BELL PEPPER RESPONSE TO SURFACE AND SUBSURFACE DRIP IRRIGATION

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ABSTRACT

A two-year field experiment was conducted in 2007 and 2008 to investigate different bell pepper responses to subsurface drip irrigation (SDI) and surface drip irrigation (DI) under four nitrogen levels: 0, 75, 150, and 300 kg/ha N (N_0, N_{75}, N_{150}, and N_{300}, respectively). Irrigation interval was set at 4 d. Bell pepper yield under SDI was significantly higher than that under DI by 4% in 2007 (13% in 2008). Water consumption under SDI was lower than that under DI by 6.7% in 2007 (7.3% in 2008). Meanwhile, root length density under SDI was obviously higher than that under DI by 11.8% in 2007 (12.5% in 2008). The percentage of root length below 10 cm soil depth under SDI were higher than that under DI by 7%, proving that SDI promotes crop root growth and enhances downward root development. Soil N residue under SDI was lesser than that under DI. Lastly, SDI with N application of 150 kg/ha is recommended as an optimal fertigation practice in improving bell pepper yield and water use efficiency, as well as, in NO_3^--N leaching.

1. Introduction

Agricultural production is the largest water consumer, accounting for more than 60% of total water consumption in China (Ministry of Water Resources of the People's Republic of China, 2009). Hence, in resolving water shortage, more and more countries are paying greater attention to agricultural practices. The efficient utilization of available water resources is crucial because although China hosts 22% of the global population, it only has 7% and 6% of the world's farmlands and water resources, respectively (National Economic and Social Development, 2008). Therefore，techniques to save irrigation water and increase crop water use efficiency (WUE) are necessary.

Levels of nitrogen fertilizer application have increased sharply in north China in recent years (Zhu et al., 2005), resulting in nitrate leaching and groundwater contamination (Rossi et al., 1991; Cameron et al., 1997; Zhu et al., 2004). It was reported that over fertilization in North China is leading to high concentrations of nitrate in groundwater and drinking water (average of 68 mg/L) (Li et al., 2001; Zhu et al., 2004), whereas the percentage of applied N intake by crops is below 40% (Zhang et al., 1996).

Therefore, there is an urgent need to maximize the use of water and fertilizer to minimize nitrate leaching and groundwater contamination, and to achieve optimal agronomic, economic, and environmental benefits.

Surface drip irrigation (DI) introduces water and nutrients to soil surface near roots

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through emitters. Subsurface drip irrigation (SDI) laterals are buried underground, supplying water and nutrients directly to root zones (Phene and Beale, 1979; Lamm, 1995; Camp et al., 1997). DI and SDI are modern and enhanced water and fertilizer saving methods (Phene et al., 1991; Solomon and Jorgensen, 1992; Lamm, 1995, 2002; Camp, 1998; Ayars et al., 1999).

There are limited comparative studies on SDI and DI under different fertigation conditions. Several studies have compared the effects of SDI and DI on crop yield, proving that SDI generally results in higher crop yield (Hanson et al., 1997; Hanson and May, 2004; Gencoglan et al., 2006; Patel, 2009).

Under SDI or DI, irrigation volume and irrigation intervals have significant impacts on crop growth, development, and yield. Shorter irrigation intervals from 3–6 d could result in higher crop yield and water use (Sezen et al., 2005, 2006; Sensoy et al., 2007). However, different SDI frequencies (1 and 7 d) only have a slight effect on corn yields (Howell et al., 1997).

Irrigation methods affect root distribution and nitrogen utilization. Under DI, roots grow preferentially around the wetted emitter area and are concentrated within the top 40 cm of the soil profile (Oliveira et al., 1996; Machado et al., 2003). Larger concentrations of crop roots around the drip tube are found under SDI (Coelho and Dani, 1999; Machado et al., 2003). The center of gravity of the root system in SDI and DI fertigation is near the emitter below the soil surface (Hernandez et al., 1991). Moreover, SDI treatment results in a wider distribution of roots across the bed compared to DI (Zotarelli et al., 2009). Hence, SDI can reduce percolation below the root zone (Hanson and May, 2004) and decrease groundwater NO_3^--N pollution (Phene, 1999). Meanwhile, too much N fertilizer application does not increase crop production (Camp et al., 1997; Thompson et al., 2002a-b; Sorensen et al., 2004; Mahajan and Singh, 2006; Cabello et al., 2009). SDI has higher soil fertility after potato harvesting compared to DI, although this effect is not significant (Selim et al., 2009).

This study aims to investigate the root development, root distribution, nitrogen distribution, and crop yield of bell pepper under SDI and DI, considering different nitrogen fertilization levels, and to determine best management practices for bell pepper production.

2. Materials and methods

2.1. Site description

Table 1. Historical monthly and growing season climatic data of the experimental area

Mont	Mean temperatures(℃)									Relative			Precipitation(		
	Minimum			Maximum			Average								
	20	20	Lo	20	20	Lo	20	20	Lo	20	20	Lo	20	20	Lo
May	9.	7.	8.	24	22	23	17	15	15	34	37	41	26.	15	28.
June	16	13	13	29	26	27	22	19	20	51	64	50	44.	72	48.
July	17	16	16	29	29	28	22	23	22	59	61	64	62.	33	10
Augu	16	14	14	29	26	26	22	20	20	57	71	68	75.	86	86.
Septe	10	10	8.	25	23	21	8.	16	14	59	72	61	38.	90	51.
Sum													24	29	31

* 1956-2006

Field experiment was conducted at Yuhe Irrigation Experiment Station, Datong, Shanxi Province (40°06′ N, 113°20′ E, and elevation of 1052 m above sea level). The soil is gravelly loam with 22.5% field capacity. Groundwater level was kept at about 19 m deep. The climate in Datong is semiarid, with an average annual precipitation of approximately 379 mm and an annual evaporation of about 1152 mm. More than 60%

of the annual precipitation occurs during the growing season, which extends from late May to mid September. The frost-free period is about 110–130 d. Table 1 summarizes the monthly mean climatic data of 2007 and 2008 compared with the mean long term data for the experimental district. The growing season temperatures in both years were typical of the long term means at the site, Precipitations in 2007 growing season were all smaller than the long term means. Total precipitation in 2008 was coincident with the long term means. However, precipitations of June and September in 2008 were greater than the long term means. Precipitation in July 2008 was 68mm lower than the long term means. The daily rainfall and temperature at the experimental site in 2007 and 2008 are shown in Figure.1. The monthly average temperatures in 2008 were lower than those in 2007 except July, and a very low temperature (2.4 °C) in May 30, 2008 inhibited seedling establishment.

