2009

Effect of Amount and Timing of Subsurface Drip Irrigation on Corn Production

Simon van Donk
University of Nebraska-Lincoln, simon.vandonk@unl.edu

James Petersen
University of Nebraska - Lincoln, jpetersen2@unl.edu

Don Davison
University of Nebraska - Lincoln, ddavison1@unl.edu

2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

An ASABE Meeting Presentation, ***Paper Number: 095610***

Effect of Amount and Timing of Subsurface Drip Irrigation on Corn Production

Simon van Donk, University of Nebraska, North Platte, Nebraska, email: svandonk2@unl.edu
James Petersen, University of Nebraska, North Platte, Nebraska
Don Davison, University of Nebraska, North Platte, Nebraska

**Written for presentation at the
2009 ASABE Annual International Meeting
Sponsored by ASABE
Grand Sierra Resort and Casino, Reno, Nevada
June 21 – June 24, 2009**

Abstract. *Subsurface drip irrigation (SDI) has the potential of being a more efficient irrigation system compared to systems such as center pivot and furrow irrigation. The objective of this study was to determine the effect of the amount and timing of irrigation, using SDI, on corn (Zea mays) production. A field study was conducted at North Platte, Nebraska in 2007 and 2008, using two SDI systems. The study was replicated eight times on the older SDI system (SDI1) and four times on the newer SDI system (SDI2). On SDI1, there were nine treatments to impose different irrigation regimes, ranging from dryland to fully irrigated. Five of the nine treatments allowed water stress only after tasseling and silking. On SDI2, there were eight treatments that were very similar to the nine on SDI1.*

In 2007, on SDI1, mean corn yield ranged from 7.8 Mg ha^{-1} with a season total of 57 mm of irrigation water to 11.1 Mg ha^{-1} for the fully irrigated treatment (253 mm of irrigation water). On SDI2, yield increased from 8.9 Mg ha^{-1} with 41 mm to 11.5 Mg ha^{-1} with 264 mm (fully irrigated). The least-irrigated treatment (158 mm) of the four treatments allowing water stress only after tasseling and silking, had a mean yield of 10.9 Mg ha^{-1}, only 0.6 Mg ha^{-1} less than the fully irrigated treatment (264 mm). Soil water content fell well below 0.20 m^3 m^{-3} (below 50% depletion of soil available water) in the second part of August and in September for the former treatment (158 mm), suggesting that some drying out of the soil below 50% depletion towards the end of the growing season causes only a modest reduction in corn yield. In 2008, yields were suppressed across the irrigation treatments. Amount or timing of irrigation did not have much of an effect on yields, except for the dryland treatment where yield was substantially less than for the other treatments. Water conservation with SDI has the potential to help irrigators to significantly reduce pumping cost and more water would be available for competing needs. More research is needed to document and quantify this water conservation potential of SDI.

Keywords: corn, subsurface drip irrigation, soil water, water stress

Introduction

In western Nebraska, as in many other parts of the USA, irrigation water is becoming scarcer. Groundwater levels have been falling (McGuire, 2004; McGuire and Fischer, 1999), and stream flow has been decreasing, leading to some conflicts. For example, it has been a challenge for Nebraska to supply the required amount of water to Kansas through the Republican River. Irrigated agriculture is a major water user and a reduction in use of irrigation water throughout the Republican Basin would be additional water that could help meet stream flow requirements in the Republican River. Also, by saving irrigation water, irrigators will be able to reduce pumping cost and more water would be available for competing needs including those of wildlife, endangered species, and hydroelectricity plants.

Subsurface drip irrigation (SDI) has the potential of being a more efficient irrigation system compared to systems such as center pivot and furrow irrigation. With SDI, the soil surface is not wetted when irrigating, which greatly reduces water losses by evaporation from the soil surface and eliminates runoff of irrigation water. With proper management, deep percolation can be reduced, so that application efficiency with SDI can be close to 100%.

However, the cost of an SDI system is high. Currently, SDI may not be competitive with a center pivot for irrigating a row crop such as corn on a quarter section (800 m by 800 m) of land, which is a typical irrigation scenario for the western US Great Plains region. Also, rodents are often a problem with SDI (Lamm and Camp, 2007). They chew on the underground drip tape, causing leaks that may be difficult to find and repair. There is no easy solution to solve this problem. Maintaining less crop residue on the field may help – providing a less attractive habitat for the rodents, but this would counteract the water-savings objective of having an SDI system; maintaining more residue has been shown to conserve water (Klocke et al., 2009; Todd et al., 1991; van Donk et al., 2004; van Donk et al., 2008). Nonetheless, with water becoming scarcer, SDI may become more interesting for large-scale row-crop production.

The response of a crop to irrigation is affected by the system (surface, center pivot, SDI) used for irrigation. Past research focus has been mostly on the more common sprinkler and surface irrigation systems (Payero et al., 2005; Payero et al., 2006a, Payero et al., 2006b; Schneekloth et al., 2006). Local information on the response of SDI-irrigated corn is limited. The objective of this study was to determine the effect of the amount and timing of irrigation, using SDI, on corn (*Zea mays*) production.

Methods

The study was conducted in 2007 and 2008 at the University of Nebraska-Lincoln, West Central Research and Extension Center (WCREC) in North Platte, Nebraska (41^o 10’ N, 100^o 45’ W, 861 m elevation above sea level) on a Cozad silt loam (fine-silty, mixed, mesic Fluventic Haplustoll) with an average water content at field capacity of 0.29 $m^3\ m^{-3}$ and at wilting point of 0.11 $m^3\ m^{-3}$ (Klocke et al., 1999). The climate at North Platte is semi-arid, with an average annual precipitation of 508 mm and a reference evapotranspiration of 1403 mm. On average, approximately 80% of the annual precipitation occurs during the growing season, which extends from late April to mid October (USDA, 1978).

The experiment was conducted on a set of plots planted to field corn. Two SDI systems were used. The study used a randomized complete block design and was replicated eight times on the older SDI system (SDI1) and four times on the newer SDI system (SDI2). On SDI1 there were nine treatments to impose different irrigation regimes (Table 1). On SDI2 there were eight treatments, which were essentially the same as the SDI1 treatments, except that the SDI1 treatment B1 was omitted. The rationale for the A and B treatments was to allow no water stress during the critical period of tasseling and silking and to allow different levels of stress before and after this period.

