Response of Bell Pepper to Subsurface Drip Irrigation and Surface Drip Irrigation under Different Water and Nitrogen Coupling Conditions

Revised manuscript submitted to

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Abstract

Subsurface drip irrigation is a new irrigation technique. A 2-year field experiment was conducted in 2007, 2008 to investigate the response of bell pepper to subsurface drip irrigation (SDI) and surface drip irrigation (DI). Four nitrogen levels of 0, 75, 150, 300kg•ha^{-1} (N0, N75, N150, N300) comprised the fertilization treatments. The irrigation interval is 4 days. The results showed that SDI resulted in higher bell pepper yield than DI by 4% in 2007, and 13% in 2008. The water consumption of SDI is lower than of DI by 6.7% in 2007, and 7.3% in 2008. The root length densities under SDI and DI were1.46 and 2.44 times higher than that under BI (border irrigation). The percent of root length below 10 cm soil depth under SDI were higher than that under DI by 7 percentage points. The results revealed that SDI not only promote crop root growth, but also enhanced the root development downwards the deep soil depth, which could increase nitrogen uptake, reduce nitrogen leaching, increase bell pepper yield and nitrogen use efficiency. The SDI N150 treatment were recommended as the optimal irrigation and fertilization practices for improving bell pepper yield and WUE and reducing NO_3^--N leaching.

Key words: Water and nitrogen coupling; Pepper; Subsurface drip irrigation;
Surface drip irrigation

1. Introduction

The efficient utilization of available water resources is crucial since China shares 22% of the global population with only 7% of farmland and 7% of the world's water resource. So far, water shortage has become a threat to human survival. Agricultural production is the largest consumer of water, which accounts for more than 70% of the total water consumption. To meet the food security, human health and the balance of natural ecosystems, all countries paid more attention on agricultural practices to get a solution for water shortage.. Therefore , the techniques for saving irrigation water and thereby increasing crop water use efficiency (WUE) are important in China, in particular in the water-shortage regions.

Nitrogen fertilizer application rates have increased dramatically in agricultural systems in north China in recent years (Zhu et al., 2005), which resulted in nitrate leaching and groundwater contamination (Rossi et al., 1991; Barraclough et al., 1992; Cameron et al., 1997; Li et al., 2001; Zhu et al., 2004). It was reported that over fertilization in north China has led to high concentrations of nitrate in groundwater and drinking water (average of 68 mg L^{-1}) and crop recoveries below 40% of applied N in some areas (Zhang et al., 1996). It's now an urgent need to regulate irrigation and fertilization practices to ensure better distribution of soil moisture and fertilizer, so as to maximize the use of water and fertilizer, to minimize nitrate leaching and groundwater contamination and to obtain the optimal agronomic, economic and environmental benefits.

Subsurface drip irrigation, the latest method of irrigation, was developed from surface drip irrigation. Subsurface drip irrigation laterals are buried underground. Therefore, this method can supply water and nutrients to the roots as needed (Phene and Beale, 1979; Lamm, 1995; Camp et al., 1997). Compared to other irrigation systems, subsurface drip irrigation have significant advantages including more efficient water use, slight water quality decline, greater water application uniformity, enhanced plant growth, crop yield and quality, improved plant health, better weed control, improved farming operations and management, system longevity and less pest damage (Lamm, 2002). In particular,, subsurface drip irrigation systems keep the topsoil drier, which lead to fewer surface soil evaporation, lower air humidity of canopy, less disease and pest damage and deeper crop roots. Therefore, subsurface drip systems reduce crop respiration, increase photosynthesis and efficiency water and nutrients uptake, improve WUE, increase nitrogen utilization, reduce nitrate leaching, and decrease NO_3^--N pollution in groundwater (Phene, 1999).

Based on the results at the Water Management Research Laboratory over a period of 15 years, Ayars et al. (1999) demonstrated that SDI led to significant increase of yield and WUE for all crop because of the reduced deep percolation by using high frequency irrigation. Sezen et al. (2006) reported that yield and water use of bell pepper was affected by surface drip irrigation regimes. He recommended I_1K_{cp3} (interval: 3 to 6 days; K_{cp3}=1.00) irrigation regime for bell pepper in order to attain higher yields with improved quality. Using the same method in green bean production, Sezen et al. (2005) also found that the yield, WUE and Irrigation Water Use Efficiency (IWUE) were significantly influenced by the irrigation intervals and plant-pan coefficients. Howell et al. (1997) found that different subsurface drip irrigation frequencies (1day and 7days) show little effect on corn yield. Payero et al. (2008) found that irrigation amount applied with subsurface drip irrigation and envpotranspiration significantly affected corn yields. According to Mahajan et al. (2006), low irrigation amount

(0.5Ep) and low nitrogen fertilizer amount (137kg N·ha^{-1}) didn't decrease greenhouse tomato yield, but increased root length. Sensoy et al. (2007) reported that irrigation amount and evapotranspiration significantly influenced melon growth and yield under surface drip irrigation and 6days interval and Kcp=0.9 were recommended for melon production. Cabello et al. (2009) also has taken out drip irrigation experiment to investigate yield and quality of melon under different irrigation and nitrogen rates, it's reported that moderate water deficit and reduce nitrogen input to 90 kg·ha^{-1} didn't reduce crop yield. Under subsurface drip irrigation, nitrogen application also affected broccoli yield and quality (Thompson et al., 2003). However, according to Sorensen et al. (2004), low N rate (67 kg N·ha^{-1}) yield of cotton was similar to high N rate (101 kg N·ha^{-1}) for subsurface drip irrigation.

