Precision drip irrigation on hot pepper in arid Northwest China area

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Abstract: An experiment was conducted to study the effects of different soil water potential (SWP) on soil water content, hot pepper's yield, water consumption and water use efficiency (WUE) under plastic-mulched drip irrigation in the North-West China in order to find a suitable SWP to guide the pepper irrigation. Five treatments were set based on SWP, they were -10kPa (N1), -20kPa (N2), -30kPa (N3), -40kPa (N4) and -50kPa (N5). A control treatment (N6) was set based on local irrigation practice, i.e. border irrigation. SWP was measured using tensiometers at 0.2 m depth immediately under drip emitters. Pepper leaf area, plant height, soil water content, yield and total soluble solid (TSS) were measured, soil water content and WUE were calculated. Results shows that the differences in leaf area index and plant height were not significant ($P>0.05$) among treatments of N1, N2, N3 and N4. While the pepper yields, WUE and TSS were higher for treatments N3 and N4. Controlling SWP at -50kPa greatly decreased crop yield and WUE. Therefore, we recommend -30 ~ -40 kPa as the irrigation threshold for pepper cultivation under mulched drip irrigation in arid areas of the North-West China.

Keywords: soil water potential; yield, water use efficiency; mulched drip irrigation, Northwest China

1 Introduction

Hot pepper is an important economic crop in China. Areas for pepper production is 35 000 ha [1], mainly distributed in the North-West China and South-West China. The annual pepper production is about 215,000 t. In the North-West China, especially in Gansu Province, the hot pepper is widely cultivated with a high capsaicin and haematochrome content, mainly due to its special climatic condition [2]. During the long history of hot pepper cultivation in Gansu Province, the crop is generally irrigated with surface irrigation, mainly including border irrigation and furrow irrigation. Under these irrigation practices, crop water use ranges from 330 mm to 540 mm. Annual precipitation in this region is from 150 mm to 300 mm[3]. It can be found that precipitation cannot satisfy the water requirement of the pepper. Agricultural water use generally accounts for 92.57 % of the total water use in this region [4]. With the development of economy, water allocation for agriculture will be decreased. Therefore, water-saving irrigation technology and irrigation scheduling are the ways to saving water and maintaining high crop yield and quality, especially for cash crops, for example hot pepper.

Water-saving irrigation method is one of the key factors not only to save irrigation water but also increase crop yield in the arid region. Drip irrigation is one of the Water-saving irrigation methods. Hanson

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and May (2004) indicated that drip irrigation applies water both precisely and uniformly, in comparison with furrow and sprinkler irrigation, resulting in the potential to reduce subsurface drainage, control soil salinity, and increase yield[5]. Liu et al. (2005) pointed out that plant growth and yield under drip irrigation were higher than those under flood irrigation, the soluble solid contents under drip irrigation also increased [6]. Li et al. (2007) found that drip irrigation can save irrigation water by 49.83% as compared to surface irrigation, and the crop yield increased by 9.99% [7]. Under most experiments, drip irrigation can save irrigation water by 30% to 40% [8].

Hot pepper is sensitive to water stress. Soil water deficit seriously affects the growth and yield of hot pepper. Therefore, many experiments were carried out to seek suitable soil water content for pepper. Wang et al. [9] found in a greenhouse experiment that yields of hot pepper were 53.4%, 72.3% and 79.1% of the maximum yield for irrigation amounts of 45, 67.5 and 90 mm, respectively, the highest hot pepper yield was achieved when moisture in the root-zone soil maintains between 60% and 80% of field capacity. Yang et al. [10] found that pepper yield and dry matter accumulation increased with the increase of reasonable amount of water and fertilizer, and the highest yield was achieved when soil moisture maintain between 70% and 75% of field capacity. Huo et al. [11] also found that the highest pepper yield was achieved when soil moisture maintains 70% of field capacity, while too high or too low soil moisture greatly affects pepper production. In practice, the soil water content measurements generally require special equipments, and the measuring process is complicated, which are difficult for farmers to use in field practice.

Soil water potential is related to soil water content [12], and also used as an indicator to directly guide irrigation [13-20]. Some experiments showed that, the proper soil water potential is -25kPa for potato, -35kPa for radish, -50kPa for tomato. The objectives of this paper are to investigate the effects of different soil water potentials to soil water content, pepper's growth, yield, water consumption and water use efficiency under plastic mulched drip irrigation condition, and finally find suitable soil water potential to guide pepper irrigation in the arid region of the North-West China.

