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Impact of Deficit Irrigation on Yield Components, Water use Efficiency and Yield Response Factor of Cowpea in Khorramabad Iran

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Abstract: Due to arid and semi-arid area of Iran, applying optimized irrigation water management solutions to reduce consumption and efficient use of water in plants is essential. In this regard, this research is done in 94-93 crop year in a template design of randomized complete blocks with five treatments of 120% of complete irrigation (T1), 100% (Complete irrigation) (T2), 80% (T3), 60% (T4), 40% of complete irrigation (T5) with four replications at the agricultural research farm of Lorestan University to study the effects of different irrigation levels on yield, yield components, water use efficiency and reaction factor of cowpea product. The results of the study showed that different levels of irrigation water by reducing water consumption, traits such as weight of 100 grains, seeds per pod, seed size, number of pods per plant, pod length, plant height, biological yield and harvest index by reduction and efficiency of water use showed a significant increase. The most efficient water use based on the seed was observed in treatment T80 (0.54). Yield response factor to moisture stress in treatments of 100 and 80% at doses of 0.274 and 0.25 had low sensitivity and in treatments of 60 and 40 the water requirement values of 0.747 and 0.911 had average sensitivity. In this study, the treatment of 80% (T3) with grain yield of 2458 kg/ha by reducing 3.7% in comparison to complete irrigation and saving 20% of water was determined as the best treatment for the cultivation of cowpea in Khorramabad.

Key words: Yield, yield components, yield response factor, cowpea, cultivation of cowpea in Khorramabad

INTRODUCTION

In most places of the world water is a limiting factor in agricultural production. Due to limitations in the quality and quantity of water resources and increasing need for food production, the importance of optimal exploitation of this vital resource will be more than ever before. In terms of water scarcity, understanding the response of plants and determination of different growth stages sensitivity to water deficit is of great importance. Tolerance to drought is defined as the ability of plants to survive, grow and satisfactory perform under limited water conditions in the soil or low irrigation (Ashsley, 1993). Legumes, a class of important crop plants which due to having high nutritional value are an important source of human and animal nutrition. Among legumes, cowpea is an important source of protein (Dadson *et al*., 2005). It ranked third in global production and devoted 10.7 million hectares to its cultivation in the world in 2004 (Duzdemir *et al*., 2009). It is also one of the most resistant food crops suitable for growing in semi-arid regions where drought is one of the main production constraints (Pejic *et al*., 2013). Cowpea, compared with other species, shows a better compatibility in times of drought, high temperatures and biological stresses. Effect of drought stress on yield of cowpea depends on the genotypes, intensity and duration of stress and exposure to water stress during the growth phase (Martinz *et al*., 2003). Cowpea can produce more than one thousand kilograms of grain which is decreased to almost 360 kg/ha in drought stress conditions (Bastos *et al*., 2011). The sensitivity to water stress in cowpea starts before or during blooming, grain filling stage and vegetative stage to flowering stage and continues until yielding.

Bean yield is a complex quantitative trait and its components are number of pods, number of seeds per pod and seed weight (Adams, 1982; Bennett *et al*., 1997). Rezaei and Kamkar Haghighi in 1998 studied the effect of water stress on yield, yield components and relative sensitivity coefficient of cowpea was inspected. Their results showed that water stress during flowering, pod production and pod filling reduces seeds weight by

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25%. This tension also caused seeds to shrink and wrinkle. Shouse *et al.* (1981) reported that cowpea under drought stress has a good product as well as non-stressed plants during vegetative stage. Nascimento *et al.* (2004) studied the effect of available water in the soil on the growth and yield of snap bean and cowpea with randomized complete block design with six replications and four treatments in four levels 80, 60, 40 and 100% of available water in the soil after irrigation, respectively. According to the results of their research yield of snap bean and cowpea showed a significant decrease on levels 40-60%. Wakrim *et al.* (2005) compared water use efficiency of beans in normal and deficit irrigation methods and reported that the value of these two methods were equal to 1.91 and 2.58 kg/m^3, respectively. While the deficit irrigation dry weight and pod dry weight decreased. Gohari (2012) reported beans are most sensitive to excess water in the soil and irrigation during the flowering and irrigation during flowering and pod production increases yield while deficit irrigation decreases yield. Water use efficiency is the amount of the product per unit volume of irrigation water and usually presented in kilograms per cubic meter (Seckler *et al.*, 2002). Relations between the plants, climate, water and soil are extremely complex and influenced by biological, physiological, physical and chemical processes and crop production depends on soil fertility, climatic conditions and irrigation management. Where all factors are optimized in the growing season, evapotranspiration and crop production are maximized. In other words, the most important factor in this process is plant response to the amount of water that is consumed on the farm for evapotranspiration. The product subject to plant water use (ET). Different relationships between evapotranspiration and crop yield is expressed. In this regard, equation by FAO (2002) has been presented as follows:

$$1-\frac{Y}{Y_{max}} = K_y\ (1-\frac{ET}{ET_{max}})$$

Where:

- Y = Amount of product obtained
- Y_{max} = Maximum product
- K_y = Crop reaction to deficit irrigation factor
- ET = Real evapotranspiration
- Et_{max} = The maximum evapotranspiration

The yield response factor depends on the location, climate, plant varieties, irrigation, management and its cultivation stage. Understanding this factor will improve management practices to reduce water consumption and leads to the production of highest yield in drought conditions. The yield response factor (K_y) is the ratio of the yield reduction slope to evapotranspiration reduction slope. (K_y>1) indicates that the product has fallen more this sharply toward evapotranspiration that means the plant has a high sensitivity to dehydration. If (K_y<1) the process of reducing evapotranspiration will be more than the yield loss and ultimately, the plant will be less susceptible to dehydration and in the case of (K_y = 1) product reduction is tailored to consumed water reduction (FAO, 2002).

Considering bean plants worth in human nutrition, large-scale cultivation and massive production of beans in Khorramabad, this study investigated the effect of different irrigation levels on yield, yield components, water use efficiency and crop response factor of cowpea in 2014, crop year which was conducted at the agricultural research farm of Lorestan University.

MATERIALS AND METHODS

The characteristics of the soil this study is conducted at the agricultural research farm of Lorestan university located in North-Western part of Khorramabad City, Lorestan Province, using randomized complete block design with five treatments T1: 120% of full irrigation, T2: 100% of full irrigation, T3: 80% of full irrigation, T4: 60% of full irrigation, T5: 40% of full irrigation and four replications in longitude 48° 15 min East and latitude 33° 26 minutes North in 2014 crop year. Before conducting the experiment, eight randomized zigzag samples were taken from 0-30 cm depth after preparation of the composite samples they were delivered to laboratory to the determine physical and chemical properties of soil (Table 1-3).

Agricultural operations and the implementation of the plan: A fter preparing the land operation and furrow, based on soil test results, base fertilizers distributed and placed in subsoil. Based on climate and customs of the region in the second half of may planting in each experimental plot with size of 3×2.5 m (7.5 m^2) with four rows spaced 50 cm was done manually.

Practices, weed and pest control also took place during the growing season. Before each watering the soil moisture content was measured at 100% water requirement and the net depth of irrigation and water volume were calculated by Eq. 1 and 2:

Table 1: Some soil physical properties

Silt (%)	Clay (%)	Sand (%)	Permanent wilting point water (cm^3/cm^3)	Field capacity (cm^3/cm^3)	Soil bulk density (g/cm^3)
42.7	23.5	33.8	0.13	0.27	1.3

Table 2: Some soil chemical properties

$CaCO_3$	Available phosphorus (ppm)	Available potassiusm (ppm)	Total nitrogen (%)	Electrical conductivity (dS/m)	pH	Soil depth (cm)
37.5	8	390	0.27	0.71	7.6	0-30

Table 3: Some irrigation water chemical properties

Sodium adsorption ratio $(meq/L)^{0.5}$	Na (meq/L)	Mg (meq/L)	Ca (meq/L)	Total dissolved solids (meq/L)	Electrical conductivity (dS/m)	pH
0.727	1.28	1.6	4.6	397	0.621	6.97

$$d_n = (FC - \theta_i).\ D.\ \rho_b$$

Where:
d_n = Net irrigation depth (cm)
FC = Soil moisture at field capacity (decimal)
θ_i = Soil moisture before irrigation (decimal)
D = The depth of root development (cm)
ρ_b = Soil bulk density (g/cm^3)

$$V = A.\ d_n$$

Where:
V = The volume of water for each plot
A = The area of plot

After determining the recipient plot of complete irrigation water, irrigation water volume of all treatments was calculated by applying coefficients related to irrigation levels (0.4, 0.6, 0.8 and 1.2) considering the volume of irrigation water needed was 100% and irrigation of all treatments was performed by volume counter with an accuracy of a tenth of a liter. To determine Water Use Efficiency (WUE) Eq. 3 was used:

$$WUE = \frac{Y}{W}$$

Where:
Y = Yield (kg/ha)
W = Volume of water (m^3/ha)

