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Field Study Aiming at Higher Grain Yield and Nutrient Use Efficiency in Wheat Grown in Alkaline Calcareous Soil

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Abstract

Fertilizers are very crucial agricultural inputs in the present era of intensive cropping systems. Nevertheless, the developing world is facing the scarcity of major nutrients, primarily due to energy crises, price hiking, geopolitics and finite phosphate rock reserves. Balanced fertilization ensures better crop production and optimizes the nutrient use efficiency, thereby sustaining yields on low input agro-ecosystems. A field study was conducted for two consecutive years to evaluate a recently evolved wheat genotype WBG-1-14 for grain yield and nutrient use efficiency. Three N and nine P_2O_5 levels were combined into 4:1, 4:2, and 4:3 N-P_2O_5 ratios to formulate ten treatments, including control. The analysis of pooled data revealed that the tested wheat genotype produced maximum grain and straw yield at 120-90 and 150-110 kg N-P_2O_5 ha^{-1}, respectively. Maximum total N and P uptake were recorded in treatment having N-P_2O_5 at the rate of 150-110 kg ha^{-1} that were at par to treatment with 120-90 kg N-P_2O_5 ha^{-1}. Various N and P efficiency indices, *i.e.*, recovery efficiency (RE), agronomic efficiency (AE), physiological efficiency (PE) and internal utilization efficiency (IUE) were markedly influenced in response to varying regimes of both nutrients. The highest values for N efficiency indices (RE_N, AE_N, PE_N and IUE_N) were recorded at 120-90, 90-70, 90-23 and 90-70 kg N-P_2O_5 ha^{-1}, respectively. The maximum RE_P was observed at 150-40, while AE_P, PE_P and IU_P were noticed higher at 90-23 kg N-P_2O_5 ha^{-1}. Overall, the treatment 120-90 kg N-P_2O_5 ha^{-1} was found as the most suitable dose for higher grain yield production and nutrient accumulation by the tested genotype.

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Introduction

Wheat (*Triticum aestivum* L.) holds a central position in agriculture of Pakistan. It accounts for 9.1% of value addition in agriculture and 1.7% of GDP of the country. During 2017-18, area under wheat cultivation was 8730 thousand hectares with the total production of 25.49 million tons, while average yield stood at 2.92 tons per hectare, which was considerably below the potential yield [1]. Nitrogen (N) and phosphorus (P) are essential macronutrients required for normal crop growth and development. Nevertheless, most of the arable lands in Pakistan exhibit moderate to severe deficiencies of these nutrients [2]. The addition of inorganic fertilizers to enhance crop yields is a promising approach on such soils. But the economic and environmental challenges have compelled researchers to introduce efficiency-improving strategies and practices to enhance productivity and profitability of the cropping systems [3]. In Pakistan, fertilizer use has been rising over the years but the yield of various crops is stagnant mainly due to imbalanced fertilizer application. Farmers usually apply higher rates of nitrogen fertilizer whilst lower quantities of phosphorus and potassium [4].

Nitrogen is a vital nutrient for plant growth and structural constituent of proteins, nucleic acids, chlorophyll and enzymes [5]. It stimulates root growth and accelerates the uptake of nutrients and water [6]. Optimum concentration of N within plant body results in the higher leaf area and carbon assimilation, which ultimately contributes towards improved grain yield [7]. It is a highly mobile element in plants, thus its deficiency symptoms first appear on older leaves. The N deficiency causes imbalance in metabolic activities and reduces leaf area, photosynthetic rate, interception of solar radiation and overall plant biomass [8]. Phosphorus is another essential plant nutrient and key component of nucleic acids, ATPs, phosphate esters and phospholipids. It plays a central role during the processes of energy production, storage and transfer, photosynthesis, respiration, root growth, plant reproduction and seed formation [9]. Like N, P is also a mobile element in plants and remobilized actively from old to young growing tissues under P deficiency. Inadequate P reduces carbohydrate utilization and imparts dark green color of leaves [10].

Fertilizers are essential agricultural input required for enhancing crop productivity by ensuring the optimum supply of nutrients. Adequate and balanced nutrient supply on soils with low fertility status is a pre-requisite to achieve maximum yield potential of any crop [11]. Balanced fertilization is the addition of nutrients in appropriate quantities for a particular crop and agro-climatic conditions [12]. The prime aim of the balanced fertilization is to improve crop yield and profit, enhance produce quality, overcome inherent nutrient deficiencies in soil, maintain and restore soil fertility [13]. Balanced fertilization is among the important factors responsible for sustainable productivity, maintaining soil fertility, achieving a cost-effective return from any crop and reducing the environmental problems caused by inefficient fertilization [14].

