



## Growth, productivity and economics of fenugreek (*Trigonella foenum-graecum*)-pearl millet (*Pennisetum glaucum*) cropping system as influenced by phosphorus, zinc and zinc solubilizer

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### ABSTRACT

A field experiment was conducted in split plot design with three replications during winter and rainy seasons of 2015–17 at Rajasthan Agriculture Research Institute (RARI), Durgapura-Jaipur to study the growth, productivity and economics of fenugreek (*Trigonella foenum-graecum*)-pearl millet (*Pennisetum glaucum*) cropping system by using four levels of phosphorus (0, 20, 40 and 60 kg P<sub>2</sub>O<sub>5</sub>/ha) and six treatments of zinc and zinc solubilizer (0, 2.5 and 5.0 kg Zn/ha, zinc solubilizer (*Bacillus endophyticus*), 2.5 kg Zn/ha + zinc solubilizer and 5 kg Zn/ha + zinc solubilizer) applied to fenugreek. Results revealed that application of 40 kg P<sub>2</sub>O<sub>5</sub>/ha and 5 kg Zn/ha + zinc solubilizer resulted in significant increase in all growth and yield attributes while application of 60 kg P<sub>2</sub>O<sub>5</sub>/ha and 5 kg Zn/ha + zinc solubilizer increased 37% and 26%, respectively, higher seed yield of fenugreek, when compared to control (1367 and 1340 kg/ha). Residual effects of 60 kg P<sub>2</sub>O<sub>5</sub>/ha and 5 kg Zn/ha + zinc solubilizer applied to fenugreek increased grain yield of pearl millet up to 2400 kg/ha and 2375 kg/ha, respectively. Combined application of 60 kg P<sub>2</sub>O<sub>5</sub>/ha and 5 kg Zn/ha + zinc solubilizer resulted in the highest yield of fenugreek. The net return and B:C ratio was also the highest in 60 kg P<sub>2</sub>O<sub>5</sub>/ha and 5 kg Zn/ha + zinc solubilizer. Thus application of 60 kg P<sub>2</sub>O<sub>5</sub>/ha and 5 kg Zn/ha + zinc solubilizer to fenugreek improved the productivity and economics of the fenugreek –pearl millet cropping system.

**Key words:** Fenugreek, Growth characters, Pearl millet, Phosphorus, Yield characters, Zinc solubilizer

Fenugreek (*Trigonella foenum-graecum*) is important winter season seed spice crop in Rajasthan. It occupies the prime place among seed spices and its area under cultivation is increasing in the region due to assured prices. Similarly, pearl millet (*Pennisetum glaucum*) is main rainy season crop and more than 80% of the area under pearl millet falls in arid and semi-arid region of the country. Thus, fenugreek-pearl millet is an upcoming cropping system in this region. Phosphorous (P) is backbone of energy related activities and development of root system. It plays vital role in production of fenugreek as it enhances the symbiotic N-fixation. Zinc is activator of several enzymes in plants and is directly involved in the biosynthesis of growth substances such as auxin which produces more plant cells and more dry matter (Hafeez *et al.* 2013). Zinc (Zn) content of seeds of fenugreek is the highest among the seed spices, and for sustainable and profitable yields, its external application is essential (Rethinam and Sadanandan 1994) as the soils of this region are deficient in zinc. Pearl millet also responds to Zn application to a great extent (Jain 2004). A greater part of applied P and Zn

remains in soil as unutilized residue because combination of different factors seldom allows use of more than 1/3<sup>rd</sup> of applied zinc by the first crop and also phosphorus use efficiency by first crop is only 15-20% (Shahane *et al.* 2017). Therefore, it would be desirable to optimize the nutrient use efficiency and curtail the cost of fertilizers for making the system more remunerative. P application to legumes not only benefits that particular crop and increases its yields but also favourably affects performance of succeeding non-legume crop (Ganeshamurthy *et al.* 2003). Pearl millet due to its finer efficient extracting roots is capable of giving good production even on residual fertility (Sammauria and Yadav 2010). Hence, it is of paramount importance to study effect of P and Zn with respect to their direct and residual effect in fenugreek- pearl millet cropping system. In view of this present investigation was conducted.

### MATERIALS AND METHODS

The experiment was conducted during the winter and rainy seasons of 2015–16 and 2016–17 at research farm of Rajasthan Agricultural Research Institute (RARI), Durgapura-Jaipur (SKNAU, Jobner). The soil was loamy sand, containing available nitrogen, phosphorous, potassium and zinc content (139.2, 26.6, 182 kg/ha and 0.37 ppm) during 2015–16 and (134.2, 24.5, 180 kg/ha and 0.35 ppm)

