Productivity of grain cowpea in high phosphorus soils as influenced by nutrient interactions

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ABSTRACT
A field experiment was conducted in a high phosphorus soil in the southern district of Kerala during January to March 2018 to assess the effect of varying levels of P, K and Zn and their interactions on the productivity of grain cowpea. The treatments included two levels of P, three levels of Zn and two levels of K and was laid out in factorial RBD with three replications. The results of the study revealed that significantly higher yield attributes and yield (pod and grain) were realized through foliar application of Zn as ZnSO$_4$ twice @ 0.025% at branching and at flowering, along with 10 kg K$_2$O ha$^{-1}$ in the high P soil. The yield was 58 per cent higher than the yield at the lower levels of P, K and Zn tried. Economic analysis also revealed higher benefit cost ratio (1.36) for the combination. Phosphorus application may be skipped in the nutrient package for grain cowpea in high soils. Based on grain yields, it could be interpreted that a negative interaction existed between P and Zn and also between Zn and K. The interaction between P and K was not significant.

Key words: Cowpea, Interaction, Nutrient, Phosphorus, Potassium, Zinc.

INTRODUCTION
Phosphorus nutrition has received wide attention with the increased use of fertilizers in crop management and the subsequent build up of P in soil (Withers et al., 2001). The nutrient has specific role in plants being part of the chemical structure of nucleic acids, co-enzymes, proteins, phospholipids and is crucial for energy transfer. According to reports, consumption of rock phosphate in 2016-17 was twice that in 2015-16 and in amophos, it was 100 percent of its production in the country (FAI, 2018). The dynamics of P in soil is controlled by the adsorption and fixation reactions in soil (Sanyal and Datta, 1991), as a result of which continued application of P fertilisers can lead to the accumulation of the nutrient in soil. This has a marked influence on the availability of other nutrients and hence P management in these soils is of paramount importance.

Cowpea [*Vigna unguiculata* (L.) Walp] is a quick growing short duration pulse crop that fits well in almost all cropping systems. The nutritional importance of the crop as a good source of protein, calcium, iron, dietary fibre, uses as food, feed, forage, fodder are indispensible. Anitha et al. (2006) had recorded that cowpea ranks first among the pulses cultivated in Kerala. Although pure crop cultivation of cowpea is not extensive, it is commonly grown as intercrop in perennial crop combinations and as catch crop in summer fallows.

Phosphorus is an important nutrient in legume production systems on account of its role in nitrogen fixation (Walley et al., 2005). Soil test values of more than 25 kg available P ha$^{-1}$ are rated as high and such excess levels of P are reported in the southern laterite soils of Kerala (KSPB, 2013). The high P status is expected to have a positive influence on the growth and yield of the legume. Tomar et al. (1994) had documented that high P contents in soil adversely affect the availability of the micro nutrient, zinc in plants. Kumar et al. (2016) also observed that availability of Zn in soils and its absorption and translocation in plants are influenced by other plant nutrients especially P. Zinc is critical especially in legumes as it facilitates protein synthesis, energy production, gene expression and also maintains structure of enzymes (Habbasha et al., 2013). Potassium is involved in enzyme activation, photosynthesis, transport of sugars, protein and starch synthesis (Tiwari et al., 2002). Daliparthy et al. (1994) reported that increasing levels of K can reduce the severity of P induced Zn deficiency in plants. Thus, in a P rich soil, nutrient management practices should emphasize on balanced nutrition taking into account the interactions that can occur and influence crop performances. It is in this background that a study was undertaken to evaluate the effect of different levels of P, K and Zn on productivity of grain cowpea in a P rich soil of southern Kerala.

MATERIALS AND METHODS
The field experiment was conducted in a farmer’s field in Thiruvananthapuram district, south Kerala during January to March 2018. The site situated at 8.43°N latitude,
RESULT AND DISCUSSION

Growth attributes: The variations in growth attributes due to the individual and interaction effects of N, P and K are presented in Tables 1a, 1b and 1c.

