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Utilisation of Thermal Plant Wastewater and Coal Fly Ash to Improve Growth and Yield of Chickpea *(Cicer Arietinum L.)*

Irfan Ahmad

Department of Biotechnology,
Dr B R Ambedkar National Institute of Technology,
Jalandhar, Punjab, India

Abstract

In recent decades, recycling or safe disposal of solid industrial wastes has become a prime environmental concern throughout the world; and, fly ash (FA) is major amongst them. As a coal combustion residue, FA is generated in large amounts by the thermal power plants. In India alone, more than 112 million tons of FA is generated annually, and the production is projected to exceed 170 million tons per year, by the year 2015. Normally, the bulk of the FA was dumped in landfills of open lands by dry and wet methods; but stringent environmental regulations are continuously enhancing the cost of these types of disposal. Hence, many potential applications have been identified for the utilization and management of FA such as its use in cement, concrete, bricks, wood substitute products, soil stabilization, road base/embankments and consolidation of ground, land reclamation, and as soil amendments in agricultural fields. Therefore, an experiment was performed to assess the impact of thermal power plant wastewater (TPWW), generated during dumping of FA, and fly ash (as soil amendment) in earthen pots on growth, physiological and yield responses of *Cicer arietinum* L. Four different doses of FA amendments i.e. 0, 10, 20 and 40% were taken. Uniform dose of NPK fertilizers were applied and the seeds were sown. Growth and yield of chickpea were found to be increased under Thermal power plant wastewater and fly ash application. Fly ash (10%) showed better response as compared to control i.e. FA_0 whereas, FA_{20} and FA_{40} proved deleterious for chickpea.

Keywords: Fly ash, thermal power plant wastewater, chickpea, growth and yield.

INTRODUCTION

Water and plant nutrients, among others inputs, are the two most important factors for normal growth of any crop. The former, being the most abundant molecular species in plants, is also a carrier of nutrients. Since India is a monsoon-dependent land and the bulk of rainfall is confined to a brief period only, a large part of the country remains deficient in water supply for a greater part of the year. A situation therefore arises when most Indian farmers have no option but to grow their crops totally under rain fed conditions. Depletion of groundwater reserves at a faster rate, coupled with the problem of water pollution, has created a new challenge of providing sufficient water for agricultural production and even for our daily use. At the same time, the need to increase food production to feed the hungry mouths of the ever-increasing population is also growing. In many arid and semi-arid countries around the world, water is becoming an increasingly scarce resource and this has forced scientists to consider alternate sources of water which might be used economically and effectively. Despite concerns over water shortages, irresponsible overuse and misuse of water continue unabated even in water-starved countries. Therefore there is an urgent need to conserve and protect fresh water by the reuse of water (1). The re-use of wastewater in agriculture is gaining wider acceptance in many parts of the world. It represents an agronomic option that is increasingly being investigated and taken up in regions with water scarcity, growing urban populations, and rising demand for irrigation water (2 and 3). Its application might ensure the transfer of fertilizing elements, such as nitrogen (N), phosphorous (P), potassium (K), organic matter, and meso-nutrients and micro-nutrients, into agricultural soil (4). Hence, wastewater nutrients can contribute to crop growth.

A few also make indiscriminate and unscientific use of municipal or industrial wastewater, including thermal power plant wastewater (TPPW), which is easily available due to growing urbanization and industrialization. One such source of water in India is based on 89 coal fired thermal power plants of 100 MW or higher capacity, generating about 66,860 MW electricity day^{-1}. These burns about 65% of the total coal produced in India and simultaneously discharge huge quantities of water as well as fly ash (FA). Both are rich in a variety of beneficial as well as toxic elements, including N, P, K, Ca, Mg, SO_4^{2-}, Cl^-, B, Mo, Se and Sr (5, 6). It is noteworthy that efforts made to modify the properties of low grade agricultural soil by adding FA have proved encouraging in improving soil fertility and crop yield. Thus, it has been observed that FA not only improves the water holding capacity of some sandy soils (7 and 8) but also augments their capacity for providing some essential nutrients (9). Admittedly, being phytotoxic as well as deficient, especially in N, the utility of FA in agriculture is limited. This could, however, be enhanced by blending it with sludge or by irrigating the crop with water containing this essential nutrient. Interestingly, plants that are N_2 fixers can tolerate comparatively high salinity and B toxicity and, therefore, are successful colonizers under these poor soil conditions. Such limited utilization of FA alone for a limited number of crops including N_2 fixing legumes, is known. So is that of TPPW. It also helps at least partly, in solving the problem of their disposal. In addition, it also decreases the total dependence of our farmers upon chemical fertilizers whose indiscriminate use in the last century from the sixties onward due to Government of India sponsored subsidies and attraction of higher productivity for short term economic gains has created serious problem of nutrient pollution.

In view of the known beneficial role of wastewater and of FA separately in augmenting crop productivity and for helping the disposal management of the two waste products and keeping the importance of pulses in mind, an experiment was conducted on chickpea, a popular N_2 fixing pulse crop, to show that it could be grown profitably using minimal inputs by judiciously substituting them with the two waste products of TPP, namely fly ash (FA) and waste water (TPPW).

Therefore, a pot experiment was conducted in the year 1999 to compare the effect of TPPW and ground water (GW) on chickpea (*Cicer arietinum* L.) cv. BG-256 under four levels of FA application.

MATERIALS AND METHODS

To achieve the aim, five pot experiment was performed in the net house of Environmental Plant Physiology, Department of Botany, Aligarh Muslim University, Aligarh, during the rabi (winter) season of 1999. TPPW was collected from the outlet of the leachate reservoir of Harduaganj Thermal Power Plant, Kasimpur, located 13km away from Aligarh city, whereas tap water was the source of GW. Fly ash was also collected from the fly ash pond of the same thermal power plant. Each pot received 500ml water on alternate days for the duration of about 125 days starting from 10^{th} day after sowing (DAS) i.e. after seedling emergence. Four different concentrations of fly ash as 0, 10, 20 and 40% were thoroughly mixed with soil making the total of soil/fly ash weight up to 7kg pot^{-1}. The control consists of only soil without fly ash. Uniform starter basal dose of nitrogen (20kg ha^{-1}), phosphorus (20kg ha^{-1}) and potassium (20kg ha^{-1}) was also applied before sowing. The sources of NPK were urea, single super phosphate (SSP) and muriate of potash (MoP) respectively.

Seeds were procured from Indian Agricultural Research Institute (IARI), New Delhi and viable *Rhizobium* culture (*Rhizobium sp*.) specific for chickpea was also obtained from IARI, New Delhi. Healthy seeds were surface sterilized with absolute alcohol and dried in shade before applying the inoculum (10). For this, 200g colourless gum Arabic (coating material) and 50g sugar were dissolved in 500ml warm water. The solution was allowed to cool and 100g *Rhizobium* culture was properly mixed. Required quantity of seeds was mixed with inoculum and spread in a clean tray to let the coating get dried in shade. Before irrigation the water samples were collected and analyzed for physico-chemical characteristics adopting the procedures outlined in the standard methods (11). The soil/flyash samples were collected before the start of the experiment. These samples were also analyzed for standard physico-chemical properties (12, 13, 14, 15, 16, 17 and 18).