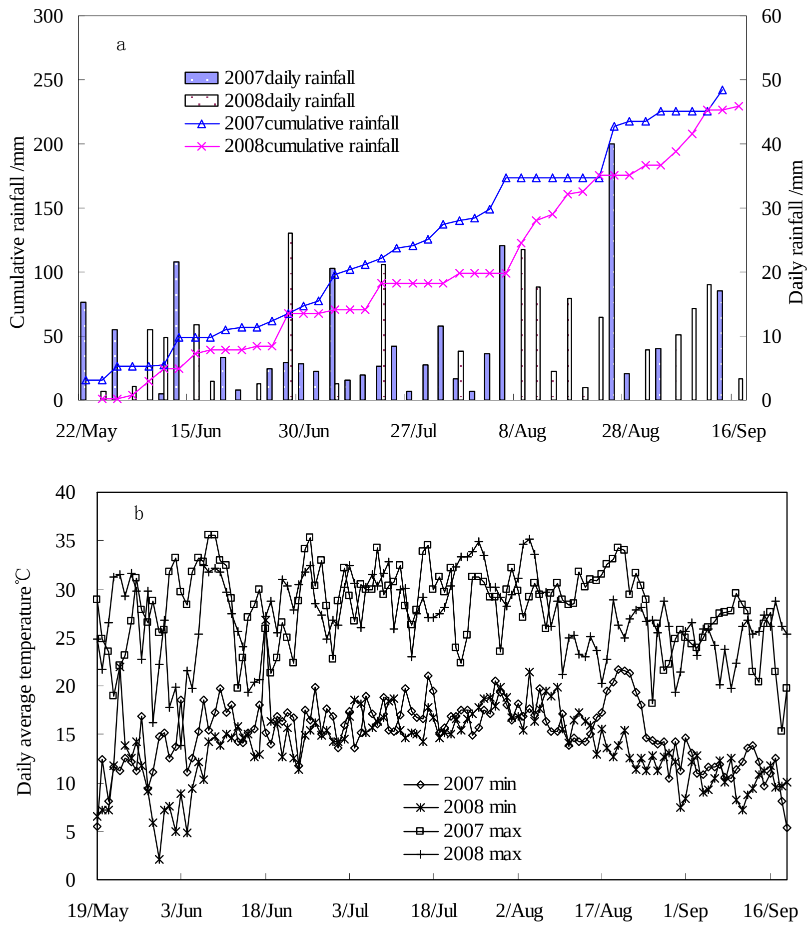


Figure 1. Meteorological data during the crop growth season.(a) Cumulative and daily average rainfall during the crop season, and (b) daily average temperature

2.2. Experimental treatments and field preparation

The field experiment was conducted using a randomized complete block design with eight treatments, including two irrigation techniques (SDI, DI) and four fertilization levels of 0, 75, 150, and 300 kg/ha N (N_0, N_{75}, N_{150}, and N_{300}, respectively) (Table.2). Each treatment was replicated thrice. There were 24 plot measuring 7 m × 3 m (6 rows per plot) (Fig.2).

Table 2. Experimental treatments

Irrigation method	Treatment	Nitrogen application rate (kg N·ha^{-1})		
		Blossom and	Full bearing	Late stages of
SDI	SDI N_0	0	0	0
	SDI N_{75}	30	30 (2007) 0	15(2007)
	SDI N_{150}	60	60(2007) 0	30(2007)
	SDI N_{300}	120	120(2007)	60(2007)
DI	DI N_0	0	0	0
	DI N_{75}	30	30 (2007) 0	15(2007)
	DI N_{150}	60	60(2007) 0	30(2007)
	DI N_{300}	120	120(2007)	60(2007)

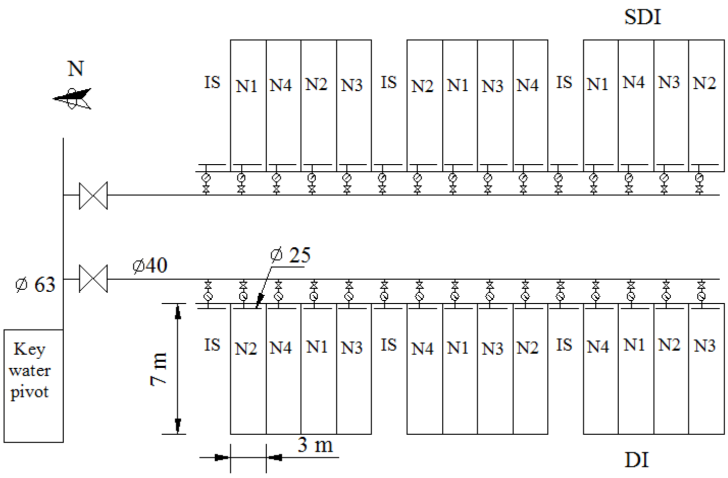


Figure 2. Experimental plot arrangement
IS stands for isolation strip; N_1, N_2, N_3, and N_4 stand for nitrogen levels of 0, 75, 150, and 300 kg/ha, respectively

The test crop was Tongfeng 16， a local variety of bell paper. Two-month-old pepper plants were transplanted in the field 40 cm in rows and 50 cm between plants on May 20, 2007 and May 21, 2008. The plants were irrigated with either SDI or DI systems installed prior to planting. The laterals were installed between every other crop row at a space of 1 m, whereas the SDI laterals were buried at a depth of 20 cm between crop rows. Water was supplied every 4 d using laterals (Netafim super Taphoon 125) with 1.1 L/h of drippers discharge at a spacing of 40 cm.

Soil water content was measured by a portable time domain reflectometry (TDR). Three access tubes were placed at a distance of 0, 25 and 50 cm from lateral pipes for each plot at a depth of 1 m. A total of 24 PVC access tubes were installed (Fig.3). Volumetric water content for all treatments at 0–20, 20–40, 40–60, 60–80 and 80–100 cm layers were measured before and after each irrigation and after each rainfall.

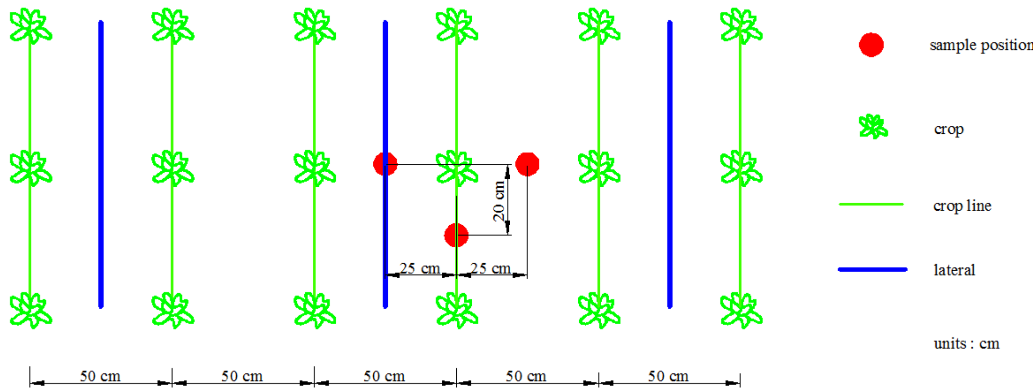


Figure 3. Layout of trime PVC tubes

To measure leaching, a lysimeter (Fig.4) was installed for each treatment. The lysimeter is a rectangular plastic box measuring 70×50×90 cm. The top of the lysimeters were buried at 10 cm below the soil surface. The soil was back-filled in layers to maintain its original structure. Drainage water was collected from the outlet at the bottom of lysimeters using a bottle placed in a separate tube next to the lysimeters, and measured once every 2 d. Two crops were transplanted in each lysimeter.