Plant height: Plant height increased as growth progressed. There was no significant variation in plant height due to the individual effect of nutrients. Among interactions, P x Zn and Zn x K significantly influenced the plant height at both stages. The treatment in which P and Zn were not applied (p\(\times\)z\(_1\)) was found to be superior (111.18 and 119.95 cm) which was at par with p\(\times\)p\(_2\), p\(\times\)z\(_2\), and p\(\times\)z\(_3\). It was evident that the available P in soil and Zn from the FYM applied could bring about effects on plant height similar to the treatments in which Zn was given through an external source in p\(_1\) and p\(_2\). Significantly taller plants (121.68 cm) were recorded in the treatment combination of foliar Zn and K\(_2\)O @ 20 kg ha\(^{-1}\) (z\(_1\)k\(_2\)). It was thus observed that application of Zn was found to be effective in increasing plant height in combination with P or with K but, the P x Zn x K interaction was not significant.

Number of leaves plant\(^{-1}\): The influence of P, K and Zn on the number of leaves was significant for K at 2 MAS (Months After Sowing) and it was higher (21.2) with 20 kg K\(_2\)O ha\(^{-1}\). The increase in number of leaves might be due to the positive influence of K on vegetative growth of cowpea through augmentation of cell division and expansion (Ali et al., 2007). Among the interaction effects, P x Zn interaction alone significantly influenced the number of leaves at 2 MAS.

Yield and yield attributes: The data on the yield and yield attributes are presented in Tables 2 (a, b, c) and 3.
**Days to 50 per cent flowering:** Perusal of the data in Table 2a revealed that foliar application of Zn (z$_2$) and K$_2$O at 10 kg ha$^{-1}$ (k$_1$) recorded earlier flowering (39.8 and 43.6 days, respectively) compared to the different levels of the other nutrients. The role of K in enhancing flowering and fruiting in vegetables have been documented by Erel et al. (2008), while Zn when applied as foliar spray could trigger flowering (Dhanya, 2014). Iqbal et al. (2011) have reported early flowering in tomato with K application. The delayed flowering with the higher dose of K @ 20 kg ha$^{-1}$ (k$_2$) recorded in the present study is in consonance with the reports of Zubair et al. (2006). The interaction effect of Zn x K was also significant with foliar spray of Zn and soil application of K$_2$O at 10 kg ha$^{-1}$ combination (z$_2$k$_1$) recording

Table 1b: Interaction effects of P, Zn and K on plant height and number of leaves.

| Interactions | *Plant height (cm)* | Number of leaves |
|--------------|---------------------|------------------|
|              | 1 MAS               | 2 MAS            | 1MAS  | 2 MAS  |
| P x Zn interaction |                   |                  |       |        |
| p$_1$z$_0$   | 111.18(10.54)       | 119.95(10.95)    | 28.1  | 16.5   |
| p$_1$z$_1$   | 5.18(7.36)          | 70.02(8.37)      | 23.1  | 16.8   |
| p$_1$z$_2$   | 78.16(8.84)         | 112.30(10.60)    | 25.6  | 21.5   |
| p$_2$z$_0$   | 57.30(7.57)         | 91.57(9.57)      | 26.3  | 20.4   |
| p$_2$z$_1$   | 76.07(8.72)         | 111.60(10.56)    | 25.4  | 18.6   |
| p$_2$z$_2$   | 74.53(8.63)         | 105.64(10.28)    | 23.4  | 15.3   |
| SEm (±)      | 0.71                | 0.46             | 1.33  | 1.52   |
| CD(0.05)     | 2.089               | 1.351            | NS    | 4.469  |
| P x K interaction |                |                  |       |        |
| p$_0$k$_1$   | 5.18(9.18)          | 101.14(10.06)    | 26.6  | 15.4   |
| p$_0$k$_2$   | 74.93(8.66)         | 97.77(9.89)      | 24.6  | 21.2   |
| p$_1$k$_1$   | 63.15(7.95)         | 90.84(9.53)      | 25.2  | 15.0   |
| p$_1$k$_2$   | 43.71(8.67)         | 115.41(10.74)    | 25.1  | 21.2   |
| SEm (±)      | 0.58                | 0.38             | 1.09  | 1.24   |
| CD(0.05)     | 1.01                | 0.65             | NS    | NS     |
| Zn x K interaction |            |                  |       |        |
| z$_0$k$_1$   | 75.38(8.68)         | 90.52(9.51)      | 27.1  | 13.4   |
| z$_0$k$_2$   | 88.96(9.43)         | 121.15(11.01)    | 27.3  | 23.5   |
| z$_1$k$_1$   | 80.35(8.96)         | 100.44(10.02)    | 25.8  | 15.6   |
| z$_1$k$_2$   | 50.67(7.12)         | 79.37(8.91)      | 22.6  | 19.8   |
| z$_2$k$_1$   | 64.58(8.04)         | 96.90(9.84)      | 25.0  | 16.6   |
| z$_2$k$_2$   | 89.09(9.44)         | 121.68(11.03)    | 24.6  | 20.3   |
| SEm (±)      | 0.71                | 0.46             | 1.33  | 1.52   |
| CD(0.05)     | 1.01                | 0.65             | NS    | NS     |