During late spring and summer, precipitation was measured using several rain gauges located at the SDI plots. For the rest of the year precipitation data from a High Plains Regional Climate Center (HPRCC, http://www.hprcc.unl.edu/) weather station, located less than one km from the study site, were used. Measurement of precipitation in the form of snow at this HPRCC station did not seem very reliable. Therefore, for water equivalent data from snow, we used data from the WCREC dryland farm, which is located a few km NW of the SDI plots. Thus, using these three sources, a precipitation record was constructed for the entire two years of 2007 and 2008. Precipitation for the growing season portion of these two years is shown in Figure 1.

Data from the HPRCC weather station were used to obtain daily corn crop evapotranspiration for fully watered conditions (ET_c). The HPRCC algorithm for calculating ET_c uses emergence date and corn maturity as inputs. A corn variety of medium maturity and the actual emergence dates (Table 6) were used to calculate ET_c. During the growing season it was verified that the actual crop growth stage did not differ significantly from the growth stage calculated by the HPRCC algorithm. This ET_c was used to determine the amount of irrigation for the 100% ET treatment. The irrigation amounts for all other treatments were based off of the 100% ET treatment (Tables 2-5).

The SDI1 system applies 25.4 mm (1 inch) of water in approximately 13 hours and the SDI2 system applies this amount in approximately 17.5 hours. We irrigated three times a week unless rain made irrigation unnecessary. For example, there was no irrigation between 7/27 and 8/10/2007 (Tables 2 and 3) because of abundant rain (Figure 1) and low ET_c values. In 2007, the dryland treatment was not exclusively rainfed, because we fertigated all plots, including the dryland plots, at the beginning of the irrigation season, which used some water: 57 mm on SDI1 (Table 2) and 41 mm on SDI2 (Table 3).

The first irrigation of the season was determined by not allowing the mean soil water content of the top 0.9 m (approximately representing the rooting depth at this time) to drop below 0.20 $m^3 m^{-3}$. For our silt loam soil, a soil water content of 0.20 $m^3 m^{-3}$ is halfway between soil water content at field capacity (0.29 $m^3 m^{-3}$) and that at wilting point (0.11 $m^3 m^{-3}$). In other words, half of the available water is depleted at a soil water content of 0.20 $m^3 m^{-3}$. As a general rule, crop water stress can be expected when soil water content falls below this point. In both years, the spring was so wet, that it was not necessary to start irrigation before tasseling. Thus, the crop in the A and B treatments was not subjected to water stress before tasseling as prescribed by the treatments (Table 1).

In SDI 2, soil water content was measured approximately once a week during the growing season in each of the 32 plots at six depths (0.15, 0.46, 0.76, 1.07, 1.37, and 1.68 m) using a neutron probe (CPN Hydroprobe). There was one neutron tube per plot, always located within a row of corn. Corn rows were 0.76 m apart. The drip tape is spaced 1.52 m apart, which is twice the corn row spacing, so two rows of corn ‘drink’ from one drip tape, which is located approximately 0.40 m below the soil surface.

Corn yield was measured on both SDI1 and SDI2. A 3-row plot combine was used to harvest the corn crop. Corn that was harvested in two combine passes (six corn rows) in each plot was used in the yield calculation. Rows on the plot borders were excluded. Grain weight and percent grain moisture were measured and recorded with a combine computer. Yield was standardized (adjusted) to 15.5 % grain moisture content.

Results and discussion

Both 2007 and 2008 were wetter than average years (Figure 1). In both years, the spring and especially the month of May was very wet, which ensured that the soil profile was approximately filled to field capacity with water at the beginning of each growing season. Total season ET_c was 589 mm for 2007 and 623 mm for 2008. The maximum daily ET_c was 10.9 mm in 2007 and 10.7 mm in 2008.

In 2007, there was a rain event of over 40 mm in late July (Figure 1a). The effect of this rain can be seen in the soil water content in all eight irrigation treatments: soil water content increased at several of the measured depths (Figure 2). The corn crop in the dryland treatment started depleting substantial amounts of soil water later in July to a depth of approximately 1.07 m (Figure 2a). In August, the crop also used a significant amount of water from the 1.37 and 1.68 m depths. It is not clear from these data how much of the soil water depletion at these lower depths was direct water uptake by corn roots and how much was soil water redistribution (water moving upwards towards drier soil).

In the second half of July in the dryland treatment, soil water content dropped below 0.20 m^3 m^{-3} (below 50% available soil water depletion) for the first time in the season, although at the deeper depths, it was still well above 0.20 m^3 m^{-3} at this time (Figure 2a). The crop probably experienced some stress at this time, because soil water at these deeper depths is not the most accessible to the crop. In the middle of August, soil water content was well below 0.20 m^3 m^{-3} at all depths, except for the 1.68 m depth, suggesting that the crop most likely experienced water stress at this time.

The corn crop in the 50% ET treatment was likely stressed also during the second part of July since soil water content fell below 0.20 m^3 m^{-3} for the top two measured depths and was exactly at 0.20 m^3 m^{-3} for the 0.76 m depth (Figure 2b). Soil water content at the deeper depths was still above 0.20 m^3 m^{-3}, as it was for the dryland treatment, but that could probably not prevent the crop from experiencing water stress at this time. Crop water stress during this critical period of tasseling and silking (Table 6) is undesirable and can have a serious negative impact on crop yield. At the end of July crop stress was relieved by the 40 mm rain. After this, soil water content decreased again and water stress was likely back by mid August and stayed into September.

Soil water content for the 75% ET treatment (Figure 2c) was somewhat greater than that for the 50% ET treatment (Figure 2b). Thus, from the soil water data, it is expected that the crop on the 50% ET treatment would have been under greater water stress than the crop on the 75% ET treatment. Indeed, the crop yield on the 50% ET treatment was lower than that on the 75% ET treatment (Figure 3b). Soil water content in the 100% ET treatment stayed above 0.20 m^3 m^{-3} for the entire season (Figure 2d), so it is not expected that the crop in this treatment experienced water stress at any time during the growing season. As expected, the 100% ET treatment yielded higher than the 0.75% ET treatment (Figure 3b).

All A and B treatments received full irrigation (the same as the 100% ET treatment) until August 10 (Tables 2 and 3) when pollination was complete and silks were brown (Table 6). The A4 treatment received full irrigation until August 17. After this, in the last three weeks of the irrigation season, it received less than full irrigation, so that at the end of the season it had received 33 mm less than the 100% ET treatment (Table 3). This resulted in a soil water content being somewhat lower towards the end of the season (Figure 2h) than in the full irrigation treatment (Figure 2d), but yields for both treatments were the same at 11.5 Mg ha^{-1} (Figure 3b), so this lower soil water content apparently did not impose water stress on the crop.