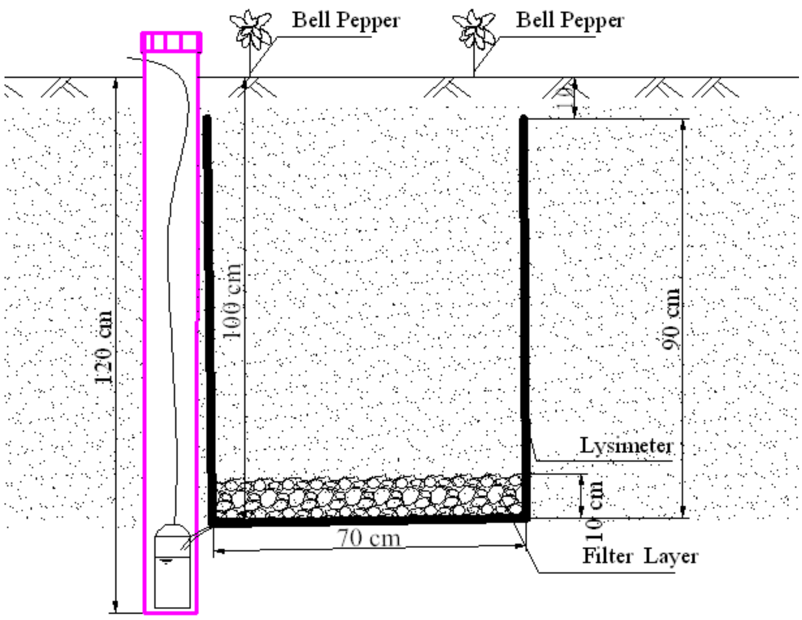


Figure 4. Structure of a simple lysimeter

Table 3. Average soil physical parameters at the experimental site

Soil layers (cm)	Texture	Bulk density ($g \cdot cm^{-3}$)	Field capacity (V/V, %)	Wilting point (V/V, %)
0–20	Silt loam	1.29	27.7	11.3
20–60	Silt loam	1.46	33.3	12.7

Before the plants were transplanted, three sampling points were randomly selected from the entire experimental field to determine basic soil parameters, including soil texture, bulk density, field capacity, and permanent wilting point (Table 3).

2.3. Irrigation application

Irrigation volume was determined every 4 d based on the difference between estimated ET_p and measured effective rainfall. Penman-Monteith's formula, multiplying crop coefficients from FAO-56 (Allen et al., 1998), was used to estimate ET_p. Weather data were collected from an automatic weather station, 20 m away from the field site.

2.4. Evapotranspiration estimation

Actual crop evapotranspiration was estimated using the following water balance equation:

$$ET_c = \Delta W + I + P - R - D \quad (1)$$

where ΔW is the change of soil water storage (mm), I is irrigation amount (mm), P is precipitation (mm), R is surface runoff (mm), and D is the deep percolation (mm). The calculation soil layer was set at 0–100 cm.

The ΔW was estimated using the change in soil water content in the soil profile. Surface runoff was ignored, and D was considered as the volume of water drained from the lysimeters.

2.5. Nutrient management

Organic fertilizer (chicken manure: 11.1 m^3/ha) was uniformly applied in all plots as basal fertilizer before land leveling. During the growth season, urea dissolved in irrigation water in a fertilizer tank was applied according to nitrogen fertilization application levels of the different treatments. In 2007, nitrogen application was applied at 23 Jul, 16 Aug, 9 Sep for three different growth stages. But in 2008, nitrogen was applied only two times at 31 Jul, 3 Sep.

Before and after fertilization, soil samples were collected from 0–20, 20–40, 40–60, 60–80 and 80–100 cm soil layers and at 0, 25 and 50 cm distance from the lateral pipes. Soil samples were then pulverized and sifted out using a 2 mm sieve, soil (10 g) was weighed with an electronic balance, and 50 ml KCl solution (1 mol/L) was added to the soil through a pipette. The samples were then shook for 1 h on a shaker, and filtrated through a 0.45 μm membrane after clarification. NO_3^--N content in the soil leach liquor was calculated assuming that all NO_3^--N was dissolved in water. After leaching, dissolved NH_4^+-N and NO_3^--N were determined directly by flow injection analysis (SAN^{++}5000).

2.6. Yield

Bell pepper was manually picked eight times in two years (Aug 4, Aug 23, Sep 12, and Sep 14, 2007; and Jul 29, Aug 24, Sep 8, and Sep 12, 2008). Bell pepper yield was determined by harvesting bell pepper from two adjacent center rows in each plot. ANOVA was performed using the SPSS software package (SPSS V17.0). Significant differences between means for different treatments were compared using Duncan's test at P <0.05.

2.7. Root sampling and analysis

Soil samples containing crop roots were taken from center rows 1 d after harvest. The soil surface sampling area was 40 cm × 50 cm, with a plant at the middle. 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 0.5 mm sieve, crop roots and organic debris were stored in plastic bags at 4 °C until further cleaning and then placed in a glass bowl. Crop roots were handpicked and placed in glass dishes. Root length and other root characteristic parameters were determined with using the Winrhizo (Re´gent Instrument Inc., Quebec City, Canada) software and hardware. ANOVA was performed using the SPSS software package.

3. Results and discussion

3.1. Water application

Rainfall during the crop growing season and the volume of irrigation water are shown in Table 4. The crops were irrigated 14 times and the total irrigation volume was 257 mm in 2007. However, irrigation frequency was reduced to 10 times in 2008 (164 mm).

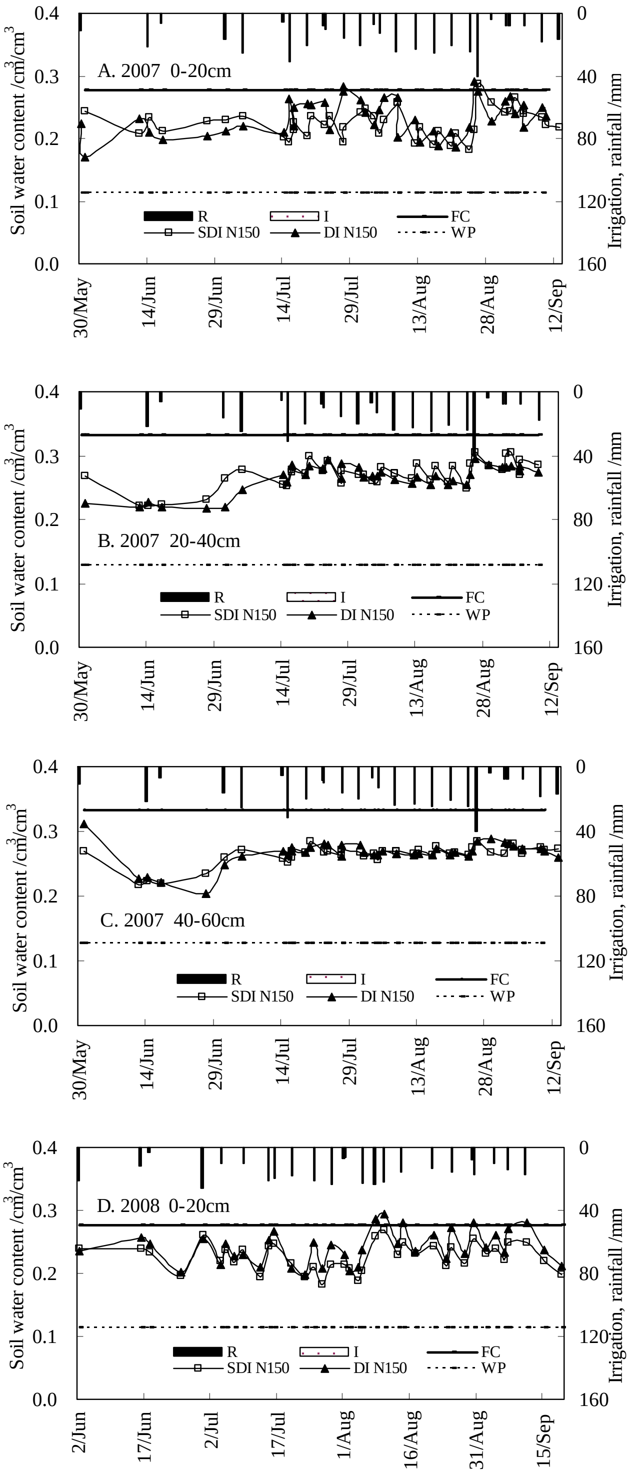
Table 4. Irrigation application and rainfall (mm)