For investigating the comparative effect of TPPW, GW and fly ash under inoculated conditions, 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 (19 and 20). Healthy leaves were collected at different samplings stages for the estimation of N, P and K contents (21 and 22). Potassium was estimated with the help of flame photometer. Ten milliliters 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 (23) in the seeds was measured.

The data for the growth and yield of each experiment were analysed statistically taking into consideration the variables (24). 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		Determinations	
Texture	Sandy loam	CEC (meq $100g^{-1}$ fly ash)	9.20
CEC (meq $100g^{-1}$ soil)	2.78	pH	8.70
pH	7.6	Organic carbon (%)	1.42
Organic carbon (%)	0.382	EC (µ mhos cm^{-1})	990.00
EC (µ mhos cm^{-1})	226.00	NO^-_3–N (g kg^{-1} fly ash)	0.02
NO^-_3–N (g kg^{-1} soil)	0.217	Phosphorus (g kg^{-1} fly ash)	2.13
Phosphorus (g kg^{-1} soil)	0.109	Potassium	13.00
Potassium	16.00	Calcium	21.24
Calcium	32.37	Magnesium	16.37

Magnesium	18.66	Sodium	13.29
Sodium	11.01	Carbonate	12.37
Carbonate	19.65	Bicarbonate	51.86
Bicarbonate	62.17	Sulphate	26.13
Sulphate	16.34	Chloride	19.71
Chloride	22.43		

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

Determinations	1999			
	Sampling I		Sampling II	
	GW	WW	GW	WW
Ph	7.6	7.7	7.8	8.3
EC (µ mhos cm^{-1})	750	930	720	930
TS	934	1281	917	1314
TDS	519	622	504	630
TSS	423	674	431	687
BOD	17.28	70.34	16.16	68.29
COD	40.24	129.37	38.31	120.17
Mg	18.83	26.24	16.58	25.19
Ca	26.21	42.31	25.39	43.17
K	8.34	17.29	8.09	18.36
Na	16.30	47.20	16.11	48.34
HCO_3^-	62	90	60	86
CO_3	18	37	19	35
Cl^-	72.48	104.18	68.37	100.24
PO_4	0.73	1.15	0.65	1.04
NO_3–N	0.80	1.04	0.78	1.10
NH_3–N	2.58	5.27	2.41	5.22
SO_4	49	75	51	70

RESULTS AND DISCUSSION

A perusal of the results clearly indicates that irrespective of all other inputs, chickpea performed better when irrigated at regular intervals with wastewater than with groundwater. Obviously, it could be due to optimum growth and development of this crop under wastewater. Let us, therefore, consider the presence of three major essential macronutrients, viz. N, P and K, in addition to S, Ca, Mg and Cl (Table 2) could have played an important role in this ameliorating effect. N is the single most important element limiting plant growth and is invariably required in large quantities deserves special consideration in this regard. As vegetative growth includes the formation of new leaves, stems and roots, the involvement of N through protein metabolism controls the growth (Fig 1-6). It may also be added that, on application to soil, most of the non-organic forms of N remain readily available for uptake, during vegetative plant growth. In comparison, only about 5-75% of the organic forms is commonly mineralized and that too in about one year after application (25). This lends support to the above observation of the suitability of wastewater as a good source of this nutrient. Another aspect that requires consideration here is the fact that both NH_4^+–N and NO_3^-–N were present in wastewater, the former being about five times more than the latter (Table 2). It is noteworthy that applied NH_4^+–N is toxic for some higher plants, including bean and pea (26 and 27). However, in the presence of NO_3^-–N, it has been reported to benefit sunflower (28), wheat (29) and chickpea (30). The observed nutritional superiority of wastewater (containing both NH_4^+–N and NO_3^-–N) for growth of chickpea in our study is thus not exceptional. Similarly, the presence of additional P in wastewater might have primarily influenced root growth (Fig. 3). It is known that for the effective use of P, various factors operate together, such as rooting pattern, length of crop growth, soil characteristics including pH as well as dose and source of P, in addition to the presence of water. Since wastewater was one source of irrigation and was comparatively richer than the other source (GW) by about 58%, the observation of improved performance of the crop under wastewater is understandable. It is all the more noteworthy because application of phosphate fertilizers was its limitation as P fertilizer applied to the soil are very rapidly changed to less soluble forms and, therefore, become less and less available with time (31). Admittedly in short season crops, like some vegetables, growth responses to applied P may persist up to harvest. However, long season crops, like corn and chickpea, show only early growth responses and comparatively much lesser effect at seed formation and maturity. Frequent wastewater application until this late stage, therefore, enhanced P availability to the crop and ultimately lead to higher seed productivity (Fig 7b) in chickpea. It is well known that N is fully utilized for crop production only when K is adequate (32 and 1). 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 (33) 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 (34), it is not surprising that this nutrient (along with Mg) improved the chlorophyll content in the present study also (Fig 5b).

The presence of higher NPK contents in leaves (Fig 6) grown under wastewater led to increase 100 seed weight (Fig 7a) and seed yield (Fig 7b). In addition to N, P and K, presence of S also improves growth and N fixation (35). Therefore, in our study S as well as Ca and Cl present in wastewater (Table 2) might have contributed further towards enhanced growth and led to the promotion of the crop's yield. It may be pointed out that yield potential is the yield of a crop grown in an environment to which it is adapted and is provided with sufficient nutrients and water, in addition to other stresses being effectively controlled. Thus, considerable yield increases are possible by improving one or more physiological or morphological traits of crop, which in turn are dependent upon the availability of essential nutrients (36). Obviously, all these were provided by the wastewater.

Nodule number and nodule fresh weight, as well dry weight, was increased under wastewater. With the increased amount of nutrients in the medium, roots had a better chance to exploit them. This could not only result in increased root proliferation but also nodulation. Franco (37) has cited several authors who obtained increased nodulation and N_2 fixation in legumes by utilizing optimum amounts of N in the medium. Similarly, frequent supply of additional P and K in the wastewater also play an important role in enhancing nodulation (38). Moreover, the importance of K for tropical legumes, especially in N_2 fixation by increasing either nodulation or nodule productivity (39) further strengthens our assertion. Add to it the role of Ca (Table 2) in symbiotic N_2 fixation (40 and 41) and the picture becomes brighter.