Wheat genotypes differed extensively for acquiring nutrients and their utilization to produce more yields illustrating their differential nutrient requirements [15]. These variations depend on the genetic makeup of a genotype, plant architect and agro-climatic conditions of the region [2]. Formulating balanced fertilizer recommendations for newly evolved genotypes is imperative to get higher yields and economic return per unit area [4]. Various earlier investigations have shown considerable differences among wheat genotypes for their nutrient requirements for optimum yields. Khan et al. [16] reported fertilizer requirement of 150-110 kg N-P_2O_5 ha^{-1} for wheat variety NIA-Sunder. Likewise, Abbas et al. [17] recommended the balanced fertilizer dose of 150-75-60 kg NPK ha^{-1} for wheat genotype BWQ-4 for achieving maximum economic harvest. Results of another study revealed that the application of 120 kg N and 90 kg P_2O_5 ha^{-1} was estimated optimal dose for wheat genotype NIA-MB-2 [18]. In a field study, wheat genotype SD-998 was successfully grown for maximum yield with 150-110-60 kg NPK ha^{-1} [2]. The current study was therefore planned to devise balanced fertilizer dose for a recently evolved wheat genotype WBG-1-14 for higher grain yield production and nutrient accumulation.

Materials and Methods

Plant material and site description

The seeds of a newly evolved wheat genotype WBG-1-14 were kindly provided by the Plant Breeding and Genetics Division of Nuclear Institute of Agriculture (NIA), Tandojam, Pakistan. A field study was conducted for two repeated years (2015-16 and 2016-17) at the NIA experimental farm (Latitude 25º 25ˈ 19.8ˈˈ North and Longitude 68º 32ˈ

27.8" East). Five samples from the experimental site (0-15 cm surface layer) were collected randomly prior to crop sowing and then a composite sample of the collected soil was analyzed for various soil properties, *i.e.*, soil texture [19], soil pH, electrical conductivity [20], organic matter [21], Kjeldahl nitrogen [22], available phosphorus and potassium [23], and total calcium carbonate contents [24]. Briefly, the soil was silty clay loam in texture characterized by alkaline in soil reaction (pH 7.9), non-saline (2.43 dS m^{-1}), high in total calcium carbonate contents (8.17%) and potassium (170 mg kg^{-1}) while low in organic matter (0.69%), nitrogen (0.058%) and phosphorus (2.74 mg kg^{-1}).

Treatment application and management practices

Experiments were conducted following randomized complete block design during both years on a fixed layout. Sowing of wheat crop was done with hand drill in individual plots of size 4m × 4m using seed rate of 125 kg per hectare. Three N levels (90, 120 and 150 kg per hectare) and nine P_2O_5 levels (23, 30, 40, 45, 60, 70, 75, 90 and 110 kg per hectare) were combined into 4:1, 4:2, and 4:3 N-P_2O_5 ratios to formulate ten treatments, including control (without external N and P_2O_5). The detail of treatments is presented in Table 1. All treatments including control were also supplied with a constant dose of potassium at the rate of 60 kg K_2O per hectare. The commercial fertilizers, *i.e.*, urea [$CO(NH_2)_2$, 46% N], diammonium phosphate [$(NH_4)_2HPO_4$, 46% P_2O_5 + 18% N] and sulphate of potash (K_2SO_4, 50% K_2O) were used as the sources for N, P and K, respectively. The required quantities of P according to treatment plan and K were applied at the time of crop sowing while required N was supplied into three equivalent splits (*i.e.* sowing, tillering, and booting stage). All other crop management practices were implemented uniformly to all treatments throughout the crop period. Wheat was harvested at maturity, grains were separated from the straw by threshing and data regarding yield was recorded.

Nutrient assay and efficiency indices

The grain and straw samples collected from each treatment were dried for 72 hours in a forced air-driven oven at 70ºC. The dried samples were ground using Thomas Wiley's mill (3383L10, Thomas Scientific, USA) to pass through a 0.42 mm screen. Samples were analyzed for total nitrogen following the method of Jackson [22] using fully automated distillation apparatus (2200 Kjeltic, FOSS, UK). Total P concentration in samples was determined according to procedure as described by Estefan et al. [24] at 470 nm wavelength using spectrophotometer (U-2900UV/VIS, Hitachi, Japan). Various nutrient efficiency indices under different fertilizer regimes were calculated using the following formulas:

- $\text{Nutrient uptake (kg ha}^{-1}) = \frac{\text{Yield (kg ha}^{-1}) \times \text{Nutrient concentration (\%)}}{100}$
- $\text{Recovery efficiency (\%)} = \frac{\text{TNU}_{\text{Treatmnet}} - \text{TNU}_{\text{Control}}}{\text{Nutrients applied}} \times 100$

Where TNU is the total nutrient uptake (grain + straw).