2007	Rainfall	Irrigation	2008	Rainfall	Irrigation
22 May	15		26 May	2	
30 May	11		1 Jun	2	
5 Jun		30	3 Jun	11	
13 Jun	22		10 Jun	10	
18 Jun	7		15 Jun	12	
26 Jun		10	17 Jun	3	
28 Jun	5		27 Jun	2	
29 Jun	6		29 Jun	26	
30 Jun	6		4 Jul	3	10
3 Jul	5		8 Jul		10
4 Jul	21		14 Jul	21	
9 Jul	4		16 Jul		19
14 Jul	5		20 Jul		18
15 Jul		31	24 Jul		21
19 Jul		20	28 Jul		23
22 Jul	8		31 Jul	7	
23 Jul		10	1 Aug		6
27 Jul		16	5 Aug		22
29 Jul	5		8 Aug	24	
30 Jul	12		9 Aug	18	
31 Jul	3		10 Aug	5	
2 Aug	7		13 Aug	16	
4 Aug		13	18 Aug	2	
7 Aug	24		21 Aug	13	
12 Aug		23	25 Aug		16
16 Aug		25	29 Aug	8	17
20 Aug		21	3 Sep	10	
24 Aug		24	7 Sep	14	
26 Aug	40		9 Sep	18	
28 Aug	4		16 Sep	3	
1 Sep		8	Total	230	162
2 Sep	8				
5 Sep		8			
9 Sep		18			
13 Sep	17				
Total	234	257			

Average soil moisture of different points (0, 25, and 50 cm from the lateral pipes) in different profiles (0–20, 20–40, 40–60 cm) for two years (2007 and 2008) under the 150 kg/ha nitrogen treatment is presented in Fig. 5a as an example for the same nitrogen application. Soil water content in the 0-20 cm layer fluctuating violently, and the moisture there under DI N_{150} was slightly higher than under SDI N_{150}. Soil water content under SDI N_{150} was higher than under DI N_{150} in the 20–40 cm layer, and there were also significant fluctuations of the moisture. However, soil moisture remained almost the same level and fluctuations were not obvious in 40-60 cm layer under SDI and DI.

Figure.5b showed the average soil moisture of three points (0, 25, and 50 cm from the lateral pipes) and two profiles (0–20, 20–40 cm) for two years (2007 and 2008) under different nitrogen application amount. All average soil moisture from 0 to 40 cm depth in whole growth period were maintained at above 50% available soil moisture except SDI N_{75} under SDI and DI irrigation method.

3.2. Seasonal patterns of soil moisture



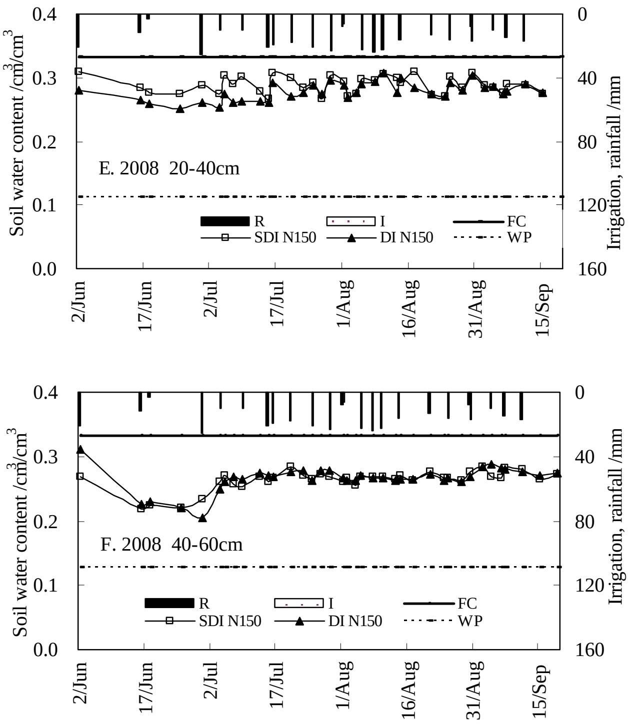
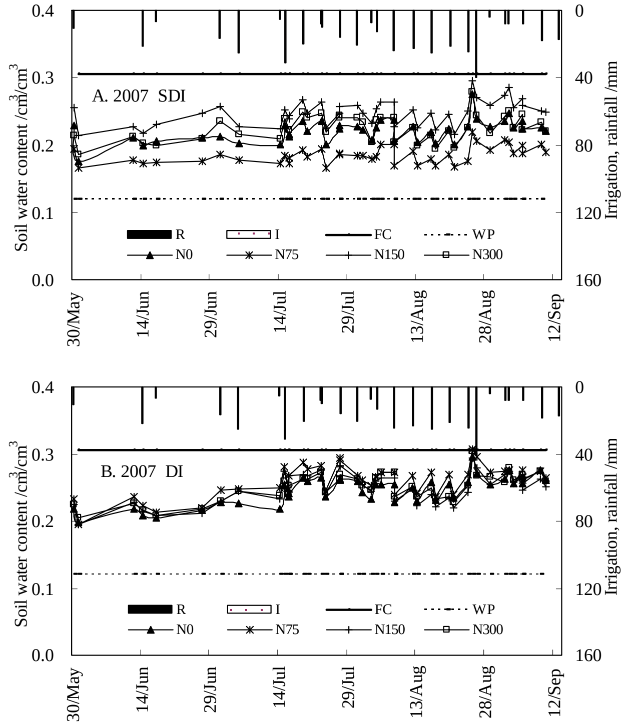
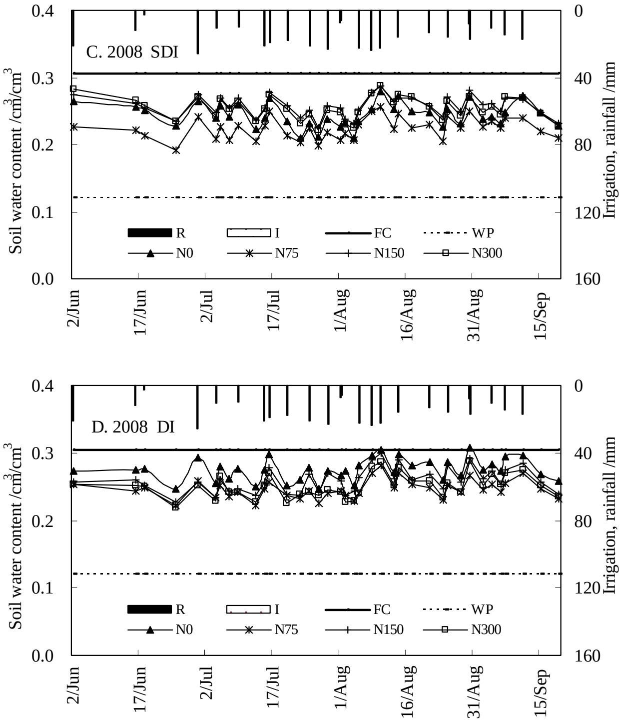


