Effect of Moisture Stress and Growth Regulators on Growth and Yield of Chickpea (*Cicer arietinum* L.)

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Abstract

The effect of moisture stress and growth regulators on chickpea was studied during the *rabi* season of 2011 in a field experiment with split plot design. Two levels of moisture regime were maintained *viz.* I_1= fully irrigated condition (control) and I_2= without irrigation (moisture stress). Before sowing, chick pea seeds were soaked with different growth regulators like Glycine betaine plant extract (0.5%), *Ascophyllum nodosum* extract (0.2%), Triacontanol (10ppm), CCC (300ppm) and Gibberellic acid (300ppm) for 16 hours. Water soaked seeds were sown in the control plot. Moisture stress (I_1) significantly reduced growth attributes like plant height, dry matter accumulation, LAI at 30, 60, 90 and 120 DAS and CGR during 30-60, 60-90 and 90-120 DAS. Moisture stress also significantly reduced physiological parameters like chlorophyll content (chlorophyll a, chlorophyll b and total chlorophyll), relative water content (RWC) and membrane stability index (MSI) recorded at 50 and 75 DAS; yield and yield attributes like number of pods per plant, number of seeds per plant, 1000 seed weight, seed yield, stick yield, harvest index. Different growth regulators like Glycine betaine, *Ascophyllum* extract, Triacontanol and GA_3 significantly increased plant height, dry matter accumulation, LAI, CGR, number of branches per plant, chlorophyll content, RWC, MSI, number of pods/plant, 1000 seed weight, seed yield, harvest index over control. Highest yield in terms of pods/plant, test weight of seeds, seed yield/ha and stick yield/ha was recorded from GA_3 treatment followed by Triacontanol. Glycine betaine, *Ascophyllum nodosum* extract and GA_3 recorded significantly higher value of above growth, physiological and yield parameters under moisture stress condition as compared to control. Glycine betaine treatment recorded highest total chlorophyll content (2.521mg g^{-1}), RWC(77.69) and MSI(74.45) of leaves, pod wt(g) $plant^{-1}$, seeds $plant^{-1}$, seed yield ha^{-1} (14.13 q ha^{-1}) and harvest index under moisture stress closely followed by *Ascophyllum nodosum* extract and GA_3.

1. Introduction

Chickpea is the most important pulse crop of *rabi* season cultivated mainly under rainfed condition. India is the largest chickpea producer as well as consumer in the world. India grows chickpea on about 6.67 million ha area producing 5.3 million tonnes which represents 30% and 38% of the national pulse acreage and production, respectively. Major chick pea growing states are Madhya Pradesh, Rajasthan, Maharashtra, Uttar Pradesh, Karnataka and Andhra Pradesh together contribute 91% of the production and 90% of the area of the country. However, the productivity of chickpea is quiet lower as compared to other pulses. Several reasons have been attributed for low productivity, of which, the major one is 90 per cent of its area is under rainfed condition and essentially it is grown as a post-monsoon winter crop on conserved soil moisture. As a consequence, the plant experiences progressively increasing degree of moisture stress and thus, assumes a major limiting factor determining growth and yield of chickpea.

Different plant growth regulators like GA_3, glycine betaine and seaweed extracts of *Ascophyllum nodosum* are known to induce tolerance of crops against drought or moisture stress when applied exogenously.

2. Materials and Methods

A field experiment was conducted at the Agriculture Farm, Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati, Sriniketan, during *rabi* season of 2011.The experiment consisted of twelve treatment combinations including two levels of irrigation *i.e.* I_1= Irrigated, I_2=Unirrigated (moisture stress) and six levels of growth regulators *viz.* Water soaked seeds, Glycine betaine plant extract (0.5%), *Ascophyllum nodosum* extract (0.2%), Triacontanol (10ppm), CCC (300ppm) and Gibberellic acid (300ppm) and were replicated thrice. The experiment was laid out in split plot design. Adequate numbers of irrigation channels were also constructed to provide irrigation independently to each plot. Recommended dose of NPK at the rate of 20:50:30 was applied to the experimental plots. Adequate intercultural operations and plant protection measures were taken. After 15 days of sowing, thinning was done to maintain optimum population. To measure plant height, 10 plants from each plot were randomly selected at 30, 60, 90, and 120 DAS. The heights were measured and the average plant height was calculated for each plot. Leaf area was measured at 30, 60, 90 and 120 DAS by using Leaf Area Meter (Systronics). Leaf area index was calculated by formula given by Watson (1952). The leaves were then dried in a hot air oven at 65°C for 12-15 hours till constant weights were obtained and then weights were recorded. The ratio of leaf area /weight of these leaves were used to measure the leaf area indices. To determine dry matter accumulation, chickpea plants were cut at ground level from 1 meter row length within the earmarked area in each plot kept for the purpose of destructive sampling at 30, 60, 90, and 120 DAS. Plants of each plot were separated into green leaves, stems, and pods and dried in a hot air oven, kept at 65°C for 48 hours till constant weights were obtained. The dry weight of leaves, stems, and capsules were recorded and used for determination of dry matter accumulation. Crop growth rate (CGR) was calculated during 30-60, 60-90 and 90-120 DAS using the formula given by Watson *et al*. (1952).