*Square root transformed values in parentheses

Table 1c: Effect of P x Zn x K interaction on plant height and number of leaves.

| Treatment combinations | *Plant height (cm)* | Number of leaves |
|------------------------|---------------------|------------------|
|                        | 1 MAS               | 2 MAS            | 1MAS  | 2 MAS  |
| p$_0$z$_0$k$_1$        | 108.68(10.43)       | 119.84(10.95)    | 27.5  | 12.8   |
| p$_0$z$_0$k$_2$        | 113.70(10.66)       | 120.03(10.96)    | 28.7  | 20.2   |
| p$_0$z$_1$k$_1$        | 65.77(8.11)         | 79.89(8.94)      | 25.5  | 13.3   |
| p$_0$z$_1$k$_2$        | 43.71(6.61)         | 60.81(7.80)      | 20.6  | 20.3   |
| p$_0$z$_2$k$_1$        | 80.80(8.99)         | 105.76(10.28)    | 26.8  | 20.0   |
| p$_0$z$_2$k$_2$        | 75.59(8.69)         | 119.03(10.91)    | 24.4  | 23.1   |
| p$_1$z$_0$k$_1$        | 48.15(6.94)         | 65.30(8.08)      | 26.6  | 14.1   |
| p$_1$z$_0$k$_2$        | 67.26(8.20)         | 122.26(11.06)    | 26.0  | 26.7   |
| p$_1$z$_1$k$_1$        | 96.39(9.82)         | 123.37(11.11)    | 26.2  | 17.8   |
| p$_1$z$_1$k$_2$        | 58.14(7.63)         | 100.42(10.02)    | 24.6  | 19.3   |
| p$_1$z$_2$k$_1$        | 50.17(7.08)         | 88.44(9.40)      | 23.1  | 13.2   |
| p$_1$z$_2$k$_2$        | 103.71 (10.18)      | 124.34(11.15)    | 24.7  | 17.5   |
| SEm (±)                | 1.01                | 0.65             | 1.88  | 2.16   |

*Square root transformed values in parentheses
lesser number of days to flowering (42.1 days) compared to other combinations. This is in congruence with the reports of Cakmak (2002) who corroborated that proper nutritional status i.e. N, K, Zn etc. and hormonal level within the plants might be the reason for the early induction of flowering. Sucrose and phyto-hormones could have moved in combination from leaves to shoot apical meristem due to application of micronutrients to induce early flowering (Singh et al., 2015).

Average pod length: There were no significant variations in the average pod length due to the individual and interaction effects of P, K and Zn (Tables 2a, b and c).

