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Regulated Deficit Irrigation Impact at Various Growth Stages and Productivity of Soybean

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Abstract
Regulated deficit irrigation (RDI) is being used as a valued and sustainable strategy in the worldwide arid and semi-arid regions. By limiting the water usage at drought-sensitive stages of plant, the pivotal aim of this practice is to improve water usage efficiency for productivity and to stabilize it instead of maximizing yields in numerous countries. The current study was undertaken in order to investigate the various RDI regimes at different stages of plant growth and development (seedling, branching, flowering, bearing pod, seed filling and maturity) of Chinese soybean plant. For the purposed study, a pot-based experiment was conducted by imposing the total 23 RDI treatments along thrice replications in randomized complete block design (RCBD) condition. The retrieved statistical analysis exposed that the RDI regimes have differential outcomes at various plant stages of soybean. Overall, the most favorable growth condition was observed at various stages under T_1 (55-65% field capacity) at seedling stage and branching stage, under T_9 (65-75% field capacity) at flowering stage and T_{15} (65-75% field capacity) in seed filling stage among the all regulated deficit irrigation treatments but when the plants were fully irrigated with T_{23} (90-100% field capacity), they expressed severe affect during seedling and branching stage due to water logging but owing to full irrigation during critical stages plant growth it showed the utmost yield.
Keywords: Regulated Deficit Irrigation (RDI), Field Capacity, Soybean, Black Soil, Growth Stage and Production

Introduction

Soybean, a local Chinese crop and among the most important crops of the country, has been around for more than 5000 years. The earth's ninety two percent of soybean is produced by United States, Brazil, Argentina, China and India. As a key soybean producer of the world, China is the leading country with production of twenty six million Mg (Liu & Bi 2006). The three northeast provinces of China (Heilongjiang, Jilin and Liaoning) are the major producers of soybean and Heilongjiang province is still being the top soybean producer. Soybean is cultivated and grown during spring in these areas. Northeast region of China boasts thirty three and forty four percent of total cultivated area and yield of soybean of the country's total (Liu & Herbert 2002). Almost thirty percent of soybean crop of the country is produced in the Henan, Shandong, Hebei and Anhui regions, and twenty five percent is produced in southern region of Yangtze River, China. Soybean plant has low productivity in relation of water use, and it needs sizeable amount of water for maintenance, which makes irrigation restriction quiet distressing (Yang *et a*l. 2003). Efficient usage of water is important in any irrigation system, most importantly in arid and semi-arid areas. Drought occurs every year in several regions of the world with brutal effects on crop yield (Tonkaz 2006). Soybean yield could be increased considerably through irrigation (Heatherly, 1983) and can upturn profits (Salassi *et al*. 1984) where soil moisture is decreased soybean crop has shown to excerpt soil water to a depth of 1.5 m (Willet and Taylor 1978; Reicosky & Deaton 1979), indicating some tolerance under limited irrigation. However, Cox and Jolliff (1986) indicated that soybean crop is unable to resist prolonged droughts. They also discovered that evapotranspiration of soybean crops was seventeen and sixty eight percent less in deficit-irrigated and non-irrigated plants, than for the well-irrigated plants. With the shortage of water worldwide the need for water saving is increasing thus indicating that deficit irrigation should be practiced. Often times Deficit Irrigation is a good choice (Gheysari *et al*. 2015). The notion behind deficit irrigation is to save water with minimum decrease in crop yield by introducing water stress in least sensitive stages of crop growth stages (Costa *et al*. 2007; Geerts and Raes 2009). In order to successfully implement deficit irrigation it needs knowledge about the crops and how to manage restricted water availability (Farré & Faci 2009) and how it changes in various seasons and years. The response of soybean crop to irrigation at deficit level was reported by (Bustomi Rosadi *et al*. 2005), in a pot-based experiment conducted in a greenhouse, and the soybean plant initiated to experience the stress phase at 4th week from sowing, if the soil water was sustained at forty to sixty percent available water deficit for complete growth period. It showed the end of vegetative period (4th week) the available water-deficit intensely affected the growth of soybean and water deficit showed no noteworthy effect to the growth of soybean at vegetative phase except at 4th week. The crop yield was considerably reduced at either flowering (R_2) or pod elongation (R_3) due to water deficit. (Brown *et al*. 1985) also showed greater loss of yield at flowering stage instead of pod elongation due to water stress. According to (Krote *et al*. 1983) if the drought stress is introduced in early reproductive stages of growth it could increase the pod and flower abortion, thus reducing the number of seed and increased seed weight. Momen *et al*. (1979) and Cox and Jolliff (1986) showed that soybean is very sensitive to water-stress during pod filling stage (R_6 stage).

