Original Research Article

Residual and Cumulative Effects of Organic and Inorganic P on Economics of Soybean (Glycine max L.) - Onion (Allium cepa L.) Cropping Sequence in a High P Alfisol

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A B S T R A C T

A field experiment was conducted during kharif (soybean), 2012 and rabi (onion) 2012-13 in a sandy clay loam soils of college farm, College of Agriculture, Rajendranagar, Hyderabad to study the response of P levels (0, 30 and 60 kg P₂O₅ ha⁻¹) either alone or in combination with PSB @ 5 kg ha⁻¹, biochar @ 5 t ha⁻¹, humic acid @ 20 kg ha⁻¹ and citric acid @ 10 mM concentration to study the direct, residual and cumulative effects of the treatments imposed on yield of soybean (direct) and onion (Residual and Cumulative), soybean equivalent yield (Residual and Cumulative) and benefit : cost ratio of soybean (direct) and onion (Residual and Cumulative). The mean seed yield of the soybean with biochar was 2077 kg ha⁻¹ which was significantly higher against the control seed yield of 1329 kg ha⁻¹. Biochar resulted in a significant increase in mean onion yield to 22.1 t ha⁻¹ against 15.8 t ha⁻¹ when organics were not supplemented, the yield response being 39.9 per cent across inorganic P and mode of effect. Yield of soybean - onion cropping sequence was higher with biochar and humic acid when applied along with 30 kg P₂O₅ ha⁻¹ with corresponding soybean equivalent yields of 7063 and 6740 kg ha⁻¹. For soybean-onion cropping sequence, residual effect of 30 kg P₂O₅ ha⁻¹ + humic acid was economically better with higher B: C ratio of 2.0 followed by 30 kg P₂O₅ ha⁻¹ + biochar in both residual and cumulative effects which showed 1.9.

Keywords
Biochar, B: C ratio, Humic acid, Nutrient removals, Residual - cumulative effect, Soybean equivalent yield

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Introduction

Phosphorus is a component of the complex nucleic acid structure of plants, which regulates protein synthesis. Phosphorus is, therefore, important in cell division and development of new tissue. Phosphorus is also associated with complex energy transformations in the plant. P requirement for soybean crop is more during pod and seed development where more than 60% of P ends up in the pods and seeds. Soybean is a P dependent crop, and application of proper P concentrations coordinated production, improved physiological characteristics, and enhanced nutrient uptake (Yan et al., 1995). Onion is one of the most commercially valuable vegetables grown in India. It is considered as a rich source of carbohydrates,
proteins and vitamin C besides minerals like phosphorus and calcium. P fertilizer recommendation for soybean and onion crops was same.

The use of fertilizer is one of the most important factors to increase crop yield in soya bean production. Phosphorus is an important element which application is necessary for growth, development and yield of soya beans (Kakar et al., 2002). Reasonable yield and profit can be obtained from the production of soybean if farmers concern themselves with the various ways in which growth and yield of the crop can be enhanced. One of these ways is to consider the nutrient requirement of the crop. This is important because of the depletion of nutrients in the soil caused by continuous cropping. Basso and Rictchie (2005) suggested that for continuous use of land for crop production, organic and inorganic fertilizers must be incorporated into the soil as this will provide multiple benefits for improving the chemical and physical status of the soil as well as improve yield of soya bean.

Application of mineral fertilizer as soil fertility management under intensive continuous cropping is no longer feasible due to non-availability, high cost where available and the numerous side effects on the soil (Akindede and Okeleye, 2005). Farmers using mineral fertilizer for years usually notice signs of soil exhaustion shown by sick appearance of the plant, leaf discolorations, retarded growth and low yield. A combined use of both organic and inorganic fertilizer is beneficial.

Most of the P present in soils is in unavailable forms and added soluble forms of P are quickly fixed by many soils. The inoculation of phosphorus solubilizing microbes has been shown to increase the P availability, P uptake and crop yields. Biochar, a solid co product from the thermo chemical production of bioenergy, has been reported to increase nutrient availability in soils through increased cation retention and decreased phosphate adsorption (Lehmann et al., 2006). In addition, biochar is highly recalcitrant to microbial decomposition and thus guarantees a long term benefit for soil fertility (Steiner et al., 2007). Low molecular weight organic acids have been shown to decrease P adsorption and increase P availability through complexation of cations such as Ca, Al, and Fe (Geelhoed et al., 1999).

Keeping in view the significance of optimization of phosphorus fertilizers by using organics in maintaining the soil health and improvement in the productivity of crops and less study on this cropping sequence, an investigation entitled “Residual and Cumulative Effects of Organic and Inorganic P on Economics of Soybean (Glycine max L.) -Onion (Allium cepa L.) Cropping Sequence in a High P Alfisol” was planned.