In order to assess the product's sensitivity to water deficiency of soil, yield response factor (K_y) was calculated from Eq. 4. The results were analyzed using statistical software and the average of the data was compared using Duncan's multiple domain tests. Excel software was used to plot charts.

RESULTS AND DISCUSSION

Analysis of variance showed in Table 4 indicates that grain yield and yield components 100-grain weight, number of seeds per pod, seed size, number of pods per plant, pod length, plant height, biological yield) harvest index and water use efficiency in cowpea is influenced by the amount of irrigation water.

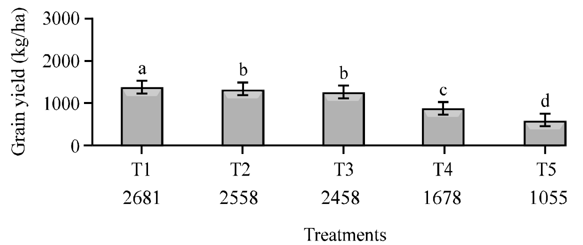

Fig. 1: Grain yield in different treatments

Grain yield: Analysis of variance in Table 4 shows that the effect of different levels of irrigation was significant on seed yield at the 1% level. Mean comparison done by Duncan method at the level of 1% in Fig. 1 indicates that there is significant difference between the yields of T1 treatment with other treatments. But there was no significant difference between grain yields of T2-T3, treatments. T1 treatment with 2681 kg/ha produced the highest grain yield and T5 treatment with 1055 kg ha is the lowest grain yield. Also, the increase of grain yield in treatment T1 compared to treatment T2, 4.8% and reduction of yield in treatments T-T5-T2 were 4, 34 and 58.8%, respectively.

According to the results of this study, cowpea grain yield decreases with increasing moisture stress because of the intense heat of August during growth period, reduction in the length of vegetative growth, lower production of vegetative organs and reduction in the flowering. Turk and Hall (1980) reported that irrigation stress reduces yield during flowering and grain filling stages about 44 and 29% compared to full irrigation system, respectively. Acosta-Gallegos and Adams (1991) said that water stress significantly reduces grain yield and yield components in beans Hosein Zadeh concluded that

Table 4: Analysis of yield variance, grain water use efficiency and some agronomic traits of cowpea in different treatments

Variation source	Degree of freedom	Grain yield (kg.ha^{-1})	Weight of 100 grains (g)	Grains each pod	Pods each plant	Plant height (cm)	Biomass (g)	Protein (%)	Harvest index	Grain water use efficiency (kg.m^{-3})
Repeat	3	1.98^{NS}	0.48^{NS}	0.75^{NS}	2.18^{NS}	0.33^{NS}	1.86^{NS}	2.26^{NS}	1.1^{NS}	1.86^{NS}
Treatment	4	360.81**	77.04**	3.82*	7.06**	11.39**	30.64**	44.72**	84.68**	26.66**
Error	12	-	-	-	-	-	-	-	-	-
Total	19	-	-	-	-	-	-	-	-	-
Coefficient variation	-	3.52	3.44	12.40	17.64	8.93	3.82	1.11	5.74	4.63

NS: Not Significant; *, **significant at the 0.05 and 0.01 probability levels, respectively

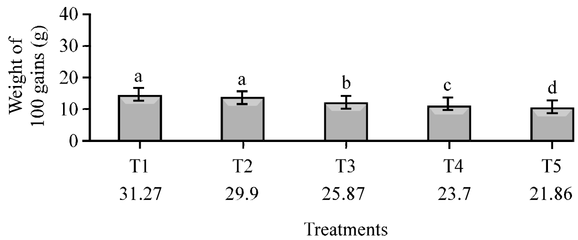

Fig. 2: The 100 grain weight in different treatments

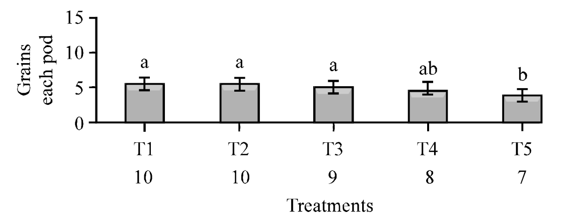

Fig. 3: Number of grains in each pod in different treatments

if the stress be severe and president during the growing season of beans yield reduction is caused by low seed weight. Babazadeh reported that drought stress reduces yield and yield components of beans during flowering and grain filling stages. The results of this study are consistent with the results of the presented investigations.