Deficit Irrigation (DI) was made by delaying irrigation for two weeks during different growth stages (full bloom, grain enlargement and at mature grain) and control was full irrigated plots. They found that the most significant grain yield reduction (28%) happened in deficit irrigation during grain enlargement stage. They also found that water use efficiency (WUE) at DI regime was up to 13% higher compared to control. WUE is affected by soil moisture level. When water is limited (drought or deficit irrigation regime) WUE is higher (Burriro *et al*. 2002; Ouda *et al*. 2007). Since water use efficiency (WUE) in the narrow sense does not take into concern the role of irrigation, the term irrigation water use efficiency (IWUE) was introduced. IWUE is more suitable in agronomical practice, because it considers the change in yield, depending on various irrigation regimes (Howell 2006; Blümling *et al.* 2011). (Doorenbus & Kassam 1979) reported that soybean plants use approximately 450-700 mm of water depending on its hybrid characteristics. Although some researchers claim that the most important stages for water stress are flowering and the stages after flowering. (Doorenbus & Kassam, 1979; Constable and Hearn 1980; Meckel *et al.* 1984). Foroud *et al.* (1993) showed that soybean plants are more vulnerable to water-stress at the beginning of flowering stage (R_1) through beginning of seed stage (R_5). Water stress inflicted on soybean plants through the growing stages reduced the vegetative growth and affected flowering and crop yield (Hodges & Heatherly 1983; Boyer *et al*. 1980). Likewise, Yazar *et al*. (1989) has shown that soybean crop is quite vulnerable to water stress during seed-filling stage, flowering stage and vegetative stage, correspondingly. Meckel *et al*. (1984) claims that water stress reduces the seed-filling stage). Contrary to Kassam, 1979 the most perilous period for water stress in previous studies, Sutherland & Danileson (1980) found out that soybean plant was argued by some researchers to be the water stress during flowering followed by full-irrigations would increase yield.

Water deficit in vegetative stage reduces growth of leaf which in return reduces dry matter and seed yield (Constable & Hem 1978; Sivakumar & Shaw 1978; Scott & Batchelor 1979). Constable & Hem (1978) described that stress at the seed-filling stage induces rapid leaf senescence and consequently reduced total yield. Sivakumar & Shaw (1978) discovered that leaf growth reduced at -0.8 MPa and totally stopped at leaf water potentials of -1.0 to -1.2 MPa, and Carlson *et al*. (1979) established that conductance and leaf water potential are related linearly. Momen *et al*. (1979) reported a sizeable reduction in the height of soybean plant due to short phases of water stress. Ashley & Ethridge (1978) found that irrigation during the vegetative phase greatly improved growth, but had little or no effect on the yield. Soybeans cultivated in the Southeast U.S. during the reproductive-stage soil water stress seems to influence the number of pods and seeds. Sionit & Kramer (1977) specified that the reduction in crop yield were proportional to pod number reductions. Momen *et al*. (1979), however, indicated that water stress also effected the seeds per pod. Sionit & Kramer (1977) and Constable & Hem (1978) have also revealed that water stress during later reproductive phase sped senescence, shortened the seed filling phase and caused in smaller seed size. So, keeping in view all the scientific aspects, the current research was conducted to optimize and to check the various level of deficit irrigation at different growth and developmental stages of soybean.

Material and methods

Experimental material

For the current experiment, the site was selected at rain shed area of College of Water Conservancy and Civil Engineering, N.E.A. University, Harbin, China. Seeds of soybean variety was No.1 high yield. The experiment was conducted in the duration from May to September 2017. It was a typical continental monsoon climate in the middle temperate zone. The annual mean climate was 3.2 degree Celsius, the annual average effective precipitation is 550 mm, the crop growth period was 140 days to 170 days, and the frost-free period was over 130 days. The plants were cultivated in pots to analyze the results of different water treatments on development and growth, yield, water-consumption and water-use efficiency of soybean irrigation, to optimize the best water deficit irrigation treatment mode. Before initiating the experiment, the soil physio-chemical characteristics (sand, silt, clay, pH, organic carbon, available N, P, K, field capacity, permanent wilting point (PWP) and bulk density) were studied, respectively. The field water holding capacity of 1m soil layer was 39.32 percent and soil bulk density was 1.03g/cm^3. The basic physio-chemical properties after the soil testing were as followed; 39.20 g/kg organic matter, 6.67 pH, 14.78 g/kg total nitrogen and 14.82 g/kg total phosphorus. Soybean seeds were sown totally in sixty-nine plastic pots and all RDI treatments were applied with thrice replications at each growing stage (table 1).

Design of experimnt

The plastic pot-based experiment was conducted according to RCBD (Randomized Complete Block Design). The size of each pot was 40 cm high and 38 cm in diameter, the black clay was sifted and air dried, it was put into the barrel . Each plastic pot contained 15 kg of prepared black soil media and 5-7 seeds of Chinese soybean variety (No.1 high yield) was planted in each pot and water treatment will be applied at six phenological stages. The growth period of soybean was divided into 6-phenological stages of seedling, branching, flowering, bearing pod, seed filling and maturity. A total of 23 treatments (18 treatments were controlled by the percentage of the field capacity, i.e. the lower limit of 55-65, 60-70, and 65-75 percent and the highest 100 percent of field capacity (full irrigation) was applied at growth stages of soybean), and remaining 5 treatments were accounted for same level of regulated deficit irrigations having field capacity of 55-65%, 60-70%, 65-75%, 70-80% and 90-100%) along with thrice replications comprising a total of 69 pots (table. 1).

