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Interaction Effect of Skipping Irrigation and Co-inoculation with *Bradyrhizobium* and Some Strains of *Bacillus* Bacteria on Growth Dynamics of Cowpea (*Vigna radiata* L.), Its Yield and Water Productivity

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A FIELD experiment was conducted at Sakha Agricultural Research Station, Kafr El-Sheikh Governorate, North Nile Delta area, Egypt during the two successive growing seasons 2018 and 2019 to assess the interaction effect of skipping irrigation and co-inoculation of cowpea (Vigna 2019 to assess the interaction effect of skipping irrigation and co-inoculation of cowpea (*Vigna radiata* L.), with *Bradyrhizobium* sp. and some strains of *Bacillus* bacteria on growth dynamics, yield and water productivity. Spilt- plot design was used, the main plots were assigned to four treatments of water stress; I_1: control treatment (no stress); I_2: withholding one irrigation at the vegetative growth stage; I_3: withholding one irrigation at the flowering growth stage; I_4: withholding one irrigation at pod formation stage; while inoculation treatments were assigned to sub main plots which were: T_1: inoculation with *Bradyrhizobium* sp. TAL 169 (control); T_2: inoculation with *Bradyrhizobium* sp. TAL 169 $_+$ *B. subtilis* MF497446;$T_{3:}$ inoculation with *Bradyrhizobium* sp. TAL 169$_+$ *B. coagulans* NCAIM B.01123; $T_{4:}$ inoculation with *Bradyrhizobium* sp. TAL 169$_+$ *B. circulance* NCAIM B.02324. Our results of this present investigation showed that the flowering stage is the most sensitive stage in connection with cowpea watering following with vegetative and pod formation stages. Also, treatment I_4T_4 recorded high values 7.61 g plant^{-1}, 39.00, 0.388 g plant^{-1}, 256.00 mg plant^{-1} and 1.054 mg g^{-1} FW at the first growing season for dry weight of plant, number of nodules plant^{-1}, dry weight of nodules, N and total chlorophyll contents compared to other treatments at 45 days after sowing (DAS), respectively. A similar trend was observed at 60 DAS. Irrigation at all stages accompanied with inoculation by *Bradyrhizobium* $_+$ *B. circulance* (I_1T_4 treatment) gave the highest number of pods plant^{-1}, 100 seed weight and yield which the corresponding decrease in yield was 11.8, 1.4 and 0.4 %, for flowering, vegetative and pod formation stages, respectively. On the contrary, withdrawn irrigation at formation (I_4) under T_4 produced the highest values of productivity of irrigation water (PIW) and water productivity (WP). Herein, irrigation treatments followed the descending order of $I_1 > I_2 > I_3 > I_4$. However, it followed as $T_4 > T_3 > T_2 > T_1$ under inoculation treatments. Thus, inoculation with *Bradyrhizobium* sp. $_+$ *B. circulance* under withholding one irrigation at pod formation stage could be efficiently used to partially eliminate the effects of water stress on growth dynamics of cowpea.

Keywords: Water stress, Cowpea, Co-inoculation, Yield, Crop-Water relations.

Introduction

The arid and semi-arid zones of Africa as well other areas worldwide are facing a massive challenge in agriculture as the climate changes, and improving the efficiency of water use by plants constitutes one of the most important challenges for crop breeders (Simova-Stoilova et al., 2015, Gagné-Bourque et al., 2016 and Ali et al. 2019). Among the most important of abiotic

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stresses, drought is particularly detrimental to plant growth and yield in agricultural production, affecting the world's food security (Vurukonda et al., 2016), and if current trends continue, drought-affected areas are expected to double, and water resources will decrease by 30% by 2050 (Kasim et al., 2013).Therefore, the presence of water in the rhizosphere area is a major parameter that determines the availability of water, oxygen, and nutrients to plants and microorganisms (Van Gestel et al., 1993). Also, the complex interactions among microorganisms, roots, soil, and water in the rhizosphere induce changes in physico-chemical and structural properties of the soil (Haynes and Swift, 1990 and Ali et al., 2018). In addition to, the behavior growth of legumes are affected by drought, which can due to reduction in vegetative growth, nodulation, yield and yield component, with a gradual decrease in nutrients of the plants (Costa et al., 2011, Omara and El-Gaafarey, 2018, Abd-Elrahman and Taha, 2018 and Abdelhameid, 2019).

Moreover, one of the most important leguminous crops is cowpea which its high protein content, heat tolerant, rich in amino acids and low fertilizer requirements as well as irrigation is an important factor that affects the yield and quality. Therefore, under harsh environmental conditions we should be develop strategies to enhance water stress tolerance. One of these strategies is to use microorganisms which can play a significant role to improve growth and productivity of cowpea through several topics such as their interaction with plants, genetic diversity, tolerance to water stress conditions, biosynthesis of osmolytes and production of hormones (Lebrazi and Benbrahim, 2014, Bertrand et al., 2015, Etesami and Maheshwari, 2018, Faiyad et al., 2019 and Hafez et al., 2019). Also, the application of rhizosphere microorganisms can encourage plant growth directly by N_2 fixation, phytohormone and siderophore production, P solubilization, NH_4 production, and indirectly by protecting plants from pathogens by antibiotic production, secretion of lytic enzymes (Nadeem et al., 2010 and Omara & El-Gaafarey, 2018).

There are a lot of reports that demonstrate the efficacy of bio-inoculation by rhizosphere microorganisms such as *Arthrobacter*, *Azotobacter*, *Azospirillum*, *Bacillus*, *Burkholderia*, *Pseudomonas*, *Azorhizobium*, *Bradyrhizobium*, and *Mesorhizobium* under both normal conditions as well as in drought soils and other stressed environments (Saharan and Nehra, 2011, Nadeem et al., 2012, Singh et al., 2017, Bhise et al., 2017 and Hafez et al., 2019). With respect to drought stress, positive trend from application of bio-inoculation is well documented. Raheem et al. (2018) showed that application of the drought-tolerant rhizobacteria *B. amyloliquefaciens*, *B. thuringiensis* and *Enterobacter aerogenes* can help to ameliorate negative effects of wheat plant grown in drylands. On the contrary, AbdouRazakou (2013) found that negative effects of cowpea genotypes, water treatments and their interaction were observed on biomass, water use, water use efficiency and root/shoot ratio.

Omara and El-Gaafarey (2018) reported that applying dual inoculation with tolerant *Bradyrhizobium* SARSRh3 + *Bradyrhizobium* SARS-Rh5, can improve nodulation, growth dynamics as well as increase K% uptake and reduce Na % uptake of cowpea plants. Also, co-inoculation with *Paenibacillus polymyxa* and *Rhizobium tropici* enhancement growth, nitrogen content, and nodulation of common bean (*Phaseolus vulgaris* L.) under a water-deficit environment (Figueiredo et al., 2008). Also, Moursi et al. (2013) showed that application of cowpea with *rhizobium* and different rates of nitrogen enhancement yield and yield components, nitrogen, phosphorus % and protein content under the highest mean values for water productivity and productivity of applied irrigation water.

