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

E. M. Abd El Lateef1*, Asal M. Wali2 and M. S. Abd El-Salam1

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 P2O5 ha−1 and potassic fertilization at 0 and 57.6 kg K2O ha−1 on the yield and yield components of two mungbean varieties, viz. Kawmy-1 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 P2O5 + 57.6 kg K2O is preferable for V2010 and 75 kg P2O5 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). EI-Karamany (1997) under Egyptian conditions reported increases in mungbean yield up to 62 kg P2O5 ha−1. However, with such high phosphatic fertilizer level a depression in yield response to N may occur Chatterjee and Bhattacharyya (1986). On the other hand, Ikombo (1989) suggested that the sub-optimal P supply to mungbean plants may depress the symbiotic N fixation. Therefore,
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 Burriro 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$_2$O$_5$ ha$^{-1}$, as well as two potassium fertilizer levels, i.e., 0 and 57.6 kg K$_2$O 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$_2$O$_5$ 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$_2$O as potassium sulfate (48–52% K$_2$O). 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.

$$\left( \frac{y_{ab}}{y_0} = \frac{y_a}{y_0} \times \frac{y_b}{y_0} \right)$$ (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-1 variety significantly surpassed V2010 in seed yield ha\(^{-1}\) at the second harvest (95 days

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\(_2\)O\(_5\) 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                     | 0.96                       | Ns                     | Ns                       | 98                      | 192                     |
| Potassic fertilizer \(K\) (kg K\(_2\)O 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                         | Ns                     | Ns                       | Ns                      | 238                     |
| Phosphatic fertilizer \(P\) (kg P\(_2\)O\(_5\) 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                  | 0.4                           | 3.1                             | Ns                     | 0.6                        | 2.6                    | 92                       | 58                      | 145                     |
| Potassic fertilizer \(K\) (kg K\(_2\)O 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$_2$O$_5$ 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$_2$O$_5$ 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$_2$O$_5$ 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$_2$O$_5$ ha$^{-1}$.

**Effect of potassic fertilization**

Data given in Table 1 and Fig. 2 show that potassium application at 57.6 kg K$_2$O 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$_2$O$_5$ 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 level (75 kg P$_2$O$_5$ 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$_2$O$_5$ ha$^{-1}$. The variety V2010 showed the best response to P at 37.5 kg P$_2$O$_5$ 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 V2010 in 2019 season gave the highest seed yield ha$^{-1}$ at 75 kg P$_2$O$_5$ ha$^{-1}$, which was statistically insignificant with the level 37.5 kg P$_2$O$_5$ ha$^{-1}$.

