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Impact of Combining Mineral and Biofertilizers on Bread Wheat (*Triticum aestivum vulgare* L.) Yield and its Economic Viability

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ABSTRACT

A fundamental strategy for raising crop yields is to keep soil fertility and nutrient capacity within balanced ranges. During the winter seasons of 2020–21 and 2021–22, two field experiments were performed at the experimental farm of Tag El-Ezz station, Agricultural Research Center (ARC), Dakahlia Governorate, Egypt, aiming to estimating the impacts of four combinations of nitrogen and phosphorus mineralfertilizers , and four bio nitrogen and phosphorus treatments in addition their interactions on wheat productivity and its grain quality, Additionally, , N and P uptake were assessed and a cost-benefit analysis was also conducted. Split plot design with three replicates was used. Results confirmed significant effects of mineral and bio fertilization treatments on all studied traits. 31 kg P_2O_5 plus 120 kg N/ fad (F_3) showed superiority in most of the studied traits resulting in higher grain yield compared to other treatments. F_3 recorded the highest grain yield and harvest index in both seasons, and the highest harvest index in the 1st season. Dual application of bio N and P (B_3) led to the highest yield components, hence, higher grain and straw yields in both seasons. Protein content, N and P uptake, were higher due to with F_3 treatment, followed by F_2 treatment. The interaction between mineral and bio-fertilization treatments was significant in favor of the combination (F_3 plus B_3). Economically, the higher levels of combined mineral and bio-fertilizers resulted in increasing grain and straw yields without significant increase in net revenue. Based on the yield-dose response curves predicted, maximum grain yield was obtained from 110.35 kg N/ fad and 28.82 kg P_2O_5/ fad.

***Keywords**:* Wheat, mineral, bio-fertilization, economic feasibility.

INTRODUCTION

Wheat (*Triticum aestivum vulgare* L.) is considered the most harvested cereal crop internationally and locally in Egypt. The wheat acreage harvested in Egypt was about 3.64 million faddan "one faddan equal 4200 m^2" (1.53 million hectare) in the 2021/2022. The local total production was about 9.8 million tonnes of wheat grains with an average productivity of 17.94 ardab/faddan (6.4 tonnes/ha) (Index Mundi, 2022). Consumption demands of wheat in Egypt are significantly higher than the production, so enhancing the situation is inevitable through incrementing productivity per unit area (vertical expansion) and increasing the wheat cultivated area (horizontal expansion). Enhancing wheat productivity could be possible through cultivating high-yielding cultivars adapted to the changeable Egyptian environments coupled with better agronomic practices like fertilization.

Maintaining soil fertility and nutritive capacity in balanced ranges is one of the keystones to increase crop yield (Diacono *et al.*, 2013). Actually, mineral fertilizers are decisive available easy source of nutrients especially macro nutrients such as nitrogen and phosphorrus; but what can not be denied is that excessive use affects seriously environmental and human health, in addition to its high priced. Hence, all attempts to decrease the excessive dosages of mineral fertilizations, which are frequently used and or substitute it by bio-fertilizers are appreciated.

For cereal crops, including wheat, nitrogen (N) is the most crucial nutrient. protein, amino acids, protoplasm, and chlorophyll concentration are all influenced by the amount of N supplied to plants. Additionally, according to Kandil *et al.* (2011), Daneshmand *et al.* (2012), and Piccinin *et al.* (2013), N affects photosynthetic activity, leaf area, and cell size. Numerous studies (Abdul Galil *et al.*, 2003; Amin *et al.*, 2011; Farag and El-Khawaga, 2013; Khatab *et al.*, 2016) documented the noteworthy impact of N-fertilizers on wheat production and its constituent parts.supply of N fertilizer at level of 90 kg N/ fad resulted in a significant increment in number of tillers, leaf area, grain and biological yields (Amal *et al.*, 2018). El-Seidy *et al.* (2017) confirmed that applying 100 kg N/fad recorded the highest significant yield and its components, while the lowest ones were obtained through applying 50 kg N/fad, except harvest index which was higher operatively at 75 kg N/fad. Rekaby *et al.* (2016) summarized that applying 100 kg nitrogen per fad increased the number of spikes per m^2, number of grains per spike and grain weight per spike as well as the grain yield by 26%, compared to 50 kg N/fad.

Phosphorus plays a substantial function in plant physiology. It utilizes sugars in transfer energy, strengthen the biological yield and increase flower formation (Bechtaoui *et al.*, 2021). Once it is applied in soil, it becomes fixed and subsequently limits plant growth (Mandal and Khan, 1972). The recapture efficiency of P is beneath of 20% of the applied P in the world soil (Khattab, 2019). In point of fact, utilization of fertilizers is less than 30% because soluble P is rapidly fixed by reacting with free ions of Al^{3+}, Ca^{2+}, Mg^{2+} and Fe^{3+} up on its addition in the soil (Johan *et al.*, 2011). Application of phosphorus improves soil structure and enhances root

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growth and photosynthesis (Lambers *et al*., 2006). Phosphorus application improves yield and increases soil water retention (Lamyaa *et al*., 2019). Globally, P fertilizer efficiency ranges from 10% to 25% (Mubeen *et al*., 2023). According to Kabir *et al*. (2014), plants fertilized with 100 kg P showed the greatest values for wheat grain production, harvest index, and 1000-grain weight. One of the key characteristics of phosphate-solubilizing bacteria (PSB) and arbuscular mycorrhizal fungi (AMF) is their ability to convert insoluble forms of phosphorus into an accessible form for plants, known as ortho-phosphate.

Using bio-fertilizers could reduce the amount of mineral fertilizers through increasing the efficiency of nutrient availability and uptake as well as plant growth promoting. Biofertilizers pledged to balance many obstacles of the conventional mineral-based technology fertilizes (Zaki *et al*., 2012; Minaxi *et al*., 2013; Khattab *et al*., 2016; Zaki *et al*., 2016). Abdelkader (2014) reported that using biofertilizers (Cerealine and Phosphorein) significantly increased grain and straw yields as well as NPK uptaked by wheat plants.The commercial nitrogen biofertilizer "cerealine", which was utilized in this study, comprises free-living N-fixing bacteria (*Azospirillum brasilense* and *Bacillus polymyxa*). In Egypt, Subba Rao (1982) found that introducing free-living N_2-fixing bacteria, such as Azospirillum and Azotobacter, into wheat grains resulted in an increase in grain weight/spike, No. of grains/spike, 1000 grain wt. and grain yield/spike. Zaki *et al.* (2012) demonstrated that inoculating wheat grains with N_2-fixing bacteria greatly enhanced No. of spikes/m^2, No. of grains/spike, weight of grains/spike, 1000-grain weight, grain yield/fad, and harvest index.

