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Effect of soil matric potential on wolfberry (*Lycium barbarbum* L.) yield, evapotranspiration and water use efficiency under drip irrigation

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The experiment was undertaken in order to investigate the effect of soil matric potential (SMP) on wolfberry yield, evapotranspiration (ET), water use efficiency (WUE) and the implications for soil water management under drip irrigation in the Yinchuan Plain arid region of Northwest China. The experiment consisted of five treatments, which maintained SMP at a depth of 0.2 m immediately under a drip emitter releasing water at -10 (S1), -20 (S2), -30 (S3), -40 (S4) and -50 kPa (S5), respectively, after wolfberry had been planted. The results showed that during the growing season, the target SMP value of the five different treatments was maintained within the experimental design range and the irrigation volume and ET declined as the target SMP value decreased. The temporal and spatial soil water content (SWC) changes observed in the soil profile suggested that the S1 and S2 treatments could meet the crop water absorption demand because the soil moisture was over 15 % and soil water was in excess of crop needs. However, the soil water content for S3, S4 and S5 was less than 15 %, which produced visible water stress in the crop. Statistical analysis for the change values in the electrical conductivity of the saturated soil-paste extract (ECe) showed the significant differences between the different SMP treatments in the middle layer (40 – 80 cm) and the plots S2 (-20 kPa) had the better effect of the soil salinity leached. The highest yield was achieved in the S2 plots and the lowest fresh to dry weight ratio was found in the S3 plots, which also produced the highest quality seed. WUE was in the order S3 > S5 > S2 > S4 > S1. Based on a comprehensive analysis that included irrigation volume, ET value, crop yield and WUE, it is recommended that the SMP threshold should be controlled in the range from -20 to -30 kPa, which was the most favorable drip irrigation schedule for increasing yields and irrigation efficiency. The study should provide information that could be used in other regions suffering from drought and water scarcity.

Key words: Deep percolation, irrigation volume, soil salinity, soil water content (SWC), vacuum tensiometers.

INTRODUCTION

The wolfberry (*Lycium barbarbum* L.) grown in the Ningxia Hui Autonomous Region is famous around the world. Ningxia wolfberry production represents 60% of Chinese wolfberry production and this has developed rapidly over recent years, e.g. in 2010, the Forestry Bureau of the Ningxia Hui Autonomous Region reported that the land used for wolfberry plantations was over 4.67 × 10^4 hm^2 and production value was more than 2 billion

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Yuan. However, in local areas, for some aspect poor irrigation management has led to water resources being wasted and poor practices, such as flood irrigation.

Drip irrigation is able to apply water at a low discharge rate and at a high frequency over a long time period. It can maintain high soil water content in the root zone (Keller and Bliesner, 1990) and can be used to overcome problems associated with water stress or over irrigation. In the past few years, sensor technology, that permits continuous on-farm monitoring of soil water status, has become increasingly accessible to commercial producers (Zotarelli et al., 2009). Tensiometers, which measure soil matric potential (SMP), can be used to more accurately balance specific crop water requirements. A number of studies on scheduling irrigation, using tensiometers to measure SMP, have been reported (Phene et al., 1989; Clark et al., 1996; Shock et al., 2000; Wilson et al., 2001). The SMP results presented by Kang (2004a) in a report on an applied method for drip irrigation scheduling are used as the SMP target value in China. They suggested that the SMP at 0.2 m depth immediately under the drip line was a good indicator of the soil water condition in the crop root zone layer.

In the north China plain, research has shown that when SMP was kept at -35 kPa, radishes absorbed more N, P, and K, accumulated more nutrients and had an increased dry matter weight (Feng et al., 2004). With potatoes, the highest yield and WUE values were achieved when the soil matric potential threshold was around -25 kPa and with an irrigation frequency of once a day (Kang et al., 2004b). Moreover, using tensiometers to measure SMP is a feasible and simple method that improves crop growth by controlling soil water-salts in arid and semi-arid areas (Kang et al., 2007). When there was not enough fresh water for irrigation in semi-humid areas, the soil matric potentials at 0.2 m depth immediately under drip emitters were kept higher than -20 kPa during the growing season. Saline water with salinity ranging from 2.2 to 4.9 dS m^{-1} could be applied to irrigate field grown tomatoes about 30 days after transplanting if appropriate management strategies were adopted (Wan et al., 2007a). Cucumber, a moderately salt-sensitive plant, could be irrigated with saline water (EC = 2.2 - 4.9 dS m^{-1}) if the SMP was maintained between -25 kPa and -35 kPa after the seeding stage (Wan et al., 2007b). In the northwest arid area, a 3-year experiment was carried out in a heavily saline field in Jinshawan, Ningxia Autonomous Region. When the SMP was maintained at over -10 kPa, soil salinity was well leached and waxy corn and oil sunflower planted in the experimental plots grew well. Tomato, cucumber, sorghum and some other plants also grew well, achieving normal or near normal yields (Jiao et al., 2007; Kang et al., 2007).