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during 2016–17, respectively, in 0-30 cm soil depth with soil pH 8.3 and 8.1, and 0.17 and 0.14% organic carbon content in respective years. Treatments comprised 24 treatment combinations consisting of four phosphorous levels (0, 20, 40 and 60 kg P<sub>2</sub>O<sub>5</sub>/ha) as main plot treatments and six zinc treatments (0, 2.5 kg Zn/ha, 5.0 kg Zn/ha, zinc solubilizer, 2.5 kg Zn/ha + zinc solubilizer and 5 kg Zn/ha + zinc solubilizer) as sub plot treatments were tested in split plot design with three replications. A uniform dose of 20 kg N/ha along with phosphorous and zinc as per treatments were given through urea, diammonium phosphate and zinc sulphate (21%), respectively, to raise fenugreek. To compensate the sulphur obtained from different levels of zinc compensatory doses of sulphur were applied through Elemental Sulphur. The zinc solubilizing bacteria (*Bacillus endophyticus*) was brought from IARI, New Delhi and applied as per treatment. The 50 ml bottle of solubilizer (*Bacillus endophyticus*) was diluted with 10 liters of water and this diluted solution was mixed with well decomposed fine farmyard manure (FYM) @1 kg/plot and applied as per the treatment plots. Equal amount of FYM without solubilizer culture, was also added to plots where solubiliser was not applied as treatment. Zinc solubilising bacteria play crucial role in dissolution of

insoluble source of zinc, and convert it into soluble form and makes it available to the plant through secretion of organic acids and other metabolites. It helps augment 2 to 5 kg Zn/ha and the formulation has a shelf life of one year. The fenugreek variety ‘Rmt 305’ was sown on 03 November 2015 and 15 November 2016, with 30 cm row to row and 10 cm plant to plant spacing. To assess the residual effect of phosphorous and zinc treatments applied to preceding crop, succeeding crop of pearl millet (var. RHB 177) was raised during rainy seasons of 2016 and 2017 in same layout and was sown on 18 July 2016 and 20 July 2017, respectively. Recommended dose of nitrogen (90 kg/ha) was applied to pearl millet in two splits through urea, half as basal and remaining as top dressed 30 days after sowing and no other nutrient was applied. Economics of treatments was worked out using market price of inputs and minimum support price of outputs.

RESULTS AND DISCUSSION

Growth attributes and productivity of crops

*Fenugreek:* Application of 40 kg P<sub>2</sub>O<sub>5</sub>/ha recorded significant improvement in growth attributes like plant height, leaf area, LAI, chlorophyll content, symbiotic root nodules/plant and their dry weight, primary branches/plant, dry matter accumulation, crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR) recorded, during periodical growth stages of fenugreek than 20 kg P<sub>2</sub>O<sub>5</sub>/ha, being at par with 60 kg P<sub>2</sub>O<sub>5</sub>/ha, however, CGR during 60-90 DAS and RGR during 90 DAS to at harvest were not influenced by phosphorous application (Table 1 & 2 and Fig 1 & 2). Significant increase in plant height, leaf area, LAI, chlorophyll content, symbiotic root nodules/plant and their dry weight, primary branches/plant and dry matter accumulation were recorded with application of 5.0 kg Zn/ha + zinc solubilizer followed by 2.5 kg Zn/ha + zinc solubilizer and 5 kg Zn/ha. The application of 5 kg Zn/ha was at par with treatment effect of 2.5 kg Zn/ha + zinc solubilizer, however, application of zinc solubilizer alone was also at par with 2.5 kg Zn/ha except symbiotic root nodules/plant recorded at