Average pod weight: Perusal of the data shown in (Table 2a) revealed that foliar application of Zn recorded superior pod weight (1.50 g) and was at par with the soil application (1.44 g) but significantly superior than pod weights (1.35 g) realized with no Zn application. Zinc takes part in the metabolism of plant as an activator of several enzymes which in turn can

### Table 2a: Effect of levels of P, Zn and K on yield attributes of cowpea.

| Treatments | Days to 50 % flowering | Number of pods plant⁻¹ | Average pod length (cm) | Average pod weight (g) | Number of seeds pod⁻¹ | Pod yield (kg ha⁻¹) | Grain yield (kg ha⁻¹) |
|------------|-------------------------|-------------------------|-------------------------|------------------------|----------------------|-------------------|------------------------|
| **Levels of Phosphorus** | | | | | | | |
| P₀ (0 kg ha⁻¹) | 43.8 | 11.46 | 13.98 | 1.42 | 14.56 | 1222.48 | 919.94 |
| P₁ (7.5 kg ha⁻¹) | 44.9 | 10.69 | 14.43 | 1.44 | 14.95 | 1188.67 | 829.19 |
| SEm (±) | 0.45 | 0.33 | 0.59 | 0.03 | 0.17 | 36.46 | 40.56 |
| CD (0.05) | NS | NS | NS | NS | NS | NS | NS |
| **Levels of Zinc** | | | | | | | |
| Z₀ (0 kg ha⁻¹) | 47.4 | 10.87 | 14.35 | 1.36 | 14.75 | 1185.27 | 859.82 |
| Z₁ (2.5 kg ha⁻¹) | 46.0 | 10.53 | 13.34 | 1.44 | 14.94 | 1129.29 | 830.94 |
| Z₀ (0.025% foliar) | 39.8 | 11.83 | 14.92 | 1.50 | 14.57 | 1302.16 | 932.94 |
| SEm (±) | 0.55 | 0.40 | 0.72 | 0.03 | 0.20 | 44.65 | 49.67 |
| CD (0.05) | 1.606 | NS | NS | NS | 0.092 | NS | 130.836 | NS |
| **Levels of Potassium** | | | | | | | |
| K₀ (10kg ha⁻¹) | 43.6 | 11.70 | 13.81 | 1.44 | 14.71 | 1276.33 | 939.12 |
| K₁ (20 kg ha⁻¹) | 45.2 | 10.45 | 14.60 | 1.42 | 14.79 | 1134.82 | 810.01 |
| SEm (±) | 0.45 | 0.33 | 0.59 | 0.03 | 0.17 | 36.46 | 40.56 |
| CD (0.05) | 1.311 | 0.961 | NS | NS | NS | 106.827 | 118.837 |

