Research Article

Impact of Fertilizer and Planting Geometery on Garlic (*Allium sativum* L.) Yield in Saline-Sodic Soil

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Abstract | The present research work was undertaken from 2013 to 2016 to evaluate the efficacy of different phosphorus (P) rates and planting geometry for the successful garlic production under saline environment. The experimental design was split-plot with three repeats. Three planting geometry (10cm x 20cm, 15cm x 20cm and 20cm x 20cm) and four phosphorus levels i.e. (i) control (no phosphorus), (ii) P (60 kg ha^{-1}) recommended dose (RD), (iii) 125% P of RD (75 kg ha^{-1}) and (iv) 150% P of RD (90 kg ha^{-1}) were used. Observations included were; plant height, bulb mass, bulb diameter, cloves bulb^{-1} and bulb yield. Data revealed that phosphorus @ 125% of RD with planting geometry 15cm x 20cm recorded maximum yield and yield attributes with higher economic returns, therefor, under saline-sodic conditions it is proposed as a most cost-effective management practice for garlic cultivation.

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Introduction

Pakistan lacks arable land resources and due to salinity problem 6.67 million hectares (Khan, 1998) further extension in the vegetable production area is limited. The increasing demand of vegetables for a rapidly growing population will be met only by improving the yield potential of crops and increasing crop productivity per unit area. This objective would be achieved only through economical, suitable, highly productive and environmentally favorable production technologies. A huge gap exists between actual and yield potential of existing crops. Some of the main reasons for this difference are inadequate supply of inputs, lack of comprehensive production technologies and non-judicious use of fertilizers (Sankaran *et al*., 2005). Rate of a fertilizer that produces most profitable economic yield at the minimal cost is considered as optimal dose of that fertilizer (Ananthi *et al*., 2010). For maximum yield potential, nutrient requirement also increases considerably (Castellanos *et al*., 2001), so it is imperative to reassess the fertilizers rate for sustainable crop productivity under a salinized environment.

Phosphorus is an indispensable macronutrient for sustaining plant growth. According to Alam *et al*. (2009) maximum yield potential of a crop cannot be achieved without supply of optimum dose of phosphorus. Phosphorus plays a critical role in plant root system, flowering, uniform grain filling, seed maturity, regulation of metabolic pathways, photosynthates and enzymatic activities (Bhattacharyya and Jain, 2000).

Salt-affected soils pose severe constraints associated with their deteriorated physical and chemical properties, poor infiltration rate, water and nutrient availability and consequently affect plant growth. Moderate salinity may increase the availability of P, but high salinity decreases P availability (Dhanushkodi and Subrahmaniyan, 2012). Plants growing in saline conditions are usually subjected to ionic imbalance because different toxic nutrients are taken up in large quantity and in varying ionic ratio as compared to the plant growing in normal soil conditions. Cl^{-1} inhibits the uptake of P to plants under hyper salinized environment (Awad *et al*., 1990). So, there is a need to employ multiple approaches to manage the salt-induced stress field. Use of stress-resistant cultivars, planting methods, fertilizers application and soil amendments are some common practices to improve crop yield in salt-affected soils (Yusuf *et al*., 2008; Zhang and Rue, 2012).

To ensure the maximum yield potential of vegetable crops optimum spacing is necessary. According to Dayi (2008) the ideal plant spacing is that which provides enough space for each plant with uniform distribution of existing space. Wide spacing in garlic caused the low plant population and consequently crop production is reduced (Karaye and Yakubu, 2006).

Garlic (*Allium sativum* L.) is grown for domestic use and as a source of earnings to many peasants in many parts of the countries (Getachew and Asfaw, 2000). In Pakistan, its production was 1698.1 tons during 2011-12 with an area of 172.4 thousand hectares (GoP, 2012). From 2001 to 2010, Pakistan was among the top ten garlic importing countries of the world (Sobia *et al*., 2014). Production of garlic crop in country can be improved by increasing its yield per unit area via increasing the efficacy of existing technology or introducing new production technology. In our country, farmers hesitate to adopt new technology. Therefore, improvement in efficacy of existing production technology is the most suitable choice to enhance agriculture productivity. Previously few attempts have been made to explore the full yield potential of garlic in salt-affected soils.

