EFFECT OF IRRIGATION REGIME ON SOYBEAN BIOMASS, YIELD, WATER USE EFFICIENCY IN A SEMI-ARID AND SEMI-HUMID REGION IN NORTHEAST CHINA

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ABSTRACT

Soybean growth is sensitive to soil water conditions. Seasonal drought can cause the loss of soybean yield due to the uneven distribution of annual precipitation in Northeast China. Irrigation could be an effective practice to mitigate the effect of water stress on soybean. The response of soybean growth, yield, water use efficiency (WUE) and irrigation water use efficiency (IWUE) to four amounts of water inputs was investigated. The experiment was conducted in the National Field Research Station of Agro-ecosystem in the Chinese Academy of Science in Hailun County Heilongjiang province Northeast China in 2011 and 2012, and included four water application treatments, they were no irrigation (R), soil water content was kept at 80% (T80), 60% (T60) and 40% (T40) of field water capacity (FWC). Rainproof shelters were used to control rainfall. The effect of different water entry on soybean biomass and plant height was shown in an increasing order of T40 < R < T60 < T80. Soil water kept at about 60% (T60) increased soybean 100-weight by over 5.1% than T40, T80 and R, and reduced flat pod per plant. The soybean yield was the highest in the treatment of T60, and increased averagely by 16.58% compared with that in the treatments of R, T80 and T40. WUE reached the largest values at T40 in 2011 and at T60 in 2012, IWUE were the largest at T80 in 2011 and 2012. . Though more water of 35.7% and 50.3% was applied in the treatment of R than that in the treatment of T60, respectively, in 2011 and 2012, higher soybean yield was found in T60 treatment, suggesting time of water applied was more important than the amount of water entry. Soil water content kept at about the 60% of FWC was optimum in terms of increasing soybean yield and saving irrigation amount in Northeast China.

KEYWORDS:
Irrigation, Soybean yield, Water use efficiency, Northeast China

INTRODUCTION

Northeast China is a vast, semi-arid and semi-humid region with an average annual precipitation ranging from 300 to 865 mm. Water stress is a major factor limiting soybean production in this region. In general total annual precipitation could meet the crop demand for water in Northeast China [1], but the frequency and amount of rainfall during the growing seasons is often quite variable [2]. Under non-irrigated conditions in humid areas, variability in seasonal rainfall leads to year-to-year variability in the uptake of water and nutrients, and in the growth, development and yield of the crop [3]. In other words, even though annual precipitation should be adequate, rainfall might be limited at critical growth stages, resulting in the decrease in crop yield. Daniel et al. [4] had documented that crop could benefit from supplemental irrigation in humid areas when uneven rainfall distribution happened in growing seasons. Therefore, under semi-arid and sub-humid climate conditions, well-scheduled irrigation can be an essential step to increase seed yield and ensure stability in yields.

Soybean (*Glycine max (L.)* Merill.) is one of the major crops in the Northeast China. The sown proportion of soybean accounts for 33% of the nation's total area [5, 6], and the soybean production in 2010 reached 6.02×10^6t, nearly 31.73% of total production in China with over 80% was supplied to other regions in China as an important resource of vegetable protein and oil [7]. Therefore, soybean plays very important role in maintaining and increasing economical development in Northeast China, how to increase soybean yield is attracting more and more attention. Soybean yield was impacted by cultivars [8, 9], tillage practices [10, 11, 12], fertilization practices [13, 14], soil texture [15], irrigation [10, 16]. In all of above conditions water was one important controlling factor for soybean growth and development in semi-arid and semi-humid region in Northeast China [1]. Large quantity of water was required to produce acceptable yield of soybean and