The objectives of this study were to maintain soil water levels, based on SMP at 0.2 m depth immediately under the drip emitter, and to evaluate the effect of SMP on wolfberry plant yield and WUE. The aim was to suggest a SMP threshold for wolfberry irrigation scheduling in the Yinchuan Plain located in the arid region of Northwest China.

MATERIALS AND METHODS

Experimental site and soil

The field experiment was conducted at the Zhongning *L. barbarbum* L. Drip-irrigation and Effective Cultivation Technique integration Experimental Area (latitude 37° 25′ 30″ N, longitude 105° 46′ 12″ E), Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences. The study site was located at the Ningxia Yellow River Irrigation Area in arid Northwest China at an altitude of 1290 m. Average annual precipitation is 184 mm, of which 72% is received during June to September, and average annual evaporation is 2100 mm. Average annual temperature is 7.4°C with the coldest temperature being around -30 to -38°C and the warmest being 38°C. Throughout the year, the mean wind speed is 2.1 m s^{-1}. The groundwater table is approximately 20 - 40 m below the surface with a mineral content of 3 - 13 g L^{-1}. Data on the soil physical-chemical properties and nutrient composition within the different soil horizons are presented in Tables 1 and 2.

Experimental design

The experiment consisted of five treatments, which maintained the SMP at 0.2 m depth immediately under drip emitter at -10 kPa (S1), -20 kPa (S2), -30 kPa (S3), -40 kPa (S4) and -50 kPa (S5), respectively, after the wolfberry plants had been planted. Each treatment was replicated three times in a randomized complete block design. Each treatment plot had dimensions of 12 m × 5 m. The plant row spacing was 3 m and the interplant spacing was 1 m in each row. Each treatment was equipped with one pipe branch unit of the drip irrigation system. Each pipe branch unit had one valve, one flow meter, one pressure gauge and one fertilizer tank to control operating pressure and measure fertilizer-irrigation quantity. The drip tapes, with 0.5 m dripper spacing and a dripper discharge of 1.38 L h^{-1}, were placed 10 cm away from the plants.

Agronomic practices

Wolfberry (*L. barbarbum* L.), which is characterized as being drought resistant, salt tolerant, and tolerant of poor nutrient levels, is a typical halophyte and also a medicinal herb (Bai, 1999). In March 2009, the experimental land was leveled and the wolfberry plants were transplanted in April. The drip irrigation system was installed in May 2009. Meanwhile, all treatment plots were irrigated with the same quantity of water at the same frequency in order to ensure initial seeding survival.

Irrigation

In 2010, irrigation treatments were carried out from 15 May to 22 September. Irrigation was applied only when the SMP at 0.2 m depth immediately under drip emitter (measured with a vacuum tensiometer) reached the respective target value for that treatment plot. Irrigation volume at each application was about 5 mm for all the treatments. Based on experience, irrigation for recovery and winter water was added to allow salts to leach away and preserve soil moisture in March and November respectively. These application volumes were around four times that of the irrigation treatments (about 20 mm).

Table 1. Physical and chemical properties of the experimental soil.

Soil layers (cm)	ECe ($dS\ m^{-1}$)	PH	Bulk density ($g\ cm^{-3}$)	K_s ($cm\ h^{-1}$)	Soil texture
0-20	1.77	8.01	1.45	1.385	Silty clay
20-40	1.40	8.07	1.45	1.053	Silty clay
40-60	1.21	8.09	1.34	2.968	Silty clay
60-80	2.08	8.04	1.39	3.059	Silty clay
80-100	3.06	8.00	1.35	4.838	Silty clay

Table 2. Nutrient content of the experimental soil.

Soil layers cm	Organic carbon $g\ kg^{-1}$	Total nitrogen $mg\ kg^{-1}$	Total phosphorus $mg\ kg^{-1}$	Nitrate nitrogen $mg\ kg^{-1}$	Available phosphorus $mg\ kg^{-1}$	Available potassium $mg\ kg^{-1}$
0-20	5.7	627.0	528.4	52.2	7.0	147.1
20-40	6.7	629.2	508.3	47.6	3.4	91.8
40-60	7.0	561.1	566.9	14.6	1.5	30.6
60-80	5.7	403.4	528.1	1.4	1.5	22.7
80-100	4.7	421.7	553.5	1.3	1.9	34.6

Fertilizer

After the experiment had started, fertilizer solution was put into the tanks at each irrigation event until the last irrigation. During the growing period, a top dressing of urea (46% N) and potassium dihydrogen phosphate (34% K; 51% P) was applied with the irrigation applications, amounting to 600 kg ha^{-1} and 360 kg ha^{-1}, respectively.

Observation

The weather data

A weather station was located within 200 m of the experimental field and used to measure rainfall, temperature, relative humidity, solar radiation and wind speed.