### Table 2b: Interaction effects of P x Zn, P x K and Zn x K on yield attributes of cowpea.

| Interactions | Days to 50 % flowering | Number of pods plant⁻¹ | Average pod length (cm) | Average pod weight (g) | Number of seeds pod⁻¹ | Pod yield (kg ha⁻¹) | Grain yield (kg ha⁻¹) |
|--------------|-------------------------|-------------------------|-------------------------|------------------------|----------------------|-------------------|------------------------|
| **P x Zn interaction** | | | | | | | |
| P₀ Z₀ | 47.5 | 11.52 | 14.22 | 1.32 | 14.35 | 1178.25 | 886.36 |
| P₀ Z₁ | 44.8 | 10.81 | 12.22 | 1.43 | 14.90 | 1138.88 | 874.03 |
| P₀ Z₂ | 39.3 | 12.04 | 15.50 | 1.52 | 14.42 | 1350.29 | 999.44 |
| P₁ Z₀ | 47.3 | 10.22 | 14.48 | 1.39 | 15.15 | 1192.29 | 833.29 |
| P₁ Z₁ | 47.1 | 10.25 | 14.46 | 1.46 | 14.97 | 1119.69 | 787.85 |
| P₁ Z₂ | 40.3 | 11.61 | 14.34 | 1.48 | 14.72 | 1254.03 | 866.44 |
| SEm (±) | 0.77 | 0.57 | 1.02 | 0.04 | 0.29 | 63.15 | 70.25 |
| CD (0.05) | NS | NS | NS | NS | NS | NS | NS |
| **P x K interaction** | | | | | | | |
| P₀ k₀ | 43.0 | 12.52 | 13.23 | 1.48 | 14.64 | 1362.16 | 1028.20 |
| P₀ k₁ | 44.7 | 10.40 | 14.74 | 1.37 | 14.47 | 1082.79 | 811.68 |
| P₀ k₂ | 44.2 | 10.89 | 14.39 | 1.41 | 14.78 | 1190.50 | 850.04 |
| P₀ k₃ | 45.6 | 10.50 | 14.46 | 1.48 | 15.11 | 1186.85 | 808.35 |
| SEm (±) | 0.63 | 0.46 | 0.83 | 0.04 | 0.23 | 51.56 | 57.36 |
| CD (0.05) | NS | NS | NS | 0.106 | NS | 151.077 | NS |
| **Zn x K interaction** | | | | | | | |
| Z₀ k₀ | 47.6 | 10.60 | 14.12 | 1.34 | 14.37 | 1180.45 | 818.39 |
| Z₀ k₁ | 47.1 | 11.14 | 14.58 | 1.38 | 15.13 | 1190.09 | 901.26 |
| Z₀ k₂ | 45.6 | 11.63 | 12.35 | 1.46 | 15.30 | 1230.27 | 939.20 |
| Z₀ k₃ | 46.3 | 9.43 | 14.33 | 1.43 | 14.58 | 1028.31 | 722.68 |
| Z₁ k₀ | 37.5 | 12.87 | 14.95 | 1.53 | 14.47 | 1418.27 | 1059.77 |
| Z₁ k₁ | 42.1 | 10.78 | 14.89 | 1.47 | 14.67 | 1186.06 | 806.11 |
| SEm (±) | 0.77 | 0.57 | 1.02 | 0.04 | 0.29 | 63.15 | 70.25 |
| CD (0.05) | 2.271 | 1.665 | NS | NS | 0.841 | NS | 205.831 |
Table 2c: Effect of P x Zn x K interaction on yield attributes of cowpea.

| Treatments combinations | Days to 50 % flowering | Number of pods plant$^1$ | Average pod length (cm) | Average pod weight (g) | Number of seeds pod$^1$ | Pod yield (kg ha$^{-1}$) | Grain yield (kg ha$^{-1}$) |
|-------------------------|------------------------|--------------------------|-------------------------|------------------------|--------------------------|--------------------------|--------------------------|
| p$^1$z$^1$k$^1$         | 48.3                   | 11.20                     | 14.05                   | 1.28                   | 13.93                    | 1217.28                  | 815.97                   |
| p$^1$z$^1$k$^2$         | 46.6                   | 11.84                     | 14.40                   | 1.37                   | 14.78                    | 1139.21                  | 956.75                   |
| p$^1$z$^1$k$^3$         | 43.6                   | 11.51                     | 10.24                   | 1.50                   | 15.47                    | 1193.60                  | 980.19                   |
| p$^1$z$^2$k$^1$         | 46.0                   | 10.11                     | 14.20                   | 1.36                   | 14.34                    | 1084.17                  | 767.87                   |
| p$^1$z$^2$k$^2$         | 37.0                   | 14.84                     | 15.39                   | 1.65                   | 14.53                    | 1675.60                  | 1288.45                  |
| p$^1$z$^2$k$^3$         | 41.6                   | 9.24                      | 15.61                   | 1.39                   | 14.31                    | 1024.99                  | 710.43                   |
| p$^1$z$^3$k$^1$         | 47.0                   | 10.00                     | 14.19                   | 1.40                   | 14.81                    | 1143.62                  | 820.81                   |
| p$^1$z$^3$k$^2$         | 47.6                   | 10.44                     | 14.76                   | 1.39                   | 15.49                    | 1240.97                  | 845.77                   |
| p$^1$z$^3$k$^3$         | 47.6                   | 11.76                     | 14.47                   | 1.42                   | 15.13                    | 1266.94                  | 898.21                   |
| p$^2$z$^1$k$^1$         | 46.6                   | 8.75                      | 14.45                   | 1.50                   | 14.81                    | 972.45                   | 677.48                   |
| p$^2$z$^1$k$^2$         | 38.0                   | 10.91                     | 14.51                   | 1.41                   | 14.40                    | 1160.93                  | 831.10                   |
| p$^2$z$^1$k$^3$         | 42.6                   | 12.31                     | 14.17                   | 1.54                   | 15.04                    | 1347.13                  | 901.79                   |
| SEm (±)                 | 1.10                   | 0.80                      | 1.45                    | 0.06                   | 0.41                     | 89.31                    | 99.35                    |
| CD(0.05)                | NS                     | 2.355                     | NS                      | 0.183                  | NS                       | 261.672                  | 291.089                  |