- $\text{Agronomic efficiency (kg kg}^{-1}\text{ of nutrient applied)} = \frac{\text{Grain yield}_{\text{Treatment}} - \text{Grain yield}_{\text{Control}}}{\text{Nutrients applied}}$
- $\text{Physiological efficiency} \left(\begin{matrix}\text{kg kg}^{-1}\text{ of nutrient} \\ \text{absorbed}\end{matrix}\right) = \frac{\text{BY}_{\text{Treatment}} - \text{BY}_{\text{Control}}}{\text{TNU}_{\text{Treatment}} - \text{TNU}_{\text{Control}}}$

Where BY is the biological yield (grain + straw) and TNU is the total nutrient uptake.

Table 1 Detail of treatments used in individual experimental plot.

Treatments	Treatment abbreviations	Nitrogen applied (kg ha^{-1})	Phosphorus applied (kg ha^{-1})	N – P_2O_5 ratio
T_1	Control	0	0	-
T_2	$N_{90} – P_{23}$	90	23	4:1
T_3	$N_{90} – P_{45}$	90	45	4:2
T_4	$N_{90} – P_{70}$	90	70	4:3
T_5	$N_{120} – P_{30}$	120	30	4:1
T_6	$N_{120} – P_{60}$	120	60	4:2
T_7	$N_{120} – P_{90}$	120	90	4:3
T_8	$N_{150} – P_{40}$	150	40	4:1
T_9	$N_{150} – P_{75}$	150	75	4:2
T_{10}	$N_{150} – P_{110}$	150	110	4:3

Each treatment including control was also fertilized with potassium at the rate of 60 kg K_2O ha^{-1}

- Internal utilization efficiency $\left(\begin{array}{c}\text{kg kg}^{-1}\text{ of}\\ \text{nutrient}\\ \text{applied}\end{array}\right) = \frac{\text{BY}_{\text{Treatment}} - \text{BY}_{\text{Control}}}{\text{Nutrients applied}}$

Where BY is the biological yield.

Statistical analysis

The obtained data relevant to yield, nutrient uptake and efficiency indices during both years were subjected to statistical analysis using software STATISTIX 8.1 (Analytical Software, Inc., Tallahassee, FL, USA) following the procedures of Steel et al. [25]. For analysis of variance, a randomized complete block design was employed and to separate the differences between treatment means, least significant difference test at 5% probability level was used.

Results

Yield response of wheat

The data regarding grain, straw and biological yield (grain + straw) of the tested wheat genotype WBG-1-14 under varying N and P regimes are presented in Table 2. Different N and P levels significantly ($P \leq 0.05$) influenced the yield parameters, which enhanced linearly with the successive addition of P at each N level. On an averaged of both years, highest grain yield (5025 kg ha^{-1}) was obtained from $N_{120} - P_{90}$ treatment, which was statistically at par to grain yield of treatment $N_{150} - P_{110}$ (4813 kg ha^{-1}). However, the least grain yield of 2381 kg ha^{-1} was recorded in the control treatment. Straw yield increased considerably against increasing rates of P at either N level and showed a maximum response at the highest fertilizer inputs, *i.e.*, $N_{150} - P_{110}$ (8959 kg ha^{-1}). Similarly, the higher biological yield (13771 kg ha^{-1}) was observed in treatment $N_{150} - P_{110}$, which differed statistically from other treatments. Control plots produced minimum biological yield (5305 kg ha^{-1}).