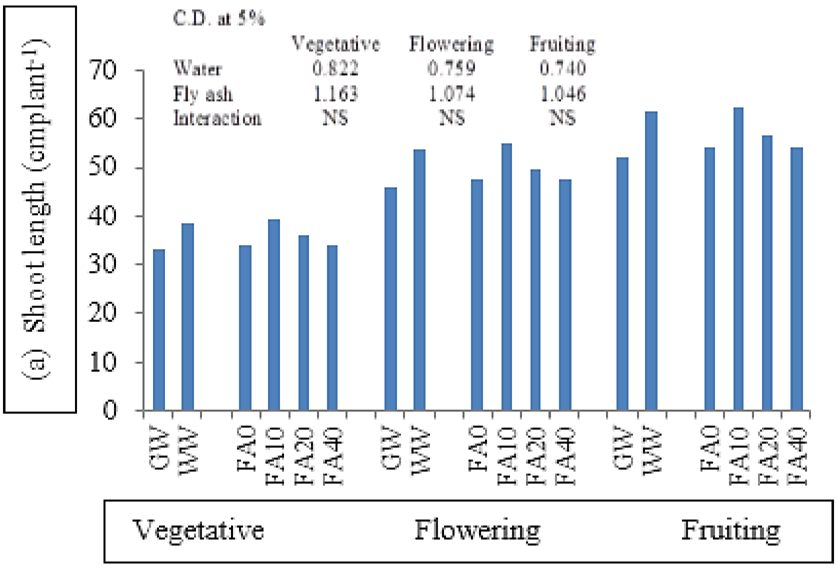
Increase in NRA was observed throughout the course of study. The presence of nitrate-nitrogen in the irrigation wastewater (TPPW) as recorded in Table 2 could be mainly responsible for it. NR is a substrate-dependent enzyme (42 and 43). After absorption by roots the N was translocated to leaves (Fig 6), which is a major site for its reduction. NRA seems to be indirectly affected by the presence of P in wastewater. P is involved in phosphorylation and diversion simple sugars towards respiration as a result of which oxidation of photosynthates produces more reducing power subsequently for nitrate-mediated NO_3^- reduction. In comparison to N and P, K is proved to be an activator of many enzymes including NR (44). The data reveals that protein content of seeds of the plants grown with wastewater was at par with the seed protein content of those grown under GW. This was also observed earlier at Aligarh by Aziz *et al*. (45) while working with petrochemical refinery wastewater. The reason may be traced to the "dilution factor". Seed yield was increased apparently due to enhanced seed production in wastewater treated plants. Thus, the tendency to cross the level of significance was nullified by the dilution effect. To confirm this assertion, the seed yield obtained with wastewater was computed with seed protein percentage which showed a marginal increase in protein yield plant^{-1} over the ground water-irrigated plants. However, it may be inferred that wastewater has neither deleterious nor beneficial effect on seed quality. This may still be considered as a plus point for wastewater irrigation of chickpea.

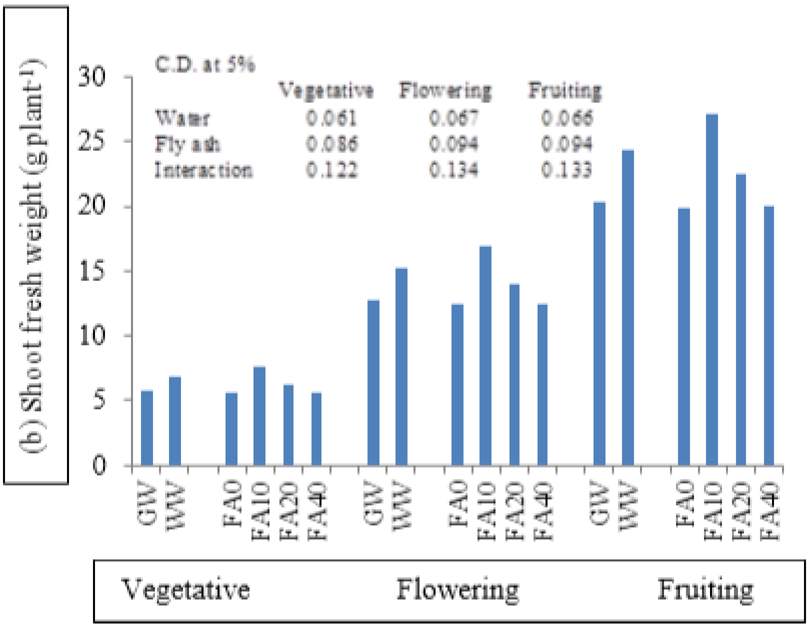
In the experiment shoot length (Fig 1a), shoot fresh weight (Fig 1b) and dry weight (Fig 1c), root length (Fig 3a) and root fresh weight (Fig 3b) and dry weight (Fig 3c) increased progressively up to the fruiting stage which is a common phenomenon among various cereals and pulses. Considering nodule formation and growth, nodule number (Fig 4a), nodule fresh weight (Fig 4b) and dry weight (Fig 4c) was noted to increase only up to the flowering stage and decreased thereafter. It may be due to the fact that initially the competition for photosynthates was confined to roots, nodules and aerial vegetative organs, but when flowering and fruiting started, these new sinks might have provided more demanding sites for the photosynthates, thus creating shortage for the nodules as a result of which their degradation set in. It is noteworthy that chlorophyll and NRA also decreased with increasing age of the plants, comparatively more slowly from vegetative to flowering stage and more sharply from flowering to fruiting stage. This may be attributed to the mobilization of organic and inorganic substances to sink. The concomitant increase in leaf area would thus result in further dilution. This confirms that the density of the photosynthetic pigments (chlorophylls) and the enzymes (NR) unit^{-1} leaf area becomes lesser and lesser with advancing age (46, 47 and 48). Among the three major nutrients (N, P and K), assayed in leaves, K content was highest (Fig 6c), followed by that of N (Fig 6a) and P (Fig 6b) in that order. For higher plants K is the only essential monovalent cation among the macro-nutrients and generally it is also the most abundant cation in plant tissues (49). Further, like chlorophyll and NRA, leaf N, P and K contents also decreased with increase in age of the plants. A rapid decline in leaf K concentration has been reported (50) with maturity in forage legume herbage. Similarly, decline in leaf P concentration with growth was observed in six tropical grasses (51). They were of the opinion that this decline was due to the dilution factor because of increased growth and/or redistribution of these nutrients to younger plant parts. Like P and K, the observed decreased in N was due to exponential increase in growth (weight and volume) due to which any increase in nutrient concentrations is nullified and even higher quantities of nutrients appear to be less when expressed on unit^{-1} basis (52). In addition, the translocation of nutrients to sinks (seeds) during their formation could also be responsible for such observations.

Considering the effect of fly ash on growth and yield parameters, including seed significant increase due to 10% fly ash (FA10) application was noticed, higher levels being less effective (Figs. 1-7). It has been supported that fly ash can increase the soil fertility by improving its texture (53) and water holding capacity (54), thereby affecting the plant growth indirectly. Its most important direct role is to correct the nutrient balance in the medium (9) as some of the naturally existing essential nutrients enrich it (55 and 56). It is known to be source of B (57), Ca (58), Cu (59), K (60), Mg (9), Mo (61), S (62) and Zn (63). 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 as noted above. The decrease in yield was probably due to increased levels of sulphate, chloride, carbonate and bicarbonates (Table 1). Some toxic compounds i.e. dibenzofuran and dibenzo-p-dioxine mixture (64 and 65) and elements like Ni, As, Cd, Cr, Pb, Se, Zn, Cu (66) were reported to occur in fly ash might have also contributed towards the lesser yield under higher fly ash concentrations. Detrimental effect of higher levels of fly ash on plants has also been reported earlier due to either the phytotoxicity of B (67) or a shift in the chemical equilibrium of the soil (68).