Table 1. Regulated Deficit Irrigation (RDI) Treatments at Several Stages

Treatments	Seedling Stage	Branching Stage	Flowering Stage	Bearing Pod Stage	Seed Filling Stage	Maturity
T_1	**55-65**	75-85	75-85	75-85	75-85	75-85
T_2	**60-70**	75-85	75-85	75-85	75-85	75-85
T_3	**65-75**	75-85	75-85	75-85	75-85	75-85
T_4	75-85	**55-65**	75-85	75-85	75-85	75-85
T_5	75-85	**60-70**	75-85	75-85	75-85	75-85
T_6	75-85	**65-75**	75-85	75-85	75-85	75-85
T_7	75-85	75-85	**55-65**	75-85	75-85	75-85
T_8	75-85	75-85	**60-70**	75-85	75-85	75-85
T_9	75-85	75-85	**65-75**	75-85	75-85	75-85
T_{10}	75-85	75-85	75-85	**55-65**	75-85	75-85
T_{11}	75-85	75-85	75-85	**60-70**	75-85	75-85
T_{12}	75-85	75-85	75-85	**65-75**	75-85	75-85
T_{13}	75-85	75-85	75-85	75-85	**55-65**	75-85
T_{14}	75-85	75-85	75-85	75-85	**60-70**	75-85
T_{15}	75-85	75-85	75-85	75-85	**65-75**	75-85
T_{16}	75-85	75-85	75-85	75-85	75-85	**55-65**
T_{17}	75-85	75-85	75-85	75-85	75-85	**60-70**
T_{18}	75-85	75-85	75-85	75-85	75-85	**65-75**
T_{19}	**55-65**	**55-65**	**55-65**	**55-65**	**55-65**	**55-65**
T_{20}	**60-70**	**60-70**	**60-70**	**60-70**	**60-70**	**60-70**
T_{21}	**65-75**	**65-75**	**65-75**	**65-75**	**65-75**	**65-75**
T_{22}	**70-80**	**70-80**	**70-80**	**70-80**	**70-80**	**70-80**
T_{23}	**90-100**	**90-100**	**90-100**	**90-100**	**90-100**	**90-100**

Observation index and their determination method

The total observation indexes were divided into six phenological stages in order to distinguish the irrigation. Pots were irrigated and water consumption was calculated. The data was collected at each phenological stage (seedling, branching, flowering, bearding pod, seed filling and maturity).

Soil moisture contents (%)

Soil moisture contents were determined by oven drying method. Soil samples were taken with a soil drill, and the balance of 0.1 g precision was weighed and the soil samples were dried in an oven at 105 °C for 8 hours to obtain the constant weight, later the soil samples were measured as prescribed (Atti *et al*. 2013).

$$\text{Soil Moisture Content} = \frac{\text{wet earth quality} - \text{dry soil quality}}{\text{dry soil quality}} \text{ x } 100\%$$

Field water capacity (%) of soil

Ring knife was used for collecting the soil sample, immersed in water, removed after 24 hours until the ring cutter soil seepage, at this time (Marković *et al*. 2016).

$$\text{Field capacity} = \frac{\text{Water saturated soil quality} - \text{quality of dried soil}}{\text{drying soil quality}} \text{ x } 100\%$$

Determination of growth and development index

Plant height (cm) and leaf area (cm^2): These parameters were measured with a meter scale. The plant height was measured from the base of the plant to the uppermost stem tip before heading, while the leaf area was measured from the base of leaf to the tip of leaf, and its highest width as previously described (Amanullah & Ahmed 2016).

$$\text{Leaf area} = \text{length of leaf x width of leaf}$$

Stem thickness (cm): The thickness of stem was measured from the base with a Vernier caliper.
Numbers of branches: The numbers of branches were noticed at every growth stage.
Water consumption (kg): The amount of water content needed per pot was determined using electronic balance by weighing method, each pot was weighed every day at 8:00 a.m. and the amount of water needed was applied using standard cup until crop maturity.
Water use efficiency (g/kg): Water Use Efficiency for each water treatment was analyzed as total seed-weight divided by total amount of water consumption.

$$\text{Water use efficiency (WUE)} = \frac{\text{total seed weight}}{\text{total water consumption}}$$

Soybean yield and its components
Numbers of seeds per plant: The total seed number per plant was counted and noted.
Number of seeds per pod: The total seed number per pod was counted and noted (Fehr & Caviness 1977).
100 seed weight (g): All the seed was weighed for the 100-seed weight (g) value.
Production (total yield): After harvesting the grains were air dried and weighed.
Biological yield (g): The biological yield was calculated after harvesting all the pots, dried and weighed in grams.
Grain yield (g/m^2): Grain yield was collected for each pot after threshing and carefully cleaning, the grain yield was then converted into g/m^2 for each treatment (Howell *et al*. 1998).
Data analysis: Collected data was statistically analyzed by usage of statistical software (SPSS version 23.0) and Microsoft Excel (version 2016) for means and standard deviations.