As phosphorus biofertilizers, Egyptian PSB (*Bacillus megatherium* var *phosphaticum*), also known by its trade name Phosphorien, was utilized. Hussein and Radwan (2001) found that phosphorus biofertilizer inoculation greatly enhanced harvest index, spike grain weight, 1000-grain weight, and grain yield/fad. Phosphate dissolving bacteria (PDB) significantly boosted wheat number of spikes/m^2, 1000-grain weight, grain number/spike, harvest index, and grain yield, according to studies by El-Gizawy (2009) in Egypt and Saber *et al*. (2012).

Regarding the interaction effects, Khattab *et al*. (2016) in Egypt investigated the impact of seven phosphorus fertilization regimes (PFR) *i.e.* control; 15 kg P_2O_5/fad; Phosphorein; Mycrohiza; 7.5 kg P_2O_5/fad +Phosphorein; 7.5 kg P_2O_5/fad +Mycrohiza; Phosphorien+Mycrohiza on wheat grain yield and its components. Their results cleared that phosphorus availability through the supply of any PFR surpassed the control in each of number of spikes/m^2, 1000 grain weight, harvest index and grain yield/fad They added that the PFR comprised 7.5 kg P_2O_5/fad+phosphorein out yield other regimes and was excellence in each of number of spikes/m^2, number and weight of grains/spike as well as the harvest index. According to Esaad *et al*. (1997), bio-fertilization can make up between 30 and 40% of the required amount of nitrogen. In fixing atmospheric N and producing compounds that promote plant development, bio-fertilizers can be very helpful.

Thus this study aimed to investigate the response of wheat plants to different regimes of N and P mineral fertilizers. In addition, studying the effect of applying Bio-N and P in the form of Cerealine and Phosphorein.

MATERIALS AND METHODS

Description of experimental site, and the aim of study

Two filed experiments were conducted in an experimental field belonging to Tag El-Ezz Agricultural Research Station, Agricultural Research Center, Dakahlia Governorate, Egypt (30°57'25.5"N 31°35'56.8"E) during the winter seasons of 2020/2021 and 2021/2022. The study aimed at investigating the response of bread wheat cv. Gemmiza 11 to different combinations of mineral nitrogen (N) and phosphorus (P) in the form of Urea (46.5 % N) and ordinary Super phosphate (15.5% P_2O_5), respectively. In addition, to study the effect of applying bio-nitrogen fertilizer (nitrogen-fixing bacteria) which is commercially named "Cerealine" and bio-phosphorus (*Bacillus megatherium* var *phosphatircum*) which is phosphate dissolving bacteria and commercially named Phosphorein. All bio-fertilizers were obtained from Agricultural Research Center, Ministry of Agric. Egypt. Table (1) shows data about the used fertilizers.

treatments under study

The study consisted of two factors, the first is four combinations of mineral nitrogen and phosphorus (control *i.e.* without NP supplies, 15.5 kg P_2O_5 + 60 kg N, 23 kg P_2O_5 + 90 kg N and 31 kg P_2O_5 + 120 kg N/fad); the second factor included four bio-fertilization treatments (control *i.e.* without NP inoculations, Cerealine, Phosphorein and dual application Cerealine+ Phosphorein).

Table 1. Treatments under study and their costs in Egyptian pound (LE)

Mineral fertilizers			Bio-fertilizers		
Treatment		Cost (LE/fad)	Treatment		Price (LE/fad)
F_1	Check	0	B_1	Check	0
F_2	15.5 kg P_2O_5 + 60 kg N	782.5	B_2	Cerealine	175
F_3	23 kg P_2O_5 + 90 kg N	1300	B_3	Phosphorien	175
F_4	31 kg P_2O_5 + 120 kg N	1565	B_4	Cerealine + Phosphorien	350

Experimental design and agricultural practices

The experiment was conducted using split plot design with three replicates including 48 plots, each of 12 m^2 (3×4 m). A distance of 50 cm between plots was left to vanish the overlapping among treatments. The applied experimental design was according to Steel and Torrie (1980). Mineral combinations of N and P were laid out in main plots; bio fertilizers were occupying the sub-plots. Sowing was broadcasting on Nov. 7th in both seasons. In accordance with regional recommendations, all agronomic treatments were carried out according to The common agricultural practices for growing wheat according to the recommendations of Ministry of Agriculture and Land Reclamation, Egypt.

Soil sampling and aalysis

Soil samples from the experimental location were collected during soil preparation from the top 30 cm of the soil surface. Chemical and physical analyses of the soil were conducted using **Lindsay and Norvell's (1978)** and

Jackson's (1958) techniques. Table (2) illustrates the clay soil texture, pH of 7.85, and salinity of the soil extract of 1.9 dSm^{-1}. Because the soil had been farmed and well-tended for many years, the levels of accessible N, P, and K as essential elements were 8.5, 29 and 186 ppm, respectively. This suggested that the fertility of the soil was good.