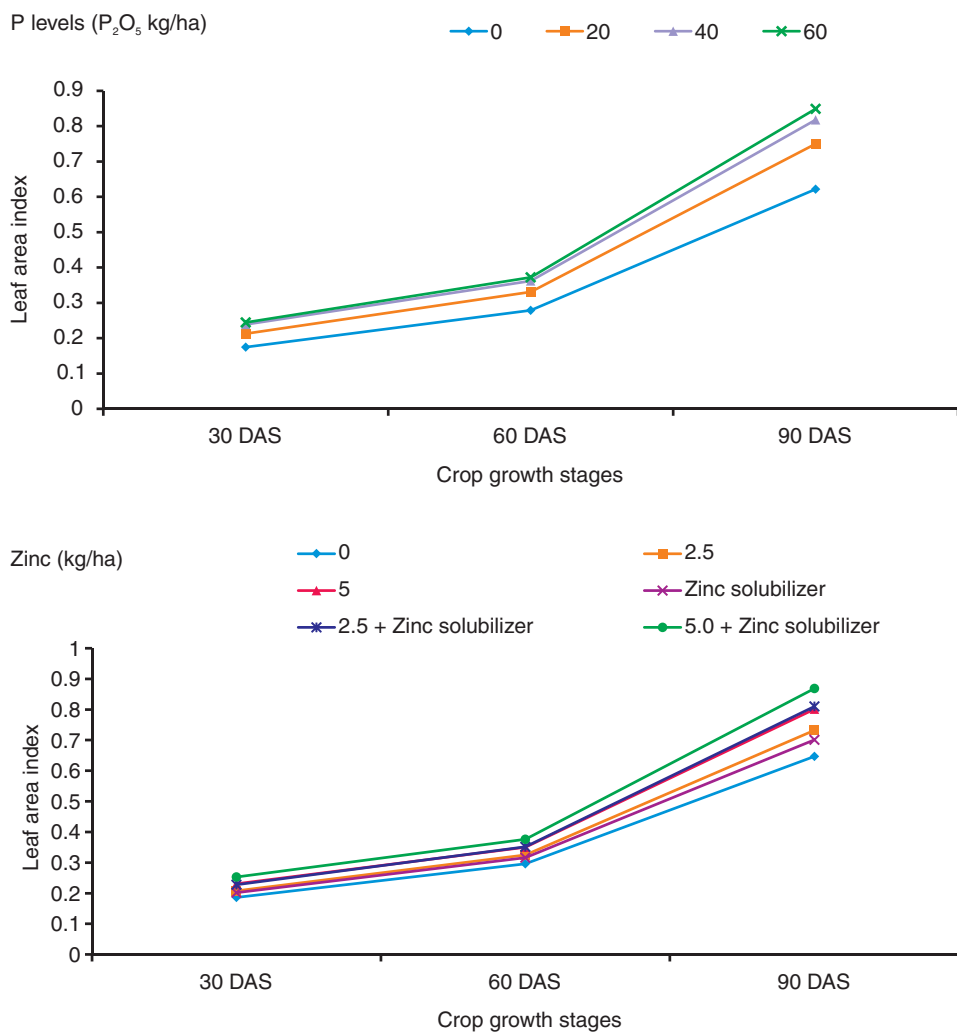


Fig 1 Effect of phosphorous and zinc fertilization on LAI of fenugreek (on pooled basis).

Table 1 Effect of phosphorus and zinc fertilization on growth attributes of fenugreek (pooled data of 2 years)

| Treatment   | Plant height (cm) |        |        | Leaf area (dm <sup>2</sup> /plant) |        |        | Symbiotic root nodules (No.) |        |        | Dry weight of root nodules (mg/plant) |        |        | Chlorophyll content (mg/g) |        |            | Primary branch/plant (No.) |        |        | Dry matter accumulation (g/plant) |        |        |        |
|---|-------------------|--------|--------|------------------------------------|--------|--------|------------------------------|--------|--------|---------------------------------------|--------|--------|----------------------------|--------|------------|----------------------------|--------|--------|-----------------------------------|--------|--------|--------|
|   | 30 DAS            | 60 DAS | 90 DAS | 30 DAS                             | 60 DAS | 90 DAS | 45 DAS                       | 90 DAS | 45 DAS | 90 DAS                                | 45 DAS | 90 DAS | 45 DAS                     | 90 DAS | At harvest | 30 DAS                     | 60 DAS | 90 DAS | At harvest                        | 30 DAS | 60 DAS | 90 DAS |
| <i>Phosphorous (P<sub>2</sub>O<sub>5</sub> kg/ha)</i> |                   |        |        |                                    |        |        |                              |        |        |                                       |        |        |                            |        |            |                            |        |        |                                   |        |        |        |
| 0.0   | 3.99              | 13.73  | 35.31  | 42.42                              | 0.525  | 0.836  | 1.865                        | 4.54   | 8.39   | 2.22                                  | 13.08  | 1.91   | 6.00                       | 0.362  | 1.69       | 7.49                       | 9.05   |        |                                   |        |        |        |
| 20  | 4.82              | 15.15  | 38.56  | 46.41                              | 0.638  | 0.992  | 2.251                        | 5.43   | 9.56   | 2.86                                  | 14.24  | 2.40   | 6.63                       | 0.449  | 2.81       | 8.82                       | 11.05  |        |                                   |        |        |        |
| 40  | 5.25              | 16.23  | 41.16  | 50.14                              | 0.717  | 1.085  | 2.455                        | 5.87   | 10.34  | 3.27                                  | 15.13  | 2.70   | 7.08                       | 0.502  | 3.35       | 9.53                       | 12.15  |        |                                   |        |        |        |
| 60  | 5.41              | 16.32  | 41.39  | 50.66                              | 0.736  | 1.116  | 2.547                        | 5.96   | 10.68  | 3.33                                  | 15.36  | 2.76   | 7.19                       | 0.521  | 3.52       | 9.72                       | 12.68  |        |                                   |        |        |        |
| SEm±  | 0.07              | 0.19   | 0.42   | 0.66                               | 0.012  | 0.014  | 0.032                        | 0.05   | 0.10   | 0.05                                  | 0.17   | 0.04   | 0.07                       | 0.008  | 0.05       | 0.09                       | 0.19   |        |                                   |        |        |        |
