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Impact of Irrigation at Different Growth Stages on Yield, Crop Water Productivity and Profitability of Cowpea (*Vigna unguiculata* L.) in Bangladesh

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***Abstract*— Usually, farmers apply irrigation once in cowpea production or cultivate in rainfed conditions. Randomized complete block design (RCBD) with three replications and five irrigation treatments were considered to explore the crucial crop stages for irrigation with respect to judicious water use and more economic return in cowpea production. There were irrigations at three weeks interval (T_2), irrigation at flowering stage (T_3), irrigation at pod formation stage (T_4), irrigation at flowering plus pod formation stages (T_5), and rainfed condition was regarded as control (T_1). The highest yield (2.26 ton Kg^{-1}) occurred in the most frequent irrigation events (T_2) which were about two times of rainfed condition yield (T_1). Irrigation at pod formation (T_4) was more responsive to yield, crop water productivity, benefit-cost ratio than irrigation at the flowering stage (T_3). Therefore, when there is a scope of one irrigation event, irrigation at pod formation should be applied. However, cowpea is a drought-tolerant crop since the yield response factor (K_y) of cowpea was 0.98 at a 1% level of significance which was less than the unity.**

Keywords*— Benefit-cost ratio (BCR), Crop water productivity, Evapotranspiration (ET), Soil moisture content, Yield response factor (K_y)

I. INTRODUCTION

Cowpea (*Vigna unguiculata* L) is the leguminous crop which is a rich protein source (19 to 35%) including tryptophan and lysine types of essential amino acids. The nitrogen fixation of cowpea improves the soil nutrients status of agricultural land. Approximately, 14.5 million ha land is cultivated cowpea all over the world [1].

Cowpea, known as "Felon" in Bangladesh, is almost cultivated in the south-east part of it (Chittagong, Feni, Vola) which is about seven thousand ha [2].). Although suitable to grow in all regions of Bangladesh, it is extensively grown in this region at the rice-based cropping systems after the harvest of transplant Aman rice. The cowpea is produced by either maximum twice irrigation or rainfed condition at Rabi season (Nov to March) as the soil conserves the moisture in monsoon. BBS [2] reported that the average yield of cowpea is 1 to 1.5 tons per ha. Horn and Shimelis [1] found that the potential yield of cowpea was up to 3 tons per ha and they also observed the cause of lower yield being abiotic and biotic stress. Farmers irrigate the cowpea field randomly since they have a lack of technology about time and quantity of irrigation to boost up the yield of it. Thus, this study was performed to detect the optimal stages of irrigation in cowpea production with more economic return and water productivity.

II. MATERIALS AND METHODS

The experiment was conducted in the research field of the Regional Agricultural Research Center of Bangladesh Agricultural Research Institute at Hathazari in Chittagong during the Rabi season (18 Nov to 24 March) of 2018-2019 and 2019-2020. The field is located at $22^0$33'08.85'' N and $91^0$47'39.14'' E which is elevated at 12.5m above the mean sea level. The site is situated at agro-ecological zone (AEZ) number 23 named as Chittagong coastal plain. The soil of the study field was silt clay loam and pH ranging from 5.5 to 6.5. The weather data of two growing seasons are shown in Figure A3. Field capacity and wilting point of soil were 38.9% and 21% respectively.

The experimental field was cultivated with roto-tilling as per suitable to sow cowpea seed. The local popular variety of cowpea (BARI Cowpea 1) was sown maintaining 50 cm spacing from line to line and 10 cm from plant to plant during 18 November 2018 and 18 November 2019. The fertilizers of urea, triple superphosphate, and muriate of potash were applied at the rate of 30kg, 45kg, and 30 kg per ha respectively with spitting into three through growing reasons [3]. The intercultural operation like weeding was performed on time when it was required. Cowpea was harvested on 25 March.

The most widely and common design of a randomized complete block in this research was used. The experimental area was divided into three blocks which were known as replications. The blocks were subdivided into equal five plots where treatments were applied randomly. Each plot was $16m^2$ (4m×4m). The five treatments were: a) farmer's practice (rain-fed cultivation, T_1) b) irrigation at three weeks interval (T_2) c) irrigation at flowering stage (T_3) d) irrigation at pod formation stage (T_4) e) irrigation at flowering and pod formation stages (T_5).

