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Growth, Physiological and Yield attributes of Chickpea as Influenced by Thermal Power Plant Wastewater, Coal Fly Ash and Different Levels of Phosphorus

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Abstract

The use of wastewater in agriculture is an unavoidable. In order to evaluate its effect on agricultural crops, an experiment was conducted to study its impact on *Cicer arietinum* L. along with different levels of phophorus. Thermal power plant wastewater (TPPW) and ground water (GW) were used for irrigation along with varying levels of phosphorus (P0, P_{10}, P_{20}, P_{30} and P_{40}) with the basal application of nitrogen and potassium at the rate of 10 and 20 kg ha^{-1} respectively. Fly ash at the rate of 10 kg ha^{-1} (FA_{10}) was amended with soil to make the soil nutrient rich as fly ash can provide various nutrients. The effect was evaluated on the basis of growth, biochemical attributes and yield of the crop. From the results it was clear that the wastewater (TPPW) proved not only effective source of water but the nutrients also. Enhanced growth led to the better yield of the plants. Moreover the fertilizer (P) requirement of the crop was also reduced. In conclusion wastewater and fly ash (FA_{10}) showed no inhibitory effect on the growth of the crop and thus could effectively supplement not only the nutrient requirement of the crop but may also act as the source of water.

Keywords Wastewater, fly ash, Phosphorus, Yield and Chickpea.

INTRODUCTION

Pulses occupy a unique position in every known systems of farming all over the world. Among pulses chickpea (*Cicer arietinum* L.), the premier pulse crop of India, popularly known as Gram or Bengal gram is mainly grown in rabi season. It is the member of family Leguminaceae and sub family Papilionaceae. Chickpea is a rich source of highly digestible dietary protein (17-21%), carbohydrate (61.5%) and fat (4.5%). It is also rich in Ca, Fe, niacin, vitamin-B and vitamin C. Its leaves contain malic acid which is very useful for stomach ailments and blood purification. It being a pulse crop enriches the soil through symbiotic nitrogen fixation (1). The supply of phosphorus to legumes is more important than of nitrogen because, later being fixed by symbiosis with rhizobium bacteria. The beneficial effects of phosphorus on nodulation, growth, yield and general behaviour of legume crop have been well established because it plays an important role in root development. Phosphorus application to legumes plays a key role in the formation of energy rich phosphate bonds, phospholipids and for development of root system and nitrogen fixation (2). Recent researches revealed that there is a good response of chickpea to phosphorus fertilizer (3). If the phosphate availability from the soil is limited, the growth and nitrogen fixation are affected (4).

Exploding population growth, industrialization and urbanization (5 & 6) posed declination of fresh water, on one hand, and the production of huge volume of wastewater day by day, very fast, throughout the world, on the other hand. This is creating a pressure on farmers to adopt their farming with wastewater irrigation, as they are unaware of the pollution of air, water and land and that the cost of treatment of wastewater is too high in developing countries including India. However, in this context, using of wastewater for agriculture practices is a potential solution to reduce fresh water demand and a feasible option of various nutrients, which are believed to have a positive effect on soil properties and crop production in a sustainable way. But, it is the necessity of the present era to think about the existing wastewater disposal infrastructure, wastewater agriculture practices, quality of water used and awareness related to pollution issues. The important references in the aspect of use of wastewater come from fourteenth and fifteenth centuries in the Milanese Marcites and in the Valencian huertas, respectively (7). It is still continued in practices and has gained interest worldwide due to it being rich in essential nutritive plant elements, especially in N, P and K in addition to Na, Ca, Mg, S, Cl, Cu, Fe, B, Zn, salts, pH, and organic matter. Wastewater irrigation is now quite common in many countries like Europe, the USA, Mexico, Australia, China, Chile, Peru, Egypt, Lebanon, Morocco, Vietnam, South Africa and India, where it has been used as a source of crop nutrients and concluded that the use of wastewater in agriculture irrigation responds to multiple benefits: solving the problem of disposal, minimizing the risk of high demand for clean drinking water, reducing the direct input and need of high amounts of inorganic fertilizers and improving soil with its fertile quality (8). Further, it encountered the food demand, as it consequently permits higher yield of various range of field crops, including vegetables as compared to clean water irrigation (9, 10, 11 & 12). Another waste, fly ash (solid waste), is defined as an end by-product produced after coal combustion at high temperature in thermal power stations. Like water scarcity and increased food demand, the energy/power crisis is one of the considered factors in India. In order to meet the energy demand, use of coal as the prime energy source, calls for burning in large amount, leading to the generation of large amount of this solid waste product. It has been expected that the production of fly ash will likely exceed up to 225 million tons in the next two years, i.e. by 2017 (13). However, the utilization percentage of fly ash in India is still very low, especially in the agriculture sectors. But the use has increased substantially year wise (14). Fly ash due to its efficacy in modification of soil's physical and chemical health has been reported with great potency to improve crop productivity in Indian agriculture. As a matter of fact, fly ash practically consists of all the essential elements present in the soil except very low amount of organic carbon and nitrogen, if any. Thus, its utilization would not only be a solution of disposal but might also reduce the inorganic fertilizers, especially non-nitrogenous (15).

Considering vital importance of chickpea and disposal problem of wastewater (TPPW) and coal fly ash (FA) a five pot experiment was conducted to assess the effect of TPPW, fly ash and P on growth parameters, yield attributes and yield of chickpea.

MATERIALS AND METHODS

A five pot experiment was conducted during the rabi (winter) season of the year 2001 on chickpea cultivar BG-256, to strengthen the findings of earlier experiment (1999 and 2000) with inorganic fertilizer doses. Here again the comparative effect of TPPW and GW was studied. On the basis of observations made during 1999 and 2000, the best concentration of fly ash i.e. 10% and nitrogen at the rate 10 Kg ha^{-1} were selected. Fly ash (FA_{10}) was added to the soil, making the final weight of fly ash amended soil up to 7kg ha^{-1}. Different doses of phosphorus i.e. 0, 10, 20, 30 and 40kg ha^{-1} were supplemented in order to work out the optimum dose for cultivar BG-256. A uniform basal dose of nitrogen and potassium at the rate of 10 Kg ha^{-1} and 20kg ha^{-1} were also applied, respectively before sowing. Healthy seeds of more or less uniform size were surface sterilized and then inoculated (16). Before irrigation the water samples were again collected and analysed for physico-chemical characteristics (17). The soil/fly ash samples were collected before the start of the experiment. These samples were also analysed for standard physico-chemical properties (18, 19, 20, 21, 22, 23 & 24). Observations were carried out at vegetative, flowering, fruiting and at harvest stages. For the study of the root, the plants were uprooted carefully and washed gently to clear all the adhering particles. For assessing dry weight, three plants form each treatment were dried, after taking their fresh weight, in hot air oven at 80ºC for two days and weighed. The area of leaves was measured using leaf area meter (*LA 211*, *Systronics*, *India*). For nodule number, whole plant was uprooted with the precaution that the roots or the nodules may not be damaged. Samples were washed gently to wipe away all the adhering foreign particles and the number was carefully counted.