Table 3: Effect of P x Zn x K on net income and benefit cost ratio.

| Treatments | Net income(Rs ha$^{-1}$) | BCR |
|------------|--------------------------|-----|
| p$^1$z$^1$k$^1$ | -9650                    | 0.86 |
| p$^1$z$^1$k$^2$ | 602                      | 1.01 |
| p$^1$z$^2$k$^1$ | 2666                     | 1.04 |
| p$^1$z$^2$k$^2$ | -13564                   | 0.81 |
| p$^1$z$^2$k$^3$ | 25786                    | 1.36 |
| p$^1$z$^3$k$^1$ | -17872                   | 0.75 |
| p$^1$z$^3$k$^2$ | -9549                    | 0.87 |
| p$^1$z$^3$k$^3$ | -7984                    | 0.89 |
| p$^2$z$^1$k$^1$ | -3744                    | 0.95 |
| p$^2$z$^1$k$^2$ | -20605                   | 0.71 |
| p$^2$z$^1$k$^3$ | -8778                    | 0.88 |
| p$^2$z$^2$k$^1$ | -3782                    | 0.95 |

directly or indirectly affect synthesis of carbohydrates and protein. The effect was more pronounced when applied in combination with K and high available P in soil, as evident in Table 2c. The treatment p$^1$z$^1$k$^1$ recorded the highest value (1.65 g).

Number of pods plant$^1$: The individual effect of K alone had significant influence on number of pods plant$^1$. Potassium @ 10 kg ha$^{-1}$ (k$^1$) recorded a significantly higher number of pods (11.7) compared to 20 kg ha$^{-1}$ (10.5). The significant influence of K was reflected in the interaction effects also. Among the interactions, Zn x K and P x Zn x K significantly influenced the number of pods plant$^1$ (Table 2b and 2c). The highest number (14.8) was observed in the treatments p$^1$z$^1$k$^1$ which included soil application of 10 kg K$_2$O ha$^{-1}$ along with foliar spray of Zn and no P application and was significantly superior to all other interactions.

Pod yield: Phosphorus application did not record any significant influence on the pod yield of cowpea. Nevertheless, significantly superior pod yields were recorded with foliar application of Zn, z$_i$ (1302.16 kg ha$^{-1}$) and among the K levels, 10 kg K$_2$O ha$^{-1}$ (1276.33 kg ha$^{-1}$) recorded highest yield. The interaction effect of P x K resulted in significant variations in pod yield. At different levels of P and K, maximum yield (1362.16 kg ha$^{-1}$) was recorded when K$_2$O was applied @ 10 kg ha$^{-1}$ in P rich soil and was significantly superior indicating that higher doses of the two nutrients reduced pod yields in cowpea. The treatment combination p$^1$z$^1$k$^1$ recorded the significantly highest yield (1675.60 kg ha$^{-1}$) followed by p$^1$z$^1$k$^1$ (1347.13 kg ha$^{-1}$) and p$^1$z$^1$k$^1$ (1266.94 kg ha$^{-1}$).