Weight of 100 grains: Comparison of means by Duncan's method at the level of 1% in Fig. 2 shows that the weight of 100 seeds of T1-T2 treatments had no significant difference. But there is a significant difference between T1 with other treatments. Treatments T1-T2 having 31.27 and 29.9 g weight of 100 grains had maximum weight of 100 grain and treatment T5 with 21.86 g had minimum weight of 100 grains.

The increase in weight of 100 seeds per treatment in T1 compared to T2 is 4.6% and 100 seeds weight reduction in treatments T3-T5 compared to T2 is 13.5, 20.7 and 26.9%, respectively. According to the results of the study, 100 seed weight in cowpea is decreased with increasing water stress. In fact in conditions of water stress, biomass production is decreased, resulting in less photosynthetic material transfer to grain. On the other hand, weight loss of grains is connected to early loss of leaves and shortened period of formation and grain filling. German *et al*. (2006) concluded that effect of irrigation on 100 grains weight is significant and it's due to stress. Teran and Singh (2002) claimed that during of low irrigation stress due to reduction in mass transfer to grains and also reduction in grain filling period grain weight is reduced. Results of this study are consistent with this research.

Grains per pod: According to Table 4 at the level of 5%, the effect of different irrigation levels on the number of grains per pod is significant. Comparison of average data in Fig. 3 indicates that between the number of seeds per pod in treatments T1-T3, there was no significant difference and all treatments were in same level but there was a significant difference between grains per pod in T1-T5. Treatment T1 and T2 had the maximum grains per pod with 10 grains and T5 had the minimum grains in each pod with 7 grains.

According to the results, increasing water stress reduced the number of seeds per pod. Abdzad and Amiri (2012) stated that the number of seeds per pod will be reduced due to drought conditions. These researchers considered reduced leaf photosynthesis and shortage of assimilate for grain growth as main reason of this situation. The mentioned results were consistent with the findings of this research.

Number of pods per plant: Table 4 shows the effect of significantly different amounts of water on the number of pods per plant at the level of 1%. Review and comparison of average data using Duncan's method at 1% level shows that the number of pods per plant for T1 is significantly different with other treatments but no significant differences exist between the number of pods per plant in treatments T3-T4 (Fig. 4). The highest

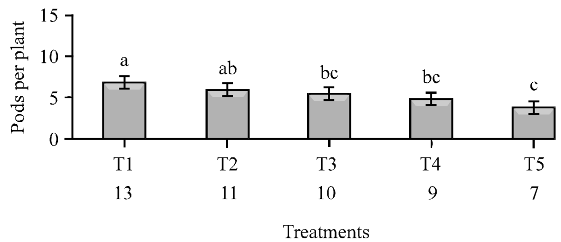

Fig. 4: Pods per plant in different treatments

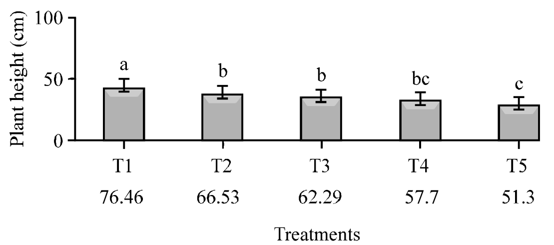

Fig. 5: Plant height in different treatments

number of pods per plant was observed in treatment T1 with 13 and the lowest are in treatment T5 with 7.

According to results by reduction of water consumption, number of pods per plant is reduced. The reason of this reduction is lower number of flowers, pods and severe loss of them in early reproductive growth under stress conditions. Bayat *et al*. (2010) showed that tension causes decreased number of pods per plant which is consistent by the results of this study. Khastehband *et al*. (2013) reported that the stress at pre-flowering reduces the bean pods. During water stress due to a reduction in the number of flower buds and flower loss, the number of pods per plant is reduced.