A review of numerous investigations has revealed that yield of garlic can be remarkably increased if the appropriate planting geometry is adopted. Similarly, Naruka and Dhaka (2001) stated that increasing the row space had significant effect on yield of garlic crop. Kilgori *et al*. (2007) experimented with three planting dates (29 November, 13 and 17 December) and four planting spaces (5, 10, 15, 20 cm) on two garlic varieties. They concluded that planting space of 10 cm in a combination of 29 Nov. and 13 Dec. produced the highest garlic bulb yield. Abubaker (2008) also revealed that with 20 and 30 cm spacing, highest yield of bean was divulged as compared to 10cm. Gebrehawaria (2007) stated a positive response of garlic to application of P and N fertilizers and recorded the maximum number of leaf with the supply of N (120 kg ha^{-1}) and P (60 kg ha^{-1}). Hore *et al*. (2014) suggested that maximum garlic yield can be achieved when 125 kg P_2O_5 ha^{-1} is supplied with 150 kg K_2O and 200 kg N ha^{-1}. Mohammad and Arshadi (2012) stated that planting the garlic with 0.12 × 0.20 m spacing on Nov. 21, was a suitable recommendation for farming this crop in terms of cloves mass and economic yield.

Considering what has been discussed above, the present work was conducted in saline-sodic soil to explore the simultaneous effects of row spacing and four different doses of phosphorus on growth and yield attributes of garlic crop.

Materials and Methods

The present work was investigated from 2013 to 2016 at Soil Salinity Research Institute (SSRI), Pindi Bhattian, Hafizabad, to explore the effect of different planting geometry (10cm x 20cm, 15cm x 20cm and 20cm x 20cm) and four phosphorus levels i.e. (i) control (no phosphorus), (ii) P (60 kg ha^{-1}) recommended dose (RD), (iii) 125% P of RD (75 kg ha^{-1}) and (iv) 150% P of RD (90 kg ha^{-1}) on growth performance and yield components of garlic in salt-affected soil. Whereas, N and K were applied uniformly @ 125-60 kg ha^{-1} in all the treatments. A salt-affected field, EC_e= 4.50 (dS m^{-1}), pH_s = 8.77 and SAR= 32.0 was selected. The experimental design was split-plot keeping a sub-plot size of 4m x 6m and three repeats. Planting geometry was allocated in main plots whereas, phosphorus doses in sub plots. Cloves of garlic cultivar (Lehsin Gulabi) were planted in 1st week of November and all fertilizers were applied at the field preparation. Agronomical practices and plant protection measures were assumed uniformly in all the treatments. Agronomic attributes like plant height, leaves $plant^{-1}$, bulb diameter (cm), bulb mass (gm), cloves $bulb^{-1}$ and bulb yield (t. ha^{-1}) were recorded. Collected data was subjected to analysis of variance according to Steel *et al*. (1997) to calculate the significant differences among treatments means LSD at 5% probability level was employed using STATISTIX 8.1 package software. To evaluate the economic feasibility of planting geometry and phosphorus rates, an economic analysis was estimated (Shah *et al*., 2013).

Results and Discussion

Plant height (cm)

Plant height, showed a positive response with increasing phosphorus doses, P application @ 150% of recommended dose produced the statistically ($P \leq 0.05$) maximum plant height (76.1 cm) significantly different by 125% P of recommended dose (74.0 cm) and shortest plant height (65.7 cm) was divulged in control (Table 1). Planting geometry also significantly affected the plant height, 15cm x 20cm recorded significantly greater plant height (74.3 cm) followed by 20cm x 20cm (72.1 cm) and lowest plant height (66.9 cm) was noted with plant spacing of 10cm x 20cm. The interaction of phosphorus doses and planting geometry was also significant, phosphorus @ 150% of RD with planting geometry of 15cm x 20cm recorded maximum plant height of (79.0 cm) followed by planting geometry of 20cm x 20cm with phosphorus @ 150% of RD. According to Blackshaw *et al*. (2004) supplementation with phosphorus is one of the most essential input in crop production as it is structural component of phospholipids and phosphoproteins and performs a critical role in photosynthesis and cellular energy transfer (Sharif *et al*., 2014). More plant height with increasing levels of phosphorus (125 and 150% of RD) may be accounted for the favorable effects of phosphorus under salt stress conditions. The positive response of phosphorus supply on growth parameters have also been stated by Khiriya *et al*. (2001). Whereas plant height of garlic crop planted at 15cm x 20cm tends to established better with more plant height than those closely spaced in 10cm x 20cm, as widely spaced plants enjoy more favorable growth conditions with less competition for nutrients and can intercept more solar light, so produced more plant height. Hussen *et al*. (2014) also reported that row spacing significantly affected the plant height of garlic crop.