Nodulation, like growth and yield, was increased on adding fly ash albeit up to a limited level (10%). More than 10% amendment decreased it due to variation in pH. At higher levels, toxic amounts of soluble salts released from fly ash seem to affect roots and rhizosphere adversely. It may also be added 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 (68). This could not only delay nodulation but also cause a decrease in their number as noted (69). NRA and leaf N, P and K were also decreased by higher doses of fly ash. Although fly ash contained an extremely small amount of nitrogen, an increase in NRA by its application was observed in the present study. The presence of Mo (61) in fly ash and sufficient quality of available nitrogen in the soil (Table 1) might have accelerated the rate of NR activity. Considering the increase in seed protein content due to the application of fly ash (Fig 7c) the pressure of additional P and K in it may be responsible for it. This has also been reported (70, 71, 72 and 73). Similarly, due to phytotoxicity of some heavy metals and conversion of some trace elements like Mo and B into some inorganic complexes availability of nutrients including NPK was adversely affected under high levels of fly ash (74).

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} may be recommended under TPPW irrigation. Finally, TPPW and fly ash, which is by all means waste product of Thermal Power Plant, may be profitably utilized for agriculture purpose.





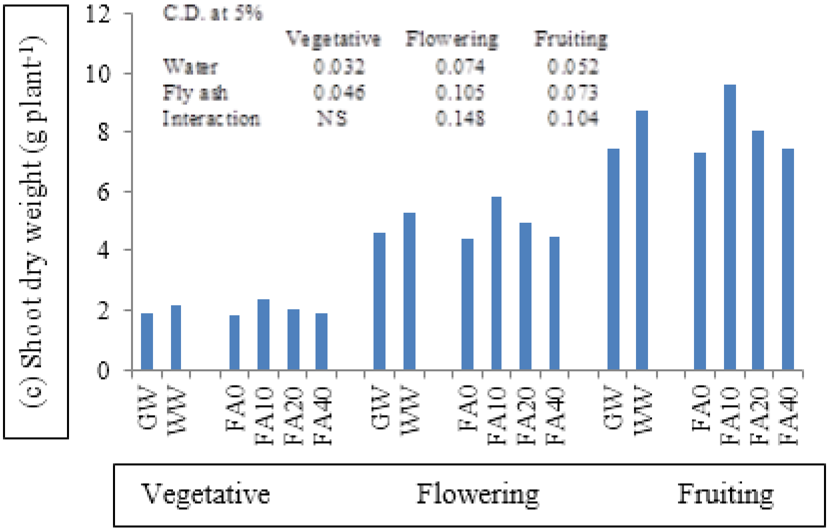
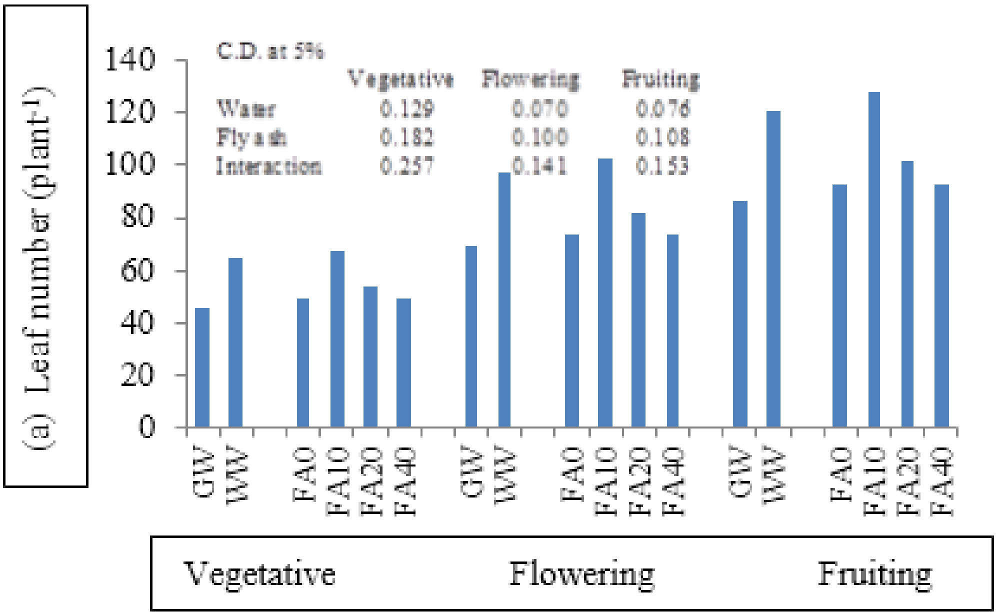
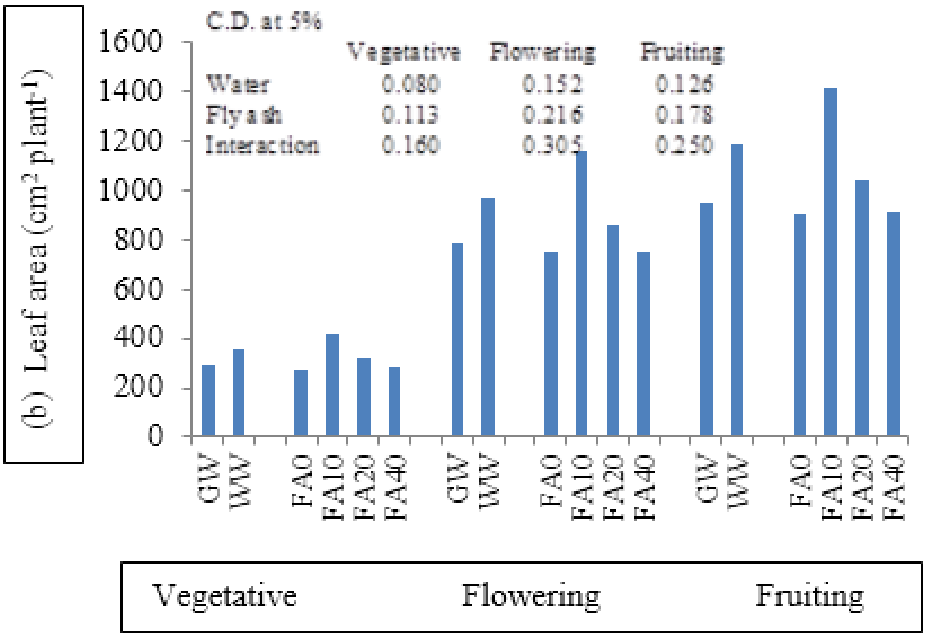


Figure 1. Effect of wastewater and fly ash on chickpea cv. BG-256


(a) Leaf number (plant-1)
C.D. at 5%
Vegetative Flowering Fruiting
Water 0.129 0.070 0.076
Fly ash 0.182 0.100 0.108
Interaction 0.257 0.141 0.153
140
120
100
80
60
40
20
0
GW WW FA0 FA10 FA20 FA40 GW WW FA0 FA10 FA20 FA40 GW WW FA0 FA10 FA20 FA40
Vegetative Flowering Fruiting