Number of seeds pod$^{-1}$: Number of seeds pod$^{-1}$ varied significantly with Zn x K interaction alone (Table 2a, 2b and 2c). Maximum number of seeds pod$^{-1}$ (15.30) was recorded for z$_i$k$_i$ at par with all combinations except for z$_i$k$_{10}$.

Grain yield: It is evident from the data given in Table 2a that the individual effect of the nutrients on grain yield was significant for K alone. Application of K$_2$O @ 10 kg ha$^{-1}$ recorded the highest grain yield (939.12 kg ha$^{-1}$) significantly superior to the higher dose of 20 kg ha$^{-1}$ in line with the pod yields. This is interpreted as the manifestation of the role of K in pod and grain development. Although K is not a constituent of any compound or structurally bound, it is required for translocation of assimilates, synthesis of sugar and starch that promote pod growth and filling (Singh, 2007). The significantly higher number of pods plant$^1$ observed in this treatment would have contributed to the higher grain yields. Favourable effects of K on the number of pods and seed yield have been reported in green gram (Burairo et al., 2015; Ranpriya et al., 2017).

Nutrient interactions revealed significant influence for Zn x K (Table 2b). Foliar application of Zn with lower dose of K resulted in maximum grain yield (1059.77 kg ha$^{-1}$). This was at par with z$_i$k$_{10}$ and z$_i$k$_1$. The grain yield was significantly influenced by P x Zn x K interaction and the treatment combination p$^1$z$^1$k$^1$ recorded the highest yield (1288.45 kg ha$^{-1}$).
In a soil that contained high amounts of P, an additional dose of P could not record significant effects on the growth and yield attributes and hence grain yields, confirming that a crop of cowpea could be taken without P application in this soil. Potassium application could record significant influence on the days to flowering, number of pods plant$^{-1}$, pod and grain yields. However, as in the case of P, the initial soil analysis had revealed high K status and hence responded up to 10 kg ha$^{-1}$ alone. Further increase to 20 kg ha$^{-1}$ did not record any improvement in yield, on the contrary showed lower yields. It could thus be concluded that the influence of K in biomass production and grain yield in cowpea was clearly evident, but the higher dose was not required in cowpea in view of the high K status in soil.

Zinc application as ZnSO$_4$ proved significantly better than no zinc application. Zinc is required for the biosynthesis of plant growth regulator (IAA) and for carbohydrate and N metabolism which leads to higher yield and yield components (Taliee and Sayadian, 2000). In the present study, the yield attributes viz. number of pods plant$^{-1}$, average pod length and weight were comparatively higher for foliar Zn application due to the advantages of increased absorption, reduced losses, fixation and higher nutrient use efficiency, over the soil application. These effects were reflected in the final yield too. The results are in accordance with the reports of Dhanya (2014). Foliar application was adjudged as a rapid and effective method of nutrient application (Haytova, 2013) with better nutrient use efficiency compared to soil application and can be recommended for field correction of micronutrient deficiencies.

The nutrient interactions, P x Zn, P x K and Zn x K were evaluated based on the grain yields. The interaction effect of P x Zn was found to be non significant on pod, grain and haulm yields signaling the occurrence of a negative interaction between the two nutrients. In a soil that is low in zinc, application of a Zn fertilizer is expected to bring about a response in the crop to Zn which would result in higher yields than no zinc application. Increased yields in cowpea with increased doses of P (Singh et al., 2011, Shekara et al., 2013, Rathore et al., 2015) and with Zn (Chavan et al., 2012; Bhoya et al., 2013) have been documented. However, in the present experiment such a response of increased grain yields with Zn application was not observed.
in the high P soil. This has brought to focus the antagonistic interaction that might have occurred due to the high P content in soil. Kumar et al. (2016) recorded reduced green fodder yields in cowpea at higher levels of both phosphorus and zinc.

P x K interaction recorded the highest pod yields (1362.16 kg ha\(^{-1}\)) with p\(_{k1}\) and the lowest (1082.79 kg ha\(^{-1}\)) with p\(_{k2}\). A similar but non-significant effect was observed for grain yield. The non significant effects on grain yield implied the absence of an interaction between P and K and this was plausible as the soil was high, both in available P and K contents.