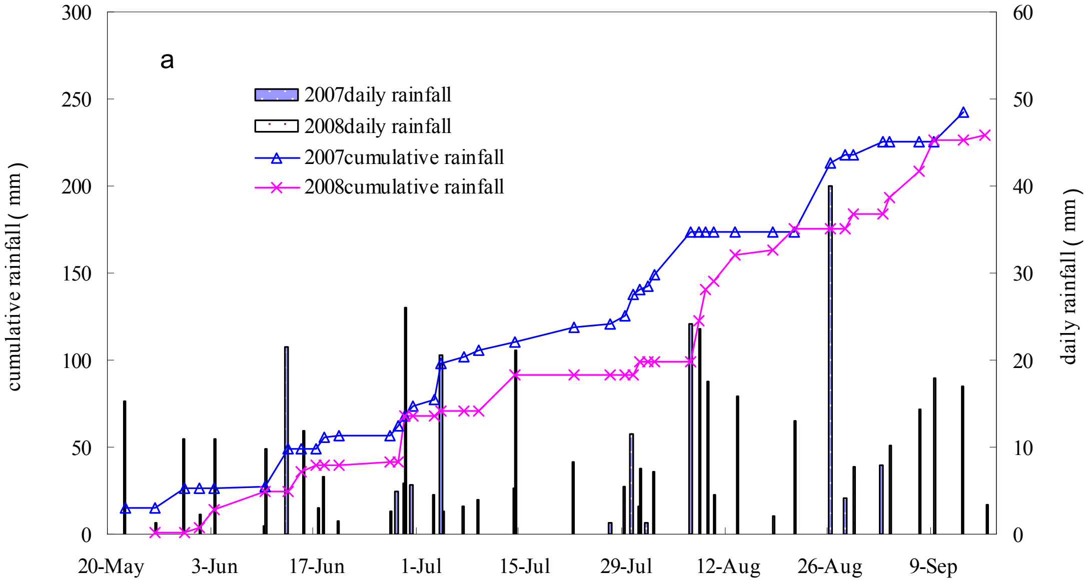
Comparative studies of subsurface drip irrigation with other irrigation systems under different water and nitrogen coupling conditions are scanty. Patel et al. (2008) has conducted a 3-years experiment to study the effect of depth of drip lateral. The results showed that the subsurface drip irrigation had higher onion yield than surface drip systems. Hanson et al. (1997) compared the lettuce yield and applied water among furrow, surface drip and subsurface drip irrigation. He found that surface drip irrigation resulted in lower lettuce yield than furrow and subsurface drip irrigation, but drip irrigation consumed only 43%-74% water amount of furrow. Hanson et al. (2004) compared subsurface drip irrigation with sprinkler irrigation and the results revealed that subsurface drip systems could increase tomato yield and reduce percolation below the root zone. Gencoglan et al. (2006) compared the response of green bean to subsurface drip irrigation and partial rootzone-drying irrigation. According to their results, the dry weight the green bean under subsurface drip irrigation was found slightly higher than that under partial rootzone-drying irrigation.

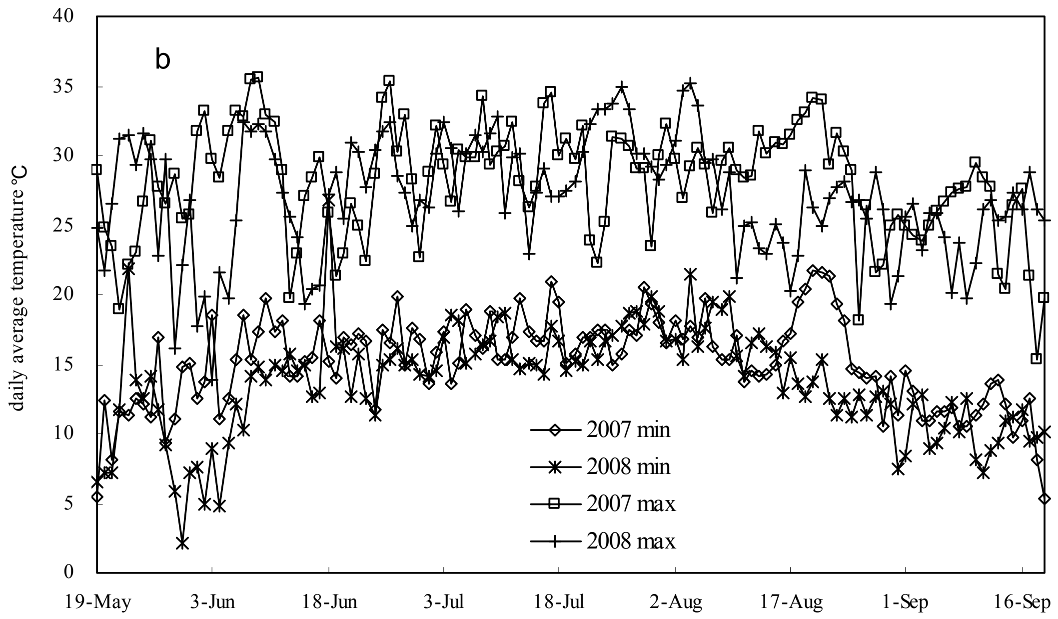
Therefore, the objective of this study was to compare the different influence of SDI and DI on bell pepper from the perspective of water content distribution, NO_3^--N distribution in soils, root distribution, crop yield and WUE, under different nitrogen fertilization levels.