NRA and chlorophyll were estimated (25 & 26). Healthy leaves were collected at different samplings stages for the estimation of N, P (27 &28) and K contents. Potassium was estimated with the help of flame photometer. Ten millilitres of aliquot was taken and K was read using the filter for potassium. A blank was also run side by side with each set of determinations. The readings were compared with a calibration curve plotted against known dilutions of standard potassium chloride solution. At harvest, yield attributes including seeds per pod, pods per plant, 100-seed weight, and seed yield per plant were noted and protein content (29) in the seeds was measured. The data for the growth and yield of each experiment were analysed statistically taking into consideration the variables (30). The 'F' test was applied to assess the significance of data at 5% level of probability ($p \leq 0.05$). The error due to replication was also determined.

Table 1. Chemical characteristics of soil and fly ash before sowing. All determinations in mg l^{-1} in 1: 5 (soil-water extract) or as specified.

Soil		Fly ash	
Determinations	Year 2001	Determinations	Year 2001
Texture	Sandy loam	CEC (meq $100g^{-1}$ fly ash)	9.37
CEC (meq $100g^{-1}$ soil)	3.24	pH	8.50
pH	8.10	Organic carbon (%)	1.59
Organic carbon (%)	0.803	EC (µ mhos cm^{-1})	1101.00
EC (µ mhos cm^{-1})	373.00	NO^{-}_{3}–N (g kg^{-1} fly ash)	0.03
NO^{-}_{3}–N (g kg^{-1} soil)	0.303	Phosphorus (g kg^{-1} fly ash)	2.03
Phosphorus (g kg^{-1} soil)	0.127	Potassium	15.00
Potassium	18.00	Calcium	18.61
Calcium	28.37	Magnesium	16.73
Magnesium	15.29	Sodium	13.21
Sodium	12.63	Carbonate	11.24
Carbonate	20.16	Bicarbonate	66.19
Bicarbonate	97.35	Sulphate	24.21
Sulphate	17.42	Chloride	17.17
Chloride	38.29		

Table 2. Chemical characteristics of ground water (GW) and thermal power plant wastewater (TPPW). All determinations in mg l^{-1} or as specified.

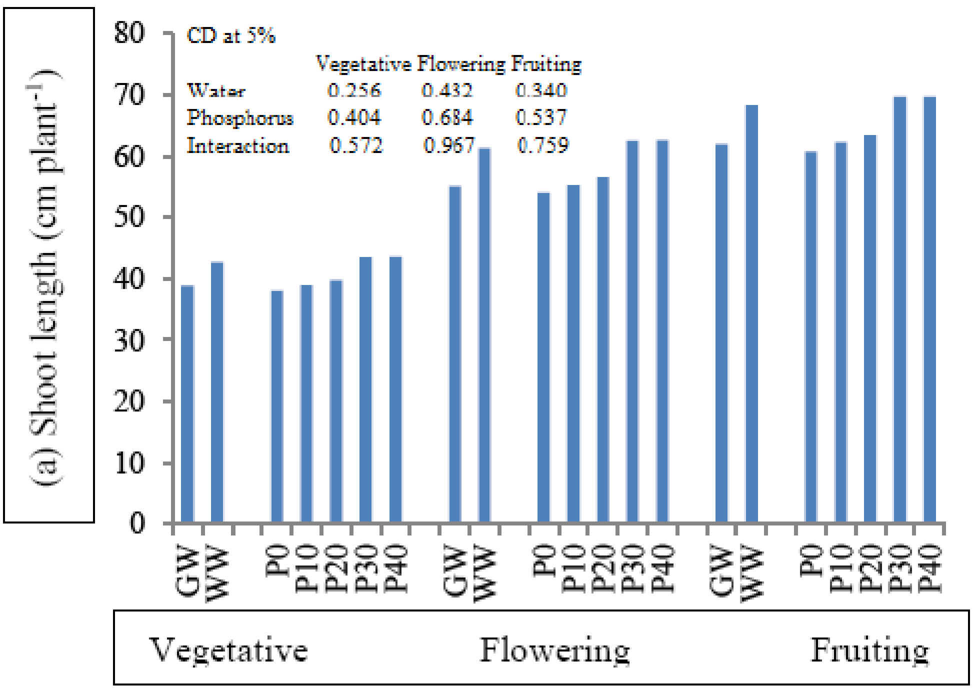
Determinations	2001			
	Sampling I		Sampling II	
	GW	WW	GW	WW
Ph	7.8	8.2	7.6	8.3
EC (µ mhos cm^{-1})	770	800	730	850
TS	913	1328	927	1324
TDS	515	639	552	689
TSS	417	682	410	711
BOD	17.22	68.18	16.04	55.78
COD	35.18	134.24	36.20	119.82
Mg	18.36	27.17	17.35	28.21
Ca	25.21	44.19	24.37	42.34
K	8.06	16.13	8.20	16.29
Na	17.36	44.39	17.21	42.19
HCO_3^-	61	91	58	87
CO_3	19	52	20	41
Cl^-	75.31	105.34	74.18	108.19
PO_4	0.69	1.12	0.72	1.19
NO_3–N	0.73	1.04	0.77	1.03
NH_3–N	2.57	5.81	2.64	5.64
SO_4	47	66	49	68

RESULTS AND DISCUSSION

The wastewater contained considerable amount of nutrients which are considered essential for maintaining the soil fertility as well as for enhancing the plant growth and productivity. Wastewater in general proved beneficial in increasing the plant growth characteristics and dry matter accumulation was higher in plants receiving it as a source of irrigation water compared to those receiving ground water (GW).