Plant height: As shown in Fig. 5, there was no significant difference between plant height in treatment T2-T3 but significant difference between T1 with other treatments was observed. The maximum height of plant was in T1 equal to 76.46 and the minimum height of 51.3 cm in T5.

Reduced plant height by reducing water consumption can be due to cell inflammation and decreased production of cells and ultimately short-stay vegetative plant. This result is consistent with the findings of Abdzad Gohari and Amiri (2011) that stated because of stress at vegetative stage, plant height will be reduced.

Biomass yield: Results indicate significant effect of irrigation levels on biomass yield at the level of 1% (Table 4). Average biomass comparisons made by

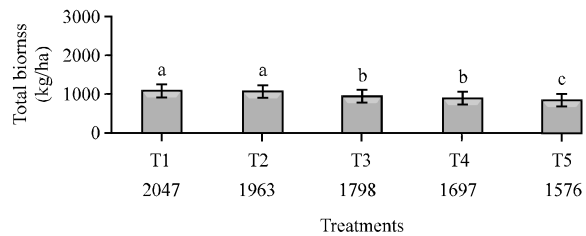

Fig. 6: Biomass for different treatments

Duncan method at the level of 1% showed that there is no significant difference between T1-T4 treatments (Fig. 6) But there is a significant difference in biomass yield between T5 and other treatments. The maximum yield of biomass was in T1-T2 treatments 2047 and 1963 kg/ha, respectively and minimum biomass yield was for T5 with 1576 kg/ha.

In this study, reducing the amount of biomass with different irrigation levels can be justified that during drought conditions, leaves openings are half-closed and it would limit the plant's gas exchange and by reducing the plants photosynthesis dry weight is reduced. In condition of deficient irrigation leaves openings are closed by signals of roots, leading to a reduction in leaf gas exchange and the mechanisms ultimately lead to decreased yield (Saradadevi *et al*., 2014). German *et al*. (2006) stated that drought reduced the biomass, grain yield, harvest index and the grain weight.

Honar *et al*. (2012) reported significant effect of irrigation on biomass weight shows that photosynthesis and ultimately the plant dry matter has inseparable relation with amount of available water and increasing the irrigation will increase dry weight of plant. These results are consistent with the findings of this study.

Grain protein percent: Investigating the average protein content in level of one percent shows no significant difference between treatments T1-T3 but the protein content in these three treatments were different with treatments T4 and T5. The highest protein content was in the treatment T5 and the lowest value was obtained in treatment T1. The increased amount of protein in treatment T5-T1 was 3.9%.

During deficit irrigation by reduction in grain size protein occupy more space of grain volume in comparison to normal conditions. This fact is observed by protein increase during reduction in irrigation levels. Findings of Oktem (2008) showed that increased water stress will increase the protein content of the plant that is consistent with the results of this research. Also, Abedi Koupai in their study on cowpea reported that higher water stress will increase the protein content.

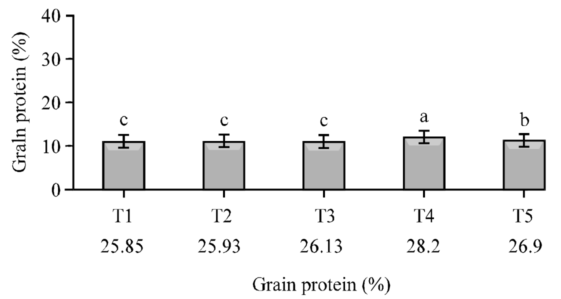

Fig. 7: Grain protein percent in different treatments

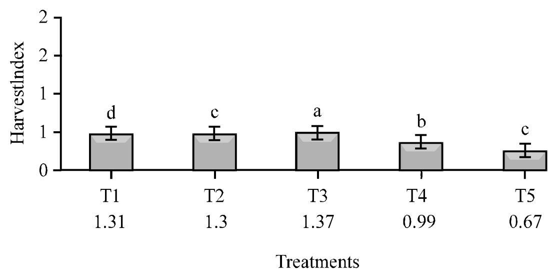

Fig. 8: Harvest index in different treatments

Harvest index: According to analysis of variance as shown in Table 4, the effect of different irrigation levels on harvest index were significant at the 1% level. It is shown in Fig. 7 and 8 that the harvest index in treatments T1-T3 were not significantly different. But significant differences in harvest index were observed in treatments T4 and T5 with other treatments. The maximum harvest index of 1.37 was in treatment T3 and the lowest harvest index was equal to 0.67 in treatment T5.