The number of branches per plant was counted at the time of harvest. At maturity the plants were cut from the ground level and dried in sun before threshing. The chickpea seed, husk and stalk yields were recorded at the time of harvesting and expressed in q ha^{-1}. Test weight of seeds was determined by taking the weight of 1000 sun dried seeds. The harvest index was calculated by dividing economic yield by total biological yield and expressed in percentage.

Chlorophyll a as well as chlorophyll b and total chlorophyll content were measured adopting the method of Hiscox and Israelstam (1979), using Dimethyl sulfoxide (DMSO). The chlorophyll content was determined by using the formula given by Arnon (1949) and expressed as mg g^{-1} of fresh leaf. Leaf relative water content (RLWC) estimation was determined by using the methods of Weatherley (1950). Membrane stability index (MSI) was determined by using the methods of Sairam et al. (1994).

3. Results and Discussion

The results obtained from this field trial (Table 1 and 2) re-

Table 1: Effect of moistures stress (levels of irrigation) and growth regulators on plant height, dry matter accumulation and number of branches plant-1 of Chickpea

Treatments	Height(cm)				Dry matter accumulated (g m^{-2} day^{-1})				Number of branches Plant^{-1}
	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS	at harvest
Irrigation levels									
Irrigated	17.71	30.70	42.64	52.59	16.28	75.02	254.06	390.98	6.63
Unirrigated	16.11	26.43	37.10	46.08	14.37	64.99	206.97	312.01	5.37
SEm±	0.11	0.58	0.39	0.88	0.012	0.80	0.70	4.73	0.02
CD (p=0.05)	0.64	3.50	2.39	5.37	0.075	4.86	4.23	28.77	0.11
Growth regulators									
Water soaked	15.25	25.87	37.03	46.07	12.44	63.98	201.95	305.68	4.82
Glycine betaine	17.27	29.00	41.50	50.98	15.78	71.35	234.73	358.81	6.10
A. nodosum extract	17.33	29.45	40.87	50.68	15.89	71.44	234.82	362.71	5.93
Triacontanol	17.07	29.52	40.48	50.12	16.06	70.65	233.97	358.27	6.00
CCC	15.10	25.07	35.90	44.42	12.50	65.64	217.76	314.30	5.80
GA_3	19.43	32.50	43.45	53.75	19.28	76.95	259.87	409.22	7.35
SEm±	0.14	0.23	0.36	0.38	0.16	0.77	2.78	3.84	0.13
CD (p=0.05)	0.40	0.68	1.07	1.13	0.48	2.27	8.21	11.36	0.39

Where, I_1=Irrigated, I_2=Unirrigated and WS=Water soaked seeds, GB=Glycine Betaine, AN=*Ascophyllum nodosume* tract, TR=Triacontanol, CCC=Cycocel Chloride and GA_3=Gibberellic acid

Table 2: Effect of moisture stress (levels of irrigation) and growth regulators on LAI, CGR of Chickpea