Soil matric potential (SMP)

One tensiometer with a vacuum gauge was installed at 0.2 m depth immediately under the emitters in each treatment to determine irrigation timing. The tensiometers were observed three times daily at 8:00, 14:00 and 18:00 h. When the data reached the target SMP, the drip-fertilization was started.

Soil water content (SWC %)

In 2010, soil samples were collected three times from each plot. They were taken before the treatments started (March 30), in the middle of experimental period (June 20) and after the experimental period had ceased (September 22). Using a 0.05 m diameter soil auger, soil cores were extracted at eight different depths (0 - 0.1, 0.1 - 0.2, 0.2 - 0.3, 0.3 - 0.4, 0.4 - 0.6, 0.6 - 0.8, 0.8 - 1.00, 1.00 - 1.20 m) and at six different horizontal distances from the emitter (0, 0.1, 0.2, 0.3, 0.4 and 0.5 m). The samples were immediately weighed and were oven-dried at 105° for 8 h in order to obtain the gravimetric soil water content θ (%).

Soil salinity (ECe)

In 2010, the collected soil samples at before the treatments started (March 30) and after the treatments (September 22) were air-dried and sieved through a 1-mm sieve. A plot soil samples were mixed by the weighted mean method in order to get three mixed samples along 0 - 0.5 m horizontal distance from the emitter with three difference depths 0 - 0.4, 0.4 - 0.8 and 0.8 - 1.2 m. Each mixed sample of the extrat electrical conductivity of the saturated soil (ECe) was measured by a conductivity meter (DDS - 11A, Shanghai Rex Instruments, China).

Yield

Plots were harvested on 4, 18, 28 July, 6, 20 August and 12 September in 2010. Four plants, each with a listing number, were selected from each plot. The weight of the fruits and the weight of 100 fresh seeds were recorded per plot for each harvest date. Then the picked fruits were air-dried over time and the dry weight recorded. The ratio of fresh to dry weight was calculated as the weight of the fresh seeds divided by dry weight.

Calculations

In the present study, crop evapotranspiration (ET) during the growing period was estimated using the water balance relationship from soil moisture and irrigation data as

$$ET = I + P \pm \Delta S - R - D \tag{1}$$

where I is irrigation (mm), P is precipitation (mm), R is surface

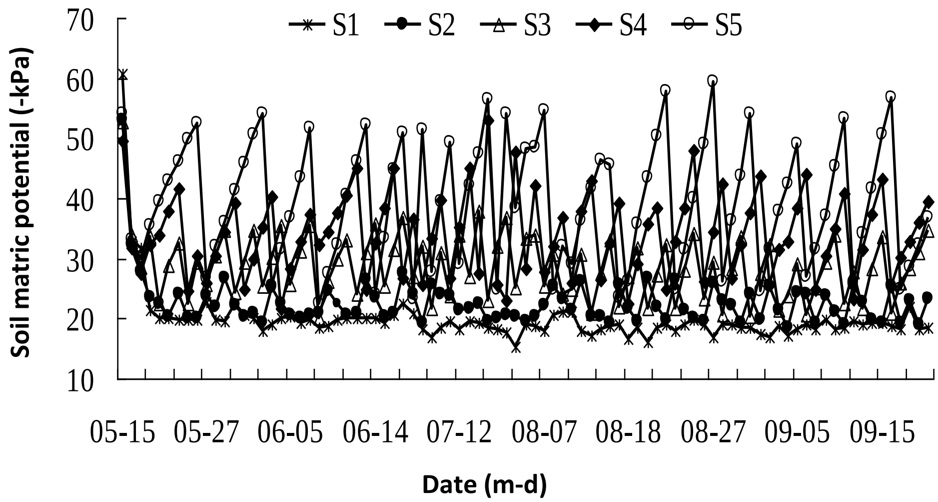

Figure 1. Soil matric potentials at 0.2 m immediately under drip emitter for different treatments.

runoff (mm), $\triangle S$ is the water storage change of the soil profile over the growing season (mm), and *D* is the drainage or deep percolation below the crop root zone (mm).

To estimate $\triangle S$, the soil water content in the soil profile (down to 90 cm) just before sprouting and after harvesting was determined by gravimetric measurement. Surface runoff (*R*) was negligible due to the controlled water application on each plot. Deep percolation (*D*) was estimated according to Darcy's equation (Azevedo et al., 2003; Kang et al., 2004b) as:

$$D = -K(\bar{\theta})\left(\frac{\psi_{m2} - \psi_{m1}}{Z_2 - Z_1} + 1\right) \tag{2}$$

where *D* is deep percolation at 80 cm depth between t_1 and t_2; Ψ_{m2} and Ψ_{m1} are matric potentials at 90 and 70 cm, respectively; Z_1 and Z_2 are soil depths under the crop root zone (Z_1 = 70 cm, Z_2 = 90 cm); θ is the mean of the volumetric soil water content at Z_1 and Z_2 and $K(\theta)$ is the unsaturated hydraulic conductivity (mm h^{-1}) estimated according to Lei et al. (1988):

$$K(\theta) = K_s\left(\frac{\theta}{\theta_s}\right)^m \tag{3}$$

where K_s is saturated hydraulic conductivity; θ_s is saturated volumetric water content; *m* is the regression coefficient and θ is the volumetric water content.