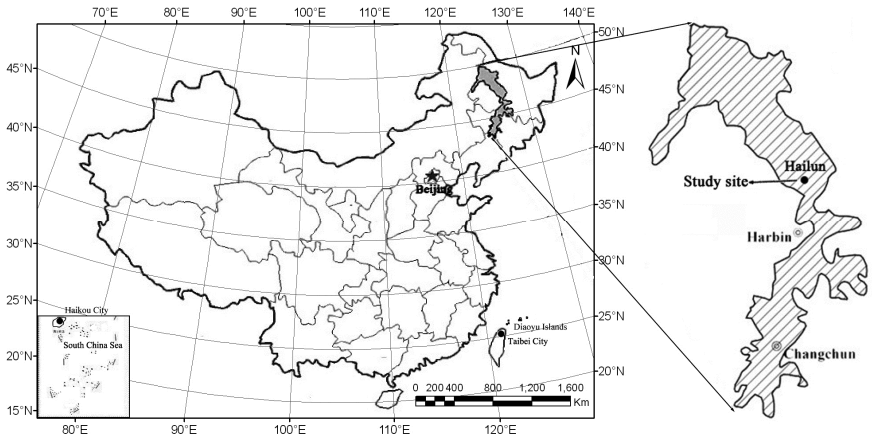

FIGURE 1
Location of the study site (Hailun)

work from Ashley [17] showed that water requirements of soybean usually equaled or exceeded those of other summer row crops. Irrigation could alleviate the effect of seasonal precipitation deficit on soybean yield. Supplemental irrigation during the growing season can sustain a high yield when there is less rainfall [18, 19]. Inadequate soil water limits root exploration of stored soil water, and supplemental water could increase crop yield [20]. Reasonable water entry could increase soybean photosynthetic rates of soybean [21].

The impacts of irrigation on crop production is usually quantified using crop water production functions which related crop yield to amounts of water applied [22, 23]. The rational irrigation could significantly increase the crop yield [24, 25, 26, 27]. Excessive irrigation delayed the maturity and harvesting, decreased crop yield and crop water use efficiency (WUE) [28, 29]. The responses of grain yield and WUE to irrigation varied considerably due to differences in soil water contents and irrigation regimes [30, 31]. Many literatures have documented that the impact of irrigation and soil water deficit on crop yield or WUE depends on the particular growth stage of the crop [32, 33, 34]. Ashley and Ethridge [25] have demonstrated that irrigation applications prior to blooming greatly increased vegetative dry weight, number as well as dry weight of pods, and irrigation during reproductive development had little effect on vegetative dry weight, but usually resulted in a greater number of pods in the season. Brown et al. [35] reported that a moisture deficit initiated at R4 growth stage significantly reduced soybean seed size and seed number whereas seed size was not significantly reduced by deficits initiated at R2 growth stage. An occurrence of drought stress during early reproductive growth may increase flower and pod abortion [36], thus decrease seed number and increase seed weight. The studies on the irrigation regimes for soybean have demonstrated that avoiding irrigation during the vegetative growth stages could result in yields as high as those obtained if the crop was fully irrigated during the entire growing season [25, 30, 24]. But more research focused on the effect of irrigation regimes on soybean yield and water use efficiency in different growth stages, less attention was put on the impact of irrigation during whole reproductive stage on soybean biomass, yield, WUE. The effect of water applied on soybean yield, quantity and physiological characteristics were considered in Northeast China [21], however, the research result obtained only based on one year experiment and one irrigation level in normal year with 535 mm precipitation (the mean annual precipitation is about 550 mm), the information regarding the effect of different irrigation levels on soybean yield and WUE was lack, and climatic conditions also should be considered.

In this paper we discussed the impacts of irrigation schedule on soybean biomass, yield, WUE and IWUE in black soil region in Northeast China. On the basis of our results, guidelines would provide for farmers irrigation strategies to achieve efficient use of water resources for soybean production in Northeast China. So objectives of this study are: (1) to investigate the effects of irrigation on ET, soybean yield and WUE and IWUE, (2) to propose a suitable amount of irrigation under semi-arid and semi-humid conditions.

MATERIALS AND METHODS

Field study was conducted in 2011 and 2012 at the National Field Research Station of Agro-ecosystems (126°38′W, 47°26′N; 240 m above sea level) at Hailun County, Heilongjiang province in Northeastern China (Fig.1). The climate in Hailun County is described as a temperate continental monsoon type with an average annual precipitation of 550 mm (from 1957 to 2008);

TABLE 1
Basic properties of initial soil profile

soil layers (cm)	Soil texture	Organic matter (g kg^{-1})	Bulk density (g cm^{-3})	Total porosity (%)	Field water capacity (mm)	Saturation water capacity (mm)	Wilting point values (mm)
0-29	Heavy loam	50.64	1.08	53.65	121.02	176.61	36.9
29-60	Light clay	14.66	1.24	49.18	117.55	179.67	34.3
60-83	Light clay	4.07	1.29	49.21	85.98	128.5	32.3
83-100	Light clay	3.12	1.32	48.33	63.21	91.11	33.9

approximately 70% of rainfall occurred between July and September. The annual mean temperature is 1.5°C with an annual frost-free period of about 120 days, and soybean is planted around 1st May. The soil is described as Black soil (Mollisol in American Soil classification system), derived from loam loess, with approximately 40% clay content [38]. Local soil characteristics and parameters were shown in Table 1.