Nutrient uptake

Nitrogen uptake by grains, straw as well as total (grain + straw) of wheat genotype varied significantly ($P \leq 0.05$) in response to different combinations of N and P levels (Table 3). Averaged across two years, the magnitude of grain N uptake ranged from 33.1 kg ha^{-1} in control treatment to 91.3 kg ha^{-1} in $N_{150} - P_{110}$ treatment. However, grain N uptake showed statistically identical results against each P level at the N level of 150 kg ha^{-1} contrarily to other treatments. Nitrogen uptake by straw of wheat plants was recorded minimum (6.6 kg ha^{-1}) in control plots while maximum (37.7 kg ha^{-1}) was noticed in $N_{150} - P_{110}$ treatment showing statistical similarity to 35.6 kg ha^{-1} recorded in $N_{120} - P_{90}$ treatment. Numerically, total N uptake illustrated the increasing trend in relation to subsequent addition of P at each N level. The control treatment exhibited a minimum total N uptake (39.7 kg ha^{-1}). However, the highest total N uptake (129.0 kg ha^{-1}) was recorded in treatment $N_{150} - P_{110}$, which was at par to treatments $N_{150} - P_{75}$ (122.2 kg ha^{-1}) and $N_{150} - P_{40}$ (118.6 kg ha^{-1}). The tested wheat genotype performed differently in terms of P accumulation in above ground plant parts *i.e.*, grain, straw (Table 4). The P uptake by wheat plants enhanced significantly ($P \leq 0.05$) in response to increasing P rates at every N level. The treatment $N_{120} - P_{90}$ revealed highest grain P uptake (16.2 kg ha^{-1}) and showed statistical

Table 2 Grain yield, straw yield and biological yield of wheat in relation to varying rates of nitrogen and phosphorus under field conditions for two consecutive years.

Treatments	Grain yield (kg ha^{-1})			Straw yield (kg ha^{-1})			Biological yield (kg ha^{-1})		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
Control	2354 e	2407 g	2381 g	2883 f	2963 f	2923 g	5238 f	5370 g	5304 f
$N_{90} - P_{23}$	4229 b-d	4293 ef	4261 ef	5354 e	5607 e	5481 f	9583 e	9900 f	9742 e
$N_{90} - P_{45}$	4115 cd	4426 d-f	4270 d-f	6285 d	6407 d	6346 e	10400 d	10833 e	10617 d
$N_{90} - P_{70}$	4375 a-c	4726 c-e	4550 c	6938 c	6963 c	6950 cd	11313 c	11689 d	11501 c
$N_{120} - P_{30}$	4021 d	4167 f	4094 f	6567 cd	6922 c	6744 c-e	10588 d	11089 e	10838 d
$N_{120} - P_{60}$	4198 b-d	4822 b-d	4510 cd	6948 c	7019 c	6983 c	11146 c	11841 cd	11493 c
$N_{120} - P_{90}$	4583 a	5467 a	5025 a	6250 d	6793 cd	6521 de	10833 cd	12259 c	11546 c
$N_{150} - P_{40}$	4208 b-d	4796 b-d	4502 c-e	7858 b	7944 b	7901 b	12067 b	12741 b	12404 b
$N_{150} - P_{75}$	4344 a-c	4989 bc	4666 bc	7988 b	8037 b	8012 b	12331 b	13026 b	12679 b
$N_{150} - P_{110}$	4458 ab	5167 ab	4813 ab	8677 a	9241 a	8959 a	13135 a	14407 a	13771 a
LSD $_{0.05}$	294	440	242	554	490	434	558	469	411

Treatment explanations are in Table 1. Treatment means not sharing similar letter(s) in the same column differ significantly from each other at $P \leq 0.05$. Values are means of three replications (n = 3).

Table 3 Grain, straw and total (grain + straw) nitrogen uptake by wheat in relation to applied nitrogen and phosphorus rates under field conditions for two consecutive years.

Treatments	Grain N uptake (kg ha^{-1})			Straw N uptake (kg ha^{-1})			Total N uptake (kg ha^{-1})		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
Control	32.0 f	34.3 f	33.1 f	6.3 e	6.9 e	6.6 e	38.3 g	41.1 f	39.7 g
$N_{90} – P_{23}$	46.4 ef	51.5 e	49.0 e	12.4 de	16.8 d	14.6 d	58.8 f	68.3 e	63.5 f
$N_{90} – P_{45}$	50.8 de	53.5 de	52.2 e	18.0 cd	22.7 c	20.3 c	68.9 ef	76.1 de	72.5 ef
$N_{90} – P_{70}$	56.6 c-e	58.1 c-e	57.4 de	20.7 c	24.6 c	22.6 c	77.3 de	82.8 c-e	80.0 de
$N_{120} – P_{30}$	65.1 a-d	65.9 b-d	65.5 cd	21.8 c	24.4 c	23.1 c	86.9 cd	90.3 cd	88.6 cd
$N_{120} – P_{60}$	64.7 b-d	69.8 bc	67.3 cd	32.5 b	27.5 bc	30.0 b	97.2 bc	97.4 bc	97.3 c
$N_{120} – P_{90}$	76.5 ab	74.8 b	75.7 bc	36.8 ab	34.4 a	35.6 a	113.3 ab	109.2 b	111.3 ab
$N_{150} – P_{40}$	73.0 a-c	92.3 a	82.7 ab	38.3 ab	33.5 a	35.9 a	111.3 ab	125.8 a	118.6 ab
$N_{150} – P_{75}$	78.0 ab	94.5 a	86.3 ab	39.4 a	32.4 ab	35.9 a	117.4 a	126.9 a	122.2 ab
$N_{150} – P_{110}$	83.0 a	99.5 a	91.3 a	41.9 a	33.4 a	37.7 a	124.9 a	133.0 a	129.0 a
$LSD_{0.05}$	17.9	14.4	13.1	6.2	5.2	4.4	17.3	16.5	13.4