| CD (P=0.05)   | 0.22              | 0.58   | 1.28   | 2.02                               | 0.038  | 0.043  | 0.099                        | 0.15   | 0.32   | 0.14                                  | 0.52   | 0.13   | 0.22                       | 0.023  | 0.16       | 0.28                       | 0.58   |        |                                   |        |        |        |
| <i>Zinc (kg/ha)</i>                                   |                   |        |        |                                    |        |        |                              |        |        |                                       |        |        |                            |        |            |                            |        |        |                                   |        |        |        |
| 0.0   | 3.94              | 13.59  | 35.50  | 42.74                              | 0.557  | 0.888  | 1.940                        | 4.60   | 8.42   | 2.32                                  | 12.84  | 1.96   | 5.81                       | 0.387  | 2.44       | 7.65                       | 9.71   |        |                                   |        |        |        |
| 2.5   | 4.69              | 14.83  | 37.88  | 45.87                              | 0.625  | 0.975  | 2.195                        | 5.23   | 9.50   | 2.76                                  | 14.06  | 2.32   | 6.53                       | 0.439  | 2.76       | 8.57                       | 10.79  |        |                                   |        |        |        |
| 5.0   | 5.18              | 16.04  | 40.47  | 49.10                              | 0.693  | 1.050  | 2.404                        | 5.80   | 10.37  | 3.16                                  | 14.99  | 2.64   | 7.09                       | 0.482  | 2.98       | 9.36                       | 11.75  |        |                                   |        |        |        |
| Zinc solubilizer                                      | 4.48              | 14.61  | 37.63  | 45.80                              | 0.606  | 0.947  | 2.102                        | 5.01   | 8.93   | 2.65                                  | 13.65  | 2.2    | 6.23                       | 0.420  | 2.58       | 8.32                       | 10.51  |        |                                   |        |        |        |
| 2.5 + Zinc solubilizer                                | 5.20              | 16.02  | 40.36  | 49.00                              | 0.685  | 1.055  | 2.430                        | 5.78   | 10.21  | 3.13                                  | 15.20  | 2.63   | 7.12                       | 0.494  | 3.05       | 9.35                       | 11.91  |        |                                   |        |        |        |
| 5.0 + Zinc solubilizer                                | 5.70              | 17.05  | 42.79  | 51.93                              | 0.758  | 1.128  | 2.606                        | 6.28   | 11.03  | 3.52                                  | 15.97  | 2.93   | 7.58                       | 0.530  | 3.23       | 10.10                      | 12.74  |        |                                   |        |        |        |
| SEm±  | 0.07              | 0.21   | 0.48   | 0.64                               | 0.010  | 0.013  | 0.031                        | 0.05   | 0.12   | 0.04                                  | 0.13   | 0.04   | 0.09                       | 0.008  | 0.05       | 0.09                       | 0.13   |        |                                   |        |        |        |
| CD (P=0.05)   | 0.19              | 0.59   | 1.35   | 1.79                               | 0.029  | 0.037  | 0.086                        | 0.15   | 0.33   | 0.13                                  | 0.37   | 0.10   | 0.25                       | 0.023  | 0.14       | 0.26                       | 0.36   |        |                                   |        |        |        |