The data of the interaction effect between variety and potassium application are given in Table 2. Application of 57.6 K$_2$O 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 V2010 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$_2$O alone or the phosphatic fertilization with 75 kg P$_2$O$_5$ 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$_2$O$_5$ ha$^{-1}$, alone or P at 37.5 kg P$_2$O$_5$ ha$^{-1}$ combined with 57.6 kg K$_2$O ha$^{-1}$, for Kawmy-l variety, while application of 57.6 kg K$_2$O ha$^{-1}$ alone or combined with 37.5 kg P$_2$O$_5$ 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$_2$O$_5$ + 57.6 kg K$_2$O gave the highest seed yield for both varieties.
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) | LSD at 0.05 |
|-----------------|--------------------------|-----------------------------|--------------------|------------------------|------------------------|----------------------|-------------|
| Variety P level |                          |                             |                    |                        |                        |                      |             |
| Kawmy-1 0.0     | 5.8                      | 17.6                        | 13.0               | 9.64                   | 44.7                   | 1213                 | 2.2 Ns      |
| 37.5            | 6.5                      | 20.6                        | 13.0               | 8.51                   | 45.3                   | 1268                 | 7.0 Ns      |
| 75.0            | 6.3                      | 15.0                        | 12.6               | 9.16                   | 47.6                   | 1501                 | 10.0 Ns     |
| V2010 0.0       | 7.0                      | 10.0                        | 11.5               | 6.17                   | 67.1                   | 1225                 | 210 140 Ns  |
| 37.5            | 6.5                      | 14.1                        | 11.7               | 7.55                   | 69.9                   | 1342                 | 218 210 Ns  |
| 75.0            | 6.1                      | 9                           | 12.0               | 5.57                   | 71.1                   | 1163                 | 210 210 Ns  |
| LSD at 0.05     |                          |                             |                    |                        |                        |                      |             |
| Variety K level |                          |                             |                    |                        |                        |                      |             |
| Kawmy-1 0.0     | 5.7                      | 16.6                        | 12.6               | 8.60                   | 44.2                   | 1338                 | 0.7 Ns      |
| 57.6            | 6.7                      | 18.9                        | 12.8               | 8.61                   | 47.5                   | 1317                 | 2.5 Ns      |
| V2010 0.0       | 6.2                      | 9.3                         | 11.7               | 5.48                   | 68.3                   | 1123                 | 0.7 Ns      |
| 37.5            | 6.8                      | 12.7                        | 11.7               | 7.38                   | 70.3                   | 1363                 | 3.7 Ns      |
| 75.0            | 6.1                      | 9                           | 12.0               | 5.57                   | 71.1                   | 1163                 | 210 210 Ns  |
| LSD at 0.05     |                          |                             |                    |                        |                        |                      |             |
| P level K level |                          |                             |                    |                        |                        |                      |             |
| 0.0             | 5.9                      | 16.6                        | 12.6               | 8.60                   | 44.2                   | 1338                 | 0.7 Ns      |
| 37.5            | 6.7                      | 18.9                        | 12.8               | 8.61                   | 47.5                   | 1317                 | 2.5 Ns      |
| 75.0            | 6.1                      | 9                           | 12.0               | 5.57                   | 71.1                   | 1163                 | 210 210 Ns  |
| LSD at 0.05     |                          |                             |                    |                        |                        |                      |             |
| Variety P level |                          |                             |                    |                        |                        |                      |             |
| Kawmy-1 0.0     | 4.2                      | 9.5                         | 12.7               | 3.61                   | 38.2                   | 970                  | 0.9 Ns      |
| 37.5            | 5.3                      | 14.0                        | 12.8               | 4.90                   | 41.4                   | 1178                 | 2.5 Ns      |
| 75.0            | 6.4                      | 13.4                        | 13.0               | 6.50                   | 41.6                   | 1337                 | 1.1 Ns      |
| V2010 0.0       | 4.2                      | 8.2                         | 11.4               | 4.60                   | 57.5                   | 838                  | 1.5 Ns      |
| 37.5            | 5.3                      | 10.5                        | 12.4               | 6.45                   | 70.6                   | 942                  | 0.7 Ns      |
| 75.0            | 5.9                      | 12.9                        | 12.8               | 6.95                   | 61.8                   | 1003                 | 1.5 Ns      |
| LSD at 0.05     |                          |                             |                    |                        |                        |                      |             |
| Variety K level |                          |                             |                    |                        |                        |                      |             |
| Kawmy-1 0.0     | 5.1                      | 12.8                        | 12.5               | 4.9                    | 39.9                   | 1166                 | 0.7 Ns      |
| 57.6            | 5.4                      | 12.5                        | 13.1               | 5.3                    | 40.9                   | 1158                 | 0.7 Ns      |
| V2010 0.0       | 4.9                      | 10.2                        | 11.9               | 5.8                    | 59.6                   | 889                  | 0.7 Ns      |
| 57.6            | 5.9                      | 12.6                        | 11.9               | 6.9                    | 66.9                   | 967                  | 0.7 Ns      |
| LSD at 0.05     |                          |                             |                    |                        |                        |                      |             |
| P level K level |                          |                             |                    |                        |                        |                      |             |
| 0.0             | 4.1                      | 9.2                         | 11.5               | 4.0                    | 46.5                   | 874                  | 0.7 Ns      |
| 37.5            | 4.4                      | 13.3                        | 12.6               | 4.5                    | 49.2                   | 926                  | 0.7 Ns      |
| 75.0            | 5.0                      | 12.1                        | 12.5               | 5.4                    | 51.8                   | 1067                 | 1.1 Ns      |
| 75.0            | 5.6                      | 12.4                        | 12.7               | 6.0                    | 60.2                   | 1054                 | 0.7 Ns      |
| 75.0            | 6.3                      | 14.1                        | 12.8               | 6.7                    | 50.9                   | 1129                 | 1.5 Ns      |
| LSD at 0.05     |                          |                             |                    |                        |                        |                      |             |
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 of the individual applications of the nutrients

\[ \frac{y_{pk}}{y_0} > \frac{y_p}{y_0} \times \frac{y_k}{y_0}, \]

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.

\[ \frac{y_{pk}}{y_0} < \frac{y_p}{y_0} \times \frac{y_k}{y_0} \]

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.

\[ \frac{y_{pk}}{y_0} = \frac{y_p}{y_0} \times \frac{y_k}{y_0} \]

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 \( \frac{y_{pk}}{y_0} > \frac{y_p}{y_0} \times \frac{y_k}{y_0} \) 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).
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-1 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.