The A3 treatment received full irrigation until August 15. After this, it received less than full irrigation, so that at the end of the season it had received 68 mm less than the 100% ET treatment (Table 3). This resulted in a soil water content being lower towards the end of the season (Figure 2g) than in the full irrigation treatment (Figure 2d) and also somewhat lower compared to the A4 treatment (Figure 2h), which may have resulted in some water stress, but yield for the A3 treatment was only a little less (11.2 versus 11.5 Mg ha^{-1}, Figure 3b). Soil water content fell below 0.20 m^3 m^{-3} in the second part of August and in September for the A1 (Figure 2e) and A2 (Figure 2f) treatments, but yields for these treatments were not much less than those for the A3 and A4 treatments (figure 3b), suggesting that some drying out of the soil below 0.20 m^3 m^{-3} towards the end of the growing season has a minimal impact on corn yield.

In 2007, there was a clear response of corn yield to total season irrigation amount on SDI1, from a mean yield of 7.8 Mg ha^{-1} for the DL treatment to 11.1 Mg ha^{-1} for the 100% ET treatment (Figures 3a and 4a). The 100% ET treatment received a total of 253 mm of irrigation water for the season (Table 2). The DL treatment was not truly dryland (rainfed) in 2007, because at the beginning of the irrigation season it received 57 mm of irrigation with fertigation through the SDI system. Corn yield increased steadily with increasing irrigation water in the treatments from B1 (8.7 Mg ha^{-1} with 113 mm of irrigation water) through B5 (10.5 Mg ha^{-1} with 241 mm of irrigation water, Figure 3a).

On SDI2, there was also a clear response to irrigation water when going from DL to full irrigation: yield increased from 8.9 Mg ha^{-1} with a seasonal irrigation total of 41 mm to 11.5 Mg ha^{-1} with an irrigation total of 264 mm (Figure 3b). Because of fertigation, the DL treatment on SDI2 was not truly dryland (rainfed) in 2007 either. There was only a slight yield increase for the A treatments going from 10.9 Mg ha^{-1} with158 mm of irrigation water for the season for A1 to 11.5 Mg ha^{-1} with 231 mm of irrigation water for A5.

Irrigation was not needed before tasseling, so the effect of water stress before tasseling on corn yield could not really be tested in this experiment. A strong linear relationship (r^2 = 0.95 for SDI1 and 0.94 for SDI2) of corn yield as a function of total seasonal irrigation water was found (Figure 4). Yield increase per mm of additional irrigation water was 15 kg ha^{-1} for SDI1 and 12 kg ha^{-1} for SDI2.

In 2008, as in 2007, the soil profile was approximately filled to field capacity with water at the beginning of the growing season (Figure 5). Soil water content in the dryland treatment was also close to field capacity at the beginning of the season (Figure 5a), even though the same dryland plots were well depleted of soil water at the end of the 2007 growing season (Figure 2a).

In 2008, corn in the dryland treatment started depleting substantial amounts of soil water in July to a depth of about 1.07 m (Figure 5a). In August, the crop also used a significant amount of water from the 1.37 and 1.68 m depths. In the middle of July, soil water content dropped below 0.20 m^3 m^{-3} for the first time in the season, but only at the 0.46 m depth. At the other depths, it was still well above 0.20 m^3 m^{-3} at this time, so it is unlikely that the crop experienced water stress. At the beginning of August, soil water content was well below 0.20 m^3 m^{-3} at the 0.46, 0.76, and 1.07 m depths, suggesting that the crop most likely experienced water stress at this time. Soil water content in the 100% ET treatment stayed above 0.20 m^3 m^{-3} for most of the season, as it should to avoid water stress on the crop (Figure 5d). Only in late July did it drop slightly below this level, but only at the 0.46 m depth, so it is not expected that the crop experienced water stress at any time during the growing season.

In 2008, yields were suppressed across the irrigation treatments, especially in SDI1. Amount or timing of irrigation did not have much of an effect on yields, except for the dryland treatment where yield was substantially less than for the other treatments (Figure 6). Reasons for the low yields were not obvious. There was probably not one single culprit, but a number of factors may have played a role. Planting was later than average, because of the wet and cool spring weather and because of some logistical challenges. The corn only emerged in the beginning of June (Table 6). The planting operation itself was not very successful: the planting equipment was not well suited to deal with the heavy no-till residue, especially because on the SDI plots we plant as close as possible to the rows of previous years, so that the drip tape is kept halfway between corn rows as much as possible. Planting on top of the old corn stalks and crowns was a challenge. The result was a corn stand that was not as uniform as desired. Also, a hail storm in July damaged many leaves, although later in the season many more undamaged leaves seemed to take over, but perhaps the hail storm did more damage than we originally thought it would do. A difference with 2007 was that in 2007 we fertigated the crop through the drip tape, whereas in 2008 we did not. The low yields were not unique to our experiment; the majority of the fields at WCREC had low yields, similar to the ones on SDI2.

It is unlikely that the low 2008 yields were caused by water stress: more irrigation water on the 100% ET treatment did not increase yield compared to e.g. the yields on the 75, A1, A2, A3 treatments (Figure 6). Also, soil water content does not indicate crop water stress on the 100% ET treatment (Figure 5d). Only towards the end of July soil water content dropped below 0.20 $m^3\ m^{-3}$ and only for one of the six measured depths.

Conclusions

In 2007, there was a clear response of corn yield to total season irrigation amount on SDI1, from a mean yield of 7.8 Mg ha^{-1} for the DL treatment (a season total of 57 mm of irrigation water) to 11.1 Mg ha^{-1} for the 100% ET treatment (253 mm of irrigation water). Corn yield increased steadily with increasing irrigation water in the treatments from B1 (8.7 Mg ha^{-1} with 113 mm of irrigation water) through B5 (10.5 Mg ha^{-1} with 241 mm of irrigation water).

On SDI2, yield increased from 8.9 Mg ha^{-1} with a seasonal irrigation total of 41 mm to 11.5 Mg ha^{-1} with an irrigation total of 264 mm. There was only a slight yield increase for the A treatments going from 10.9 Mg ha^{-1} with 158 mm of irrigation water for the season for A1 to 11.5 Mg ha-1 with 231 mm of irrigation water for A4. Soil water content fell below 0.20 $m^3\ m^{-3}$ in the second part of August and in September for the A1 and A2 treatments, but yields for these treatments were not much less than those for the A3 and A4 treatments, suggesting that some drying out of the soil below 0.20 $m^3\ m^{-3}$ (below 50% depletion of soil available water) towards the end of the growing season has a minimal impact on corn yield.