Table 2 Effect of phosphorus and zinc fertilization on yield attributes and yields of fenugreek (pooled data of 2 years)

| Treatment   | Relative growth rate (RGR) (g/g/day) |            |                    | Net assimilation rate (NAR) (g/dm <sup>2</sup> /day) |            | Pods/plant (No) | Pod length (cm) | Seeds/pod (No) | Seed yield/plant (g) | Straw yield/plant (g) | Test weight (g) | Speed yield (kg/ha) | Straw yield (kg/ha) | Biological yield (kg/ha) | Harvest index (%) |
|---|--------------------------------------|------------|--------------------|--|------------|-----------------|-----------------|----------------|----------------------|-----------------------|-----------------|---------------------|---------------------|--------------------------|-------------------|
|   | 30-60 days                           | 60-90 days | 90 days at harvest | 30-60 days   | 60-90 days |                 |                 |                |                      |                       |                 |                     |                     |                          |                   |
| <i>Phosphorous (P<sub>2</sub>O<sub>5</sub> kg/ha)</i> |                                      |            |                    |  |            |                 |                 |                |                      |                       |                 |                     |                     |                          |                   |
| 0.0   | 0.0509                               | 0.0502     | 0.0038             | 0.0667   | 0.1519     | 19.54           | 8.80            | 9.68           | 3.35                 | 5.94                  | 10.39           | 1001                | 1959                | 2960                     | 33.97             |
| 20  | 0.0609                               | 0.0385     | 0.0045             | 0.0977   | 0.1316     | 22.66           | 10.53           | 11.66          | 3.95                 | 6.89                  | 11.35           | 1167                | 2334                | 3501                     | 33.45             |
| 40  | 0.0631                               | 0.0351     | 0.0049             | 0.1067   | 0.1231     | 24.78           | 11.55           | 12.99          | 4.25                 | 7.63                  | 12.12           | 1315                | 2562                | 3877                     | 34.05             |
| 60  | 0.0636                               | 0.0340     | 0.0053             | 0.1098   | 0.1192     | 25.72           | 12.10           | 13.43          | 4.35                 | 7.83                  | 12.22           | 1367                | 2650                | 4017                     | 34.01             |
| SEm±  | 0.0008                               | 0.0009     | 0.0004             | 0.0027   | 0.0031     | 0.37            | 0.18            | 0.16           | 0.05                 | 0.09                  | 0.12            | 18                  | 30                  | 47                       | 0.35              |
| CD (P=0.05)   | 0.0024                               | 0.0027     | NS                 | 0.0085   | 0.0095     | 1.14            | 0.57            | 0.51           | 0.17                 | 0.28                  | 0.36            | 55                  | 93                  | 145                      | NS                |
| <i>Zinc (kg/ha)</i>                                   |                                      |            |                    |  |            |                 |                 |                |                      |                       |                 |                     |                     |                          |                   |
| 0.0   | 0.0601                               | 0.0396     | 0.0047             | 0.0943   | 0.1310     | 20.81           | 9.17            | 10.44          | 3.55                 | 6.16                  | 10.57           | 1067                | 2060                | 3127                     | 34.23             |
| 2.5   | 0.0600                               | 0.0393     | 0.0045             | 0.0963   | 0.1306     | 22.80           | 10.50           | 11.60          | 3.92                 | 6.89                  | 11.28           | 1176                | 2330                | 3507                     | 33.78             |
| 5.0   | 0.0598                               | 0.0394     | 0.0045             | 0.0955   | 0.1326     | 24.05           | 11.53           | 12.34          | 4.09                 | 7.47                  | 11.87           | 1254                | 2494                | 3747                     | 33.48             |
| Zinc solubilizer                                      | 0.0588                               | 0.0409     | 0.0046             | 0.0923   | 0.1344     | 21.90           | 9.72            | 11.05          | 3.72                 | 6.53                  | 11.04           | 1138                | 2182                | 3321                     | 34.38             |
| 2.5 + Zinc solubilizer                                | 0.0598                               | 0.0384     | 0.0048             | 0.0980   | 0.1287     | 24.26           | 11.32           | 12.85          | 4.20                 | 7.45                  | 11.89           | 1300                | 2540                | 3839                     | 33.81             |
| 5.0 + Zinc solubilizer                                | 0.0591                               | 0.0393     | 0.0047             | 0.0949   | 0.1313     | 25.21           | 12.23           | 13.35          | 4.37                 | 7.95                  | 12.47           | 1340                | 2652                | 3992                     | 33.55             |
| SEm±  | 0.0008                               | 0.0006     | 0.0002             | 0.0020   | 0.0027     | 0.26            | 0.13            | 0.13           | 0.03                 | 0.08                  | 0.10            | 11                  | 28                  | 40                       | 0.43              |
| CD (P=0.05)   | NS                                   | NS         | NS                 | NS   | NS         | 0.74            | 0.37            | 0.37           | 0.09                 | 0.22                  | 0.29            | 32                  | 79                  | 111                      | NS                |

Table 3 Interaction effect of phosphorous and zinc fertilization on yield attributes and yield of fenugreek (pooled data of 2 years)

| Zinc levels (kg/ha)    | Phosphorous levels (P <sub>2</sub> O <sub>5</sub> kg/ha) |       |       |       |                      |      |      |      |                    |      |      |      |  |
|------------------------|--|-------|-------|-------|----------------------|------|------|------|--------------------|------|------|------|--|
|                        | Seeds/pod (no.)  |       |       |       | Seed yield/plant (g) |      |      |      | Seed yield (kg/ha) |      |      |      |  |
|                        | 0.0  | 20    | 40    | 60    | 0.0                  | 20   | 40   | 60   | 0.0                | 20   | 40   | 60   |  |
| 0.0                    | 8.79   | 10.19 | 11.04 | 11.74 | 3.11                 | 3.49 | 3.72 | 3.91 | 899                | 1049 | 1144 | 1177 |  |
| 2.5                    | 9.48   | 11.99 | 12.66 | 12.28 | 3.30                 | 4.21 | 4.15 | 4.02 | 995                | 1190 | 1268 | 1251 |  |
| 5.0                    | 9.89   | 11.53 | 13.63 | 14.32 | 3.41                 | 3.91 | 4.46 | 4.60 | 1032               | 1162 | 1386 | 1435 |  |
| Zinc solubilizer       | 9.23   | 10.87 | 12.05 | 12.03 | 3.23                 | 3.67 | 3.99 | 3.98 | 937                | 1120 | 1237 | 1259 |  |
| 2.5 + Zinc solubilizer | 10.18  | 12.66 | 14.00 | 14.55 | 3.49                 | 4.14 | 4.51 | 4.66 | 1052               | 1243 | 1412 | 1492 |  |
| 5.0 + Zinc solubilizer | 10.53  | 12.69 | 14.55 | 15.65 | 3.58                 | 4.26 | 4.68 | 4.96 | 1092               | 1240 | 1444 | 1586 |  |
| SEm±                   |  | 0.26  |       |       |                      | 0.07 |      |      |                    | 22   |      |      |  |
| CD (P=0.05)            |  | 0.73  |       |       |                      | 0.19 |      |      |                    | 63   |      |      |  |

45 DAS where only application of 5 kg Zn/ha was at par with 2.5 kg Zn/ha + zinc solubilizer. However, application of zinc solubilizer alone non significantly differed with control in dry matter accumulation recorded at 60 DAS and CGR during all growth stages, similarly all treatments of zinc did not exert significant effect on RGR and NAR.