Table 2. Physical and chemical properties of the experimental site at sowing

Soil particle distribution	2020/2021	2021/2022
Sand (%)	11.5	12.61
Silt (%)	32.9	35
Clay (%)	55.4	52.3
Soil texture	Clay	Clay
Organic matter,(g kg^{-1})	11	12
pH*	7.8	7.9
EC, (dSm^{-1}) **	1.8	2
Chemical properties		
Soluble cations and anions, (meq L^{-1})**		
Na^+	11	12
K^+	0.36	0.30
$Ca^{++} + Mg^{++}$	6.20	7.2
CO_3^-	--	--
HCO_3^-	2.60	2.20
Cl^-	13	14
SO_4	1.35	1.3
Available N, (mg kg^{-1}soil)	8	9
Available P, (mg kg^{-1}soil)	28	30
Available K, (mg kg^{-1}soil)	185	187.5

*** Soil-water suspension 1: 2.5 ** Soil water extract 1: 5**

***Source: Soil and Water Analysis Unit, El-Mansoura Laboratory, Agricultural Research Center**

Studied characters

Chlorophyll content was estimated as an average of the two experimental seasons at 100 days after sowing as the method described by Gavrilenko and Zigalova (2003). after 155 days from sowing date a sample of 25 x 25 cm^2/ plot (625 cm^2) was randomly taken at harvest to determine the following characters, plant height (cm), number of tillers/plant. No. of spikes/m^2.. No. of grains/spike, 1000-grain weight (g), grain yield (ardab/fad)). It was calculated by harvesting whole plants in each experimental plot and air dried, then threshed and the grains at 13 % moisture were weighted in kg and converted to ardab per faddan (one ardab = 150 kg)., straw yield (tonne/fad) the straw resulted from previous sample was weighted in kg/plot, and then it was converted to ton per feddan. Harvest index (%) is used to quantify the yield of a crop species versus the total amount of biomass which has been produced and it was estimated according to Donald (1962) as follows:

$$\textbf{Harves index} = \frac{\textbf{Grain yield (kg/fad)}}{\textbf{Biological yield (kg/fad)}} \times \textbf{100}$$

A sample of harvested grains from each plot was dried at 70º C for 24 hour to estimate N content using the micro-Kjeldahl method according to Jackson (1973). P uptake was determined using a colorimeter method according to Jackson (1967). Grain protein content (%) was calculated through multiplying N uptake by 5.75 according to AOAC (1990).

Statistical Analysis

ANOVA was applied to the data recorded from each plot using the split plot design as per Gomez and Gomez (1984) and the COSTAT-Statistics Software 6.400 package, which can be accessed at https://cran.r-project.org/web/packages/costat/citation.html. This software was outlined by Cardinali and Nason (2013). The Least Significant Difference test was used to compare the means of the treatments (LSD). According to Waller and Duncan (1969), the symbols * and ** in the analysis of variance (ANOVA) tables denote significance at the 0.05 and 0.01 levels of probability, respectively. Bartlett's test indicated that the error mean squared of the split plot design was homogeneous, hence the combined analysis was computed for every character under study in both seasons.

RESULTS AND DISCUSSION

Results presented in Tables (3-9) clarify the effect of mineral and bio-fertilization treatments as well as its interaction on wheat growth, yield and its components; in addition to chlorophyll content and grain quality of bread wheat cultivar Gemmiza 11 under Mediterranean environmental conditions of Egypt.

Wheat growth and yield

A. Effect of mineral fertilization levels:

Results presented in Tables (3, 4, 5 and 6) quoted that plant height (cm) in both seasons, number of tillers/plant in the 2nd season, chlorophyll content (a, b and total as combined of both seasons), as well as number of spikes/m^2, number of grains/spike and 1000 grain weight where significantly affected by mineral fertilization levels in the two seasons. F_3(31 kg P_2O_5+ 120 kg N) recorded the highest value for each of plant height (cm), number of tillers per plant, number of spikes/m^2, number of grains/spike and 1000 grain weight. Wheat plant heights were at par under both F_2 (23 kg P_2O_5+ 90 kg N/fad) and F_3 (31 kg P_2O_5+ 120 kg N/fad) application in the 1st season. Eke No. of tillers/plant were also at par under F_1, F_2 and F_3 supply. No. of spikes in both seasons and No. of grains/ spike in the 1st season were at par under F_2 and F_3 applications. The effective impacts of mineral nitrogenic and phosphatic fertilizers on wheat growth and productivity were elucidated by several investigators such as Ali *et al.* (2011), Singh and Prasad (2011), Farag and El-khawaga (2013); Kakraliya *et al.* (2017), Abdel-Lateef (2018) as well as Mona Hussein and Hala El-Sayed (2023).

The uppermost grain yield/fad (21.65 and 23.58 ardab/fad) was the resultant of the F_3 fertilization treatment (31 kg P_2O_5 +120 kg N/fad) application in the 1st and the 2nd seasons in respective order. Referring to the harvest index, supply of the F_3 (31 kg P_2O_5 +120 kg N/fad) outturn the highest value (41.13%) which was at par with the application of F_1 (15.5 kg P_2O_5 +60 kg N/fad) in the 1st season; while in the 2nd one, superiority in harvest index was conjugated with the application of either F_3 (31 kg P_2O_5 +120 kg N/fad) or F_2 (15.5 kg P_2O_5 + 60 kg N). In fact, harvest index represents plant efficiency in transfer of photosynthesis from source to sink. Nitrogen and phosphorus fertilizers are having consequential impact on partitioning of dry matter and allocating more dry biomass to the grains, would increase grain yield and harvest index. Results of Abd El-Hameed (2002), Abdul Galil *et al*. (2003 and 2008), Kattab *et al.* (2016) as well as Seleiman *et al*. (2021) confirmed the results of the current study. Excellency of the fertilization treatment F_3 in each of plant height, No. of spikes/m^2, No. of grains/spike as well as 1000- grain weight paved the way to its superiority in grain yield/fad over the other fertilization treatments.

Avail of mineral nitrogenous and phosphorus fertilizers were asserted in many previous studies (El-Far and Ramadan, 2000; Darwesh and Esmail, 2008; Khan *et al*., 2010; Saber *et al*., 2012; El-Habbasha *et al*., 2013; Abd El-Salam *et al*., 2016 *et al.*; Khattab, 2016; Ibrahim *et al*., 2019; Hlisnikovsky *et al*., 2020). Results of the current study are keep ink with the findings reported by Seleiman *et al.* (2021) wherein they purported that application of 80 kg N/fad followed by supply with 40 kg N/fad+2 tonne biogas fertilizers caused operative increase in grain yield/fad More and above, Mona Hussein and Hala El-sayed (2023) divulged that application of the fertilization regime comprised of 75% NPK+ biofertilzers (PGPR)+2 tonne compost/fad produced the outmost grain yield/fad (1903 kg/fad) whilst the lowermost grain/fad (755 kg/fad) was the resultant of applying 25% NPK.