Treatment explanations are in Table 1. Treatment means not sharing similar letter(s) in the same column differ significantly from each other at $P \leq 0.05$. Values are means of three replications (n = 3).

Table 4 Grain, straw and total (grain + straw) phosphorus uptake by wheat genotype under various nitrogen and phosphorus rates in the field for two consecutive years.

Treatments	Grain P uptake (kg ha^{-1})			Straw P uptake (kg ha^{-1})			Total P uptake (kg ha^{-1})		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
Control	4.5 e	5.9 f	5.2 e	1.4 e	1.7 f	1.5 h	5.9 f	7.6 f	6.7 g
$N_{90} – P_{23}$	8.8 d	8.1 e	8.4 d	2.0 de	1.9 f	1.9 gh	10.8 e	10.0 e	10.4 f
$N_{90} – P_{45}$	11.0 d	9.5 de	10.2 c	3.2 c-e	3.1 e	3.1 ef	14.2 d	12.5 d	13.3 e
$N_{90} – P_{70}$	15.1 bc	12.3 c	13.7 b	4.0 bc	4.6 b-d	4.3 b-d	19.1 bc	16.9 c	18.0 c
$N_{120} – P_{30}$	10.3 d	10.4 d	10.3 c	2.5 c-e	3.1 e	2.8 fg	12.7 d	13.4 d	13.1 e
$N_{120} – P_{60}$	13.6 c	12.4 c	13.0 b	4.2 a-c	4.1 c-e	4.1 c-e	17.8 c	16.5 c	17.1 c
$N_{120} – P_{90}$	17.5 ab	14.9 a	16.2 a	5.5 ab	5.1 bc	5.3 ab	22.7 a	19.9 a	21.3 a
$N_{150} – P_{40}$	9.3 d	12.8 c	11.0 c	3.7 b-d	3.6 de	3.6 d-f	12.9 d	16.4 c	14.7 d
$N_{150} – P_{75}$	15.9 a-c	13.0 bc	14.4 b	4.2 a-c	5.5 ab	4.8 bc	20.1 b	18.5 b	19.3 b
$N_{150} – P_{110}$	17.5 a	14.7 ab	16.1 a	6.0 a	6.3 a	6.1 a	23.7 a	21.0 a	22.4 a
$LSD_{0.05}$	2.3	1.9	1.6	1.9	1.2	1.2	1.8	1.4	1.2

Treatment explanations are in Table 1. Treatment means not sharing similar letter(s) in the same column differ significantly from each other at $P \leq 0.05$. Values are means of three replications (n = 3).

similarity to treatment $N_{150} – P_{110}$ (16.1 kg ha^{-1}). Averaged over two years, the straw P uptake ranged from 1.5 kg ha^{-1} in the control treatment to 6.1 kg ha^{-1} in $N_{150} – P_{110}$ treatment. Likewise, total P uptake was recorded maximum in $N_{150} – P_{110}$ treatment (22.4 kg ha^{-1}) which was at par to 21.3 kg ha^{-1} recorded in $N_{120} – P_{90}$ treatment, while control plots accumulated least total P (6.7 kg ha^{-1}).