Lower harvest index is due to further reduction of grain yield to biological yield in condition of deficit water stress, especially during flowering. In other words in terms of water loss due to the reduced number of pods per plant, harvest index in bean is decreased (Rosales-Serna *et al*., 2004). Kafi attribute reduced harvest index under drought conditions to reduced photosynthesis as well as reduction in pressure potential in the phloem. Harvest index reduction because of water stress was reported in studies by Andria *et al*. (1995), Razi and Asad (1999) and Soriano *et al*. (2004). But Karam *et al*. (2007) observed no significant change in this regard.

The effects of different irrigation level on grain water use efficiency: Analysis of variance showed that different irrigation levels show a significant effect on grain water use efficiency based on dry weight at the level of 1% (Table 4). In Fig. 9, it is observed that there are significant differences between the efficiency of water use based on

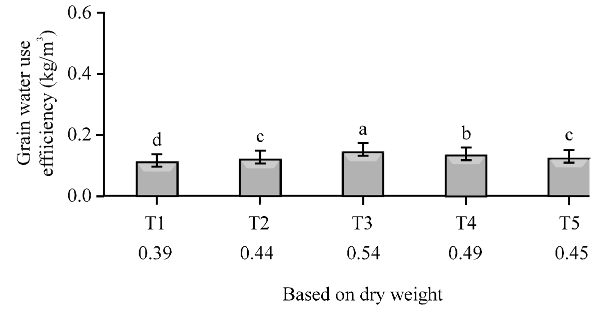

Fig. 9: Grain water use efficiency in different treatments

seed in T3 and other treatments. Maximum water use efficiency was for T3 with 0.54 kg/m^3 and lowest seed water use efficiency as compared to other treatments is related to the treatment T1 with 0.39 kg/m^3.

The results of this study indicated that water stress is associated with increased water use efficiency. Increased water use efficiency in bean seed production in drought conditions could be due to wasting more water through evaporation and transpiration and deeper penetration in optimum irrigation, disrupted photosynthesis because of the closing of the stomata and leaf area reduction and ultimately because of severe dehydration stress yield. In other words in conditions close to water stress in comparison with no water stress conditions more yield is produced compared to amount of water used.

In this regard results of this study is consistent with results by Dalla Costa and Gianquinto (2002), Ferrara *et al*. (2011) that indicated high water use efficiency is necessarily coupled with low growth rate and the growth rate is the main factor in achieving this efficiency.

The yield response factor (K_y): Using the FAO relationship and the quantities of seed yield and plant evapotranspiration in different irrigation treatments (Table 5) yield response factor values (K_y) were calculated in different irrigation levels.

Product response factor (K_y) indicates the product is resistant to water stress. For (K_y) smaller and equal to one plant is resistant and for (K_y) bigger and equal to one plant is susceptible to water stress. In the present study values of (K_y) are in the range of 0.25-0.911 (Table 5). The values obtained for the (K_y) are in good agreement with the results by Duzdemir *et al*. (2009) that obtained value of (K_y) equal to 0.92 in Turkey weather condition and also similar to the results by Pejic *et al*. (1991) that obtained yield response factor (K_y) for cowpea genotypes in semi-arid climatic conditions between 0/91

Table 5: Yield response factor (K_y) calculation in different water treatments

Treatment	ET	ET_{max}	1-ET/ET_{max}	Y	Y_{max}	1-Y/Y_{max}	K_y
T_1	887	887	-	2681.59	2681.59	-	-
T_2	739	887	0.167	2558.77	2681.59	0.046	0.274
T_3	592	887	0.333	2458.77	2681.59	0.083	0.250
T_4	443	887	0.501	1678.43	2681.59	0.374	0.747
T_5	296	887	0.666	1055.23	2681.59	0.606	0.911

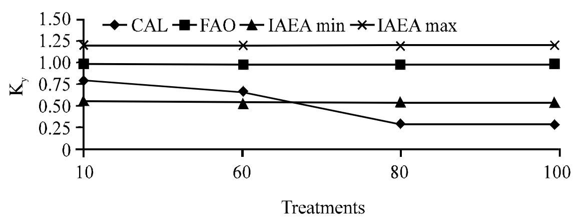

Fig. 10: Comparison of calculated (K_y) with (K_y) provided by FAO and International Atomic Energy Agency (IAEA)

and 1/17. Sepaskhah and Ilampour (1996) obtained yield response factor (K_y) equal to 1.02 for cowpea in Iran which is close to results of this study.