Materials and Methods

During kharif (soybean) 2012, the experiment was laid out in split plot design consisting 3 main levels of inorganic P (0, 30 and 60 kg P2O5 ha⁻¹) and 5 sub levels of organics (no organics, PSB, biochar, humic acid and citric acid). In rabi (onion) 2012-13, the experiment was laid out in split-split plot design, with 2 sub – sub levels (no application, application of best combination from kharif to study the residual and cumulative effects respectively). For this all the plots were divided into two equal halves. For one half, neither inorganic P nor organics were applied to know the residual effect on onion grown during rabi after harvest of soybean crop. In another half, the best combination from kharif was applied to study the cumulative effects. For all the treatments N and K were be applied uniformly at the rate of 30 kg N ha⁻¹ and 40 kg K2O ha⁻¹ for soybean, 150 kg N ha⁻¹ and 60 kg K2O ha⁻¹ for onion.
for onion in the form of urea and MOP respectively. Inorganic P will be applied in the form of DAP and N was adjusted with urea.

The experimental soil was sandy clay loam in texture, slightly alkaline (pH 7.64) in reaction, non-saline (0.195 dS m\(^{-1}\)) in nature and medium in organic carbon (0.57 %). The soil was low in available nitrogen (177 kg N ha\(^{-1}\)), high in available phosphorus (29.9 kg P ha\(^{-1}\)) and potassium (449 kg K ha\(^{-1}\)) (Table 1). Nutrient uptake (kg ha\(^{-1}\)) by soybean and onion were calculated using the values of percent nutrient concentrations and dry matter production (kg ha\(^{-1}\)). Soybean equivalent yield of soybean – onion cropping sequence was calculated.

The benefit cost ratios were computed through partial budgeting technique by taking into consideration the additional cost incurred due to imposition of the treatments and the additional returns realized, expressed in monetary terms. The treatment without inorganic phosphorus and organic application was taken as control for the purpose of comparison.

The data on various parameters was statistically analysed following the method of analysis of variance for split and double split designs and the significance was tested by ‘F’ test (Snedecor and Cochran, 1967). Critical difference for comparing the treatment means and their interactions were calculated at 5 per cent level of probability.

**Results and Discussion**

**Seed yield of soybean**

The mean seed yield of the soybean with biochar was 2077 kg ha\(^{-1}\) which was significantly higher against the control seed yield of 1329 kg ha\(^{-1}\), PSB seed yield of 1287 kg ha\(^{-1}\) and citric acid yield of 1463 kg ha\(^{-1}\) (Table 2). However, the seed yield put forth by biochar and humic acid were at a par with the per cent yield response being 56 and 55 per cent respectively, across the inorganic P application. The beneficial effects of biochar are determined primarily by some of its properties like high porosity, responsible for its high water retention capacity; high cation exchange capacity, which favours the retention of nutrients and intercept their losses and it has the ability to habitat most of the beneficial organisms, which can increase the release and uptake of nutrients by plants (Atkinson et al., 2010 and Sohi et al., 2010). Beneficial effects of humic substances were shown on plant growth, mineral nutrition, seed germination, seedling growth, root initiation, root growth shoot development and the uptake of macro and micro nutrients, in addition to the claim that 1kg of HA can substitute for 1 ton of manure (Tahir et al., 2011).

When organics were applied alone, humic acid recorded significantly higher seed yield of 1906 kg ha\(^{-1}\) over the yields obtained with the control, PSB and citric acid treatments. However, it was on a par with the biochar. Integration of inorganic P at 30 kg P\(_2\)O\(_5\) ha\(^{-1}\) with biochar showed significantly higher seed yield of 2453 kg ha\(^{-1}\), which was 63.1 per cent higher when compared to inorganic P at 30 kg P\(_2\)O\(_5\) ha\(^{-1}\) when applied alone. The beneficial effects of biochar are more pronounced when applied in combination with inorganic nutrients rather alone (Baronti et al., 2010).

**Bulb yield of onion**

Among the organics, biochar application lead to a statistically significant positive effect on both biomass and yield. Biochar resulted in a significant increase in mean onion yield to 22.1 t ha\(^{-1}\) against 15.8 t ha\(^{-1}\) when organics were not supplemented, the yield response being 39.9 per cent across inorganic P and mode of effect. Biochar addition can increase
crop production by improving the physical, chemical properties and soil fertility via effects on the microbial community Lehmann et al., 2011. Among the mode of effect (residual/cumulative), cumulative effect was found to show significant influence resulting in a mean yield of 21 t ha$^{-1}$ which was higher by 22.1 per cent as against 17.2 t ha$^{-1}$ due to the residual effect. Cumulative application of 50% reduced level of inorganic P (30 kg P$_2$O$_5$ ha$^{-1}$) along with biochar to onion, the treatment found to fare well with soybean, showed significantly higher yield than the residual effect across organics and inorganic P (Table 3).