TPPW increased dry mater as compared to GW used. This is primarily due to the retention of the WW components mainly due the incorporation of the elements in the dry matter of plants (31) leading to decreasing concentration in the surrounding ground and surface waters. Wastewater contained nitrogen in both nitrate (NO^{3-}) as well as in the form of ammonia (NH^{4+}) and as the vegetative growth includes formation of new leaves, stems and roots, the involvement of N through protein metabolism controls them. This was also clearly indicated by the observed enhanced growth and N content in the leaves under the wastewater irrigation (Fig. 1-6). Suitability of NH^{4+} or NO^{3-} for the growth and development of plants depends upon many factors (32). However, normally the highest growth rate and plant yield are obtained by combined supply of both and therefore, in the present study, the improvement in growth could be due to the cumulative effect of ammonium as well as nitrate ions together (33, 34 & 31). Therefore, observed nutritional superiority of the wastewater (containing both ammonium-N and nitrate-N) for growth of chickpea was not exceptional and possibly explains the reason of better performance of the crop grown under WW irrigation. Another possible explanation of the increased dry matter is possibly because of the increased leaf area and expansion (Fig. 2b) brought about by N supply (Taylor *et al.* (35) and Gastal and Lemaire (36) which may be through its effect on cell division and cell expansion (37). Besides nitrogen, phosphorus when supplied in limiting amounts has much greater impact on growth than on photosynthesis and has been reported in sugarbeet (38). During the present study better growth and yield of plants were observed receiving wastewater having considerable amount of P (Table 2) in addition to other nutrients. The observation of the improved performance of the crop receiving it as a source of irrigation water was therefore, understandable. Although it further needs emphasis that application of phosphorus has its limitations as “P” when applied to the soil is very rapidly changed to less soluble form and therefore, becomes less and less available with time. Therefore, irrigation through wastewater up to close to harvest could have ensured its availability and thus might have improved the growth and development which ultimately led to higher seed productivity (Fig. 7b). Similarily “K” is known to play a significant role in stomatal opening and closing (39). It is well known that N is fully utilized for crop production only when K is adequate (40). The presence of K is almost double the amount in wastewater than in groundwater (Table 2), therefore, benefited the treated crop not only due to its own physiological role (41) but also by enhancing the effect of N. While it increased the chlorophyll content of alfalfa leaves and also the CO_2 exchange rate on plant^{-1} basis (42), it is not surprising that this nutrient (along with Mg) improved the chlorophyll content in the present study also (Fig. 5b). This was also strengthened by the presence of higher N in the leaves of the plants receiving the wastewater (Fig. 6a). On the other hand presence of other essential nutrient like sulphur could have also played a vital role in plant metabolism as its deficiency is common (43). It may be pointed out that the application of nitrogen in the form of urea is ineffective unless sulphur is applied simultaneously and its deficiency reduces the leaf area (44), chlorophyll contents (45). Moreover in sulphur deficient plants, not only the protein content decreases but also the sulphur content in the proteins indicating that the proteins with lower proportions of methionine and cysteine but higher proportion of other amino acids such as arginine and aspartate are synthesized (46) and the lower sulphur content of the proteins influences the nutritional quality considerably(47). Although in the present study, quality of the protein was not worked out but the total protein was significantly enhanced in the wastewater irrigated plants (Fig. 4). Similarly, the presence of Ca^{2+} and Mg^{2+} (Table 2) could have further added the benefits as Ca^{2+} being an essential component of cell wall is involved in the cell division (48) while Mg^{2+} is a central atom of chlorophyll and is required for structural integrity of chloroplast (49). It may be pointed out that the chlorophyll content was enhanced in plants grown under wastewater (Fig. 5b) indicating the possible involvement of Mg^{2+} in addition to other nutrients. Similarly, the presence of Cl^{-}, one of the essential micronutrients, could also have played an important role in stomatal regulation (50). The observed enhanced growth and development ultimately led to increase in 100 seed weight (Fig. 7a) because of the ensured supply and availability of above mentioned nutrients might have played a cumulative role in enhancing the metabolic activities and finally the seed yield and protein content (Fig. 7c). In the present study 10% fly ash was taken along with varying doses of phosphorus. From the five doses of phosphorus, P_{30} when supplied with wastewater and fly ash (FA_{10}) proved optimum for growth as well as yield. It has been supported that fly ash can increase the soil fertility by improving its texture (51) and water holding capacity (52), thereby affecting the plant growth indirectly. Its most important direct role is to correct the nutrient balance in the medium (53) as some of the naturally existing essential nutrients enrich it (54 & 55). It is known to be source of B (56), Ca (57), Cu (58), K (59), Mg (53), Mo (60), S (61) and Zn (62). Expectedly, it was due to the presence of these essential elements in our fly ash samples (Table 1) that supplemented those supplied by the soil and wastewater. However, the benefit of fly ash proved only of limited nature. Nodulation was also increased on adding fly ash (10%). It may be noted that high doses of fly ash added to the soil decrease the microbial activity due to change in soil salinity or concentrations of potentially toxic elements (63). This could not only delay nodulation but also cause a decrease in their number as noted by Martensson and Witter (64). Although fly ash contained an extremely small amount of nitrogen, an increase in NRA was observed because of the presence of Mo (60) in fly ash and sufficient quality of available nitrogen in the soil (Table 1) might have accelerated the rate of NR activity. Increase in seed protein content was observed due to the pressure of additional P and K in fly ash may be responsible for it. This has also been reported by Bhaisare *et al*. (65), Khan *et al*. (66), MiLovsky (67), Sriramachandrasekharan (68).