No. of leaves plant^{-1}

A distinguished increased in the number of leaves plant^{-1} was observed with increasing rates of P (Table 2). Planting geometry also exhibited a distinct effect and 15cm x 20cm proved superior (9.6 leaves plant^{-1}) than 20cm x 20cm (9.0 leaves plant^{-1}) and planting geometry of 10cm x 20cm. The data also reflected that the greater number of leaves (9.7) were documented with 150% P of RD while 9.44 leaves plant^{-1} were produced by 125% P of RD however, both the treatments were statistically alike and control recorded the minimum number of leaves (8.0). The interactive effect of P and planting geometry also had a substantial effect on the leaves production. Planting geometry of 15cm x 20cm produced greater number of leaves (10.6 plant^{-1}) with phosphorus @ 150% of RD followed by 125% P of RD (10.3). The results of our study that the more leaves plant^{-1} in planting geometry of 15cm x 20cm are correlated with previous outcomes of Bodnar (1998) they reported that garlic plants at wide space show more vegetative growth and produced more leaves. The positive effect of higher dose of phosphorus (P @ 125% and 150% of RD) on leaf number might be ascribed to the beneficial effects on plant growth as plants did not suffer severe competition for plants nutrients to such degree that can reduce plant growth. Our outcomes are inconsistent with findings of (Jat and Shaktawat, 2001) they concluded that higher level of P progressively effects the growth parameters of crop plants.

Table 1: *Interactive influence of phosphorus and planting geometry on plant height (cm) of garlic.*

Phosphorus levels	Planting geometry			Mean
	10cm x 20cm	15cm x 20cm	20cm x 20cm	
Control	62.0 h	69.6 e	65.6 f	65.7 d
Recommended dose	63.6 g	72.0 d	70.3 e	68.6 c
125 % P of RD	70.0 e	76.6 bc	75.3 c	74.0 b
150 % P of RD	72.0 d	79.0 a	77.3 b	76.1 a
Mean	66.9 c	74.3 a	72.1 b	

LSD for planting geometry: 1.1015; LSD for phosphorus levels: 0.8470; LSD for interaction: 1.4671

Table 2: *Interactive influence of phosphorus and planting geometry on leaves plant^{-1} of garlic.*

Phosphorus levels	Planting geometry			Mean
	10cm x 20cm	15cm x 20cm	20cm x 20cm	
Control	7.6 g	8.3 efg	8.0 fg	8.0 c
Recommended dose	8.6 def	9.3 cd	9.0 cde	9.0 b
125 % P of RD	8.6 def	10.3 ab	9.3 cd	9.4 ab
150 % P of RD	9.0 cde	10.6 a	9.6 bc	9.7 a
Mean	8.5 c	9.6 a	9.0 b	

LSD for planting geometry: 0.4998; LSD for phosphorus levels: 0.4859; LSD for interaction: 0.8417.

Bulb diameter (cm)

Data regarding the bulb diameter revealed that planting geometry, phosphorus rates and their interaction significantly affected the bulb diameter (Table 3). The results exhibited that maximum bulb diameter of 3.76 cm was documented by 150% P of RD and was non-significant with 125% P of RD which produced bulb diameter of 3.6 cm. Similarly planting geometry of 15cm x 20cm recorded the maximum bulb diameter of 3.6 cm. The interaction of planting geometry and phosphorus was also significant. Phosphorus @ 150% of RD had a higher bulb diameter of 4.0 cm which was similar with 125% P of RD giving 3.8 cm in planting geometry of 15cm x 20cm. Adequate phosphorus nutrition significantly influences physiological processes such as photosynthesis, cell division and flowering (Sharif *et al*., 2014). Better results with planting geometry of 15cm x 20cm and phosphorus applied @ 125 and150% of RD might be corelated to effective exploitation of plant nutrients and accessibility of adequate amount of light, water and more area available to roots for nutrients acquisition. Tuncurk (2011) also reported that fenugreek produces the highest yield with the row spacing of 30cm and P @ 90 kg ha^{-1}.

Table 3: *Interactive influence of phosphorus and planting geometry on bulb diameter (cm) of garlic.*

Phosphorus levels	Planting geometry			Mean
	10cm x 20cm	15cm x 20cm	20cm x 20cm	
Control	3.1 g	3.3 ef	3.0 g	3.1 c
Recommended dose	3.4 de	3.5 cd	3.2 fg	3.3 b
125 % P of RD	3.7 bc	3.8 ab	3.4 de	3.6 a
150 % P of RD	3.7 bc	4.0 a	3.5 cd	3.7 a
Mean	3.5 b	3.6 a	3.3 c	

LSD for planting geometry: 0.0596; LSD for phosphorus levels:0.1129; LSD for interaction:0.1955.

