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Improving Water Productivity of Chickpea by the Use of Deficit Irrigation with Treated Domestic Wastewater

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Abstract**—**An experiment was performed in the south of Morocco in order to evaluate the effect of deficit irrigation by treated wastewater on chickpea production. We applied six irrigation treatments on a local variety of chickpea by supplying alternatively 50 or 100% of ETm in a completely randomized design.

We found a highly significant difference between treatments in terms of biomass production. Drought stress during the vegetative period showed highest yield with 6.5 t/ha which was more than the yield obtained for the control (4.9 t/ha). The optimal crop stage in which deficit irrigation can be applied is the vegetative growth stage, as the crop has a chance to develop its root system, to be able to cover the plant needs for water and nutrient supply during the rest of cycle, and non stress conditions during the flowering and seed filling stages allow the plant to optimize its photosynthesis and carbon translocation, therefore increase its productivity.

Keywords**—**chickpea, crop stages, drought stress, water productivity

I. Introduction

WATER scarcity exacerbated by climate change is expected to define food production in the coming decades [1, 2]. Demand for food is growing, in line with population and income growth. Globalization and urbanization are also contributing to dietary preferences switching towards more resource-intensive food [1]. Today it is required to pay attention to the balances in the use and distribution of water more than ever and to use the sources wisely with new strategies [3, 4, 5].

Wastewater has been reused extensively as a source of irrigation water for centuries [6].

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Irrigation does not usually require high-grade water quality compared to drinking water. In addition, reusing wastewater for agriculture has several advantages, such as reducing the amount of effluent discharged into receiving water bodies, nutrient recovery as fertilizers, and increase crop production [7]. So wastewater reuse for agriculture could be a key alternative water source [8, 9].

Among the irrigation strategies that can be sustainable for agriculture is the deficit irrigation strategy [10, 11, 12, 13], Deficit irrigation provides a means of reducing water consumption while minimizing adverse effects on yield [14, 15, 16, 17]. The potential advantages of deficit irrigation appear to be quite significant, particularly in a water-limiting situation, and the associated risks may be quite acceptable [18].

Many studies was conducted on chickpea to evaluate the effect of water stress using deficit irrigation strategy showed that stressing the crop early during the crop cycle stabilize yield and biomass production, while flowering and pod filling stay sensitive to water deficit [19, 20, 21, 22].

An experiment was performed in the south of Morocco in order to evaluate the effect of deficit irrigation by treated wastewater on biomass production parameters of chickpea.

II. Materiels and Methods

The experiment was performed in the south of Morocco, on the IAV-CHA institute farm in Agadir within the SWUPMED project, Soil type was loamy with low salinity, irrigation water was a treated wastewater with EC equal to 1,4 dS/m and very rich in terms of nutrients.

Experimental design was completely randomized with 6 treatments and 4 replications for each treatment. Table I and Fig. 1 show treatments and trial design:

TABLE I
IRRIGATION TREATMENTS (% OF ETM)

Treatment	Germina-tion	Vegetative growth	Flowering	Grain filling	Senescence
T1	100	100	100	100	0
T2	100	50	50	50	0
T3	100	100	50	100	0
T4	100	100	100	50	0
T5	100	50	100	100	0
T6	100	50	50	100	0

Sowing of a local variety of chickpea took place in April, 11th 2010, the distance between 2 seeds was 20 cm and between 2 was 50 cm. The length of plots was 6 m and width was 3 m.