B. Effect of the bio fertilization levels:

Results presented in Tables (3, 4 and 5) imparts that plant height (cm) in both seasons and chlorophyll content (a, b and total) as combined of both seasons as well as No. of spikes/m^2, No. of grains/spike and 1000 grain weight (g) displayed significant variation in both seasons due to bio-fertilization treatments. However, nullity variations in No. of tillers were noted in both seasons.

Table 3. Plant height (cm) and No. of tillers/plant as affected by mineral and bio fertilization treatments in 2020-21 and 2021-22 winter seasons

Treatment	Plant height (cm)		No. of tillers/plant	
	2020/21	2021/22	2020/21	2021/22
Mineral fertilization (F)				
Check (F0)	106.17 bc	108.27 c	3.94	4.17 b
15.5 kg p + 60 kg N (F1)	108.41 b	111.44 b	4.32	4.53 ab
23 kg p + 90 kg N (F2)	109.34 ab	112.22 b	4.55	4.78 ab
31 kg p + 120 kg N (F3)	113.95 a	115.63 a	4..90	5.20 a
F. test	*	*	NS	*
LSD 0.05	2.49	2.24	1.10	0.80
Bio fertilization (B)				
Check (B0)	105.73 c	108.67 c	3.96	4.40
Cerealiene (B1)	109.93 b	113.08 ab	4.10	4.73
Phosphorein (B2)	108.15 b	110.35 b	4.35	4.46
Cerealiene + Phosphorein (B3)	114.13 a	115.60 a	4.69	5.06
F. test	*	*	NS	NS
LSD 0.05	2.16	3.10	1.11	0.79
Interaction (F * B)	NS	NS	NS	NS

At the 5% and 1% probability levels, * and ** denote significance; NS denotes not significant.

Table 4. Chlorophyll a, b and the total chlorophyll as affected by mineral and bio fertilization treatments in 2020-21 and 2021-22 winter seasons

Treatment	Chlorophyll a	Chlorophyll b	Total Chlorophyll
Mineral fertilization (F)			
Check (F0)	0.837 d	0.505 d	1.342 d
15.5 kg p + 60 kg N (F1)	0.882 c	0.542 c	1.424 c
23 kg p + 90 kg N (F2)	0.955 a	0.59 a	1.545 a
31 kg p + 120 kg N (F3)	0.928 b	0.571 b	1.499 b
F. test	*	*	*
LSD 0.05	0.007	0.006	0.013
Bio fertilization (B)			
Check (B0)	0.847 d	0.514 d	1.361 d
Cerealiene (B1)	0.921 b	0.566 b	1.488 b
Phosphorein (B2)	0.932 a	0.574 a	1.506 a
Cerealiene + Phosphorein (B3)	0.903 c	0.557 c	1.460 c
F. test	*	*	*
LSD 0.05	0.007	0.004	0.011
Interaction (F * B)	NS	NS	NS

At the 5% and 1% probability levels, * and ** denote significance; NS denotes not significant.

Table 5. No. of spikes/m^2, No. of grains/spike and 1000 grain weight (g) as affected by mineral and bio fertilization treatments in 2020-21 and 2021-22 winter seasons

Treatment	No. of spikes/m^2		No. of grains/spike		1000 grain weight (g)	
	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
Mineral fertilization (F)						
Check (F0)	516.24 b	512.64 a	38.67 d	38.28 d	38.77 c	39.30 c
15.5 kg p + 60 kg N (F1)	472.32 c	472.68 b	42.21 c	41.83 c	40.62 b	41. 35 b
23 kg p + 90 kg N (F2)	527.4 a	524.52 a	44.78 a	44.35 b	40.72 b	41.55 b
31 kg p + 120 kg N (F3)	528.64 a	520.72 a	45.13 a	46.81 a	42.37 a	43.20 a
F. test	*	*	*	*	*	*
LSD 0.05	12.61	11.89	1.19	1.67	0.31	0.32
Bio fertilization (B)						
Check (B0)	497.88 b	495.72 b	38.66 c	39.11 d	39.67 d	40.20 d
Cerealiene (B1)	519.12 a	506.16 a	41.46 b	41.64 c	41.02 b	41.92 b
Phosphorein (B2)	512.28 a	514.8 a	44.83 a	44.36 b	40.27 c	40.80 c
Cerealiene + Phosphorein (B3)	514.96 a	513.52 a	45.77 a	45.85 a	41.77 a	42.45 a
F. test	*	*	*	*	*	*
LSD 0.05	11.18	10.10	1.88	1.09	0.38	0.29
Interaction (F * B)	*	*	NS	NS	NS	NS

At the 5% and 1% probability levels, * and ** denote significance; NS denotes not significant.

Table 6. Grain yield (ardab/fad), straw yield (tons/fad) and harvest index (%) as affected by mineral and bio fertilization treatments in 2020-21 and 2021-22 winter seasons

Treatment	Grain yield (ardab/fad)		Straw yield (tons/fad)		Harvest index (%)	
	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
Mineral fertilization (F)						
Check (F0)	17.05 d	15.23 d	5.06 c	4.84 c	33.21 c	35.14 c
15.5 kg p + 60 kg N (F1)	19.50 c	19.82 c	4.47 d	4.88 c	40.98 b	38.67 b
23 kg p + 90 kg N (F2)	21.54 b	22.84 b	5.16 b	5.19 b	40.49 b	40.94 a
31 kg p + 120 kg N (F3)	21.65 a	23.58 a	5.52a	5.61 a	41.13 a	40.58 a
F. test	**	*	*	**	*	*
LSD 0.05	0.03	0.04	0.04	0.04	0.63	0.61
Bio fertilization (B)						
Check (B0)	17.10 d	17.46 d	4.80 d	4.89 d	36.63 c	36.88 c
Cerealiene (B1)	19.28 c	19.79 c	5.08 b	5.17 b	38.79 b	38.63 b
Phosphorein (B2)	21.31 b	21.87 b	5.04 c	5.02 c	40.11 a	40.59 a
Cerealiene + Phosphorein (B3)	22.05 a	22.39 a	5.26 a	5.35 a	40.61 a	40.76 a
F. test	*	*	*	*	*	*
LSD 0.05	0.03	0.04	0.03	0.02	1.39	1.30
Interaction (F * B)	* *	*	*	* *	*	*

At the 5% and 1% probability levels, * and ** denote significance; NS denotes not significant.

