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RESEARCH

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Synergistic effect of P and K interaction on yield and yield components of mungbean (*Vigna radiata* (L.) Wilczek) varieties

E. M. Abd El Lateef[1*], Asal M. Wali[2] and M. S. Abd El-Salam[1]

Abstract

Background: The relation between the macronutrients P and K seems to be synergistic due to the beneficial effects of the interaction between (P × K) and varies according to the variety used. Therefore, two field experiments were conducted during 2018 and 2019 summer seasons to study the effect of interaction of phosphatic fertilization at 0, 37.5 and 75 kg P_2O_5 ha^{-1} and potassic fertilization at 0 and 57.6 kg K_2O ha^{-1} on the yield and yield components of two mungbean varieties, viz. Kawmy-I and V2010, as well as determining the relationship between the two nutrients interaction.

Results: The results showed that there were varietal differences in yield and yield components regardless fertilizer application. Either phosphatic or potassic fertilization significantly increased mungbean yield and yield components traits. Significant effects due to the interaction (V × P) were reported on yield component traits in both seasons. Furthermore, the triple interaction (V × P × K) indicates that synergistic effect was reported for the two varieties and was more clearer for V2010 where it needed both of P and K nutrients to out yield the greatest seed yield ha^{-1}, while Kawmy-1 gave the greatest seed yield ha^{-1} without K application.

Conclusion: It could be concluded from this study that mungbean varieties differ in their response to the synergistic interaction effect of P and K and the combination of 75 kg P_2O_5 + 57.6 kg K_2O is preferable for V2010 and 75 kg P_2O_5 alone for Kawmy-1 to produce the greatest yield.

Keywords: Mungbean, Phosphorus, Potassium, Synergistic effect, Yield

Background

Mungbean (*Vigna radiata* (L.) Wilczek) is regarded as a promising crop in several countries, *i.e.*, Australia and China (Imrie and Lawn 1991), Egypt (Hozayn et al 2013; Abd El-Llateef et al. 2015). Abd El-Lateef et al. (2020) evaluated the potentiality of incorporating mungbean as a new crop in the crop structure in the Egyptian agriculture and found its suitability for different cropping purposes.

It is an important edible legume in the human diet worldwide, Yin et al (2018) and Mahgoub et al (2020). Mungbean is a symbiotic legume that fixes N as well as its high content of the nutritive elements Frauque et al (2000). Mungbean seems to be responsive to phosphatic fertilization, Abd El-Lateef et al (2012). It is essential in many metabolic processes and wide variety of biochemicals, Khan et al (2003) and Havlin et al (2004). El-Karamany (1997) under Egyptian conditions reported increases in mungbean yield up to 62 kg P_20_5 ha^{-1}. However, with such high phosphatic fertilizer level a depression in yield response to N may occur Chatterjee and Bhattacharrya (1986). On the other hand, Ikombo (1989) suggested that the sub-optimal P supply to mungbean plants may depress the symbiotic N fixation. Therefore,

*Correspondence: profabdellateef@gmail.com
[1] Field Crops Research Dept., Agricultural Division, National Research Centre, 33 El-Behooth St, Giza, Egypt
Full list of author information is available at the end of the article

adjusting P level may achieve sustainable nutritional balance for mungbean. Meanwhile, potassium is another important macronutrient which is recommended for mungbean in conjugation with N and Buriro et al (2015) reported the role of K on yield and yield components of crops. The recommended rates of potassium fertilization in Thailand range from 35 kg K ha^{-1} in the soils yielding > 800 kg ha^{-1} to 50 kg K ha^{-1} in the soils yielding < 800 kg ha^{-1} (FAO 2016). Some reports indicated that mungbean yield could be increased due to K application, Tariq et al (2001), Naeem et al (2006) and Abdalgafor and Al-Jumaily (2016).

Synergistic effects are expressed as the yield expected (y_{ab}) on the basis of the individual responses to the nutrients which could be determined by using relative yields, Wallace (1990), while antagonism refers to the yield in response of two nutrients in which the combined effect is less than expected from the individual responses Fageria (2001) and Fageria et al. (2001) and Aulakh and Malhi (2005).