K_s was estimated by the flow of water measured using the invariable hydraulic head method and θ_s was calculated from the mass water content and soil bulk density. Both K_s and θ_s (3.058 cm h^{-1} and 0.433 cm^3 cm^{-3}, respectively) were measured using soil obtained from a depth of 80 cm in the field where the experiment was conducted. The constant, *m*, was fitted as 3.7295 for this soil. θ was derived from a soil water characteristic curve based on field measurements. A set of nine vacuum tensiometers were installed at nine different soil depths (0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95, 1.0 m) in a relatively flat and homogenous position in the experimental field. After a large water event, SMP was recorded form the different depths of tensiometers at 8 h intervals until the lowest values of SMP were recorded. At the same time, soil samples were collected from the zone around the bottom of each tensiometer installed to measure soil water content. The soil water retention curves were drawn using a series of soil water content measurements and the corresponding SMP. Therefore at 80 cm soil depth, θ is expressed as

$$\theta = 0.5589e^{-0.0035\psi_m} \tag{4}$$

where Ψ_m is soil matric potential measured in the field within a range of -1 to -50 kPa.

According to Huang et al. (2004) the water use efficiency (WUE, kg ha^{-1} mm^{-1}) was calculated as

$$WUE = Y/ET \tag{5}$$

Where Y is fruit yield (kg ha^{-1}) (Kundu et al., 2008).

Statistical analysis

Statistical analysis of *L. barbarbum* L. fruit yields was undertaken using SPSS software (Statistics Package for Social Science). The ANOVA was performed at P < 0.05 level of significance to determine if significant yield differences existed among different SMP treatments.

RESULTS AND DISCUSSION

Soil matric potential (SMP)

Figure 1 shows the daily changes in soil matric potential at 0.2 m depth, immediately under a drip emitter, for the different soil matric potential treatments at 8:00 h each day. Soil matric potential varied considerably over the experimental period, while its fluctuation cycle and range increased as the SMP target level decreased. As the SMP target level decreased, the interval time between

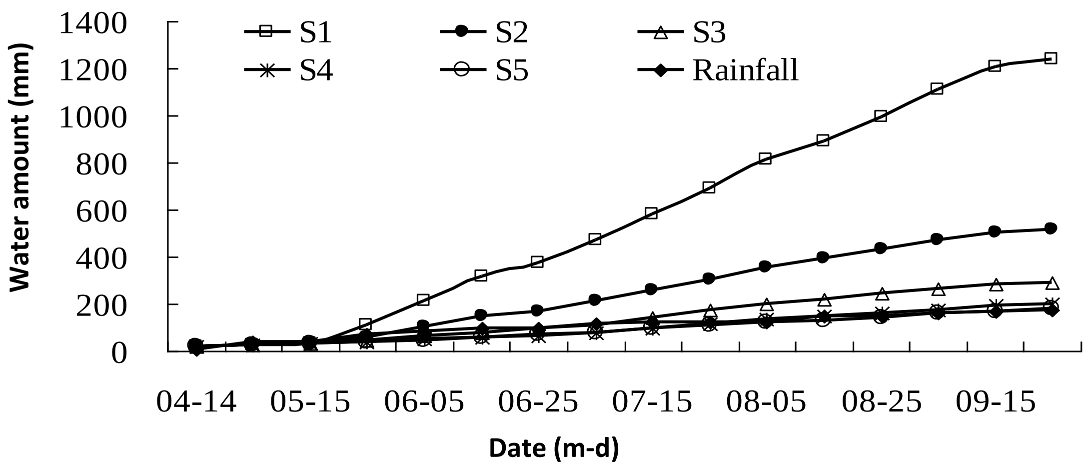

Figure 2. Accumulative amount of irrigation and rainfall during the growing season.

two irrigation events increased. The SMP target levels for the different treatments were controlled to within the experimental design range.

Irrigation and rainfall

Figure 2 shows the accumulative irrigation volume for the different SMP treatments and the accumulative rainfall during the growing season. The irrigation frequency differed between treatments. S1 received the most frequent irrigation and irrigation occurred almost twice a day, except for short periods when precipitation exceeded 5 mm. S5 had the lowest irrigation frequency and the average irrigation was once every five days. As the SMP control level increased, irrigation accumulative volume rose.

The volumes were 1263, 542, 319, 224 and 203mm (including irrigation for recovery and the winter water) for S1, S2, S3, S4 and S5, respectively. The largest irrigation volume (S1, 1263 mm) was 6.2 times greater than the lowest irrigation volume (S5, 203 mm). However, it should be noted that there was only S1 treatment of which the accumulative irrigation volume reached the average value of flooding-water at local plantation (He, 2004).