Experimental layout. A total of twelve plots measured by 3 x 7 m were divided by concrete wall built in 2010 for four water irrigation treatments, Treatments were laid out in a randomized complete block design and replicated three times. The concrete walls are 25 cm thick and extend 1.7 m beneath thesurface, according to specifications Food and Agricultural Organization specifications.

Soybean (*Glycine max (L.)* Merill.,Dongsheng 5), was planted on 5 May 2011 and 4 May 2012, harvested on 24 September 2011 and 25 September 2012, respectively. Before planting, the land was leveled precisely to aid uniform irrigation water distribution from surface flooding irrigation. The seed rate was set at 0.28 million plants hm^{-2} with 5 cm seeding depth. Fertilizer rates applied at sowing were 20 kg N ha^{-1} as urea, 53 kg P_2O_5 ha^{-1} as $NH_4H_2PO_4$ and 60 kg K_2O ha^{-1}as K_2SO_4, and completely mixed with topsoil by manual work using shovels. The tillage practices, weeding and pest control were consistent with typical field conditions. The planting pattern is continuing soybean, row space is 67 cm, plant-plant space is 10 cm.

The experiment included four treatments: one rain-fed only treatment (R) as the control, irrigation at 80% of field water capacity (T80), at 60% (T60) and 40% (T40), respectively. We closed 0-100 cm soil depth as irrigation depth. Therefore, we started irrigation in the end of June when soybean began to go into reproductive growth stage in this study site. The irrigation period was among 18 June and 1 September in 2011 and among 20 June and 7 September in 2012. Irrigation water was applied to corresponding plots using surface flooding irrigation. The rubber tubes were used to transfer water from a small reservoir near experiment to the treated plots. Rainproof shelters that can be open and closed were built for these treatments to prevent rainfall into these plots in raining days. Monitoring device for soil moisture was set in the field plots to determine when and how much water was needed for each treatment. Rainfall or irrigation water applied to plots was defined as water entry during soybean growing seasons.

Aluminum access tubes were installed at the center of each of twelve plots. Neutron probe (CNC503DR, Nanjing, China) and a Time Domain Reflectrometry (TDR) probe (Trase system 6050X1, Soil Moisture System, Santa Barbara, USA) were used to measure the soil volumetric water content every 2 days during the growing seasons in 2011 and 2012. The TDR probe was used to measure the soil water content at the depths of 0-10 and 10-20 cm, respectively. The neutron probe was used to measure soil water content at the intervals of 10 cm for the 20-50 cm layer and 20 cm for the 50-100 cm layer. Weather data was collected from the standard weather station about 100 m away from plots. The irrigation application to each plot was measured using a meter installed at the hydrant of a low-press tube water transportation system.

ET was calculated using the soil water balance equation in the growing seasons as following:

$$ET = SWC + P + I - D - W_g - R \quad (1)$$

Where ET is evapotranspiration (mm), SWC the soil water change in the measured soil depth during the growing stage, P rainfall (mm), I irrigation application (mm), D soil water drainage (mm), R surface runoff (mm), Wg in equation 1 water used by crop through capillary raise from groundwater (mm). Wg, D and R was negligible according to the reference from Han et al. (2003).

Soybean biomass and plant height were examined during the growing seasons in 2011 and 2012. Ten plants for biomass and plant height at R1 and R4 were selected randomly. R1 stage is beginning bloom stage with one open flower at any node on the main stem, and was observed on 4th July in 2011 and 28th June in 2012; R4 stage is full pod stage with pod 2 cm long at one of the four uppermost nodes on the main stem with a fully developed leaf, and was observed in 2th August in 2011 and 28th July in 2012. Soybean developmental stages were based on the staging system described by [39]. Plant samples were dried in a force air

TABLE 2
Precipitation and irrigation applied to treatment plots in 2011 and 2012 in Hailun