2 Materials and methods:

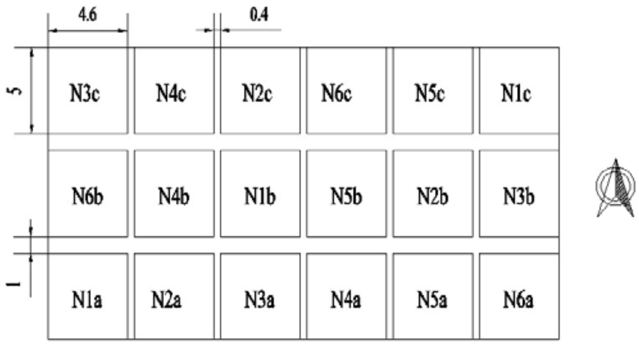
2.1 Experimental sites:

The experiment was conducted at Shiyanghe Experimental Station for Water-saving in Agriculture and Ecology of China Agricultural University, located in Wuwei City, Gansu Province of northwest China (N 37° 52′ , E102° 50′ 50″ , altitude 1581m) during April to October of 2009. The experimental site is in a typical continental temperate climate zone, mean annual temperature is 8 ℃, annual accumulated temperature (>0 ℃) is 3550 ℃, annual precipitation is 164.4 mm, mean annual pan evaporation is about 2000 mm, arid index (the ratio of yearly water evaporation to year precipitation) is 15 -- 25, average annual sunshine duration is 3000 h and free frost days in a year is 150 days. The groundwater table is 40 – 50 m below the ground surface. Soil texture is sandy loam, with a mean dry bulk density of 1.5 g/cm^3, and mean volumetric soil water content at field capacity is 0.243 cm^3/cm^3.

2.2 Experimental design

The experiment consisted of five treatments based on soil water potential (SWP), -10 kPa, -20 kPa, -30 kPa, -40 kPa and -50 kPa, they are referring to N1, N2, N3, N4 and N5, respectively. A control treatment (N6) was set according to the local irrigation. SWP for each treatment was measured using two tensiometers, which was installed at 20 cm depth immediately under the emitter. Each treatment included three replications, with a dimension of 4.6 m in width and 5 m in length for each replicated subplot. Each subplot was divided into three raised beds. The spacing between raised beds was 0.4 m; the width and height of the bed were 1.0 m and 0.2 m, respectively. All experimental subplots were following a complete randomized design, seeing Figure 1. The two tensionmeters were installed in the middle raised bed of each experimental treatment.

(a)



(b)

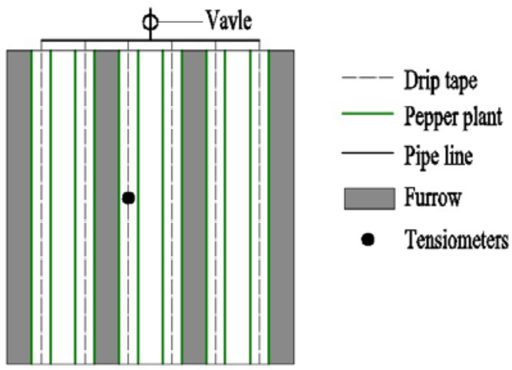


Fig. 1. Schematic diagram of the treatment layout (a) and detail drawing of a replicated subplot (b), length unit in figure (b) is meter.

Before the experiment, soil water content and SWP were measured simultaneously in the experimental field to determine the soil water characteristic curve. This curve was used to calculate soil water content and then to determine irrigation amount for each irrigation event using the measured SWP. The relationship between soil water content and SWP is expressed using Eq. (1).

$$\psi = -94.661 \bullet \ln(\theta) - 130.83 \quad (n = 21, R^2 = 0.9584) \tag{1}$$

Where θ is volumetric soil water content in cm^3/cm^3, ψ is SWP in kPa. When the SWP was below the target SWP, irrigation begins. Each irrigation amount was determined using soil water content and field capacity with the Eq. (2).

$$M = AH(FC - \theta)p/\eta \tag{2}$$

Where M is irrigation amount in m^3; A is the plot area in m^2; H is irrigation depth in m and is set 0.25 m based on the root distribution; θ is the volumetric water content before irrigation, which is calculated from measured SWP; FC is the field capacity; p is the percentage of wetted area and is 0.652; η is irrigation efficiency and set 1.0 under drip irrigation.

