

Original Research Article

Growth, physiological, yield and quality response in chilli (*capsicum annuum* L.) under wastewater irrigation and different levels of phosphorus

ABSTRACT

Aims: In many countries around the world, water is becoming an increasingly scarce resource and it forced scientists to consider alternate sources of water which might be used economically and effectively. India is one of the most densely populated, developing and industrially fast growing country of the earth that not only facing the problem of water scarcity, but also the mismanagement of tremendous amount of wastewater (WW) produced every day. Therefore a study was conducted in the Aligarh city of India on chilli (*Capsicum annuum* L.) cv. Pusa Sadabahar to observe the suitability of wastewater for irrigation along with different levels of phosphorus and how minimize the use of chemical fertilizers in agriculture by supplementing mineral nutrients through WW.

Study design: Factorial randomized block design

Place and Duration of Study: The pot experiment was conducted during 2011-2012 in the net house of the plant physiology, Department of Botany, Aligarh Muslim University, Aligarh.

Methodology: Three levels of water 50%WW, 100%WW and GW were used along with four basal doses of phosphorus at the rates of 0, 20, 40 and 60kgPha¹ with a uniform basal dose of nitrogen and potassium with the rates of 60kgNha¹ and 50kgKha¹ respectively. Fertilizers were applied one day before sowing. Both the waters and soil were analyzed for various physico-chemical characteristics.

Results: All the growth, physiological, yields as well as quality parameters were recorded at 60 days after sowing. Results revealed that WW irrigation significantly increases the growth, photosynthesis, yield and quality of the crop. Lower dose of phosphorus fertilizer @ 40 kg ha⁻¹ together with WW proved optimum and gave greater shoot and root length, shoot fresh and dry mass, leaf area, photosynthetic rate, chlorophyll content, nitrate reductase, carbonic anhydrase, ascorbic acid and leaf nitrogen content than control and even to higher nitrogen doses along with groundwater.

Conclusion: The wastewater proved an effective source of essential nutrients and even it could not be supplemented the whole nutrient requirement of the crop but it can reduced the quantity of fertilizers because wastewater also a source of nutrients.

Keywords: Ascorbic acid, Photosynthetic rate, Yield, Nitrogen, ¹

1. INTRODUCTION

Water is undoubtedly a requirement for all of the living organisms in the biosphere [1]. Man has used the water systems for numerous purposes such as drinking, irrigation, fisheries, industrial processes, transportation and waste disposal, but due to increased human population, industrialization, use of fertilizers in the agriculture and man-made activity it is highly polluted with different harmful contaminants and also widened the gap between the supply and demand for water up to such alarming levels that in some parts of the world it posing a threat to human existence. Scientists around the globe are working on new ways of conserving water. On other hand the disposal of wastewater is a major problem faced by municipalities, particularly in the case of large metropolitan areas, with limited space for land based treatment and disposal. It is an suitable time, to refocus on one of the ways to recycle water-through the reuse of urban wastewater, for

irrigation and other purposes [2] because the use of wastewater as a source of irrigation not only solves its disposal problem but also serve as a source of plant nutrients and organic matter. Its reuse can delivers positive benefits to the farming community [3]. However, wastewater may contain some undesirable constituents that may pose negative environmental effects and health risks. Thus, it can be considered as both a resource and a problem and there is urgent need for the wastewater management in a scientific manner. In many parts of the world, treated municipal wastewater and raw sewage wastewater and even industrial wastewater has been successfully used for the irrigation of various crops [4-5].

Nutrient supply in general considered to be most important limiting factor for growth and productivity [6]. Most of the plants require seventeen essential elements including Ni which was added more recently [7] for their normal growth and development. Of these N, P and K are the three major macronutrient effective in promoting the crop yields and required in large quantity, thus the maintenance of an adequate supply of nutrients to crop is one of the most basic and vital requirements for sustained crop growth and productivity. Agro ecosystems exports large quantities of nutrients in crop biomass and therefore, require large inputs regardless of internal cycling [8]. Use of inorganic and organic fertilizers has amused a great significance in recent years in vegetables production, for two reasons. Firstly, the need for continued increase production and per hectare yield of vegetables requires the increase amount of nutrients. Secondly, the results of a large number of experiments on inorganic and organic fertilizers conducted in several countries reveal that inorganic fertilizer alone cannot sustain the productivity of soils under highly intensive cropping systems [9]. Among nutrients nitrogen increases the yield of chilli [10] and potassium is reefed as quality element and known to improve colour and glossiness of chilli fruits. After nitrogen phosphorus is being considered second major element whose deficiency has become widespread in Indian soils [11]. Phosphorus fertilizer is an expensive input and its use efficiency by crops may range from 10 - 25% [12]. Farmers mostly use single superphosphate as P source, which contains 16% P_2O_5 and 12% S [13]. Role of phosphorus in increasing tillering and growth is well recognized. Phosphorus is an essential element and is involved in energy transfer through ATP. It is also involved in root development and in metabolic activities especially in synthesis of protein [14]. An adequate supply of phosphorus to the crop plants during their early growth period is very important for the initiation of leaves and florets primordial [15]. Application of phosphorus improves various growth parameters like, plant height, biomass and yield. Thus the main objective was to minimize the use of inorganic fertilizers and optimize the utilization of nutrients present in the wastewater and also safeguard the pollution of water and soil by using it in crop cultivation.