2. Materials and methods

2.1. Location description

Field experiments were located at the Yuhe Irrigation Experiment Station, in Datong, Shanxi Province (40°06′ N; 113°20′ E; 1052m above sea level). The soil at the experimental sites is a gravelly loam, and the field capacity was 22.5%. The groundwater table is about 19m. The climate in Datong is semiarid, with average annual precipitation of approximately 379.3mm. Overall, most of the annual precipitation occurs during the growing season, which extends from late-May to mid-September. The frost-free period is about 110-130days. Weather data of the experimental site for 2 years 2007, 2008 are shown in Fig.1 .





(a) cumulative and daily average rainfall during the crop season; (b) daily average temperature

Fig.1 Weather data during the crop season

2.2. Experimental treatments and field preparation

The field experiment was conducted using a randomized complete block design with 9 treatments including two irrigation techniques (SDI, DI), four fertilization levels of 0, 75, 150, 300 kg nitrogen ·ha^{-1} (N_0, N_{75}, N_{150}, N_{300}) and a control treatment border irrigation (BI) (Table.1). Each treatment had three replications. The experiments were conducted during the crop growing seasons in 2007 and 2008.

Table 1 Nitrogen-fertilizer application rate during the growth period of bell pepper .

Irrigation method	treatment	Nitrogen application rate (kg N·ha^{-1})		
		blossom and fruit set period	the full bearing period	the late stages of development
SDI	SDI N_0	0	0	0

	SDI N_{75}	30	30	15
	SDI N_{150}	60	60	30
	SDI N_{300}	120	120	60
DI	DI N_0	0	0	0
	DI N_{75}	30	30	15
	DI N_{150}	60	60	30
	DI N_{300}	120	120	60
BI	BI	120	120	60

The field plot size was 15.0 m × 81.0 m. The field plot was divided into two equal sub-plots of 7.0 m × 81.0 m by a farming road (1 m in width). The plot with 7.0 m × 81.0 m size was divided into 27 equal plots of 7.0 m × 3.0 m.

The test crop was Tongfeng 16 , a local variety of bell paper. Two-month-old pepper seedlings were transplanted in the field with 40.0 cm in row spacing and 50.0 cm in plant spacing. The crop was irrigated with SDI or DI systems that were installed prior to planting in 2007. The laterals were installed between every other crop rows at space of 1.0 m, and the SDI laterals were buried at a depth of 20.0 cm between the two crop rows. Water was applied every 4 days using laterals (Netfaim super Taphoon 125) with 1.1 $L \cdot h^{-1}$ of drippers discharge at a spacing of 40.0 cm. A border irrigation treatment was also carried out in both in 2007 and 2008.

Soil water content was measured by a Time domain reflectometry (TDR). Three access tubes were placed at a depth of 1.0 m at a distance of 0, 25.0 and 50.0 cm from lateral pipe and water content (volumetric) was measured in all treatments (Fig.2). Total 48 PVC access tubes were installed. Soil water content at 0.0-20.0, 20.0-40.0, 40.0-60.0, 60.0-80.0 and 80.0-100.0 cm layers in root zone were measured before and after irrigation and after rainfall..

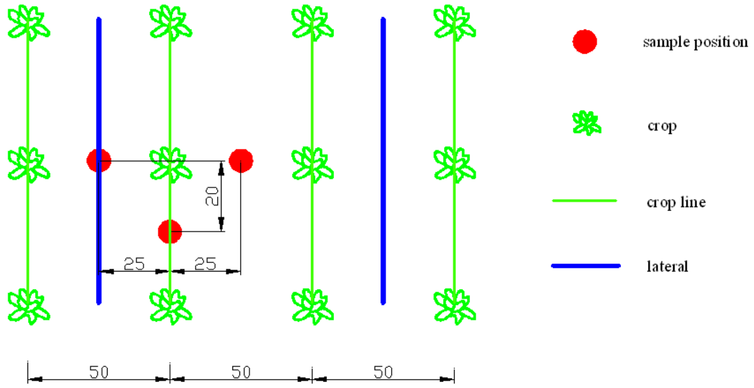


Fig.2 Layout for trime PVC tubes

2.3. Estimation of water requirement and irrigation application

The reference crop evapotranspiration (ET_0) was calculated by a Penman-Monteith's formula. The weather data were collected from an automatic weather station, 20 m away from the field site. The potential crop evapotranspiration was estimated by multiplying reference evapotranspiration with crop coefficient ($ET_C = ET_0 \times K_C$) at different crop growth stages. The adopted crop coefficients were recommended by FAO56. The total rainfall druing the crop growing season in 2007 and 2008 were 242.6 and 229.6 mm, respectively. Irrigation water requirement was calculated from the difference between ET_C and the effective rainfall. For the control treatment, the lowest water limit was set at 65-70% of field capacity and the designed moist layer was 40 cm. The applied water volume was monitored by a flow meter for each treatment. The crop was irrigated for 14 times in 2007. The irrigation amount was 257 mm for drip irrigation and 282 mm for border irrigation. However, the irrigation was reduced to 10 times in 2008 with 164 mm of the irrigation amount for drip irrigation and 165 mm for border irrigation.