The relation between P and K seems to be synergistic due to the beneficial effects of the interaction between (P × K). Abd El-Lateef (1996) found beneficial effects of the interaction (P × K) on mungbean seed yield per plant and per hectare compared with the untreated control. These responses of mungbean to K were attributed to the nutritional status of mungbean during the stage of early pod formation which was relevant for mungbean to benefit from the K applied.

Most of the yield of mungbean is produced under rainy areas mainly in southern east countries of Asia Lawn and Ahn (1985), and fertilizer requirements under such conditions are not relevant to arable lands. In Egypt, few reports dealt with mungbean fertilizer interactions. Thus, the aim of this work is to study the effect of phosphatic and potassic fertilizers interaction on the yield and yield components of mungbean varieties as well as determining the relationship between the two nutrients if it is antagonism or synergism.

Methods

Two field experiments were conducted during 2018 and 2019 summer seasons in clay soil at private farm El Aiatt District, Giza Governorate, Egypt. The experimental soil was clay in texture with pH 7.8, OM 1.28%, N 0.47%, P 0.48% and K 0.27% (average of two seasons). Mungbean (*Vigna radiata* (L.) Wilczek) variety Kawmy-l and imported V2010 strain were used in the study. The experiments included 12 treatments which were the combinations of the above-mentioned mungbean varieties, three phosphatic fertilizer levels, i.e., 0, 37.5 and 75 kg P_2O_5 ha^{-1}, as well as two potassium fertilizer levels, i.e., 0 and 57.6 kg K_2O ha^{-1}. The experimental design was split–split plot with four replicates where the main plots were assigned to the mungbean varieties, the phosphatic fertilizer levels were allocated in the sub-plots and the potassium fertilizer levels in the sub-sub-plots. The soil was ploughed twice, ridged and divided to experimental units each of 18 m^2 area. During seed-bed preparation, the phosphatic fertilizer levels were applied as calcium superphosphate 15.5% at 0, 37.5 and 75 kg P_2O_5 ha^{-1}. Mungbean seeds were inoculated with the specific *Rhizobium* strain and immediately sown in hills on both sides of the ridge at 15 cm space to attain the theoretical number of plants (440×10^3 plants ha^{-1}). A starter dose of nitrogen at the rate of 36 kg N ha^{-1} was applied as ammonium nitrate (33.5% N) just before the first irrigation took place. Two weeks later the plants were thinned and two plants were left per hill, and before the second irrigation (35 days from sowing). The potassic fertilizer was applied at the rate of 0 and 57.6 kg K_2O as potassium sulfate (48–52% K_2O). Weeds were controlled manually twice after 18 and 32 days from sowing, and irrigation was carried out every two weeks.

At maturity, two harvests for the mature pods were carried out after 80 and 95 days from sowing. A random sample of 10 guarded plants from each experimental unit was taken at 95 days from sowing, and the following characters were studied: 1—Number of branches $plant^{-1}$. 2—Number of mature pods $plant^{-1}$. 3—Number of seeds pod^{-1} 4—1000-seeds weight (g). 5—Seed yield $plant^{-1}$ (g). 6—Seed yield ha^{-1} at 80, and 95 days from sowing and the total seed yield ha^{-1} (kg). The two central ridges of each experimental unit were devoted for the determination of seed yield ha^{-1}.

Synergistic effects determination

The calculation of the expected yield (y_{ab}) as a product of the individual responses according to Eq. (1) is based on Wallace (1990) by using relative yields. Synergistic or antagonistic effects determination was carried out by calculating the yield expected (y_{ab}) on the basis of the individual responses (y_a and y_b) for both P and K.

$$\left(y_{ab}/y_0 = y_a/y_0 \times y_b/y_0\right) \quad (1)$$

where y_0 is the yield of control treatment, the yield expected (y_{pk}) on the basis of the individual responses (y_p and y_k) as a product of the individual responses of P and K according to Eq. (1).

The statistical analysis

The obtained results were subjected to the proper statistical analysis of the split–split plot design as described by MSTAT-C (1988). For means comparison, least significant differences (LSD) at 5% probability level were used.