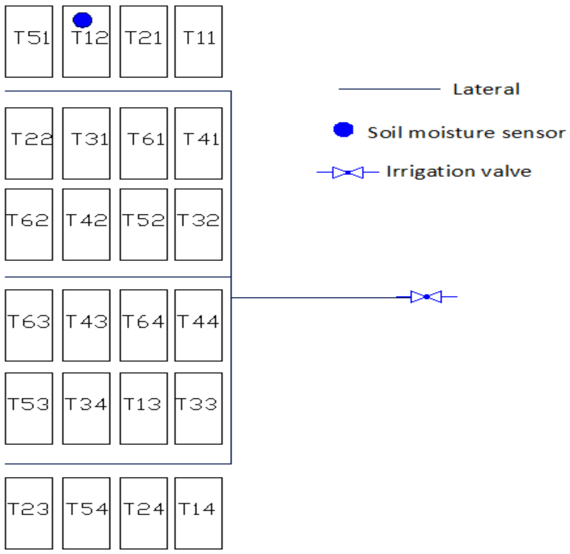

Fig. 1 Experimental design

In order to supply exactly the correct water quantity for each treatment, we developed an irrigation system based on two kinds of telemetry, short and long range. We used several soil moisture sensors, and installed two kinds of drippers with two different discharges: 2 l/hr to apply 100% of ETm and 1 l/hr to apply 50% of ETm.

To calculate net irrigation requirement we have used four approaches, related to soil, climate, crop and irrigation system. From the soil approach we use the net maximal dose (NMD) expressed in mm and equal to [23]:

$$NMD = f \times (FC_{RH} - PWP_{RH}) \times Z \times \%\, SH \qquad (1)$$

Where (1):

- f: allowable depletion = 10%
- H_{cc} : field capacity humidity = 30%
- H_{pfp}: permanent wilting point humidity = 15%
- Z: roots depth = 25 cm
- % SH: percentage of wet area = 30%

So NMD = 1.125 mm

In our system we had 6 drippers per m^2 and the nominal discharge of each dripper is equal to 2 l/h, so the hourly pluviometry (PH) is equal to: PH = 2 x 5 = 10 mm/hr, so the irrigation time (Tirri) required to give one NMD is equal to

$$T_{irri} = NMD/PH = 1.125/10 = 7 \text{ min} \qquad (2)$$

Equation 2 means that to supply 1 NMD to satisfy the allowable depletion we need about 7 min.

The net irrigation requirement (NIR) is equal to NIR = ETm/Eff, where ETm is the maximal evapotranspiration and Eff is the system efficiency which is equal to 0.85 (drip irrigation).

$$ETm = Kc \times ETo \qquad (3)$$

In the equation 3 the crop approach (Kc) and the climate approach (ETo) were used, The Kc coefficient serves as an aggregation of the physical and physiological differences between crops [24]. ETo represents the climate approach, provided by the IAV-CHA weather station. It is calculated by the Penman equation which was the first to combine energy and atmospheric vapor transport components to estimate ETo [25].

For example if we yesterday had ETo = 4, and Kc = 0.95, so for irrigation today we must supply:

$$NIR = ETm/Eff = Kc \times ETo/Eff = 0.95 \times 4/0.85 = 4.47 \text{ mm} \qquad (4)$$

Irrigation frequency is one of the most important factors in drip irrigation scheduling. Due to the differences in soil moisture and wetting pattern, crop yields may be different when the same quantity of water is applied under different irrigation frequencies [26].

Frequency is equal to (5):

$$F = NIR/NMD = 4.47 / 1.125 = 3.97 \qquad (5)$$

So we have to irrigate 3 times, 7 min each time, and the rest we have to give it tomorrow so we should add it to the irrigation supply of tomorrow, and so for all the next days.Differences between response variables to deficit irrigation treatments were assessed with a general linear model in the StatSoft STATISTICA 8.0.550. All statistical differences were significant at $\alpha = 0.05$ or lower. Tukey HSD test was used to reveal homogeneous groups.

III.Results

A. Climatic data

It was very necessary to record the climatic parameters such as temperature during the crop cycle of chickpea because the high temperature especially in this zone of arid climate affects negatively the biomass production of crops [27, 28, 29].