2.4. Evapotranspiration estimation

The actual crop evapotranspiration was estimated using the following water balance equation:

$$ET_c = \Delta W + I + P - R - D \tag{1}$$

where ΔW is the change of soil water storage (mm); I is irrigation amount (mm); P is precipitation (mm); R is surface runoff (mm); D is the deep percolation (mm).

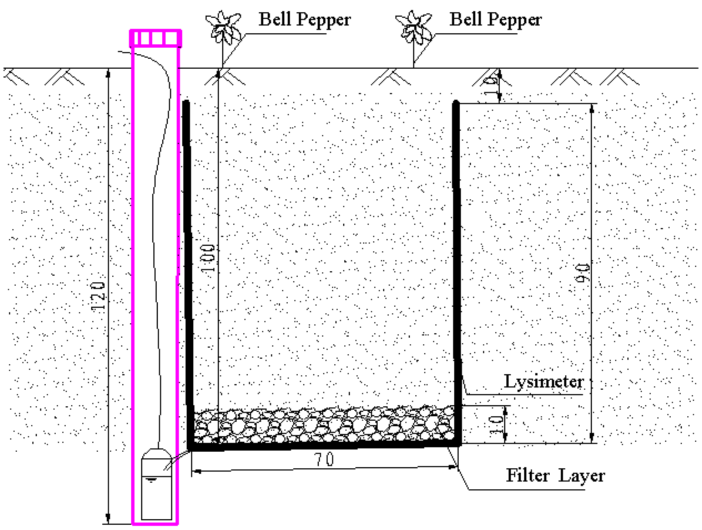


Fig.3 Structure of the simple lysimeter

ΔW was estimated using soil water content in the soil profile. Surface runoff was ignored throughout the stage. D is considered as water amount drained from a lysimeter (Fig.3 .).

2.5. Nutrient management

To meet the nutrition requirement of bell pepper, organic fertilizer (chicken manure: 11.1 m^3/hm^2) was homogeneously applied in all of the plots as basal fertilizer before land leveling. The contents of N, P(P_2O_5), K(K_2O) of organic fertilizer were about 1.63%, 1.54% and 0.085%. In addition, urea was applied as nitrogen fertilization that was supplied at different growth stages (Table.1).

Before and after fertilization, soil samples were collected from 0.0-20.0, 20.0-40.0, 40.0-60.0, 60.0-80.0 and 80.0-100.0 cm soil depths at 0.0, 25.0 and 50.0 cm distance from the lateral pipe. NO_3^--N content in soil water extract was calculated assuming that NO_3^--N was dissolved in the water. The extractable NH_4^+-N and NO_3^--N with 1 M KCl was performed by Flow Injection Analysis.

2.6. Yield

Bell pepper was manually harvested 4 times every year and its yield were determined by harvesting bell pepper at the physiological maturity in the two adjacent center rows in each plot. An analysis of variance was carried out by a SAS software package. Significant differences between means for different treatments were compared by means of the LSD test at $P < 0.05$.

2.7. Root sampling and analysis

Soil samples containing crop roots were taken in center rows after havest. The sampling area was 40.0 cm × 50.0 cm. Samples were taken at three different depths (0-10, 10-20 and 20-30 cm) in 2007, and four different depths (0-10, 10-20, 20-30 and 30-40 cm) in 2008. After washing away soils using a fine sieve, crop roots and organic debris were stored in plastic bags at 4℃ until further cleaning and then placed in a glass bowl. Crop roots were handpicked and placed in glass dishes. Root length density (RLD) and other root characteristic parameters were determined with Winrhizo (Re´gent Instrument Inc., Quebec City, Canada) software and hardware.

3. Results and discussion

3.1. Root distribution

Root system, the most active organ to absorb nutrients and moisture, is crucial for crop growth. Irrigation, fertilization and other agronomic practices affect the root growth, distribution and function and thereby affect crop production. The growth and development of crop root also influence the distribution and concentrations of water, nutrient and salt in soils.

Table 2 The percent of root length at different soil depths

	BI		DI N_{150}		SDI N_{150}	
Depth (cm)	root length (cm)	percentage (%)	root length (cm)	percentage (%)	root length (cm)	percentage (%)
0-10	4801	45.85	11582	66.26	15235	59.45
10-20	3731	35.64	4588	26.25	7353	28.69
20-30	1612	15.40	1089	6.23	2319	9.05
30-40	326	3.11	219	1.25	719	2.81
0-40	10470	100	17479	100	25625	100

As seen in Table 2, there was an obvious difference of root distribution between SDI and DI. The root length and its percentage decreased with soil depths. At 30-40 cm soil depth, the root percentage under BI, DI N_{150} and SDI N_{150} were as small as 3.11%, 1.25% and 2.81%, respectively. Below 40 cm soil depth, almost no root was observed. Drip irrigation, especially subsurface drip irrigation, can significantly promote the growth of roots. The total root lengths under SDI and DI were higher than that under BI by 2.44 and 1.67 times. Moreover, the root length under SDI was 1.46 times longer than that under DI. The percent of root length under SDI at 10 cm soil depth were higher than under DI by 7 percentage points, indicating that SDI not only promoted the root growth, but also result in deeper development of root.

The impact of different nitrogen amounts on RLD was showed in Fig.4. At 0-10 cm soil depth, RLD gradually increased with increasing nitrogen amounts. However, at 10-20 cm soil depth, RLD declined sharply when nitrogen amount was higher than 300 kg·ha^{-1}. The results implied that over nitrogen application would inhibit root growth into deeper soil layers.