Therefore, the objective of this study was to find out the interaction effect of skipping irrigation at different growth stages and co-inoculation on cowpea yield, its parameters and crop-water productivity.

Materials and Methods

Location of the studied site

A field experiment was carried out during the two cowpea seasons of 2018 and 2019 at Sakha Agricultural Research Station, Kafr El-Sheikh Governorate. The site is located at 31°- 07' N latitude, 30°- 57' E longitude. It has an elevation of about 6 meters above the mean sea level (altitude). It represents the conditions and circumstances of middle northern part of the Nile Delta region.

Microorganisms and Culture Conditions

In this study, one strain of *Bradyrhizobium* sp. TAL 169 and three strains of *Bacillus* (*B. subtilis* MF497446, *B. coagulans* NCAIM B.01123 and *B. circulance* NCAIM B.02324), were obtained from Bacteriology Laboratory, Sakha Agricultural Research Station, Kafr El-Sheikh, Egypt. The standard culture conditions was prepared by Yeast Extract Mannitol (YEM) liquid medium (Vincent 1970), for *Bradyrhizobium* sp. TAL 169, whereas, Nutrient Broth medium (Atlas 1997), for growth of *B. subtilis*, *B. coagulans* and *B. circulance*.

Climatic conditions

Climatic elements were collected from Sakha Agro Meteorological Station and recorded during the two seasons of cowpea and presented in Table 1.

Soil characteristics

Soil samples were taken before cowpea cultivation from successive depths: 0-20, 20-40 and 40-60 cm, air dried, grounded, sieved for physical and chemical analysis as presented in Table 2. Particle size distribution for soil was done using the pipette method as described by Gee and Bauder (1986), and consequently to find out the soil texture. Bulk density was determined as described by Black et al. (1965). Soil-water constants: field capacity (FC) and permanent wilting point (PWP) were determined by using pressure membrane method at 0.33 and 15 atmosphere (Klute 1986), and the chemical analysis of the experimental soil before sowing were determined as described by Jackson (1973).

TABLE 1. Climatological data of Sakha Agricultural Research Station during the two cowpea growing seasons 2018 and 2019

Month	T (C°)			R.H. (%)			W.S.	P. E.
	Max.	Min.	Mean	Max.	Min.	Mean	m sec^{-1}	(mm day^{-1})
1st season								
June	32.6	25.3	29.0	75.5	48.2	61.9	1.14	7.72
July	34.2	25.4	29.8	82.5	51.0	66.8	1.03	79.0
August	33.9	25.3	29.6	79.5	51.9	65.7	0.87	6.42
Sept.	32.8	23.51	28.2	83.1	48.3	65.7	0.79	4.99
Oct.	29.5	20.6	25.1	82.5	49.6	66.1	0.66	32.4
2nd season								
June	33.0	28.0	30.5	81.5	50.0	65.8	1.19	8.46
July	33.5	28.4	31.0	85.3	54.4	69.9	0.97	8.08
August	34.2	25.9	30.1	89.7	55.6	72.7	0.80	6.82
Sept.	32.4	27.9	30.2	83.4	52.9	68.2	0.66	3.84
Oct.	30.1	26.7	28.4	87.3	54.3	70.8	0.61	3.53

T: Temperature; R.H.: Relative Humidity; W.S.: Wind Speed at 2 m height; P.E.: Pan Evaporation; Max.: Maximum and Min.; Minimum.

TABLE 2. Some soil physical properties, soil moisture constants and chemical properties for the studied site

Soil depth (cm)	Particle Size Distribution %			Texture Class	Soil - water constants			Bulk density (Kg m³)
	Clay	Silt	Sand		FC* (%, wt / wt)	PWP** (%, wt / wt)	AW*** (%, wt / wt)	
0 – 20	51.6	29.8	18.6	Clayey	42.83	21.61	21.22	1.23
20 – 40	52.2	28.6	19.2	Clayey	39.63	21.03	18.60	1.28
40 – 60	52.9	28.3	18.8	Clayey	37.56	21.31	16.25	1.31
Mean	52.2	28.9	18.9	Clayey	40.01	21.32	18.69	1.27

Soil chemical characteristics

Soil depth (cm)	pH	Ec dSm^{-1}	Soluble cations, meq L^{-1}				Soluble anions, meq L^{-1}			
			Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}
0 – 20	8.22	2.90	6.9	5.6	16.4	0.3	0.00	4.8	12.0	12.4
20 – 40	8.27	3.00	7.9	6.1	16.8	0.3	0.00	5.0	14.1	12.0
40 – 60	8.36	4.10	10.6	9.5	21.6	0.4	0.00	5.2	15.2	21.7
Mean	---	3.30	8.5	7.1	18.3	0.3	0.00	5.0	13.8	15.4

FC* = Field capacity, PWP** = Permanent wilting point and AW*** = Available water.

Experimental layout

Cowpea seeds (cv. Karim 7) were grown during the two growing seasons of 2018 and 2019. Dates of sowing were 12th and 16th June, while the dates of harvesting were 15th and 18th October in the first and second seasons, respectively. The plot area was 52.5 m^2 (1/80 fed., 1 fed=0.42ha), and the seeds of cowpea were treated with the inoculation treatments (15 ml of 10^8 CFU ml^{-1} from each culture per thirty grams of the sterilized carrier) then mixed carefully with the seeds using a sticking material and sowing at the rate of 2 seeds per hole with15 cm space. The design of the experiment was split plot with three replicates. The water stress treatments were assigned to the main plots which were I_1: control treatment (no stress); I_2: withholding one irrigation at the vegetative growth stage; I_3: withholding one irrigation at the flowering growth stage andI_4: withholding one irrigation at pod formation stage, while inoculation treatments were assigned to sub main plots which were T_1: inoculation with *Bradyrhizobium* sp. TAL 169; T_2: inoculation with *Bradyrhizobium* sp. TAL 169 $_+$ *B. subtilis* MF497446; $T_{3:}$ inoculation with *Bradyrhizobium* sp. TAL 169$_+$ *B. coagulans* NCAIM B.01123; $T_{4:}$ inoculation with *Bradyrhizobium* sp. TAL 169$_+$ *B. circulance* NCAIM B.02324.

For mineral fertilizers, phosphorus (15.5% P_2O_5), with the rate of 100 Kg fed^{-1} and potassium (48% K_2O) with the rate of 50 Kg fed^{-1} were broadcasted during soil tillage. In addition, ammonium nitrate (33.5% N) was used as nitrogen fertilizer with the rate of 50 Kg fed^{-1} in one dose before the first irrigation for all treatments.

Measurements and analyses

Irrigation water (IW)

Irrigation water was measured by water meter and applied as local farmers irrigate their fields in the area.