2. MATERIAL AND METHODS

Present study was aimed to evaluate the effect of wastewater along with different phosphorus levels on plant morphology, photosynthetic activity, yield and quality of the chilli. Wastewater includes wastewater from the households and sewage together with the wastewater from local industries of lock and electroplating as well and was collected from the outside of Aligarh city nearly 5 km from the town where it was being used by local formers to irrigate crops especially vegetable crops. The experiment was carried out in the naturally illuminated net house of the department of Botany, Aligarh Muslim University, Aligarh, and each treatment was set simultaneously in triplicate using a complete randomized block design with four different phosphorus treatments at the rate of 0, 20, 40 and 60 kg/ha being watered by tap water (GW) and wastewater (50%WW and 100%WW). A uniform basal dose of nitrogen at the rate of 60 kg ha⁻¹ and potassium 50kg ha⁻¹ were also applied along with different doses of P. The dilution of 50% wastewater was obtained by mixing the GW and WW in a 1:1 ratio. Many physio-chemical characteristics were analysed by adopting the procedures outlined in the standered methods [16] (Table 1). The soil for pot filling was collected from University Agriculture Farm and analysed for various physico-chemical properties [17] (Table 2). Microbiological analysis was also carried out and the mean values were obtained from three random samples (Table 3). Heavy metals (Cd, Pb, Ni and Cr) in the water and the soil samples were also analyzed using the atomic absorption spectrophotometer (Table 1&2). The plants were sampled at 60 DAS to make various observations. The plants were uprooted gently and washed under running tap water to remove adhering soil. The plant length and fresh mass of the whole plant were assessed. The samples were then dried in an oven at 80°C for 48h. The dehydrated samples were then weighed to recorded dry mass. Leaf area was measured using a portable leaf area meter (LA-21, Systronics, India). Nitrate reductase (NR) and carbonic anhydrase activities (CA) were determined in fresh leaves of plants by the method of [18-19] and Net photosynthetic rate (P_N) and Transpiration rate (E) were measured in upper most fully expended leaves on clear sunny days between 11.00 and 12.30h, using a portable photosynthetic system (LICOR 6400, Lincoln, NE, USA). Leaf nitrogen was estimated by the method of [20] while the method of [21] was used to calculate the total chlorophyll content. Ascorbic acid was calculated by adopting the method of [22]. At harvest, yield attributes including fruit length, fruit number and fruit fresh yield were measured.

Table 1. Physico-chemical characteristics of groundwater (GW) and 100% wastewater (100%WW). All determinations in mg l⁻¹ or as specified.

Determinants	GW	WW	FAO irrigation water quality
Colour	Colourless	Dark black	--
Odour	Odourless	Unpleasant	--
p ^H	7.3	7.9	6.5-8.4
Electrical conductivity (dS m ⁻¹)	0.75	1.42	0.25-3.0
Total solids	915	1627	--
Total dissolved solids	549	1088	<2000
Total suspended solids	385	549	--
Biological oxygen demand	17.40	122.52	--
Chemical oxygen demand	55.22	152.44	--
NO ₃ -N	0.73	3.17	--
NH ₄ -N	0.00	5.24	<10
PO ₄ ⁻³	0.24	1.13	5.0
K ⁺	4.21	19.23	<2.0
Ca ²⁺	22.52	59.48	<400
Mg ²⁺	22.12	138.56	<61
CO ₃ ⁻²	49.48	138.44	--
HCO ₃ ⁻¹	59.56	89.24	<610
Cl ⁻	35.28	82.18	<350
Na ⁺	16.37	49.26	<460
Cd	ND	0.006	--
Cr	ND	0.004	--
Ni	ND	0.347	--
Pb	ND	0.031	--

Table 2 Physico-chemical characteristics of soil collected before sowing. All determinations in mg l⁻¹ in 1:5 (soil-water extract) or as specified.

Determinants	142 Soil	Table
Texture	Sandy loam	
Cation exchange capacity (CEC) (meq 100 g ⁻¹ soil)	2.25	
p ^H	7.72	
Organic carbon (%)	0.355	
Electrical conductivity (μ mhos cm ⁻¹)	282.00	
NO ₃ ⁻¹ -N(g kg ⁻¹ soil)	0.317	
Phosphorus (g kg ⁻¹ soil)	0.125	
Potassium	10.2	
Calcium	27.15	
Magnesium	17.548	
Chloride	30.52	
Carbonate	25.25	
Bicarbonate	95.43	
Sodium	13.98	
Sulphate	17.05	

Table 3. Microbiological analysis of wastewater

Bacteria	Method used	Bacterial count
Total heterotrophic bacteria	Spread Plate method	28.4×10 ⁶ CFU 100 ml ⁻¹
Coliforms	MPN method	1.9×10 ³ 100 ml ⁻¹
Faecal coliforms	MPN method	8.2×10 ² 100 ml ⁻¹
<i>Salmonella-Shigella</i> sp	Spread plate method	1.3×10 ² 100 ml ⁻¹

MPN= Most probable number

CFU= Colony forming unit

2.1 Data analysis

The data recorded from the experiment were subjected to two-way analysis of variance (ANOVA) using the SPSS software package, and the mean were compared following the method given by [23]. An F test was applied to assess the significance of the data at 5% level of probability ($P=0.05$).

3. RESULTS AND DISCUSSION

Among the three water treatments, 100% WW proved more effective in enhancing the growth, enzymatic activity, photosynthesis, fruit yield and ascorbic acid content of fruit. Even 50% WW was also better when compared to ground water (GW), thus proving the utility of wastewater as a source of nutrients and irrigation water. The analysis of the wastewater has revealed that it was alkaline in nature with average EC, pH, TDS. The observed nutrients including some heavy metals also were within the permissible limits of [24] guideline for irrigation water quality except for Mg^{2+} and K^+ through all were higher than that of the groundwater (Table 1). Wastewater obtained from urban source has a great potential for the reuse as a source of irrigation water and nutrient as well as a soil conditioning agent [25] because it contains considerable amount of nutrients essential for maintaining soil fertility and enhancing plant growth and yield. The pH (7.3-7.9) of the wastewater was within the range important for nutrient availability because it is the indicator of acidity and basicity of water. EC is widely used as a reliable indicator of the salinity of soils and its major effect on crop productivity is the inability of the plants to compete with ions present in the soil for water thus EC is the most useful and easily obtained property of the soil that influences the crop productivity [26]. The wastewater has considerably higher BOD and COD than groundwater, it determines the pollution power or strength of wastewater in terms of oxygen that micro-organism would require for complete stabilization. Chloride content of wastewater $82.18mg\ l^{-1}$ was comparatively low and may not cause toxicity problems. When nutrients are added though effluent and their accumulation are either equal or less than the demand of the crop, the build up in the soil is normally minimal. But there are various researchers that demonstrated that continuous irrigation with wastewater may lead the accumulation of nitrate in the soil [27] that leached to down layers and ultimately contaminated the groundwater.