Bulb mass (gm)

Data about bulb mass (Table 4) showed a remarkable positive response with increasing doses of phosphorus. Treatment receiving phosphorus @ 150% of RD recorded the highest bulb mass (25.6 gm) followed by 125% P of RD producing bulb mass of 25.3 gm. The results also reflected that planting geometry of 15cm x 20cm produced more bulb mass 25.4 gm. Interaction of phosphorus levels and planting geometry revealed that phosphorus applied @ 125% and 150% of RD documented highest bulb mass i.e. 26.1 gm with planting geometry of 15cm x 20cm which was at par with phosphorus @ 150% of RD and planting geometry of 10cm x 20cm producing the bulb mass 25.2 gm. Phosphorus governs the several metabolic pathways, enzymatic activities and development of reproductive organs (Sharif *et al*., 2014). Similarly, Pandey *et al*. (2012) stated that N (120), P (80) and K (60) kg ha^{-1} was a best combination in improving the length of leaves and bulb mass of garlic. Phosphorus increment in fenugreek significantly improved the yield attributes (Nehara *et al*., 2006).

Table 4: *Interactive influence of phosphorus and planting geometry on bulb mass (gm) of garlic.*

Phosphorus levels	Planting geometry			Mean
	10cm x 20cm	15cm x 20cm	20cm x 20cm	
Control	23.5 f	24.2 de	22.9 g	23.5 d
Recommended dose	24.4 d	25.2 bc	23.9 ef	24.5 c
125 % P of RD	25.5 b	26.1 a	24.2 de	25.3 b
150 % P of RD	25.7 ab	26.1 a	25.0 c	25.6 a
Mean	24.8 b	25.4 a	24.0 c	

LSD for planting geometry: 0.2618; LSD for phosphorus levels: 0.3000; LSD for interaction: 0.5196.

Table 5: *Interactive influence of phosphorus and planting geometry on cloves bulb^{-1} of garlic.*

Phosphorus levels	Planting geometry			Mean
	10cm x 20cm	15cm x 20cm	20cm x 20cm	
Control	25.0 g	25.6 fg	24.2 h	24.9 c
Recommended dose	25.9 ef	26.7 cd	25.3 fg	26.0 b
125 % P of RD	26.9 bcd	27.6 a	25.5 fg	26.7 a
150 % P of RD	27.2 abc	27.5 ab	26.4 de	27.0 a
Mean	26.2 b	26.8 a	25.3 c	

LSD for planting geometry: 0.3177; LSD for phosphorus levels:0.3572; LSD for interaction:0.6187

Number of cloves bulb^{-1}

Data in Table 5, showed substantial differences among the phosphorus levels and planting geometry for number of cloves bulb^{-1}. Phosphorus @ 150 and 125% of RD were the most effective doses in number of cloves (27.0 and 26.7 bulb^{-1} respectively) and the lowest mean value of cloves (24.9 bulb^{-1}) was divulged in control. With respect to planting geometry, 15cm x 20cm has better effect on number of cloves bulb^{-1} (26.8) as compared to 10cm x 20cm (26.2 cloves bulb^{-1}) and 20cm x 20cm (25.3 cloves bulb^{-1}) of planting geometry. Interaction of phosphorus levels and planting geometry indicated that highest cloves bulb^{-1} (27.6) was produced with phosphorus used @ 125% of RD followed by phosphorus @ 150% of RD (27.5) with planting geometry of 15cm x 20cm and minimum number of cloves was produced in control with planting geometry of 15cm x 20cm (24.2 cloves bulb^{-1}). Our results buttressed those of Mulatu *et al.* (2014) they observed a significant increase in bulb yield with use of N at rate of 100 and phosphorus at rate of 50 kg ha^{-1}. Ahmadi and Rohaninezhad (2005) also described an increase in number of cloves through reducing inter-row spacing.

Table 6: *Interactive influence of phosphorus and planting geometry on bulb yield (Mg ha^{-1}) of garlic.*

Phosphorus levels	Planting geometry			Mean
	10cm x 20cm	15cm x 20cm	20cm x 20cm	
Control	3.3 f	3.5 e	2.8 g	3.2 c
Recommended dose	5.1 c	5.7 b	4.7 d	5.2 b
125 % P of RD	5.8 b	6.5 a	5.7 b	6.0 a
150 % P of RD	5.8 b	6.6 a	5.7 b	6.0 a
Mean	5.0 b	5.6 a	4.7 c	

LSD for planting geometry:0.1016; LSD for phosphorus levels: 0.1039; LSD for interaction: 0.1800

Bulb yield (Mg ha^{-1})