The cumulative precipitation depth for 2010 is shown in Figure 2. Total precipitation during the experiment was 219.5 mm, which was higher than the average annual precipitation. Overall precipitation distribution was more uniform from April to October except in July where precipitation was only 8.6 mm. There were 28 precipitation events, with five events of more than 20 mm, three events of 10 to 20 mm and five events of 5 to 10 mm. A major 29.2 mm rain event occurred at the beginning of growing season on 20 April when the wolfberry needed more water as it was at the new twig growth stage.

Soil water content (SWC)

Figure 3 shows the spatial distribution of soil moisture in a vertical transect for each SMP treatment before (30 March), during (20 June) and after (22 September) the experimental period. It can be seen that the soil water content transect was affected by the SMP target levels. As the SMP declined, the average soil moisture and the wetted perimeter decreased. Before the experimental period began (30 March), the vertical transect for soil water content was about 6 to 11% lower with a layered distribution. Soil moisture in the 30 to 60 cm horizon was nearly 11% higher than the soil moisture levels in the surface and deep soil horizons. Under drip irrigation, the results for the measurements taken on the 20 June and after the experimental period had ceased (22 September), showed that the vertical transect for average soil moisture was 17.5 and 17.1% for treatment S1 and 16.0 and 16.7% for treatment S2, respectively. The soil moisture content of the major root horizon (30 to 60 cm) retained about 17 to 18% of the water. In contrast, S3, S4 and S5 retained less than 15% of the soil water throughout the whole of the experimental period.

These results suggest that a soil water content of 15 to 18% in the root layer was most favorable for wolfberry growth (Science and Technology Department of National Forestry Bureau et al., 2008) in the Yinchuan Plain. The S1 and S2 treatments have been shown to meet crop water demand but treatments S3, S4 and S5 did not.

Soil salinity (ECe)

Figure 4 shows the changes in the extract electrical conductivity of the saturated soil (ECe) value at the difference soil depths for each SMP treatment before (30 March) and after (22 September) the experimental period. It can be seen that the soil electrical conductivity