Soil moisture depletion

Soil moisture depletion which considered as actual water consumed by the growing crop was calculated using the following equation according to Hansen et al. (1979).

$$Cu = \frac{\theta_2 - \theta_1}{100} * Db * d * A \qquad \text{----- (1)}$$

where:

CU = Actual water consumptive use by the growing plants,

Ө2 = Mean soil moisture percentage, 48 hours following irrigation event,

Ө1= Mean soil moisture percentage before the next irrigation,

Db = Mean soil bulk density (Mg m-3) of 60 cm soil depth,

d = Soil wetting depth, *i.e.* effective root depth of 60 cm and

A =Irrigated area, m2.

Growth dynamics and yield components

At 45 and 60 days after sowing, plant samples were taken to determine plant dry weight (g $plant^{-1}$), number of nodules $plant^{-1}$ and dry weight of nodules (g $plant^{-1}$). Also, nitrogen and total chlorophyll were determined according to the methods described by Black et al. (1965) and Mousa et al. (2007), respectively. While number of pods $plant^{-1}$, 100 seeds weight (g) and seed yield (ton ha^{-1}) of cowpea plants were determined at harvest.

Crop-water relations

Water productivity (WP)

Water productivity (WP) reflects the capability of consumed water by the growing crop in producing the marketable yield. Water productivity is generally defined as crop yield per each unit of water consumption. It was calculated according to Ali et al. (2007).

$$WP = \frac{Y}{ET} \qquad \text{….. (2)}$$

where:

WP = Water productivity (kg m^{-3} consumed),

Y = Yield (kg), and

ET = Seasonal water consumed by the growing crop (m^3).

Productivity irrigation (PIW)

Productivity of irrigation water (PIW) reflects the capability of applied irrigation water to the growing crop in producing the marketable yield. Productivity of irrigation water (PIW) was calculated according to Ali et al. (2007).

$$PWa = \frac{Y}{Wa} \qquad \text{... (3)}$$

where:

PIW = productivity of irrigation water (kg m^{-3} applied),

Y = Yield (kg), and

Wa = Applied water.

Statistical analyses

The data collected during the experiment were analyzed at three replicates by using CoStat program version 6.303. By two ways analysis (ANOVA), differences at $p \leq .05$ were considered to be significant.

Results and Discussion

Water applied and crop-water consumptive use

Values of water applied (Wa) and crop-water consumptive use (CU) are presented in Table 3. The highest seasonal Wa of 89.6 and 91.2 cm were recorded, respectively under I_1T_4 in the two seasons. In the same treatment I_1T_4 has also, the highest seasonal has also CU of 75.9 and 77.2 cm in the first and second seasons, respectively. This finding is due to the increasing of water applied to that control treatment without stress at any growth stage (I_1) under T_4 inoculation compared to other stress treatments (I_2 to I_4). Regarding the influence of water stress at different physiological growth stages. Data in Table 3, also show that both applied water and seasonal CU decreased by increasing water deficit. Comparing with the control non-stress treatment I_1 of 100% Wa Withholding irrigation at vegetative, flowering and pod formation recorded 83.7, 79.5 and 79.6% compared to I_1. In other words, the corresponding reduction in Wa was 16.3, 20.5 and 20.4%. The highest mean values of CU were recorded from irrigation traditional I_1 which were 72.5 cm in the first season and 74.4 cm in the second season, respectively. Mean values of the two seasons of Wa and CU are presented in Fig. 1. Regarding the effect of inoculation treatments under each irrigation treatment, it is cleared that T_4 treatment has the highest values of CU and vice versa for T_1. In other words, under each irrigation treatment, values of Wa and CU for inoculation treatments could be arranged in descending order as $T_4 > T_3 > T_2 > T_1$. As mention before, the most critical growth stage for cowpea is flowering followed by vegetative and pod formation stages. The trend of seasonal values of Wa and CU could be attributed to the fact that during the vegetative growth crop evapotranspiration is small for the young plants at that stage, and then increased gradually to reach the maximum during the flowering stage. At that stage, the plants become more healthy and reached the highest rate of photosynthesis which ultimately reflects in the higher yield. The obtained results are in a good agreement with those supported by Abdelhameid (2019), AbouKherira (2009) and Sakamoto et al. (2012).

TABLE 3. Seasonal water applied (cm) and consumptive use (cm) of cowpea as affected with different water stress and inoculation treatments in 2018 and 2019 growing seasons

Irrigation treatment	Inoculation treatment	2018 season		2019 season		Average	
		Wa	CU	Wa	CU	Wa	CU
I_1	T_1	82.4	69.8	85.0	72.0	83.7	70.9
	T_2	83.1	70.4	86.1	72.9	84.6	71.7
	T_3	87.4	74.0	89.2	75.5	88.3	74.8
	T_4	89.6	75.9	91.2	77.2	90.4	76.6
Mean		85.6	72.5	87.9	74.4	86.8	73.5
I_2	T_1	69.8	60.1	72.5	62.5	71.1	61.3
	T_2	70.5	60.8	73.2	62.9	71.9	61.9
	T_3	71.1	61.3	74.3	63.1	72.7	62.2
	T_4	73.9	63.7	75.8	65.3	74.9	64.5
Mean		71.3	61.5	74.0	63.4	72.7	62.5
I_3	T_1	66.9	58.6	68.5	60.0	67.7	59.3
	T_2	67.2	58.9	68.7	60.2	68.0	59.6
	T_3	68.7	60.2	70.8	62.1	69.8	61.2
	T_4	69.5	60.9	71.2	62.4	70.4	61.7
Mean		68.1	59.7	69.8	61.2	69.0	60.5
I_4	T_1	64.0	54.7	66.3	56.7	65.2	55.7
	T_2	67.8	57.9	69.9	59.7	68.9	58.8
	T_3	68.9	58.9	73.2	62.6	71.1	60.8
	T_4	69.6	59.5	72.1	61.6	70.9	60.6
Mean		67.6	57.8	70.4	60.2	69.0	59.0

Wa: water applied; CU: crop-water consumptive use; I_1: control treatment tradition no stress; I_2: withholding one irrigation at the vegetative growth stage; I_3: withholding one irrigation at the flowering growth stage; I_4: withholdingone irrigation at pod formation stage; T_1: inoculation with *Bradyrhizobium* sp.; T_2: inoculation with *Bradyrhizobium* sp. $_+$ *B. subtilis*; $T_{3:}$ inoculation with *Bradyrhizobium* sp. $_+$ *B. coagulans*; $T_{4:}$ inoculation with *Bradyrhizobium* sp. $_+$ *B. circulance*.