As wastewater has beneficial effect on the physical, chemical and biological properties of soils [28-30], it could be used not only as a substitute of chemical fertilizer but also as the soil conditioner that would increase crop yield and enhance soil fertility and productivity [31-32]. It also increases the density of soil microorganisms including bacteria, fungi and actinomycetes that helps in nutrient availability of plants [33]. Concentrations of some essential inorganic ions were higher in wastewater than in groundwater. These could have played a beneficial role as these are essential for plants [34]. Dry matter accumulation (Fig 1) was 16.18% higher in plants receiving wastewater than the plants irrigated with groundwater and among wastewater, 100%WW recorded much more dry matter because of the retention of the effluent components mainly due to the incorporation of the elements in the dry matter of the plants [35] leading to decreasing concentration in the surrounding groundwater. Although there is various studies, dilution has been described as an effective means to minimize toxicity [36-38], while in the present study source of irrigation is the urban wastewater which was sufficiently diluted by the mixing of household wastewater did not cause any toxicity problem. Use of urban wastewater without any dilution was also described by various researchers on different crops [39-42]. Among nutrients, comparatively higher phosphate and nitrogen in water may be a cause of concern, nitrogen is the most important element, which is invariably required in large quantities and in wastewater it was present in both ionic forms (Table 1). Higher nitrogen and phosphate in wastewater is very important for the plants because if it properly utilized by irrigation management can reduce the fertilizer demand and also contribute to solve the environmental degradation problem. In addition mineral nutrients wastewater also contains some heavy metals, which were within permissible limit of [24] guideline. 100% WW produced 11.63% and 13.46% higher shoot length and root length respectively over GW, while 14.38% (Fig. 1) increase was recorded by 100%WW in shoot fresh weight over GW. This enhanced vegetative growth under wastewater irrigation was due to the presence of both ionic forms of nitrogen in wastewater. Wastewater contains considerable high amount of nitrate, which is the sole source of nitrogen supply and most important for better growth and yield of crop plants [43], because it involves in cell division and elongation and it is also an important structural constituent of many important metabolites amino acid, protein. Generally the highest growth and yield are obtained by the combined supply of both ions, but it may be noted that the form of N plays a key role in the cations-anion relationship in plants as about 70% of cations and anions taken up are represented by either NH_4^+ or NO_3^- [44]. A substantial increase of 18.82% in leaf area (Fig 2), that might stimulated the photosynthetic rate (P_N) by influencing the light absorption within plant. The increase in leaf area brought by the N supply causing expansion of individual leaves has also been reported by [45-46] because N stimulated the cell division and cell expansion [47].

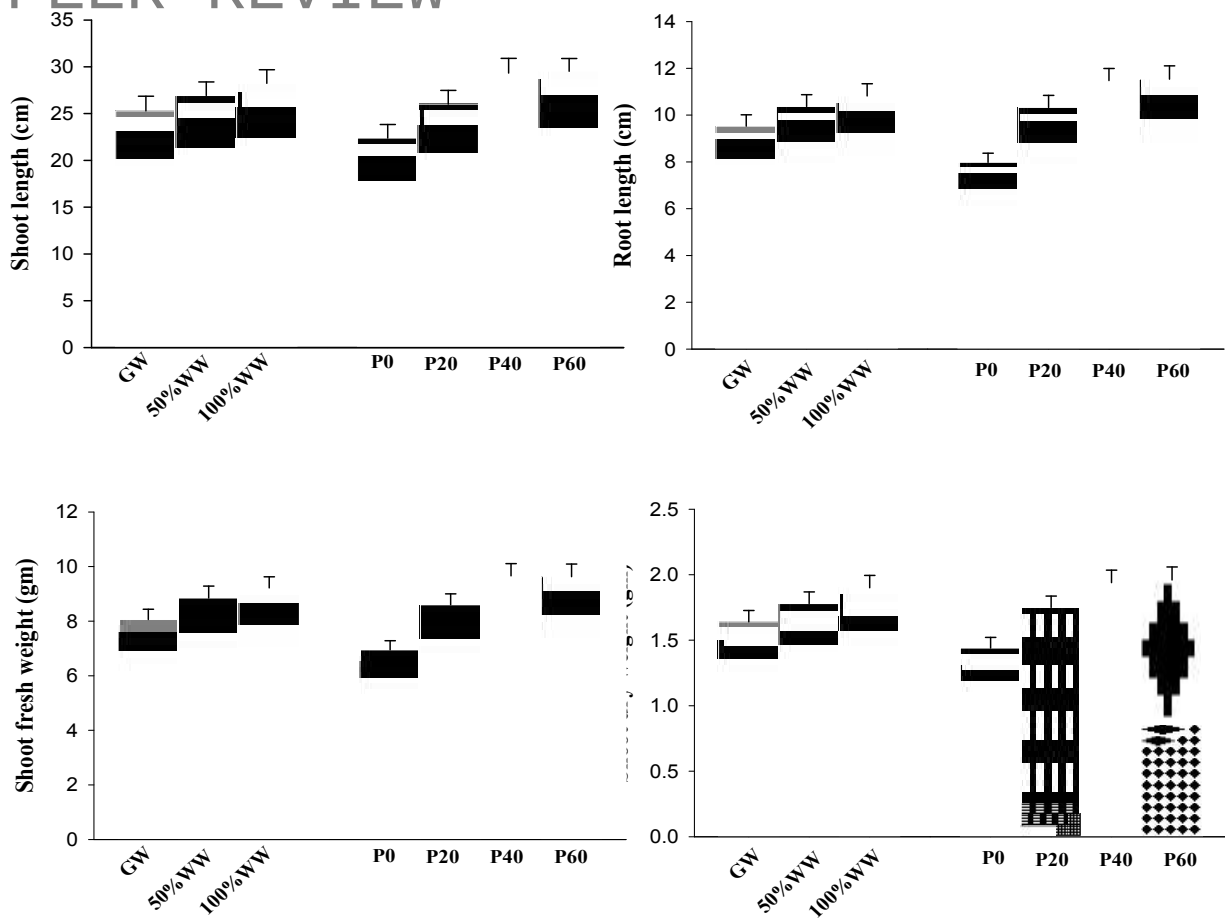


Figure 1.

Effect of groundwater and wastewater irrigation and different levels of phosphorus (P) on shoot length (cm), root length (cm), shoot fresh weight (gm) and shoot dry weight (gm) of chilli (*Capsicum annum* L.) at 60 DAS. Values represent means of three replicates ± standard error (SE).