According to the FAO (2002) because the reaction factor values at 100 and 80% were equal to 0.274 and 0.25, respectively which have lower sensitivity and this means cowpea sensitivity in 100 and 80% treatments to moisture tension was lower and with effective control of stomata on transpiration and better regulation of osmosis process it can maintain its water balance. Therefore, when faced with stress it will be able to compensate for the lack of water. The reaction factor values in this study for treatments 60 and 40% of water requirement were 0.747 and 0.911, respectively which have higher sensitivity to dehydration in comparison to 80 and 100% treatments.

By comparing values of (K_y) calculated in this study with the values provided by FAO (FAO) and the International Atomic Energy Agency (IAEA) for bean (in the case of deficit irrigation during season) suggests the amount of (K_y) proposed by FAO (1.15) is much higher than the values calculated in the present study (Fig. 10). In treatments of 100 and 80% calculated values of (K_y) to values provided by FAO has declined by 76 and 78%. On the other hand (K_y) values calculated in comparison to (K_y) values provided by FAO in treatments of 60 and 40 reduced 21 and 35%, respectively.

Investigating reduced rate of reaction factor of beans in the study area in different treatments it can be concluded that this factor is a function of incoming water and considering it fixed creates error. These differences may be due to differences in climate, soil and water conditions, irrigation management and growing conditions. The results of this study are in good agreement with the findings by Gohari *et al.* (2012) which evaluated yield response factor, offered by FAO in Iran. On the other hand, cowpea crop reaction factors calculated in this study has a different process with minimal yield response factor reported by the International Atomic Energy Agency (IAEA) for beans.

So that in treatments of 100 and 80%, amounts of calculated (K_y) values in comparison to (K_y) values provided by the International Atomic Energy Agency (IAEA) for the bean is reduced 54 and 58%, respectively. But although the amount of calculated (K_y) values in comparison to (K_y) values provided by the International Atomic Energy Agency (IAEA) for bean plant in treatments 60 and 40% has increased 27 and 54%, respectively. By examining the different values in determining bean reaction factor in the study area in different treatments it can be concluded that the average bean reaction factor calculated for the region compared to the FAO is 53% different and 48% with a minimal amount provided by International Atomic Energy Agency (IAEA).

CONCLUSION

The results of this research shows that the effect of different irrigation levels on yield and some traits of cowpea such as plant height, biomass, grain yield, 100 seed weight, number of pods per plant and harvest index at the level of 1% and number of seed per pod in 5% is significant. Different levels of treatment by reducing irrigation water requirement of 120-40% of water demand, reduced plant height, biomass, grain yield, 100 seed weight, number of seeds per pod, number of pods per plant and harvest index. Also, number of pods per plant had the greatest effect on grain weight per plant. On the other hand, the amount of product increase in 120% treatment compared to the complete irrigation treatment was 4.8% and yield reduction in 80% treatment compared to complete irrigation treatment wasl <4%. Also, there was no significant difference between the grain yield, 100 grain weight and number of seeds per pod at 100 and 80% of water demand. So, there is no need for complete watering and by 20% reduction of used water in the treatment T3 (80%) best yield is obtained.

Also between different treatments significant difference in water use efficiency was observed on the level of one percent so that maximum water use efficiency (0.54) based on the dry weight of the grain was in the treatment T3 (80% of full irrigation). Increased water use efficiency in bean seed production during dehydration is connected with water lose through evaporation and deeper percolation of efficient irrigation, disrupting photosynthesis due to the closing of stomata, leaf area reduction and ultimately linked to the yield of severe drought stress treatment.

According to the results, water requirement values of 100 and 80% treatments are 0.247 and 0.25, respectively that had low sensitivity and treatments 60 and 40% with water requirement values of 0.747 and 0.911 had moderate sensitivity. The result of this study shows that treatment T3 is the best treatment for the cultivation of cowpea in Khorramabad.

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