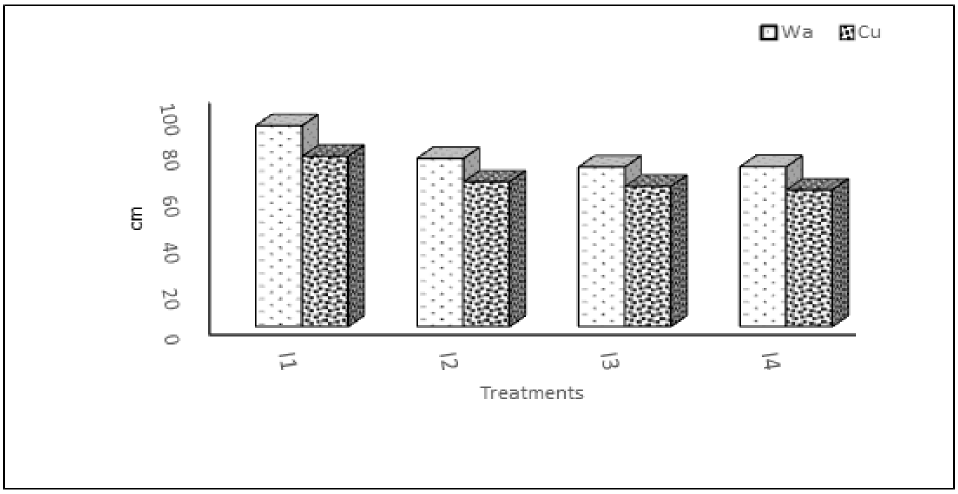

Fig. 1. Mean values of applied water (Wa) and Consumptive use (CU) of cowpea

Vegetative growth parameters

Some growth parameters of cowpea plants at 45 and 60 day after sowing (DAS) grown under different water stress treatments and inoculation treatments are presented in Table 4. No significant differences were observed between water stresses treatments whereas inoculation treatments showed a significant effect (P≤0.05) during the two growing seasons.

Generally, co-inoculation with *Bradyrhizobium* sp. and different strains of *Bacillus* increased the dry weight, number of nodules and dry weight of nodules per plant over inoculation with *Bradyrhizobium* sp. only (control) under different water stress conditions.

In respect to different water stress treatments (Table 4), I_4 treatment (withholding one irrigation at pod formation stage) attained high values 6.84 g plant $^{-1}$ for dry weight of plant, 34.50 for number of nodules plant $^{-1}$ and 0.299 g plant $^{-1}$ for dry weight of nodules at 45 DAS, compared to other different treatments. Similar trend was observed at 60 DAS. On the other hand, inoculation treatments showed that inoculation treatment with *Bradyrhizobium* sp. + *Bacillus circulance* (T_4) was more efficient which recorded 7.47 and 11.84 g plant $^{-1}$ dry weight, 38.41 and 31.66 number of nodule plant $^{-1}$, 0.333 and 0.269 g plant $^{-1}$ dry weight of nodules at 45 and 60 DAS for the first growing season compared to other inoculation treatments and control, respectively. The same trend was observed in the second growing season (Table 4).

The interaction effect between the different water stress and the inoculation with *Bradyrhizobium* sp. and different strains of *Bacillus* showed significant effects on different growth parameters of cowpea (Table 4). At 45 DAS, treatment I_4T_4 (withholding one irrigation at pod formation stage and inoculation with *Bradyrhizobium* sp. + *B. circulance*) recorded high values 7.61 g plant $^{-1}$, 39.00 and 0.388 g plant $^{-1}$ at the first growing season and 7.94 g plant $^{-1}$, 41.00 and 0.342 g plant $^{-1}$ at the second growing season for dry weight of plant, number of nodules plant^{-1} and dry weight of nodules compared to other different treatments, respectively. Similar trend was observed at 60 DAS.

Co-inoculation are commonly used as plant biostimulants for improvement root growth, promote elongation of the shoots and nutrient uptake which due to production of extracellular polysaccharide (EPS), IAA, siderophores, and phosphate solubilization activity (Nadeem et al., 2010 and Zahran, 2017). Therefore, several studies mentioned that combined inoculation of legumes with rhizobia and PGPB can increase vegetative growth and nodulation compared with rhizobia alone and thereby may improve crop yields under stressful conditions. Figueiredo et al. (2008), showed that co-inoculation of common bean with *R. tropici* and *P. polymyxa* strains resulted in greater growth, shoot dry matter accumulation, nodule number and nodule dry matter than inoculation with *Rhizobium* alone. Also, Santos et al. (2018) reported that cowpea plants inoculated with *Bradyrhizobium* and *P. graminis* or *Bradyrhizobium* and *Bacillus* increased number of nodules and dry weight of plant as compared to inoculation with *Bradyrhizobium* only.

TABLE 4. Effect of different irrigation and inoculation treatments and their interaction on dry weight of plant (g plant^{-1}), Number of nodules and dry weight of plant (g plant^{-1}) of cowpea during 2018 and 2019 growing seasons