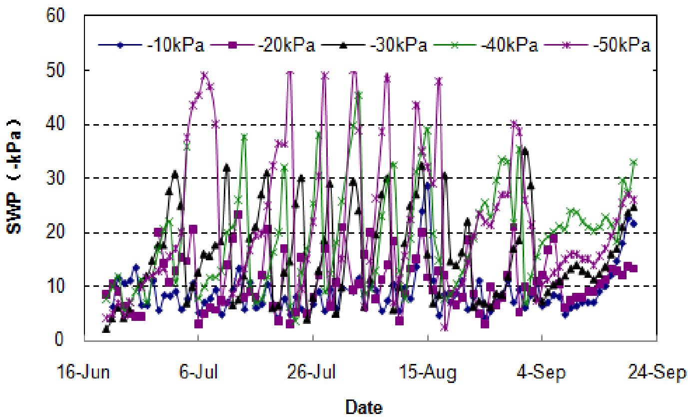


Fig. 2. Soil water potential (SWP) variations of different treatments in the experimental period

2.3 Agronomic practices

Peppers were planted in a raised bed (Fig 1 b). In each bed, there were four pepper rows, with row spacings between the four lines of 0.3 m - 0.4 m - 0.3 m and plant spacing of 0.3 m. Two pepper rows was irrigated using one drip tape with emitters spacing of 0.3 m and emitter discharge of 2.7 l/h at the operating pressure of 0.1 MPa. (Lvyuan Inc, Beijing). The drip tape was deployed between the middle line of two pepper rows (Fig 1 b). Therefore, there were two drip tapes in each raised bed. The raised beds and drip tapes were covered with a 1.4 - m - width black plastic sheet to reduce surface evaporation and control weed growth. Organic fertilizer (cow manure) was applied uniformly to each plot with a rate of 12000 kg/ha when the soil was plowed. Nitrogen fertilizer (urea) was applied to the peppers using the drip irrigation system by three times with a total amount of 180 kg/ha. The hot pepper (American Red) was seeded on 4 May and harvested on 25 September in 2009.

2.4 Measurements

(1)Meteorological factors

Meteorological factors included temperature, humidity; solar radiation, wind speed, and precipitation were recorded by an automatic weather station in the experimental station.

(2) Soil water potential

Soil water potential (SWP) was measured using tensiometers, which were installed at a depth of 0.20 m immediately below the emitter in one replicate subplot of each treatment. The tensiometers were investigated three times a day, at 8:00, 14:00 and 18:00. When the measured SWP is approaching the set values, irrigation begin.

(3) Soil moisture

Soil moisture was measured every 10 cm from 0 to 60 cm soil layer by thermo-gravimetric method using augers every 15 d during the experimental period.

(4) Leaf area index

Leaf area index (LAI) was measured by leaf area meter AM300 (AM300 Portable Leaf Area Meter, ADC Bioscientific Ltd., Hoddesdon, UK) at 15-day intervals during the pepper-growing season in 2009. For each event, LAI at three to five sites in each treatment were measured and the average value was used for data analysis.

(5)Total soluble solids

Total soluble solid (TSS) was measured by handheld digital refractometer (PR-32α, Tokyo, Japan) during the harvest time in 2009. Three pepper fruits were random selected for each treatment and the average value was calculated.

(6) Yields

Pepper yields were determined at harvest. Twenty plants in the middle subplot of each treatment were randomly selected, and the numbers per pepper plant and weight of each pepper were investigated.

2.5 Calculations

Water consumption (ET) of hot pepper was estimated using the water balance method as:

$$ET = I + P_e + K - (W_t - W_0) \tag{3}$$

Where ET is the evaportranspiration, mm, I is the irrigation amount in mm; P_e is the effective precipitation in the pepper growth period in mm; W_t is the soil water storage at time of t in the 0-60 cm soil layer, mm; W_0 is the initial soil water storage in the 0-60 cm soil layer, mm; K is the groundwater recharge and was set 0 considering the groundwater table of 40 – 50 m.