When inorganic P was not applied to soybean, biochar resulted in a significantly higher mean yield of 18.9 t ha$^{-1}$ against 14.2 t ha$^{-1}$ in the treatment that did not receive any organics resulting in a 33 per cent increase in the yield. However, biochar and humic acid were comparable in the yield and at a par. Application of 30 kg P$_2$O$_5$ ha$^{-1}$ alone to the soybean across organics and mode of effects resulted in a mean onion bulb yield of 16.4 t ha$^{-1}$ against 14.2 t ha$^{-1}$ in the control, the per cent increase being 15.5 per cent. However, 30 and 60 kg P$_2$O$_5$ ha$^{-1}$ levels were on par with each other. Similar response up to 30 kg P$_2$O$_5$ ha$^{-1}$ level was observed when integration was exercised with the organics. At this level of inorganic P, the combination with biochar showed significantly higher yield of 23.1 t ha$^{-1}$. Chandrika and Reddy (2011) also reported similar yields of onion i.e., 31.18 and 23.60 t ha$^{-1}$ respectively in 2004 and 2005 years (Agrifound light red).

**Soybean equivalent yield of soybean – onion cropping sequence**

When inorganic P was applied alone showed a sharp increase to 4783 kg ha$^{-1}$ at 30 kg P$_2$O$_5$ ha$^{-1}$ and later showed a marginal increase to 4920 kg ha$^{-1}$ at 60 kg P$_2$O$_5$ ha$^{-1}$ (Table 4). Humic acid when applied alone resulted in the highest soybean equivalent yield of 5629 kg ha$^{-1}$ closely followed by biochar with 5496 kg ha$^{-1}$. While, at 30 kg P$_2$O$_5$ ha$^{-1}$, biochar put forth higher system yield of 7063 kg ha$^{-1}$ against 6740 kg ha$^{-1}$ with humic acid. Similar trend was observed at the highest level of inorganic P application with a marginal reduction in soybean equivalent yields of 7223 and 6661 kg ha$^{-1}$ respectively. The soybean equivalent yield due to residual and cumulative effects was 5083 and 5848 kg ha$^{-1}$ respectively.

**Soybean B-C ratio**

Highest B: C ratio was observed with 30 kg P$_2$O$_5$ ha$^{-1}$ + humic acid (2.33) followed by 30 kg P$_2$O$_5$ ha$^{-1}$ + biochar (2.14). It may be due to the low cost of cultivation i.e., 57,067 Rs ha$^{-1}$ for 30 kg P$_2$O$_5$ ha$^{-1}$ + humic acid and a little difference in yield between 30 kg P$_2$O$_5$ ha$^{-1}$ + humic acid and 30 kg P$_2$O$_5$ ha$^{-1}$ + biochar. Similar results were obtained with Madhavi (2014) in sandy loam soils with high in P status using maize as a test crop and reported that the highest B: C ratio (3.84) was obtained in treatment receiving 75 percent NPK with biochar @ 7.5 t ha$^{-1}$ followed by 75 percent NPK with biochar @ 7.5 t ha$^{-1}$ and humic acid @ 30 kg ha$^{-1}$ (3.77), while recommended NPK alone realized a B: C ratio of 3.66. Treatment receiving 75 percent NPK alone shows lowest (3.30) B: C ratio (Table 5).

**Onion B-C ratio**

Rabi Among all the treatments, superior B: C ratio recorded with 60 kg P$_2$O$_5$ ha$^{-1}$ + biochar in residual effect (2.0) followed by 30 kg P$_2$O$_5$ ha$^{-1}$ + biochar in cumulative effect (1.9). It may be due to the low cost of cultivation for residual effect i.e., 1,12,933 Rs ha$^{-1}$ than cumulative effect the value being 1,24,667 Rs ha$^{-1}$ (Table 6).
Table 1: Salient soil characteristics of experimental site

| S. No. | Name of the property | Value      |
|--------|----------------------|------------|
| I.     | Physical properties  |            |
| a)     | Textural fraction    |            |
| 1) Sand (%) | 72.04                |
| 2) Silt (%)  | 7.4                 |
| 3) Clay (%)  | 20.56               |
| b)     | Textural class       | Sandy clay loam |
| II.    | Physico-chemical analysis |     |
| a)     | Soil reaction (pH)   | 7.64       |
| b)     | Electrical conductivity (dSm⁻¹) | 0.195 |
| III.   | Chemical properties  |            |
| a)     | Organic carbon (%)   | 0.57       |
| b)     | Available Nitrogen (kg ha⁻¹) | 177     |
| c)     | Available phosphorus (kg P ha⁻¹) | 29.9   |
| d)     | Available potassium (kg K ha⁻¹) | 449    |