Treatment	2018 season						2019 season					
	D. W. (g plant^{-1})		N. Nod.		D.W. Nod. (g plant^{-1})		D. W. (g plant^{-1})		N. Nod.		D.W. Nod. (g plant^{-1})	
	45	60	45	60	45	60	45	60	45	60	45	60
(Irrigation treatments)												
I_1	6.70 a	11.78 a	34.25 a	27.41 ab	0.297 a	0.235 a	7.03 a	12.05 a	36.25 a	29.25 a	0.301 a	0.239 a
I_2	6.70 a	10.40 c	34.33 a	26.83 b	0.298 a	0.235 a	7.03 a	10.68 b	36.33 a	29.33 a	0.301 a	0.239 a
I_3	6.64 a	10.13 d	34.00 a	27.58 ab	0.295 a	0.232 a	6.97 a	10.41 c	36.00 a	29.00 a	0.299 a	0.236 a
I_4	6.84 a	11.56 b	34.50 a	28.08 a	0.299 a	0.237 a	7.15 a	11.84 a	36.50 a	29.50 a	0.302 a	0.241 a
LSD 0.05	0.247	0.213	0.828	0.815	0.007	0.006	0.247	0.212	0.818	0.828	0.007	0.006
(Inoculation treatments)												
T_1	5.88 d	10.14 d	30.00 c	23.08 d	0.260 d	0.199 d	6.21 d	10.41 d	32.00 d	25.00 d	0.263 d	0.203 d
T_2	6.60 c	10.77 c	33.25 c	26.50 c	0.288 c	0.226 c	6.93 c	11.05 c	35.25 c	28.25 c	0.292 c	0.230 c
T_3	6.92 b	11.12 b	35.41 b	28.66 b	0.307 b	0.244 b	7.24 b	11.40 b	37.41 b	30.41 b	0.311 b	0.248 b
T_4	7.47 a	11.84 a	38.41 a	31.66 a	0.333 a	0.269 a	7.80 a	12.12 a	40.41 a	33.41 a	0.337 a	0.273 a
LSD 0.05	0.140	0.187	0.890	1.022	0.007	0.007	0.143	0.187	0.888	0.890	0.008	0.007
Interaction												
I_1T_1	5.95 g	10.46 gh	30.33 fg	23.66 h	0.263 fg	0.202 fg	6.28 g	10.72 gh	32.33 fg	25.33 fg	0.267 fg	0.206 fg
$I_1 T_2$	6.66 ef	11.71 cd	34.00 d	27.33 def	0.295 d	0.233 d	6.99 ef	11.99 cd	36.00 d	29.00 d	0.299 d	0.237 d
$I_1 T_3$	6.82 de	11.99 c	34.66 cd	27.66 cde	0.301 cd	0.238 cd	7.15 de	12.27 c	36.66 cd	29.66 cd	0.305 cd	0.242 cd
$I_1 T_4$	7.37 ab	12.97 a	38.00 ab	31.00 ab	0.330 ab	0.266 ab	7.70 ab	13.23 a	40.00 ab	33.00 ab	0.334 ab	0.270 ab
$I_2 T_1$	5.63 h	9.62 jk	28.66 g	20.33 i	0.248 g	0.188 g	5.96 h	9.90 jk	30.66 g	23.66 g	0.252 g	0.192 g
I_2T_2	6.50 f	10.47 g	33.33 de	25.33 fgh	0.289 de	0.227 de	6.83 f	10.75 g	35.33 de	28.33 de	0.293 de	0.231 de
$I_2 T_3$	7.06 cd	10.54 g	36.33 bc	29.33 bcd	0.315 bc	0.252 bc	7.39 cd	10.82 g	38.33 bc	31.33 ab	0.319 bc	0.256 bc
$I_2 T_4$	7.61 a	10.97 f	39.00 a	32.33 a	0.338 a	0.274 a	7.94 a	11.25 f	41.00 a	34.00 a	0.341 a	0.278 a
$I_3 T_1$	5.87 gh	9.90 ij	30.00 fg	23.66 h	0.260 fg	0.199 fg	6.20 gh	10.18 ij	32.00 fg	25.00 fg	0.264 fg	0.203 fg
$I_3 T_2$	6.66 ef	9.50 k	34.00 d	27.33 def	0.295 d	0.233 d	6.99 ef	9.78 k	36.00 d	29.00 d	0.299 d	0.237 d
$I_3 T_3$	6.74 ef	10.09 hi	34.33 d	28.00 cde	0.298 d	0.235 d	7.07 ef	10.37 hi	36.33 d	29.33 d	0.302 d	0.239 d
$I_3 T_4$	7.29 bc	11.06 ef	37.66 ab	31.33 ab	0.327 ab	0.263 ab	7.62 bc	11.34 ef	39.66 ab	32.66 ab	0.331 ab	0.267 ab
$I_4 T_1$	6.10 g	10.58 g	31.00 f	24.66 gh	0.268 f	0.208 f	6.42 g	10.86 g	33.00 f	26.00 f	0.270 f	0.212 f
$I_4 T_2$	6.58 ef	11.42 de	31.66 ef	26.00 efg	0.274 ef	0.213 ef	6.91 ef	11.70 de	33.66 ef	26.66 ef	0.278 ef	0.217 ef
$I_4 T_3$	7.06 cd	11.87 c	36.33 bc	29.66 bc	0.315 bc	0.252 bc	7.36 cd	12.15 c	38.33 bc	31.33 bc	0.319 bc	0.256 bc
$I_4 T_4$	7.61 a	12.38 b	39.00 a	32.00 a	0.338 a	0.274 a	7.94 a	12.66 b	41.00 a	34.00 a	0.342 a	0.278 a
LSD 0.05	0.280	0.374	1.781	2.044	0.015	0.014	0.286	0.375	1.780	1.781	0.016	0.014

D. W.: dry weight; N. Nod.: number of nodules; D.W. Nod.: dry weight of nodules; I_1: control treatment tradition no stress; I_2: withholding one irrigation at the vegetative growth stage; I_3: withholding one irrigation at the flowering growth stage; I_4: withholding one irrigation at pod formation stage; T_1: inoculation with *Bradyrhizobium* sp.; T_2: inoculation with *Bradyrhizobium* sp. $_+$ *B. subtilis*; $T_{3:}$ inoculation with *Bradyrhizobium* sp. $_+$ *B. coagulans*; $T_{4:}$ inoculation with *Bradyrhizobium* sp. $_+$ *B. circulance.* Means in the same column followed by the same letter are not significantly different according to Duncan's test at 0.05 level.

Nitrogen and chlorophyll content

Changes in nitrogen and total chlorophyll in different growth stages of cowpea plants were shown as response to both water stress and bacterial inoculation treatments (Table 5). The amount of N and total chlorophyll were enhanced in I_1 treatment (control), I_2: treatment (withholding one irrigation at the vegetative growth stage) and I_4: treatment (withholding one irrigation at pod formation stage). However, it reduced in I_3 treatment (withholding one irrigation at the flowering growth stage) during the two growing seasons. In addition, when bacteria were present, an increase in N and total chlorophyll were also observed regardless of water stress. Among bacterial treatments, *Bradyrhizobium* sp. + *B. circulance* treatment (T_4) caused the greatest effect over *Bradyrhizobium* sp. treatment at 45 and 60 DAS (Table 5).

Our findings for the interaction effect indicated that there was a statistically significant positive relationship ($p \leq 0.05$) between water stress and inoculation treatments. Data showed that an increase in N content was observed with I_4T_4 treatment (withholding one irrigation at pod formation stage and inoculation with *Bradyrhizobium* sp. + *B. circulance*) resulted 256.00 and 319.60 mg plant^{-1} for the first growing season and 258.30 and 323.00 mg plant $^{-1}$ for the second growing season followed by I_2T_4 treatment (withholding one irrigation at the vegetative growth stage and inoculation with *Bradyrhizobium* sp. + *B. circulance*) which attained 256.00 and 283.20 mg plant $^{-1}$ for the first growing season and 258.30 and 286.00 mg plant $^{-1}$ for the second growing season at 45 and 60 DAS, respectively. Regarding chlorophyll content, there was an increase with I_4T_4 treatment which recorded high values 1.054 and 1.124 mg g^{-1} FW at 45 days from sowing and 1.250 and 1.290 mg g^{-1} FW at 60 days from sowing for the first and second growing seasons compared to other treatments, respectively (Table 5).

As previously mentioned, improvement of N_2-fixation and chlorophyll content in cowpea plants grown under water stress conditions could be attributed to the increase in infection sites on roots for rhizobial invasions (Kurdali et al., 2013). On the other hand, the occurrence of N_2-fixation under stresses, regardless to co-inoculation effects, could be explained by the presence of effective PGPR drought tolerant which lead to increase nodulation and nitrogen fixation as well as soil N uptake (Kurdali et al., 2019). Under drought stress, Mouradi et al. (2016), showed higher growth, nodulation and N content of alfalfa plants inoculated with *Sinorhizobium meliloti* (high tolerant drought). Also, the shoot nitrogen and chlorophyll content of common bean was significant ($P \leq 0.05$) in relation to the treatment that inoculated with *R. tropici* and *P. polymyxa* strains as compared to *R. tropici* only (Figueiredo et al., 2008).

Number of pods, 100 seeds weight and yield

Under field conditions, different strains of *Bacillus* (*B. subtilis*, *B. coagulans* and *B. circulance*) were used for inoculation studies on number of pods, 100 seeds weight and yield of cowpea plants grown in clayey soil under different water stress treatments (Table 6).