Results
Effect of regulated deficit irrigations on plant height at seedling, branching, flowering, bearing pod, seed filling and maturity stages
The graphical presentation (1A, 1B, 1C, 1D, 1E and 1F) in figure 1 is showing the different RDI (Regulated Deficit Irrigations) effect on the height of Soybean plant at various stages (seedling, branching, flowering, bearing Pod, seed filling and maturity stage). The plants subjected to T_1 (55-65 field capacity %) expressed the utmost growth (4.50 cm) as shown in graph 1A. Regarding the plant height during growth at seedling stage, subjected to T_{23} RDI treatment (90-100 field capacity %) was minimum (1.50 cm) due to water logging as shown in graph 1A, and 60-80 percent RDI showed slight change with almost same height. While the plants subjected to T_3 to T_{18} RDI treatments (75-80 field capacity %) expressed highest change in the height of the plants as shown in graph 1B, 1C, 1D, 1E and 1F (47.2 cm, 70.6 cm, 71.6 cm, 72.6 cm and 73.6 cm), respectively, but the plants subjected to T_{23} RDI treatment (90-100 field capacity %) were still affected due to water logging. The plant height increased slowly but gradually at bearing pod stage by showing utmost growth (73.6 cm) at T_{14} RDI treatment (70-80 field capacity %). From the above graphs of figure 1, it is cleared that during seedling stage the low water levels are better for the growth of the plant.

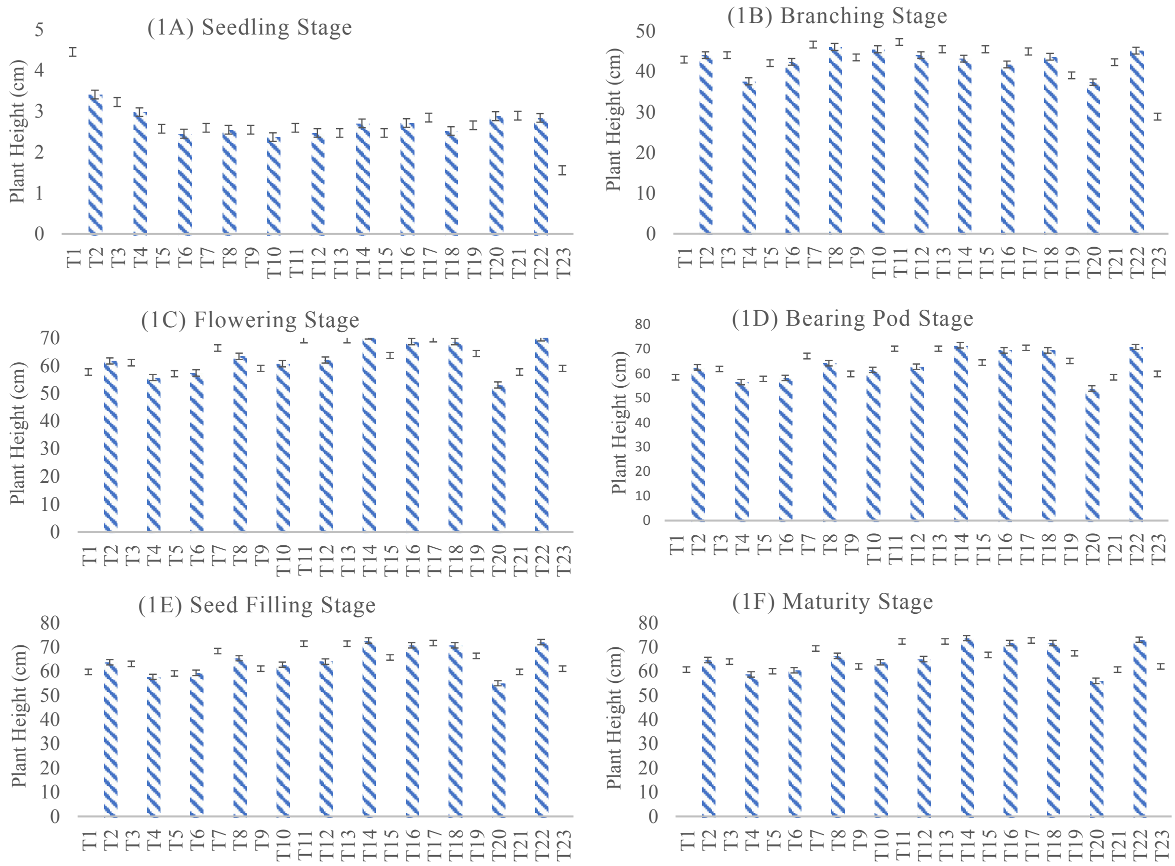

Figure 1. Plant height (cm) at differential stages of soybean plant under various RDI treatments