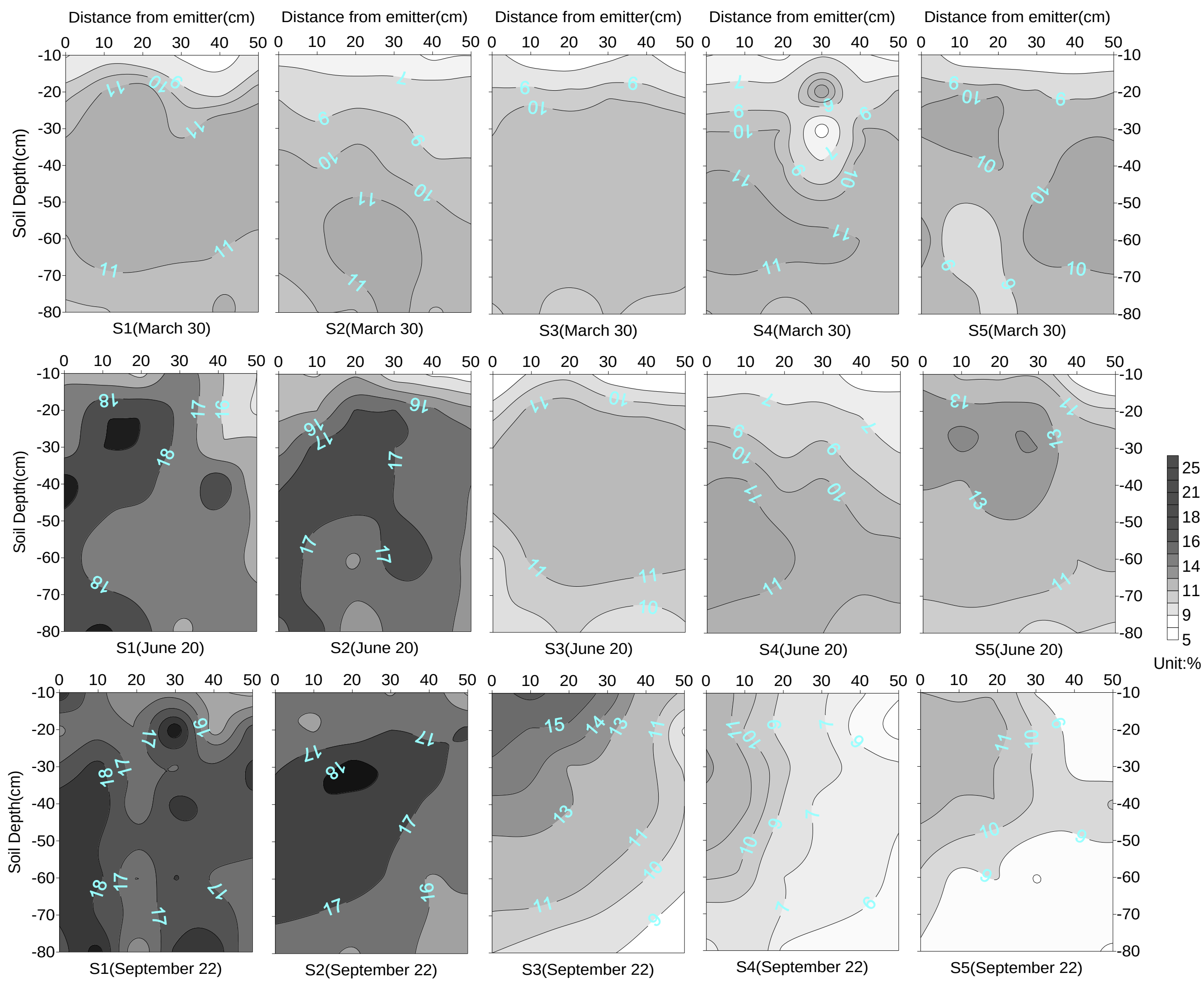

Figure 3. The vertical transect of spatial distribution of soil water content θ for different treatments.

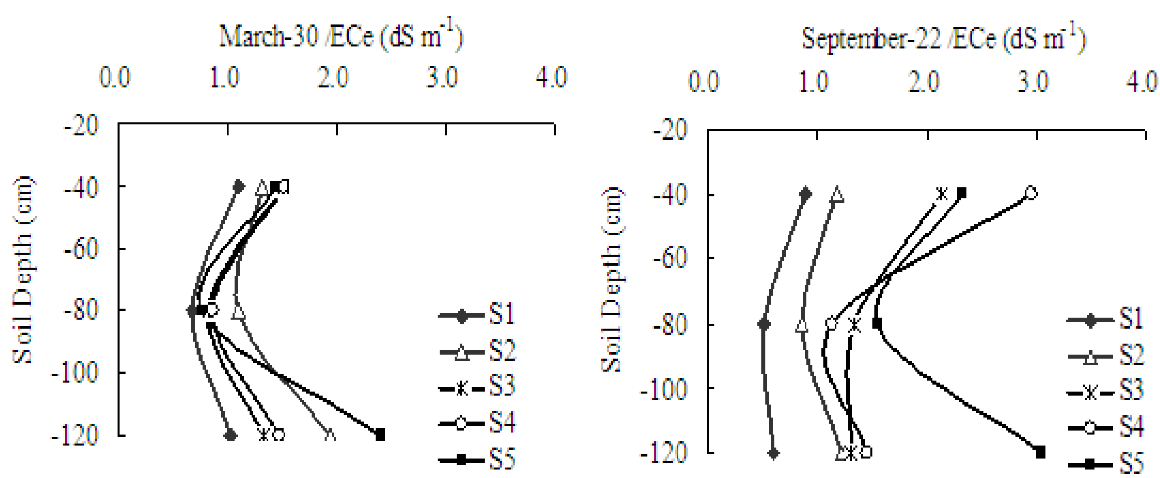

Figure 4. The changes of the soil salinity (ECe) for different treatments.

Table 3. Crop yield, evapotranspiration and agronomic properties.

Parameter	S1	S2	S3	S4	S5
I (mm）	1220	497.4	271.5	177.2	156.5
P (mm）	167	167	167	167	167
D (mm)	-96.65	-69.17	7.37	4.86	15.11
△S (mm)	25.33	32.88	7.54	-59.96	-12.38
ET (mm)	1265.0	562.3	438.3	409.0	351.0
Fruit yield (kg ha^{-1})	1278.3	1453.3	1257.4	912.6	993.6
Dry yield (kg ha^{-1})	307.7	361.5	328.2	229.4	247.0
Weight of per 100 fresh seeds (g)	69.31	66.96	63.65	66.76	61.52
Ratio fresh to dry weight	4.15	4.02	3.83	3.98	4.02
WUE for fruit (kg ha^{-1}.mm^{-1})	1.01	2.58	2.87	2.23	2.83

(ECe) was affected by the SMP target values. Before the experimental period (30 March), the average ECe was 0.93, 1.46, 1.22, 1.29 and 1.54 dS m^{-1} in the S1, S2, S3, S4 and S5 plots, respectively. The soil salinity in the middle horizon (40 to 80 cm) was lower than in the upper horizon (0 to 40 cm) and the deeper horizon (80 to 120 cm) on the vertical transect.

Under drip irrigation, after the experimental treatment period had ceased (22 September), the average ECe values increased as the target SMP decreased. Compared to the samples taken before the experimental treatments began (30 March), the soil transect of average ECe for S1 and S2 declined by 27.9 and 24.8%, respectively. This was in contrast to treatments S3, S4 and S5 where ECe increased 30.9, 43.8 and 50.0%, respectively.