The amount of irrigation water was applied on the basis of the estimation of soil moisture depletion from field capacity. Before two days of irrigation, the soil sample was collected with an auger from 1-15cm, 15-30cm, and 30-45cm depth. The moisture content was measured by the gravimetric method. It was measured by weighing a mass of wet soil, drying the soil for 24 hours at 105 ^{0}C in Oven, and then reweighing the soil sample [4].

$$\theta_m = \frac{M_{wet} - M_{dry}}{M_{dry}} \quad (1)$$

$$\theta_v = \theta_m \times \rho_{bulk} \quad (2)$$

Where, θ_m = soil moisture content on mass basis (gm/gm), θ_v = soil moisture content on volume basis (cm^3/cm^3), ρ_{bulk} = soil bulk density (gm/cm^3), M_{wet} = mass of wet soil (gm), M_{dry} = mass of dry soil (gm).

The depth of irrigation water requirement was estimated with the guideline of Michael [5] as follows in equation (3).

$$d_{IR} = \frac{(FC - RL) \times A_s \times D}{100} \quad (3)$$

Where, d_{IR} = depth of irrigation water requirement (mm), FC= field capacity (%) which measured by ponding water method on the soil surface [5], RL= residual moisture content (%) which measured before irrigation gravimetrically, A_s = apparent specific gravity of soil, D= depth of effective root zone to be irrigated (mm).

The time, required to be irrigation, was calculated following equation (4).

$$t = \frac{d_{IR} \times A}{Q \times 1000} \quad (4)$$

Where t = time to be irrigated (min), d_{IR} = depth of irrigation water requirement, A = area of plot (m^2), Q= discharge (m^3/min).

Crop water productivity (CWP) is the ratio of the actual marketable crop yield (Y_{act}) and actual seasonal crop water consumption by evapotranspiration (ET_{act}) [6] as follows in equation (5).

$$CWP = \frac{Y_{act}}{ET_{act}} \quad (5)$$

Crop water requirement was calculated with the following formula in equation (6).

$$ET_c = K_c \times ET_0 \quad (6)$$

Where, ET_c = crop water requirement, K_c = crop coefficient for cowpea initial 0.5, mid 0.7, end 0.35 [7], ET_O = Reference crop evapotranspiration calculated by FAO Penman-Monteith equation [8].

Actual crop water requirement or adjusted crop water requirement due to water stress was calculated by

$$ET_{act} = ET_c \times K_s \quad (7)$$

Where, Ks = water stress coefficient $=\frac{\theta - \theta_{pwp}}{\theta_t - \theta_{pwp}}$; Θ_t= threshold water depletion and θ_{pwp}= permanent wilting point [4].

The estimation of profitability was done by following the benefit-cost ratio for the assessment of which treatment was more beneficial. There were two types of cost involvement-one was fixed cost and the other was variable cost. The lease of land for one season was regarded as a fixed cost and land preparation, labor, insecticide, pesticide, fertilizers, and irrigation costs were variable costs. The sum of fixed and variable costs was the total cost. Gross return was the marketable price of yield and the net return was gross return minus total costs. The benefit–cost ratio was the net return dividing by total costs [9]. The formulae are given below:

$$Benefit\ cost\ ratio = \frac{Gross\ return - (fixed\ costs + variable\ costs)}{fixed\ costs + variable\ costs} \quad (8)$$

Unit production cost was the total costs divided by the total marketable yield of cowpea.

The data were analyzed with "agricolae" R version 4.0.0 software package [10]. The figures were plotted in Microsoft Excel 2007.