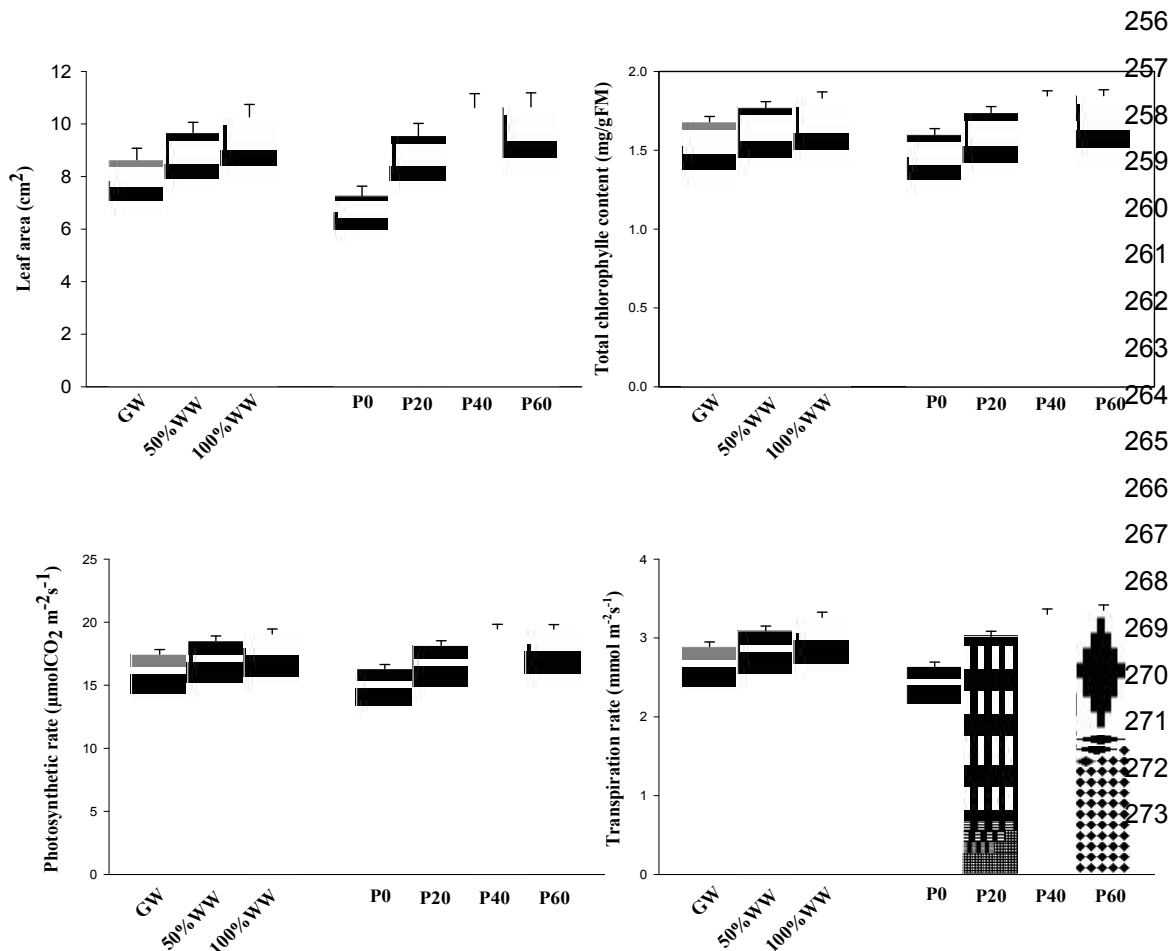


Figure 2. Effect of groundwater and wastewater irrigation and different levels of phosphorus (N) on leaf area (cm²), chlorophyll content (mg/g FM), photosynthetic rate [$\mu\text{mol (CO}_2\text{) m}^{-2}\text{s}^{-1}$] and transpiration rate [$\mu\text{mol m}^{-2}\text{s}^{-1}$] of chilli (*Capsicum annuum* L.) at 60 DAS. Values represent means of three replicates $\pm$ standard error (SE).

Increased nitrogen supply has also been found to enhance the activity of CA and RuBP carboxylase as reported by [48] and the stimulation in the activity of CA was also observed in this study (Fig 3). Likewise vegetative growth wastewater also recorded higher values for the physiological parameters. It recorded an increase of 9.22% and 11.64% in photosynthetic rate and chlorophyll content over GW. Increase in total chlorophyll content may be due to higher availability of Mg^{2+} in wastewater as Mg^{2+} is the central atom of chlorophyll molecule which is required for the structural integrity of chloroplasts [49] and quantitative estimation of chlorophyll may be considered as an index of primary productivity. Like growth and physiological parameters wastewater application recorded an increase of 10.98, 8.75 and 6.60% in fruit length at I, II and III fruit pickings respectively over GW while an increase of 34.32, 16.66% and 11.92% were also registered in fruit number at I, II and III pickings respectively. Fruit yield recorded an increase of 35.57, 24.14 and 24.50 under WW at I, II and III pickings respectively (Fig 4 & 5). This increase in yield under WW application may be explained on the basis of increase in leaf area by wastewater application. Increased leaf area might have allowed plants to trap more radiant energy required for enhanced photosynthetic activity which in turn might have increased the yield.