Treatments	LAI				CGR (g m-2 day-1)		
	30DAS	60DAS	90DAS	120DAS	30-60 DAS	60-90 DAS	90-120 DAS
Irrigation levels							
Irrigated	0.134	0.372	1.301	0.761	1.958	5.968	4.564
Unirrigated	0.119	0.334	1.192	0.657	1.687	4.733	3.501
SEm±	0.0014	0.0045	0.0153	0.0018	0.027	0.047	0.168
CD (*p*=0.05)	0.0085	0.0274	0.0930	0.0109	0.162	0.285	1.020
Growth regulators							
Water soaked	0.113	0.132	1.109	0.640	1.718	4.599	3.458
Glycine betaine	0.129	0.363	1.298	0.722	1.852	5.446	4.136
A. nodosum extract	0.131	0.365	1.269	0.725	1.852	5.446	4.263
Triacontanol	0.130	0.369	1.276	0.735	1.820	5.444	4.143
CCC	0.112	0.309	1.158	0.645	1.771	5.071	3.218
GA_3	0.144	0.418	1.367	0.786	1.922	6.098	4.978
SEm±	0.0007	0.0038	0.0165	0.0045	0.024	0.091	0.155
CD (*p*=0.05)	0.0021	0.0112	0.0488	0.0133	0.070	0.270	0.459

vealed that the growth attributes like plant height, dry matter accumulation, leaf area index (LAI), crop growth rate (CGR) and number of branches per plant were significantly reduced due to moisture stress as compared to irrigated control. Lower plant height, LAI and CGR under moisture stress may be attributed to reduced vegetative growth due to lack of water at peak growth period. Similar results were reported by Haripriya et al. (2010) and Nautiyal et al. (1994).

GA_3 (300 ppm) treatment resulted in significantly taller plants (53.75 cm) with higher dry matter accumulation (409.22g), LAI (1.367 at 90 DAS), CGR (6.098 g m^{-2} day^{-1}) at 60-90 DAS and number of branches per plant (7.35). This treatment was closely followed by *Ascophyllum nodosum* extract (0.2%) and Glycine betaine plant extract (0.5%), while the lowest was recorded from water soaked seeds (control). The effect of CCC (300ppm) treatment on LAI and CGR was at par with soaked seeds except the CGR recorded at 60-90 DAS. Higher plant height from GA_3 treatment was also obtained by Sontakey et al. (1991). Higher dry matter accumulation, LAI and CGR from GA_3 application may be attributed to its role in cell division and cell elongation leading to more expansion of leaves and production of more biomass. This result is in conformity with the findings of Alhadi et al. (1999) and Kaur et al. *(*1998).

The interaction effect of irrigation levels and growth regulators was found to be significant on different growth attributes except CGR during 90-120 DAS. GA_3 (300 ppm) recorded highest plant height, dry matter accumulation, LAI, CGR, number of branches per plant closely followed by glycine betaine (0.5%) and *Ascophyllum nodosum* extract (0.2%) treatment under moisture stress (Table 4).

There was a significant reduction in chlorophyll content under moisture stress as compared to fully irrigated condition (Figure 1). Lower chlorophyll content under moisture stress may be attributed to reduced mineral nutrition and reduced biosynthesis of chlorophyll pigments under moisture stress. This result corroborates the findings of El-Tayeb (2006) and Haripriya et al. (2010).

Different growth regulators had significant effect on the chlorophyll content in leaves of chick pea. GA_3 (300 ppm) recorded highest total chlorophyll content where as lowest was recorded from water soaked seeds. Similar result was also obtained by Wheeler et al. (1963) and Mishra (1995).

The interaction between irrigation levels and growth regulators on chlorophyll content leaves was also significant (Figure 3). Under irrigated condition, highest total chlorophyll content was recorded from GA_3 (300 ppm). This result is in conformity with the findings of Kaur et al. (1998).Under moisture stress, Glycine betaine plant extract recorded highest total chlorophyll content where as lowest was recorded from water soaked seeds. It might be due to alleviation of stress effects by inducing production of antioxidative enzymes by glycine betaine treatment under moisture stress (Chen and Murata, 2011).

There was a significant reduction in relative leaf water content (RWC) and membrane stability index (MSI) under moisture stress as compared to fully irrigated condition (Figure 2). This result is in conformity with the findings of Sairam et al. (2001).

Lower RWC under moisture stress may be attributed to reduced turgidity of the leaf cells under moisture stress where as lower MSI may be due to ion leakage from membrane injury caused by moisture stress. This result is in conformity with the findings of Deivanai et al. (2010).

Different growth regulators had significant effect on RWC and MSI of leaves of chick pea (Figure 2). GA_3 (300 ppm) recorded highest RWC and MSI where as lowest was recorded from water soaked seeds. Similar result was also obtained by Wheeler et al. (1963) and Mishra (1995). Higher relative water content of leaves from GA_3 treatment was also reported by Kaya et al. (2006).