Results

Varietal differences

Data presented in Table 1 show significant differences between Kawmy-1 and V2010 varieties in number of branches, number of mature pods and seed yield per plant in 2018 season as well as 1000-seeds weight and seed yield per ha in both seasons. The V2010 variety surpassed Kawmy-1 in number of branches in both seasons; however, the later variety possessed greater significant number of mature pods plant^{-1} in 2018 season. Kawmy-1 gave greater seed yield per plant than that of V2010 in both seasons. The increase in seed yield per plant was significant in 2018 season. The data also show that most of the harvestable seed yield ha^{-1} was obtained at the first harvest at 80 days from sowing. Kawmy-l variety significantly surpassed V20l0 in seed yield ha^{-1} at the second harvest (95 days

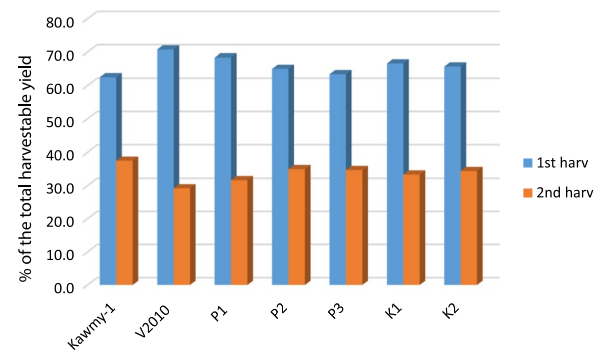

Fig. 1 Effect of variety, P and K fertilizer on mungbean seed yield percentage at the 1st, 2nd harvest of the total seed yield (combined mean of 2018 and 2019 seasons)

Table 1 Effect of variety, phosphatic and potassic fertilizer levels on mungbean yield and yield components

Treatment	No. of branches plant^{-1}	No. of mature pods plant^{-1}	No. of seeds pod^{-1}	Seed yield plant^{-1} (g)	1000-seeds weight (g)	Seed yield ha^{-1} (kg)		
						80 days	95 days	Total
2018								
Variety (V)								
Kawmy-l	5.7	17.3	12.2	8.63	45.3	1327	956	2283
V2010	6.0	10.5	11.2	5.93	68.9	1243	391	1634
LSD 5%	0.2	4.8	Ns	0.96	4.56	Ns	205	275
Phosphatic fertilizer p (kg P_2O_5 ha^{-1})								
0	5.85	13.3	11.8	7.41	55.4	1218	571	1789
37.5	6.00	16.8	11.9	7.53	57.1	1305	704	2009
75.0	5.70	11.5	11.8	6.87	58.9	1332	747	2079
LSD 5%	Ns	2.5	Ns	Ns	Ns	Ns	98	192
Potassic fertilizer K (kg K_2O ha^{-1})								
0	5.43	12.5	11.2	6.54	55.8	1231	603	1834
57.5	6.25	15.3	11.8	7.99	58.4	1340	743	2083
LSD 5%	Ns	1.9	0.3	0.50	Ns	Ns	68	222
2019								
Variety (V)								
Kawmy-l	4.7	10.0	11.7	5.5	39.9	1162	537	1699
V2010	4.8	12.2	12.3	4.6	62.8	928	504	1432
LSD 5%	Ns	Ns	Ns	Ns	4.6	135	Ns	238
Phosphatic fertilizer p (kg P_2O_5 ha^{-1})								
0	3.7	8.4	11.6	3.8	47.4	904	410	1314
37.5	4.8	11.8	12.1	5.2	55.5	1060	568	1628
75.0	0.4	12.1	12.4	6.2	51.2	1098	583	1681
	0.4	3.1	Ns	0.6	2.6	92	58	145
Potassic fertilizer K (kg K_2O ha^{-1})								
0	4.5	11.0	11.7	4.9	49.3	1027	526	1553
57.5	4.9	11.2	12.3	5.3	53.4	1062	514	1576
LSD 5%	Ns	Ns	Ns	0.4	Ns	Ns	Ns	Ns

from sowing) in 2018 seasons and at the first harvest (80 days from sowing) in 2019 season as well as the total seed yield in both seasons (Fig. 1).