Growth and yield of chickpea responded favourably to P application. It has to be kept in mind that plant factors as well as soil factors have great influence over the utilization of this indispensable nutrient. Its effect on leaf area enhancement has been reported by Rao and Subramanian (69) in cowpea and by Reddy *et al*. (70) in groundnut. Similarly, increase in branch number has been noted due to P application in chickpea by Parihar (71), in dry matter accumulation by Khokar and Warsi (72), in nodule number and nodule dry weight by Idris *et al*. (73) as well as Singh and Ram (74) and in seed yield by Parihar (71). Legumes show an evident preference for phosphatic fertilizers (75). In the present study, P_{30} proved optimum for most of the growth, yield (Fig. 1-7) and physiological parameters (Fig. 5). As mentioned earlier, the enhanced leaf area (Fig. 2b) enabled the plants to produce more photosynthates and dry matter (Fig. 1c, 3c & 4c) and also more pods (Fig. 7a). These observations are pertinent, as P is known to facilitate the partitioning of photosynthates between source and sink (76). It has been observed earlier that dinitrogen fixation by *Rhizobium* is enhanced if the plants are supplied P along with K (77, 78 & 79). It has been further reported that P fertilization especially on N and P deficient soils, enhanced nodule development by increasing nodule number, dry weight and nodule growth rate. In the present study, the observed increase in nodulation due to P application (Fig. 4) was through its role in the proliferation of roots which provided larger surface area as indicated by higher root dry weight (Fig. 3c) of the P-treated plants. This favourable response regarding dry matter accumulation was probably due to increased production of photosynthates in the shoot and its transfer to root. This assumption is strengthened by the observed increase in leaf area (Fig. 2b) and shoots dry weight (Fig. 1c). In our study, P_{30}, a dose comparatively lower than that recommended for chickpea, seems to have become sufficient probably due to the presence of additional P especially in wastewater and to a lesser extent in fly ash. It may be pointed out that P is often limiting nutrient due to its low availability in comparison to K which is not only easily recycled from organic residues but is also readily available from the fertilizers applied to the soil. Hence, the ameliorating roles played by the P present in wastewater and fly ash. A deficiency of N, on the other hand, is largely compensated in the legume corps through nitrogen fixation. Therefore, the quality of P fertilizer to be applied to such crops is critically important as the amount of available P often declines with time. Therefore, the regular supply of P, through wastewater application, proved effective and useful as mentioned above. P also increased leaf N content but it remained ineffective in increasing leaf P level. Such observations of enhanced N concentration due to P fertilization in tropical legumes were also reported by Shaw *et al*. (80), Andrews and Robins (81) and Dradu (82). Higher nodulation due to P application might have increased the N content in leaf through more efficient nitrogen fixation, followed by that of K, thus indirectly enhancing the growth performance of the corp. The application of P also proved beneficial for seed protein content (Fig. 7c) due to its assured availability and continuous utilization by carbon skeletons for amino acid synthesis as well as that of energy rich ATP and manifesting this in enhanced protein synthesis in the seeds. Being a part of the protein molecules enhanced N levels in leaves due to the application of P (Fig. 6a) might have triggered and maintained the conversion of various organic acids (produced from carbohydrates during respiration) into amino acids. The known role of K (also present in sufficient quantity) in activating various enzymes involved in protein synthesis (83 & 84). The ameliorative effect of nutrients present in the applied wastewater and fly ash, together with the N and P applied as fertilizers, was pronounced when interaction was considered. On defining interaction, Russell (85) states that if two factors are limiting or nearly limiting growth, adding only one of them will have little effect, while adding both together will have a very considerable effect. In the context of crop plants, two such factors show a positive interaction if the response of the crop to both together is larger than the sum of responses to each separately. In this context, mention may be made of the work conducted by Bouldin and Sample (86 & 87) who observed that such a positive interaction was also due to the increased solubility of P because of close association of the two fertilizers applied as sources of N and P. Similarly Kilcher *et al*. (88) observed that N dose had little effect on yield increases while the combination of N and P increased the yield in forages. Similarly, Black (89) observed that N and P together increased the forage yields in wheat grass and no yield increase was observed under P alone. It may be emphasized that wastewater and fly ash supplemented these nutrients thereby proving economically efficacious on the one hand and environmentally acceptable on the other. To conclude, the addition of P in combination with other inputs (TPPW × FA_{10} × N_{10} × P_{30}) significantly increased growth, yield (Fig. 1-7) and nodulation in chickpea cv. BG-256 which ultimately led to higher pod number, heavier seeds (7a) and higher seed protein content (Table 65). This improvement was due to the combined effect of N and P applied to the soil together with the nutrients present in wastewater and fly ash, confirming their suitability as a combined source of irrigation water and nutrients (Table 2). These findings thus provide a positive conclusion with regard to the objectives of the present study. Therefore, for the cultivation of chickpea, basal application of 10 kg fly ash ha^{-1}, 10 kg N ha^{-1} and 30 kg P ha^{-1} may be recommended under TPPW irrigation. Finally, TPPW and fly ash, which are by all means waste product of Thermal Power Plant, may be profitably utilized for agriculture purpose.