Table 2: Effect of organics, inorganic P and their interaction on seed yields (kg ha⁻¹) of soybean

| Sub         | Main levels (kg ha⁻¹) | Seed yield (kg ha⁻¹) | Mean |
|-------------|-----------------------|----------------------|------|
| No organics |                       |                      | 1329 |
| PSB         | 938                   | 1507                 | 1541 | 1287 |
| Biochar     | 1311                  | 1253                 | 1295 | 2077 |
| Humic acid  | 1717                  | 2453                 | 2062 | 2062 |
| Citric acid | 1906                  | 2283                 | 1996 | 1463 |
| Mean        | 1389                  | 1899                 | 1683 |      |

S.E.m.± CD (P=0.05)

|                      | Main | Sub | Main at Sub | Sub at Main |
|----------------------|------|-----|-------------|-------------|
|                      | 25   | 53  | 92          | 65          |
|                      | 98   | 155 | 269         | 195         |
### Table 3 Residual and cumulative effects of organics, inorganic P and their interaction on onion yield (t ha\(^{-1}\))

| Organics-Sub treatments | Inorganic P levels (kg P\(_2\)O\(_5\) ha\(^{-1}\)) -Main treatments | 0 | 30 | 60 | Means | Mean for Organics |
|-------------------------|----------------------------------------------------------|---|----|----|-------|-----------------|
|                         | Residual | Cumulative | Mean | Residual | Cumulative | Mean | Residual | Cumulative | Mean | Residual | Cumulative |
| No organics             |          |            |     |          |            |      |          |            |      |          |            |
| PSB                     | 11.9     | 16.5       | **14.2** | 14.5     | 18.3       | **16.4** | 16.3     | 17.5       | **16.9** | 14.2     | 17.5       | **15.8** |
| Biochar                 | 13.0     | 18.7       | **15.8** | 17.5     | 22.9       | **20.3** | 18.4     | 22.5       | **20.4** | 16.3     | 21.4       | **18.8** |
| Humic acid              | 16.3     | 21.5       | **18.9** | 21.2     | 24.9       | **23.1** | 22.6     | 25.8       | **24.2** | 20.0     | 24.1       | **22.1** |
| Citric acid             | 16.1     | 21.1       | **18.6** | 21.3     | 23.3       | **22.3** | 21.0     | 23.3       | **22.2** | 19.5     | 22.6       | **21.0** |
| Mean                    | **14.2** | **19.1**   | **16.6** | **18.2** | **22.0**   | **20.1** | **19.3** | **21.9**   | **20.6** | **17.2** | **21.0**   | **19.1** |

|                  | MT | ST | SST | MT at ST | MT at SST | ST at MT | ST at SST | SST at MT | SST at MT, ST | MT at ST, SST |
|------------------|----|----|-----|----------|-----------|----------|-----------|------------|---------------|---------------|
| SEm± CD \(P=0.05\) | 0.3 | 0.2 | 0.4 | 0.3 | 0.4 | 0.3 | 0.2 | 0.5 | 0.3 | 0.1 |
|                  | 1.1 | 0.6 | 0.4 | 1.2 | 1.2 | 1.1 | 0.8 | 0.8 | NS | NS | NS |

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**Table 4** Soybean equivalent yield of soybean – onion cropping sequence