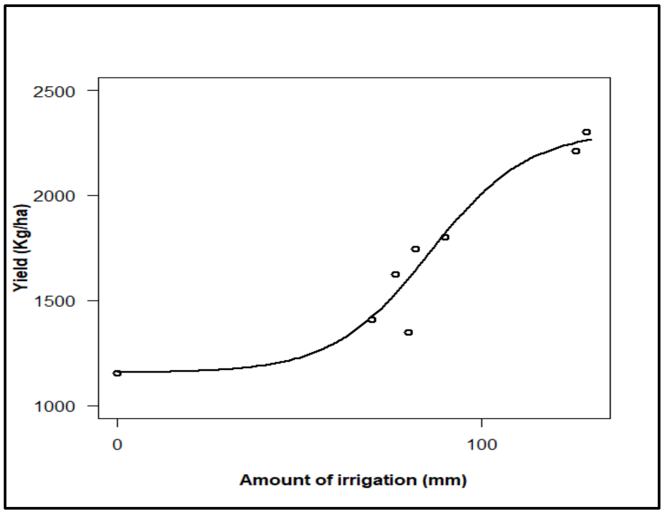
III. RESULTS AND DISCUSSIONS

There were five irrigation treatments at different growing stages of cowpea including rain-fed practice as a control. The high frequency of irrigation events (5 no) which was three weeks interval yielded high (average 2.26 ton/ha) and rainfed condition yielded lower (average 1.25 ton/ha). Irrigation at pod formation was more responsive to yield, plant height, and plant branches than the flowering stage although both Irrigation at flowering stage (T_3) and irrigation at pod formation stage (T_4) were once irrigation events (Table 01 and Table A1). The severe crop water stress coefficients (k_s) at different stages irrigation treatments were rain fed condition (T_1)> pod formation (T_4)> flowering (T_3) stages chronologically (Figure A1 and Figure A2). The unitary value of water stress coefficients implied that there was a non-stress condition and soil moisture content was at field capacity (FC). In the case of k_s being less than unity, the soil moisture content remained below field capacity and water stress condition. However, the more crucial stage for irrigation was pod formation in cowpea production.

Irrigation responses to yield during the two growing seasons are shown in Figure 01. The sigmoid curve was the best fit at a 1% significance ($p<0.01$). The lower and upper limits of the response curve were 1155.31 and 2306.1 respectively. The slope at point of inflection was -3.25 and the 50% reduction response was 72.15. The irrigation (mm) and yield (Kg/ha) relation was in equation (9).

$$Yield = 1155.31 + \frac{1150.8}{1 + e^{-3.25 loglog \frac{irrigation}{72.15}}} \quad (9)$$

Freitas et al. [11] also showed the evidence that the irrigation and yield relation curve of cowpea was sigmoid. Irrigation beyond the lower and upper limits was almost given yield at a constant rate. When irrigation was about to null (T_1), the yield of cowpea was about 1155 Kg/ha.



Figrure 01. Yield vs. Amount of Irrigation water applied (mm). The curve was fitted at a 1% level of significance: $[Yield = 1155.31 + \frac{1150.8}{1+e^{-3.25 loglog \frac{irrigation}{72.15}}}]$

The potential crop water requirement (ET_c) was hampered due to water stress and the yield of cowpea (Y_{act}) reduced from its maximum yield (Y_{max}) in treatments (T1, T_3, T_4, T_5). The relative yield reduction was linearly related to the relative deficit crop evapotranspiration ($1-ET_{act}/ ET_c$) as shown in Figure 02. The rate of yield reduction was 10.6 kg/ha in one millimeter (or m^3/ha) deficit of crop evapotranspiration. The regression analysis at a 1% level of significance between relative yield reduction ($1-Y_{act}/Y_{max}$) and relative crop evapotranspiration decrease ($1-ET_{act}/ET_c$) revealed that crop water response factor (K_y) was 0.98. Since the value, Ky was less than unity, cowpea had drought tolerance in crop production [12]. The yield response to evapotranspiration (ET) for cowpea is given below in equation (9). Ëzdemir et al. [13] also found that the crop water response factor (K_y) was 0.98. The 10% reduction of evapotranspiration (ET_c) would decrease the 9.8% yield of potential yield in cowpea production. When there is no reduction of ET_c (no water stress), the yield produces potential yield.

$$\left(1-\frac{Y_{act}}{Y}\right) = 0.98 \times (1-\frac{ET_{act}}{ET_c}) \quad (9)$$

Where, Y_{act}= actual yield (Kg/ha), Y_{max}= maximum yield without water stress (Kg/ha), ET_{act}= actual evapotranspiration (mm), ET_c = potential or crop evapotranspiration (mm).