Irrigation treatment	2011		2012	
	Rainfall (mm)	Irrigation (mm)	Rainfall (mm)	Irrigation (mm)
T80	127.5	432	192.9	335
T60	127.5	227	192.9	171
T40	127.5	110	192.9	64
R	480.2	0	546.1	15
Sowing date	5th May		4th May	
Harvest date	24th September		25th September	

oven at 80 ℃ to a constant weight. Soybean grain yield were sampled from the 2 x 2 m portion in the center row of each plot followed by cleaning, and weighing of samples. All grain yields were adjusted to water content of 13% (kg kg^{-1}). Yield components including pod number per plant, node number per plant, and flat pod number per plant and 100-seed weight were determined based on 10 plants selected randomly from each plot. The seed yield component was separated and processed by hand.

Water use efficiency was calculated as follow [40]:

$$WUE = \frac{GY}{ET} \qquad (2)$$

Where WUE (kg m^{-3}) is the water use efficiency for GY (soybean grain yield, kg ha^{-1}) and ET (mm) is calculated as in Eq. (1).

$$IWUE = \frac{GY}{I} \qquad (3)$$

Where IWUE (kg m^{-3}) is the irrigation water use efficiency for GY (soybean grain yield, kg ha^{-1}) and I (mm) is total irrigation water amount in each treatment in each year.

Analysis of variance (ANOVA) was used to assess the difference in ET, biomass, plant height, yield, WUE between different treatments. Mean comparisons were made by the LSD (the least significant difference) method within $P<0.05$ and $P<0.01$. The analyses were conducted using the SPSS 13.0 program.

RESULT AND DISCUSSION

Climate, precipitation and the amount of water entry. Weather. The variation of weather in 2011 and 2012 has been shown in Fig.2. The variation of precipitation in different growing seasons was larger, while the distribution also was uneven in different growing stage. The distribution of precipitation in 2011 and 2012 was similar to the distribution of mean precipitation from 1957 to 2012 with the peak in July (Fig. 2). The Total precipitation was 552 mm in 2011, which was 2.47% more than mean precipitation from 1957 to 2012. Ninety-three percent of precipitation occurred from May to September. In 2012, the total precipitation was 681 mm, and mainly in the growing season (May to September). The total precipitation in 2012 was 26.62% more than mean precipitation from 1957to 2012, and 23.57% more than 2011. There was the similar distribution of monthly temperature in 2011 and 2012, however, temperature in growing season was greater in 2012 than 2011 (Fig. 2). Because there were more rainfall events during the late growing season in 2012, it was relative more humid than 2011.

Irrigation/precipitation. Rainfall and the irrigation depth applied to each treatment plot were listed in Table 2. All four treatments were fed with 15 mm of irrigation sing a sprinkle irrigation system before sow in 2012 due to low soil water content limiting soybean germination.. Since the rainfall in 2012 was greater in 2011 before irrigation application started, which resulted in higher pre-irrigation soil water content in 2012, less irrigation water was applied in 2012 for all irrigated treatments. There was 13.72 mm more of rainfall during growing season in 2012 than in 2011. Total water entry in 2012 was 8.65%, 25.22%, 41.85% and 16.85% more than in those in 2011 for T80, T60 and T40 and R treatments, respectively. Moreover, the rates of rainfall to the total irrigation water in 2012 were higher than those in 2011.

Soybean biomass and plant height. The effect of different water entry on biomass is shown in Fig.3. The irrigation schedule had different impact on biomass in both 2011 and 2012. Soybean biomass increased with the increase of water entry amount in R1 growth stage in 2011, soybean in rainfall treatment (R) has its biomass 12.86% more than T40; maximum water entry (T80) increased significantly biomass compared to T40 and R. Water stress (T40) significantly limited soybean biomass accumulation in R4 growth stage ($P<0.05$), and biomass decreased by 30.92%, 29.29% and 27.82% compared with T80, T60 and R. There was no statistical difference between T80, T60 and R in soybean biomass in R4 growth stage in 2011. Sufficient water supply increased soybean