Effect of regulated deficit irrigations on leaf area seedling, branching, flowering, bearing pod, seed filling and maturity stages

The graphical presentation (2A, 2B, 2C, 2D, and 2E) in figure 2 is presenting the different RDI regime effect on the leaf area of Soybean plant at various stages (seedling, branching, flowering, bearing pod, seed filling stage). The plants subjected to T_1 RDI treatments (55-65 field capacity %) expressed the utmost growth (8.3 cm^2) as shown in graph 2A. Regarding the plant leaf area during growth at seedling stage, subjected to T_{23} RDI treatments (90-100 field capacity %) was reduced (2.3 cm^2) due to water logging as shown in graph 2A, and T_{20} RDI treatment (60-70 field capacity %) showed slight change with almost same leaf area. While the plants subjected to T_1 to T_3 and T_7 to T_{18} RDI treatments (75-85 field capacity %) expressed highest change in the leaf area of the plants as shown in graph 2B, 2C, 2D, and 2E (133.8 cm^2), respectively. The plant leaf area increased till branching stage by showing utmost growth (133.8 cm^2) at T_1 to T_3 and T_7 to T_{18} RDI treatments (75-85 field capacity %).

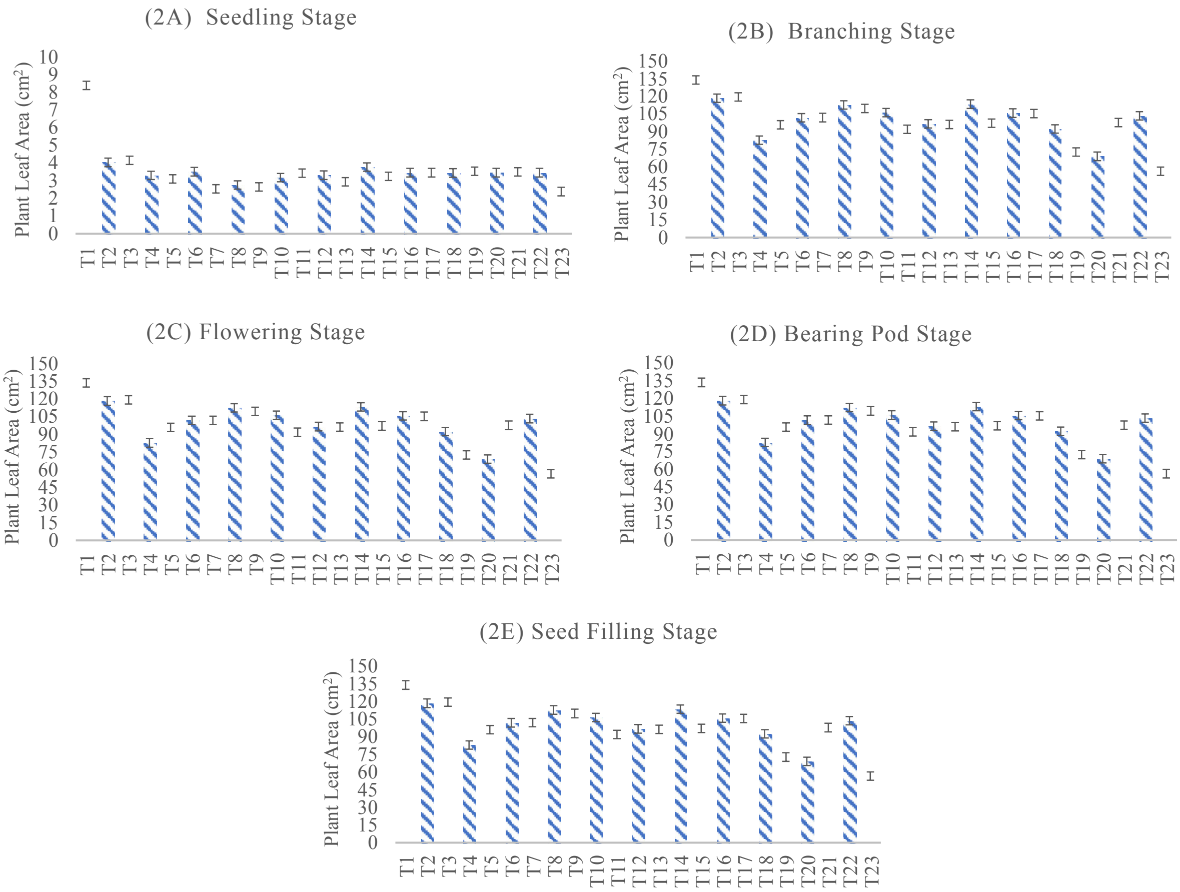

Figure 2. Leaf area (cm^2) at differential stages of soybean plant under various RDI treatments