Figure 5. Soil moisture at different layers
a. Soil moisture in 0-20, 20-40, 40-60 cm depth under N_{150}.





b. Average soil moisture of 0-40 cm depth under different nitrogen treatment.

3.3. Root distribution

Table 5. Root length density (RLD) of bell pepper as influenced by irrigation method and N application levels

Treatment	RLD(cm/cm^3)	
	2007	2008
*Nitrogen**		
N_0	0.42c	0.18d
N_{75}	0.51b	0.30b
N_{150}	0.61a	0.33a
N_{300}	0.39c	0.22c
*Irrigation***		
SDI	0.51a	0.27a
DI	0.45b	0.24b

*Average of two irrigation methods. **Average of four different nitrogen levels.

Table 5 shows a significant difference in RLD between SDI and DI and among the different nitrogen levels. RLD obviously increased with increasing nitrogen levels until the nitrogen level reached 150 kg/ha in both years, and then it sharply decreased. The effect of irrigation methods on RLD was apparent; the RLD of SDI was obviously higher than that of DI.

At the same fertilization level, the root length and percentage of root length in each layer to total root length decreased with soil depths (Table 6). The percentages of root length at 30-40 cm soil depth to total root length under DI and SDI were 1.25% (DI N_{150}) and 2.81% (SDI N_{150}), respectively, indicating that there were almost no bell pepper roots below 40 cm soil depth. Root lengths under SDI N_0, SDI N_{75}, SDI N_{150}, and SDI N_{300} were 1.06, 1.06, 1.46, and 1.07 times longer than those under DI N_0, DI N_{75}, DI N_{150}, and DI N_{300}, respectively. The percentage of root length below 10 cm soil depth under SDI N_{150} was higher than that under DI N_{150} by 7%. Hence, SDI does not only promote root growth but also results in deeper root development.

Table 6. Bell pepper root length at different soil depths

	Depth (cm)	0–10	10–20	20–30	30–40	0–40
DI N_0	Root length(cm)	7431	3772	719	431	12354
	Proportion (%)	53.47	27.14	5.18	3.10	100
SDI N_0	Root length(cm)	6038	4976	1370	750	13135
	Proportion (%)	45.97	37.88	10.43	5.71	100
DI N_{75}	Root length(cm)	8263	6917	1922	937	18038
	Proportion (%)	45.81	38.34	10.65	5.19	100
SDI N_{75}	Root length(cm)	6923	8017	3035	1255	19231
	Proportion (%)	36.00	41.69	15.78	6.53	100
DI N_{150}	Root length(cm)	11582	4588	1089	219	17479
	Proportion (%)	66.26	26.25	6.23	1.25	100
SDI N_{150}	Root length(cm)	15235	7353	2319	719	25625
	Proportion (%)	59.45	28.69	9.05	2.81	100
DI N_{300}	Root length(cm)	8555	4076	919	827	14377
	Proportion (%)	59.51	28.35	6.39	5.75	100
SDI N_{300}	Root length(cm)	7199	6419	951	820	15390
	Proportion (%)	46.78	41.71	6.18	5.33	100

Under the same irrigation methods, the impact of different nitrogen levels on RLD at harvest is shown in Fig.6. At 0–10 cm soil depth, RLD gradually increased with increasing nitrogen levels. However, at 10–20 cm soil depth, RLD declined sharply when the nitrogen level exceeded 150 kg/ha. These findings imply that too much nitrogen application inhibits root growth in deeper soil layers.

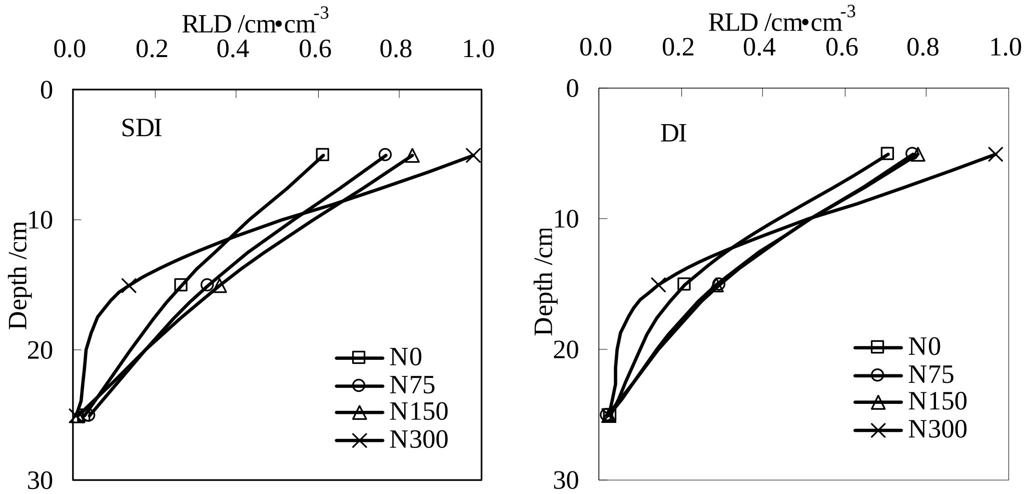


Figure.6 RLD distribution during the 2007 growing season in all treatments

3.4. NO_3^--N distribution in soils

Figure.7 shows NO_3^--N concentrations in soil 2 d before fertilization (Aug 14), 2 d after fertilization (Aug 18), and 22 d after fertilization (Sep 7).

Before fertilization, there was no significant difference in NO_3^--N distribution between SDI and DI. However, 2 d after fertilization, NO_3^--N concentrations under SDI treatment were distributed with a parabolic curve; the maximum value (14.2 mg/kg) was found at 20–40 cm soil depth. In contrast, NO_3^--N concentrations under DI treatment declined with increasing soil depth, and a maximum concentration (15.7 mg/kg) was obtained at the top soil (0–20 cm). Furthermore, 22 d after the fertilization, NO_3^--N gradually moved downward due to water movement, crop growth, and root activities. The maximum NO_3^--N concentration 22 d after fertilization under SDI and DI occurred at 40–60 cm and 60–80 cm, respectively.