The interaction between irrigation levels and growth regulators on RWC and MSI of leaves was also significant (Figure 4 and 5). Under irrigated condition, highest RWC and MSI were recorded from GA_3 (300 ppm). Glycine betaine recorded highest RWC and MSI where as lowest was recorded from water soaked seeds under moisture stress.

Moisture stress (I_2) significantly reduced the yield and yield attributes like number of pods plant^{-1}, 1000 seed weight, seed yield, stick yield, harvest index except harvest index as compared to fully irrigated control. Similar reduction in yield under moisture stress was also reported by Haripriya et al. (2010).

Different growth regulators had significant effect on the yield and yield attributes of chick pea (Table 3). GA_3 (300 ppm) recorded highest value of the yield (16.93 q ha^{-1}) and yield parameters where as lowest was recorded from water soaked seeds. Higher yield from GA_3 application was also reported by of Khan (1996) and Mala and Selvam (1998).

The interaction between irrigation levels and growth regulators on yield and yield attributes of chickpea was also significant (Table 5). Under irrigated condition, highest value of above yield attributes were recorded from GA_3 (300 ppm) treatment. However, Glycine betaine recorded highest pod wt plant^{-1}, number of seeds plant^{-1}, seed yield ha^{-1}, husk yield ha^{-1} and harvest index which was a par with GA_3 (except harvest index) parameters, where as, highest number of pods per plant, test weight and stalk yield ha^{-1} lowest was recorded from GA_3, again which was at par with Glycine betaine. Increased yield under moisture stress by glycine betaine application was also reported by Agboma et al.(1997) The lowest value of all the above yield parameters was recorded from water soaked seeds under moisture stress.

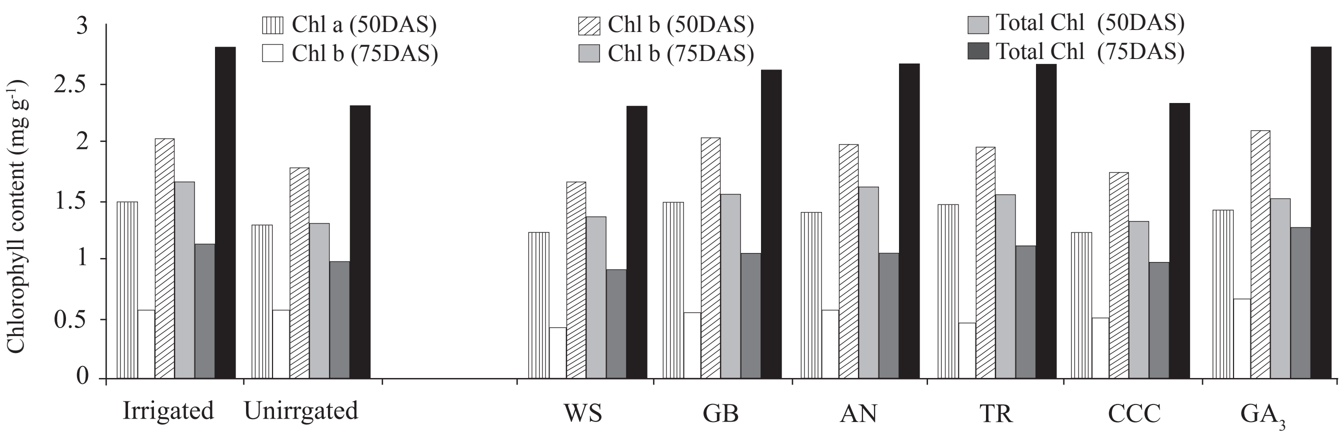

Figure 1: Effect of moisture stress (levels of irrigation) and growth regulators on the chlorophyll content in the leaves of Chickpea