Dualist supply of bio-fertilizers Cerealine and phosphorein (B_3) caused operative increase in wheat plant height which recorded 114.13 and 115. 60 cm in the 1st and the 2nd seasons, orderly. The shortest plants were those under check treatment *q.e.* uninoculated plants in the 1st season (105.73 cm) and the 2nd season (108.67 cm). Furthermore, supplying bio-fertilizers either solely (sole Cerealine or sole Phosphorein) or duality of them (B_3, Cerealine + Phosphorein) has co-ordinate impact on No. of spikes/m^2, but each outclass No. of spikes under the check treatment which recorded the lowest value 497.88 and 495.78 72 in the 1st season and the 2nd season, orderly.

Allusive to grain number per spike and 1000 grain weight, their excellency where achieved pointedly under application of B_3 fertilization regime (Cerealine + Phosphorein) in both seasons. The application of nitrogenous and phosphorus biofertilizers either solely or conjointly has an effectual impact and increasing each of plant height, spike number per m^2, grain number/spike and 1000 grain weight of wheat (Singh and Prasad, 2011; Abd El-Razek and El-Sheshtawy, 2013; Khattab, 2019; Abdel-Lateef, 2018; Badawi *et al.*, 2021; Abdullah *et al.*, 2022; Mona Hussein and Hala El-Sayed,2023).

The meliorative impact of bio-fertilizers could be ascribed to their role in fixing atmospheric nitrogen (Cerealine) or dissolving inorganic forms of phosphate (Phosphorein) to wheat plants and maintain the C/N ratio, accordingly aid in raising the grain filling rate and result in high efficacy of the effective grain filling period, thence increase wheat yield and its attributes.

Wheat grain yield/fad varied operatively due to the bio-fertilization treatments, wherein the lower most values (17.10 and 17.46 ardab/fad) fore the 1st and the 2nd seasons were recorded under check treatment (B0) i.e. under deficiency of both nitrogen and phosphorus as shown from the chemical analyses of the experimental site (Table 2). The uppermost values for grain yield/ fad (22.05 and 22.39 ardab/fad) in the 1st and the 2nd seasons were reported under the dual application of N and P fertilizers (B3) i.e. under availability of both N and P via the inoculation by the bio-fertilizers Cerealine + Phosphorein). Supply of sole bio-fertilizers (Cerealine or Phosphorein) produced moderate yields in both seasons. The increase in wheat grain productivity due to the inoculation with bio-N fixer fertilizer or with P bio-fertilizers either solitary or in combination was reported by El-Gizawy (2009), Kandil *et al.* (2011), Saber et al. (2012), Zaki *et al.* (2012), Khattab *et al.* (2016), Mohamed et al. (2019), Badawy *et al.* (2021), Seleiman et al. (2021), Abdullah et al. (2022) as well as Mona Hussein and Hala El-Sayed (2023).

Alpha and Omega similarity between straw and grain yields (tonne/fad) responses to the bio-fertilization treatments were noted in both seasons. The lowest straw yields (4.80 and 4.89 tonne/fad) in the 1st and the 2nd seasons were recorded under the check treatments, while the outmost straw yields (5.26 and 5.35 ton/fad) were the outturn of dual application of bio- N and P fertilizers (B_3).

From the perusal of the harvest index results (Table 6), it is evident that application of whichever B_2 (sole Phosphorein) and B_3 (Cereailine+ Phosphorein) recorded the highest value in each season. In fact, wheat plants under both B_2 and B_3 bio-fertilization treatments were more efficacious in transference of photosynthetic materials from source to sink. N and P fertilizers having an impact on dry matter partitioning and allocating more dry biomass to the grains (Fageria, 2013). The lowermost harvest index of wheat in both seasons was achieved under the check treatment (B_0) *i.e.* under N and P deficiency; such stress hampered the crop productivity and lessens the harvest index.

Wheat grain quality

Grain protein content as well as nitrogen and phosphorus uptake as affected by mineral and bio-fertilization treatments are compiled in Table (7). Applying 31 kg P + 120 kg N/fad (F_3) recorded the highest value for each of grain protein content (%), N and P uptake which has an average of both seasons valued as much as 11.03%, 53.64 and 10.22 kg/fad, respectively; followed by application of 23kg P + 90 Kg N (F_2) which got averages of protein content, N and P uptake amounted as 10.65%, 45.63 and 8.69 kg/fad, respectively. Inferiority each of grain protein (%), nitrogen and phosphorus uptake in both seasons was in conjugate with nitrogen and phsphorus deficiency in the check treatment (F_0). Obtained results go along with those of Khattab *et al.* (2016) , Kakraliya *et al.* (2017) and Khadhum *et al.* (2021) as well as Mona Hussein and Hala El-Sayed (2023) on wheat.

Bio-fertilizers also affected significantly on wheat grain quality wherein supplying B_3 (Cerealine+Phosphorein) recorded the highest combined values for each of protein content (11.38%), N and P uptake (51.5 and 9.5 kg/fad) respectively. Applying Cerealine singly (B_1) came in the second rank getting averages of 10.95% protein and 45.63 kg nitrogen uptake/fad, while applying Phosphorein solitary (B_2) achieved the second higher grain phosphorus uptake (8.7 kg./fad). These results assure the vital role of phosphorus solublizing bacteria (Phosphorein) in P availability and hence P uptake increased.