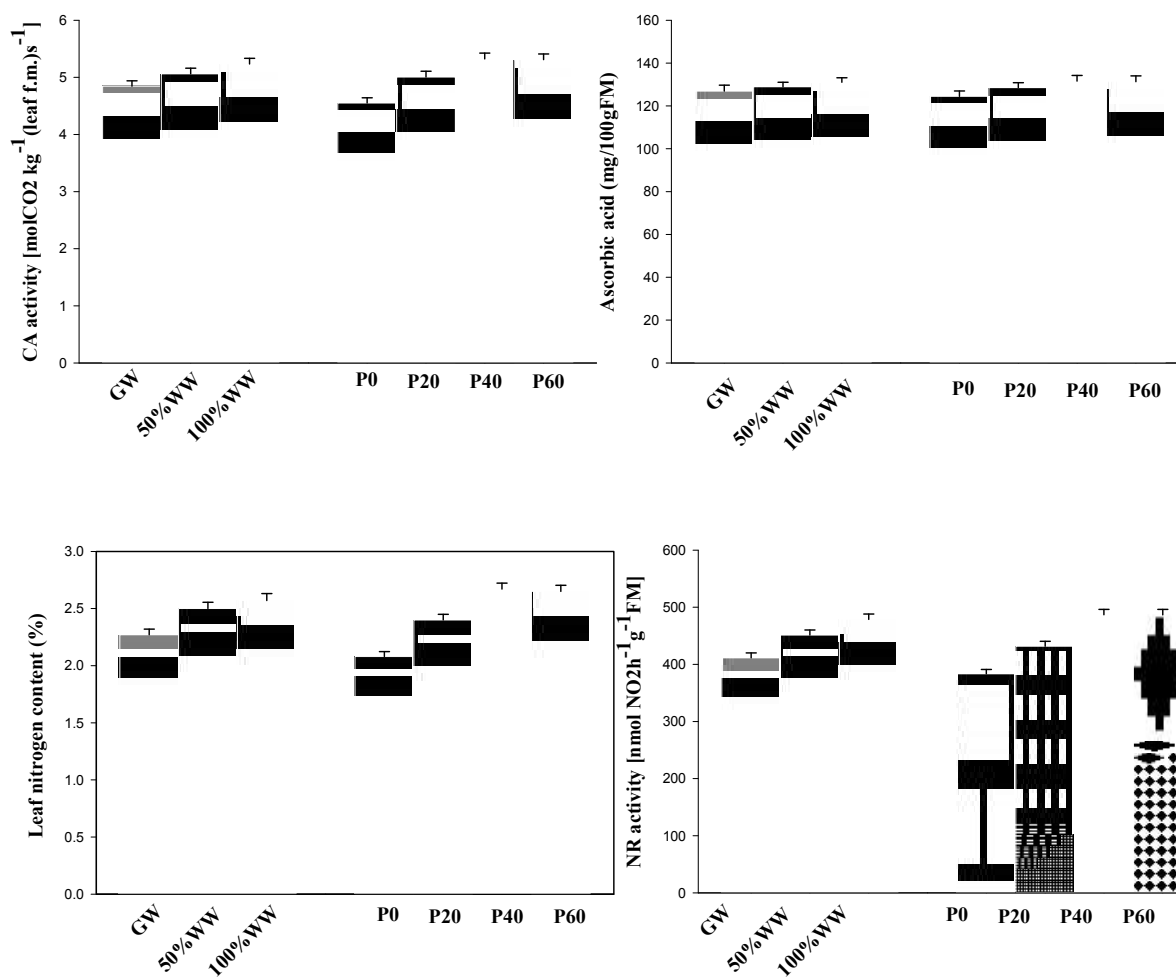


Figure 3. Effect of groundwater and wastewater irrigation and different levels of phosphorus (N) on leaf area (cm²), chlorophyll content (mg/g FM), photosynthetic rate [$\mu\text{mol (CO}_2\text{) m}^{-2}\text{s}^{-1}$] and transpiration rate [$\mu\text{mol m}^{-2}\text{s}^{-1}$] of chilli (*Capsicum annuum* L.) at 60 DAS. Values represent means of three replicates $\pm$ standard error (SE).

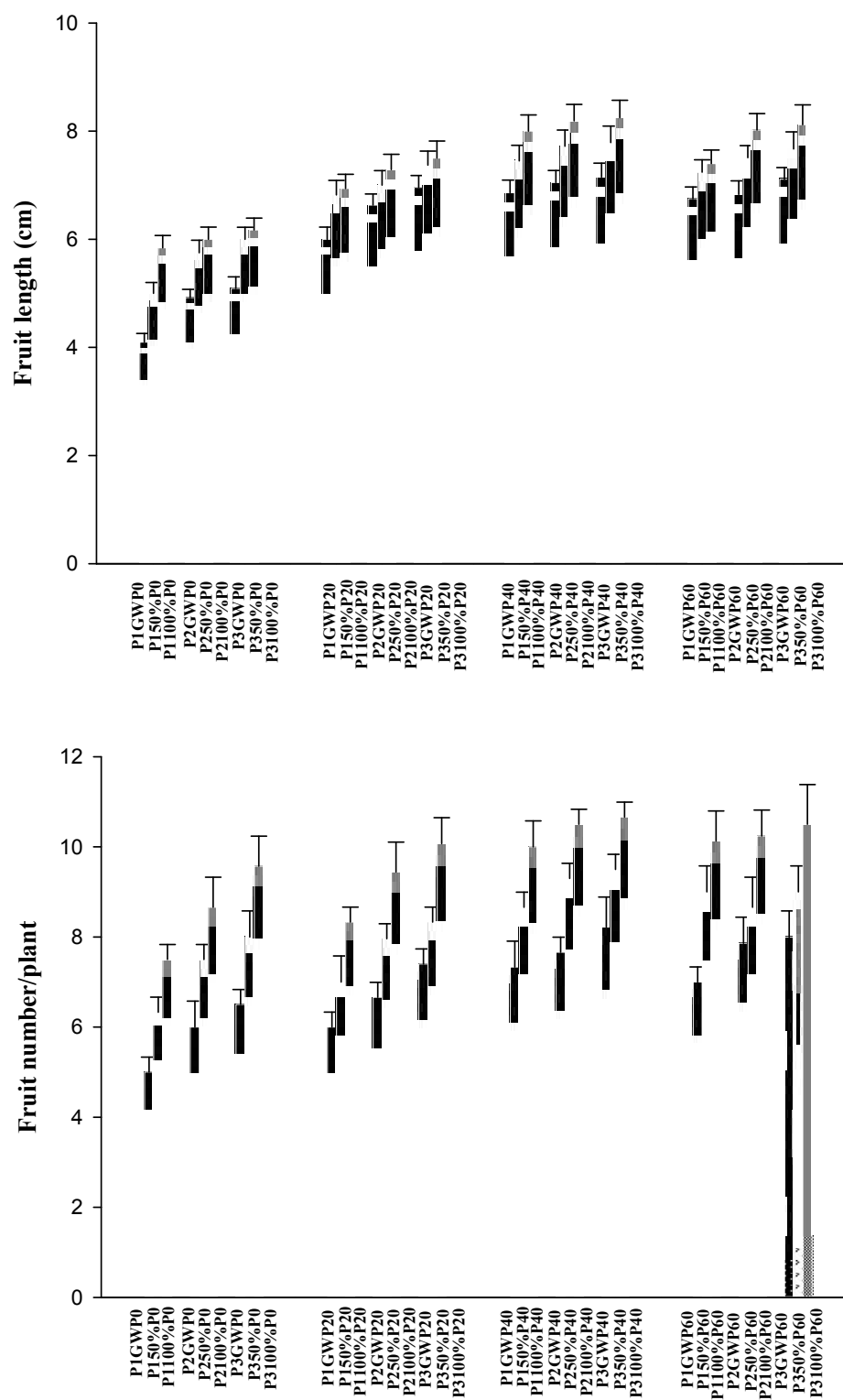


Figure 4. Effect of groundwater and wastewater irrigation and different levels of phosphorus (N) on fruit length (cm) and fruit number plant-1 of chilli (*Capsicum annuum* L.) at I, II and III fruit pickings. Values represent means of three replicates $\pm$ standard error (SE).