Effect of Regulated Deficit Irrigations on number of pods, total seed weight, 100 seed weight (g) and grain yield (g/m^2)

The graphs (3A, 3B, 3C, and 3D) in figure 3 is displaying the different regulated deficit Irrigations (RDI) regime effects on the total number of pods, total seed-weight, 100-seed weight and grain yield of soybean plant. The plants subjected to T_{23} RDI treatments (90-100 field capacity %) expressed the utmost number of pods (85.3) as shown in graph 3A, and total seed weight (270.1 g). While the plants subjected to T_{20} RDI treatment (60-70 field capacity %) showed the least number of pods (41.8) and total seed weight (24.6 g), but the 100-seed weight was almost similar in all the water regime with maximum weight (29.5g) and minimum (22.8 g). The T_{23} RDI treatment (90-100 field capacity %) exhibited the highest number of pods, total seed weight and also expressed highest grain yield (5.34 gm^{-2}) comparatively other applied water regimes.

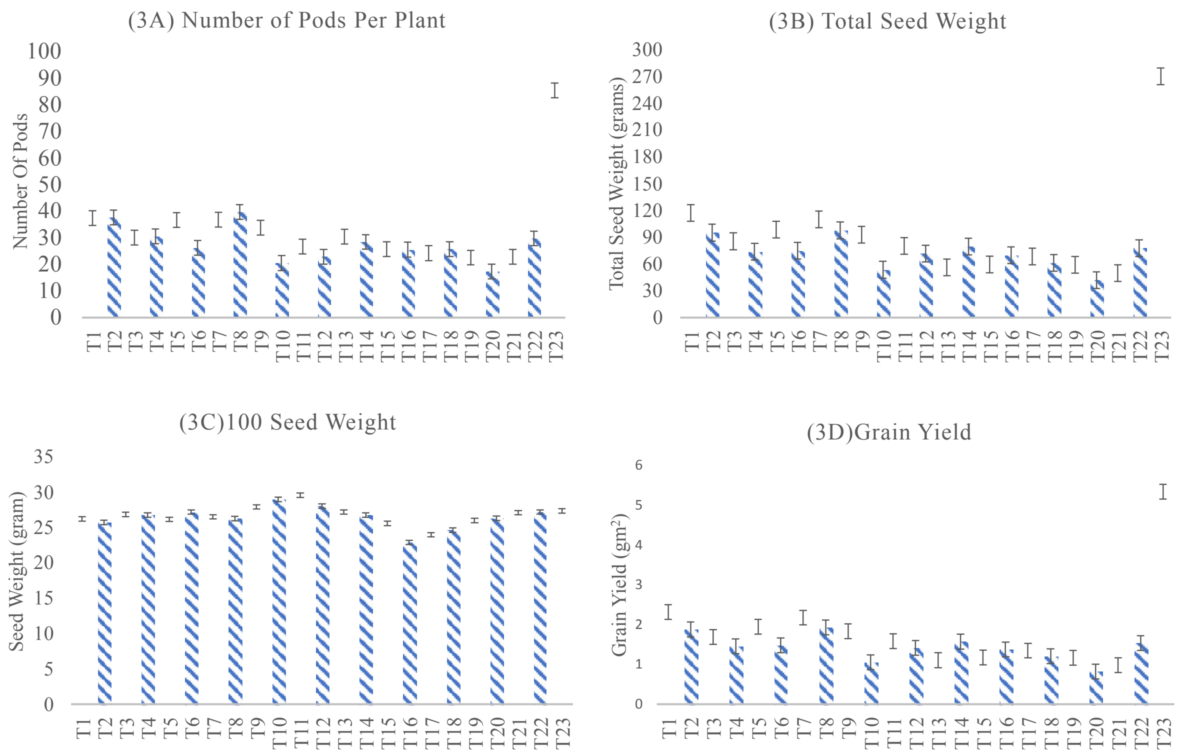

Figure 3. Number of pods, total seed-weight (g), 100-seed weight (g) and grain yield (gm^2) at differential stages of soybean plant under various RDI treatments

Effect of Regulated Deficit Irrigations on total water consumption and water use efficiency (WUE)

The graph 4A and 4B (figure 4) show total water consumption and water use efficiency during the growth period of soybean crop. The graph 4A shows that there is no significant difference in total water consumption between different RDI (regulated deficit irrigation) and the total water consumption of other adjustment deficit irrigation with the highest being (97.978 kg) for pot 2 and lowest (54.03 kg) for pot 19 which was irrigated at 55-65% field capacity in all the growth stages. While graph 4B shows that overall highest water use efficiency of T_{13} RDI treatment was (1.64 g/kg) indicating that the use of 75-85% field capacity in the whole growth period can greatly increase the water use efficiency (WUE); in addition to T_{23} RDI treatment, the water use efficiency of other treatments was below (1.50 g/kg), which indicates that water shortages in different periods all have a certain impact on WUE. Among them, the WUE of T_{23} RDI treatment is the lowest, which is (0.36 g/kg), indicating the effect of using 90-100% of water on WUE was maximum during the grain filling stage.