All yield attributes and seed, straw and biological yields of fenugreek also significantly increased up to 40 kg P<sub>2</sub>O<sub>5</sub>/ha (Table 2). On pooled basis, respective application of 20, 40 and 60 kg P<sub>2</sub>O<sub>5</sub>/ha resulted in 17, 31 and 37% higher seed yield when compared to control. Application of 5.0 kg Zn/ha + zinc solubilizer to fenugreek recorded the highest yield attributes like pods/plant, pod length, seeds/pod, test weight, seed and straw yield/plant and yields of fenugreek and also significantly superior over rest of the treatments. The application of 5 kg Zn/ha was at par with 2.5 kg Zn/ha + zinc solubilizer, however, application of zinc solubilizer alone was also at par with 2.5 kg Zn/ha in pods/plant, pod length, seeds/pod and test weight but in straw yield/plant and straw yield (q/ha) only application of 5 kg Zn/ha was at par with 2.5 kg Zn/ha + zinc solubilizer. On pooled basis, seed yield of fenugreek increased by 10,

17, 7, 22 and 26 % with the application of 2.5 kg Zn/ha, 5 kg Zn/ha, zinc solubilizer, 2.5 kg Zn/ha + zinc solubilizer, 5 kg Zn/ha + zinc solubilizer, respectively, when compared with control.

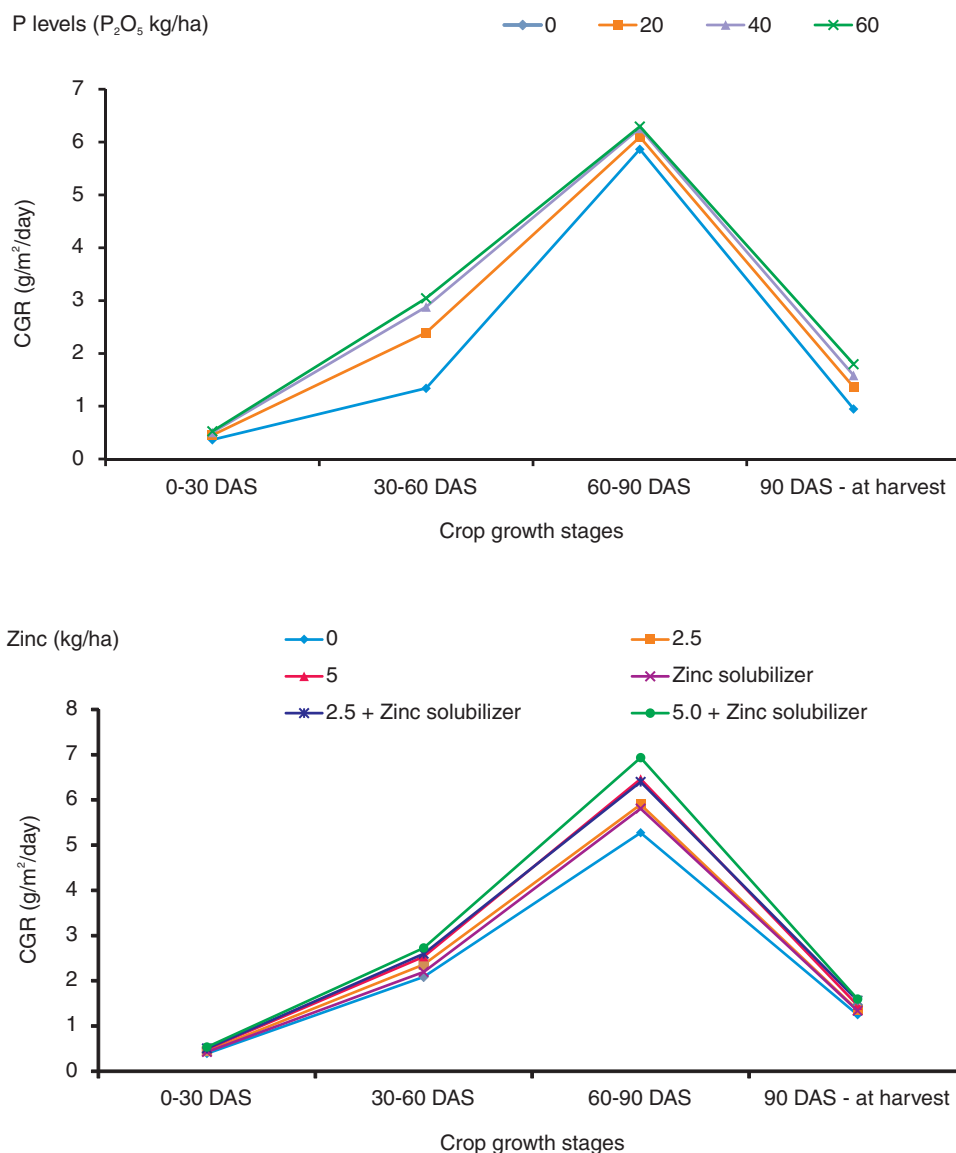


Fig 2 Effect of phosphorous and zinc fertilization on CGR of fenugreek (on pooled basis).