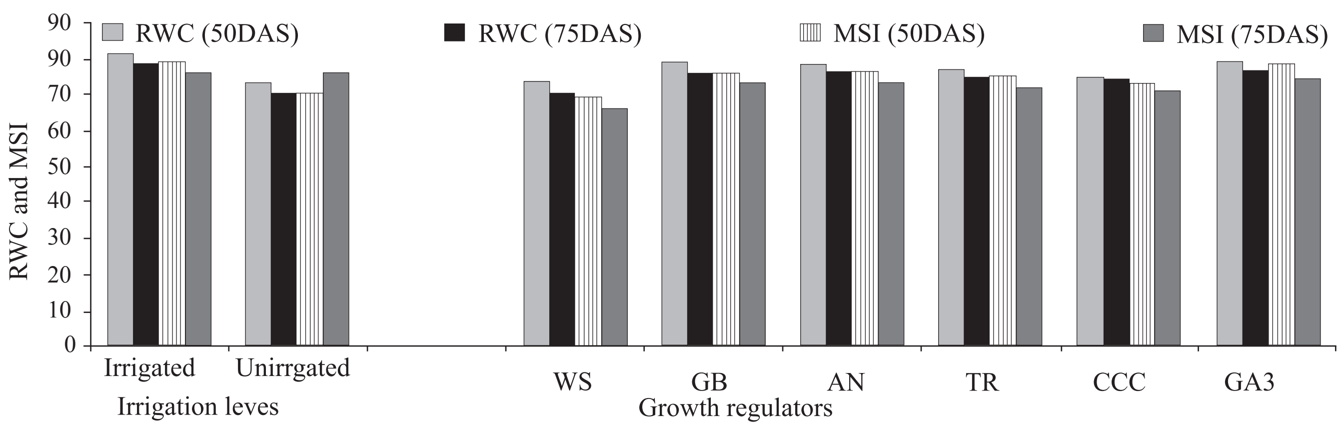

Figure 2: Effect of moisture stress (levels of irrigation) and growth regulators on the RWC and MSI of Chickpea

Table 3: Effect of moisture stress (levels of irrigation) and growth regulators on yield and yield attributes of Chickpea

Treatments	Pods Plant^{-1}	Pod wt.(g) Plant^{-1}	Seeds Plant^{-1}	1000 seed weight	Yield (q ha^{-1})	Husk yield (q ha^{-1})	Stalk yield (q ha^{-1})	Harvest Index (%)
Irrigation levels								
Irrigated	20.87	5.86	21.38	219.12	16.63	4.16	19.89	40.69
Unirrigated	17.29	5.12	17.39	206.89	12.26	3.06	15.26	39.87
SEm±	0.443	0.086	0.633	1.535	0.337	0.085	0.26	0.466
CD (p=0.05)	2.695	0.523	3.847	9.335	2.050	0.514	1.555	NS
Growth regulators								
Water soaked	16.65	4.59	16.04	205.27	11.48	2.87	16.49	37.01
Glycine betaine	19.40	5.61	20.25	213.13	14.87	3.72	17.84	40.85
A. nodosum extract	19.58	5.70	19.89	214.75	15.04	3.76	17.86	40.93
Triacontanol	19.52	5.67	19.91	215.27	15.07	3.77	18.11	40.30
CCC	17.52	5.10	18.27	210.22	13.29	3.32	16.16	40.60
GA_3	21.83	6.27	21.93	219.40	16.93	4.23	18.99	41.97
SEm±	0.136	0.069	0.214	0.632	0.160	0.040	0.329	0.408
CD (p=0.05)	0.402	0.204	0.632	1.868	0.473	0.120	0.972	1.206