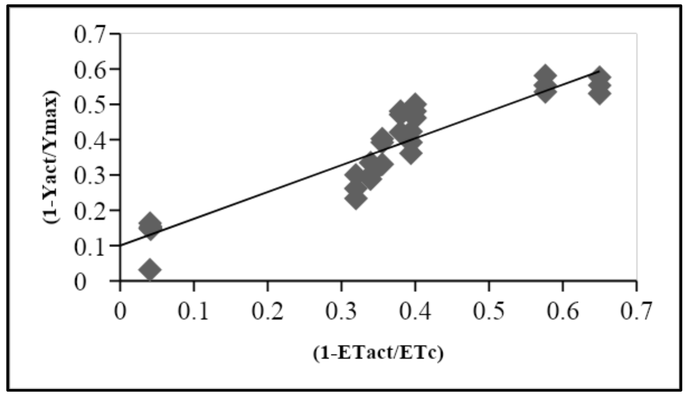


Figure02. Relative yield reduction and relative deficit evapotranspiration relationship

Crop water productivity measures the yield with respect to water consumption (ET_{act}) for crop production. Crop water productivity is inversely related to $ET_{act.}$ So, less water consumption as ET to produce yield and more crop water productivity is indicative of water-saving for crop production. In the rainfed condition (T_1), CWP was the highest (1.25 Kg/m^3) and the lowest CWP (0.98 Kg/m^3) was irrigated at three weeks interval (T_2) as shown in Table 01. The crop water productivity of irrigation at the pod formation stage (T_4) occurred at a higher value (1.07 Kg/m^3) in compassion to irrigation at the flowering stage (T_3). The more different stages of Irrigation and effective rainfall (effective rainfall was taken 70% of rainfall [14]) induces crop water productivity to decline as shown in Figure 03. If irrigation plus effective rainfall is one millimeter, CWP will be the highest value (1.45). If irrigation plus effective rainfall is greater than 220mm, CWP will be about the constant value (about 0.9). When only one irrigation event would have an opportunity, it should be irrigated at the pod formation stage. It would keep crop water productivity above unity (CWP>1) and be more water-saving in cowpea production.

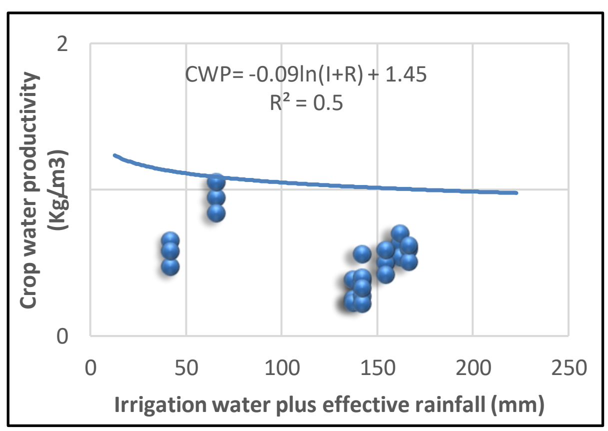


Figure 03. Crop water productivity (CWP) vs. irrigation plus effective rainfall (I+R)

Table 01. Impact of irrigation on yield and crop water productivity of cowpea during 2018-2019 and 2019-2020