Table 4 Residual effect of phosphorus and zinc fertilization of fenugreek on growth and yield attributes and yields of succeeding pearl millet and economics of fenugreek-pearl millet cropping system (pooled data of 2 years)

| Treatment   | Plant height (cm) | Total dry matter accumulation (g/plant) | Total tillers/plant (no.) | Effective tillers/plant (no.) | Ear length (cm) | Test weight (g) | Grain yield (kg/ha) | Stover yield (kg/ha) | Biological yield (kg/ha) | Economics            |                      |       |      |      |
|---|-------------------|---|---------------------------|-------------------------------|-----------------|-----------------|---------------------|----------------------|--------------------------|----------------------|----------------------|-------|------|------|
|   |                   |   |                           |                               |                 |                 |                     |                      |                          | Cost of cultivation* | Benefit : cost ratio |       |      |      |
|   |                   |   |                           |                               |                 |                 |                     |                      |                          | Fenugreek            | Pearl millet         |       |      |      |
| <i>Phosphorous (P<sub>2</sub>O<sub>5</sub> kg/ha)</i> |                   |   |                           |                               |                 |                 |                     |                      |                          |                      |                      |       |      |      |
| 0.0   | 164.57            | 35.88                                   | 3.37                      | 3.19                          | 19.61           | 5.75            | 1575                | 4007                 | 5583                     | 20289                | 22591                | 28087 | 1.11 | 1.97 |
| 20  | 169.43            | 39.26                                   | 3.63                      | 3.45                          | 20.40           | 5.97            | 1745                | 4415                 | 6160                     | 21297                | 28894                | 31994 | 1.36 | 2.32 |
| 40  | 184.65            | 48.54                                   | 4.02                      | 3.89                          | 21.66           | 6.21            | 2105                | 5170                 | 7276                     | 22281                | 33995                | 41960 | 1.53 | 2.94 |
| 60  | 196.72            | 53.87                                   | 4.22                      | 4.10                          | 21.82           | 6.36            | 2400                | 5729                 | 8128                     | 23322                | 35113                | 48844 | 1.50 | 3.43 |
| SEm±  | 1.95              | 0.92                                    | 0.05                      | 0.05                          | 0.22            | 0.05            | 31                  | 64                   | 111                      | 20289                | 22591                | 28087 | 1.11 | 1.97 |
| CD (P=0.05)   | 6.00              | 2.84                                    | 0.17                      | 0.16                          | 0.68            | 0.15            | 95                  | 198                  | 342                      | 21297                | 28894                | 31994 | 1.36 | 2.32 |
| <i>Zinc (kg/ha)</i>                                   |                   |   |                           |                               |                 |                 |                     |                      |                          |                      |                      |       |      |      |
| 0.0   | 161.35            | 38.01                                   | 3.41                      | 3.30                          | 19.72           | 5.91            | 1628                | 4260                 | 5887                     | 21139                | 24452                | 30762 | 1.15 | 2.16 |
| 2.5   | 172.64            | 42.82                                   | 3.72                      | 3.56                          | 20.71           | 6.03            | 1827                | 4627                 | 6454                     | 21749                | 28740                | 35363 | 1.32 | 2.48 |
| 5.0   | 185.81            | 47.10                                   | 3.97                      | 3.77                          | 21.25           | 6.13            | 2106                | 5106                 | 7212                     | 22349                | 31507                | 39112 | 1.40 | 2.86 |
| Zinc solubilizer                                      | 170.55            | 40.33                                   | 3.57                      | 3.47                          | 20.06           | 6.00            | 1779                | 4355                 | 6134                     | 21249                | 27326                | 33151 | 1.28 | 2.33 |
| 2.5 + Zinc solubilizer                                | 185.13            | 46.89                                   | 4.01                      | 3.84                          | 21.49           | 6.17            | 2024                | 5039                 | 7063                     | 21849                | 33794                | 40200 | 1.54 | 2.82 |
| 5.0 + Zinc solubilizer                                | 197.57            | 51.16                                   | 4.16                      | 4.03                          | 22.00           | 6.21            | 2375                | 5594                 | 7969                     | 22449                | 35071                | 47740 | 1.55 | 3.35 |
| SEm±  | 2.12              | 0.98                                    | 0.07                      | 0.07                          | 0.35            | 0.06            | 35                  | 101                  | 125                      | 21139                | 24452                | 30762 | 1.15 | 2.16 |
| CD (P=0.05)   | 5.97              | 2.77                                    | 0.20                      | 0.19                          | 0.98            | 0.16            | 97                  | 285                  | 352                      | 21749                | 28740                | 35363 | 1.32 | 2.48 |