At different water treatments, traditional irrigation (no stress) treatment I_1 gave the highest values of cowpea yield compared to those stress treatments. Seed yield data of irrigation treatments followed the descending order of $I_1 > I_2 > I_3 > I_4$.However, it followed as $T_4 > T_3 > T_2 > T_1$ under inoculation treatments. The decreasing of seed yield for stress irrigation compared to traditional irrigation were 1.4, 11.8 and 0.4% under I_2, I_3 and I_4 but under inoculation treatments compared to T_4 (the highest seed yield) followed as 27.1, 16.1 and 7.1% under T_3, T_2 and T_1, respectively.

For the interaction effect between the main plot (different water stress treatments) and sub main plot (inoculation treatments), data showed that I_4T_4 treatment (withholding one irrigation at pod formation stage and inoculation with *Bradyrhizobium* sp. + *B. circulance*) attained an increase in yield parameters reached to 35.24% for number of pods, 49.79% for 100 seeds weight and 43.22% for yield compared to the minimum treatment I_2T_1 (withholding one irrigation at the vegetative growth stage and inoculation with *Bradyrhizobium* sp.) for the first growing season. Similar trend was observed in the second growing season (Table 6). These results showed that *Bradyrhizobium* and *Bacillus* strains can increase number of pods, 100 seeds weight and yield of cowpea under water deficit conditions which due to increasing availability of soil nutrients and increasing amount of nutrients uptake. Also, from the analysis of the obtained results, it is cleared that irrigating cowpea at all growing stages in the highest yield beside its parameters. This finding could be attributed to the enough soil-water available to be consumed by the cultivated plants

TABLE 5. Effect of different irrigation and inoculation treatments and their interaction on nitrogen (mg plant^{-1}) and total chlorophyll (mg g^{-1} FW) contents of cowpea during 2018 and 2019 growing seasons.

Treatment	2018 season				2019 season			
	N (mg plant $^{-1}$)		T. ch. (mg g^{-1} FW)		N (mg plant $^{-1}$)		T. ch. (mg g^{-1} FW)	
	45	60	45	60	45	60	45	60
(Irrigation treatments)								
I_1	225.33 a	304.20 a	0.905 a	1.077 a	227.63 a	307.60 a	0.975 a	1.117 a
I_2	225.33 a	268.50 c	0.908 a	1.080 a	227.63 a	271.90 c	0.978 a	1.120 a
I_3	223.33 a	261.70 d	0.897 a	1.068 a	225.63 a	265.10 d	0.967 a	1.108 a
I_4	230.00 a	298.50 b	0.913 a	1.086 a	232.30 a	301.90 b	0.983 a	1.126 a
LSD 0.05	8.317	5.517	0.025	0.030	8.317	5.517	0.025	0.030
(Inoculation treatments)								
T_1	198.00 d	261.80 d	0.772 d	0.922 d	200.30 d	265.20 d	0.842 d	0.962 d
T_2	222.00 c	278.20 c	0.874 c	1.040 c	224.30 c	281.60 c	0.944 c	1.080 c
T_3	232.66 b	287.10 b	0.942 b	1.120 b	234.96 b	290.50 b	1.012 b	1.160 b
T_4	251.33 a	305.80 a	1.036 a	1.229 a	253.63 a	309.20 a	1.106 a	1.269 a
LSD 0.05	4.699	4.796	0.027	0.032	4.699	4.796	0.027	0.032
Interaction								
I_1T_1	200.00 g	270.00 g	0.783 fg	0.934 fg	202.30 g	273.40 g	0.853 fg	0.974 fg
$I_1 T_2$	224.00 ef	302.40 cd	0.898 d	1.068 d	226.30 ef	305.80 cd	0.968 d	1.108 d
$I_1 T_3$	229.33 de	309.60 c	0.918 cd	1.092 cd	231.63 de	313.00 c	0.988 cd	1.132 cd
$I_1 T_4$	248.00 ab	334.80 a	1.023 ab	1.214 ab	250.30 ab	338.20 a	1.093 ab	1.254 ab
$I_2 T_1$	189.33 h	248.40 ij	0.731 g	0.873 g	191.63 h	251.80 ij	0.801 g	0.913 g
I_2T_2	218.66 f	270.40 g	0.877 de	1.043 de	220.96 f	273.80 g	0.947 de	1.083 de
$I_2 T_3$	237.33 cd	272.00 g	0.971 bc	1.153 bc	239.63 cd	275.40 g	1.041 bc	1.193 bc
$I_2 T_4$	256.00 a	283.20 f	1.054 a	1.250 a	258.30 a	286.60 f	1.124 a	1.290 a
$I_3 T_1$	197.33 gh	255.60 hi	0.772 fg	0.922 fg	199.63 gh	259.00 hi	0.842 fg	0.962 fg
$I_3 T_2$	224.00 ef	245.20 j	0.898 d	1.068 d	226.30 ef	248.60 j	0.968 d	1.108 d
$I_3 T_3$	226.66 ef	260.40 h	0.908 d	1.080 d	228.96 ef	263.80 h	0.978 d	1.120 d
$I_3 T_4$	245.33 bc	285.60 ef	1.012 ab	1.202 ab	247.63 bc	289.00 ef	1.082 ab	1.242 ab
$I_4 T_1$	205.33 g	273.20 g	0.804 f	0.958 f	207.63 g	276.60 g	0.874 f	0.998 f
$I_4 T_2$	221.33 ef	294.80 de	0.825 ef	0.983 ef	223.63 ef	298.20 de	0.895 ef	1.023 ef
$I_4 T_3$	237.33 cd	306.40 c	0.971 bc	1.153 bc	239.63 cd	309.80 c	1.041 bc	1.193 bc
$I_4 T_4$	256.00 a	319.60 b	1.054 a	1.250 a	258.30 a	323.00 b	1.124 a	1.290 a
LSD 0.05	9.399	9.592	0.055	0.065	9.399	9.592	0.055	0.065

N: Nitrogen and T. ch.: Total chlorophyll; I_1: control treatment (tradition no stress); I_2: withholding one irrigation at the vegetative growth stage; I_3: withholding one irrigation at the flowering growth stage; I_4: withholdingone irrigation at pod formation stage; T_1: inoculation with *Bradyrhizobium* sp.; T_2: inoculation with *Bradyrhizobium* sp. $_+$ *B. subtilis*; $T_{3:}$ inoculation with *Bradyrhizobium* sp. $_+$ *B. coagulans*; $T_{4:}$ inoculation with *Bradyrhizobium* sp. $_+$ *B. circulance*. Means in the same column followed by the same letter are not significantly different according to Duncan's test at 0.05 level.