Treatment	Height (cm)	No of branches per plant	No of pods per plant	No of seeds per pod	Seeds weight per pod (gm)	Grain weight per plant (gm)	Yield (ton/ha)	CWP (Kg/m^3)
2018-19								
T_1	33 ^{c}	4^{b}	12^{e}	10^{b}	0.57^{e}	6.83^{e}	1.16^{e}	1.37^{a}
T_2	43.67^{a}	6^{a}	16^{a}	11^{a}	0.81^{a}	12.98^{a}	2.21^{a}	0.96^{c}
T_3	40.33^{b}	5^{ab}	13^{d}	10^{b}	0.62^{d}	7.95^{d}	1.35^{d}	0.93^{c}
T_4	31.65^{c}	5^{ab}	14^{c}	10^{b}	0.67^{c}	9.29^{c}	1.58^{c}	1.08^{b}
T_5	45.67^{a}	4^{b}	15^{b}	11^{a}	0.71^{b}	10.58^{b}	1.8^{b}	1.13^{b}
CV (%)	2.90	21.85	0.00	0.00	1.43	1.48	1.67	2.43
2019-20								
T_1	33^{d}	4^{b}	11.67^{d}	10	0.58^{e}	6.75^{d}	1.15^{e}	1.13^{ab}
T_2	43.65^{b}	6.33^{a}	16.33^{a}	11	0.83^{a}	13.49^{a}	2.30^{a}	1^{c}
T_3	40.36^{c}	4.33^{b}	13.33^{cd}	10	0.62^{d}	8.27^{c}	1.41^{d}	0.94^{c}
T_4	31.71^{e}	$5.33a^{b}$	14.33^{bc}	10	0.66^{c}	9.51^{c}	1.62^{c}	1.05^{bc}
T_5	45.68^{a}	4.33^{b}	15.33^{ab}	11	0.73^{b}	11.19^{b}	1.91^{b}	1.17^{a}
CV (%)	1.18	14.7	6.56	5.7	1.7	6.72	6.71	5.64
Mean of two seasons								
T_1	33^{d}	4^{c}	11.83^{e}	10.17^{b}	0.58^{d}	6.79^{e}	1.16^{e}	1.25^{a}
T_2	43.66^{b}	6.17^{a}	16.17^{a}	11.17^{a}	0.82^{a}	13.23^{a}	2.26^{a}	0.98^{cd}
T_3	40.35^{c}	4.67^{bc}	13.17^{d}	10.17^{b}	0.62^{cd}	8.11^{d}	1.38^{d}	0.94^{d}
T_4	31.68^{e}	5.17^{b}	14.17^{c}	10.17^{b}	0.67^{c}	9.40^{c}	1.60^{c}	1.07^{bc}
T_5	45.68^{a}	4.17^{c}	15.17^{b}	10.83^{ab}	0.72^{b}	10.88^{b}	1.86^{b}	1.15^{b}
CV (%)	2.30	16.47	4.90	5.61	5.86	5.58	5.62	7.71

T_1=Rain fed, T_2= Irrigation at 3 weeks intervals, T_3= Irrigation at flowering stage, T_4= Irrigation at the pod formation stage, T_5= Irrigation at flowering and pod formation stages; CV= Coefficient of variation and zero value of it indicates approximately zero, CWP= Crop water productivity; Values are mean of treatment with three replications and superscript letters (a-e) are different at 5% level of significance in the column.

Profitability analysis was performed through the benefit-cost ratio method to realize which irrigation treatment was the most financial return. The costs of land preparation, seeds, fertilizers, insecticide, and pesticides were equal for all treatments. Labors and irrigation costs had variability within treatments. The more frequent irrigations required more cost of labor and irrigation events. Irrigation at three weeks interval (T_2), which had five irrigation events, was the highest cost investment (23890 Tk ha^{-1}). The net return and benefit-cost ratio of T_2 were higher (66377 Tk ha^{-1}, 2.78 respectively) than any other treatments. The unit production cost of cowpea was lowest at T_2 (10.59 Tk Kg^{-1}) and highest at T_1 (15.99 Tk Kg^{-1}). However, irrigation at pod formation was more economical than irrigation at the flowering stage with respect to benefit-cost ratio and unit cost production (Table 02).