| S. No | Treatments                                      | Soybean equivalent yield (kg ha\(^{-1}\)) |
|-------|------------------------------------------------|------------------------------------------|
| 1     | No inorganic P + No organics (Res)              | 3311                                     |
| 2     | No inorganic P + No organics (Cum)              | 4239                                     |
| 3     | No inorganic P + PSB (Res)                      | 3906                                     |
| 4     | No inorganic P + PSB (Cum)                      | 5046                                     |
| 5     | No inorganic P + Biochar (Res)                  | 4970                                     |
| 6     | No inorganic P + Biochar (Cum)                  | 6021                                     |
| 7     | No inorganic P + Humic acid (Res)               | 5126                                     |
| 8     | No inorganic P + Humic acid (Cum)               | 6131                                     |
| 9     | No inorganic P + Citric acid (Res)              | 3791                                     |
| 10    | No inorganic P + Citric acid (Cum)              | 4629                                     |
| 11    | 30 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) + No organics (Res) | 4397                                     |
| 12    | 30 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) + No organics (Cum) | 5168                                     |
| 13    | 30 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) + PSB (Res) | 4764                                     |
| 14    | 30 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) + PSB (Cum) | 5842                                     |
| 15    | 30 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) + Biochar (Res) | 6685                                     |
| 16    | 30 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) + Biochar (Cum) | 7440                                     |
| 17    | 30 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) + Humic acid (Res) | 6540                                     |
| 18    | 30 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) + Humic acid (Cum) | 6939                                     |
| 19    | 30 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) + Citric acid (Res) | 5100                                     |
| 20    | 30 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) + Citric acid (Cum) | 5910                                     |
| 21    | 60 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) + No organics (Res) | 4793                                     |
| 22    | 60 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) + No organics (Cum) | 5047                                     |
| 23    | 60 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) + PSB (Res) | 4975                                     |
| 24    | 60 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) + PSB (Cum) | 5786                                     |
| 25    | 60 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) + Biochar (Res) | 6580                                     |
| 26    | 60 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) + Biochar (Cum) | 7223                                     |
| 27    | 60 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) + Humic acid (Res) | 6199                                     |
| 28    | 60 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) + Humic acid (Cum) | 6661                                     |
| 29    | 60 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) + Citric acid (Res) | 5114                                     |
| 30    | 60 kg P\(_{2}\)O\(_{5}\) ha\(^{-1}\) + Citric acid (Cum) | 5639                                     |
### Table 5: Benefit-Cost ratio for Soybean crop

| S. No | Treatments                        | Yield (t ha\(^{-1}\)) | Cost of cultivation (Rs ha\(^{-1}\)) | Gross returns (Rs ha\(^{-1}\)) | Net returns (Rs ha\(^{-1}\)) | B:C ratio |
|-------|-----------------------------------|------------------------|--------------------------------------|---------------------------------|-------------------------------|-----------|
| 1     | No inorganic P + No organics      | 0.9                    | 13235                                | 23458                           | 10223                         | 0.77      |
| 2     | No inorganic P + PSB             | 1.3                    | 13435                                | 32777                           | 19342                         | 1.44      |
| 3     | No inorganic P + Biochar         | 1.7                    | 18235                                | 42932                           | 24697                         | 1.35      |
| 4     | No inorganic P + Humic acid      | 1.9                    | 15835                                | 47652                           | 31817                         | 2.01      |
| 5     | No inorganic P + Citric acid     | 1.1                    | 13811                                | 26852                           | 13041                         | 0.94      |
| 6     | 30 kg P\(_2\)O\(_5\) ha\(^{-1}\) + No organics | 1.5 | 14542 | 37679 | 23137 | 1.59 |
| 7     | 30 kg P\(_2\)O\(_5\) ha\(^{-1}\) + PSB | 1.3 | 14742 | 31333 | 16591 | 1.13 |
| 8     | 30 kg P\(_2\)O\(_5\) ha\(^{-1}\) + Biochar | 2.5 | 19542 | 61332 | 41790 | 2.14 |
| 9     | 30 kg P\(_2\)O\(_5\) ha\(^{-1}\) + Humic acid | 2.3 | 17142 | 57067 | 39925 | 2.33 |
| 10    | 30 kg P\(_2\)O\(_5\) ha\(^{-1}\) + Citric acid | 1.8 | 15118 | 44908 | 29790 | 1.97 |
| 11    | 60 kg P\(_2\)O\(_5\) ha\(^{-1}\) + No organics | 1.5 | 15849 | 38533 | 22684 | 1.43 |
| 12    | 60 kg P\(_2\)O\(_5\) ha\(^{-1}\) + PSB | 1.3 | 16049 | 32382 | 16333 | 1.02 |
| 13    | 60 kg P\(_2\)O\(_5\) ha\(^{-1}\) + Biochar | 2.1 | 20849 | 51560 | 30711 | 1.47 |
| 14    | 60 kg P\(_2\)O\(_5\) ha\(^{-1}\) + Humic acid | 2.0 | 18449 | 49906 | 31457 | 1.71 |
| 15    | 60 kg P\(_2\)O\(_5\) ha\(^{-1}\) + Citric acid | 1.5 | 16425 | 37932 | 21507 | 1.31 |
Table 6: Benefit-Cost ratio for Onion crop