Table 7. Grain protein content (%), grain N uptake (kg/ fad) and grain P uptake (kg/fad) as affected by mineral and bio fertilization treatments in 2020-21 and 2021-22 winter seasons

Treatment	Grain protein content (%)		Grain N uptake (kg/ fad)		Grain P uptake (kg/fad)	
	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
Mineral fertilization (F)						
Check (F0)	10.26 c	10.49 c	35.95 c	37.22 c	8.53 b	8.65 b
15.5 kg p + 60 kg N (F1)	10.64 b	10.73 b	44.88 b	45.69 b	6.69 c	7.00 c
23 kg p + 90 kg N (F2)	10.61 b	10.69 b	45.02 b	46.26 b	8.64 b	8.75 b
31 kg p + 120 kg N (F3)	11.05 a	11.00 a	53.68 a	53.59 a	10.25 a	10.19 a
F. test	*	*	*	*	*	*
LSD 0.05	0.20	0.15	0.94	0.71	0.23	0.13
Bio fertilization (B)						
Check (B0)	9.92 d	10.16 d	38.60 d	40.54 d	7.46 c	7.74 c
Cerealiene (B1)	10.85 b	11.05 b	46.36 b	47.62 b	8.58 b	8.42 b
Phosphorein (B2)	10.37 c	10.39 c	43.40 c	42.67 c	8.65 b	8.56 b
Cerealiene + Phosphorein (B3)	11.42 a	11.34 a	51.17 a	51.84 a	9.41 a	9.62 a
F. test	*	*	*	*	*	*
LSD 0.05	0.18	0.26	0.39	0.60	0.75	0.21
Interaction (F * B)	*	*	NS	* *	NS	*

At the 5% and 1% probability levels, * and ** denote significance; NS denotes not significant.

Interaction effects

Results in Tables (3,4 and 5) clarify that the interaction between mineral and bio fertilization treatments affected operatively each of No. of spikes/m^2, grain yield (ardab/fad) straw yield (tonne/fad), harvest index (%) and grain protein content (%) in both seasons as well as grain N and P uptake in the 2nd season. Table (8) introduces the impact of the interaction among mineral and bio-fertilization treatment on the above named traits.

The interaction between the highest level of mineral fertilizers (31 kg P_2O_5/fad+ 120 kg N/fad) *i.e.* F_3 and the dual inoculation (Cerealine+Phosphorein) *i.e.* B_3 promoted distinctly wheat grain and straw yields, No. of spikes/m^2, harvest index, N and P uptake as well as grain protein content.

Table 8. Effect of interactions among mineral and bio fertilization treatments on No. of spikes/m^2, grain yield (ardab/fad), straw yield (tonne/fad), harvest index (%), grain N and P uptake (kg/ fad) and grain protein content (%), in 2020-21 and 2021-22 winter seasons

Treatments		No. of spikes/m^2		Grain Yield (tons/fad)		Straw Yield (tons/fad)		Harvest index (%)		N uptake (Kg/fad)	P uptake (Kg/fad)	Grain protein content (%)	
Mineral Fertilization	Bio fertilization	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22	2021/22	2021/22	2020/21	2021/22
Check (F0)	Check (B0)	503.00 bc	500.63 b	13.62 j	12.28 m	4.80 e	5.18 de	30.87 i	33.20 f	33.04 m	7.84 g	9.56 f	9.88 e
	Cerealiene (B1)	524.46 ab	513.33 ab	15.74 i	14.23 l	5.11 b	5.48 d	33.03 h	37.53 cd	38.82 k	8.32 f	10.45 d	11.62 a
	Phosphorein (B2)	517.55 ab	519.90 a	17.71 g	15.97 k	5.07 bc	5.32 d	34.17 g	36.33 c	34.78 l	8.66 e	9.99 e	10.10 e
	Cerealiene + Phosphorein (B3)	520.25 ab	518.60 ab	18.43 f	16.40 j	5.31 b	5.69 cd	35.46 f	36.47 c	42.26 i	9.72 c	11.00 c	11.03 bc
15.5 kg p + 60 kg N (F1)	Check (B0)	460.21 d	461.60 ab	16.34 h	16.68 j	4.18 de	5.22 d	35.48 f	35.42 e	40.56 j	6.34 j	9.91 e	10.11 de
	Cerealiene (B1)	479.84 c	471.33 e	18.81 e	19.27 i	4.46 d	5.52 cd	38.69 d	37.00 d	47.65 g	6.88 i	10.84 c	10.99 bc
	Phosphorein (B2)	473.52 c	479.37 c	21.10 d	21.54 g	4.42 d	5.37 d	40.02 c	38.77 bc	42.70 i	7.01 h	10.36 d	10.33 de
	Cerealiene + Phosphorein (B3)	475.99 c	478.18 d	21.94 c	22.11 f	4.63 cd	5.74 cd	41.54 ab	38.93 b	51.87 d	7.87 g	11.41 b	11.28 b
23 kg p + 90 kg N (F2)	Check (B0)	513.87 bc	512.23 ab	18.36 f	19.58 i	4.91 c	5.57 cd	35.94 f	37.41 cd	41.07 j	7.93 g	9.88 e	10.07 e
	Cerealiene (B1)	535.80 a	523.02 a	21.09 d	22.51 e	5.23 b	5.89 c	39.19 c	39.08 b	48.24 f	8.60 e	10.81 c	10.95 c
	Phosphorein (B2)	528.74 a	531.95 a	23.62 b	25.12 c	5.19 b	5.72 cd	40.54 bc	40.96 a	43.23 h	8.76 e	10.33	10.30 de
	Cerealiene + Phosphorein (B3)	531.50 a	530.62 a	24.55 a	25.78 b	5.43 b	6.11 b	42.08 a	41.13 a	52.5 c	9.84 c	11.38 b	11.24 bc
31 kg p + 120 kg N (F3)	Check (B0)	515.08 bc	508.52 ab	18.47 f	20.29 h	5.29 b	6.03 bc	36.52 e	37.97 c	47.58 g	9.23 d	10.29 d	10.36 de
	Cerealiene (B1)	537.05 a	519.23 ab	21.21 d	23.32 d	5.63 a	6.58 a	39.81 c	39.67 b	55.89 b	10.01 b	11.26 b	11.27 b
	Phosphorein (B2)	529.98 a	528.09 a	23.76 b	26.01 b	5.58 a	6.40 ab	41.19 b	41.58 a	50.08 e	10.2 b	10.76 c	10.59 d
	Cerealiene + Phosphorein (B3)	532.75 a	526.78 a	24.69 a	26.69 a	5.85 a	6.83 a	42.76 a	41.75 a	60.84 a	11.45 a	11.85 a	11.56 a
LSD 0.05		12.25	12.19	0.033	0.035	0.04	0.031	0.79	0.81	0.64	0.20	0.18	0.25

Excellency of wheat spike number/m^2 was exist under the following interactions *q.e.* $F_0 \times B_1$, $F_0 \times B_2$, $F_0 \times B_3$; $F_2 \times B_1$, $F_2 \times B_2$, $F_2 \times B_3$; besides $F_3 \times B_3$, wherein the variation, inbetween were insignificant. Superiority of harvest index in both seasons were co-ordinate under the interaction effect between $F_2 \times B_3$ as well as $F_3 \times B_3$.