Effect of phosphatic fertilization

Data in Table 1 and Fig. 2 show positive effects on mungbean yield and yield components due to the phosphatic fertilization. Such effects were significant on the characters of number of pods plant^{-1} and seed yield at 95 days from sowing as well as the total seed yield per ha in 2018 season, while, in 2019 season, with the exception for number of seeds pod^{-1}, mungbean yield and yield components were significantly affected by phosphatic fertilization. Application of 75 kg P_2O_5 ha^{-1} gave the greatest number of branches plant^{-1} in 2018 seasons, while number of mature pods plant^{-1} showed better response to phosphatic fertilization up to 37.5 kg P_2O_5 ha^{-1} in both seasons. Seed yield per plant was not significantly affected in 2018 season, but the greatest increase in 2019 season resulted from the application of 75 kg P_2O_5 ha^{-1}. Seed yield ha^{-1} increased significantly in the second harvest as well as the total seed yield in both seasons by phosphatic application up to 37.5 kg P_2O_5 ha^{-1}.

Effect of potassic fertilization

Data given in Table 1 and Fig. 2 show that potassium application at 57.6 kg K_2O ha^{-1} significantly increased number of mature pods plant^{-1} and number of seeds plant^{-1} in 2018 season and seed yield plant^{-1} in both seasons. In addition, seed yield ha^{-1} at the second harvest (95 days) and the total seed yield ha^{-1} in 2018 were also increased significantly by K application.

The interaction effects

Data presented in Table 2 show significant differences due to the interaction between variety and P level on number of mature pods plant^{-1}, 1000 seed weight, seed yield per plant and per ha in 2018 and 2019 seasons. Kawmy-l variety gave the highest number of branches and mature pods plant^{-1} at 37.5 kg P_2O_5 ha^{-1} in 2018 season, while the characters of seed yield per plant and per ha at 80 days showed better response to the highest p level (75 kg P_2O_5 ha^{-1}). In 2019 season, except number of branches and seed yield per plant the other yield components were better when Kawmy-l plants were fertilized with 37.5 kg P_2O_5 ha^{-1}. The variety V2010 showed the best response to P at 37.5 kg P_2O_5 ha^{-1} which reflected on the number of seeds pod^{-1}, 1000-seeds weight, seed yield per plant and per ha in both seasons. With regard to the total seed yield ha^{-1}, the data show that Kawmy-l in both seasons and V20l0 in 2019 season gave the highest seed yield ha^{-1} at 75 kg P_2O_5 ha^{-1}, which was statistically insignificant with the level 37.5 kg P_2O_5 ha^{-1}.

The data of the interaction effect between variety and potassium application are given in Table 2. Application of 57.6 K_2O ha^{-1} to Kawmy-l and V2010 varieties led to significant increases in number of mature pods, seed yield per plant, seed yield at 95 days and the total seed yield ha^{-1} in 2018 season. However, in 2019 season, the interaction between potassium application and mungbean varieties on 1000 seeds weight in 2019 season was significant. Moreover, the apparent increases in the total seed yield ha^{-1} due to K application for V20l0 in both seasons and Kawmy-l in 2019 season were insignificant.

Data in Table 2 show that the interaction (P × K) significantly increased number of branches plant^{-1} in 2019 seasons. The yield components of seed yield per plant, 1000-seeds weight as well as seed yield per ha at 80, 95 days and the total seed yield were significantly increased due to the interaction (P × K) in both seasons. The highest seed yield plant^{-1} was obtained by mungbean fertilizing with 57.6 kg K_2O alone or the phosphatic fertilization with 75 kg P_2O_5 in 2018 and 2019 seasons, respectively. Similar magnitude was recorded for seed yield per ha^{-1} in both seasons.