Water use efficiency (WUE) of hot pepper is expressed as the production of pepper consuming per units of water, and the calculation formula is:

$$WUE = \frac{Y}{ET} \tag{4}$$

Where WUE is the water use efficiency in kg/m^3, Y is the yield in kg/ha, ET is the evaportranspiration in m^3/ha.

In this paper, SPSS11.5 statistical software (SPSS Inc., Chicago, IL, USA) was used for statistical analysis.

2.6 Statistical analysis

Statistical differences in leaf area index, pepper yield and pepper classifications among experimental treatments were analyzed with SPSS 11.5 software (SPSS Inc., Chicago, IL, USA). A level of 0.05 was adopted for the analysis of variance (ANOVA).

3 Results and discussion

3.1 Soil water content under different SWP treatments

Zhang (2001) reported that most of the pepper roots distributes in the upper 40 cm soil layer [21]. Our measurement also shows that more than 90% of root mass distributed within the 0 - 40-cm soil layer. Therefore, we analyzed the soil water content in the upper 0 - 40-cm soil layer (Fig. 3). It can be found that the average soil water content of N1 treatment was the highest, with the smallest variation during the whole experiment period among the six treatments. The reason maybe mainly due to the higher irrigation frequency and greater irrigation amount, i.e. everyday or once two days in vigorous growth stage for treatment N1, as compared to the other five treatments. The soil water content of treatment N5 was the lowest before August 20, which is mainly because of the least irrigation amount. The soil water content of treatment N6 was also very low before August 20 because the irrigation intervals were too long, i.e. once every 15 to 20 days. In the later period of the experiment, there is a minor difference in soil water content among treatments except N1, which maybe mainly due to more precipitation. The precipitation from June 20 to August 20 was 53.4 mm, and was 38.6mm from August 20 to harvest.

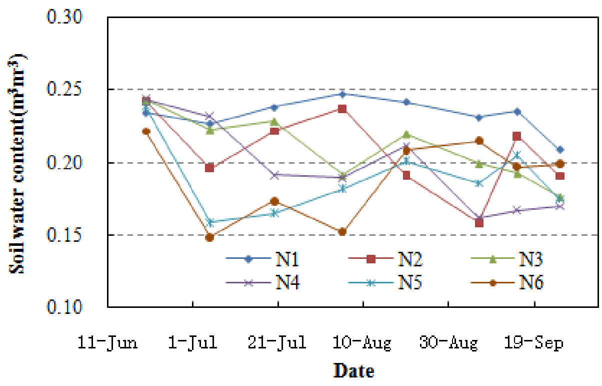


Fig. 3. Average soil moisture content over 0 - 40-cm soil layer in the experimental period

3.2 Pepper growth

3.2.1 Leaf area index

Fig. 4 illustrates the changes of leaf area index (LAI) for the six treatments during experimental period. The figure shows a sigmoid shape for the LAI in the experimental period. The maximum LAI reached generally around 7 to 27 August. During most experimental period, LAI was the least for treatment N5, which may be due to the less irrigation amount. The differences in LAI among the other five treatments were not significantly (P>0.05) during the most experimental period.

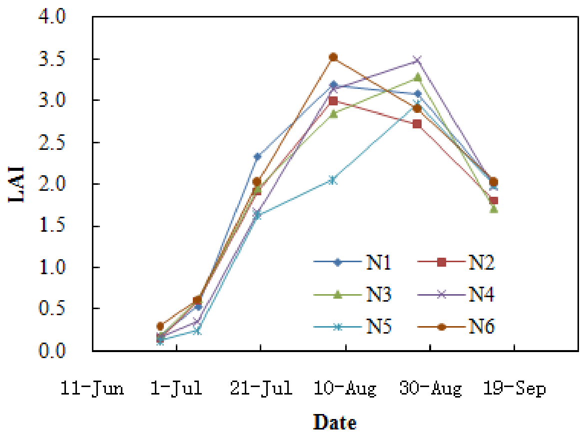


Fig. 4. Changes of leaf area index (LAI) within the pepper growth period

3.2.2 Plant height

Fig. 5 shows the changes of plant height for the six treatments during the experimental period. The figure shows that, plant height increased fast before August (generally in vegetative growth stage), afterward, it increased little or stop increasing in fruit growth stage. The plant height of N5 was the lowest and it was the highest for N6 treatment during the whole growing period. The height differences among N1, N2, N3 and N4 were insignificant (P>0.05). It can be concluded that controlling soil water potential of -50 kPa will seriously affect the growth of pepper.