(b) Leaf area (cm2 plant-1)
C.D. at 5%
Vegetative Flowering Fruiting
Water 0.080 0.152 0.126
Fly ash 0.113 0.216 0.178
Interaction 0.160 0.305 0.250
1600
1400
1200
1000
800
600
400
200
0
GW WW FA0 FA10 FA20 FA40 GW WW FA0 FA10 FA20 FA40 GW WW FA0 FA10 FA20 FA40
Vegetative Flowering Fruiting

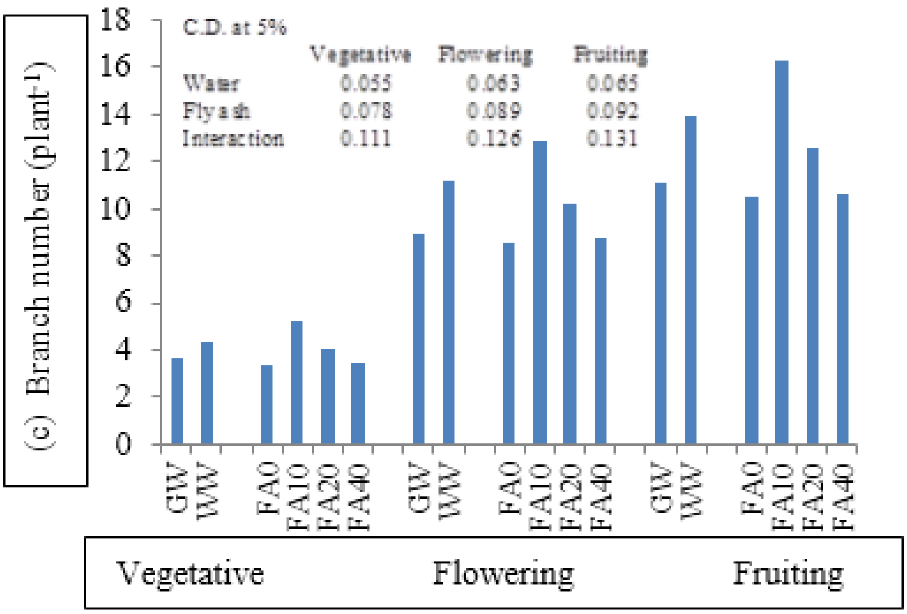
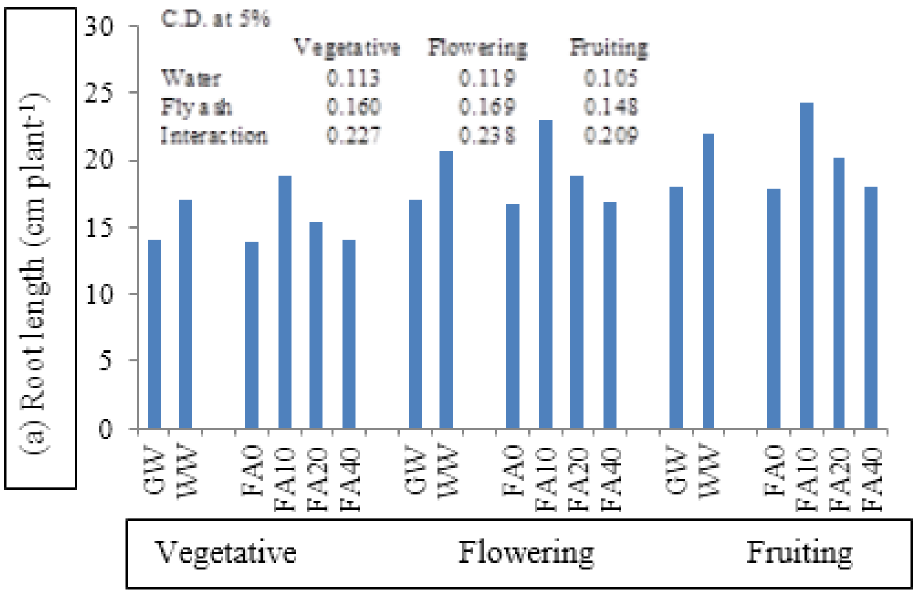
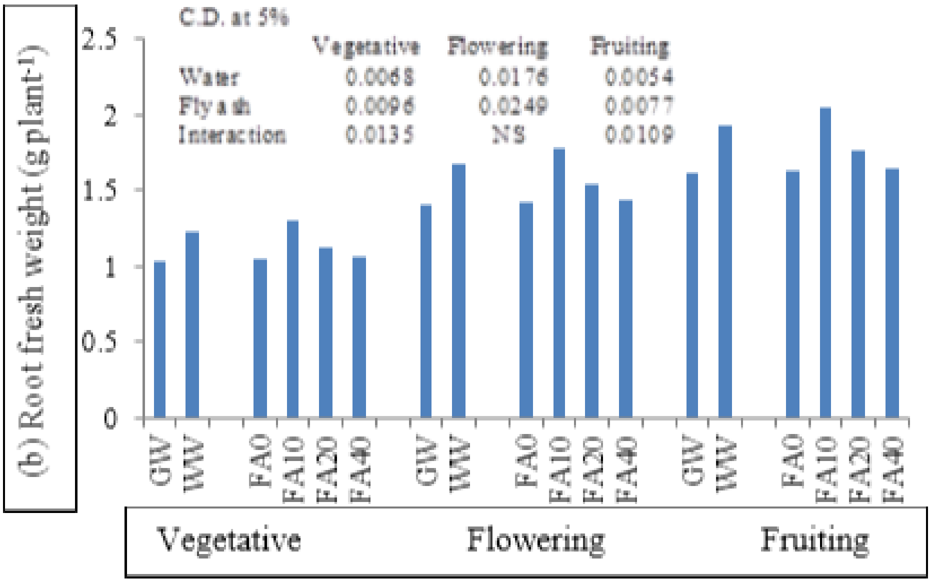