| S. No | Treatments                                      | Yield (t ha⁻¹) | Cost of cultivation (Rs ha⁻¹) | Gross returns (Rs ha⁻¹) | Net returns (Rs ha⁻¹) | B:C ratio |
|-------|------------------------------------------------|----------------|------------------------------|-------------------------|-----------------------|-----------|
| 1     | No inorganic P + No organics (Res)              | 11.9           | 37967                        | 59317                   | 21350                 | 0.6       |
| 2     | No inorganic P + No organics (Cum)              | 16.5           | 40992                        | 82533                   | 41541                 | 1.0       |
| 3     | No inorganic P + PSB (Res)                      | 13.0           | 37967                        | 64867                   | 26900                 | 0.7       |
| 4     | No inorganic P + PSB (Cum)                      | 18.7           | 41192                        | 93383                   | 52191                 | 1.3       |
| 5     | No inorganic P + Biochar (Res)                  | 16.3           | 37967                        | 81317                   | 43350                 | 1.1       |
| 6     | No inorganic P + Biochar (Cum)                  | 21.5           | 45992                        | 107600                  | 61608                 | 1.3       |
| 7     | No inorganic P + Humic acid (Res)               | 16.1           | 37967                        | 80500                   | 42533                 | 1.1       |
| 8     | No inorganic P + Humic acid (Cum)               | 21.1           | 43592                        | 105633                  | 62041                 | 1.4       |
| 9     | No inorganic P + Citric acid (Res)              | 13.6           | 37967                        | 67933                   | 29966                 | 0.8       |
| 10    | No inorganic P + Citric acid (Cum)              | 17.8           | 41568                        | 88883                   | 47315                 | 1.1       |
| 11    | 30 kg P₂O₅ ha⁻¹ +No organics (Res)              | 14.5           | 37967                        | 72250                   | 34283                 | 0.9       |
| 12    | 30 kg P₂O₅ ha⁻¹ +No organics (Cum)              | 18.3           | 42304                        | 91517                   | 49213                 | 1.2       |
| 13    | 30 kg P₂O₅ ha⁻¹ +PSB (Res)                      | 17.6           | 37967                        | 87767                   | 49800                 | 1.3       |
| 14    | 30 kg P₂O₅ ha⁻¹ +PSB (Cum)                      | 22.9           | 42504                        | 114733                  | 72229                 | 1.7       |
| 15    | 30 kg P₂O₅ ha⁻¹ +Biochar (Res)                  | 21.2           | 37967                        | 105800                  | 67833                 | 1.8       |
| 16    | 30 kg P₂O₅ ha⁻¹ +Biochar (Cum)                  | 24.9           | 43704                        | 124667                  | 80963                 | 1.9       |
| 17    | 30 kg P₂O₅ ha⁻¹ +Humic acid (Res)               | 21.3           | 37967                        | 106433                  | 68466                 | 1.8       |
| 18    | 30 kg P₂O₅ ha⁻¹ +Humic acid (Cum)               | 23.3           | 44904                        | 116400                  | 71496                 | 1.6       |
| 19    | 30 kg P₂O₅ ha⁻¹ +Citric acid (Res)              | 16.5           | 37967                        | 82600                   | 44633                 | 1.2       |
| 20    | 30 kg P₂O₅ ha⁻¹ +Citric acid (Cum)              | 20.6           | 42880                        | 102850                  | 59970                 | 1.4       |
| 21    | 60 kg P₂O₅ ha⁻¹ +No organics (Res)              | 16.3           | 37967                        | 81300                   | 43333                 | 1.1       |
| 22    | 60 kg P₂O₅ ha⁻¹ +No organics (Cum)              | 17.5           | 43611                        | 87650                   | 44039                 | 1.0       |
| 23    | 60 kg P₂O₅ ha⁻¹ +PSB (Res)                      | 18.4           | 37967                        | 92000                   | 54033                 | 1.4       |
| 24    | 60 kg P₂O₅ ha⁻¹ +PSB (Cum)                      | 22.5           | 43811                        | 112267                  | 68456                 | 1.6       |
| 25    | 60 kg P₂O₅ ha⁻¹ +Biochar (Res)                  | 22.6           | 37967                        | 112933                  | 74966                 | 2.0       |
| 26    | 60 kg P₂O₅ ha⁻¹ +Biochar (Cum)                  | 25.8           | 48611                        | 129017                  | 80406                 | 1.7       |
| 27    | 60 kg P₂O₅ ha⁻¹ +Humic acid (Res)               | 21.0           | 37967                        | 105067                  | 67100                 | 1.8       |
| 28    | 60 kg P₂O₅ ha⁻¹ +Humic acid (Cum)               | 23.3           | 46211                        | 116633                  | 70422                 | 1.5       |
| 29    | 60 kg P₂O₅ ha⁻¹ +Citric acid (Res)              | 18.0           | 37967                        | 89917                   | 51950                 | 1.4       |
| 30    | 60 kg P₂O₅ ha⁻¹ +Citric acid (Cum)              | 20.6           | 44187                        | 103050                  | 58863                 | 1.3       |
Table 7: Benefit cost ratio for Soybean-Onion cropping sequence