TABLE 6. Effect of different irrigation and inoculation treatments and their interaction on number of pods (plant-1), 100 seeds weight (g) and yield (ton ha-1) of cowpea during 2018 and 2019 growing seasons

Treatment	2018 season			2019 season		
	Number of pods (plant $^{-1}$)	100 seeds weight (g)	Yield (ton ha $^{-1}$)	Number of pods (plant $^{-1}$)	100 seeds weight (g)	Yield (ton ha $^{-1}$)
(Irrigation treatments)						
I_1	21.20 a	16.10 a	2.38 a	22.02 a	16.30 a	2.46 a
I_2	20.58 a	15.48 a	2.35 a	21.38 a	15.68 a	2.42 a
I_3	18.77 b	13.67 b	2.10 b	19.57 b	13.87 b	2.17 b
I_4	20.77 a	15.67 a	2.37 a	21.57 a	15.87 a	2.45 a
LSD 0.05	0.767	0.763	0.069	0.797	0.767	0.070
(Inoculation treatments)						
T_1	17.87 d	12.77 d	1.92 d	18.58 d	12.97 d	1.98 d
T_2	19.96 c	14.86 c	2.21 c	20.75 c	15.06 c	2.28 c
T_3	20.90 b	15.80 b	2.45 b	21.73 b	16.00 b	2.52 b
T_4	22.59 a	17.49 a	2.63 a	23.49 a	17.69 a	2.72 a
LSD 0.05	0.434	0.430	0.073	0.451	0.434	0.075
Interaction						
I_1T_1	16.92 f	11.82 f	1.62 h	17.63 f	12.02 f	1.68 h
$I_1 T_2$	18.64 d	13.54 d	2.05 fg	19.44 d	13.74 d	2.12 fg
$I_1 T_3$	18.94 d	13.84 d	2.35 d	19.76 d	14.04 d	2.42 d
$I_1 T_4$	20.56 c	15.46 c	2.40 cd	21.45 c	15.66 c	2.48 cd
$I_2 T_1$	17.45 ef	12.35 ef	1.92 g	18.12 ef	12.55 ef	1.98 g
I_2T_2	20.16 c	15.06 c	2.29 de	20.94 c	15.26 c	2.36 de
$I_2 T_3$	21.88 b	16.78 b	2.53 bc	22.73 b	16.98 b	2.61 bc
$I_2 T_4$	23.60 a	18.50 a	2.75 a	24.51 a	18.70 a	2.83 a
$I_3 T_1$	18.19 de	13.09 de	2.02 fg	18.90 de	13.29 de	2.09 fg
$I_3 T_2$	20.64 c	15.54 c	2.35 d	21.44 c	15.74 c	2.42 d
$I_3 T_3$	20.89 c	15.79 c	2.37 d	21.70 c	15.99 c	2.45 d
$I_3 T_4$	22.61 b	17.51 b	2.64 ab	23.49 b	17.71 b	2.72 ab
$I_4 T_1$	18.93 d	13.83 d	2.10 f	19.66 d	14.03 d	2.17 f
$I_4 T_2$	20.40 c	15.30 c	2.16 ef	21.19 c	15.50 c	2.23 ef
$I_4 T_3$	21.88 b	16.78 b	2.53 bc	22.73 b	16.98 b	2.61 bc
$I_4 T_4$	23.60 a	18.50 a	2.75 a	24.51 a	18.70 a	2.83 a
LSD 0.05	0.868	0.862	0.146	0.902	0.860	0.151

I_1: control treatment tradition no stress; I_2: withholding one irrigation at the vegetative growth stage; I_3: withholding one irrigation at the flowering growth stage; I_4: withholdingone irrigation at pod formation stage; T_1: inoculation with *Bradyrhizobium* sp.; T_2: inoculation with *Bradyrhizobium* sp. $_+$ *B. subtilis*; $T_{3:}$ inoculation with *Bradyrhizobium* sp. $_+$ *B. coagulans*; $T_{4:}$ inoculation with *Bradyrhizobium* sp. $_+$ *B. circulance*. Means in the same column followed by the same letter are not significantly different according to Duncan's test at 0.05 level.

during the whole growing season. Adequate soil-water resulted in healthy plants and consequently increase photosynthesis and ultimately high yield could be gained. The present results are in agreement with those supported by Pinheiro and Chaves (2011) who stated that water is typically the most limiting resource to plant growth and productivity. Also, Oliveira et al. (2017) showed that an increase in the number of seeds of 67% and 61% in cowpea inoculated with *B. elkanii* and *B. elkanii* + *R. irregularis*, respectively; and an increase of 63%, 55% and 84% in the total weight of seeds per plant inoculated with *B. elkanii*, *R. irregularis* and *B. elkanii* + *R. irregularis*, respectively under severe water deficit. Haro et al. (2018) showed that cowpea productivity was significantly improved by dual inoculation with native rhizobial and mycorrhizal strains as compared to single inoculation.

Water productivities

In this study, WP of water stress treatment I_4 was generally the highest compared to other treatments of I_1, I_2 and I_3 as shown in Table 7. The values of IWP and WP were significantly affected by water stress and inoculation in the two growing seasons. In both seasons, the average IWP and WP of water stress treatments followed as $I_4 > I_3 > I_2 > I_1$. Meaningfully, increasing CU resulted in low WP owing to CU is the dominator of the equation of WP and vice versa regarding the marketable yield as the nominator of WP and IWP equations. But under inoculation, IWP and WP can be followed as $T_4 > T_3 > T_2 > T_1$, respectively. Therefore, the mean values of IWP and WP for different irrigation treatments are presented in Fig. 2. The obtained results are in a good agreement that reported by Abdou Razakou (2013) who found high significant effects of cowpea genotypes, water treatments and their interaction were observed on biomass (BM), water use (WU), water use efficiency (WUE) and root / shoot ratio (RSR). Water stress significantly decreased BM and WUE of water stressed cowpea

TABLE 7. Seasonal cowpea water productivity (IWPand WP, kg m^3) as affected with different irrigation and inoculation treatments during 2018 and 2019 growing seasons.

Irrigation treatment	Inoculation treatment	2018 season		2019 season			
		IWP	WP	IWP	WP	IWP	WP
I_1	T_1	0.197	0.232	0.198	0.233	0.198	0.233
	T_2	0.247	0.291	0.265	0.291	0.256	0.291
	T_3	0.269	0.317	0.271	0.320	0.270	0.319
	T_4	0.268	0.316	0.272	0.321	0.270	0.319
Mean		0.245	0.289	0.252	0.291	0.249	0.291
I_2	T_1	0.275	0.319	0.273	0.317	0.274	0.318
	T_2	0.325	0.377	0.322	0.375	0.324	0.376
	T_3	0.356	0.413	0.351	0.414	0.354	0.414
	T_4	0.372	0.432	0.373	0.433	0.373	0.433
Mean		0.332	0.385	0.330	0.385	0.331	0.385
I_3	T_1	0.302	0.345	0.305	0.348	0.304	0.347
	T_2	0.350	0.399	0.353	0.402	0.352	0.401
	T_3	0.345	0.393	0.346	0.394	0.346	0.394
	T_4	0.380	0.434	0.382	0.436	0.381	0.435
Mean		0.343	0.393	0.347	0.390	0.346	0.394
I_4	T_1	0.328	0.370	0.327	0.370	0.328	0.370
	T_2	0.319	0.373	0.319	0.373	0.319	0.373
	T_3	0.367	0.430	0.356	0.417	0.362	0.424
	T_4	0.395	0.462	0.393	0.459	0.394	0.461
Mean		0.352	0.409	0.349	0.405	0.351	0.407

IWP: Productivity of irrigation water; WP: Water productivity; I_1: control treatment tradition no stress; I_2: withholding one irrigation at the vegetative growth stage; I_3: withholding one irrigation at the flowering growth stage; I_4: withholding one irrigation at pod formation stage; T_1: inoculation with *Bradyrhizobium* sp.; T_2: inoculation with *Bradyrhizobium* sp. + *B. subtilis*; T_3: inoculation with *Bradyrhizobium* sp. + *B. coagulans*; T_4: inoculation with *Bradyrhizobium* sp. + *B. circulance*.