Figure 2. Effect of wastewater and fly ash on chickpea cv. BG-256





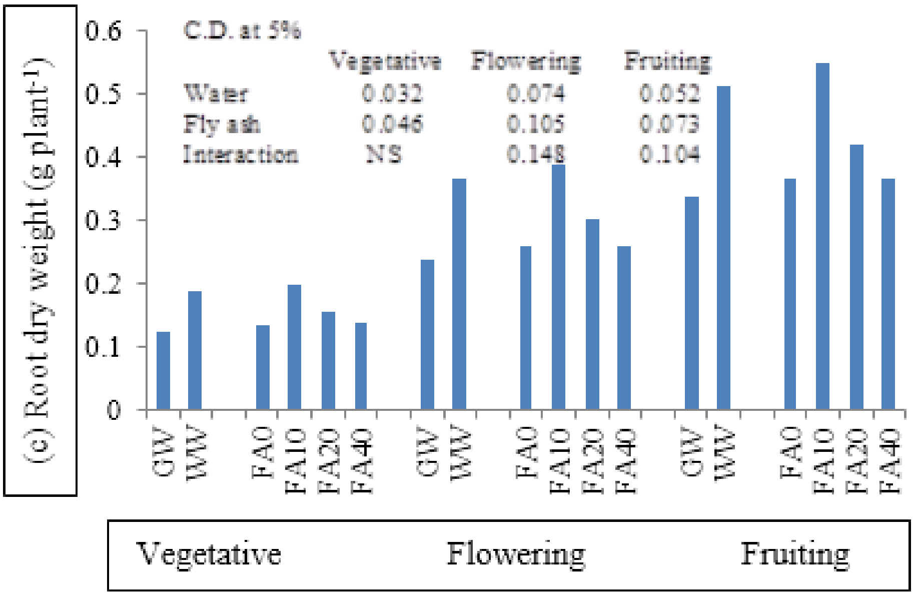
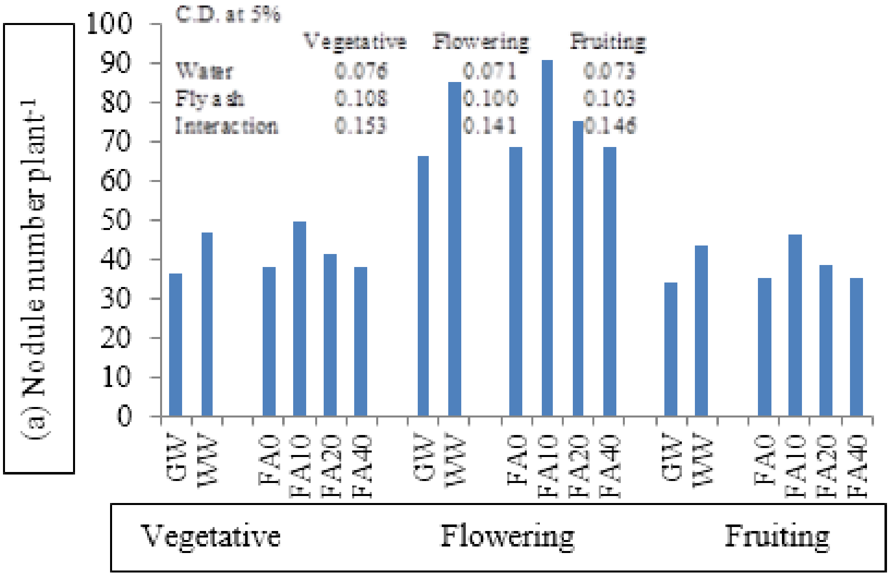
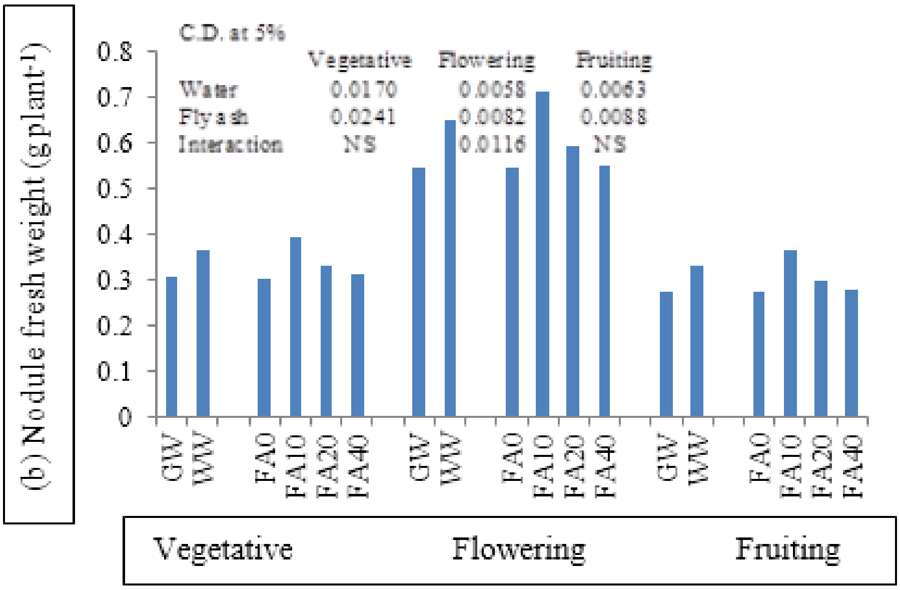


Figure 3. Effect of wastewater and fly ash on chickpea cv. BG-256


(a) Nodule number plant-1
C.D. at 5%
Vegetative Flowering Fruiting
Water 0.076 0.071 0.073
Fly ash 0.108 0.100 0.103
Interaction 0.153 0.141 0.146
100
90
80
70
60
50
40
30
20
10
0
GW
WW
FA0
FA10
FA20
FA40
Vegetative
Flowering
Fruiting


(b) Nodule fresh weight (g plant-1)
C.D. at 5%
Vegetative Flowering Fruiting
Water 0.0170 0.0058 0.0063
Fly ash 0.0241 0.0082 0.0088
Interaction NS 0.0116 NS
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
GW
WW
FA0
FA10
FA20
FA40
Vegetative
Flowering
Fruiting

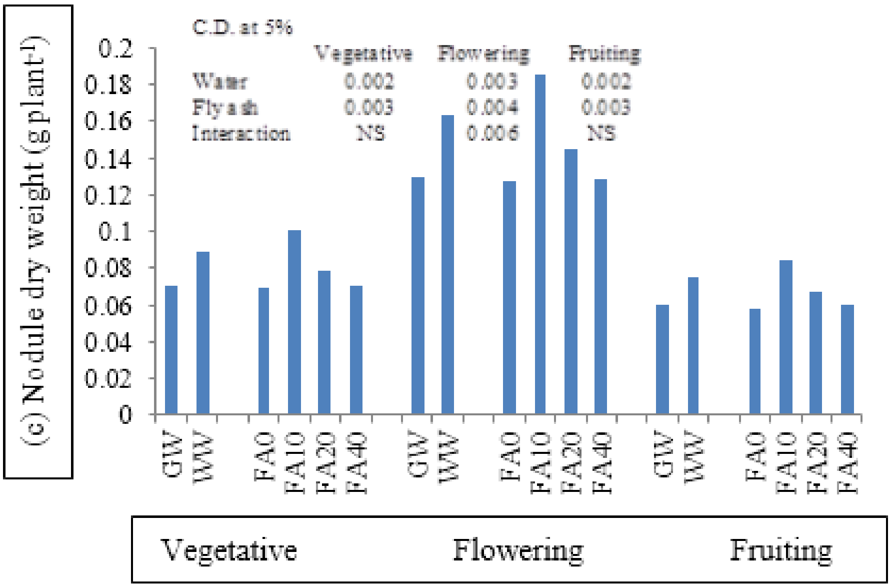
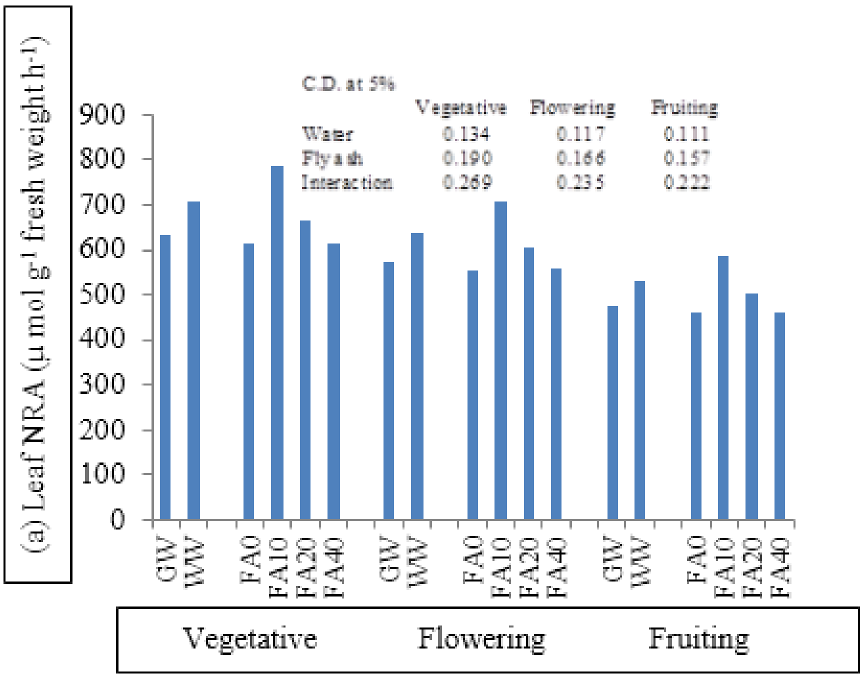