Irrigation was not needed before tasseling, so the effect of water stress before tasseling on corn yield could not be tested in this experiment. A strong linear relationship (r^2 = 0.95 for SDI1 and 0.94 for SDI2) of corn yield as a function of total seasonal irrigation water was found. Yield increase per mm of additional irrigation water was 15 kg ha^{-1} for SDI1 and 12 kg ha^{-1} for SDI2.

In 2008, yields were suppressed across the irrigation treatments, especially in SDI1. Amount or timing of irrigation did not have much of an effect on yields, except for the dryland treatment where yield was substantially less than for the other treatments. Reasons for the low yields were not obvious - a number of factors may have played a role.

Acknowledgements

The authors would like to acknowledge the assistance provided by Eugene Richter during the field study.

References

Klocke, N.L., D.G. Watts, J.P. Schneekloth, D.R. Davison, R.W. Todd, and A.M. Parkhurst. 1999. Nitrate leaching in irrigated corn and soybean in a semi-arid climate. Transactions of the ASAE 42(6): 1621-1630.

Klocke, N.L., R.S. Currie, and R.M. Aiken. 2009. Soil water evaporation and crop residues. Transactions of the ASABE 52(1): 103-110.

Lamm, F.R. and C.R. Camp. 2007. Subsurface drip irrigation. Chapter 13 in Microirrigation for Crop Production - Design, Operation and Management. F.R. Lamm, J.E. Ayars, and F.S. Nakayama (Eds.), Elsevier Publications. pp. 473-551.

McGuire, V.L. 2004. Water Level Changes in the High Plains Aquifer, Predevelopment to 2002, 1980-2002, and 2001-2002. Fact Sheet 2004-3026. U.S. Geological Survey, Lincoln, Nebraska.

McGuire, V.L. and B.C. Fischer. 1999. Water Level Changes, 1980-1997 and Saturated Thickness, 1996-97, in the High Plains Aquifer. Fact Sheet 124-99. U.S. Geological Survey, Lincoln, Nebraska.

Payero, J.O., S.R. Melvin, and S. Irmak. 2005. Response of soybean to deficit irrigation in the semi-arid environment of west-central Nebraska. Transactions of the ASABE 48(6): 2189-2203.

Payero, J.O., N.L. Klocke, J.P. Schneekloth, and D.R. Davison. 2006a. Comparison of irrigation strategies for surface-irrigated corn in West Central Nebraska. Irrigation Science 24(4): 257-265.

Payero, J.O., S.R. Melvin, S. Irmak, and D. Tarkalson. 2006b. Yield response of corn to deficit irrigation in a semiarid climate. Agricultural Water Management 84: 101-112.

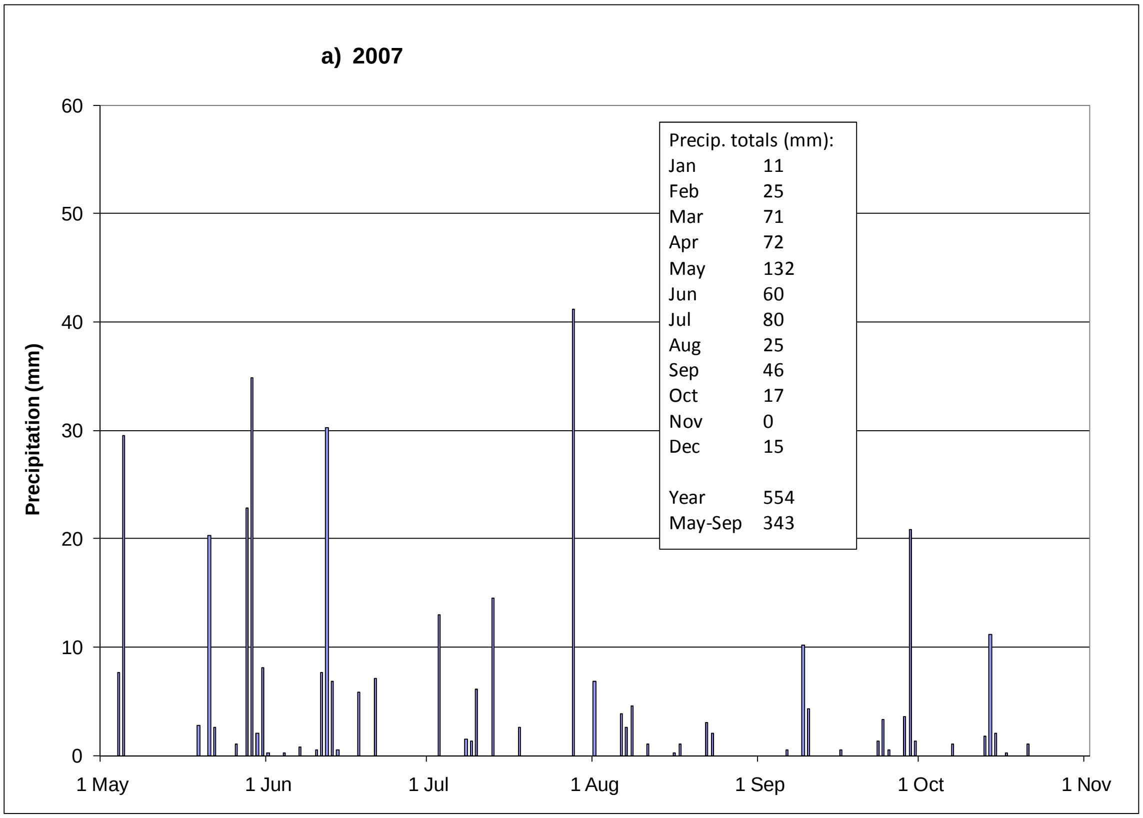
Schneekloth, J.P., N.L. Klocke, D.R. Davison, and J.O. Payero. 2006. Furrow irrigation management with limited water. Applied Engineering in Agriculture 22: 391-398.

Todd, R.W., N.L. Klocke, G.W. Hergert, and A.M. Parkhurst. 1991. Evaporation from soil influenced by crop shading, crop residue, and wetting regime. Transactions of the ASAE 34: 461-466.