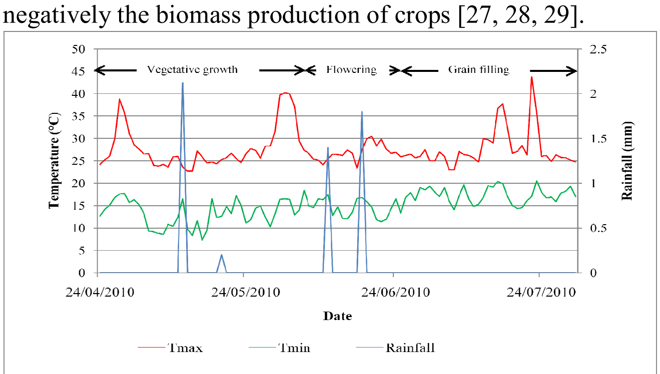

Fig. 2 Temperature and rainfall recorded during the crop cycle of chickpea

According to Fig. 2 There was 4 temperatures picks during (above 35°C) the crop cycle (Fig. 2), but just during a few days without effect on biomass production. There were also 4 rainy days during the crop cycle, in average the rainfall did not exceed 2 mm, the irrigation supplies calculation was taken in consideration water supplied by the rain. Fig. 3 shows the reference evatranspiration (ETo) that was provided by the climatic station of the IAV-CHA institute, it was calculated based on the Penman-Monteith equation, it shows also the maximal evatranspiration and the crop coefficient Kc according the FAO56 paper, the maximal evatranspiration ETm is equal to ETo x Kc [24].

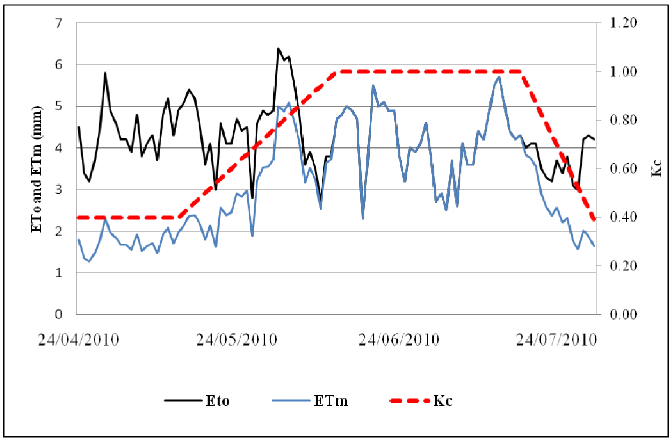

Fig. 3 Reference, maximal evatranspiration and crop coefficient of Chickpea

B. Leaf Area Index (LAI)

The statistical analysis shows a significant difference between treatments during the vegetative growth (p = 0.33) and grain filling stage (p= 0.3), treatment fully (T2) stressed shows the lowest LAI value especially during vegetative growth and flowering stages. It represents 66%, 43% and 50% of reduction compared to control (T1) successively during vegetative growth, flowering and grain filling stage (Fig. 4).

Applying stress during vegetative growth (T5) has stimulated crop growth, this treatment shows a LAI value slightly higher than the LAI obtained by control (T1) during both flowering (1.75%) and grain filling stage (0.8%).When we have put the crop under stress condition during the grain filling stage (T4) we obtained a reduction of 38% compared to the LAI of the same treatment (T4) was obtained during flowering and 42% of reduction compared to LAI of control during was obtained during grain filling stage.

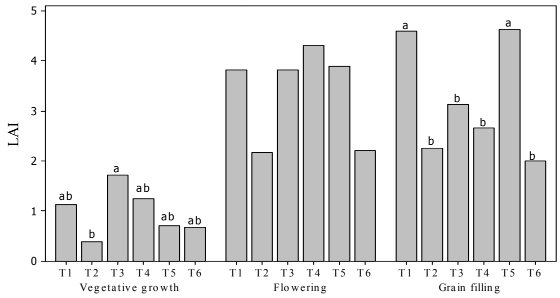

Fig. 4 Leaf Area Index during crop cycle of chickpea

C. Root weight

For fresh weight, there was a significant difference between treatments for all crop stage; p=0.03 for vegetative growth, p=0.013 for flowering and p=0.006 for grain filling stage; treatment stressed during vegetative growth (T2, T5 and T6) showed decreasing in root fresh weight successively by 50, 45 and 57%, after supplying 100% of ETm for treatment stressed during vegetative growth (T5) we recorder an increasing of root weight of 340% during flowering and 664% during grain filling stage compared to fresh weight obtained during vegetative growth stage. For treatment fully stressed (T2) showed often the lowest root weight (Fig. 5 a).