Data in Table 3 show significant effects due to the triple interaction on number of mature pods, seed yield per plant 1000-seeds weight in both season as well as the total seed yield ha^{-1} in 2018 season. The greatest seed yield ha^{-1} was attained through P application at 75 kg P_2O_5 ha^{-1}, alone or P at 37.5 kg P_2O_5 ha^{-1} combined with 57.6 kg K_2O ha^{-1}, for Kawmy-l variety, while application of 57.6 kg K_2O ha^{-1} alone or combined with 37.5 kg P_2O_5 ha^{-1} resulted in the highest seed yield for V2010 in 2018 season without significant difference. In 2019, the interaction effect on seed yield ha^{-1} was significant and application of 75 kg P_2O_5 + 57.6 kg K_2O gave the highest seed yield for both varieties.

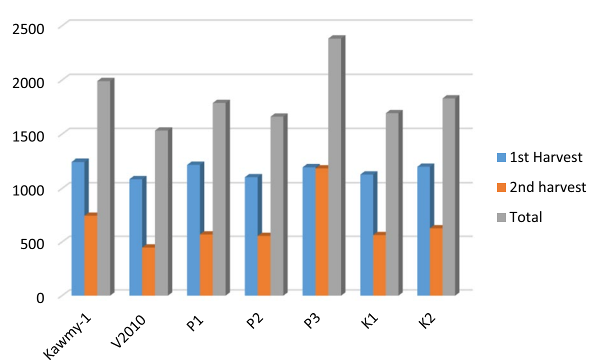

Fig. 2 Effect of variety, P and K fertilizer on Mungbean seed yield (kg ha^{-1}), combined mean of 2018 and 2019 seasons

Table 2 Effect of interactions (V × P), (V × K) and (P × K) on mungbean yield and yield components

Treatment		No. of branches plant^{-1}	No. of mature pods plant^{-1}	No. of seeds pod^{-1}	Seed yield plant^{-1} (g)	1000-seeds weight (g)	Seed yield (kg ha^{-1})		
							80 days	95 days	Total
Variety	P level	2018 *(V × P)*							
Kawmy-1	0.0	5.8	17.6	13.0	9.64	44.7	1213	781	1994
	37.5	6.5	20.6	13.0	8.51	45.3	1268	1012	2280
	75.0	6.3	15.0	12.6	9.16	47.6	1501	1028	2529
V2010	0.0	7.0	10.0	11.5	6.17	67.1	1225	358	1583
	37.5	6.5	14.1	11.7	7.55	69.9	1342	348	1690
	75.0	6.1	9	12.0	5.57	71.1	1163	465	1628
LSD at 0.05		Ns	2.2	Ns	0.5	2.1	Ns	210	140
Variety	K level	*(V × K)*							
Kawmy-1	0.0	5.7	16.6	12.6	8.60	44.2	1338	836	2174
	57.6	6.7	18.9	12.8	8.61	47.5	1317	1044	2361
V2010	0.0	6.2	9.3	11.7	5.48	68.3	1123	338	1461
	57.6	6.8	12.7	11.7	7.38	70.3	1363	444	1807
LSD at 0.05		Ns	1.9	0.7	1.8	Ns	Ns	218	210
P level	K level	*(P × K)*							
0.0	0.0	5.9	9.7	12	5.87	54.5	1003	461	1464
	57.6	6.8	17.9	12.1	9.94	57.3	1435	679	2114
37.5	0.0	5.7	19.9	12.3	7.07	56.5	1263	633	1896
	57.6	7.4	16.8	12.3	8.99	58.6	1347	775	2122
75.0	0.0	6.3	8.58	12.2	8.17	57.8	1427	717	2144
	57.6	6.2	12.7	12.4	6.56	60.9	1237	557	1794
LSD at 0.05		Ns	2.5	Ns	0.5	1.9	210	140	273
Variety	P level	2019 *(V × P)*							
Kawmy-1	0.0	4.2	9.5	12.7	3.61	38.2	970	392	1362
	37.5	5.3	14.0	12.8	4.90	41.4	1178	636	1814
	75.0	6.4	13.4	13.0	6.50	41.6	1337	583	1920
V2010	0.0	4.2	8.2	11.4	4.60	57.5	838	428	1266
	37.5	5.3	10.5	12.4	6.45	70.6	942	501	1443
	75.0	5.9	12.9	12.8	6.95	61.8	1003	1807	2810
LSD at 0.05		0.9	0.7	Ns	0.6	1.0	166	154	234
Variety	K level	*(V × K)*							
Kawmy-1	0.0	5.1	12.8	12.5	4.9	39.9	1166	542	1708
	57.6	5.4	12.5	13.1	5.3	40.9	1158	529	1687
V2010	0.0	4.9	10.2	11.9	5.8	59.6	889	508	1397
	57.6	5.9	12.6	11.9	6.9	66.9	967	502	1469
LSD at 0.05		Ns	Ns	Ns	Ns	3.7	Ns	Ns	Ns
P level	K level	*(P × K)*							
0.0	0.0	4.1	9.2	11.5	4.0	46.5	874	390	1264
	57.6	4.4	13.3	12.6	4.5	49.2	926	430	1356
37.5	0.0	5.0	12.1	12.5	5.4	51.8	1067	608	1675
	57.6	5.6	12.4	12.7	6.0	60.2	1054	529	1583
75.0	0.0	6.3	14.1	12.8	6.7	50.9	1129	583	1712
	57.6	6.2	13.2	13	6.8	52.4	1211	590	1801
LSD at 0.05		0.7	Ns	Ns	1.1	1.5	166	154	234