Odds of the interaction impact between the highest level of the mineral fertilizers (F_3, 31 kg P_2O_5/fad+ 120 kg N/fad) and the combined inoculation (B_3, Cerealine+ Phosphorein) on grain and straw yields, most yield attributes and grain quality traits could be ascribed to the availability of nitrogen and phosphorus from the mineral fertilizers to meet the plants rapid needs. Besides the N and P bio-fertilizers keep up the incessant availability of N and P on the long term. Abdel-Lateef (2018) manifested that the interaction between the mineral fertilization by N,P and K at 80% of the recommended level and the bio-fertilizers (Bio-green Markel) produced the outmost grain and straw yields.

Economic Feasibility

Results presented in Table 9 shows the average value of combined grain and straw yields (plant economical products) over the tow sowing seasons. the value of variation in yields was calculated as percentage from the "control" treatments. Costs of applying the study treatments and its revenue were evaluated and the final net revenue was calculated as in Table 9. Comparing costs with net revenue were expressed by figure 1.

The results indicated that the more increase in mineral fertilizers levels accompanied with using bio-fertilizers, the more grain and straw yields increases generally. However, the rate of increase after applying the highest level of mineral N and P decreased besides that there is no significant increase in net revenue attributed to the excessive dose of mineral N and P.

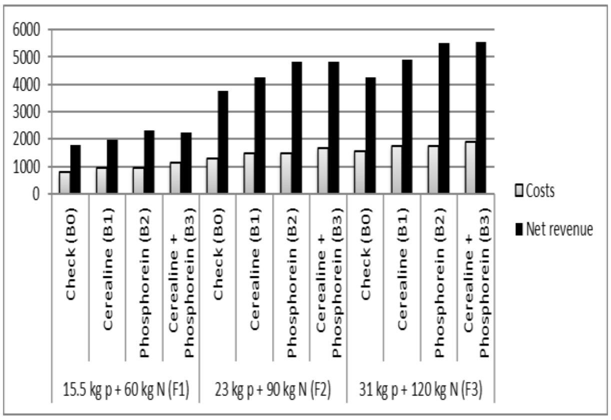

Fig. 1. Costs and net revenue of study treatments

Table 9. Economical feasibility for all study treatments and net revenue

Treatments		Combined grain yield			Combined straw yield			Value of total		
		(ardab/fed)	Increase		(tons/fed)	Increase		Increase	Costs	Net revenue
Mineral fertilization	Bio-fertilization		%	Value (LE)		%	Value (LE)	(LE/fad)		
Check (F0)	Check (B0)	12.95	--	--	4.99	--	--	--	--	--
	Cerealiene (B1)	14.985	--	--	5.29	--	--	--	--	--
	Phosphorein (B2)	16.84	--	--	5.19	--	--	--	--	--
	Cerealiene + Phosphorein (B3)	17.415	--	--	5.5	--	--	--	--	--
15.5 kg p + 60 kg N (F1)	Check (B0)	16.51	27.49	2848	4.7	-5.81	-232	2616	782.5	1833.5
	Cerealiene (B1)	19.04	27.06	3244	4.99	-5.67	-240	3004	957.5	2046.5
	Phosphorein (B2)	21.32	26.6	3584	4.895	-5.68	-236	3348	957.5	2390.5
	Cerealiene + Phosphorein (B3)	22.025	26.47	3688	5.185	-5.73	-252	3436	1132.5	2303.5
23 kg p + 90 kg N (F2)	Check (B0)	18.97	46.49	4816	5.24	5.01	200	5016	1300	3716
	Cerealiene (B1)	21.8	45.48	5452	5.56	5.1	216	5668	1475	4193
	Phosphorein (B2)	24.37	44.71	6024	5.455	5.11	212	6236	1475	4761
	Cerealiene + Phosphorein (B3)	25.165	44.5	6200	5.77	4.91	216	6416	1650	4766
31 kg p + 120 kg N (F3)	Check (B0)	19.38	49.65	5144	5.66	13.43	536	5680	1565	4115
	Cerealiene (B1)	22.265	48.58	5824	6.105	15.41	652	6476	1740	4736
	Phosphorein (B2)	24.885	47.77	6436	5.99	15.41	640	7076	1740	5336
	Cerealiene + Phosphorein (B3)	25.69	47.52	6620	6.34	15.27	672	7292	1915	5377

Average price of wheat grains during the tow sowing seasons = 800 LE (Eg. Pound)/ardab (150 kg), average price of wheat straw = 1000 LE /tons

Fitting yield - mineral fertilizer level response

The relation between wheat grain yield and the levels of applied mineral N and P was stimulated (figure 2) using SPSS Statistical tool for windows (SPSS Inc; 2008). It was found that the response of grain yield to both N and P was a linear regression presented by an equation from the first order as follows:

$$\text{Grain yield (ardab/fad)} = 0{,}06615\ N + 15.76 = 0{,}02564\ P + 15.77$$

where,

N and P are the applied levels of nitrogen and phosphorus in units.