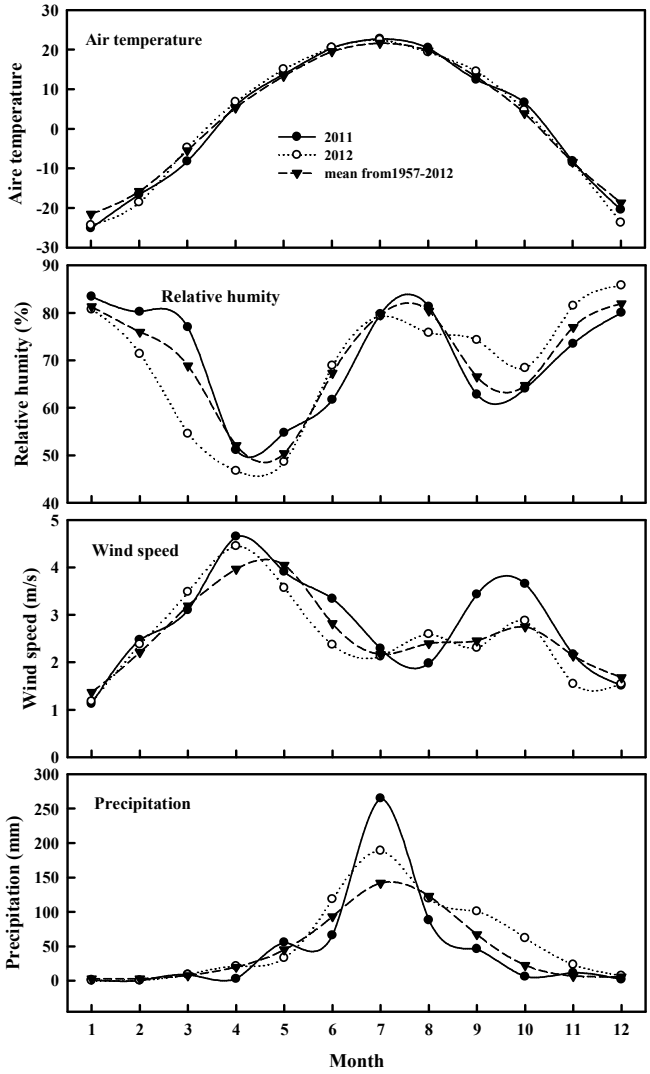

FIGURE 2
Main climate parameters in the two years of fields experiment and a long period

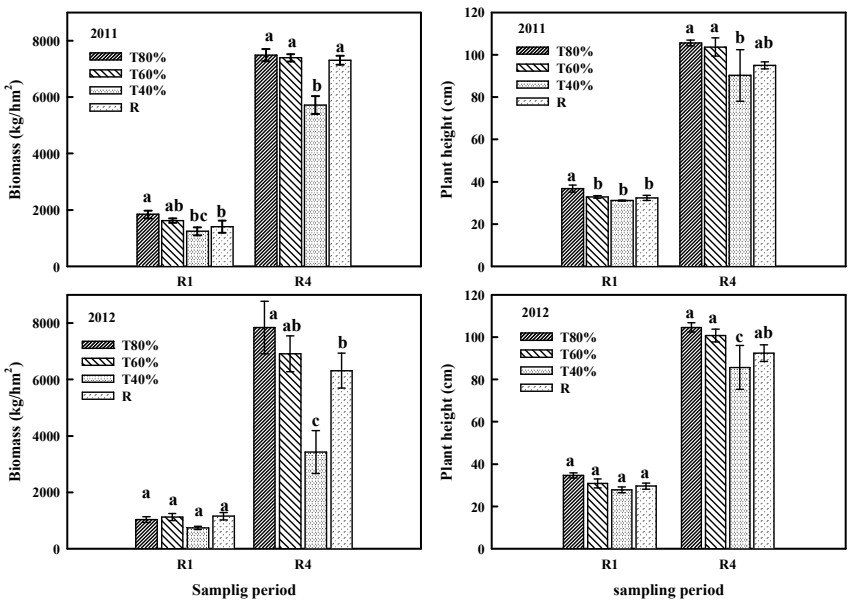

FIGURE 3
The effect of irrigation treatments on biomass and plant height in 2011 and 2012

