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Phosphorus Fertilizer Response to Onion (*Allium cepa* L.) Yield in Punjab, Pakistan

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Abstract

Background: Onion (*Allium cepa* L.) is one of the most essential plants in food with high nutritional value. However, application of right dose of phosphorous (P) is one of the constraints to the profitable onion yields in soils deficient in P.

Methods: A systematic study to confirm the best dose of P was conducted for six years in the P deficient soil in farmers' fields. Based on the findings obtained from 2008-09 to 2010-11, the research was undertaken to determine the effect of different phosphorus levels on the yield of onion in the Randomized Complete Block Design (RCBD) with a total of 114 replicates in 2011-12 to 2012-13. Four treatments (160, 210, 260 and 310 kg P_2O_5 ha^{-1}) were tested with N and K at 100 kg ha^{-1}.

Results: From the results of this investigation, the variance analysis showed the substantial P impact. The maximum marketable bulb yield (19.03 t ha^{-1}) was obtained from the fertilizer combination NPK @ 100-310-100 kg ha^{-1} and was shown to be statistically higher than all other treatments.

Conclusion: Nonetheless, the nutshell of the overall economic study is that poor farmers (Land holders >12 acres) may have options to select the NPK fertilizer combination @ 100:210:100 kg ha^{-1} and the average farmer may have options to select the NPK fertilizer combination @ 100:260:100 kg ha^{-1}. But rich farmers (Land holders >25 acres) who can spend more money on fertilizers and are interested in the higher gross margin should follow the combination of NPK fertilizers @ 100:310:100 kg ha^{-1} to profitably increase their gross margin and maintain soil fertility for onion cultivation in Punjab, Pakistan.

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Introduction

Onions (*Allium cepa* L.) are herbaceous biennial Alliaceae family member, typically grown as annuals. Onion is one of the most important condiments, usually used in green form or as a mature bulb or both and, used to make a variety of dishes such as soups, sauces and food seasoning. Mild or colorful bulb onions are often picked for salads [1]. Consumers also have specific local preferences about onion size, shape and bulb [2]. Pakistan is currently the seventh-largest onion producer worldwide [3], while China is the world's leading country. In the farmers' sector, the productivity of onions varies from 9 to 15 t ha^{-1}, which is much lower than the yield of the research area, i.e. 30-35 t ha^{-1} [4]. This may be attributed to several factors. Fertilizer use is one of the most important factors in onion production as it directly affects growth, development and yield [5]. Phosphorus deficiency (P) is one of many tropical soils' major crop production constraints due to low native content and high soil P immobilization [6]. Due to lower natural content and high soil immobilization, phosphorus is one of the most complex in many soils. P is important for rapid root growth, usually reducing bulb size and delays maturation [7, 8]. As an essential nutritional element, phosphorus plays its part in controlling many plant physiological parameters, which in turn affects total yield. One fact, however, is that the P provided to the plant or soil is largely dependent on the available reserve of this element in the soil, so the negative or positive results may be due to its quantity or sources stored in the soil [9]. Onion's response to phosphorus fertilization depends on the genotype used, plant P, source P, soil and weather conditions [10]. Excess use of inorganic nitrogen and phosphorus fertilizers results in sumptuous growth with little effect on yield, leading to bulb decay [11, 12]. Because of their small, unbranched root system, onions are more vulnerable to nutrient deficiencies than most other crop plants, so they need and often respond well to fertilizer additions [8]. Increased phosphorus from zero to highest in onion plants yielded maximum dry weight levels [13]. Many authors reported optimizing onion yields and bulb weights in phosphorous application levels of up to 200 kg P ha^{-1} [14]. Increased P levels are also known to increase bulb size and marketable bulbs [15]. Similarly, phosphorous fertilization at levels of 25 or 50 kg ha^{-1} increased yield and bulb weight in Ethiopia [16], even though the soil analysis showed no nutrient deficiency. Nonetheless, different findings were reported that P application did not significantly affect onion yield [6]. Costa *et al.*, [17] reported onion response to application of up to 90 kg ha^{-1} P_2O_5, yielding 33.4 t ha^{-1}. Resende *et al.,* [18] observed increased onion cultivar yields: Franciscan IP A-10 and Vale Ouro IPA-11 at 132 kg ha^{-1} P_2O_5, compared to 130 kg ha^{-1} P_2O_5 an economic dose. P_2O_5 application of 168.75 kg ha^{-1} accounted for maximum commercial yield of bulbs, gross income, net income, rate of return, and onion crop profitability [19]. Onion is grown mainly in Pakistan, but many constraints have led to low yields. Due to low native content and high soil phosphorus immobilization, phosphorus deficiency and use of sub-optimal phosphorus are the main constraints in Pakistani soils for onion growth. This rate is totally site specific and it is unexpected appropriate P rate has not been studied and established yet in the region. Therefore, farmers get low onion yields. To this end, this work was initiated to determine the effect of different phosphorus fertilizer levels on onion yield.