USDA. 1978. Soil survey of Lincoln County, Nebraska. A publication of the U.S. Department of Agriculture Soil Conservation Service, in cooperation with University of Nebraska Conservation and Survey Division.

van Donk, S.J., E.W. Tollner, J.L. Steiner, and S.R. Evett. 2004. Soil temperature under a dormant bermudagrass mulch: Simulation and measurement. Transactions of the ASAE 47: 91-98.

van Donk, S.J., D.L. Martin, S. Irmak, S.R. Melvin, and J.L. Petersen. 2008. Effect of crop residue on soil water content and yield of sprinkler-irrigated corn. ASABE Annual International Meeting, Providence, Rhode Island, June 29 - July 2, 2008 (Paper No. 08-4724).


a) 2007
Precipitation (mm)
0
10
20
30
40
50
60
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
Precip. totals (mm):
Jan 11
Feb 25
Mar 71
Apr 72
May 132
Jun 60
Jul 80
Aug 25
Sep 46
Oct 17
Nov 0
Dec 15
Year 554
May-Sep 343

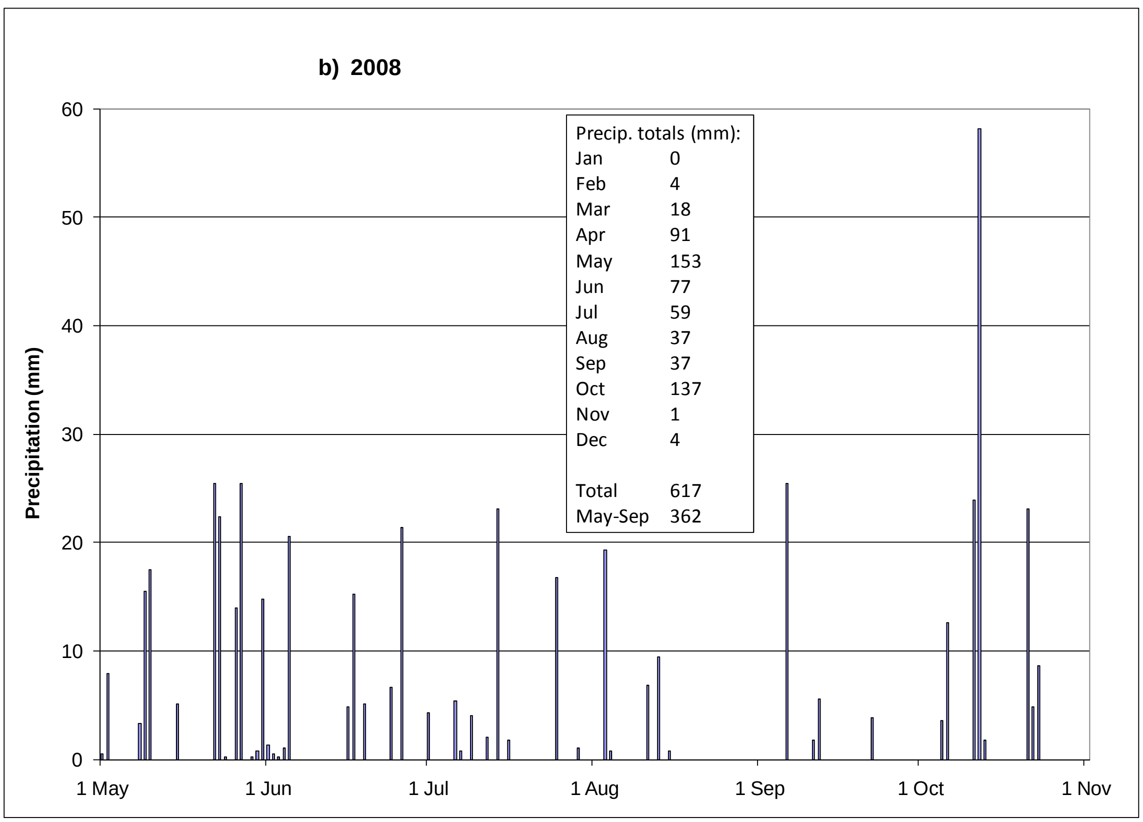

b) 2008
Precipitation (mm)
0
10
20
30
40
50
60
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
Precip. totals (mm):
Jan 0
Feb 4
Mar 18
Apr 91
May 153
Jun 77
Jul 59
Aug 37
Sep 37
Oct 137
Nov 1
Dec 4
Total 617
May-Sep 362

Figure 1. Daily precipitation at the experimental site for 2007 and 2008.