When the target SMP was above -30 kPa, the soil salts in S1 and S2 were leached away due to the higher irrigation accumulative volume, especially in the middle horizon (40 - 80 cm) and the deeper horizon (80 - 120 cm) where the ECe reduction with the S2 treatment were 0.24 and 0.70 dS m^{-1}, respectively, significantly greater than occurred with the S1 treatment. Statistical analysis of the experimental treatments showed that the change in ECe values was significantly affected ($P < 0.05$) by the target SMP in the middle horizon (40 to 80 cm). The S2 treatment (-20 kPa) showed the greatest degree of saline leaching. When the target SMP was below -30 kPa, water to leach the salts out of the soil became limiting so in plots S3, S4 and S5, salt began to accumulate in the soil.

Wolfberry evapotranspiration (ET)

Table 3 shows changes in soil water storage (ΔS), drainage below crop root zone (D), and ET values for the five SMP treatments during the plant growing period (15 April to 22 September). Cumulative ET values declined as SMP decreased. This showed that wolfberry ET was clearly affected by the SMP threshold. The highest ET value (S1 treatment) was 914 mm more than the lowest value (S5 treatment), while soil subjected to the S1 treatment held the highest volume of water and had the greatest depth percolation among the five treatments. When the target SMP was above -30 kPa, the soil in the S1 and S2 treatment plots was waterlogged, which reduced soil disturbance and leached fertilizer out of the root zone. When the target SMP was below -30 kPa, the wolfberry growing in the S4 and S5 plots suffered serious water stress and the crop ET declined significantly. When the target SMP was controlled at -30 kPa (S3), depth percolation and soil water storage improved.

In order to clarify the effects of the target SMP on crop ET, regression analysis was carried out (Figure 5). The regression model was expressed as follows:

$$ET = 0.9886\psi^2 + 79.128\psi + 1891.6$$
$$(R^2 = 0.9318) \qquad (6)$$

Wolfberry yield

Statistical analysis of the experimental treatments showed that both the fruit yield and the dry yield as significantly affected ($P < 0.05$) by the target SMP. The S2 plots (-20 kPa) produced the highest yield with a fruit yield of 1453.3 kg ha^{-1} and a dry yield of 361.5 kg ha^{-1}. The lowest fruit yield (912.6 kg ha^{-1}) and dry yield (229.4 kg ha^{-1}) were produced by the S4 plots. LSD comparisons between groups showed that treatment S2 had a significantly higher yield than treatments S4 and S5. S1 and S3 also had significantly higher yields than S4. The dry yield for S1, S2 and S3 were higher than the average yield at the local plantation. He (2004) reported the dry yield geted 300 to 450 kg ha^{-1} after the plant transplanted 2 to 3 years, and S4 and S5 dry yields were lower due to a soil water deficit.

Each treatment produced weight per 100 fresh seeds values that were higher than the 47.6 to 58.6 g achieved

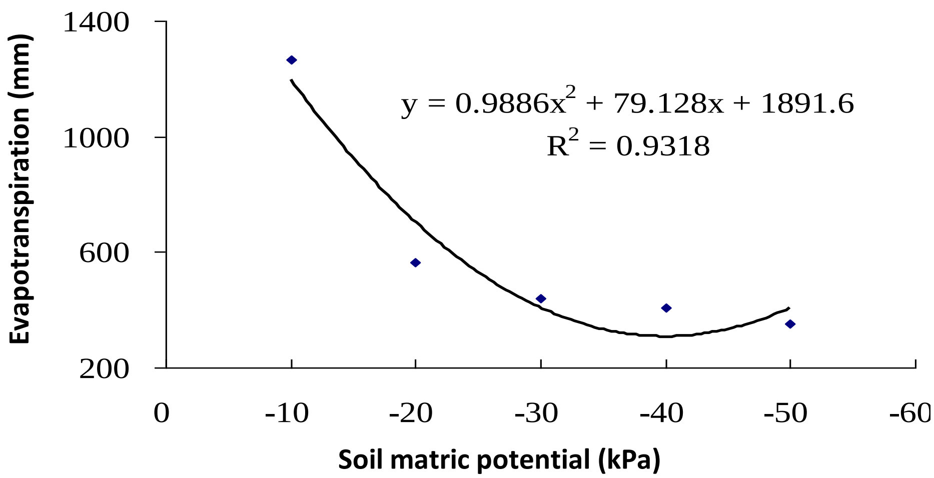

Figure 5. Relation of the crop ET to the target SMP for the five treatments.