Methods

From the results of the previous investigation, twelve experiments were carried out at various sites with a total of twenty-four replications in Randomized Complete Block Design (RCBD). The experimental sites were representative of commercial onion crop growing areas. The experiment consisted of 11 treatments. Nutrient levels for nitrogen (N) and potassium (K) were 0, 30, 60, and 90 kg ha^{-1} whereas those for phosphorus (P) were 0, 40, 80, and 120 kg ha^{-1}. From the results of this investigation, it can be concluded that, onion responded quadratically to all applied nutrients and variance analysis showed that the NPK effect was significant. The maximum (20.64 t ha-1) onion marketable blub yield was obtained from the fertilizer combination NPK @ 60-120-60 Kg ha^{-1} (T_8) treatment. In this three-year analysis, given the volume of onion response in fresh bulb yields, it appeared that the threshold for high yield of onion, P fertilizer requirements, was high. In future research, therefore, it was further recommended that more P levels be added to produce a final result with the maximum onion requirement for maximum output. Further investigations / confirmatory studies were therefore planned in the coming years on the basis of these findings. Based on the results obtained from 2008-09 to 2010-11, three experiments were conducted in two years 2011-12 and 2012-13 with treatments consisting of one nitrogen and potassium (60 kg ha^{-1}) and four phosphorus levels (80, 120, 160 and 200 kg P_2O_5 ha^{-1}) with nine replications as a confirmatory study to confirm the P requirement. Subsequently, a significant maximum marketable onion bulb yield was obtained from the fertilizer combination NPK @ 60-200-60 kg ha^{-1}. In this confirmatory test, again considering the magnitude of the onion response in the fresh bulb yield, the P fertilizer threshold for high onion bulb yield appeared to be higher. It was therefore further advisable in future research to add a higher P rate in order to produce a conclusive result with the maximum onion P requirement for the maximum yield output. Further investigations / confirmatory studies were therefore planned from 2013-14 to 2018-19 on the basis of these results. The current study has therefore been undertaken.

