23 kg P_2O_5 ha^{-1} showed minimum net income (USD 326 ha^{-1}) and least profit (USD 234 ha^{-1}). The highest values of VCR (5.85 and 5.08) were obtained in treatments fertilized with N-P_2O_5 @ 150-40 and 120-90 kg ha^{-1}, respectively. It is evident from our findings that use of fertilizers either below or above the optimum level is neither economical nor profitable. Therefore, unnecessary application of costly inputs must be avoided and nutrients should be used judiciously to achieve higher profitability.

Conclusions

With the keen observation of our findings, it may be concluded that wheat genotype NIA-MB-2 responded significantly to various combinations of applied N and P_2O_5. The addition of 120 kg N + 90 kg P_2O_5 ha^{-1} in the ratio of 4:3 was found as an optimum fertilizer dose for the tested wheat genotype. Any additional input of N and P either showed a decreasing trend in yield or increased the yield non-significantly. Furthermore, the results also directed that balanced use of nutrients, i.e. nitrogen and phosphorus can improve fertilizer use efficiency and consequently help in upholding crop productivity on low input agricultural systems.

Conflict of interest

The authors declare that they have no conflict of interest.

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