Figure 4. Effect of wastewater and fly ash on chickpea cv. BG-256



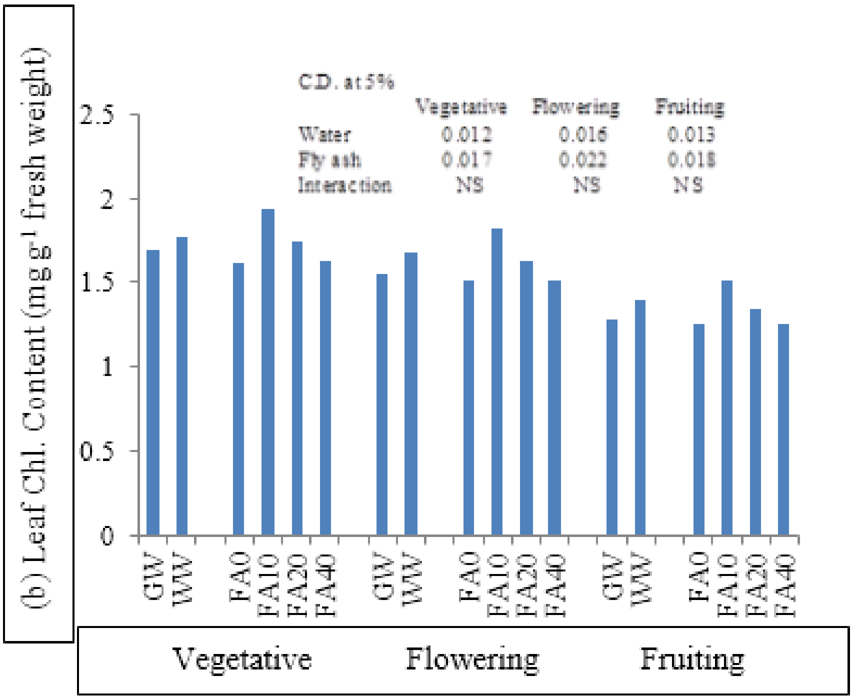
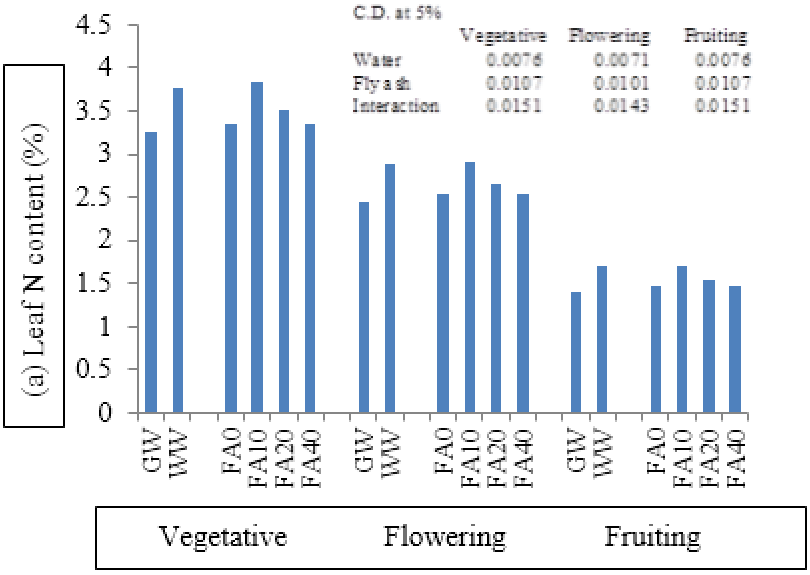