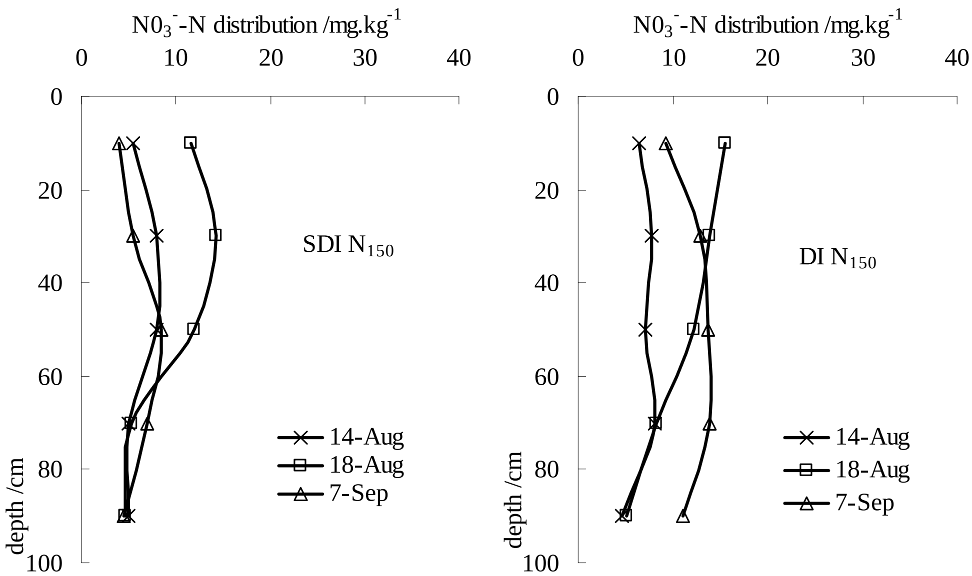
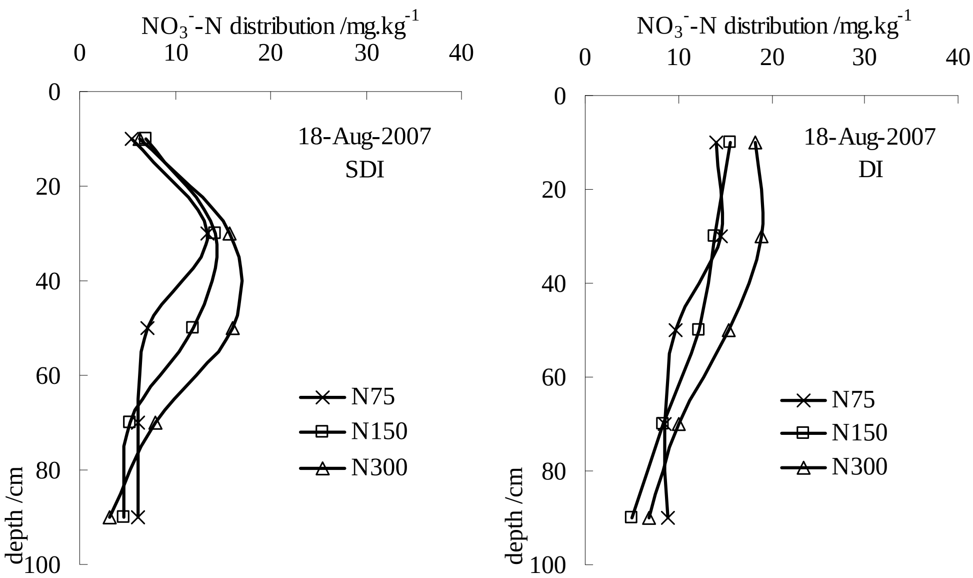


Figure 7. Vertical distribution of NO_3^--N concentration in soil profiles

As mentioned above, bell pepper roots were concentrated at 0–40 cm soil depth. Nitrogen leaching below 40 cm, which was hardly useful to the plants, was of residual value. The maximum residual NO_3^--N concentration at 40-60 cm under SDI (8.4 mg/kg) was far lower than that under DI treatment (13.8 mg/kg at 60–80 cm).
Residual NO_3^--N concentrations in soil profiles increased with increasing levels of nitrogen fertilizers (Fig. 8), but the residual of N_{150} was only slightly higher than N_{75}. The NO_3^--N residual concentration for N_{300} treatment was sharply higher than that for N_{150} treatment 22 d after fertilization. This tend was found in all nitrogen treatments. The data above show that SDI promoted the development of bell pepper roots and favored the establishment of intensive root layers, which can prevent nitrate leaching. At nitrogen level lower than 150 kg/ha, fertigation produced lesser residues.



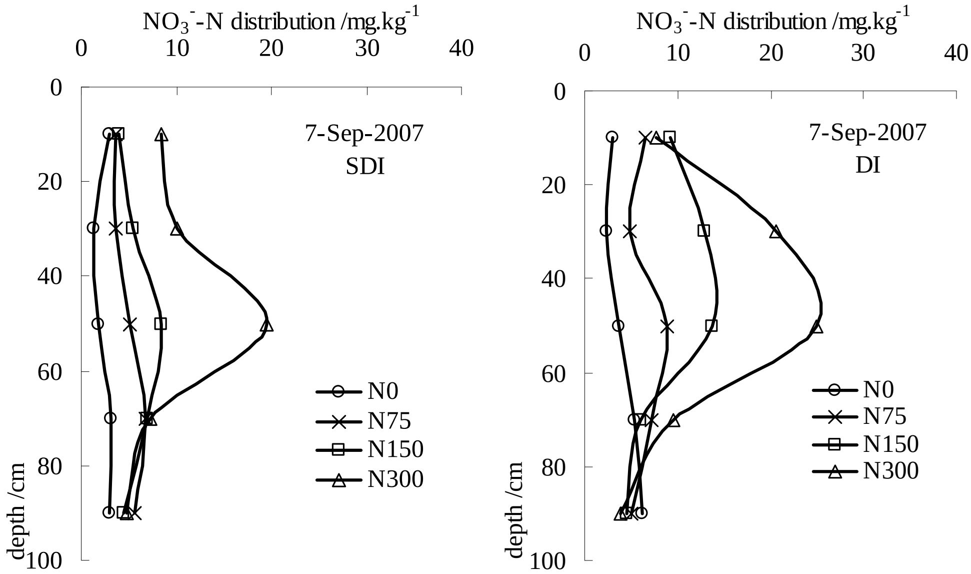


Figure 8. Vertical distribution of NO_3^--N as influenced by different nitrogen levels 3.5. ET_c

Bell pepper plants were transplanted at May 20 in 2007 and May 21 in 2008. The growth seasons last 118 d and 115 d separately in 2007 and 2008.

Bell pepper ET_c was calculated by formula (1). D in formula (1), the amounts of drainage water collected from the lysimeter are shown in Table.7.

Table.8 shows the cumulative water consumption of bell pepper and ET_0 calculated by Penman-Monteith's formula during the two growing seasons. The ET_c and ET_0 of all treatments in 2008 were lower than those in 2007 due to the lower monthly average temperature in 2008. as compared with 2007. A very low temperature (2.4 °C) in May 30, 2008 inhibited seedling establishment.