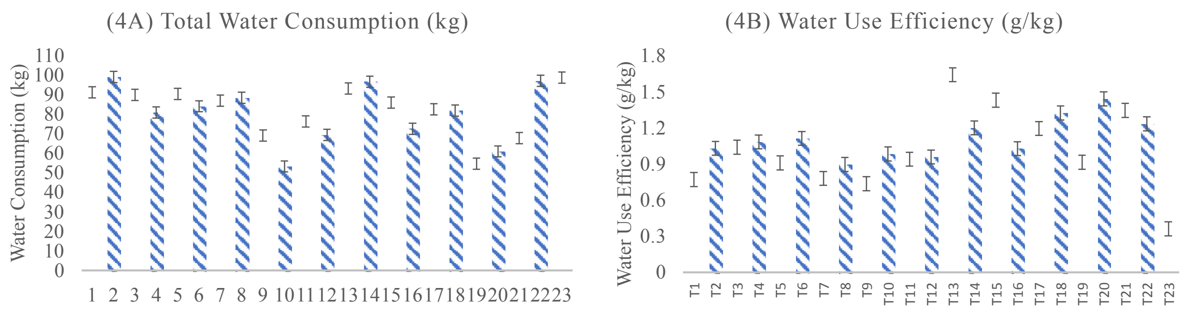

Figure 4. Total water consumption (kg) per pot and water use efficiency (g/Kg) in RDI treatments

Discussion

Irrigation has great influence on plant productivity and also at differential stages of growth. In our study we applied regulated deficit irrigation levels to assess the irrigation efficacy on different stages (plant height, leaf area, total number of pods, total seed-weight, 100-seed weight, water consumption, water use efficiency) of soybean plants. A pot based experiment was conducted and each pot was weighed 15 kg of black soil media and RDI treatments were imposed according to the field capacity for germination. Soybean varieties were continued to grow their vegetative and reproductive growth, for affected water stress treatment to several morphological growth variables. In general, early-season stress (seedling emergence, branching, or flowering) reduced plant height, seed numbers, and yield (figure 1 and 2). Decreases in plant height (measured from the base to the tip of the plant stem), number of fully developed leaves on the stem and, to a lesser extent, number of primary branches, were morphologic effects of water stress that were visually detectable from the retrieved data it was noticed that the height of soybean plant at various stages (seedling, branching, flowering, bearing pod, seed filling and maturity stage).

The plants subjected to T_1 RDI treatments (55-65 field capacity %) expressed the utmost growth (4.5 cm), regarding the plant height during growth at seedling stage, regarding T_{23} RDI treatment (90-100 field capacity %) was reduced (1.5 cm) due to water logging, and T_2 RDI treatment (60-70 field capacity %) showed slight change with almost same height. While the plants subjected to T_3 to T_{18} RDI treatments (75-80 field capacity expressed change in the height of the plants 47.2 cm, 70.6 cm, 71.6 cm and 72.6 cm, respectively, but the plants subjected to T_{23} RDI treatment (90-100 field capacity %) were still affected due to water logging. The plant height increased slowly but gradually at bearing pod stage by showing utmost growth (73.6 cm) at T_{22} RDI treamtment (70-80 field capacity %). Furthermore, the statistical analysis showed difference in plant height at different water regimes. Water stress decreased plant height (figure 1). Our results are in the same line to the Atti *et al*. 2004, who studied from zero to 23 DOS, plant height at the severe stress level W_1 increased from 41 to 57 cm, whereas, for the same period, plant height at the control level increased from 41 to 142 cm. Thus, at W_1, the reduction in height increase was 84%. Water stress decreased plant heights detectably by nine DOS for severe stress (W_1, 33%) and medium stress (W_2, 28%). At 16 DOS, plant height, for the control, W_2, and W_1 levels, were 127, 68 and 56 cm, respectively, corresponding to decreases in plant height of 47 and 56%, at W_2 and W_1.

Plant leaf area was severely affected during growth stages of soybean, there was significant difference between leaf area of T_1 RDI treatment (55-65 field capacity %) and other RDI treatments, the plants subjected to T_1 RDI treatment (55-65 field capacity %) expressed the utmost growth (8.3 cm^2) in seedling stage. Regarding the plant leaf area during growth at seedling stage, subjected to T_{23} RDI treatment (90-100 field capacity %) was reduced (2.3 cm^2), and the other RDI treatments showed slight change with almost same leaf area. The T_{23} RDI treatment (90-100 field capacity %) continued to see reduced leaf area until maturity. The maximum plant leaf area was measured at T_1 RDI treatment (75-85 field capacity %) (133.86 cm^2) at branching stage, while the lowest leaf area was at T_{20} RDI treatment (60-70 field capacity %) (53 cm^2) at branching stage. As earlier stated (Atti *et al*. 2004) that water stress decreased plant total leaf area, mean of LA per plant was decreased by 52.70% and 74.50%, at W_2 and W_1, respectively. In general, early-season stress (seedling initiation, branching or flowering) reduced the height of plant, the number of seeds, and total yield. Due to these stress treatments the soybean crop showed in reduction in seed number, the earliest that plants were stressed was at stage seedling stage.