Table 02. Profitability analysis of irrigation at different growing stages of cowpea

Cost and Benefit items	Treatment				
	T_1	T_2	T_3	T_4	T_5
Land preparation (roto-tilling)	2000	2000	2000	2000	2000
Insecticides and pesticides	1000	1000	1000	1000	1000
Human labors (600Tk man^{-1} d^{-1})	6000	9000	6600	6600	7200
Cowpea seeds (70 Tk kg^{-1})	2450	2450	2450	2450	2450
Fertilizers	2040	2040	2040	2040	2040
Irrigation (120 Tk hr^{-1})	0	2400	480	480	960
Total Variable cost (Tk ha^{-1})	13490	18890	14570	14570	15650
Total fixed cost (Tk ha^{-1})	5000	5000	5000	5000	5000
Total cost (Tk ha^{-1})	18490	23890	19570	19570	20650
Mean marketable yield of cowpea(Tk ha^{-1})	1.16	2.26	1.38	1.60	1.86
Gross return(Tkha^{-1})	46267	90267	55200	64067	74200
Net return (Tk ha^{-1})	27777	66377	35630	44497	53550
Benefit-cost ratio(BCR)	1.50	2.78	1.82	2.27	2.59
Unit production cost (Tk kg^{-1})	15.99	10.59	14.18	12.22	11.13

T_1=Rain fed, T_2= Irrigation at 3 weeks intervals, T_3= Irrigation at flowering stage, T_4= Irrigation at the pod formation stage, T_5= Irrigation at flowering and pod formation stages; Fertilizers: urea, triple superphosphate, muriate of potash were at the rate of 20, 22, 15 Tk per Kg; 1 USD= 80 Tk

CONCLUSION

The cowpea has drought tolerance since the crop response factor of it (K_y=0.98) was less than unity. Three weeks-interval irrigation showed the highest yield, benefit-cost ratio, and crop water productivity was the lowest value which was an indicator of more water consumption. The pod formation stage of cowpea was more critical for irrigation than the flowering stage since the yield, crop water productivity, and benefit-cost ratio of irrigation at the pod formation stage were higher than the flowering stage. The unit production cost of irrigation at pod formation was also lower than irrigation at the flowering stage. Therefore, when there are once or twice irrigation facilities, it might be recommended that irrigation at the pod formation stage is for once and irrigation at flowering plus pod formation stages is twice.

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APPENDEX A.