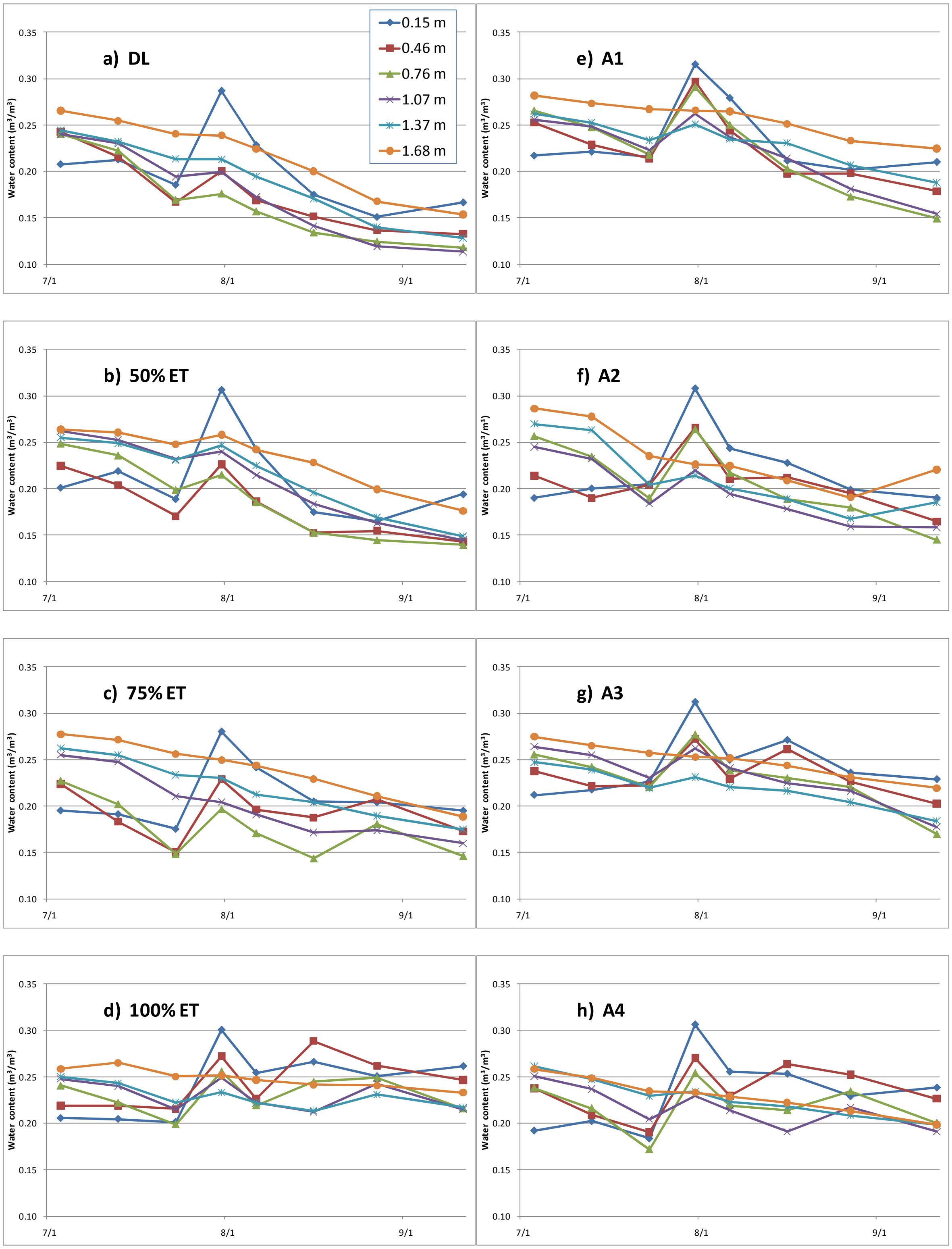
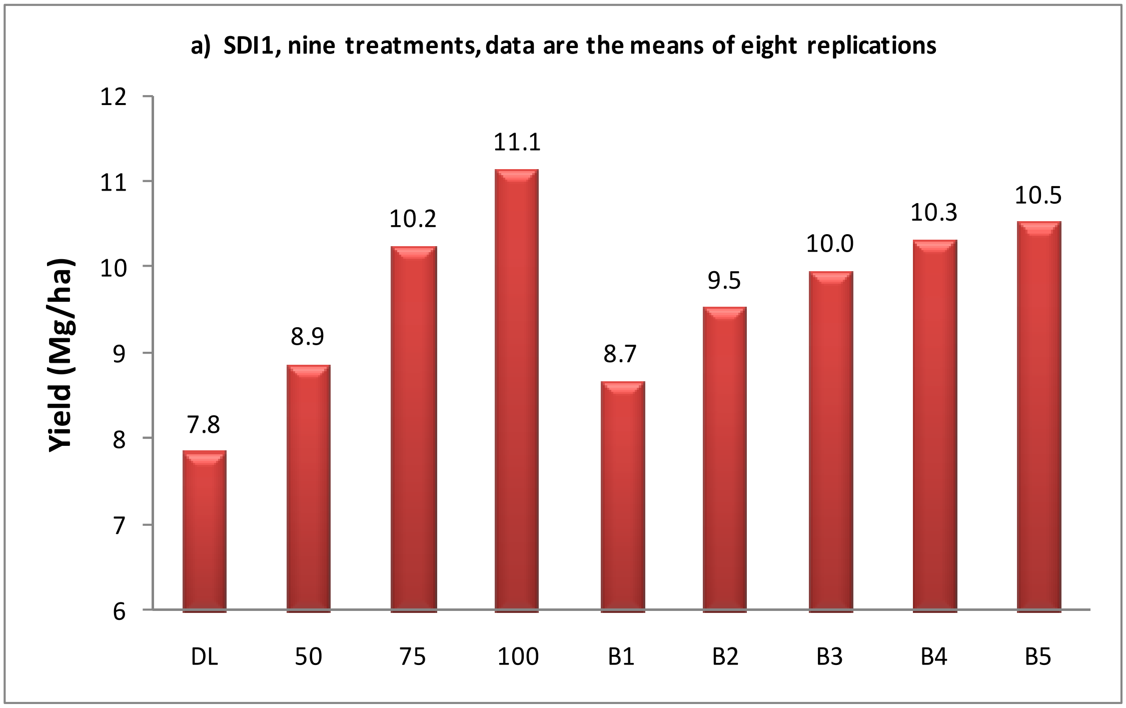

0.15 m
0.46 m
0.76 m
1.07 m
1.37 m
1.68 m
a) DL
b) 50% ET
c) 75% ET
d) 100% ET
e) A1
f) A2
g) A3
h) A4
Water content (m³/m³)
0.35
0.30
0.25
0.20
0.15
0.10
7/1
8/1
9/1

Figure 2. Soil water content at six different soil depths for eight irrigation treatments on SDI2 from July through mid-September 2007. Each data point is the mean of four replications.