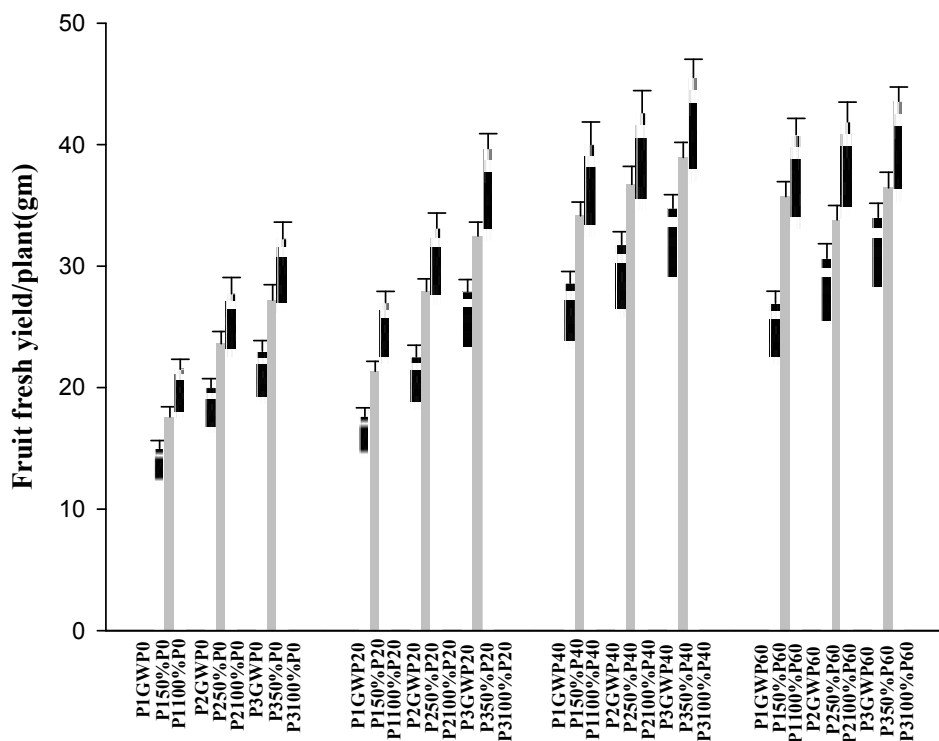


Figure 5. Effect of groundwater and wastewater irrigation and different levels of phosphorus (N) on fruit fresh yield plant-1 of chilli (*Capsicum annuum* L.) at I, II and III fruit pickings. Values represent means of three replicates $\pm$ standard error (SE).

After nitrogen phosphorus is a limiting nutrient for plant growth P inputs are also needed for crop production and in present study in addition of wastewater different levels of phosphorus with constant dose of nitrogen and potassium were also applied because nutrient supply only through wastewater is not sufficient for crop production and generally farmers use high levels of chemical fertilizers and pesticides, for higher production of vegetables [50]. Yield of the vegetables (tomato and cabbage) also increases with phosphorus application of soil [51-52]. Phosphorus limits vegetable growth because of its highly immobile nature in soil and shallow rooting characteristics of vegetables. Phosphorus directly enhanced metabolic processes and fruit set [53] and its availability at proper stage of plant growth also promoted flowering [54]. In short season crops, like vegetables growth responses to applied P may persist up to harvest. Thus irrigation through wastewater up to close to harvest could have ensured its availability and improved the growth and development which ultimately led to higher yield (Fig. 4&5). After N and P third essential nutrient K play significant role in stomatal opening and closing [55]. During photosynthetic phosphorylation guard cell produce abundant ATP under light condition that increases the uptake of K^+ with sufficient energy that create high turgor pressure that causes the opening of stomata [56], in addition it contribute up to 6% of plant dry weight [57] and also considered as a key factor for fruit quality [58].

The presence of the other essential nutrient like calcium plays a key role in plant growth and fruit development and it is involved in many biochemical and physiological processes [59]. It is an essential component of the cell wall is involved in the cell division [60]. Sulphur also played a vital role in plant metabolism as its deficiency is common [61], it is important to note here that the application of nitrogen in the form of urea is ineffective unless sulphur is applied simultaneously and its deficiency decreases the leaf area [62] besides decreasing the chlorophyll content [63]. Cl^- is also one of the essential nutrient present in wastewater could played an important role in stomatal regulation while Na^+ is not essential and has been placed in the beneficial elements for plants, its presence may be stimulated the growth that is mainly caused by its effect on cell expansion and also on the water balance of plants. In the present experiment enhanced growth (Fig. 1), physiological (Fig. 2 & 3) and yield characteristics (Fig. 4 & 5) under P_{40} were also observed, while wastewater with a comparatively lower phosphorus dose P_{20} proved beneficial. Better performance of chilli crop under higher phosphorus dose was explained on the basis of vital role of phosphorus in metabolic processes and stimulation of various enzymes, which lead higher leaf area and number provide much surface area for photosynthesis and produce much more photosynthate that finally gave higher yield. Wastewater with lower phosphorus dose proved beneficial because wastewater contains additional phosphate.

4. CONCLUSION

The results obtained from the pot experiment aimed to evaluating the use of wastewater for the cultivation of chilli especially near urban areas where it is easily and cheaply available. Four levels of phosphorus supplement were also applied for the comparison with the unfertilized treatments. The wastewater proved an effective source of essential nutrients and even it could not be supplemented the whole nutrient requirement of the crop but it can reduced the quantity of fertilizers because wastewater also a source of nutrients. Finally the wastewater irrigation in combination with lower phosphorus dose proved optimum and gave result statistically similar with GW along with higher phosphorus dose. Thus wastewater reuse as a source of irrigation water and nutrient can effectively fill the increasing gap between water demand and water availability up to some extent.