Table 7. Drainage water amounts (mm)

a. 2007

	SDI N_0	SDI N_{75}	SDI N_{150}	SDI N_{300}	DI N_0	DI N_{75}	DI N_{150}	DI N_{300}
16-Jul	5.2	2.4						
20-Jul	5.6		4.9					
24-Jul	6.0	2.9						
27-Jul	8.5	6.9						
5-Aug	5.7							
7-Aug				3.9				
13-Aug	4.9	5.3						
16-Aug	5.0							
17-Aug	13.9	5.9						
21-Aug	11.4	5.7				5.5		
25-Aug	11.8	5.6				3.5		
26-Aug	8.2	6.5	14.7	7.8	22.7	10.7		10.8
2-Sep	2.1							
5-Sep	3.4							
9-Sep	1.8							
10-Sep	11.5	6.3				8.3		
Total	105	47.5	19.6	11.7	22.7	28	0	10.8

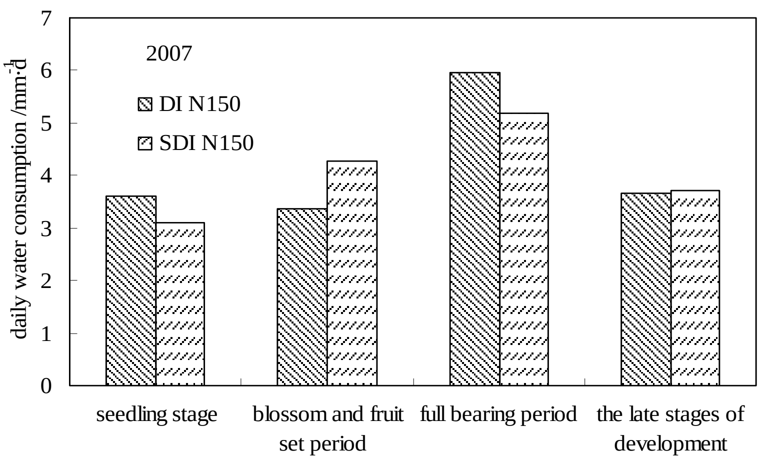
b. 2008

	SDI N_0	SDI N_{75}	SDI N_{150}	SDI N_{300}	DI N_0	DI N_{75}	DI N_{150}	DI N_{300}
9-Jul			3.6					
16-Jul	9.8	5.3	5.4	7.5				
20-Jul	16.7	15.3	12.2	18.2	3.1			
24-Jul	19.2	12.3	10.6	16.6	2.2	2.4		
25-Jul					2.3	2.1	2.6	1.2
29-Jul	2.9	5.3	2.7	5.4	4.6	5.4		5.4
5-Aug	10	8.4	3.5	7.2	9	7.0		
10-Aug	3.5		7.5		3.8	8.5		2.7
Total	62.1	33.2	31.8	42.7	25	25.4	2.6	9.3

Table 8. 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
2008	406	DI	362	387	382	382
		SDI	334	357	377	359

The maximum and minimum water consumption were recorded for DI N_{150} treatment (451 mm) and SDI N_0 treatment (301 mm), respectively, in 2007. In 2008, the maximum water consumption was recorded for DI N_{75} (387 mm), followed by DI N_{150} and DI N_{300}(382 mm). The minimum value was at 334 mm for SDI N_0. Except for N_{300} treatment in 2007, all cumulative water consumptions under SDI were lower than under DI.



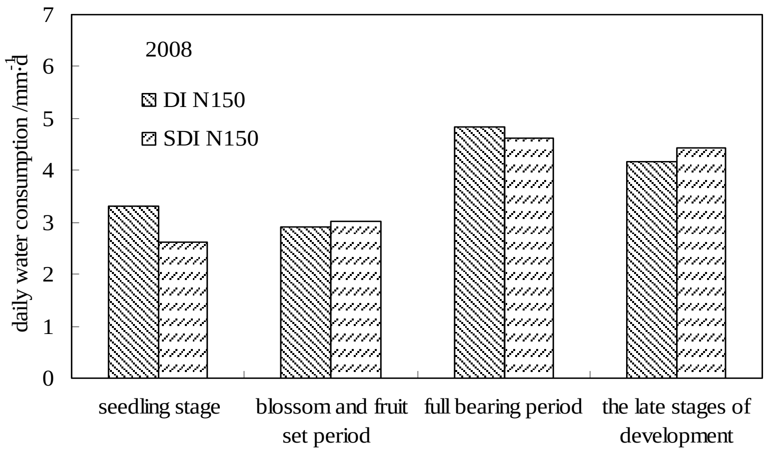
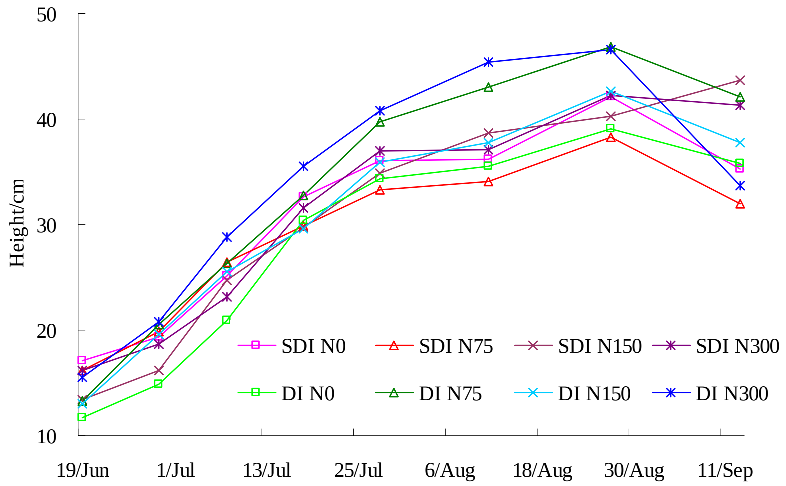
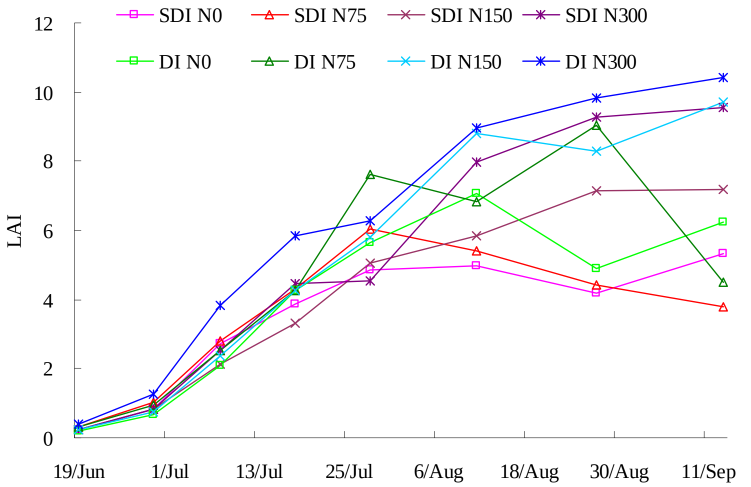


Figure 9. Daily averaged water consumption at different growth stages

Daily average water consumptions at different growth stage under different irrigation techniques (N_{150} treatment) are shown in Fig.9. During the seedling establishment period, the DI method resulted in higher daily averaged water consumption compared with SDI because of higher evaporation under DI. After entering the blossom and fruit-set period, the daily average water consumption under SDI became higher than that under DI. This result may be attributed to faster root growth under SDI than under DI. At full bearing period, the plants grew vigorously, leading water consumption to reach its maximum. Water consumption under SDI was lower than that under DI, contributing to low plant height and leaf area (Fig. 10). However, daily average water consumption under DI was slightly lower than that under SDI at the late crop growth stages.