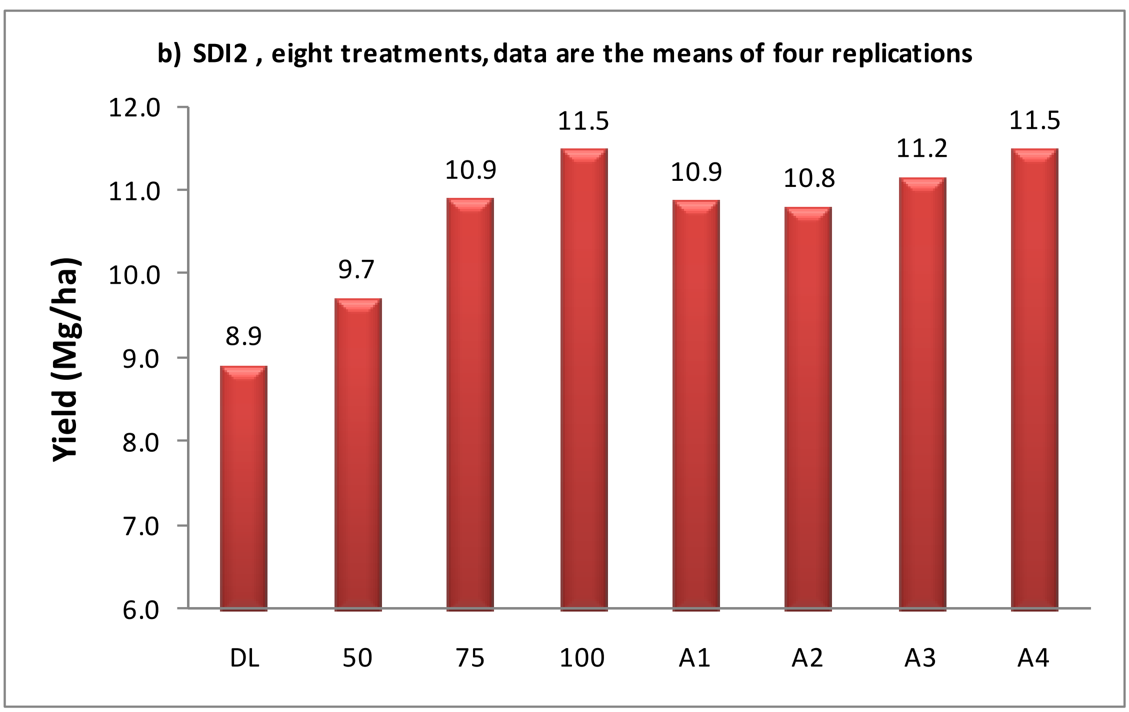
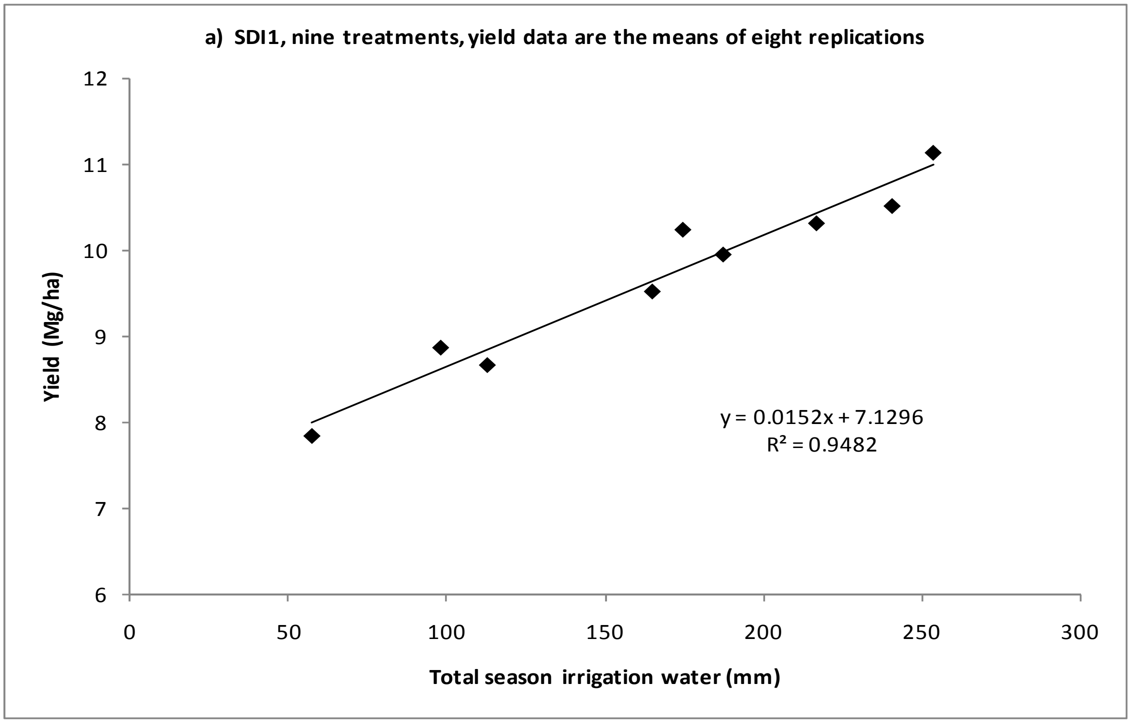


Figure 3. Mean yields for SDI1 and SDI2 in 2007.



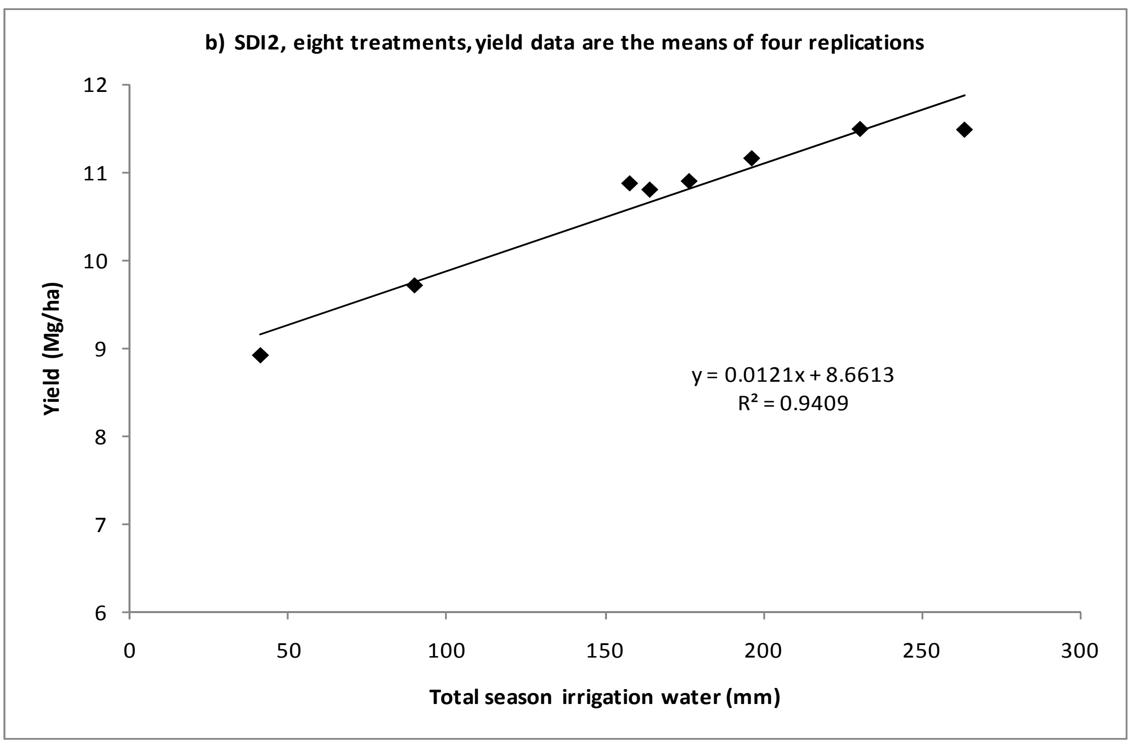


Figure 4. Mean yield versus total season irrigation water for SDI1 and SDI2 in 2007.