Table 3 Effect of interaction (V × P × K) on mungbean yield and yield components

Variety	P_2O_5 (kg/ha)	K_2O (kg/ha)	No. of branches plant^{-1}	No. of mature pods plant^{-1}	No. of seeds pod^{-1}	Seed yield plant^{-1} (g)	1000-seeds weight (g)	Seed yield (kg ha^{-1})		
								80 days	95 days	Total
2018										
Kawmy-l	0.0	0.0	4.9	11.0	12.6	6.4	43.1	1170	697	1867
		57.6	6.7	24.2	12.5	12.9	46.2	1255	984	2239
	37.5	0.0	5.6	23.8	12.8	7.7	44.1	1242	997	2239
		57.6	7.4	17.4	13.1	9.3	46.4	1295	1124	2419
	75.0	0.0	6.6	15.0	12.5	11.7	45.3	1603	1031	2634
		57.6	6.0	15.0	12.7	6.6	49.9	1400	1025	2425
V2010	0.0	0.0	6.9	8.4	11.4	5.4	65.8	1051	345	1396
		57.6	6.9	11.6	11.6	7.3	67.5	1611	401	2012
	37.5	0.0	5.7	12.0	11.8	6.4	68.9	1284	269	1553
		57.6	7.3	16.1	11.5	8.7	70.8	1400	427	1827
	75.0	0.0	5.9	7.6	11.9	4.6	70.3	1251	402	1653
		57.6	6.3	10.4	12.1	6.5	71.9	1075	529	1604
LSD at 0.05			Ns	3.5	Ns	0.69	5.3	297	114	420
2019										
Kawmy-1	0.0	0.0	4.1	9.0	11.9	3.6	36.5	994	338	1332
		57.6	4.3	9.9	13.5	4.2	39.8	946	447	1393
	37.5	0.0	4.9	13.8	13.0	4.4	41.8	1207	719	1926
		57.6	5.6	14.3	13.2	5.4	41.0	1150	553	1703
	75.0	0.0	7.1	15.5	12.8	6.7	41.3	1296	577	1873
		57.6	6.4	13.2	10.5	6.3	41.8	1378	588	1966
V2010	0.0	0.0	5.0	7.6	10.5	4.4	56.5	858	443	1301
		57.6	4.4	8.8	11.6	4.8	58.5	898	414	1312
	37.5	0.0	5.0	10.4	12.4	6.3	61.8	926	498	1424
		57.6	5.6	10.5	12.3	6.6	79.3	958	504	1462
	75.0	0.0	5.7	12.6	11.7	6.7	60.5	962	583	1545
		57.6	6.1	13.1	13.2	7.2	63.0	1044	588	1632
LSD at 0.05			Ns	5.2	Ns	1.4	6.2	211	127	332

Synergistic effects of P and K interaction

There was synergistic relationship between two nutrients P and K in yield because the combined application of two nutrients is more than the yield expected on the basis of the effects from the individual applications of the nutrients

$$y_{pk}/y_0 > y_p/y_0 \times y_k/y_0,$$

while antagonistic effect occurred when the yield due to the combined application of two nutrients is less than the yield expected on the basis of the effects from the individual applications of the nutrients.