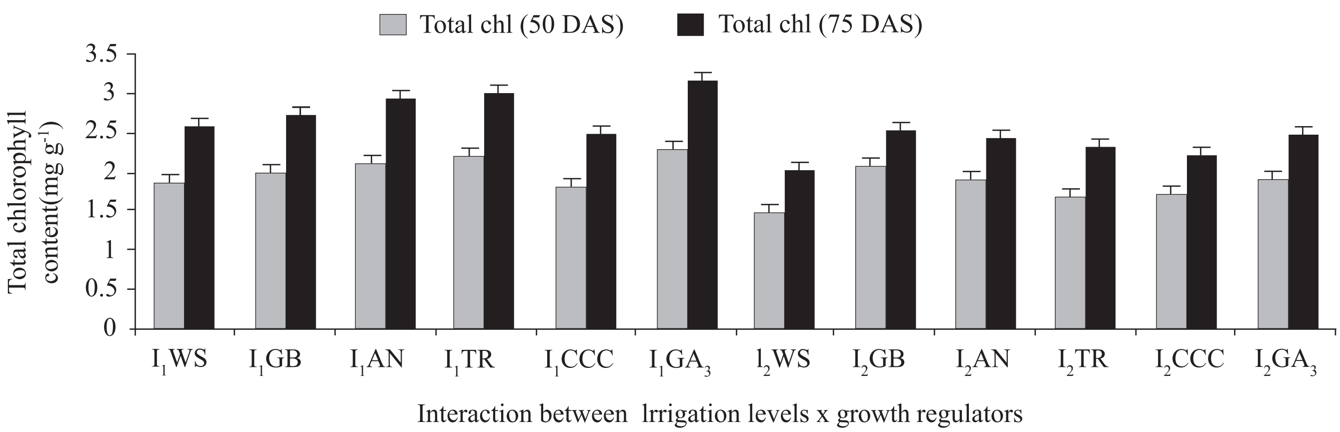

Figure 3: Interaction between irrigation levels and growth regulators on the total chlorophyll content of Chickpea

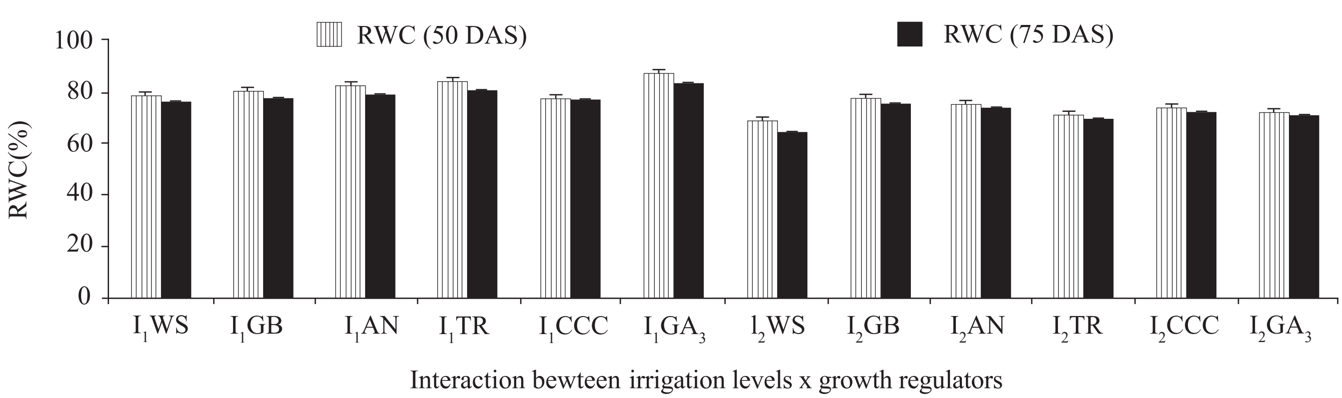

Figure 4: Interaction between irrigation levels and growth regulators on the RWC of chickpea

Table 4: Interaction effect of moisture stress (levels of irrigation) and growth regulators on LAI, Dry matter accumulation and CGR of Chickpea

Treatments	LAI				CGR (g m^{-2} day^{-1})				CGR(g m^{-2} day^{-1})		
	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS	30-60 DAS	60-90 DAS	90-120 DAS
I_1WS	0.122	0.343	1.204	0.711	13.78	71.20	234.92	352.58	1.914	5.457	3.922
I_1GB	0.130	0.358	1.286	0.746	15.11	73.10	245.71	380.72	1.933	5.754	4.500
I_1AN	0.139	0.391	1.325	0.772	16.89	75.20	258.97	399.33	1.944	6.125	4.678
I_1TR	0.146	0.416	1.374	0.811	18.78	79.20	272.37	421.55	2.014	6.439	4.972
I_1CCC	0.113	0.317	1.180	0.672	12.55	68.20	226.84	331.33	1.855	5.288	3.483
I_1GA_3	0.154	0.444	1.435	0.854	20.56	83.20	285.54	460.37	2.088	6.745	5.827
I_2WS	0.103	0.281	1.015	0.570	11.11	56.75	168.97	258.78	1.521	3.740	2.994
I_2GB	0.129	0.368	1.310	0.699	16.45	69.60	223.74	336.90	1.772	5.138	3.772
I_2AN	0.123	0.340	1.212	0.678	14.89	67.68	210.67	326.09	1.760	4.766	3.847
I_2TR	0.115	0.322	1.178	0.659	13.33	62.10	195.57	294.98	1.626	4.449	3.314
I_2CCC	0.110	0.302	1.136	0.619	12.44	63.08	208.68	297.27	1.688	4.853	2.953
I_2GA_3	0.135	0.392	1.299	0.719	18.00	70.70	234.20	358.06	1.757	5.450	4.129
SEm±	0.001	0.005	0.022	0.006	0.23	1.09	3.93	5.436	0.033	0.129	0.220
CD(p=0.05)	0.003	0.016	0.064	0.019	0.68	3.21	11.61	16.07	0.099	0.381	0.649