Bulb yield also had positive response for phosphorus fertilization and planting geometry (Table 6). The result displayed that phosphorus @ 150% of RD produced highest bulb yield (6.0 Mg ha^{-1}) nonsignificant with 125% P of RD (6.0 Mg ha^{-1}) and control produced the lowest bulb yield (3.2 Mg ha^{-1}). Planting geometry of 15cm x 20cm produced maximum bulb yield (5.6 Mg ha^{-1}) significantly different from 10cm x 20cm and 10cm x 20cm of planting distance. The interactive effect of phosphorus and planting geometry exhibited that phosphorus @ 150% of RD with planting geometry of 15cm x 20cm recorded the highest value of bulb yield (6.6 Mg ha^{-1}) statistically similar to P @ 125% of RD with planting geometry of 15cm x 20cm (6.5 Mg ha^{-1}). The improved bulb yield at a closer spacing in planting geometry of 15cm x 20cm might be explained with increased planting density/ unit area. Whereas, the low bulb yield in 20cm x 20cm spacing could be correlated with reduced plant population in this treatment. Moreover, the total yield depends not only on the individual plant performance but also on plant population per unit area as depicted in our study. Our results are supported by findings of many researchers that sustainable production of garlic responded positively to intra-row spacing (Karaye and Yakubu, 2006; Ademe *et al*., 2012; Hamma *et al*., 2013). Compatible results have also been observed by Bhunia *et al.* (2006) that increasing doses of phosphorus improved the yield characteristics of different crops.

Table 7: *Effect of phosphorus and planting geometry on net income and benefit: cost ratio (BCR) of the garlic crop.*

Phosphorus levels	Planting geometry			
	10cm x 20cm			
	Cost of production (Rs.)	Gross income (Rs.)	Net income (Rs.)	Benefit: Cost
Control	60000	166835	106835	2.780583
Recommended dose	65000	256335	191335	3.943615
125 % P of RD	70000	290165	220165	4.145214
150 % P of RD	73000	294000	221000	4.027397
	15cm x 20cm			
	Cost of production (Rs.)	Gross income (Rs.)	Net income (Rs.)	Benefit: Cost
Control	60000	179000	119000	2.983333
Recommended dose	65000	287500	222500	4.423077
125 % P of RD	70000	328500	258500	4.692857
150 % P of RD	73000	333500	260500	4.568493
	20cm x 20cm			
	Cost of production (Rs.)	Gross income (Rs.)	Net income (Rs.)	Benefit: Cost
Control	60000	143000	83000	2.383333
Recommended dose	65000	239835	174835	3.689769
125 % P of RD	70000	287665	217665	4.1095
150 % P of RD	73000	287335	214335	3.936096

Economic analysis

According to Khan *et al.* (2012) economic viability of any cropping technology has a prime importance for its acceptance among the farming community. An economic analysis was assessed to determine the best, optimum and economical phosphorus level and planting geometry to cultivate garlic under salt-affected conditions (Table 7). Economic analysis showed that maximum net income was achieved with phosphorus @ 125% of RD with planting geometry of 15cm x 20cm (Rs. 258500 ha^{-1}). Increased yield with planting geometry of 15cm x 20cm and P @ 125% of RD as compared to planting geometry of 20cm x 20cm could be attributed to increased plant density and more bulb yield per land unit area. Our findings are plausible with Doro (2012) they found that all yield characters assessed decreased when row spacing increased from 5 to 20cm in garlic.

Conclusions and Recommendations

Findings of the present work showed that tallest plant, more leaves $plant^{-1}$, maximum bulb diameter and mass, cloves $bulb^{-1}$ and superior bulb yield were found with phosphorus @ 150% and 125% of RD with planting geometry of 15cm x 20cm. However, in terms of economic return and yield of garlic, the treatment with phosphorus @ 125% of RD with planting geometry of 15cm x 20cm proved superior with high net income (Rs. 258500) and cost benefit ratio (4.69) than all other treatments.

Novelty Statement

A huge gap exists between actual and yield potential of existing crops due to inadequate supply of inputs, lack of comprehensive production technologies and non-judicious use of fertilizers. So, it is imperative to reassess the fertilizers rate for sustainable crop productivity under a salinized environment. Use of phosphorus @ 125% of RD with planting geometry 15cm x 20cm is proposed as a most cost-effective management practice for garlic cultivation.

Author's Contribution

Muhammad Qaisar Nawaz, conceived the idea, conducted the study for three years and wrote the article, Khalil Ahmed, Ghulam Qadir, wrote abstract and materials and methods, Amar Iqbal Saqib, Muhammad Rizwan, Muhammad Faisal Nawaz, did data collection and statistical analysis, Imtiaz Ahmad Warraich, provided technical input at every step.

Conflict of interest

The authors have declared no conflict of interest.

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