Nutrient efficiency indices

The data pertinent to efficiency indices for nitrogen, *i.e.*, recovery efficiency (RE_N), agronomic efficiency (AE_N), Physiological efficiency (PE_N) and internal utilization efficiency (IUE_N) is presented in Table 5. The values of all efficiency indices differed significantly ($P \leq 0.05$) under various N and P regimes but at variable rates. The mean RE_N increased linearly with the corresponding addition of N and P up to the treatment $N_{120} – P_{90}$ with maximum value of 59.6% and illustrated non-significant response at higher levels. The values of AE_N were recorded higher with lower P rates at each N level. The magnitude of AE_N ranged from 16.2 kg kg^{-1} in $N_{150} – P_{110}$ treatment to 24.1 kg kg^{-1} in $N_{90} – P_{70}$ treatment. A similar trend as AE_N was also observed for PE_N with higher values at lower rates and vice versa. The highest PE_N (214.5 kg kg^{-1}) was calculated from $N_{90} – P_{23}$ treatment, while minimum (88.2 kg kg^{-1}) was recorded in $N_{120} – P_{90}$ treatment. The IUE_N varied from 46.1 kg kg^{-1} at $N_{120} – P_{30}$ to 68.9 kg kg^{-1} at $N_{90} – P_{70}$ treatment.

Various fertilizer treatments influenced considerably on various efficiency indices for phosphorus, *i.e.*, recovery efficiency (RE_P), agronomic efficiency (AE_P), physiological efficiency (PE_P) and internal utilization efficiency (IUE_P) of tested wheat genotype under field conditions (Table 6). Averaged over two years, higher RE_P (21.2%) was observed at $N_{120} – P_{30}$ followed by 19.8% at $N_{150} – P_{40}$ while minimum

(14.2%) was observed at N_{150} – P_{110}. The values of AE_P illustrated decreasing trend against higher P rates at every N level. The treatment N_{90} – P_{23} revealed highest AE_P (81.7 kg kg^{-1}) followed by N_{120} – P_{30} (57.1 kg kg^{-1}) and N_{150} – P_{40} (53.0 kg kg^{-1}) while least was recorded in N_{150} – P_{110} treatment (22.1 kg kg^{-1}). The magnitude of PE_P ranged from 445.7 kg kg^{-1} from N_{120} – P_{90} treatment to 1198.2 kg kg^{-1} from N_{90} – P_{23} treatment. Higher values for IUE_P were calculated at lower P rates at either N level. Maximum IUE_P (1929 kg kg^{-1}) was recorded at N_{90} – P_{23} while minimum (69.4 kg kg^{-1}) was observed in N_{120} – P_{90} treatment.

Discussion

In the current study, the highest grain yield was recorded in 120-90 kg N-P_2O_5 ha^{-1} treatment, while maximum straw yield was observed in 150-110 kg N-P_2O_5 ha^{-1} treatment. The higher grain yield at 120 kg N along with 90 kg P_2O_5 ha^{-1} might be due to the elevated performance of yield driving traits, *i.e.,* spike length, No. of spikelet $spike^{-1}$, grain weight etc. at this level compared with other treatments. According to Ali et al. [26], adequate and balanced nutrient supply results in healthier grain formation because of higher chlorophyll contents and photosynthetic activity to ensure plenty of assimilates during grain development. The increase in straw yield as a result of successive addition of N and P is due to the adequate availability of these nutrients to plants which accelerated vegetative growth [27]. Moreover, improved vegetative growth with N application is the main function attribute to N thereby increasing straw yield [28]. Lea and Miflin [29] reported that substantial improvement in yield can be achieved by applying N and P in appropriate ratios. In contrast, imbalanced fertilization in wheat reduces No. of grains $spike^{-1}$ and unit grain weight. Adequate N supply causes an alteration in hormonal balance to promote shoot growth at the expense of roots and enhances protein contents in foliage and grains of cereals [30]. While adequate P has an additive effect on crop performance when applied with N in the appropriate ratio [31]. Optimum P supply is crucial for better development of plant root systems, grain formation and productive tillering [32]. Similar findings were also documented by Ahmad et al. [33] indicating an increasing trend for biomass production of wheat with a subsequent rise in N and P doses. Abbas et al. [18] have calculated 120-90 kg N-P_2O_5 ha^{-1} as the optimal dose for wheat genotype NIA-MB-2 to obtain higher yield. In another study, wheat genotype SD-998 was successfully grown for maximum yield with 150-110-60 kg NPK ha^{-1} [2].