The same results are recorded for dry weight (Fig. 5 b) with significant difference during vegetative growth (p=0.05) and very highly significant difference during grain filling stage (p=0.001)

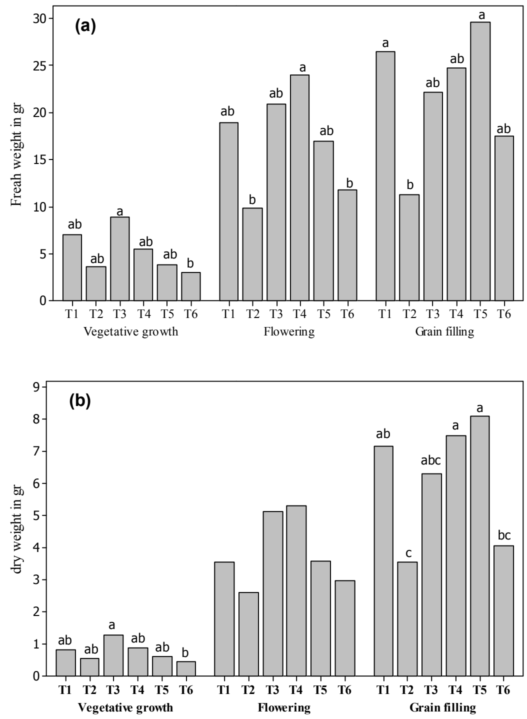

Fig. 5 Root fresh weight (a) and dry weight (b) during crop cycle

D. Stem weight

The statistical analysis revealed a significant difference in the most of crop stages, treatment fully stressed (T2) showed often the lowest stem weight, for treatment stressed during vegetative growth (T5) we assist an increasing of stem fresh weight of about 513% during flowering and 1186% during grain filling stage compared to stem fresh weight obtained during vegetative growth, while the treatment stressed during grain filling stage (T4) showed a low increasing rate of 1.3% of stem weight compared to flowering stage (Fig. 6).

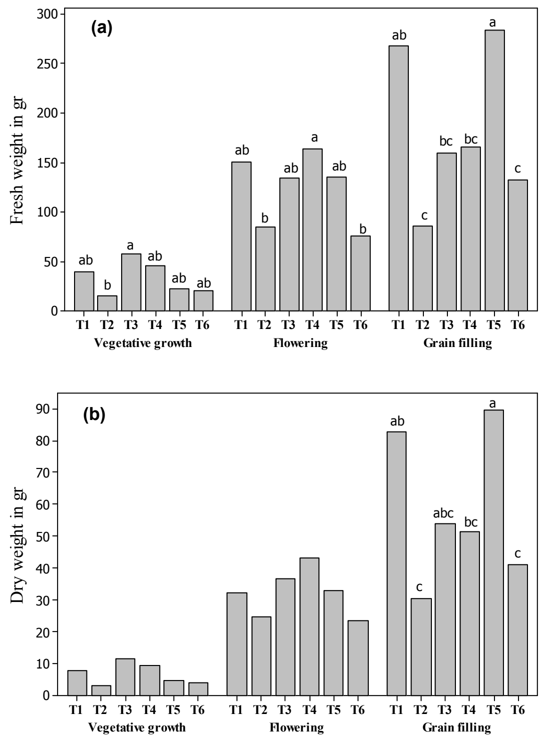

Fig. 6 Stem fresh weight (a) and dry weight (b) during crop cycle

E. Leaves weight

Leaves weight as leaf size was affected by water stress, according to Fig. 7 treatment fully (T2) stressed showed a reduction in leaves fresh weight of 60% in the end of crop cycle compared to control (T1), treatment stressed during vegetative growth (T5) showed high increasing rate (380% during flowering and 567% during grain filling) of foliar growth in the rest of cycle after it was subjected to full irrigation, whereas treatment stressed during flowering (T3) showed a low increasing rate of about 13%, when we have stressed crop during grain filling stage we have obtained reduction in leaves weight of about 24%.