REFERENCES

1. Singh KK, Mishra LC. Effects of fertilizer factory effluents on soil and crop productivity. *Water & Soil Pollut.* 1997;33(14): 309-320.
2. Srivastava RK. Effect of paper mill effluent on seed germination and early growth performance of radish and onion. *J. Ecotoxicol. Environ. Monit.* 1991;1(1):13-18.
3. Hari OS, Nepal MS, Aryo, Singh N. Combined effect of waste of distillery and sugar mill on seed germination, seeding growth and biomass of okra. *Journal of Environmental Biology.* 1994;3(15):171-175.
4. Rusan MJM, Hinnawi S, Rousan L. Long term effect of wastewater irrigation of forage crops on soil and plant quality parameters. *Desalination.* 2007;215:143–152.
5. Akhtar A, Inam A. Response of mustard and linseed to thermal power plant wastewater supplemented with nitrogen and phosphorus. *African Journal of Plant Sciences.* 2008;2(8):67–71.
6. Marschner H. *Mineral Nutrition of Higher plants.* 3rd Ed. Academic Press, London. 2002.
7. Hopkins WG, Huner NPA. *Introduction of Plant Physiology.* 4th Ed. Printed in the United State of America; 1995.
8. Hendrix PF, Crossley DA, Blair JM, Coleman DC. Soil biota as components of sustainable ecosystems. In: *Sustainable agricultural systems.* pp. 637-654. C.A. Edwards, R. Lal, P. Madden, R.H. Miller and G. Haise (eds.), Ankeny, IO: Soil and water conservation society; 1990.
9. Singh DK, Jain, SK. Interaction effect of nitrogen and phosphorus on yield and economics of chilli (*Capsicum annum* L.), cv. Pant C-1. Department of Vegetable Science, College of Agriculture, G. B. Pant University of Agriculture & Technology, Pantnagar - 263 148, India. *Scientific Horticulture.* 2004;9:97-100.
10. Khan MSI, Roy SS, Pall KK. Nitrogen and Phosphorus Efficiency on the Growth and Yield Attributes of *Capsicum*. *Academic journal of Plant Sciences.* 2010; 3(2):71-78.
11. Hasan R. Phosphorus fertility status of soils in India. In: *Phosphorus Researches in India, Potash and phosphate of Canada-India Programme, Gurgaon, Haryana;* 1994.
12. Bahl GS, Singh NT. Phosphorus diffusion in soil in relation to some edaphic factors and its influence on P up-take by maize and wheat. *J. Agric. Sci. Camb.* 1986;107(2):335–341.

13. Jaggi RC, Suri VK, Dixit SP. Comparative performance of sulphur containing and non-containing phosphorus fertilizers on dry chilli (*Capsicum annuum*) in acid Alfisol. Indian J. Agric. Sci. 2003;73(1):49–50
14. Tanwar SPS. Shaktawat MS. Influence of phosphorus sources, levels and solubilizers on yield, quality and nutrient up-take of soybean (*Glycine max*) -Wheat (*Triticum aestivum*) cropping system in southern Rajasthan. Indian J. Agric. Sci.2003;73(): 3–7.
15. Richards JF, Graham PH, Eichorn BM. Effect of super phosphate and nitrogen on yield of wheat. New Zealand J. Crop Hort.1985;11:103–8.
16. APHA. Standard Methods for the Examination of Water and Wastewater. 20th Ed. American Public Health Association, Washington, DC. 1998.
17. Ghosh AB, Bajaj JC, Hasan R, Singh D. Soil and Water Testing Methods: A laboratory manual. Indian Agricultural Research Institute (IARI), New Delhi; 1983.
18. Jaworski EG. Nitrate reductase assay in intact plant tissue. Biophys. Res. Comm. 1971;43(6):1274-1279.
19. Dwivedi RN, Randhawa NS. Evaluation of rapid test for hidden hunger of zinc in plants. Plant Soil. 1974;40(2):445-451.
20. Lindner RC. Rapid analytical methods for some of the more inorganic constituents of plant tissues. Plant Physiol. 1944;19(1):76-89.
21. Mac-Kinney YGG. Absorption of light of chlorophyll solutions. J. Biol. Chem. 1941;140:315-322.
22. Sadasivam S, Manickham A. Biochemical Methods for Agricultural Sciences. Wiely Estern Ltd., Madras. 1992
23. Gomez KA, Gomez AA. Statistical procedure for Agricultural Research. Wiley, New York; 1984.
24. FAO. Food production: Critical role of water. Tech-nical background paper, World Food Summit, Rome: Food and Agricultural Organisation; 1996.
25. Cameron KC, Di HJ, Anwar MR, Russell MJ, Barnett JW. The "critical" ESP value: does it change with land application of dairy factory effluent? New Zeal. J. Agr. Res. 2003;46(2):147-154.
26. Corwin DL, Lesch SM. Application of soil EC to precision agriculture: theory, principles, and guidelines. Agron. J. 2003;95(3):455–471.
27. Vazquez-Montiel O, Horan NJ, Mara, DD. Management of domestic wastewater for reuse in irrigation. Water Sci. Tech. 1996;33(10-11):355-362.
28. Saviozzi A, Biasci A, Riffaldi F, and Levi-Minzi R. Long-term effects of farmyard manure and sewage sludge on some soil biochemical characteristics. Biol. Fertil. Soils. 1999;30(1-2):100–106.
29. Aggelides SM, Londra PA. Effect of compost produced from town wastes and sewage sludge on the physical properties of a loamy and clay soil. Biores. Techno. 2000;71(3):253–259.