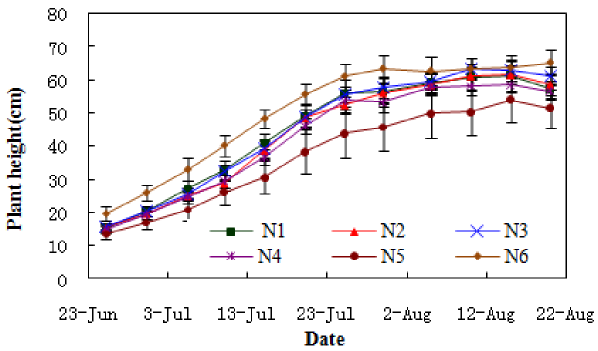


Fig. 5. Changes of plant height within the pepper growth period

3.3 Fruits quality

3.3.1 Total soluble solids

Total soluble solid is an index of soluble solids concentration in fruit and always used to evaluate fruit quality. Results on TSS for the six treatments are showed in Fig 6. The TSS content generally increased as the SWP decreased from -10 kPa to -40 kPa. The highest TSS was 9.2%, found for treatment N4. The lowest one was found for treatment N5 with a value of 7.5%. The TSS for flood irrigation treatment (N6) was similar to the treatments N1 and N2, but greatly less than those for treatment N3 and N4. It can be seen that controlling SWP of -50 kPa will greatly influence fruit quality, while controlling SWP within a relative deficit range (for example -30 to -40 kPa) maybe benefit crop quality. Findings of Ma et al (2006) [22] is similar to our conclusion, who found that the deficit irrigation treatments enhance soluble solid matter in jujube fruits and improve the fruit quality.

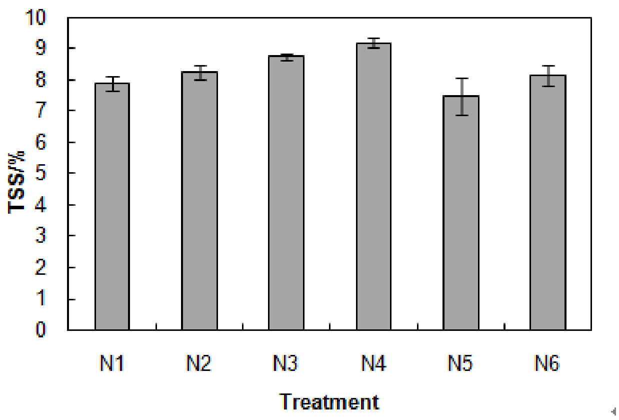


Fig.6. Content of total soluble solid (TSS) of peppers for the six treatments

3.3.2 Fruits classification

Sixty pepper plants were selected to determine the fruit yield for each treatment. The weight of each pepper fruit was measured individually for pepper classification. The pepper fruit was classified into four levels according to the pepper fruit weight, they were > 30 g (level 1), 20 – 30 g (level 2), 10 – 20 g (level 3), and < 10 g (level 4). Fig 7 shows the proportion of peppers in each level to the total yield. Except for treatment N5, the proportion was the highest in level 2 (20 – 30 g), following by level 3 (10 – 20 g), level 1 (> 30 g) and level 4 (< 10 g).There was little difference in pepper proportion of each yield level among treatments N1, N2, N3, N4 and N6. For treatment N5, about 50% of peppers were found in level 3, which means there were more small peppers as compared to other five treatments. This is the main reason for the lowest yield of treatment N5 among all treatments (Table 1). The greater amount of smaller fruit in treatment N5 will also influences pepper price and final incoming.