The number of pods was highest (85.38) in T_{23} RDI treatment (90-100% field capacity), while it was lowest (17.33) in T_{20} RDI treatment (60-70 field capacity %). while the rest of the water regimes effect showed different number of pods per pot. The response of soybean plant to water-deficit at various growth stages were told by previous research (Huck *et al*. 1983; Foroud *et al*. 1993; Karam *et al*. 2005 a, b). They discovered that water deficit during R_3 (pod elongation) and R_5 (grain enlargement) stages significantly reduced the yield of soybean.

100-seed weight was highest (27.37 g) in T_{23} RDI treatment (90-100 field capacity %), while it was lowest in T_{18} RDI treatment (65-75% field capacity) (24.67 g), while other water regimes showed almost similar weight as shown in (figure 3). The study by Dogan *et al*. 2007 correlates with our results in which he found water deficit effected seed weight in both 2003 and 2004, the smallest 1000-seed weights were acquired from the full seed (R_6) as 162.30 and 165.80 g, respectively, while the highest seed weights were from control treatments (full irrigation) as 184.10 and 194.90 g. The reason for the small 1000-seed weight from the R_5 (beginning of seed), and R_6 (full seed) treatments was related to the water stress that occurred during reproductive stages.

The total seed weight was also highest (270.16 g) in T_{23} RDI treatment (90-100 field capacity %), while it was lowest (41.83 g) in T_{20} RDI treatment (60-70 field capacity %). While the total seed weight plants subjected to T_1 and T_7 RDI treatment (55-65 field capacity %) at seedling stage and flowering stage were 117.167 and 110.167), respectively. The study by Karam *et al*. 2005 also showed the with-holding irrigation at seed enlargement (R_5 stage) showed significant reductions ($P < 0.01$) in seed number per plant (20%) and seed-weight (10%), thus showing a reduction of 28% in seed yield in the seed enlargement S_2 treatment.

The highest yield (5.34 gm^2) was obtained from T_{23} RDI treatment (90-100 field capacity %), while the lowest yield was obtained from T_{20} RDI treatment (60-70 field capacity %) (0.827 gm^2). Water stress forced during seed-filling stage is more unfavorable to yield than that imposed earlier because, with the later stress, there is no recompense for stress-induced pod abortion and reduction in seed weight, the results correlate with study conducted with Karam *et al*. 2005, in which he states withholding irrigation at maturity (R_7 stage (S_3)) didn't affect the number of seed per plant. However, the decrease of 6% ($P < 0.05$) of seed-yield at this stage compared to the control was attributed to a similar reduction in seed weight.

There was no significant difference in total water consumption between different RDI (regulated deficit irrigation). The water total water consumption of other adjustment deficit irrigation with the highest value (97.978 kg) for pot 2 and lowest value (54.03 kg) for pot 19 which was irrigated at 55-65% field capacity in all the growth stages. Water use efficiency (WUE) was highest (1.64 g/kg) in T_{13} RDI treatment, indicating that the use of 75-85% full irrigation treatment at the whole growth period can greatly increase the water use efficiency; in addition to T_{13} RDI treatment, the water use efficiency of other RDI treatments was below (1.50 g/kg), which indicates that water shortages in different periods all have a certain impact on WUE. Among them, the WUE of T_{23} RDI treatment is the lowest, which is (0.36 g/kg). Our results are in accordance with Marković *et al.* 2006, where water use efficiency (WUE) of deficit irrigated plots (a2) was 2.7 kgm^{-3} (2006), 0.3 kgm^{-3} (2007) and 3.3 kgm^{-3} (2008). Furthermore, WUE at full irrigated plots (a3) was 1.3 kgm^{-3} (2006), 0.8 kgm^{-3} (2007) and 0.3 kgm^{-3} (2008).

Conclusion

The existing study was conducted to optimize the regulated deficit irrigation regimes and to evaluate their efficacy at distinct growth stages of Chinese soybean. In general, total 23 RDI treatments were applied at all observational growth stages and a significant effect of differential RDI was noticed in various treatments. Although, the total water consumption among the treatments was same but the plant height, leaf area and other attributes were severely affected in different RDI regimens. Our presented results clearly stated and it is proposed to well irrigate the soybean plants during flowering, bearing pod and maturity (critical stages) for better production.

Conflict of interest

The authors declared that there is no conflict of interest

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