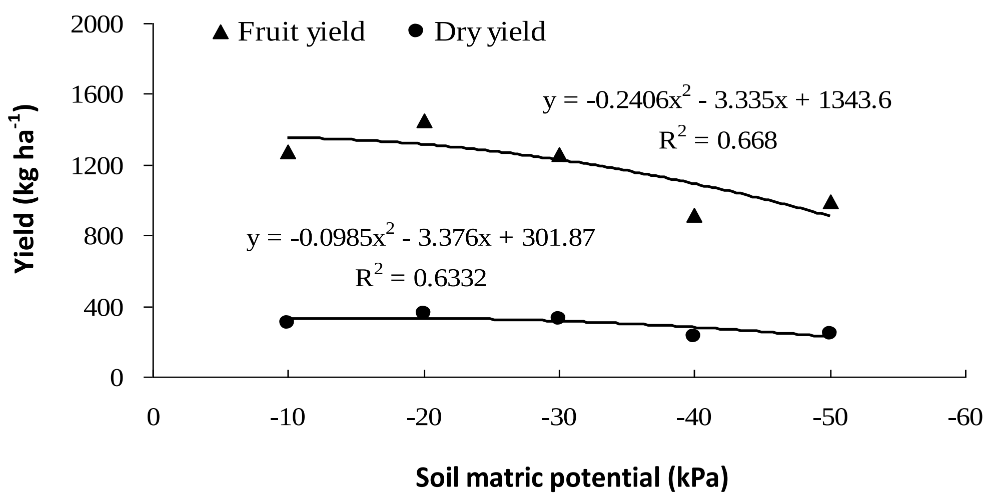

Figure 6. Relations of the crop yield to the target SMP for the five treatments.

at the local plantation and the ratio of fresh to dry weight was also lower than the 4.37 achieved by the local plantation (He, 2004). The greatest weights per 100 fresh seeds (69.31 g) and ratios of fresh to dry weigh (4.15) were achieved with the S1 treatment because there was an excess of soil water. The lowest ratio of fresh to dry weight (3.83) occurred with the S3 treatment because the wolfberry seeds contained more dry matter than the other treatments.

A regression model was constructed using correlation analysis between the target SMP for the five treatments and *L. barbarbum* L. yield (Figure 6).

$$Yield\left(fruit\right) = -0.2406\psi^2 - 3.335\psi + 1343.6 \quad (R^2 = 0.668) \qquad (7)$$

$$Yield\left(dry\right) = -0.0985\psi^2 - 3.376\psi + 301.87 \quad (R^2 = 0.6332) \qquad (8)$$

Water use efficiency (WUE)

Water use efficiency (WUE) is the relationship between yield and ET and was first calculated using tomato yields divided by ET (Kang et al., 2004a; Wang et al., 2007). This can be represented as an incremental gain in dry matter per unit water taken up and transpired by the plant (Draycott, 2006; Hassanli et al., 2010). The results from this study (Table 3) showed that the WUE for the five SMP treatments were ordered: S3 > S5 > S2 > S4 > S1. The WUE value (-30 kPa) was highest for S3 and lowest for S1 (-10 kPa), which indicated that the water was used most effectively by plants subjected to the S3 treatment. These results suggest that WUE could be a good criterion for evaluating the effectiveness of irrigation.

SUMMARY AND CONCLUSIONS

Wolfberry irrigation volume, ECe, ET, yield and WUE were affected by soil matric potential (SMP). Irrigation volume and ET decreased as the target SMP value declined. During the growing season, the accumulative water volume for irrigation was 1263, 542, 319, 224 and 203 mm in 2010 for treatments S1, S2, S3, S4 and S5, respectively, but there was only S1 treatment value in the accumulative irrigation volume data as the flooding-water at the local plantation.

Drip irrigation and a target SMP above -30 kPa (S1 and S2 treatments) should meet the crop water demand. However, when the soil moisture is over 16%, soil disturbance was reduced and fertilizer leached out of the root zone as the soil water was in excess. The soil water content for S3, S4 and S5 was less than 15% and produced visible water stress in the crop. When the target SMP for S1 and S2 was above -30 kPa, the soil salinity was leached due to the higher irrigation accumulative amount, but the soil salinity was accumulated in the plots of the target SMP for S3,S4 and S5 because the water of the soil salinity leached was shortage. Statistical analysis of the change ECe values showed the significant differences between the different SMP treatments in the middle layer 40 to 80 cm, the plots S2 (-20 kPa) had the better effect of the soil salinity leached. Cumulative ET values decreased as the target SMP declined, the highest ET (1265 mm) was with the S1 treatment and was 72.3% larger than the lowest value (S5 treatment). Statistical analysis of the experimental treatments showed that the target SMP level had a significant impact on the crop yield. The highest yield was achieved in the S2 plots. The lowest ratio of fresh to dry weight was found in the S3 plots, which also produced the highest quality seeds. The WUE for the five SMP treatments were ordered as S3 > S5 > S2 > S4 > S1. In general, the SMP at 0.2 m depth immediately under drip emitter can be used as an index for scheduling drip irrigation for wolfberry in the Yinchuan Plain, Chain. Yields and WUE were greatest when the SMP threshold was controlled in the range from -20 to -30 kPa.

ACKNOWLEDGEMENTS

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