Table 5: Interaction effect of moisture stress (levels of irrigation) and growth regulators on yield and yield attributes of Chickpea

Treatments	Pods Plant^{-1}	Pod wt.(g) Plant^{-1}	Seeds Plant^{-1}	1000 seed weight	Yield (q ha^{-1})	Husk yield (q ha^{-1})	Stalk yield (q ha^{-1})	Harvest Index (%)
I_1WS	18.60	4.95	17.97	212.90	13.50	3.37	18.86	37.73
I_1GB	20.19	5.46	20.52	216.93	15.60	3.90	19.79	39.63
I_1AN	21.27	6.09	21.93	220.40	17.30	4.32	20.28	41.23
I_1TR	22.23	6.48	23.43	223.20	18.80	4.70	20.93	42.30
I_1CCC	19.20	5.28	19.74	214.93	14.70	3.67	18.33	40.03
I_1GA_3	23.73	6.90	24.66	226.37	19.90	4.97	21.16	43.20
I_2WS	14.70	4.23	14.10	197.63	9.45	2.36	14.12	36.30
I_2GB	18.60	5.76	19.98	209.33	14.13	3.53	15.88	42.07
I_2AN	17.88	5.31	17.85	209.10	12.78	3.19	15.45	40.63
I_2TR	16.80	4.86	16.38	207.33	11.34	2.84	15.29	38.30
I_2CCC	15.84	4.92	16.80	205.50	11.88	2.97	13.98	41.17
I_2GA_3	19.92	5.64	19.20	212.43	13.95	3.50	16.82	40.73
SEm±	0.19	0.10	0.30	0.89	0.23	0.06	0.47	0.57
CD(p=0.05)	0.57	0.29	0.89	2.64	0.67	0.17	1.37	1.69

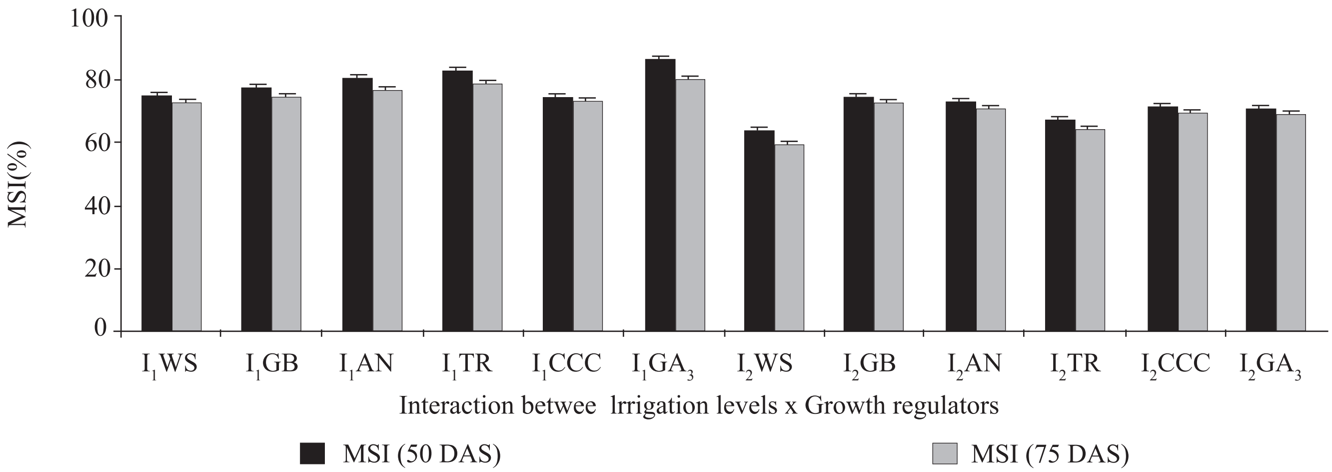

Figure 5: Interaction between irrigation levels and growth regulators on the MSI of chickpea

4. Conclusion

Moisture stress significantly reduces growth as well as yield attributes of chickpea. Pre-sowing treatment of growth regulators like Glycine betaine plant extracts (0.5%), GA_3(300ppm) and extract of the sea weed *Ascophyllum nodosum* (0.2%) are found to be beneficial in improving growth and yield of chickpea under rainfed condition.