Figure 5. Effect of wastewater and fly ash on chickpea cv. BG-256



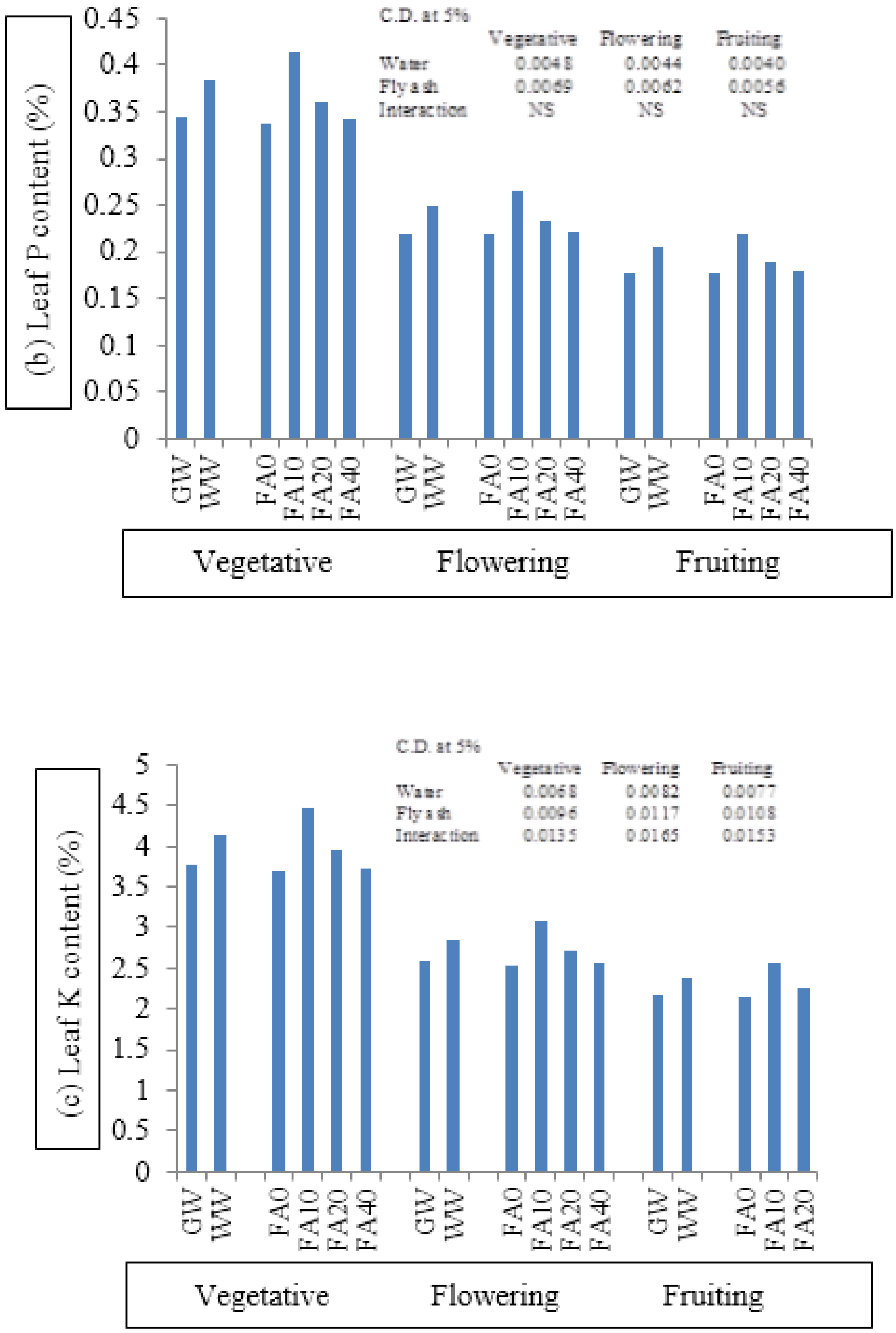
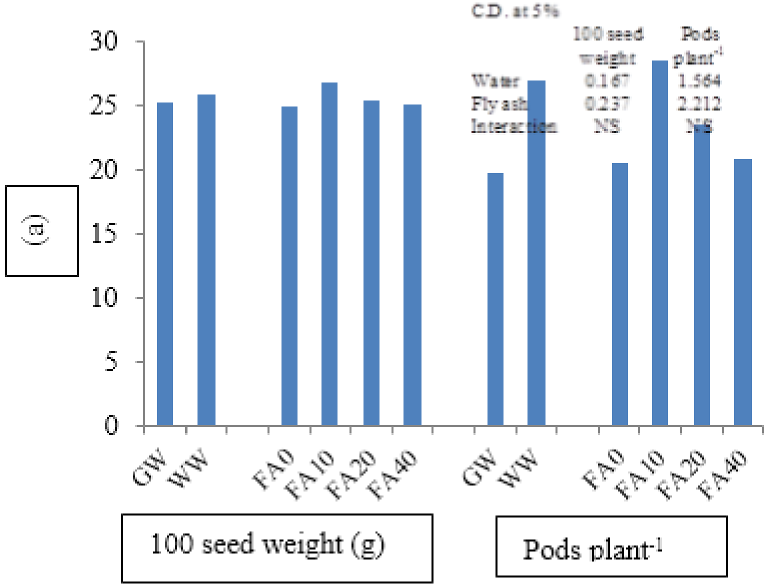
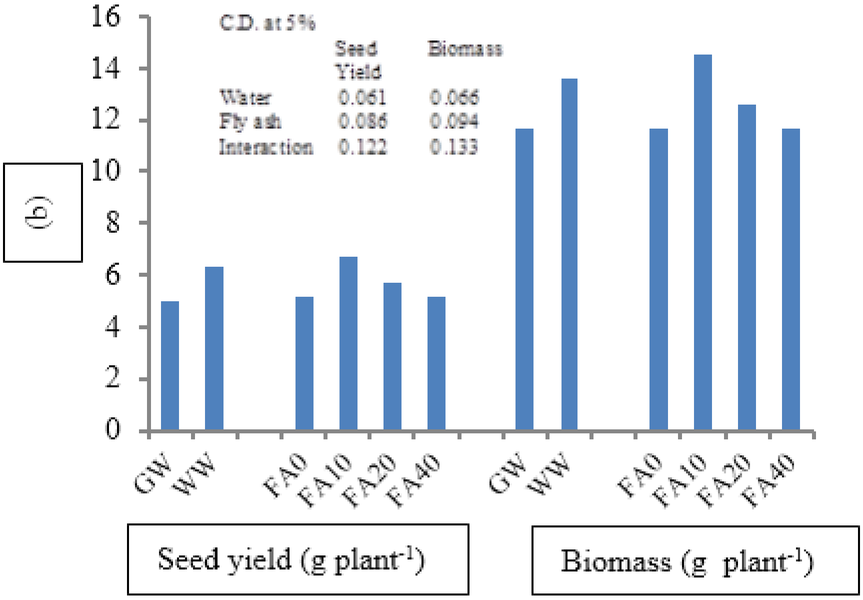


Figure 6. Effect of wastewater and fly ash on chickpea cv. BG-256


C.D. at 5%
100 seed weight
Pods plant-1
Water 0.167 1.564
Fly ash 0.237 2.212
Interaction NS NS
(a)
GW
WW
FA0
FA10
FA20
FA40
100 seed weight (g)
Pods plant-1


C.D. at 5%
Seed Yield
Biomass
Water 0.061 0.066
Fly ash 0.086 0.094
Interaction 0.122 0.133
(b)
GW
WW
FA0
FA10
FA20
FA40
Seed yield (g plant-1)
Biomass (g plant-1)

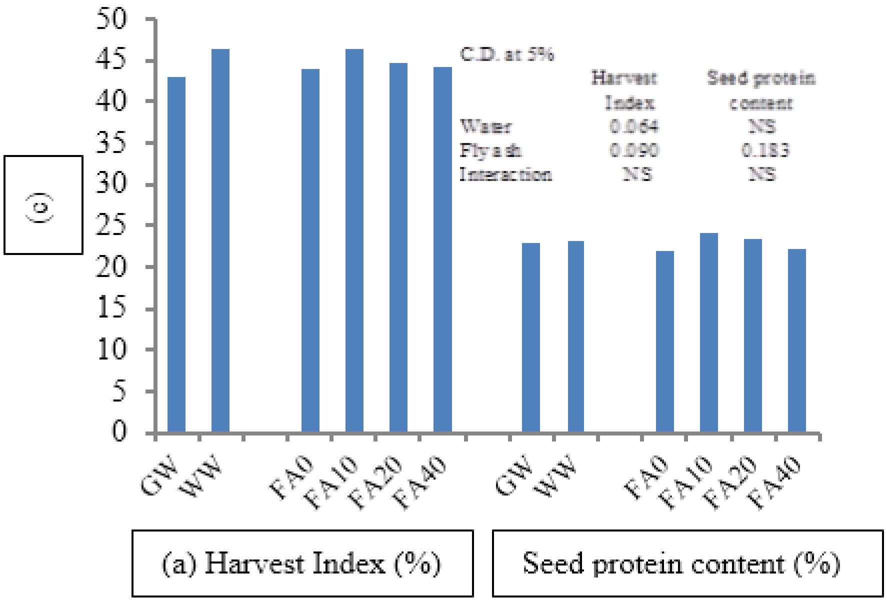


Figure 7. Effect of wastewater and fly ash on chickpea cv. BG-256

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