![Fig. 3 Synergistic effect of P and K interaction](image-url)
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 P₂O₅ + 57.6 kg K₂O is the best economic PK combination to obtain the highest yield.

**Abbreviations**

(ψₚ): Yield due to phosphatic fertilizer application; (ψₖ): Yield due to potassic fertilizer application; (ψₓ): Expected yield due to P and K fertilizer interaction.

**Acknowledgements**

The authors would like to thank Field Crop Research Department, National Research Centre, for supplying the study with mungbean seeds of Kawmy-1, the only registered mungbean cultivar in Egypt and Agriculture Research Centre for supplying the study with V2010 cultivar.

**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.

**Funding**

The work was self-funded by the authors.

**Availability of data and materials**

The datasets supporting the results are included within the article.

**Declarations**

**Ethics approval and consent to participate**

Not applicable.

**Consent for publication**

Not applicable.

**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-Rehooth St, Giza, Egypt.

2 Plant Production Dept, Arid Lands Cultivation Research Institute, at (SRTA-City), New Borg El-Arab, Alexandria 21934, Egypt.

**Received:** 7 May 2021  **Accepted:** 29 August 2021

**Published online:** 27 September 2021

**References**

Abd El-Lateef EM (1996) Mungbean (Vigna radiata (L.) Wilczek) yield response to foliar applied nitrogen and potassium under different levels of phosphatic fertilization. In: Proceedings of 7th Conf Agron Mansoura Univ, 9–10 Sept, pp 229–237

Abd El-Lateef EM, Tawfik MM, Hozynin M, Bakry BA, Elewa TA, Farrag AA, Bahr AA (2012) Soil and foliar fertilization of mungbean (Vigna radiata (L.) Wilczek) under Egyptian conditions. Elixir Agric 47:8622–8628

Abd El-Lateef EM, Bakry BA, Abd El-Salam MS, Elewa TA (2015) Mungbean (Vigna radiata L. Wilczek) varietal tolerance to biological stress. Int J ChemTech Res 8:477–487

Abd El-Lateef EM, Eata AEM, Wali AM, Abd El-Salam MS (2020) Evaluation of mungbean (Vigna radiata (L.) Wilczek) as green pod and seed crop under different cropping systems in Egypt. Asian J Crop Sci 12:115–123. https://doi.org/10.3923/ajcs.2020.115.123

Abdalgafar AH, Al-Jumaily A (2016) Effect of potash fertilization and foliar application of iron and zinc on yield and quality of two genotypes of mung bean. Iraqi J Agric Sci. https://doi.org/10.36103/ijas.v47i2.584

Abou El-Nour EA (2002) Can supplemented potassium foliar feeding reduce the recommended soil potassium. Pak J Biol Sci 5(3):259–262. https://doi.org/10.3923/pjbs.2002.259.262

Ashour Nl, Abou Khadrah Sh, Mosalem ME, Yakout GM, Zedan ME, Abd El Lateef EM, Behairy TG, Shaban ASH, Sharaan AN, Selim MM, Mahmoud SA,
Hassan MW, Darwish G, EL-Hilalfy MZ (1995) Introduction of mungbean (Vigna radiata (L.) Wilczek) in Egypt. 2. Effect of genotype, planting density and location on mungbean yield. Egypt J Agric 19(1):99–108

Aulakh MS, Malik SS (2005) Interactions of nitrogen with other nutrients and water: effect on crop yield and quality, nutrient use efficiency, carbon sequestration, and environmental pollution. Adv Agron 86:341–409. https://doi.org/10.1016/S0065-2113(05)80007-9

Burroo M, Hussain F, Talpur GH, Gandahi AW, Burroo B (2015) Growth and yield response of mungbean varieties to various potassium levels. Pak J Agric Eng Vet Sci 31(2):203–210