Zn x K interaction was significant on grain yield with the highest yield in z\(_k1\) (1059.77 kg ha\(^{-1}\)). The results are in accordance with the findings of Yadav and Nand (2004). Chavan et al. (2012) reported significant interaction of K and Zn on grain yield with 60 kg K\(_2\)O and 40 kg Zn ha\(^{-1}\) in a soil with medium N, P and K status and attributed this to better root growth, nitrogen fixation, translocation of photosynthates and yield attributes. On critical analysis of the data, it was noticed that at the lower levels of Zn (z\(_1\)), the increase in K dose from k\(_1\) to k\(_2\) caused a 10.1 per cent increase in yield. At k\(_2\), the increase in Zn dose from z\(_1\) to z\(_2\) led to 14.7 per cent yield increase. Nevertheless, increasing the doses of both K and Zn (from z\(_1\)k\(_1\) to z\(_2\)k\(_1\)), lowered yield and hence a negative interaction is construed.

Grain and pod yields were significantly influenced by P x Zn x K interaction (Fig 1). Significantly superior pod and grain yields (1675.60 kg ha\(^{-1}\) and 1288.45 kg ha\(^{-1}\) respectively) were recorded for the combination p\(_{z1}\)k\(_1\) i.e., application of 10 kg K\(_2\)O ha\(^{-1}\) and Zn as foliar spray @ 0.025 per cent with no P. This was the reflection of beneficial effects of K @ 10 kg ha\(^{-1}\) and foliar application of Zn. As Zn was applied foliar, it was absorbed and utilized effectively by the crop and the positive effect of P x K interaction that is normally observed, outweighed the antagonistic effects of P x Zn. In general, K at 20 kg ha\(^{-1}\) (k\(_1\)) recorded comparatively lower yields with the combination of p\(_{z1}\)k\(_0\), p\(_{z0}\)k\(_1\), p\(_{z1}\)k\(_2\), p\(_{z2}\)k\(_1\), p\(_{z2}\)k\(_2\). Similarly z\(_2\) was better for the combinations of P and K and p\(_z\) for combinations with Zn and K. The grain yield at p\(_z\)k\(_2\) was 36.7 per cent higher than the lowest dose combination, p\(_z\)k\(_1\), and 47.4 per cent greater than the highest dose combination, p\(_z\)k\(_2\) (Table 2c). Further, being cations the high doses would also have hampered the absorption of the other essential cations like Ca and Mg and the reduced uptake of these essential elements would have affected the yields. According to Mengel (2007), K is known to be a strong competitor against Mg, Ca, and Na, and can restrict uptake of these nutrients when in abundant supply.

**Economics of fertilization**: The variations in the cost of cultivation, gross returns, net returns and benefit-cost ratio (BCR) with the different treatments are depicted in Table 3 and Fig.2 The differences in cost of cultivation were due to the fertilizer costs and labour charges. The highest gross income (Rs 96634 ha\(^{-1}\)) and net income (Rs 25786 ha\(^{-1}\)) were computed for the combination p\(_{z1}\)k\(_1\), owing to the higher yields realized in the treatment. Maximum BCR was obtained in the same combination (1.36). This brings to light the advantage of Zn and K application in grain cowpea grown in high P soil. Addition of P fertilizer to the high P soil lowered the income, clearly depicting the need for skipping P application in the crop while K was adequate as per recommendation @ 10 kg ha\(^{-1}\), the higher dose reducing yield and returns.

**CONCLUSION**

Based on the results of the study it can be concluded that in a high phosphorus soil higher productivity and monetary gains in grain cowpea could be realized with a combination of 10 kg K\(_2\)O ha\(^{-1}\), foliar spray of ZnSO\(_4\) @ 0.025% twice, at branching and flowering along with the recommended dose of N (20 kg ha\(^{-1}\)), skipping P application.

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