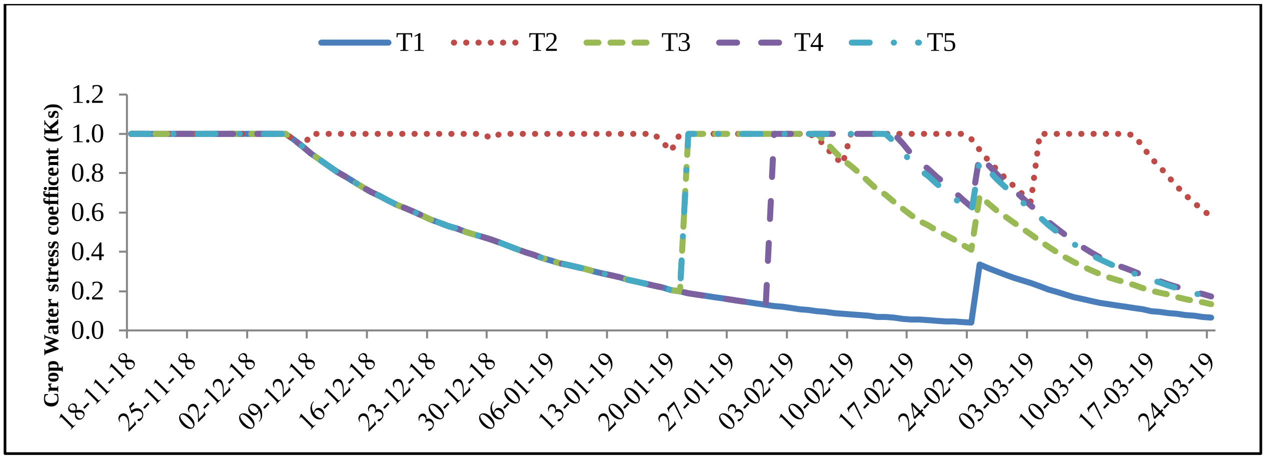


Figure A1. Crop water stress coefficient (Ks) of treatments in 2018-2019

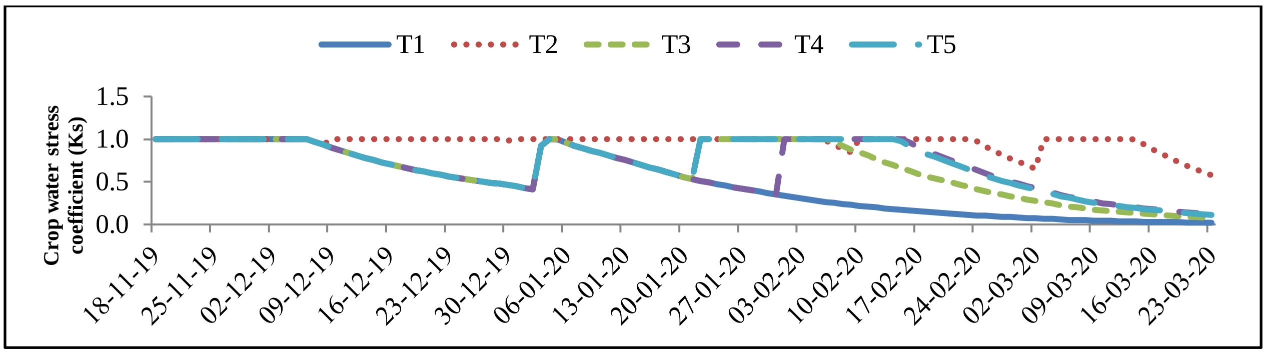
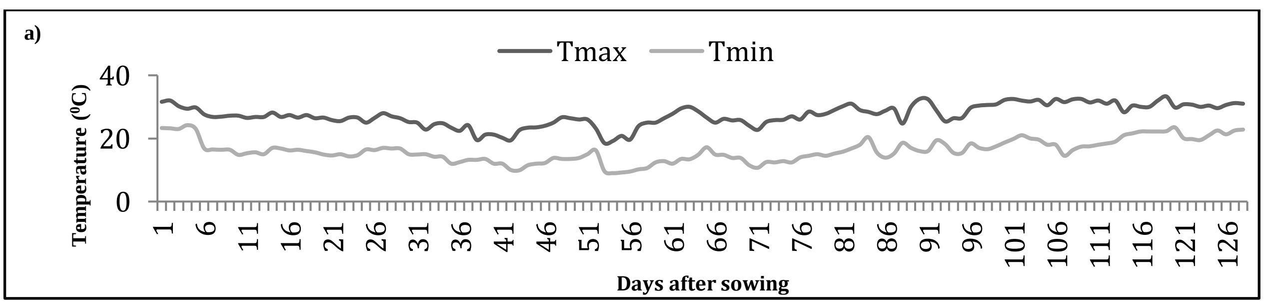
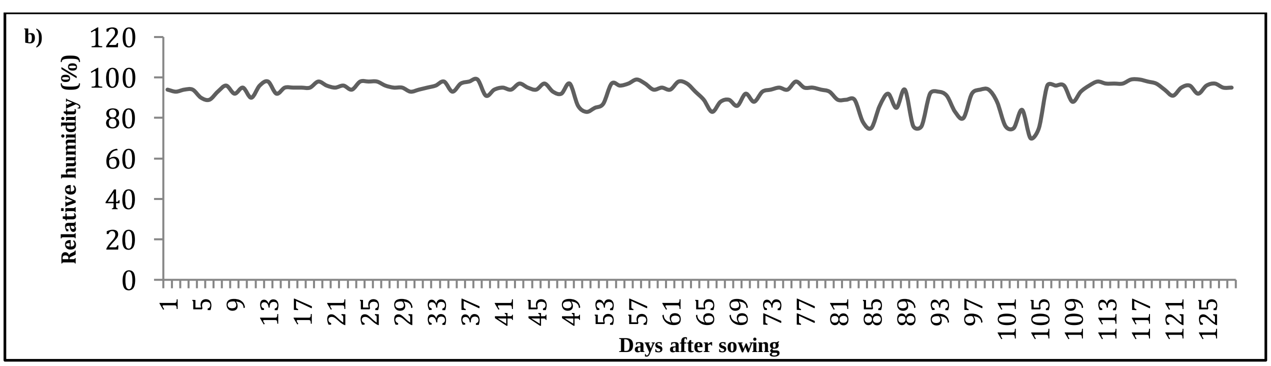
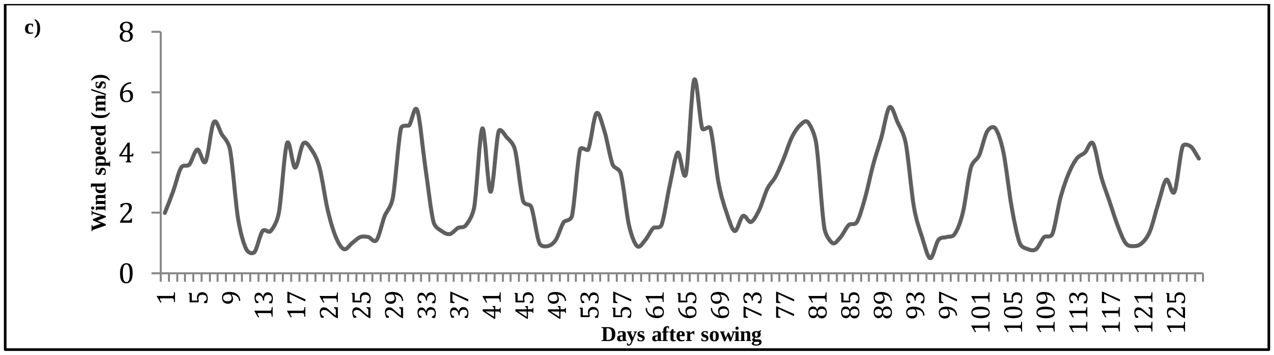