Figue 10. Plant height and LAI for different treatments (2007)

There was a polynomial correlation between crop water consumption and nitrogen levels (Fig.11). ET_c increased with increasing nitrogen levels, reaching a maximum value at 150 kg/ha nitrogen level. Thereafter, ET_c again declined. Nitrogen became excessive after 150 kg/ha and too much nitrogen restricts bell pepper growth leading to lower ET_c.

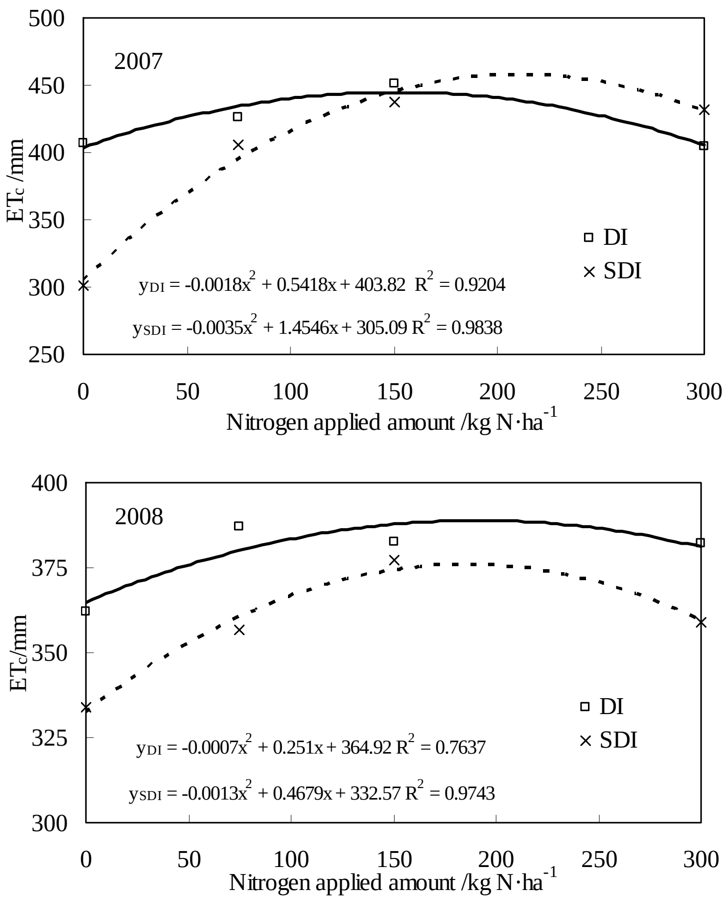


Figure 11. Relationship between ET_c and nitrogen levels

Table 9. Calculated k_c at each growth stage

a. SDI N_{150}, 2007

	ET_0	ET_c	Calculated k_c	k_c recommended by FAO-
Seedling establishment	167	115	0.69	0.6
Blossom and fruit-set period	120	101	0.84	1.05
Full bearing period	160	191	1.19	1.05
Late crop growth stages	60	44	0.74	0.9
Whole growing season	508	451	0.89	

b. SDI N_{150}, 2008

	ET_0	ET_c	Calculated k_c	k_c recommended by FAO-
Seedling establishment	115	76	0.66	0.6
Blossom and fruit-set period	107	87	0.82	1.05
Full bearing period	115	149	1.30	1.05
Late crop growth stages	69	65	0.93	0.9
Whole growing season	406	377	0.93	

Crop coefficient k_c for bell pepper at different growth stages for the experimental site under SDI N_{150} is shown in Table 9. At the seedling establishment and full bearing periods, k_c values were higher than the values recommended by FAO-56. On the contrary, k_c at the blossom and fruit-set period was higher than that recommended by FAO-56. Meanwhile, k_c at the late crop growth stages was not stable.

3.5. Yield and water use efficiency

Bell pepper yields were measured for each treatment in 2007 and 2008. Results are shown in Table10 .

Table 10. Bell pepper yield and WUE for different treatments

Year	Treatment	SDI		DI	
		Yield	WUE	Yield	WUE
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*
2008	N_0	29.72 c	8.90	28.11 b	7.76
	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

a, b, and c are significantly different between values at $p < 0.05$ using Duncan's test.
*Highest yield and highest WUE.

Yield under SDI was significantly higher than that under DI in both years. It was higher by 4% and 13% in 2007 and 2008, respectively. The maximum yield was obtained under SDI at 150 kg/ha (SDI N_{150}). SDI had a higher WUE than DI by 13% and 21% in 2007 and 2008, respectively. Maximum WUEs were obtained under SDI without nitrogen supply (SDI N_0) in 2007 and under SDI with 150 kg/ha (SDI N_{150}) in 2008.

Standard ANOVA was carried out with Duncan's test at the 0.05 level of significance. The level of fertilizer application showed a significant effect on bell pepper yield. The relationship between yield and the level of fertilization nitrogen was conical, the yield increased with urea fertilization up to a point (150–200 kg/ha N) when fertilization became excessive.

The variance analysis indicated that experimental years (Y), irrigation methods (I) and nitrogen application amounts (N), significantly influenced pepper yields (Table 11). There was no significant interaction effect among Y, I and N, except between Y×I.

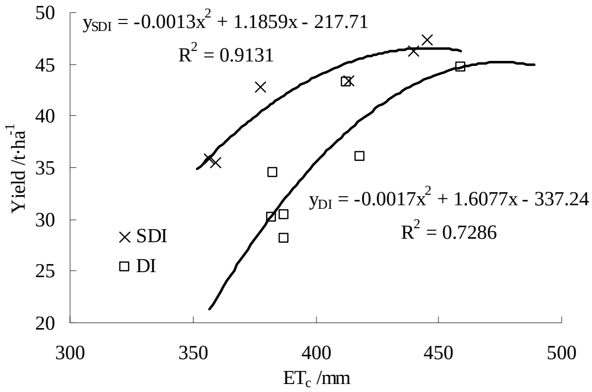


Figure 12. Relationship between yield and ET_c

There was a significantly polynomial correlation between bell pepper yield and cumulative water consumption (Fig.12). Bell pepper yield was improved when water consumption increased at a certain range.

4. Conclusions

Bell pepper yield under SDI was significantly higher than that under DI in both years. The highest yield (46.54 t/ha) was recorded in the case of SDI at 150 kg/ha (SDI N_{150}). The lowest yield (28.11 t/ha) was recorded in the case of DI with no after-manuring (SDI N_0).

Compared with DI, all treatments of SDI had lower water consumption. The total root length densities from 0–40 cm soil depth and the percentage of root length below 10 cm under SDI are higher than under DI. SDI does not only promote crop root growth; it also enhances the downward development of roots. There are lesser soil N residues under SDI than under DI. Consequently, the experiment obtained a preliminary conclusion that SDI was more beneficial to the growth of bell pepper than DI.

From the perspective of increasing bell pepper yield and WUE, as well as reducing NO_3^--N leaching, SDI with N application of 150 kg/ha is the optimal fertigation practice.

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