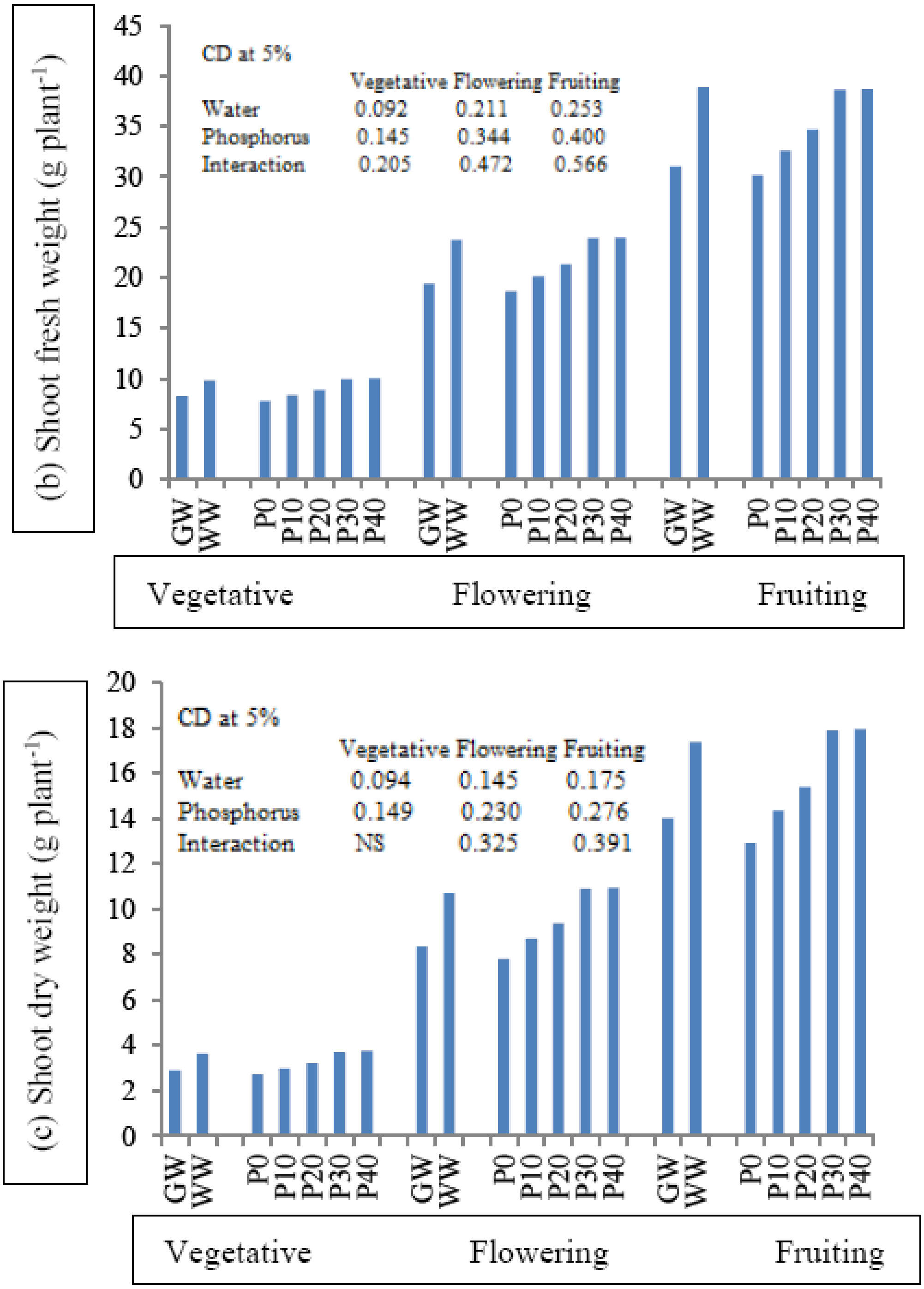
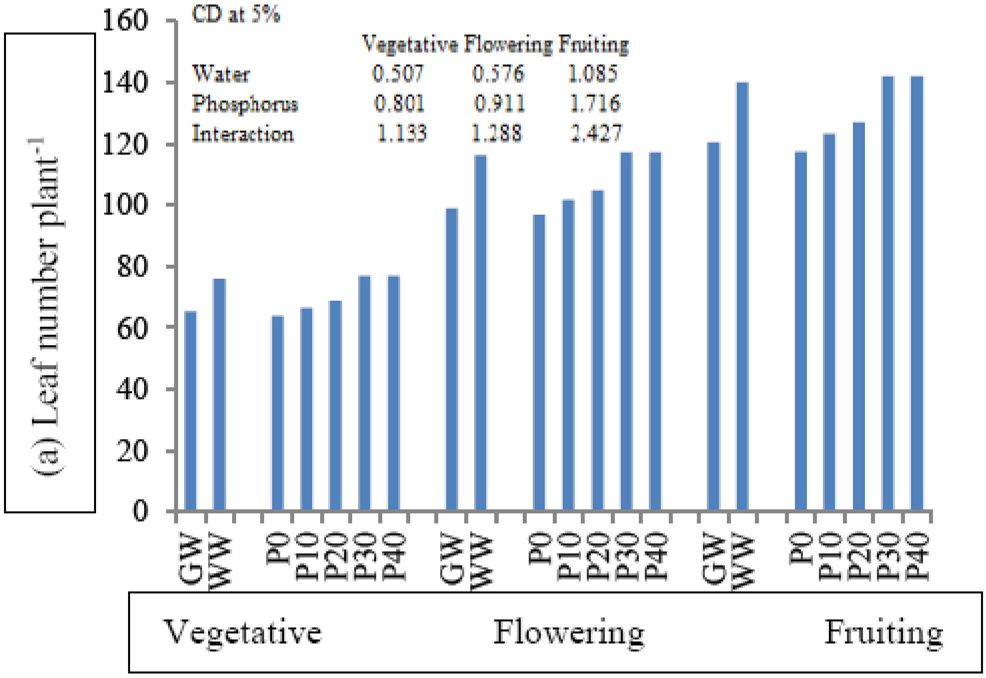
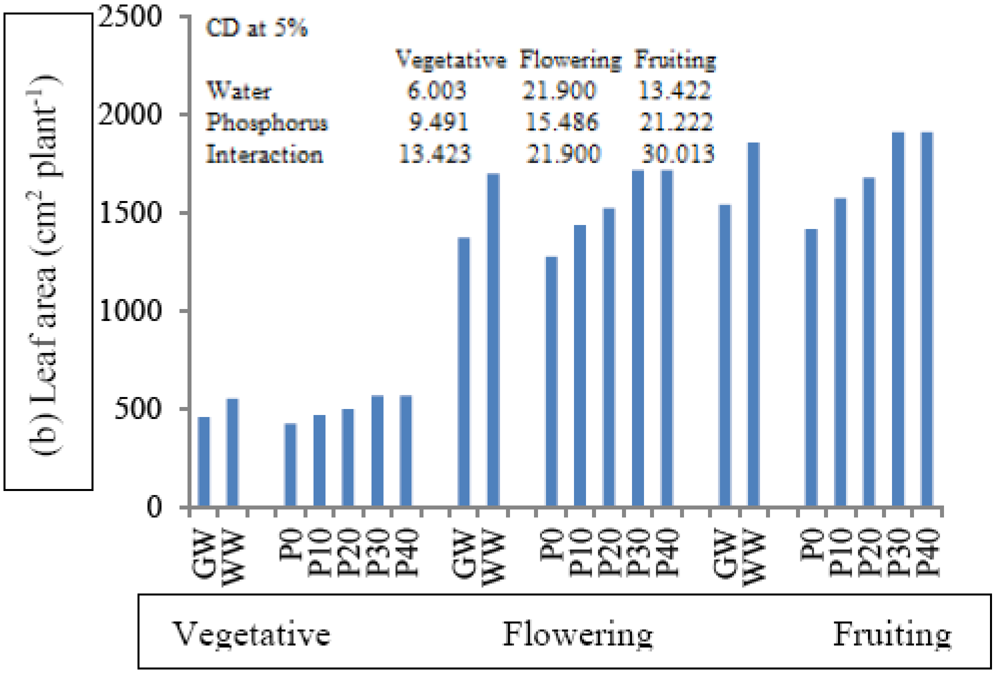


Figure 1. Effect of wastewater and phosphorus on chickpea cv. BG-256


(a) Leaf number plant-1
CD at 5%
Vegetative Flowering Fruiting
Water 0.507 0.576 1.085
Phosphorus 0.801 0.911 1.716
Interaction 1.133 1.288 2.427
160
140
120
100
80
60
40
20
0
GW
WW
P0
P10
P20
P30
P40
Vegetative
Flowering
Fruiting