Figure A2. Crop water stress coefficient (Ks) of treatments in 2019-2020







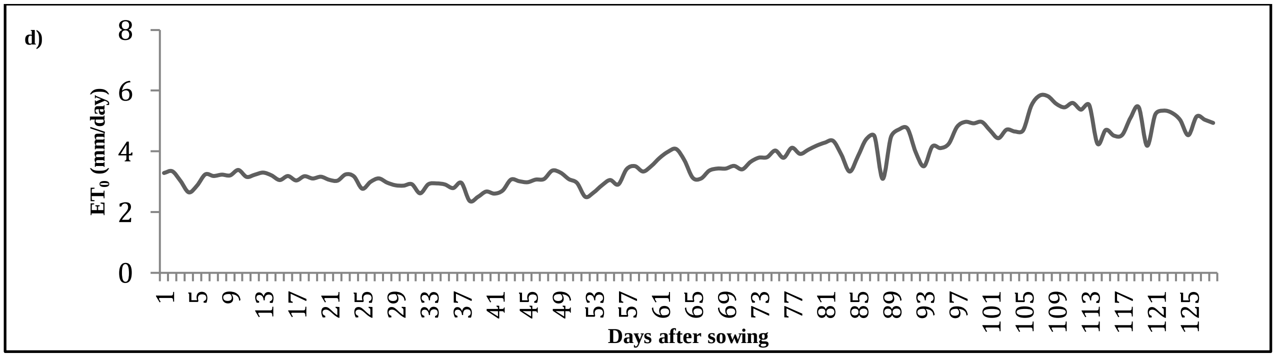


Figure A3. Mean of two seasons (2018-19 and 2019-2020) a) temperature b) Relative humidity c) weed speed d) ET_0

Table A1. Seasonal irrigation, effective rainfall and actual evapotranspiration in treatments

	Treatment									
	2018-2019					2019-2020				
	T_1	T_2	T_3	T_4	T_5	T_1	T_2	T_3	T_4	T_5
Irrigation event	0	5	1	1	2	0	5	1	1	2
Irrigation (mm)	0	181.2	63	66	79	0	194	50	58	66
Effective rainfall (mm)	12.8	12.8	12.8	12.8	12.8	28.7	28.7	28.7	28.7	28.7
Actual ET (mm)	84.4	231	144.6	146	159.2	102.1	231.3	149.4	155.4	164

T_1=Rain fed, T_2= Irrigation at 3 weeks intervals, T_3= Irrigation at flowering stage, T_4= Irrigation at pod formation stage, T_5= Irrigation at flowering and pod formation stages

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