$$y_{pk}/y_0 < y_p/y_0 \times y_k/y_0$$

For zero-interaction, the yield obtained from a combination of two nutrients is equal to the yield expected on the basis of the individual application of the nutrients, and the interaction is said to be zero-interaction.

$$y_{pk}/y_0 = y_p/y_0 \times y_k y_k/y_0$$

where y_0 is the yield in the reference or control treatment, the yield expected (y_{ab}) on the basis of the individual responses (y_p and y_k) as a product of the individual responses of P and K according to Eq. (1).

Data presented in Fig. 3 reveal that there was synergistic effect where ($y_{pk}/y_0 > y_p/y_0 \times y_k/y_0$) as a mean for both seasons. This was true either for P1 or P2 levels. However, K supply did not reveal beneficial effect on yield in 2019 season (Table 2). The data of the triple interaction (V × P × K) indicate that the synergistic effect of the two varieties was more pronounced for V2010 where it needed both of P and K nutrients to out yield the greatest seed yield ha^{-1}, whereas this attitude was not true for Kawmy-1; hence, it produced the greatest seed yield ha^{-1} without K application (Table 3).

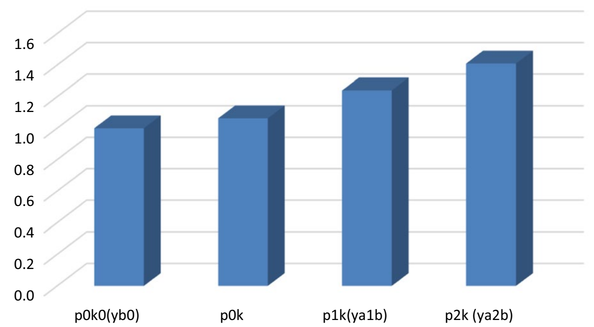

Fig. 3 Synergistic effect of P and K interaction

Discussion

Varietal differences

The obtained results reveal that there were obvious varietal differences between the two tested varieties. The superiority of Kawmy-1 variety in the total seed yield could be attributed to the increase in mature pod number formed in the second harvest which is considered as the main yield component which affect seed yield per plant and consequently per hectare. Ashour et al (1995) evaluated Kawmy-l and V2010 varieties in 11 locations and reported that Kawmy-l out yielded V2010 in seed yield per feddan. Also, Tariq et al (2001). Khan et al (2016) reported that mungbean yield components were significantly affected by cultivars and various phosphorous levels.

Effect of phosphatic fertilization

The response of mungbean yield and yield components to the phosphatic fertilizer applied could be attributed to the regulatory effect of P as well as the nutritional balance of the elements in legume due to P application which in turn reflected on yield components and the final yield Marschner (1995). The obtained results are in accordance with those reported by El-Karamany (1997). Also, Abd El-Lateef (1996) showed that P fertilization significantly increased mungbean pod weight per plant, 100-seed weight, yield per plant and per hectare and increasing P levels resulted in successive yield increases as compared with the untreated control. In another work, the results obtained by Abd El-Lateef et al. (2012) showed that P fertilization significantly increased mungbean yield traits. Khan et al (2016) found that yield characters were significantly affected by mungbean cultivars, various phosphorous levels. Also, Yin et al (2018) came to similar conclusion.

Effect of potassic fertilization

The greater response of mungbean to K confirms the fact that potassium plays an important role in many plant physiological and biochemical processes Fageria et al. (2001), Fageria and Santos (2010) and White et al (2021). Hence, supply of this element in adequate amount is essential to maintain soil fertility and sustainable crop production and improving crop yields. The positive effect of K on mungbean yield could be attributed to the biological role of potassium in increasing the net photosynthesis and storage capacity of the crops as well as the starch synthesizing Abou El-Nour (2002) and Buriro et al (2015). The increase in mungbean seed yield by K application was reported by Tariq et al (2001) and Buriro et al (2015); they reported the K applied increased yield components of mungbean, while Fageria and Melo (2014) reported that straw yield, seed yield, pods per plant, seeds per pod, 100 seed weight and seed harvest index were significantly increased with the addition of K fertilizer. These traits were also significantly influenced by genotypic treatment.