From 2013-14 to 2018-19, comprehensive experiments were scheduled covering all parts of the province of Punjab, Pakistan, so thirty-eight experiments were performed systematically at different locations, with a total of 114 replications over six years from Randomized Complete Block Design (RCBD) on different farmers' fields deficient in P across the province to determine the succinct best suited levels of phosphorus for onion production. The study involved four treatments. The phosphorus (P) nutrient amounts were 160, 210, 260, and 310 kg ha^{-1} along with N and K at a rate of 100 kg ha^{-1}. During sowing, fertilizers were used with all phosphorus (as DAP diammonium phosphate), all potassium (as SOP potassium sulphate), and half nitrogen (as urea). The remaining 1⁄2 nitrogen (as urea) was added after 3-4 weeks of transplantation. As per the policy of the department, all quality checked fertilizers were given free of charge to farmers and all other farm management practices were performed as guided by the department to the farmers. Each plot size for treatment was 1/40 of a hectare (10 Marlas). The experimental fields were prepared following conventional tillage practices of the farmers prior to the sowing of onion. Varieties Dark Red, Nasar Puri and Phulkara were selected for the current analysis. Field plans were designed to the requirements of the design and each treatment was allocated randomly to experimental plots within a block. Representative surface soil samples (0-15 cm) were collected randomly from each experimental site using an auger, and before planting, a respective composite sample was prepared from ten samples. The soil samples were air-dried and sieved with 0.02 mm sieve wire mesh and analyzed for EC, pH, organic matter [20], available P [21] and exchangeable K [22]. The crops were irrigated with both tube well water and canal water. At physiological maturity, when 70 percent of their leaves were senesced, plants were harvested and used to determine yield per treatment for all treatments harvested from randomly selected plots (3 X 3 M^2) on the same day at a site and packed directly for the fresh market. Gross margin of different fertilizer treatments for crops and fertilizer inputs was estimated at an average market price of Rs. 37 kg^{-1} using the onion bulb yield from six-year pooled results. The data were subjected to analysis of variance. The differences between onion productivity treatments were analyzed by ANOVA using the statistical software "CoStat 6.451". Partial budget analysis was used to determine the suggested most economically appropriate fertilizer dosage.

Results

a. Initial soil fertility analysis of the soil of the experimental sites

Table 1 displays the sites' initial chemical properties, soil fertility status prior to research, dates of sowing and harvesting, variety and previous crop. Thirty-eight soils / sites used over six years for testing. Five representative test sites were used during the first year. Compared to the soil fertility ratings / critical limits set by Muhr *et al.,* [23], the soils were loamy textured, non-saline (1.60-3.86 dS m^{-1}), alkaline in nature (7.9-8.4), low to medium in organic matter (0.34-0.96 per cent), low to medium in available P (2.2-10.7 ppm) and medium in exchangeable K (160-240 ppm) and sowing of all experiments was performed between December and January and harvested in May. Five representative test sites were used during the second year. The soils were loamy textured, non-saline (1.76-2.30 dS m^{-1}), alkaline in nature (8.0-8.3), low to medium in organic matter (0.82-1.19 per cent), low in available P (4.0-7.8 ppm) and medium in exchangeable K (185-280 ppm) and seeding of all experiments were carried out between December and February and harvested in May. Four representative test sites were used in the third year. The soils were loamy textured, non-saline (1.92-2.33 dS m^{-1}), alkaline in nature (7.8-8.2), low in organic matter (0.63-0.84 per cent), low in available P (4.1-9.2 ppm) and low to medium in exchangeable K (100-240 ppm), and all experiments were sown between December and January and harvested between April and May. The fourth year included the use of twelve representative research sites. The soils were loamy textured, non-saline (1.00-3.5 dS m^{-1}), alkaline in nature (8.0-8.4), low to medium in organic matter (0.55-0.91 per cent), low in available P (2.1-7.9 ppm) and medium in exchangeable K (140-204 ppm), and all experiments were sown from December to March and harvested from May to June. Five representative test sites have been used in fifth year. The soils were loamy textured, non-saline (1.14-2.74 dS m^{-1}), alkaline in nature (7.6-8.1), low to medium in organic matter (0.60-1.01 per cent), low in available P (2.0-6.3 ppm) and medium in exchangeable K (140-195 ppm), and all experiments were sown between December and February and harvested between April and May. And seven representative test sites were used in the sixth last year. The soils were loamy textured, non-saline (1.30-3.20 dS m^{-1}), alkaline in nature (7.6-8.3), low to medium in organic matter (0.62-0.84 per cent), low in available P (1.5-8.9 ppm) and low to medium in exchangeable K (100-210 ppm), and all experiments were sown between December and February and harvested between April and May.