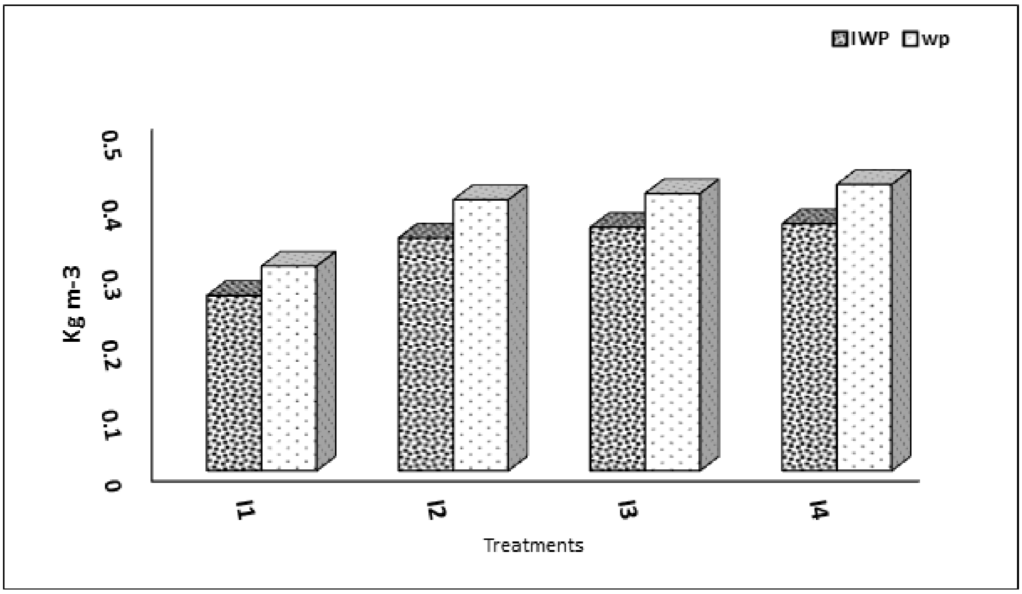

Fig.2. Mean seasonal values of water productivity (IWP and WP, kg/m3) of cowpea plants

varieties compared to the control.

Conclusion

From the previous results it could be concluded that the most sensitive stage for cowpea irrigation is the flowering stage followed by pod formation and vegetative stages. Also, control irrigation (no stress, I_1) with T_4 (inoculation with *Bradyrhizobium* sp. + *B. circulance*) gave the highest cowpea yield and its parameters. On the other hand, both IWP and WP have the same trend with water stress. However, the total yield should be taken into consideration. More researches should be carried out to find out the role of limitation factors on cowpea productivity and how to eliminate the negative impacts of such factors.

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الأثر المتداخل للحرمان من الري والتلقيح المزدوج بالبرادي ريزوبيوم وبعض سلالات الباسيلس البكتيرية علي ديناميكيات النمو لنبات اللوبيا، المحصول وانتاجية المياه

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أقيمت تجربة حقلية بمحطة البحوث الزراعية بسخا - محافظة كفر الشيخ - شمال دلتا النيل - مصر خلال موسمي ٢٠١٨ و٢٠١٩ لتقييم الأثر المتداخل للحرمان من الري والتلقيح المزدوج لنبات اللوبيا بالبرادي ريزوبيوم وبعض سلالات الباسيلس البكتيرية على ديناميكيات النمو والمحصول وإنتاجية المياه. وكان التصميم قطع منشقة مروة واحدة حيث كانت معاملات الري بالقطع الرئيسية وهي أ١- المقارنه بدون حرمان من الري أ٢- حرمان رية واحدة خلال الطور الخضري أ٣- حرمان ريه واحدة خلال طور الازهار أ٤- حرمان ريه واحدة خلال طور تكوين القرون. بينما كانت معاملات التلقيح بالقطع المنشقة هي ت١- التلقيح بالبرادي ريزوبيوم (كنترول) ت٢- التلقيح بالبرادي ريزوبيوم + بكتيريا الباسيلس ساتلس ت٣- التلقيح بالبرادي ريزوبيوم + الباسيلس كواجولانز ت٤- التلقيح بالبرادي ريزوبيوم + الباسيلس سيركيولانس.وقد أوضحت النتائج أن طور التزهير لنبات اللوبيا هي اهم الأطوار حساسية للري والحرمان منها يتسبب في نقص حاد في المحصول ومكوناته ويلي ذلك طور تكوين القرون والطور الخضري.أيضًا ، سجلت المعاملة أ٤ ت٤ قيمًا عالية ٧,٦١ جم / نبات ، ٣٩,٠٠ ، ٠,٣٨٨ جم / نبات ، ٢٥٦,٠٠ مجم / نبات و ١,٠٥٤ مجم وزن طازج / جرام في موسم النمو الأول للوزن الجاف للنبات ، عدد العقد الجذرية ، الوزن الجاف للعقد ، النيتروجين ومحتوى الكلوروفيل الكلي مقارنة بالمعاملات المختلفة الأخرى بعد ٤٥ يومًا من الزراعة ، على التوالي. ولوحظ اتجاه مماثل في عند عمر ٦٠ يوم من الزراعة. كذلك أعطى الري في جميع المراحل في المعاملة المعاملة أ١ ت٤ أعلى عدد من القرون / نبات ووزن ١٠٠ بذرة والمحصول حيث وصل الانخفاض له الي ١١,٨ ، ١,٤ و ٠,٤ ٪ ، لطور الازهار ، الطور الخضري وطور تكوين القرون ، على التوالي. على العكس من ذلك ، ادي حرمان الري في طور تكوين القرون تحت تأثير التلقيح ب ت٤ أعلى قيم لإنتاجية مياه الري وإنتاجية المياه . ومن هنا ، يمكن ترتيب معاملات الري تنازليا لـ أ١ > أ ٢> أ٣ > أ٤ بينما كان ترتيب معاملات التلقيح هي ت٤ > ت٣ > ت٢ > ت١ .لذا، فان معاملة التلقيح ب ت٤ تحت حرمان ريه واحدة في مرحلة تكوين القرون يمكنها تقليل تأثيرات الاجهاد المائي جزئيا على ديناميكيات نمو اللوبيا.