TABLE 3
The effect of irrigation treatments on soybean yield component

Years	Treatment	Node (plant)	Pod (plant)	Flat pod (plant)	100-seed weight (g)
2011	T80	16.50 a	44.86 a	1.03 b	17.89 b
	T60	16.09 ab	40.10 ab	0.87 b	18.80 a
	T40	15.37 b	35.49 b	1.90 a	16.94 c
	R	15.60 ab	36.70 b	1.10 b	17.03 c
2012	T80	18.57 a	39.23ab	0.41 a	16.96 b
	T60	18.33 a	35.67 bc	0.52 a	18.06 a
	T40	15.87 b	28.27 c	0.60 a	15.91 c
	R	18.60 a	46.13 a	0.47 a	17.67 ab

biomass in R1 growth stage in 2012, but no statistical difference was found between four treatments. As observed in 2011, insufficiently irrigation water applied (T40) limited soybean biomass accumulation, soybean in T80 treatment obtained the greatest biomass, and had statistical difference with R and T40 ($P<0.05$). Our results was similar to the work from Sincik et al. [41] who had documented that deficit irrigation treatments significantly reduced soybean biomass, and increased biomass was observed when irrigation amount wasincreased. Significant relationship ($P<0.01$) existed between water entry and soybean biomass in R4 stages in both 2011 and 2012 (Fig. 4), soybean biomass increased along with the increase of water entry.

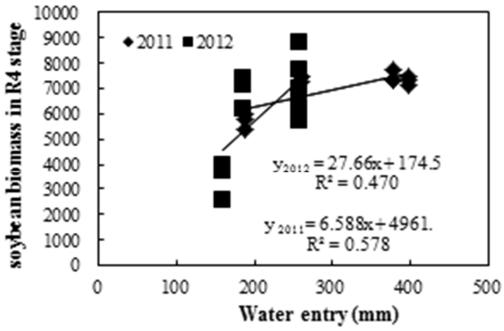

FIGURE 4
Relationships between soybean biomass and water entry in 2011 and 2012

Soybean plant height under different treatments in R1 and R4 growth stages in 2011 and 2012 was shown in Fig.3. The greatest amount of water entry (T80) increased significantly plant height by 11.97%, 18.20% and 13.58% compared with T60, T40 and R, and reached $P<0.05$ significant level in R1 growth stage in 2011. T40 treatment reduced significantly plant height compared with T80 and T60 treatments ($P<0.05$) in R4 growth stage in 2011. The effect of water entry on plant height in 2012 was similar to 2011 as shown in Fig.3. But there was no significant difference of plant height between treatments due to great amount rainfall occurrence before irrigation application, which resulted in the small difference of soil water content among T80, T60, T40 and R in 2012, with the highest plant height observed in T80 treatment in R1 and R4 growth stages. Insufficiently water applied also reduced plant height in 2012. The difference of pant height between 2011 and 2012 was small ($P>0.05$). For both the study years, mean plant heights clearly indicated that the amount of water entry increased the soybean plant heights. T40 treatment resulted in a minimum average plant height followed by R treatment (Fig.3). Hodges and Heatherly [42] indicated that water stress imposed on soybean throughout the growing stages could reduce vegetative growth, moisture stress at R5 growth stage could reduce all measured soybean traits [34]. It is well known that the overall root length of soybean increased under water stress [43] whereas its shoot growth rate was limited [44]. The growth rates of all plant components were enhanced by more frequency irrigation [45], as show in this study plant height was increased with the increase of amount of water entry, and gained greatest value in T80, which was consistent with Daniel and George [4] documented that irrigation at R1 and R4 growth stage of soybean could increase plant height compared with no irrigation treatment.

Yield, yield component. Yield component for all treatments in 2011 and 2012 were summarized in Table 3. Both the numbers of productive pod and node per plant were larger in T80 and T60 in 2011, while the highest values were observed in R treatment in 2012. T40 decreased significantly numbers of productive pod and node per plant compared with other treatments. The response of nodes per plant to irrigation treatments was similar to the work from Korte et al. [36]) who found an increasing trend in the number of nodes per plant as irrigation was applied during reproductive ontogeny. The 100-seed weight was highest in T60 treatment in both 2011 and 2012 and lowest in T40 for both experimental years, which was similar to the work from Sweeney et al. [46]. who observed that the soybean plant in the complete absence of water stress during reproductive development

TABLE 4
Yield, Evapotranspiration (ET), water use efficiency and irrigation water use efficiency for the different treatments in experimental years