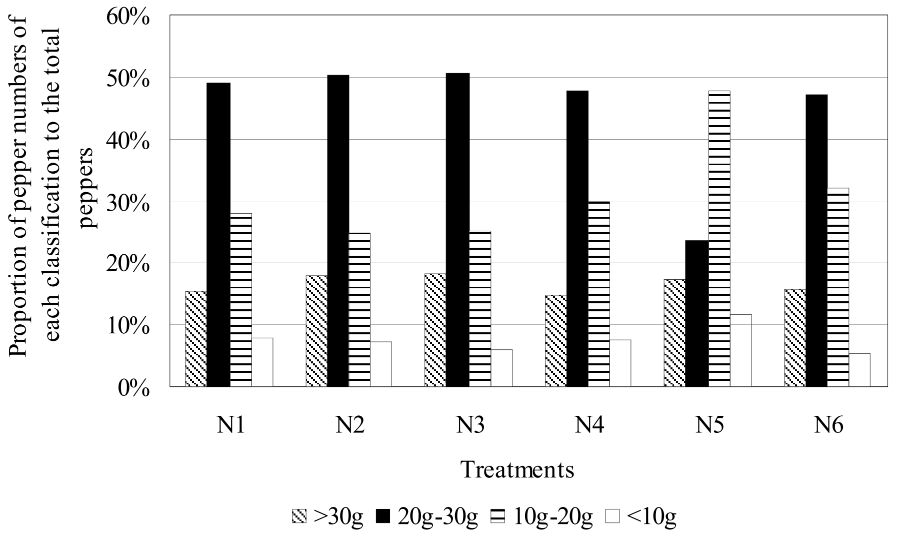


Fig.7. the proportion of pepper yield of each classification to the total yield

3.4 ET, Yield and WUE

Table 1 lists the irrigation amount, crop water consumption (ET), yield and WUE for the six treatments. Pepper ET was calculated using water balance equation, and WUE was calculated by Eq. (3).

Table 1. Irrigation amount, ET, yield and WUE of pepper for different treatments

treatments	Irrigation amount(mm)	ET(mm)	Yield（ton/ha）	WUE(kg/m^3)
-10kPa(N1)	314	412	34.1(±4.2) abc	8.3
-20kPa(N2)	204	321	31.5(±4.2) bc	9.8
-30kPa(N3)	179	311	35.6(±5.0) a	11.5
-40kPa(N4)	163	295	33.7(±5.7)abc	11.4
-50kPa(N5)	180	312	30.7(±4.8) c	9.9
Border irrigation(N6)	246	317	34.3(±4.2)ab	10.8

NS: values in the yield column with the same letter are not significantly different by one-way ANOVA test at the 0.05 probability level.

Pepper irrigation amount and ET decreased greatly from treatments N1 to N2, while differences of irrigation amount and ET were small for treatments N3, N4 and N5. These results are similar to the finding of Zhang et al. (2006) [23], who carried out a drip irrigation trial with SWP controlling on tomato, and found that irrigation amount decreases with the SWP decreasing first and then increases when SWP decreases to a certain level. We analyzed the relationship between the controlled SWP levels and irrigation water amount and crop ET, showing in the Fig. 8. The relationships between the irrigation amounts, total ET and SWPs can be expressed using a quadratic polynomial, as follows.

$$ET = 15.072\psi^2 - 113.24\psi + 503.97 \quad (n = 5, R^2 = 0.9491) \tag{5}$$

$$I_{total} = 18.648\psi^2 - 142.79\psi + 431.36 \quad (n = 5, R^2 = 0.9727) \tag{6}$$

Where Ψ is the controlling SWP, -kPa; I_{total} is the total irrigation amount for each treatment, mm.