b. Average NPK response to fresh bulb onion yield in two years

Almost similar trends in onion bulb yields were observed in the six-years. As a result, individual and pooled analysis was carried out, the results are discussed below accordingly. The fresh bulb yield of onion was significantly affected by different doses of phosphorus treatments (Table 2 to 7). In the current study, onion bulb yield analysis of variance over six years demonstrated that the yield of fresh bulb yield in each study year responded significantly ($P<0.05$) to the graded P levels. Overall, in the pooled study, the average six-year yield increased with a rise in phosphorus levels and the highest significant fresh bulb yield (19.03 t ha^{-1}) was recorded from (100:310:100 kg ha^{-1}) in T4, and was shown to be statistically higher than all other treatments. The highest significant average yield of the onion bulb in the first, second, third, fourth, fifth, and sixth years was 19.33 t ha^{-1}, 19.73t ha^{-1}, 20.89 t ha^{-1}, 18.63 t ha^{-1}, 16.78 t ha^{-1}, and 19.54 t ha^{-1} respectively, and was also obtained in T4 from treatment receiving NPK (100:310:100 kg ha^{-1}). Such highest mean yields were statistically higher than all other treatments except for the maximum yield only in the fifth year, which was statistically equivalent to the yield (16.49 t ha^{-1}) obtained from NPK @ 100-260-100 kg ha^{-1} in T3.

c. Average individual nutrient (P_2O_5) response on onion yield

Marketable yield ranged from 15.17 to 19.03t ha^{-1} attributable to P graded doses, the latter estimated at

310 kg P_2O_5 ha^{-1}. Increasing the phosphorus rate from 160 to 310 kg P_2O_5 ha^{-1} substantially increased marketable yield of fresh bulbs by 25.44 per cent.

d. Partial review of the budget

As part of the economic study, a partial budget was generated to evaluate the overall cost variability and the gross margin for each fertilizer treatment of the pooled data of 38 experiments with 114 replications. The highest gross return (Rs. 704147.00 ha^{-1}) and gross margin (Rs. 648417.00 ha^{-1}) was obtained from the treatment receiving NPK (100:310:100 kg ha^{-1}) in T4 (Table 8).

Discussion

a. Average NPK response to fresh bulb onion yield in two years

The increase in the maximum bulb yield could be explained by a higher marketable bulb weight per plant which could be due to the use of balanced fertilizers. In addition, the use of chemical fertilizers may have helped to maintain soil fertility and provided a hostile response to the required nutrient uptake by plants, expounding higher yields. Subsequently, in a pooled six-year analysis (Table 7), T4 NPK (100:310:100 kg ha^{-1}) yielded 19.03 t ha^{-1} and T3 NPK (100:260:100 kg ha^{-1}) yielded 18.38 t ha^{-1}, T2 NPK (100:210:100 kg ha^{-1}) yielding 117.34 t ha^{-1} and T1 NPK (100:160:100 kg ha^{-1}) yielding minimal fresh bulb yield (15.10 t ha^{-1}). Because of this factor, the reduced dose of P fertilizer in T1 and T2 did not display higher yields of onion. High P-response amounts have been observed and the maximum yield has been increased up to 3.86 t ha^{-1} over T1. The graded dose of P @ 210, 260, and 310 kg ha^{-1} lifted fresh bulb onion by 14.27%, 6.00% and 3.56% over T1 (P @ 160) respectively.