The N and P uptake by grains and straw was improved with the successive rise in P rates at each N level, which illustrated a synergistic interaction between both nutrients. Nitrogen uptake was greatly coincided, *i.e.,* increased with N addition. The highest total N and P uptake were determined in plots having N-P_2O_5 at 150-110 kg ha^{-1}, which were at par with that recorded at 120-90 kg N-P_2O_5 ha^{-1}. Wilkinson et al. [27] described that the synergistic effect among N and P results in stimulated plant growth and increased absorption of both elements. Nutrients are utilized more efficiently to produce higher yields when applied in sufficient and appropriate ratios [31]. Crop response to applied N is reduced under P deficiency. An appropriate quantity of applied nutrients facilitates their relative absorption by the plants [34]. Abbas et al. [17] estimated the maximum N and P uptake by wheat genotype BWQ-4 at 150 kg N and 75 kg P_2O_5 ha^{-1}. While in another study conducted by Abbas et al. [18], highest N and P uptake by wheat genotype NIA-MB-2 was recorded at 150-110 kg N-P_2O_5 ha^{-1}, which were statistically similar to 120-90 kg N-P_2O_5 ha^{-1}. Likewise, Irfan et al. [2] have also found the highest N and P accumulation by wheat genotype SD-998 at 150-110 kg N-P_2O_5 ha^{-1}.

Nutrient use efficiency is a complex attribute which involves a range of components. But the common thing regarding efficiency indices is the generalized idea that how a nutrient can efficiently be utilized to produce the final product, *i.e.,* biomass or yield [35]. Various nutrient efficiency indices in the current study were markedly influenced in relation to varying N and P regimes. The recovery efficiency of N (RE_N) illustrated a linear trend with the parallel P addition at each N level. The RE_N at a particular N level can be achieved with the joint fertilization of N, P and K instead of sole N application [36]. A rational merger of N and P by narrowing the ratio between both elements is essential to enhance their recovery efficiencies [14, 18]. Application of higher nutrient rates in excess of plant requirements diminishes their recovery efficiency [37]. Nitrogen use efficiency could be enhanced considerably with a subsequent increase in P at each N level reflecting a strong synergistic relationship between these elements [4]. Nutrient efficiency measures are influenced considerably by soil fertility status, the rate of application and crop type [38]. In the present study, as native soil available P was low, therefore, a cost-effective

Table 5 Various nitrogen efficiency indices for wheat genotype under various nitrogen and phosphorus rates in the field for two consecutive years.

Treatments	RE_N (%)			AE_N (kg kg^{-1} of N applied)			PE_N (kg kg^{-1} of N absorbed)			IUE_N (kg kg^{-1} of N applied)		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
Control	-	-	-	-	-	-	-	-	-	-	-	-
N_{90} – P_{23}	22.8 d	30.2 d	26.5 e	20.8 ab	20.9 bc	20.9 b	261.9 a	167.1 a	214.5 a	48.3 cd	50.3 de	49.3 cd
N_{90} – P_{45}	34.0 cd	38.9 cd	36.4 de	19.6 b	22.4 ab	21.0 b	168.9 b	171.4 a	170.1 b	57.4 b	60.7 b	59.0 b
N_{90} – P_{70}	43.3 bc	46.2 bc	44.8 b-d	22.5 a	25.8 a	24.1 a	156.9 b	155.4 ab	156.2 b	67.5 a	70.2 a	68.9 a
N_{120} – P_{30}	40.5 bc	41.0 cd	40.8 cd	13.9 cd	14.7 d	14.3 d	113.7 c	116.4 bc	115.0 c	44.6 d	47.7 e	46.1 d
N_{120} – P_{60}	49.1 ab	46.9 bc	48.0 bc	15.4 c	20.1 bc	17.7 c	101.7 cd	117.3 bc	109.5 cd	49.2 cd	53.9 cd	51.6 c
N_{120} – P_{90}	62.5 a	56.7 ab	59.6 a	18.6 b	25.5 a	22.0 b	74.9 d	101.5 c	88.2 d	46.6 d	57.4 bc	52.0 c
N_{150} – P_{40}	48.7 ab	56.4 ab	52.6 ab	12.4 d	15.9 d	14.1 d	97.5 cd	87.0 c	92.3 cd	45.5 d	49.1 e	47.3 d
N_{150} – P_{75}	52.8 ab	57.2 ab	55.0 ab	13.3 cd	17.2 cd	15.2 d	90.9 cd	89.5 c	90.2 cd	47.3 d	51.0 de	49.2 cd
N_{150} – P_{110}	57.8 a	61.2 a	59.5 a	14.0 cd	18.4 cd	16.2 cd	92.6 cd	102.5 c	97.5 cd	52.7 bc	60.2 b	56.4 b
$LSD_{0.05}$	13.8	13.5	10.8	2.6	3.9	2.1	28.1	43.9	24.9	5.2	3.8	3.6

RE_N = recovery efficiency of nitrogen; AE_N = agronomic efficiency of nitrogen; PE_N = physiological efficiency of nitrogen; IUE_N = internal utilization efficiency of nitrogen.
Treatment explanations are in Table 1.
Treatment means not sharing similar letter(s) in the same column differ significantly from each at $P \leq 0.05$.
Values are means of three replications (n = 3).