\*Cost of cultivation of pearl millet: ₹14325

*Interaction effect:* Fenugreek recorded significant improvement in seeds/pod and seed yield up to application of 40 kg P<sub>2</sub>O<sub>5</sub>/ha and 5 kg Zn/ha (Table 3). Significantly higher seeds/pod and seed yield was obtained with the combined application of 60 kg P<sub>2</sub>O<sub>5</sub>/ha + 5 kg Zn/ha + zinc solubilizer when compared with other combinations. The combination of sub-optimum level of Zn with higher levels of P resulted in antagonistic effect. Increased availability of P probably caused the reduction in solubility, uptake and translocation of Zn leading to significant reduction in seed yield (Sammauria and Yadav 2010). The combinations comprised of higher levels of these nutrients that were in synergy in improving the yield, however, combination of sub-optimum level of one or another gave antagonistic effects.

Phosphorus is the main constituent of energy rich phosphate compounds, which act as energy currency within the plants which is subsequently used for vegetative and reproductive growth through phosphorylation. Phosphorus is a necessary nutrient for the biosynthesis of chlorophyll and increased nitrogen availability due to biological nitrogen fixation. Increased and continuous availability of N in soil along with applied P resulted in enhanced root, shoot growth and biomass of legumes (Raju *et al.* 2005). Zinc also has definite metabolic role in different vital processes, as it is involved in biosynthesis of indole acetic acid (IAA), which is important for nodulation in legumes. Zinc solubilizing bacteria overcome zinc deficiency and increase availability of zinc to crops by solubilising the complex zinc in soil. These solubilizers also exhibited strong production of ammonia, which can be taken up by plants as a source of nitrogen for their growth.

*Pearl millet:* Significant improvement was observed in the growth and yield attributes of pearl millet due to residual effect of phosphorous and zinc. Plant height, total dry matter accumulation, total and effective tillers/plant increased significantly due to residual effect of 60 kg P<sub>2</sub>O<sub>5</sub>/ha, however, ear length and test weight improved significantly only up to 20 kg P<sub>2</sub>O<sub>5</sub>/ha (Table 4). Among Zn treatments, all growth attributes increased with residual effect of 5 kg Zn/ha + zinc solubilizer and effect of this treatment was statistically similar with residual effect of 2.5 kg Zn/ha + zinc solubilizer and 5 kg Zn/ha in total and effective tillers/plant and test weight, however, application of zinc solubilizer did not exert any significant effect on all growth and yield attributes except plant height. Significant response was obtained in grain, stover and biological yields due to residual effect of phosphorous up to 60 kg P<sub>2</sub>O<sub>5</sub>/ha (Table 4). On pooled basis, residual effects of 20, 40 and 60 kg P<sub>2</sub>O<sub>5</sub>/ha resulted in 11, 34 and 52% higher grain yield, respectively, over control. Amongst the Zn treatments, residual effect of 5 kg Zn/ha + zinc solubilizer resulted in the highest pearl millet grain, stover and biological yield, however, zinc solubilizer was at par with 2.5 kg Zn/ha and application of 5 kg Zn/ha was also at par with 2.5 kg Zn/ha + zinc solubilizer. No residual effect of zinc solubilizer was observed on stover and biological yields. On pooled basis, grain yield of pearl millet increased by 12, 29, 9, 24 and 46%

when compared with control with the residual effect of 2.5 kg Zn/ha 5 kg Zn/ha, zinc solubilizer, 2.5 kg Zn/ha + zinc solubilizer and 5 kg Zn/ha + zinc solubilizer, respectively.

Fenugreek being a legume as preceding crop acted as a catalyst and enhanced the availability of native and applied phosphorus from deeper layers, whereas pearl millet extracts most of its P from upper layer with highly extracting fine roots. Further, during rainy season, intermittent wetting and drying and higher temperature conditions increased the solubility and diffusivity of phosphorus and zinc (Raju *et al.* 2005). These results are in consonance with those reported by Sammauria and Yadav (2010). Field crops take up only 0.3–3.5% of the annually applied fertilizer zinc and consequently, fertilizer zinc accumulates in the soil (Abid *et al.* 2013). Solubilizers solubilize that fixed zinc through their acid production action and increase microbial activity in the soil led to higher uptake of these nutrients which had a favorable effect on succeeding crop.

#### Economics

Application of 60 kg P<sub>2</sub>O<sub>5</sub>/ha and 5 kg Zn/ha + zinc solubilizer gave the highest net monetary returns and benefit: cost ratios of both the crops while, application of 40 kg P<sub>2</sub>O<sub>5</sub>/ha gave highest benefit:cost ratio of fenugreek (Table 4).

Consequently application of 60 kg P<sub>2</sub>O<sub>5</sub>/ha and 5 kg Zn/ha + zinc solubilizer to fenugreek is recommended for increasing the fenugreek–pearl millet system productivity and fetching high returns

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