b. Average individual nutrient (P_2O_5) response on onion yield

Increasing the phosphorus rate from 160 to 210 kg P_2O_5 ha^{-1} increased the marketable fresh bulb production by 14.27 per cent, increased the rate from 210 to 260 kg P_2O_5 ha^{-1} increased the marketable fresh bulb production by another 6.00 per cent, and increased the rate from 260 to 310 kg P_2O_5 ha^{-1} increased the marketable fresh bulb production by 3.56 per cent (Table 4). This may be due to Onions which are highly dependent on arbuscular mycorhizal fungi for the uptake of phosphorus from soils with low to medium soil P concentrations. Mycorhizal fungi produce a network of thread like hyphae extending from the roots of the onion to the soil, greatly increasing the absorption surface of the roots. Mycorhizal fungi may also increase the uptake of zinc and other micronutrients in some high-pH calcareous soils [7] (Horneck, 2004).

c. Partial review of the budget

The lowest gross return (Rs. 561327.00 ha^{-1}) and gross margin (Rs. 524047.00 ha^{-1}) was obtained from T1 treatment, indicating that output dropped sharply with reduced use of P fertilizer and minimized benefit. The economic study reveals that treatment arrangements for total fertilizer costs per hectare in descending order appeared as T4 (Rs. 55730.00), T3 (Rs. 49580.00), T2 (Rs. 43430.00), and T1 (Rs. 37280.00). The economic research shows that treatments for gross margin per hectare in decreasing order appeared as T4 (Rs. 648417.00), T3 (Rs. 630332.00), T2 (Rs. 598002.00), and T1 (Rs. 524047.00). Gradual increase of the gross margin in the partial budget review shows that by investing exclusively Rs.6150.00 in T2 on fertilizer per hectare, farmers can benefit for Rs.73955.00 compared to T1 treatment, additional Rs.6150.00 for T3 investment, farmers can benefit for Rs.32330.00 compared to T2 and additional Rs.6150.00 for T4 investment, farmers can benefit for Rs.18085.00 compared to T3. Given the gross margin and the incremental rise in gross margin, poor farmers (Land holders 12-25 acres)will have the option of choosing T2 (NPK (100:210:100 kg ha^{-1}) care to get additional Rs.73955.00 profit by spending each extra Rs.6150.00 per hectare over T1. Average farmers may have the option of opting for treatment T3 (NPK (100:260:100 kg ha^{-1}) to benefit additionally of Rs.32330.00 by investing each additional Rs.6150.00 per hectare in excess of T2. But rich farmers who can invest more money in fertilizer use and who are interested in higher gross margins can adopt T4 (NPK (100:310:100 kg ha^{-1}) to increase their gross margin profitably and sustain soil fertility.

To assess onion phosphorus fertilizer requirements, 38 experiments were carried out at farmers' fields with a total of 114 replications in Randomized Complete Block Design (RCBD). Six years of consecutive research on farmers' fields revealed that the highest significant (19.03 t ha^{-1}) marketable fresh onion bulb yield was obtained from the NPK fertilizer combination @ 100-310-100 Kg ha^{-1} (T4) treatment and was shown to be statistically higher than all other treatments. But the nutshell of the overall economic analysis is that poor farmers (Land holders >12 acres) might have options to choose the NPK fertilizer combination @ 100:210:100 kg ha^{-1} and the average farmer (Land holders 12-25 acres) may have options to choose the NPK fertilizer combination @ 100:260:100 kg ha^{-1}. But the rich farmers (Land holders >25 acres) who can spend more money using fertilizers and who are interested in the higher gross margin should pursue the combination of NPK fertilizers @ 100:310:100 kg ha^{-1} to increase their gross margin profitably and conserve soil fertility.

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Data & Tables

Please see supplementary files on the HTML page.

Author Contributions

Muhammad Akram Qazi: Primary and main scientist, organized and conducted the experiment and wrote the manuscript.

Muhammad Nadeem Iqbal: Conducted the experiment

Muhammad Sadiq: Conducted the laboratory analysis work
Naveed Iqbal khan: Conducted the laboratory analysis work
Farah Umar: Conducted the laboratory analysis work
Khalid Mehmood Mughal: Conducted the statistical analysis
Mehrin Khalid: Conducted the statistical analysis
Balqees Akhtar: Conducted the laboratory analysis work

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