The interaction effects

The results of the interaction between the variety and phosphatic fertilizer (P) have significant positive effects on yield traits. These results are confirmed by Khan et al (2016). They found that number of seeds pod^{-1} significantly affected by cultivars and P levels and showed that highest seeds pod^{-1} through the interaction (V × P) and the reason of these interactions could be genetic.

Regarding the effect of the interaction between the variety (V) and potassic fertilization (K), it is clear that the differences between the two varieties in their response to either P or K may be attributed to the varietal differences in their nutritional requirements. It seems that the external nutrient requirements of mungbean may differ among species and cultivars. Differences among cultivars appear to be due to their differential to absorb and utilize nutrients. Fageria and Melo (2014) reported that K × genotype interactions for most of mungbean yield traits were significant, indicating variation in these traits with the variation in K level. They classified the efficient use of K by genotypes based on seed yield as efficient, moderately efficient and inefficient in K use efficiency. They reported significant effects of K and genotype treatments on yield and yield components of dry bean.

The obtained results on the interaction between P and K are in harmony with those obtained by Abd El-Lateef (1996) who reported beneficial effects of the interaction between (P × N) and (P × K) on mungbean yield and yield characters. Moreover, (P × N) interaction surpassed the (P × K) in its effect on mungbean seed yield per plant and per hectare compared with the untreated control. These responses of mungbean to late K could be attributed to the nutritional status of mungbean during the stage of early pod formation which was relevant for mungbean to benefit from the late applied nutrients.

The triple interaction (V × P × K)

The variability in the response of the two varieties to P and K application reveals the complexity in the relationship of such factors on their effects on mungbean yield. P fertilizer promotes root growth, disease resistance, drought tolerance and enhances nutrient and water absorption in the seedlings after they have depleted their endosperm reserves, Jian et al (2014). K fertilizer improves sugar metabolism, enhances osmotic cell concentration, maintains stomatal guard cell turgor, helps regulate stomatal opening, participates in photosynthesis, enhances drought resistance and increases yield, Liang et al (2011). Khan et al (2016) came to similar conclusion in terms of seed yield.

Synergistic effects of P and K interaction for mungbean varieties

The data of the triple interaction (V × P × K) indicate that the synergistic effect of the two varieties was more pronounced for V2010 where it needed both of P and K nutrients to out yield the greatest seed yield ha^{-1}, whereas this attitude was not true for Kawmy-1; hence, it produced the greatest seed yield ha^{-1} without K application and this was in accordance with Abd El-Lateef (1996). According to Fageria and Melo (2014), interactions occur when the supply of one nutrient affects the absorption and utilization of another nutrient. Also, René et al (2017) indicated that Interaction among plant nutrients can result in antagonistic or synergistic outcomes that influence nutrient use efficiency.

Conclusion

It could be concluded from this study that Kawmy-I variety is a high yielding variety than that of V2010. Synergistic interaction between P and K was evident and reflected on mungbean yield and yield components. Application of 37.5 kg P_2O_5 + 57.6 kg K_2O is the best economic PK combination to obtain the highest yield.

Abbreviations

(y_p): Yield due to phosphatic fertilizer application; (y_k): Yield due to potassic fertilizer application; (y_{pk}): Expected yield due to P and K fertilizer interaction.

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Authors' contributions

EMA and MSA conceived and designed the experiments, MSA and AW performed the experiments and analyzed the data, and EMA, MSA and AW wrote the paper and reviewed the manuscript. All authors read and approved the final manuscript.

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Declarations

Ethics approval and consent to participate

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Consent for publication

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Competing interests

The authors declare that they have no competing interests.

Author details

[1]Field Crops Research Dept., Agricultural Division, National Research Centre, 33 El-Behooth St, Giza, Egypt. [2]Plant Production Dept, Arid Lands Cultivation Research Institute, at (SRTA-City), New Borg El-Arab, Alexandria 21934, Egypt.

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