Table 6 Various phosphorus efficiency indices for wheat genotype under various nitrogen and phosphorus rates in the field for two consecutive years.

Treatments	RE_P (%)			AE_P (kg kg^{-1} of P applied)			PE_P (kg kg^{-1} of P absorbed)			IUE_P (kg kg^{-1} of P applied)		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
Control	-	-	-	-	-	-	-	-	-	-	-	-
N_{90} – P_{23}	21.3 ab	10.4 e	15.9 c	81.5 a	82.0 a	81.7 a	948.5 a	1448.0 a	1198.2 a	188.9 a	196.9 a	192.9 a
N_{90} – P_{45}	18.4 ab	11.0 de	14.7 c	39.1 d	44.9 c	42.0 c	628.5 b	1124.1 b	876.3 b	114.7 c	121.4 c	118.1 c
N_{90} – P_{70}	18.9 ab	13.3 b-d	16.1 bc	28.9 ef	33.1 de	31.0 d	461.7 b-d	694.5 de	578.1 cd	86.8 d	90.3 e	88.5 e
N_{120} – P_{30}	22.8 a	19.5 a	21.2 a	55.6 b	58.6 b	57.1 b	877.1 a	1009.0 bc	943.1 b	178.3 ab	190.6 ab	184.5 ab
N_{120} – P_{60}	19.9 ab	14.8 b	17.3 bc	30.7 e	40.2 cd	35.5 d	496.5 b-d	736.3 de	616.4 c	98.5 d	107.8 d	103.2 d
N_{120} – P_{90}	18.7 ab	13.7 bc	16.2 bc	24.8 fg	34.0 c-e	29.4 d	332.6 d	558.9 e	445.7 d	62.2 e	76.5 f	69.4 f
N_{150} – P_{40}	17.7 ab	21.9 a	19.8 ab	46.4 c	59.7 b	53.0 b	1010.1 a	845.0 cd	927.5 b	170.7 b	184.3 b	177.5 b
N_{150} – P_{75}	18.9 ab	14.5 bc	16.7 bc	26.5 ef	34.4 c-e	30.5 d	502.2 bc	709.9 de	606.0 c	94.6 d	102.1 d	98.3 d
N_{150} – P_{110}	16.2 b	12.2 c-e	14.2 c	19.1 g	25.1 e	22.1 e	444.8 cd	674.4 de	559.6 cd	71.8 e	82.2 ef	77.0 f
$LSD_{0.05}$	6.2	2.6	3.8	5.8	11.2	6.5	167.6	207.1	151.1	13.1	8.9	9.1

RE_P = recovery efficiency of phosphorus; AE_P = agronomic efficiency of phosphorus; PE_P = physiological efficiency of phosphorus; IUE_P = internal utilization efficiency of phosphorus.
Treatment explanations are in Table 1.
Treatment means not sharing similar letter(s) in the same column differ significantly from each other at $P \leq 0.05$.
Values are means of three replications (n = 3).

response was expected to added P. The agronomic efficiency of P (AE_P) was recorded highest at lower P rates. Higher RE and AE were measured when N and P were below critical levels and declined with the addition of both nutrients. Soil fertility can be sustained with the intermediate values of RE and AE when applied rates are close to removal rates [38]. According to Abbas et al. [18], the physiological efficiency of N and P dwindle considerably with elevated levels of the respective element.

Conclusions

The findings of the current study showed that wheat genotype WBG-1-14 performed differently for grain yield, nutrient uptake and use efficiency in response to varying N and P_2O_5 rates. The yield potential of tested genotype can be exploited to a higher extent by the wise management of N and P_2O_5 application. The results demonstrated that 120-90 kg N-P_2O_5 ha^{-1} (4:3 ratio) should be considered as an optimum dose for achieving its maximum potential under the agro-climatic conditions of Tandojam, Sindh, Pakistan.

Conflict of interest

The authors declare that they have no conflict of interest

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