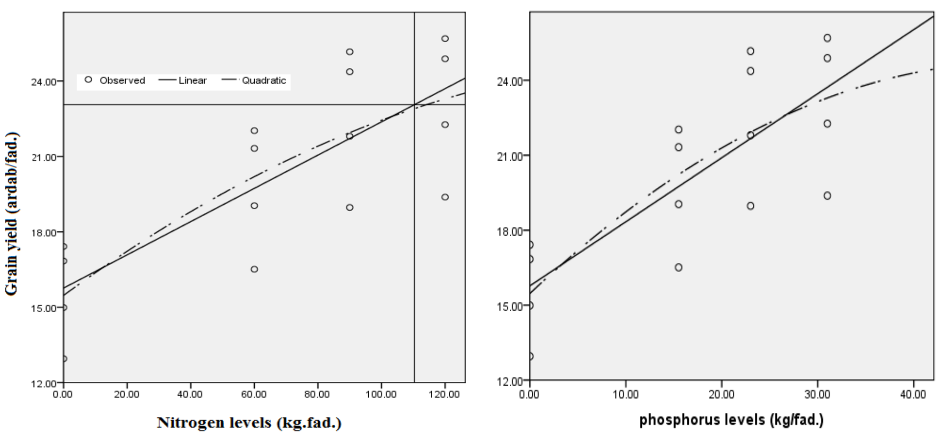

Fig. 2. Regression of grain yield on mineral N and P levels

From the equation above mentioned, it is clear that wheat grain yield without N or P application is approximately

15.75 ardab/fad, and the contribution of N and P is evaluated by multiplying the slope of regression (0.06615 and 0.02564) by the number of units applied from N and P, respectively.

A level-response curve was fitted using GraphPad Prism to estimate the optimum level of both N and P which is capable to provide the best growth and hence, the maximum productivity (figure 3). The predicted maximum grain yield evaluated by 23.06 ardab/fad was obtained from applying 110.35 kg N/fad; while the optimum level of P achieving the maximum productivity (28.82 kg. P/fad) is 23.16 ardab/fad Increasing levels of nitrogen and phosphorous may cause an adverse effect on grain yield.

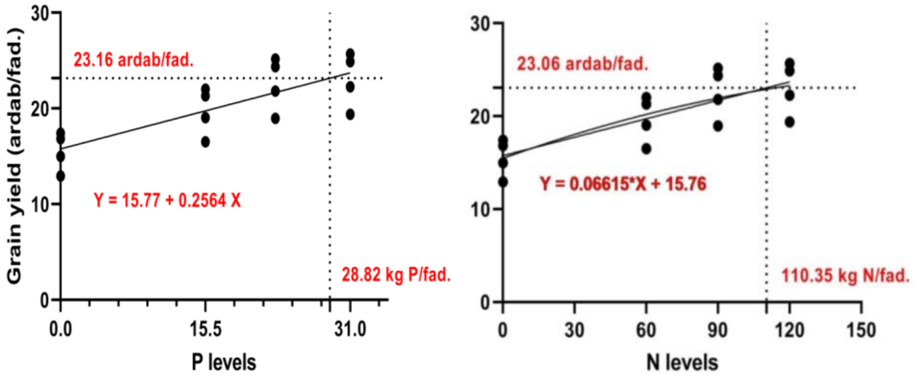

Fig. 3. Dose response curve for grain yield in a function of N and P levels

CONCLUSION

Mineral and bio-fertilization has a significant effects on plant growth parameters (yield attributes), and yield components; and hence the final dry matter productivity which is translated into grain and straw yields. The interaction between mineral and bio-fertilization treatments should be taken into account because however it is significant, but the excessive use of mineral fertilization affects negatively in microorganisms activity.

RECOMMENDATION

Based on the study results, it is recommended to add 110.35 kg mineral N/ fad and 28.82 kg mineral P/ fad, and as well, adding both N and P bio fertilizers to obtain the highest grain yield with the higher quality needed.

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تأثيرالجمع بين الأسمدة المعدنية والحيوية على إنتاجية القمح (*Triticum aestivum vulgare* L) والجدوى الاقتصادية لها

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الملخص

أُجريت تجرُبتان حقليتان خلال فصلي الشتاء للأعوام 2020-2021 و2021-2022، بالمزرعة البحثيه بمحطة تاج العز، مركز البحوث الزراعية، محافظة الدقهلية، مصر، بهدف دراسة تأثير أربع توليفات من التسميد المعدنى لعنصرى النيتروجين والفوسفور ، وأربع معاملات من النيتروجين والفوسفور الحيويين - بالإضافة إلى التفاعلات بينها- على نمو القمح والمحصول ومكوناته، بالإضافة إلى تقدير محتوى بروتين الحبوب وامتصاص النيتروجين والفوسفور. كما تم حساب الجدوى الإقتصاديه لهذه المغاملات تحت الدراسة. تم استخدام تصميم القطع المنشقه مرة واحدة في ثلاث مكررات لتنفيذ التجربه. أظهرت النتائج التأثيرات المعنوية لمعاملات التسميد المعدني والحيوي على جميع الصفات المدروسة. حقق 31 كجم وحدة فوسفور بالإضافة إلى 120 كجم نيتروجين/ فدان، تفوقًا في معظم الصفات المدروسة مما أدى إلى زيادة محصول الحبوب مقارنة بالمعاملات الأخرى. سجلت المُعامله ذاتها (31 كجم وحدة فوسفور بالإضافة إلى 120 كجم نيتروجين/ فدان) أعلى محصول حبوب ومؤشر حصاد في كلا الموسمين، وأعلى مؤشر حصاد فقط في الموسم الأول. حققت إضافة كلٍ من النيتروجين الحيوي والفوسفور الحيوى إلى أعلى قيم لمكونات المحصول، وبالتالي، أعلى إنتاجية حبوب وقش. كان محتوى البروتين وامتصاص النيتروجين والفوسفور الأعلى نتيجة إضافة 31 كجم وحدة فوسفور بالإضافة إلى 120 كجم نيتروجين/ فدان. كان التفاعل بين معاملات التسميد المعدني والحيوي معنوياً لصالح التوليفه (31 كجم وحدة فوسفور بالإضافة إلى 120 كجم نيتروجين/ فدان + النيتروجين الحيوي والفوسفور الحيوى)؛ ومن الناحية الاقتصادية، فقد حققت مستويات التسميد المعدنى والحيوى زيادة إنتاجية الفدان من الحبوب والقش دون زيادة معنويه في صافي الإيرادات. بتقدير منحنى الإستجابه (الجرعه مقابل المحصول) فإنه يُوصى بإضافة 110.35 كجم نيتروجين/ فدان و 28.82 كجم فوسفور/ فدان مع السماد الحيوى بكلٍ من النيتروجين والفوسفور، للحصول على أعلى محصول كماً ونوعاً.