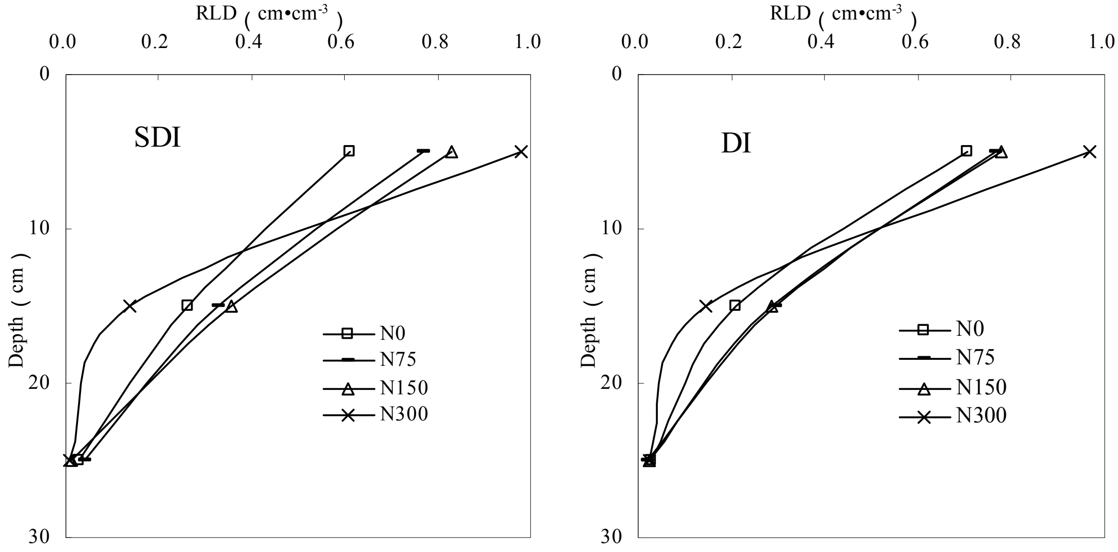


Fig.4 RLD distribution during the 2007 growing season in all treatment.

3.2. NO_3^--N distribution in soils

NO_3^--N concentrations at 0.0-20.0, 20.0-40.0, 40.0-60.0, 60.0-80.0 and 80.0-100.0 cm soil depths were determined for all treatments. Figure.5 shows NO_3^--N contents at 2 days before fertilization (14-Aug), 2 days after fertilization (18-Aug), and 22 days after fertilization (7-Sep) between different irrigation practices.

The impact of SDI and DI on NO_3^--N distribution in soil profile was compared under supplying 150 kg nitrogen ·ha^{-1}. Before fertilization, there was no significant difference of NO_3^--N distribution between SDI and DI. However, 2 days after fertilization, NO_3^--N concentration for SDI treatment appeared to be distributed with a parabolic curve with a maximum value (14.2 mg·kg^{-1}) at 20-40 cm soil depth. In the contrast, NO$_3^-$-N concentration for DI treatment declined with the increase of soil depth and a maximum concentration (15.7 mg·kg^{-1}) was obtained at the top soil (0-20 cm). After fertilizing 22 days, NO$_3^-$-N gradually moved downward with the water movement, crop growth and root activities.The maximum NO$_3^-$-N concentration after 22 days fertilization for SDI and DI treatments occurred at 40-60 cm and 60-80 cm, respectively. NO$_3^-$-N at deep soil (below 40-60 cm and 60-80 cm) were difficult to be utilized by bell pepper because of shallow root system, leading to NO$_3^-$-N leaching. As mentioned above, SDI promoted the development of bell pepper roots and favored the establishment of intensive root layer, which can prevent nitrate leaching. The maximum residual NO$_3^-$-N concentration at 40-60 cm for SDI treatment was 8.4 mg·kg^{-1} that was far less than that for DI treatment (13.8 mg·kg^{-1}, at 60-80 cm). At 300 kg N·ha^{-1} of nitrogen application amount, the residual NO$_3^-$-N concentration for BI treatment was higher than that of all the drip irrigation treatments.

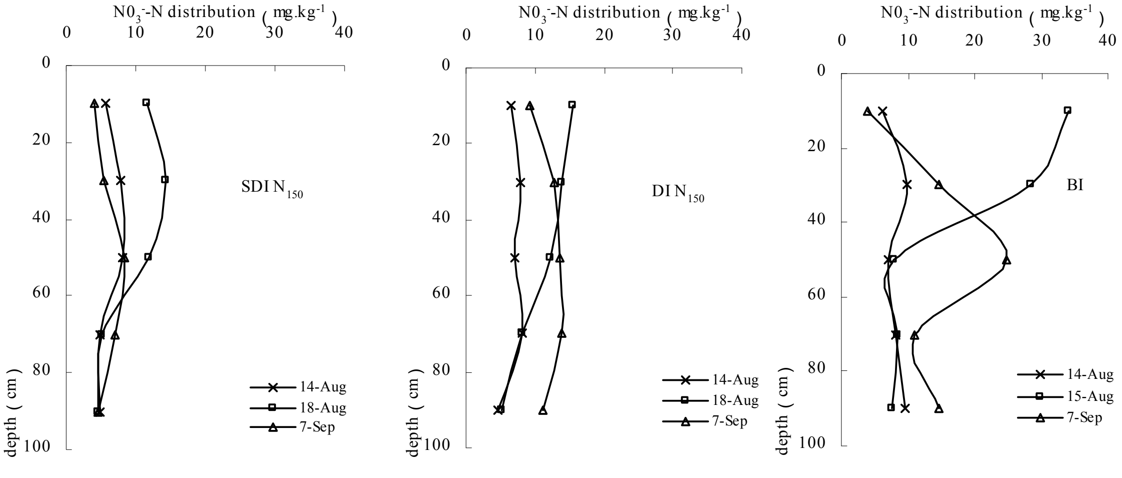


Fig.5 Vertical distribution of NO$_3^-$-N centration in soil profiles.