5. References

Agboma, P., Sinclair, T., Jokinen, K., Peltonen-Sainio, P., and Pehu, E.,1997. An evaluation of the effect of exogenous glycine betaine on the growth and yield of soybean. Field Crops Research 54, 51-64.

Alhadi, F.A., Yasseen, B. T., Jabr, M., 1999. Water stress and gibberellic acid effects on growth of fenugreek plants. Irrigation Science18(4),185-190.

Arnon, D. L.,1949. A copper enzyme is isolated chloroplast polyphenol oxidase in Beta vulgaris. Plant Physiology 24,1-15.

Chen, T. H., Murata, N., 2011. Glycinebetaine protects plants against abiotic stress: mechanisms and biotechnological applications. Plant Cell Environment 34(1), 1-20.

Deivanai, S., Sheela devi, S., Sharrmila Rengeswari, P., 2010. Physiochemical traits as potential indicators for determining drought tolerance during active tillering stage in rice (*Oryza sativa* L.). Pertanika Journal of Tropical Agricultural Science 33 (1), 61-70.

El-Tayeb, M. A., 2006. Differential response of two *Vicia faba* cultivars to drought: growth, pigments, lipid peroxidation, organic solutes, catalase and peroxidase activity. Acta Agronomica Hungarica 54(1), 25–37.

Haripriya, M., Vijaya, T., Mouli, K.C., 2010**.** Effect of water stress on growth, metabolic activities of *Withania somnifera*-an important phytoceutical plant: Ameliorative effects of VAM. Journal of Global Pharma Technology 2(3)**,** 112-116

Hiscox, J.D., Isrealstam, G.F., 1979. A method for the extraction of chlorophyll from leaf tissue without maceration. Canadian Journal of Botany 57, 1332-1334.

Kaur, S., Gupta, A. K., Kaur, N.,1998. Gibberellic acid and kinetin partially reverse the effect of water stress on germination and seedling growth in chickpea. Plant Growth Regulation 25(1),29-33.

Kaya, Cengiz., Lavent, T., Alfredo, A., 2006. Gibberellic acid improves water deficit tolerance in maize plants. Acta Physiologiae Plantarum 28(4), 331-337.

Khan, N. A.,1996. Effect of gibberellic acid on carbonic anhydrase, photosynthesis, growth and yield of mustard. Biologia Plantarum 38(1), 145-147.

Mala, S., Selvam, P.P., 1998. Effect of seed treatment along with foliar nutrition on sesame (*Sesamum indicum*) productivity. Indian Journal of Agronomy 43 (4), 729-732.

Mishra, M.,1995. Application of gibberellin to *Pogostemon cablin* plants: growth, photosynthetic pigment content and oil yield. Biologia Plantarum 37(4), 635-639.

Nautiyal, S., Badola, H. K., Pal, M., Negi, D. S., 1994. Plant responses to water stress: changes in growth, dry matter production, stomatal frequency and leaf anatomy. Biologia Plantarum 36(1), 91-97.

Sairam, R. K., Chandrasekhar, V., Srivastava, G. C., 2001. Comparison of Hexaploid and Tetraploid Wheat Cultivars in their Responses to Water Stress. Biologia Plantarum 44(1), 89-94.

Sairam, R.K.,1994. Effect of moisture stress on physiological activities of two contrasting wheat genotypes, Indian Journal of Experiemntal Biology 32, 584-593.

Sontakey, P.Y., Durga, D.V., Belasare, W.V., Deotale, R.D., 1991. Effect of hormone application in yield attributes and yield of sesame. Journal of Soil and Crops 1(2), 185-186.

Watson, D.T., 1952. The physiological basis of variation in yield. Advances in Agronomy 4, 101-145.

Weatherley, P.E.,1950. Studies in water relations of cotton plants I, the field measurement of water deficit in leaves. New Phytology 49, 81-87.

Wheeler, A. W., Humphries, E. C., 1963. Effect of Gibberellic Acid on Growth, Gibberellin Content and Chlorophyll Content of Leaves of Potato (*Solanum tuberosum*). Journal of Experimental Botany 14, 132-136.