30. Benitez E, Romero M, Gomez M, Gallardolaro F, Nogales R. Biosolid and biosolid ash as sources of heavy metals in plant-soil system. *Water Air Soil Pollut.* 2001;132(1-2):75-87.
31. Jenkins, CR, Papadopoulos I, Stylianou Y. Pathogens and wastewater use of irrigation in Cyprus. In: *Proceeding of Int. Conf. on Land and Water.* Valenzano, Bari, Italy. 1994:4-8 Sep.
32. Erfani A, Haghnia A, Alizadeh A. Effect of irrigation with sewage on yield and quality of lettuce and some soil characteristics. *J. Sci. Technol. Agric. Natu. Resour.* 2002;6(1):71-90.
33. Makki A, Dhoub A, Sayadi S. Changes in microbial and soil properties following amendment with treated and untreated olive mill wastewater. *Microbiol. Res.* 2006;161(2):93-101.
34. Gori R, Ferrini F, Nicese FP, Lubello C. Effect of reclaimed wastewater on the growth and nutrient content of three landscape shrubs. *J. Environ. Hortic.* 2002;18(2):108-114.
35. Tak HI, Inam A, Inam A. Effect of urban wastewater on growth, photosynthesis and yield of chickpea under different levels of nitrogen. *Urban water journal.* 2010;7(3):187-195.
36. Jabeen S, Sexena PK. Effect of industrial effluent on growth behaviour of *Pisum sativum*. *Geobios.* 1990;17(5-6):197-201.
37. Giri AM. Effect of pulp and peper mill effluent on germination, growth, biochemical parameters and bioaccumulation of heavy metal in *Pisum sativum*. *Res. Environ. Life Sci.* 2008;1(2):61-64.
38. Medhi UJ, Talukdar AK, Deka S. Impact of paper mill effluent on growth and development of certain agricultural crops. *J. Environ., Biol.* 2011;32(2):185-188.
39. Tak HI, Ahmad F, Babalola OO, Inam A. Growth, photosynthesis and yield of chickpea as influenced by urban wastewater and different levels of phosphorus. *Int. J. Plant Res.* 2012;2(2):6–13.
40. Akhter N, Inam A, Inam A, Khan NA. Effect of city wastewater on the characteristics of wheat with varying doses of nitrogen, phosphorus and potassium. *Resent research in science and technology.* 2012;4(5):18-29.
41. Iqbal S, Inam A, Inam A, Sahay S, Chalkoo S. Balance use of inorganic fertilizers on chilli (*Capsicum annuum* L.) irrigated with wastewater. *Biosciences International.* 2012;1(3):82-89.
42. Sahay S, Inam A, Iqbal S. Effect of wastewater irrigation on soil, metal tolerance and its remediation by four oil yielding Brassica cultivars. *International journal of environmental sciences.* 2013;4(2):158-170.
43. Kirkby EA. Plant growth in relation to nitrogen supply. In *terrestrial nitrogen cycles. Processes, Ecosystem Strategies and management impacts*, Eds. Clarke FE, Rosswell T. 1981:249-267. *Ecol. Bull. Stockholm* 33, Swedish Natural Science Research Council (NFR) Stockholm.
44. Vanlauwe B, Palm CA, Murwira HK, Merckx R. Organic resource management in sub-Saharan Africa: Validation of a residue quality-driven decision support system. *Agronomie.* 2002;22:839–846.
45. Taylor G, McDonald AJS, Stadenberg I, Freer-Smith PH. Nitrate supply and the biophysics of leaf growth in *Salix viminalis*. *J. Exp. Bot.* 1993;44(258):155–164.

46. Gastal F, Lemaire G. N uptake and distribution in crops: An agronomical and ecophysiological perspective. *J. Exp. Bot.* 2002;53(370):789–799.
47. Lemaire G. Ecophysiology of grassland: Dynamic aspects of forage plant population in grazed swards. In *Proceedings of the XIX International Grassland Congress, Brazil*, pp. 29–37. São Paulo: SBZ. 2001.
48. Terashima I, Evans JR. Effects of light and nitrogen nutrition on the organisation of the photosynthetic apparatus in spinach. *Plant Cell Physiol.* 1988;29(1):143–155.
49. Moorby J, Besford RT. Mineral nutrition and growth, In: A. Lauchli, and R.L. Bielecki, (Eds.), *Encyclopedia of plant physiology*. 15B: New York: Springer Verlag. 1983:481-527.
50. Shrestha RK, Ladha JK. Nitrate in groundwater and integration of nitrogen-catch crop in rice-sweet pepper cropping system. *Soil Sci Soc Am J.* 1998;62:1610–1619
51. Blatt CR, McRae KB. Effect of irrigation and nitrogen, phosphorus and potassium rate and placement on tomato fruit yield and size. *Can J Soil Sci.* 1986;66:653–660.
52. Peck NH, MacDonald GE, Hemmat M. Cabbage plant responses to residual phosphorus and potassium in the soil and to band applied concentrated superphosphate and potassium chloride fertilizers. *Agron J.* 1987;79(5):831–837.
53. Memon KM. Soil and fertilizer phosphorus. In: Bashie, E. (ed.) *Soil Science*. pp. 292–3. National Book Foundation, Pakistan, 2002.
54. Brady NC, Weil RR. Soil phosphorus and potassium. In: *The Nature and Properties of Soils*. 13th Ed. pp. 592–4; Pearson Education Inc., India; 2002.
55. Fischer RA, Hsiao TC. Stomatal opening in isolated epidermal strips of *Vicia faba*. II. Responses to KCl concentration and the role of potassium adsorption. *J. Plant Physiol.* 1968;43(12):1953-1958.
56. Humble GD, Hsiao TC. Light dependent in-flux and efflux of potassium of guard cells during stomatal opening and closing. *Plant Physiol.* 1970;46(3):483-487.
57. Shabala S. Regulation of potassium transport in leaves: from molecular to tissue level. *Ann Bot.* 2003;92(5):627-634.
58. Hartz TK, Miyao G, Mullen RJ, Cahn MD, Valencia J, Brittan KL. Potassium requirements for maximum yield and fruit quality of processing tomato. *Better crops.* 1999;83(2):26-28.
59. Saure, M.C. Calcium translocation to fleshy fruit: its mechanism and endogenous control. *Sci Hortic.* 2005;105(1):65-89.
60. Schmit JN. Le calcium dans le cellule generation en mitose. Etude dans le tueur pollinique en germination du *clivia nobilis* Lindl (Amaryllidaceae) C. R. Acad. Sci. Ser. (III) higher plants. Academic Press, London. 1981.
61. Murphy MD, Boggan JM. Sulphur deficiency in herbage in Ireland. I. Causes and extent. *Irish J. Agric. Res.* 1988;27(1):83–90.

- 549 **62.** Wang CH, Liem TH, Mikkelsen DS. Sulphur deficiency: A limiting factor in rice production in the
550 lower Amazon basin. II. Sulphur requirement for rice production. IRI Res. Inst. 1976:48:38.
- 551 **63.** Deitz KJ. Recovery of spinach leaves from sulphur and phosphate deficiency. Plant Physiol. 1989:134,
552 551–557.

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557