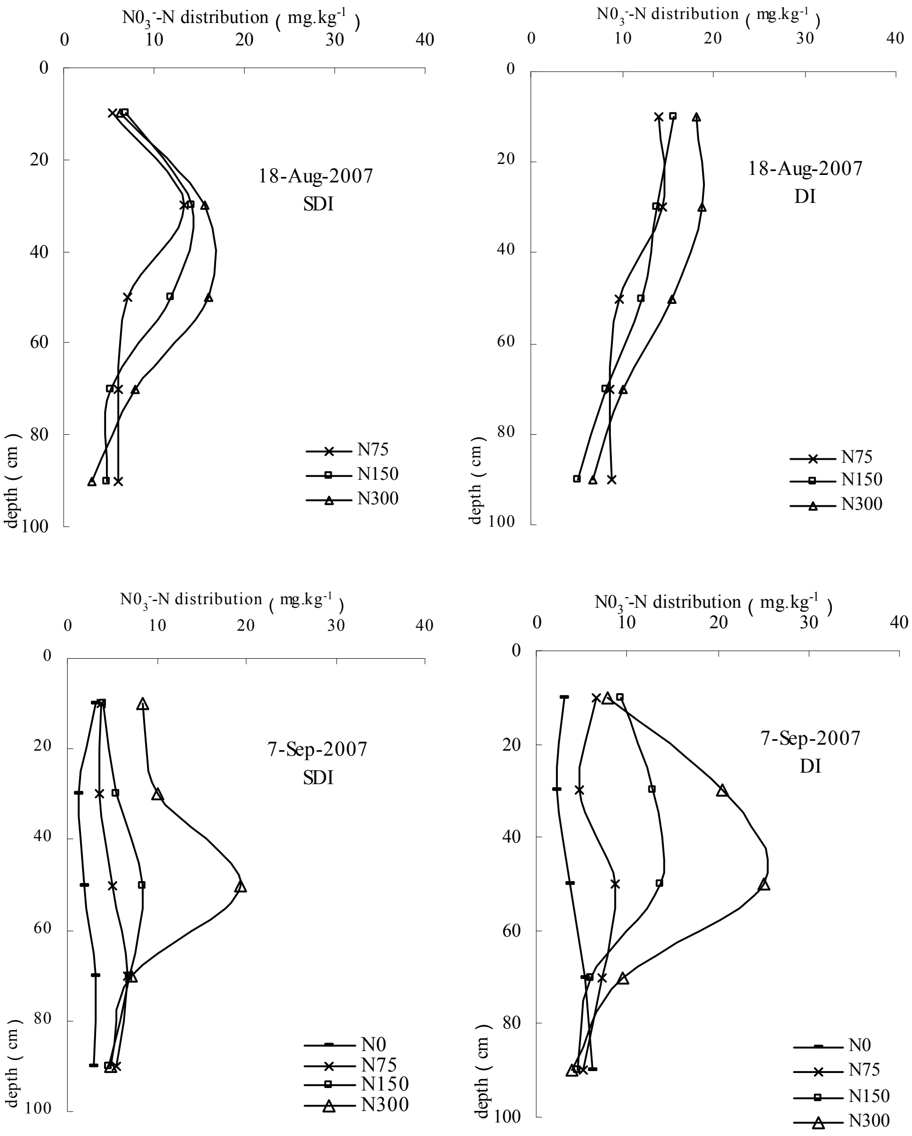


Fig.6 Vertical distribution of NO$_3^-$-N as influenced by different nitrogen amounts.

In addition, the residual NO$_3^-$-N concentration in soil profiles increased with increasing of the nitrogen fertilizer amount (Fig.6). This tend was found for all treatments of nitrogen amounts. In particular, NO$_3^-$-N residual concentration for N$_{300}$ treatment was significant higher than that for N$_{150}$ treatment at 22 days after fertilization.

3.3. ET_C

Table.3 shows the cumulative water consumption of bell pepper during the two growing seasons. The monthly average temperature in 2008 were lower than that of 2007. Especially in 30-May-2008, a very low temperature (2.4 ℃) inhibited seedling establishment, which influence the bell pepper growth in all treatments of 2008.

In 2007, the maximum water consumption (451 mm) was found for DI N_{150} treatment and the minimum water (301 mm) consumption for SDI N_0 treatment. In 2008, the maximum value was 387 mm for DI N_{75} and the minimum value was 334 mm for SDI N_0.

Except for N_{300} treatment in 2007, all of the cumulative water consumptions under SDI were lower than under DI. For example, the water consumption for SDI N_0 treatment was lower than that for DI N_0 by 26% in 2007 and by 7% in 2008.

Table 3 The cumulative water consumption under different irrigation and fertilization practices.