(b) Leaf area (cm2 plant-1)
CD at 5%
Vegetative Flowering Fruiting
Water 6.003 21.900 13.422
Phosphorus 9.491 15.486 21.222
Interaction 13.423 21.900 30.013
2500
2000
1500
1000
500
0
GW
WW
P0
P10
P20
P30
P40
Vegetative
Flowering
Fruiting

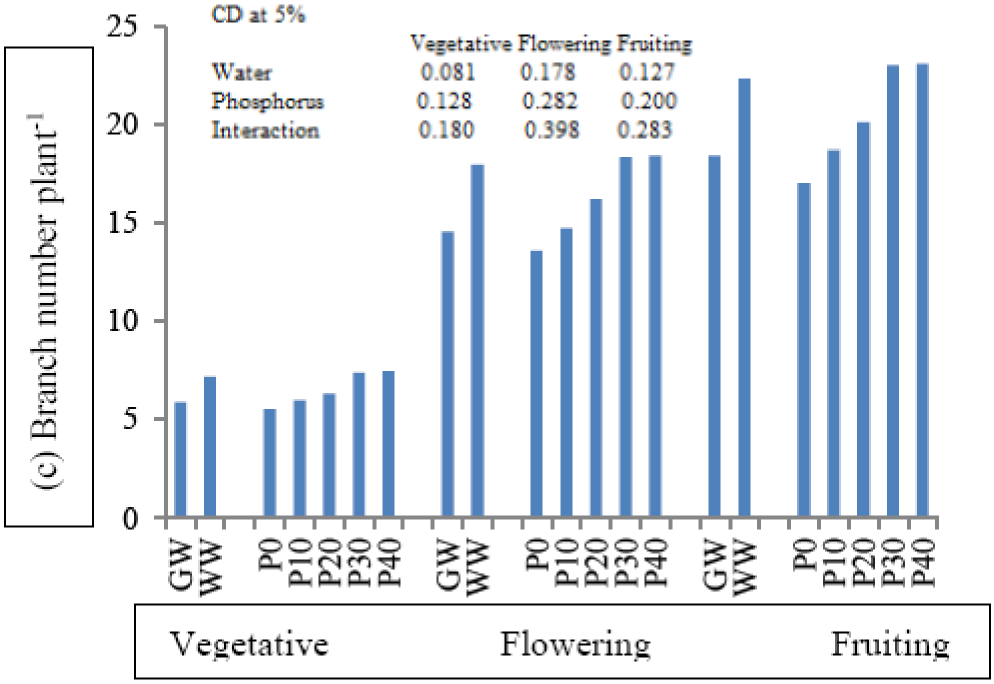


Figure 2. Effect of wastewater and phosphorus on chickpea cv. BG-256