Year	Treatment	Yield (kg ha^{-1})	ET (mm)	WUE (kg m^{-3})	IWUE (kg m^{-3})
2011	T80%	2979 b	568 a	5.25 c	6.89 c
	T60%	3350 a	373 c	8.98 a	15.16 b
	T40%	2699 c	284 d	9.52 a	24.54 a
	R	2945 b	429 b	6.87 b	------
2012	T80%	2895 ab	600 a	4.83 c	6.98 c
	T60%	3019 a	465 c	6.49 a	12.03 b
	T40%	2217 c	381 d	5.83 b	15.40 a
	R	2779 b	484 b	5.75 b	------
	Treatments	**	**	**	**
	Years	**	**	**	**
	Treatment x Year	*	**	**	**

initiated a maximal number of seeds/plant, but were limited in some way from also maximally enlarging these seeds to attain the seed size dimensions.. T40 treatment increased significantly flat pod per plant in 2011 compared with other treatments (*P<0.05*), however, there was no statistical difference among four treatments in 2012 with the biggest value also being observed in T40 treatment.

Soybean yield ranged from 2699 to 3350 kg ha^{-1} in 2011, 2217 to 3019 kg ha^{-1} in 2012. The mean yield was 2993 kg ha^{-1} in 2011 with an increase of 9.74% compared to 2012, which could be contributed to the climatic conditions, disease and insect damage. Soybean yield reached the highest in T60 treatments, and about 12.47%, 13.77% and 24.14% more than yield in the treatments of T80, R and T40, respectively in 2011, and about 4.28%, 8.63% and 36.17% more, respectively, in 2012. The highest soybean yield in the study is close to the potential yield in the area. Water availability is the key factor determining yield for soybean in the study area [21]. This is consistent with the result that irrigation at reproductive stage in soybean averaged about 20% more than yield with no irrigation [46]. Water stress (T40) is considered as the most deleterious to soybean yields during the pod formation and pod filling period [47]. The interaction of treatments and years had significant effect on soybean yield (*P<0.05*). The results from two experimental years indicated that T60 treatment was better for higher soybean yield.

The responses of soybean yield to amount of water entry could be described using quadratic equations (Fig.5), but relationships was not as significant as with the work from [45] Garcia et al., that the relationship between soybean yield and total water amount could be described using Y=7.20X ($r^{2=}$0.79**, n=48), but the trend was similar. Soybean only achieves the highest yield at a certain amount of water entry, after that point, the yield starts decrease with more water applied, and the theoretical soybean yield in 2011 and 2012 were 3223 and 3015 kg ha^{-1} at critical points of 411.64 mm and 510.43 mm, respectively. Dogan et al. [48] showed that any drought stress on reproduction stages would resulted in a significant yield reduction compared with the no water stress treatments. Their finding is consistent with our result that water entry at the level of T40 significantly decreased soybean yield. Korte et al. [33] found that irrigation during pod elongation increased seeds per-plant and irrigation at seed enlargement increased seed weight, which is consisted with our results that the largest 100 seed-weight and pod per plant were observed in T60 treatment, but irrigation during pod elongation and seed enlargement could result in the greatest yield [33, 36]. T60 treatment kept soil water content at 60% of field water capacity of Mollisol represented as supplemental irrigation relative to R treatment. In 2011, there was no rainfall from 12th to 30th June and 17th to 27th July, which meant no water entry for R treatment. During these two periods, T60 treatment received irrigation water of 27 mm and 60 mm, resulting in significant increase in soybean yield by 13.78%. In 2012, there was no dry period like in 2011, soybean yield in T60 was 8.63% higher than that in R treatment (*P<0.05*). Higher soil water content resulting from a more than 50 mm of accumulative rainfall within 5 days can lead to hypoxia in soybean root zone and thus limit soybean yield [49]. Though there was less water entry in T60 treatment than R, soybean yield was larger in T60, suggesting that the distribution of rainfall in growing season was more critical than rainfall amount in Northeast China. However, more water entry would limit soybean yield as the performance of T80 in our study compared with T60, which could contributed to higher soil water content resulted from more water entry limited the aeration in root zone [49], caused limitations to effective oxygen diffusion into the crop root zone. Plant roots required substantial amounts of oxygen

for effective root respiration. Decreased root respiration caused by low oxygen availability severely impedes plant growth by reducing transpiration [50]. Soybean yield in T80 treatment was also higher than in R treatment. Adequate water entry through irrigation shows superior to natural rainfall. Liu et al. [21] reported that in Northeast China highest soybean yield was achieved when soil water content was at 80% of field water capacity. But we found that 60% of field water capacity was the most appropriate level of soil water content for soybean yield.