	ET_0(mm)		ET_C(mm)			
			N_0	N_{75}	N_{150}	N_{300}
2007	508	DI	407	426	451	404
		SDI	301	405	438	432
		BI				451
2008	406	DI	362	387	382	382
		SDI	334	357	377	359
		BI				397

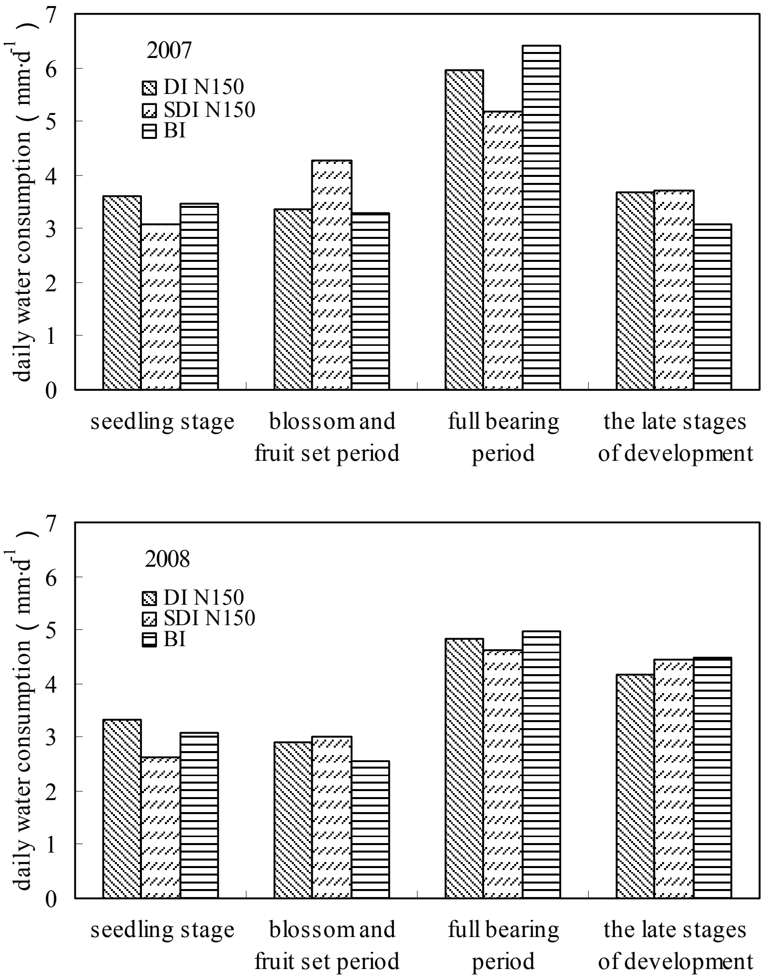


Fig. 7 Daily averaged water consumption at different growth stage

The daily averaged water consumption at different growth stage under different irrigation techniques was showed in Fig.7. At the period of seedling establishment, DI resulted in higher daily averaged water consumption than SDI. During this period, plants were small and evaporation accounted for most of evapotranspiration. Since SDI kept the surface soil dry, it decreased the evaporation, and thereby reduced the water consumption of bell pepper. After entering the blossom and fruit-set period, daily averaged water consumption under SDI was higher than that under DI. This result attributed to faster root growth under SDI than that under DI during the above main period of root growth. At the full bearing period, bell pepper grew vigorously and water consumption reached the maximum of the growth season. Water consumption under SDI were lower than that under DI and BI, which contributed to the low plant height and leaf area under SDI during the full bearing period. However, daily averaged water consumption under DI was slightly smaller than that under SDI in the late crop growth stages.