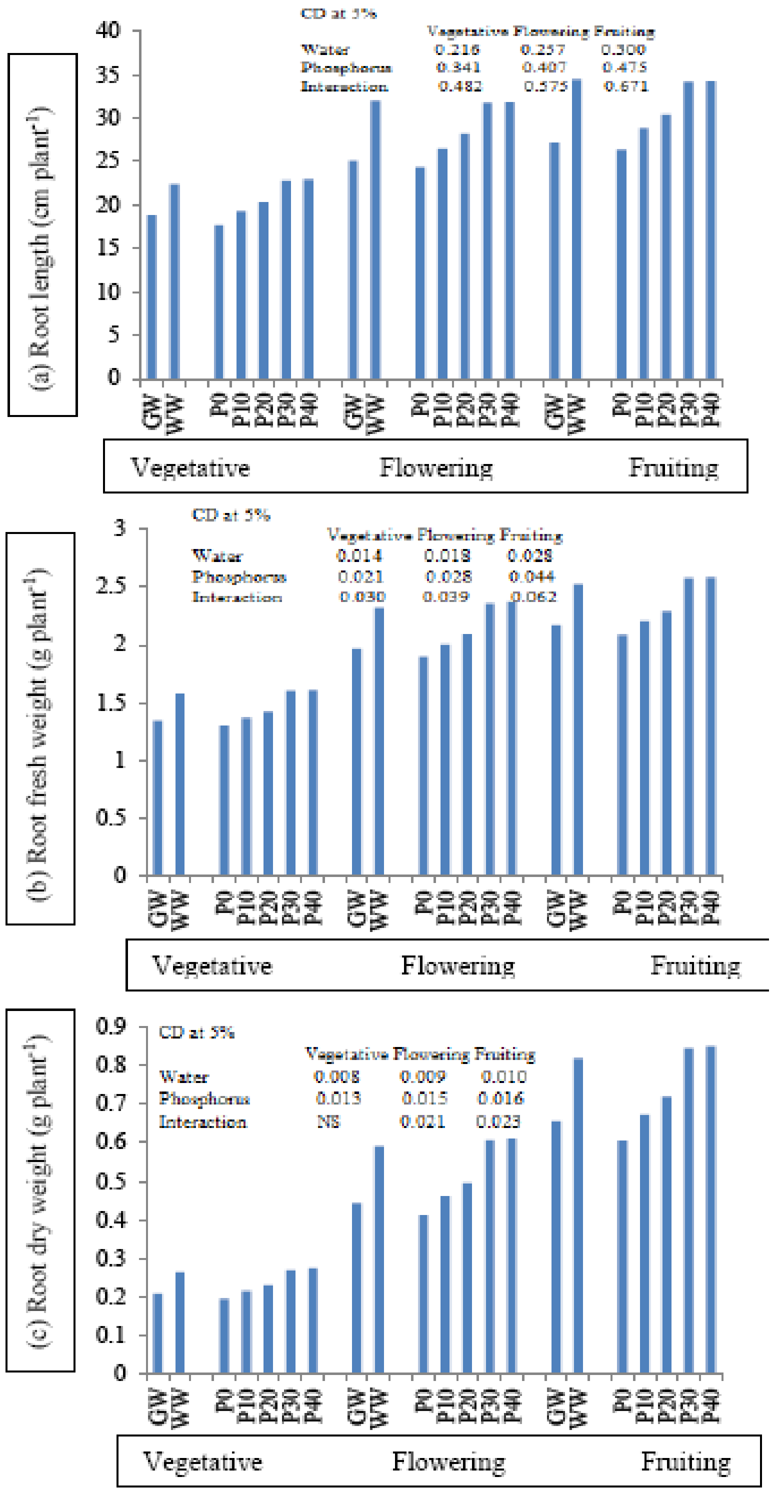


Figure 3. Effect of wastewater and phosphorus on chickpea cv. BG-256

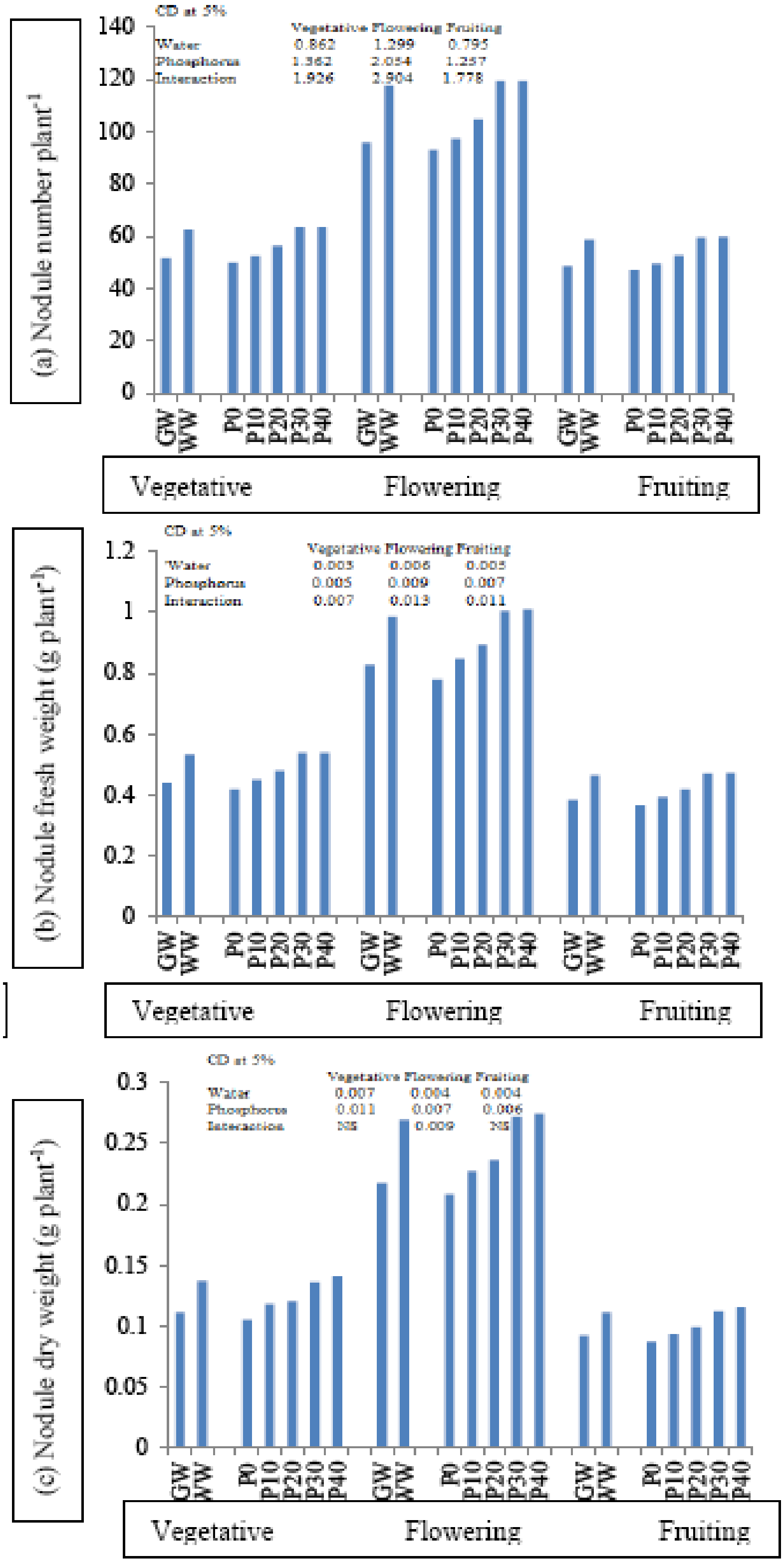


Figure 4. Effect of wastewater and phosphorus on chickpea cv. BG-256

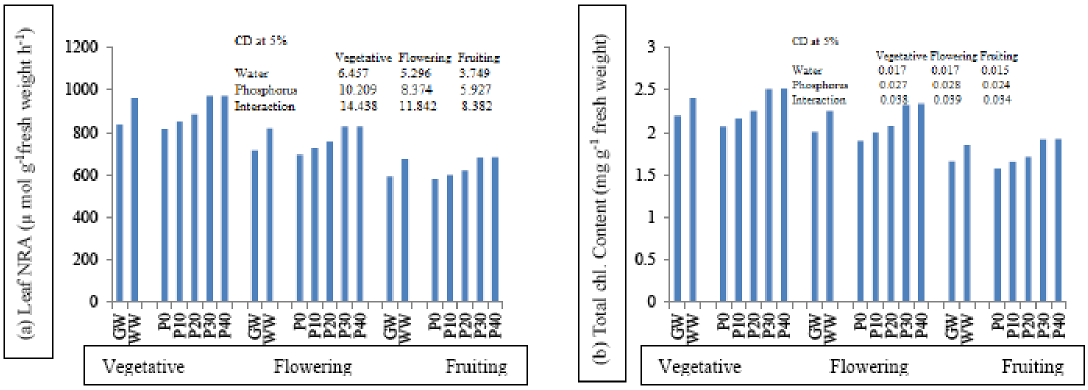
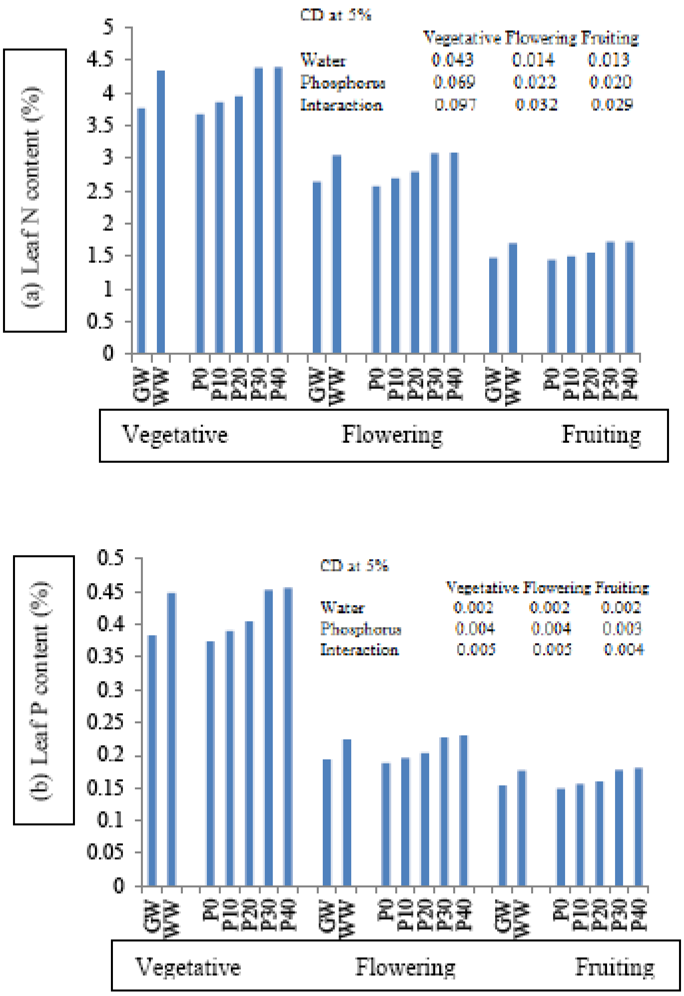