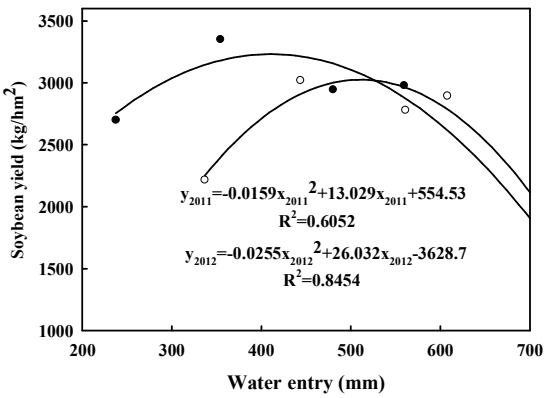

FIGURE 5
Relationship between soybean yield and water entry in 2011 and 2012

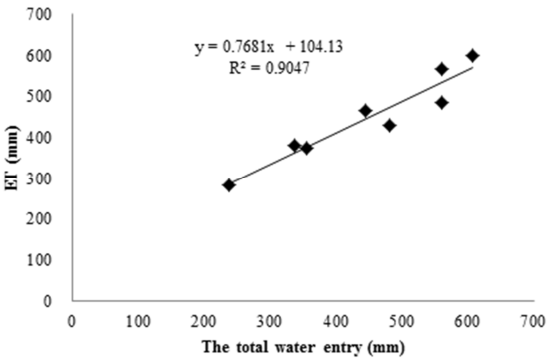

FIGURE 6
Relationships between evapotranspiration (ET) and water entry in the two crop seasons

ET, WUE and IWUE. Irrigation was one of the key factors to have impact on whether ET was close to the potential rate [23]. ET as affected by different water entry in the two crop seasons was shown in Table 4. ET of different treatments ranged from 568 to 284 mm in 2011, from 600 to 381 mm in 2012. The most water entry treatment T80 received the maximum ET, and the least water entry treatment T40 had the lowest ET. The results indicated that the ET of soybean was significantly influenced by water entry (Fig.6). They were linearly correlated with the increasing in water entry, ET increased. ET was driven by meteorological factors, crop process but was also an energy consuming process. In order to clarify the effect of irrigation on ET, regression analysis was carried out. Significant relationship (*P<0.01*) existed between water entry and ET. Candogan et al [51] also reported that ET was increased with the increasing in irrigation level.

ET was regulated by the meteorological factors and plant factors, and they were consistent in the two crop seasons. The difference in soil water storage and water entry was the main reason of the difference among the amounts of ET in two crop seasons. Thus, an irrigation strategy could be developed according to the rainfall and soil water storage in study site.

Table 4 showed the WUE of the different water entry treatments in the two soybean seasons. WUE ranged from 5.25 to 9.52 kg m^{-3} in 2011, 4.83 to 6.49 kg m^{-3} in 2012. The trend was similar among the treatments in both crop seasons. The WUE of T80 treatment was the lowest and lowest water entry (T40) treatment was highest in 2011, moderately water entry treatment (T60) was highest in 2012. IWUE ranged from 6.89 to 24.54 kg m^{-3} in 2011, 6.98 to 15.40 kg m^{-3} in 2012 with treatment T40 at the highest. WUE depended on IWUE to some extent. The results were similar in 2011 and 2012, and there was significant difference (*P<0.05*) among the treatments.

CONCLUSIONS

A field experiment with four water entries including rain-fed treatment, irrigation at 80% of field water capacity, at 60% and 40%, respectively, was carried out at the National Field Research Station of Agro-ecosystems in Northeast China in order to investigate the effects of irrigation on plant height, biomass, soybean yield, WUE and IWUE in Northeast China. The following conclusions were obtained: (1) the effect of irrigation regime of soybean biomass and plant height was showed that soybean biomass and plant height increased with the increase of water entry in experimental years. T60 was the best suitable water entry for 100-seed weight of soybean. Soybean yield reached the highest value in T60 treatment, and was decreased when water entry was in T80. Keeping soil water content at about 60% of field water capacity is a better management for irrigation in study site. Additional study is needed to determine how soybean response to water at any individual growth stages.

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