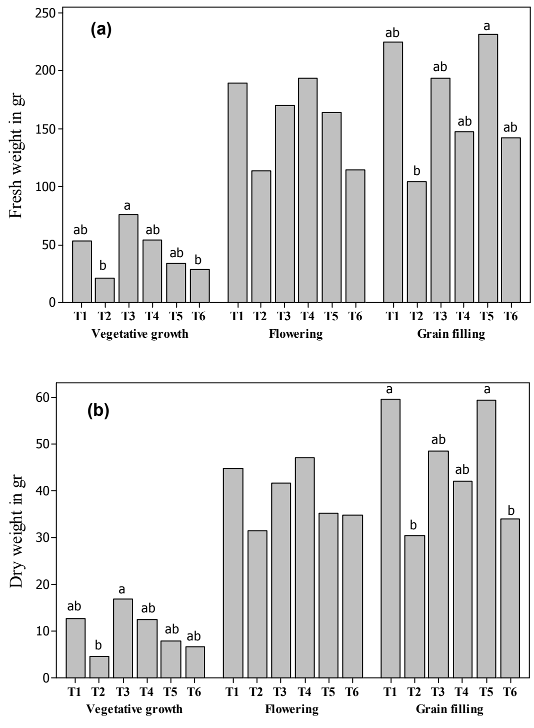

Fig. 7 Leaves fresh weight (a) and dry weight (b) during crop cycle

F. Yield and water productivity

The optimal treatment that gave the higher grain yield is that stressed during vegetative growth (T5), it gave 6.57 T/ha of grain with 34% of increasing compared to control, followed by control (T1) with 4.9 T/ha, treatment stressed during flowering (T3) showed a reduction of 26% compared to control (T1), 34% of reduction compared to control was recorded in treatment stressed in both vegetative growth and flowering stage (T6), while treatment stressed during grain filling (T4) gave a grain yield of 3.01 T/ha with 38% of reduction compared to control and when we have stressed crop during the whole cycle we have obtained the lowest grain yield of about 2.7 T/ha, 44% of reduction compared to control (Fig 8).

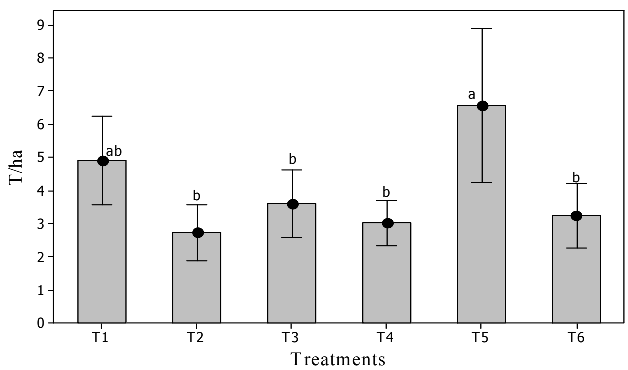

Fig. 8 Grain yield for each treatment of chickpea

The treatment most efficient in terms of water use is that stressed during vegetative growth stage (T5) which have produced 2.8 kg of grains per one tonne of water, and the lowest water use efficiency was recorded when we have stressed the crop at grain filling stage.

Under deficit irrigation during the vegetative growth (the optimal treatment) nearly 16% of whole volume of applied water could be saved.