| S. No | Treatments                                      | Cost of cultivation (Rs ha\(^{-1}\)) | Gross returns (Rs ha\(^{-1}\)) | Net returns (Rs ha\(^{-1}\)) | B:C ratio |
|-------|------------------------------------------------|--------------------------------------|---------------------------------|-------------------------------|-----------|
| 1     | No inorganic P + No organics (Res)              | 51202                                | 82775                           | 31573                         | 0.6       |
| 2     | No inorganic P + No organics (Cum)              | 54227                                | 105992                          | 51765                         | 1.0       |
| 3     | No inorganic P + PSB (Res)                      | 51402                                | 97644                           | 46242                         | 0.9       |
| 4     | No inorganic P + PSB (Cum)                      | 54627                                | 126160                          | 71533                         | 1.3       |
| 5     | No inorganic P + Biochar (Res)                  | 56202                                | 124249                          | 68047                         | 1.2       |
| 6     | No inorganic P + Biochar (Cum)                  | 64227                                | 150532                          | 86305                         | 1.3       |
| 7     | No inorganic P + Humic acid (Res)               | 53802                                | 128152                          | 74350                         | 1.4       |
| 8     | No inorganic P + Humic acid (Cum)               | 59427                                | 153285                          | 93858                         | 1.6       |
| 9     | No inorganic P + Citric acid (Res)              | 51778                                | 94785                           | 43007                         | 0.8       |
| 10    | No inorganic P + Citric acid (Cum)              | 55379                                | 115735                          | 60356                         | 1.1       |
| 11    | 30 kg P\(_2\)O\(_5\) ha\(^{-1}\) + No organics (Res) | 52509                                | 109929                          | 57420                         | 1.1       |
| 12    | 30 kg P\(_2\)O\(_5\) ha\(^{-1}\) + No organics (Cum) | 56846                                | 129195                          | 72349                         | 1.3       |
| 13    | 30 kg P\(_2\)O\(_5\) ha\(^{-1}\) + PSB (Res)   | 52709                                | 119099                          | 66390                         | 1.3       |
| 14    | 30 kg P\(_2\)O\(_5\) ha\(^{-1}\) + PSB (Cum)   | 57246                                | 146066                          | 88820                         | 1.6       |
| 15    | 30 kg P\(_2\)O\(_5\) ha\(^{-1}\) + Biochar (Res) | 57509                                | 167132                          | 109623                        | 1.9       |
| 16    | 30 kg P\(_2\)O\(_5\) ha\(^{-1}\) + Biochar (Cum) | 63246                                | 185998                          | 122752                        | 1.9       |
| 17    | 30 kg P\(_2\)O\(_5\) ha\(^{-1}\) + Humic acid (Res) | 55109                                | 163500                          | 108391                        | 2.0       |
| 18    | 30 kg P\(_2\)O\(_5\) ha\(^{-1}\) + Humic acid (Cum) | 62046                                | 173467                          | 111421                        | 1.8       |
| 19    | 30 kg P\(_2\)O\(_5\) ha\(^{-1}\) + Citric acid (Res) | 53085                                | 127508                          | 74423                         | 1.4       |
| 20    | 30 kg P\(_2\)O\(_5\) ha\(^{-1}\) + Citric acid (Cum) | 57998                                | 147758                          | 89760                         | 1.5       |
| 21    | 60 kg P\(_2\)O\(_5\) ha\(^{-1}\) + No organics (Res) | 53816                                | 119833                          | 66017                         | 1.2       |
| 22    | 60 kg P\(_2\)O\(_5\) ha\(^{-1}\) + No organics (Cum) | 59460                                | 126183                          | 66723                         | 1.1       |
| 23    | 60 kg P\(_2\)O\(_5\) ha\(^{-1}\) + PSB (Res)    | 54016                                | 124382                          | 70366                         | 1.3       |
| 24    | 60 kg P\(_2\)O\(_5\) ha\(^{-1}\) + PSB (Cum)    | 59860                                | 144648                          | 84788                         | 1.4       |
| 25    | 60 kg P\(_2\)O\(_5\) ha\(^{-1}\) + Biochar (Res) | 58816                                | 164494                          | 105678                        | 1.8       |
| 26    | 60 kg P\(_2\)O\(_5\) ha\(^{-1}\) + Biochar (Cum) | 69460                                | 180577                          | 111117                        | 1.6       |
| 27    | 60 kg P\(_2\)O\(_5\) ha\(^{-1}\) + Humic acid (Res) | 56416                                | 154973                          | 98557                         | 1.7       |
| 28    | 60 kg P\(_2\)O\(_5\) ha\(^{-1}\) + Humic acid (Cum) | 64660                                | 166539                          | 101879                        | 1.6       |
| 29    | 60 kg P\(_2\)O\(_5\) ha\(^{-1}\) + Citric acid (Res) | 54392                                | 127849                          | 73457                         | 1.4       |
| 30    | 60 kg P\(_2\)O\(_5\) ha\(^{-1}\) + Citric acid (Cum) | 60612                                | 140982                          | 80370                         | 1.3       |
**B-C ratio of soybean-onion cropping sequence**