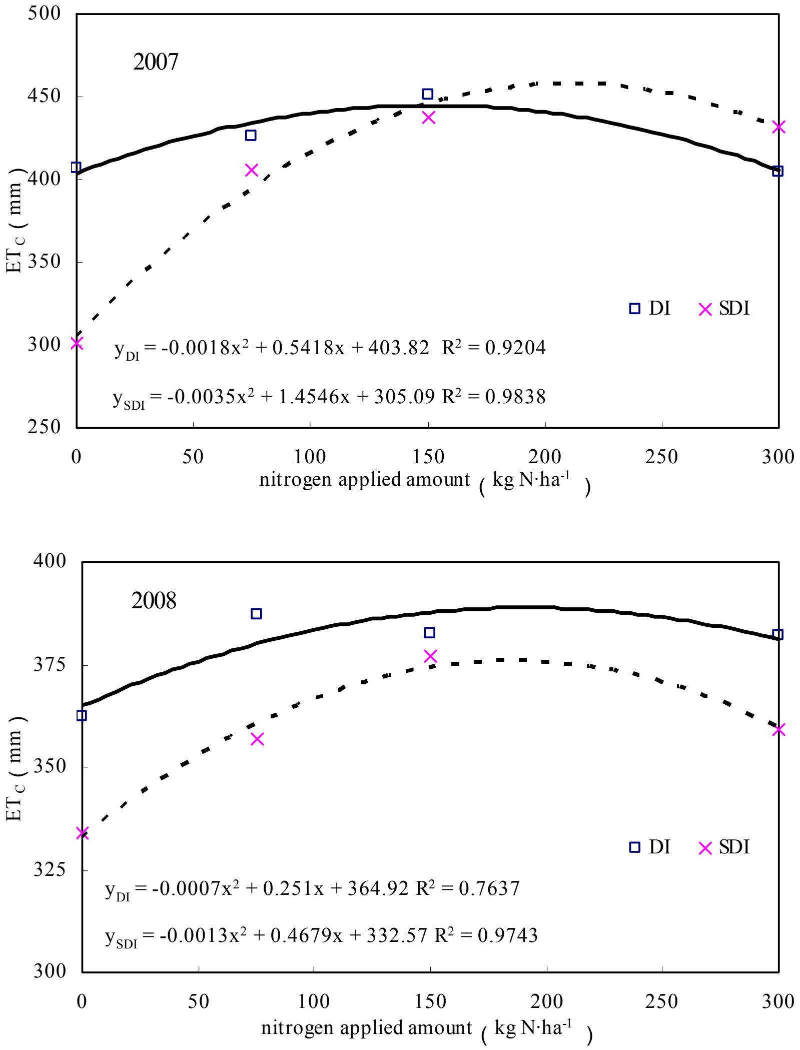


Fig.8 Relationship between ET$_C$ and nitrogen amount

There was a significantly polynomial correlation between crop water consumption and nitrogen amount (Fig.8). The ET_C increased with increasing nitrogen amount and reached up to a maximum value at 150 kg nitrogen·ha^{-1}. Thereafter, ET_C declined again. The results revealed that nitrogen became excessive after 150 kg·ha^{-1}.

3.4. Yield and water use efficiency

During 2007-2008, bell pepper yields were measured for each treatment and shown in Table.4 .

Table 4 Bell pepper yield and WUE for different treatment.

year	treatment	SDI		DI		BI	
		yield (t•ha^{-1})	WUE (kg•m^{-3})	yield (t•ha^{-1})	WUE (kg•m^{-3})	yield (t•ha^{-1})	WUE (kg•m^{-3})
2007	N_0	39.46 c	13.11*	36.07 b	8.87		
	N_{75}	43.43 b	10.71	42.70 a	10.01		
	N_{150}	46.54*a	10.64	44.72*a	9.92		
	N_{300}	46.29 a	10.72	43.29 a	10.71*	31.88	7.07
2008	N_0	29.72 c	8.90	28.11 b	7.26		
	N_{75}	35.89 b	10.06	30.44 ab	7.86		
	N_{150}	42.83*a	11.35*	34.50*a	9.02*		
	N_{300}	35.44 b	9.87	30.17 ab	7.90	23.00	6.27

Values followed by different letters are significantly different at $p < 0.05$ using Duncan's test.

* indicate the highest yield and highest WUE.

Bell pepper yield under SDI was higher than that under DI by 4% in 2007, and by 13% in 2008. Furthermore, bell pepper yield under SDI and DI were significantly higher than that under BI. For instance, bell pepper yield under SDI were higher than BI by 32.4% in 2007 and by 51.1% in 2008. The maximum yield were obtained under SDI with supplying 150 kg·ha^{-1}(SDI N_{150}) SDI had a higher WUE than DI by 13% in 2007, and 21% in 2008.

Maximum WUEs were obtained under SDI without nitrogen supply ($SDIN_0$) in 2007 and under SDI with supplying 150 kg nitrogen·ha^{-1} (SDI N_{150}) in 2008.

Standard analysis of variance test were carried out with Duncan-test considered significant at the 0.05 level of probability. The result showed the fertilizer application amount had significant effect on bell pepper yield. The relationship between yield and fertilization nitrogen amount were conics, yield increased with urea fertilization up to a point (150-200 kg N·ha^{-1}) where fertilization became excessive.

There was a significantly polynomial correlation between bell pepper yield and cumulative water consumption (Fig.9). The result indicated that the bell pepper yield was improved when the water consumption increased in a certain range.

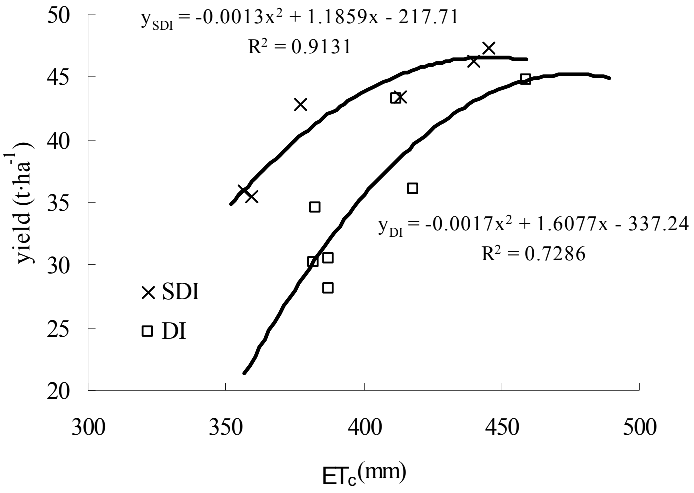


Fig.9 Relationship between yield and ET_C.

4. Conclusions

This study evaluated the different water consumption, soil water distribution, NO_3^--N content, root distribution, bell pepper yield and WUE between SDI and DI.

The cumulative water consumption under SDI is lower than that under DI. SDI not only promoted the growth of root, but also resulted in the root development towards deeper soils. The distribution of NO_3^--N in soil profile is significantly influenced by nitrogen fertilizer amount. And as compared with DI, SDI is more favorable in nitrogen fertilizer utilization, which prevents nitrate leaching. Meanwhile, SDI can prevent high variations of water and nutrients in the soils and increase bell pepper yield.

The results suggests that SDI combined with N_{150} was recommended as the optimal irrigation and fertilization practices for improving bell pepper yield and WUE, reducing NO_3^--N leaching.

Acknowledgements

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