Chatterjee BN, Bhattacharyya KK (1986) Principles and practices of grain legume production. Oxford & IBR Publishing, New Delhi, pp 228–229

El-Karamany MF (1997) Effect of some agronomic treatments on growth, yield and chemical components of mungbean (Vigna radiata (L.) Wilczek). Ph.D. Thesis Fac Agric Al Azhar Univ Cairo, pp 2–3

Fageria KD, Barbosa Filho MP, Da Costa JGC (2001) Potassium-use efficiency in common bean genotypes. J Plant Nutr 24(12):1937–1945. https://doi.org/10.1080/01904167.2014.911889

Fageria KD, Melo LC (2014) Agronomic evaluation of dry bean genotypes for potassium use efficiency. J Plant Nutr 37(12):1899–1912. https://doi.org/10.1080/01904167.2014.911889

Fageria KD, Barbosa Filho MP, Da Costa JGC (2001) Potassium-use efficiency in common bean genotypes. J Plant Nutr 24(12):1937–1945. https://doi.org/10.1080/01904167.2014.911889

Fageria KD, Dos Santos AB (2010) DE Moraes MF (2010) Yield, potassium uptake, and use efficiency in upland rice genotypes. Commun Soil Sci Plant Anal 41:2676–2684. https://doi.org/10.1080/00103624.2010.517882

FAOSTAT. FAOSTAT Data (2016) www.fao.org/faostat/ en. Accessed 14 Mar 2016

Faranzi A, Haraguchi T, Hirota O, Rahman MA (2000) Growth analysis, yield and chemical components of mungbean (Vigna radiata (L.) Wilczek). In: Proceed‑Ikombo BM (1989) Phosphorus nutrition of tropical crop legumes. Ph.D. Thesis, University of Queensland

Havlin LJ, Beaton JD, Tisdale SL, Nelson WL (2004) Soil fertility and fertilizers - 7th edition - Havlin. Academic, London

Lawn RJ, Ahn CS (1985) Mungbean (Vigna radiata (L.) Wilczek)/Vigna mungo (L.) Hepper). In: Summerfield RJ, Roberts EH (eds) Grain legume crops. Collins, London, pp 584–623

Liang J, Yin ZC, Wang YJ, Xiao HY, Zhang WQ, Yin FX (2011) Effects of different density and fertilizer application methods on the yield of mung bean. J Hortic Seed 6:81–83

Mahgoub SA, Mohammed AT, EI-A M (2020) Physiochemical, nutritional and technological properties of instant porridge supplemented with mung bean. Food Nutr Sci 11:1078–1095. https://doi.org/10.4236/fnss.2020.1112076

Marschner H (1995) Mineral nutrition of higher plants, 2nd edn. Academic, London

MSTAT-C (1988) MSTAT-C, a microcomputer program for the design, arrangement and analysis of agronomic research. Michigan State University East Lansing. https://www.canr.msu.edu/afre/projects/microcomputer_stati‑cal_package_mstat.1983_1985

Naeem M, Iqbal J, Alias MA, Bakhtsh HA (2006) Comparative study of inorganic fertilizers and organic manures on yield and yield components of mungbean (Vigna radiata L.). J Agric Soci Sci 2(4):227–229

René PJ, Heinen M, Dimkpa CO, Bindraban PS (2017) Effects of nutrient antagonism and synergism on yield and fertilizer use efficiency. Commun Soil Sci Plant Anal 48(16):1895–1920. https://doi.org/10.1080/00103624.2017.1407429

Tariq M, Khalq A, Umar M (2001) Effect of phosphorus and potassium application on growth and yield response of mungbean (Vigna radiata L.). Pak J Agric Sci 2:677–679. https://doi.org/10.3923/pjass.2003.677.679

Yin Z, Guo W, Xiao H, Liang J, Hao X, Dong N, Leng T, Wang Y, Wang Wang Q, Yin F (2018) Nitrogen, phosphorus, and potassium fertilization to achieve expected yield and improve yield components of mung bean. PLoS ONE 13(10):e0206285. https://doi.org/10.1371/journal.pone.0206285

Publisher’s Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Submit your manuscript to a SpringerOpen journal and benefit from:

► Convenient online submission  
► Rigorous peer review  
► Open access: articles freely available online  
► High visibility within the field  
► Retaining the copyright to your article

Submit your next manuscript at ► springeropen.com