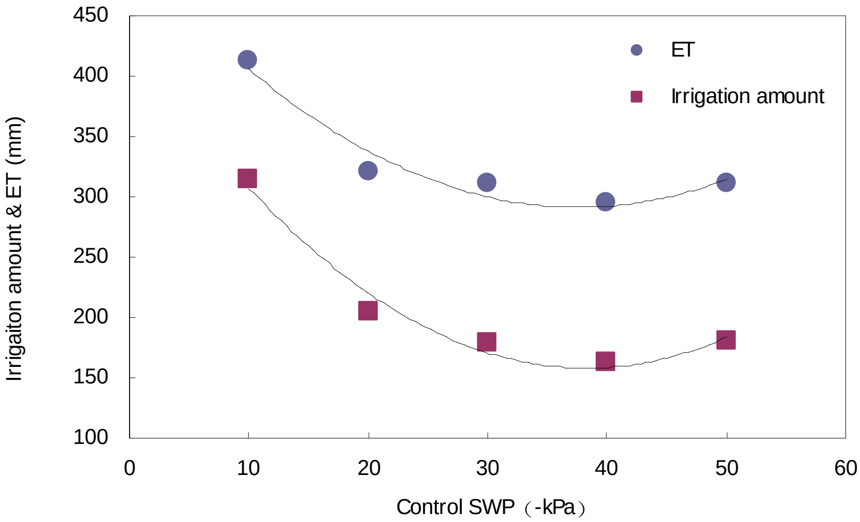


Fig. 8. Relationships of pepper irrigation amount and ET to controlling soil water potential (SWP)

Pepper yields for the six treatments were following the order: N3>N6>N1>N4>N2>N5. Statistical analysis shows that the pepper yield of treatment N3 was significantly ($P<0.05$) higher than Treatment N2 and N5, but the yield differences among treatments N3, N6, N1 and N4 were insignificant ($P>0.05$). The minimum pepper yield was obtained in treatment N5, which was lower by 16% than the maximum yield in treatment N3. This result means that the controlling SWP of -50 kPa will cause a great potential for yield reduction. This result is similar to the conclusions of the effect of different SWP to leaf area and plant height. The pepper yield of treatment N1 was less than those for treatment N3, though irrigation water amount was greater in treatment N1 as compared to N3, The lower yield for N1 may be due to excessive irrigation and high soil water content, which restrained the growth of root and thereby affected the yield. Ensico et al. (2008) studied the irrigation regimes of onion and found that higher total yields were obtained when the soil moisture was kept above -30 kPa, and total yields dropped significantly when soil water potential was below -50 kPa [24]. Du et al. (2007) studied the irrigation regime of pepper in greenhouse in North-West China, and obtained a yield of 36.5 t / ha when the irrigation amount was 217.5 mm [25]. Pepper yield in our experiment is similar to those of Du et al. (2007), while irrigation water in this study decreased by 38 mm. The yield of treatment N6 was the second highest among the six treatments, which show that the conventional irrigation method can also obtain a high yield. While, irrigation amount under conventional practice was about 40 -80 mm higher than the treatments of N2 to N5. Considering the minor differences in crop ET (Table 1) and soil water content (Figure 3), more irrigation water maybe lost through seepage under border irrigation for treatment N6, which therefore, decrease the irrigation water use efficiency.

Water use efficiency for the six treatments is listed in Table 1. WUEs of treatment N3 and N4 were 11.5 kg/m^3 and 11.4 kg/m^3, respectively, which were greatly higher than those of N2 (9.8 kg/m^3) and N5 (9.9 kg/m^3). The WUE for treatment N1 was 8.3 kg/m^3, the least one among the six treatments, which may be due to the greatest ET. Wan et al. (2007) found that high WUE of cucumber can't be obtained if the SWP threshold was too high [26]. Kang et al. (2004) found in a drip-irrigated potato fields that the highest yield and WUE were found when SWP is -25kPa and the least for -55kPa. Metin et al. (2006) studied the effect of drip irrigation regimes on field grown pepper and concluded that WUE and IWUE values decreased with increasing irrigation intervals [27], which is similar to our findings when the controlling SWP is from -10 kPa to -30 kPa.

Conclusion

From the mulched and drip irrigated pepper experiment, conducted in northwest China, we found that SWP levels greatly affected the pepper growth, fruits quality, yield and water use efficiency. The main results are summarized as follows:

Soil water content was higher and it's variation was scarce in the whole growth period when the SWP level is -10 kPa. Irrigation amount and crop water consumption decrease as the SWP threshold decrease. The relationship between crop ET and SWP can be fit as a quadratic polynomial.

Controlling SWP levels between -10kPa and -40kPa did a minor effect on leaf area index and plant height. The higher TSS, yield and water use efficiency were found when SWP levels are between -30kPa and -40kPa. SWP of -50kPa will greatly reduce crop leaf area index, height, TSS, yield and water use efficiency.

Comprehensively considering the pepper fruits quality, yield and WUE, controlling SWP levels of -30 kPa to -40 kPa at 20 cm depth immediately under drip emitter can be recommended as an indicator for pepper drip irrigation scheduling in northwest China.

Acknowledge

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