Figure 5. Effect of wastewater and phosphorus on chickpea cv. BG-256



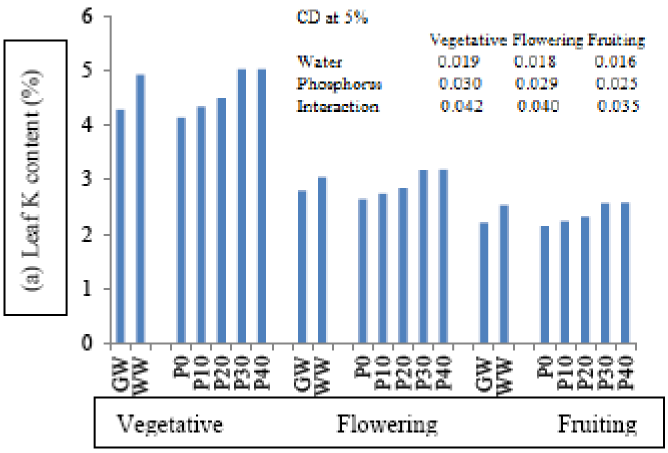
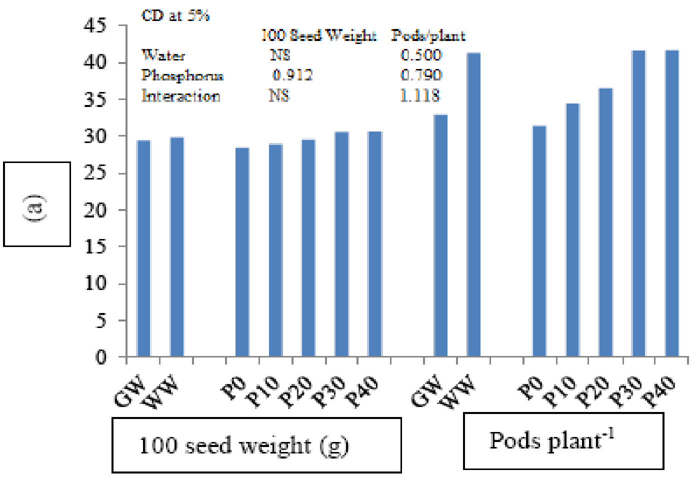
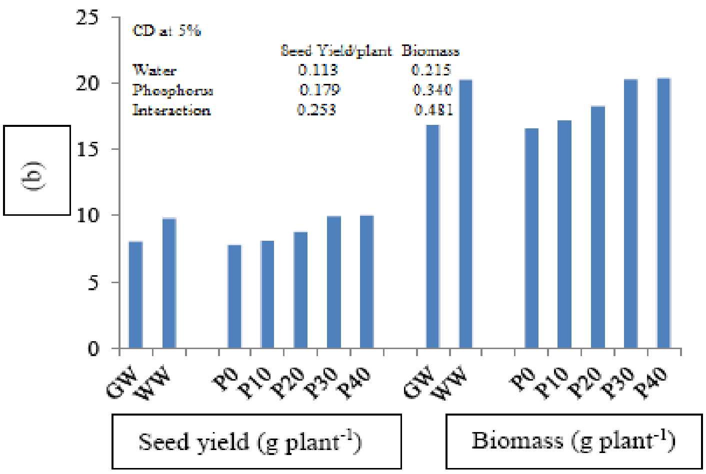


Figure 6. Effect of wastewater and phosphorus on chickpea cv. BG-256





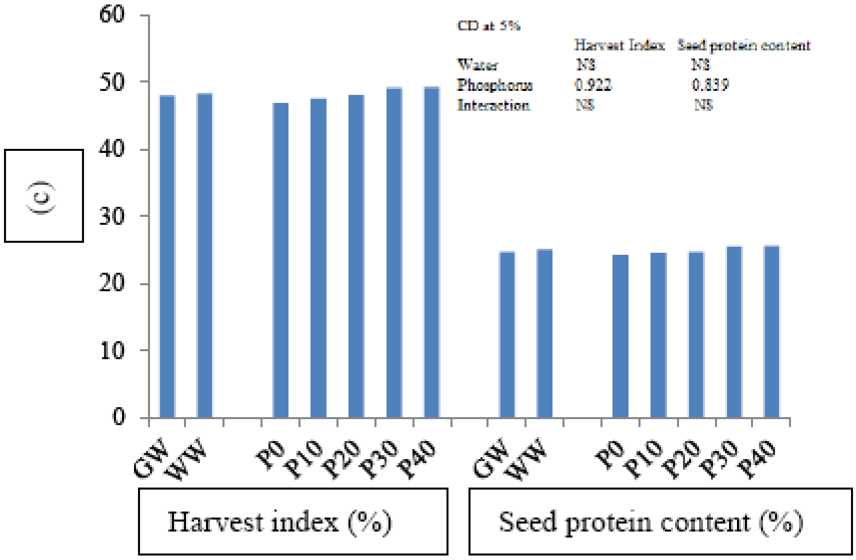


Figure 7. Effect of wastewater and phosphorus on chickpea cv. BG-256

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