Higher B: C ratio observed with 30 kg P$_2$O$_5$ ha$^{-1}$ + humic acid in residual effect (2.0) followed by 30 kg P$_2$O$_5$ ha$^{-1}$ + biochar in residual and cumulative effects i.e., 1.9.

It may be due to low cost of cultivation (55,109 Rs ha$^{-1}$) and low net returns (1,08,391 Rs ha$^{-1}$) due to 30 kg P$_2$O$_5$ ha$^{-1}$ + humic acid in residual effect (Table 7). Biochar and humic acid once applied to the field it prolongs its benefit for the next season.

Highest B - C ratio of soybean was obtained with 30 kg P$_2$O$_5$ ha$^{-1}$ + humic acid (2.33), while, 60 kg P$_2$O$_5$ ha$^{-1}$ + biochar was superior with a B:C ratio of 2.0 in putting forth the residual effect followed by 30 kg P$_2$O$_5$ ha$^{-1}$ + biochar in cumulative effect (1.9).

For soybean-onion cropping sequence, higher B: C ratio was obtained with 30 kg P$_2$O$_5$ ha$^{-1}$ + humic acid in residual effect (2.0) followed by 30 kg P$_2$O$_5$ ha$^{-1}$ + biochar in residual and cumulative effects i.e., 1.9.

Even though, the net returns are lower (1,08,391 Rs ha$^{-1}$) in case of the treatment receiving 30 kg P$_2$O$_5$ ha$^{-1}$ + humic acid in residual effect, the cost of cultivation also was less (Rs. 55,109 ha$^{-1}$) resulting in wider B-C ratio.

In soybean, Inorganic P at 30 and 60 kg P$_2$O$_5$ ha$^{-1}$ across the organics significantly increased the mean seed yield of soybean to 1899 and 1683 kg ha$^{-1}$ over 1389 kg ha$^{-1}$ in the control which accounted for 36.7 and 21.2 per cent higher yield respectively in a high P soils. The mean seed yield of the soybean with biochar was 2077 kg ha$^{-1}$ which was significantly higher than the control seed yield of 1329 kg ha$^{-1}$. In onion, Cumulative effect was found to show significant influence resulting in a mean yield of 21 t ha$^{-1}$ which was higher by 22.1 per cent than 17.2 t ha$^{-1}$ due to the residual effect. Soybean equivalent yield of soybean - onion cropping sequence when inorganic P was applied alone showed a sharp increase to 4783 kg ha$^{-1}$ at 30 kg P$_2$O$_5$ ha$^{-1}$ and later showed a marginal increase to 4920 kg ha$^{-1}$ at 60 kg P$_2$O$_5$ ha$^{-1}$. Humic acid when applied alone resulted in the highest soybean equivalent yield of 5629 kg ha$^{-1}$ closely followed by biochar with 5496 kg ha$^{-1}$. While, at 30 kg P$_2$O$_5$ ha$^{-1}$, biochar put forth higher system yield of 7063 kg ha$^{-1}$ against 6740 kg ha$^{-1}$ with humic acid. Similar trend was observed at the highest level of inorganic P application with a marginal reduction in soybean equivalent yields of 7223 and 6661 kg ha$^{-1}$ respectively. The soybean equivalent yield due to residual and cumulative effects were 5083 and 5848 kg ha$^{-1}$ respectively.

For soybean-onion cropping sequence, residual effect 30 kg P$_2$O$_5$ ha$^{-1}$ + humic acid were economically better with higher B: C ratio of 2.0 followed by 30 kg P$_2$O$_5$ ha$^{-1}$ + biochar in both residual and cumulative effects which showed 1.9. By this, one can emphasize that biochar and humic acid applied for the preceding crop of the sequence will benefit the succeeding crop by the way of sustained residual effect.

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