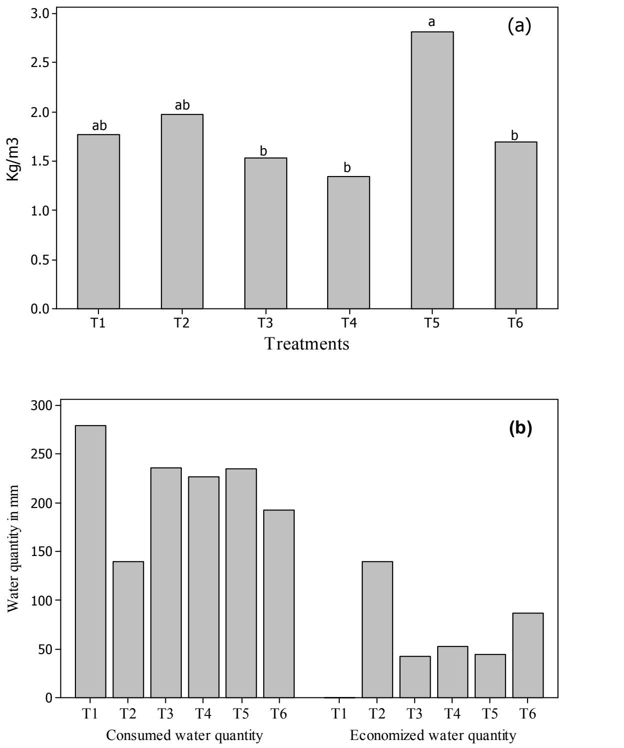

Fig. 9 Water Productivity (a), consumed and saved water quantity (b)

IV. Discussion

Leaf area index (LAI) was affected by water stress conditions, Sharma *et al.* [30] and Labidi *et al.* [31] have reported that putting chickpea in water stress conditions lead to reduction in terms of leaf weight and surface. Our results confirm what Behboudian *et al.* [32] has obtained, he reported that terminal water stress decreased the total plant dry matter including leaf area.

We can report that applying water deficit during vegetative growth stimulate root growth and development as Benjamin and Nielsen [33] who reported that water deficit applied for chickpea during vegetative growth lead to a greater proportion of its root systems developed deeper in the soil profile, which could lead to better use of stored soil water. Chickpea responded to drier soil conditions by increasing the proportion of roots deeper in the soil.

If we compare between increasing rate of stem weight of treatment stressed during vegetative growth (T5) and treatment stressed during grain filling stage we found that applying water stress during the first stage stimulate stem growth and water deficit during grain filling stage affected crop growth, Shamsi *et al.* [22] has reported that treatment of chickpea well irrigated during grain filling stage showed the highest biological yield of shoot, while treatment stressed had the lowest biomass production. Water deficit application during grain filling stage reduced leaves weight and leaf area and lead to decreasing in radiation use efficiency. The results thus suggest that whether water stress affects light interception or light use efficiency depends on the timing of water stress in relation to the canopy development [34].

The very highly significant difference ($p< 0.001$) between treatments in terms of grain yield is explained by the same difference between treatments obtained for the biological yield (leaves, roots, and stems). So applying water deficit during vegetative growth stimulate root system development and flowers production rather than vegetative production as well irrigated treatment, and this leads to more yield production.

In our study water stress conditions applied for T2 lead to reduction of grain and biomass yield by half compared to well irrigated, also many researches have emphasized on the effect of water deficit on reduction of yield and water use efficiency throughout water deficit [19, 20, 21, 35].

Applying water stress during grain or pod filling reduced severely grain yield. So grain filling stage is the most sensitive crop stage for chickpea crop, Shamsi *et al.* [22] reported that using supplemental irrigation in order to resolve stress at critical stages of plant growth had significant effect on grain yield increase and water use efficiency as well as terminal water stress decreased the total plant dry mass and seed yield [32].

V. Conclusion

This work mainly was focusing on bringing a reasonable answer to the question: can we have satisfactory yield production with less water following the deficit irrigation techniques?

The finding of the research evidently indicate that under deficit irrigation we can have a yield production even higher than where full irrigation is provided (+ 34%), The vegetative growth stage for the investigated crop is one among the others growth stages being the most resistant to water stress conditions. Flowering and grain filling stages are both the most sensitive to water stress, so it’s important to avoid that both stages to be subjected to any water stress. Under deficit irrigation during the vegetative growth (the optimal treatment) nearly 16% of whole volume of applied water could be saved.

Generally the observations recorded during the running of the experiment indicated that putting the vegetative growth under water stress conditions, the consequences are: a reduction in the vegetative growth, less water consumption beside shortening the V.G period, and entering earlier in the flowering stage and lowering the maturity and harvesting time.

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