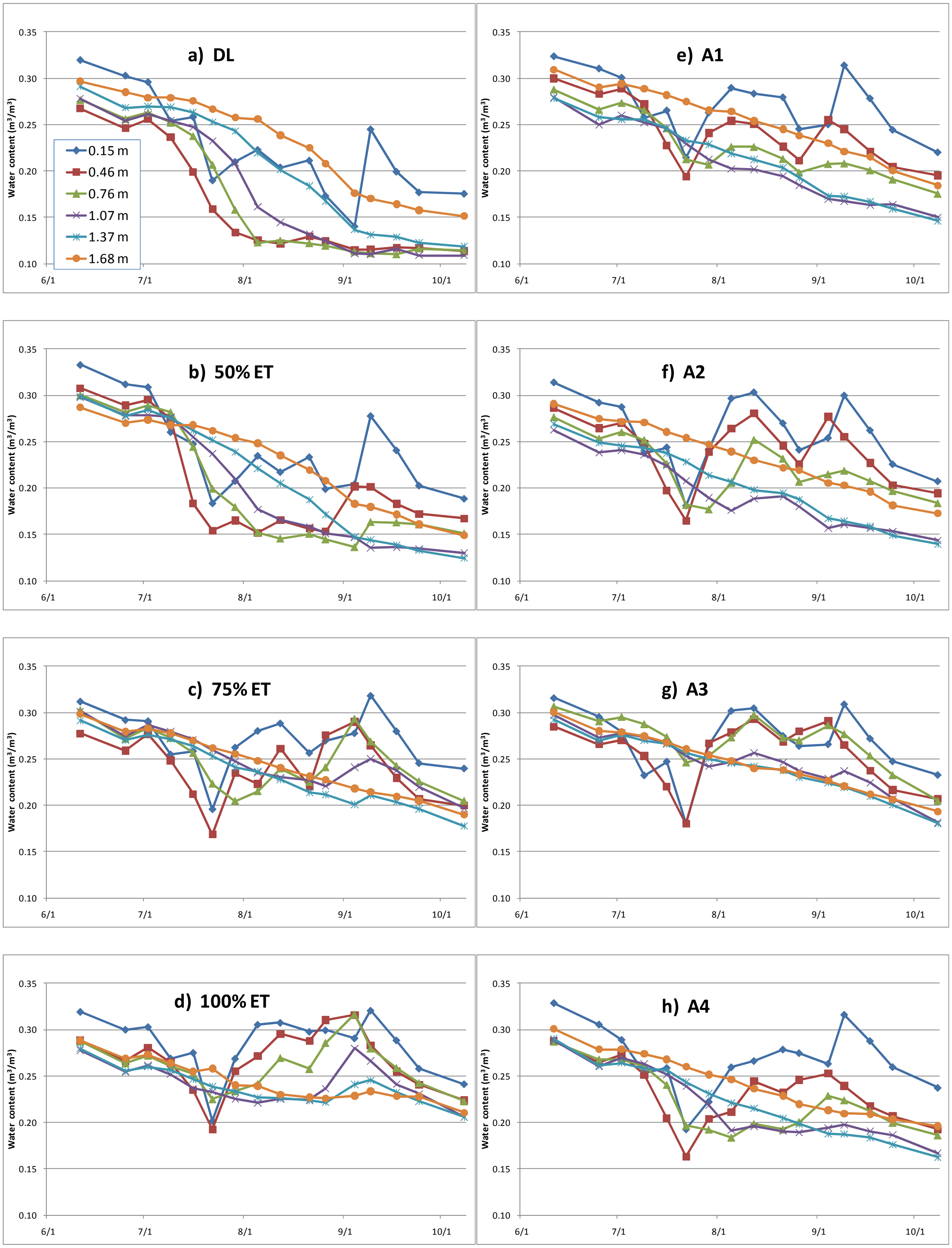
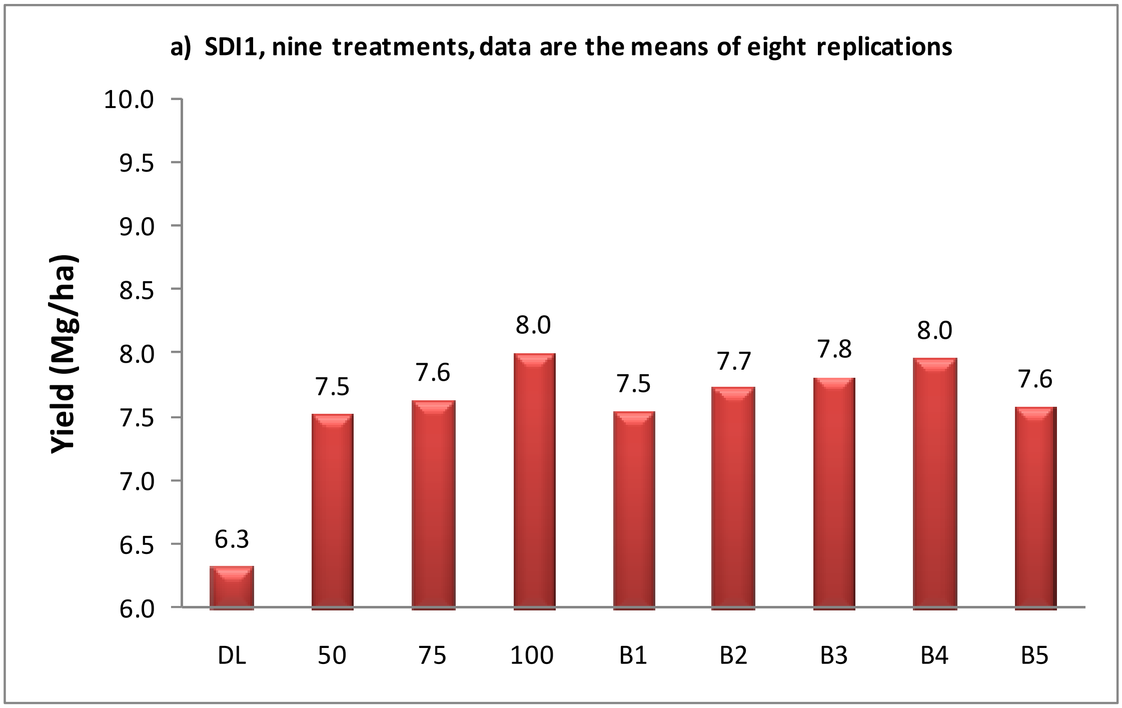


Figure 5. Soil water content at six different soil depths for eight irrigation treatments on SDI2 from June through the beginning of October 2008. Each data point is the mean of four replications.



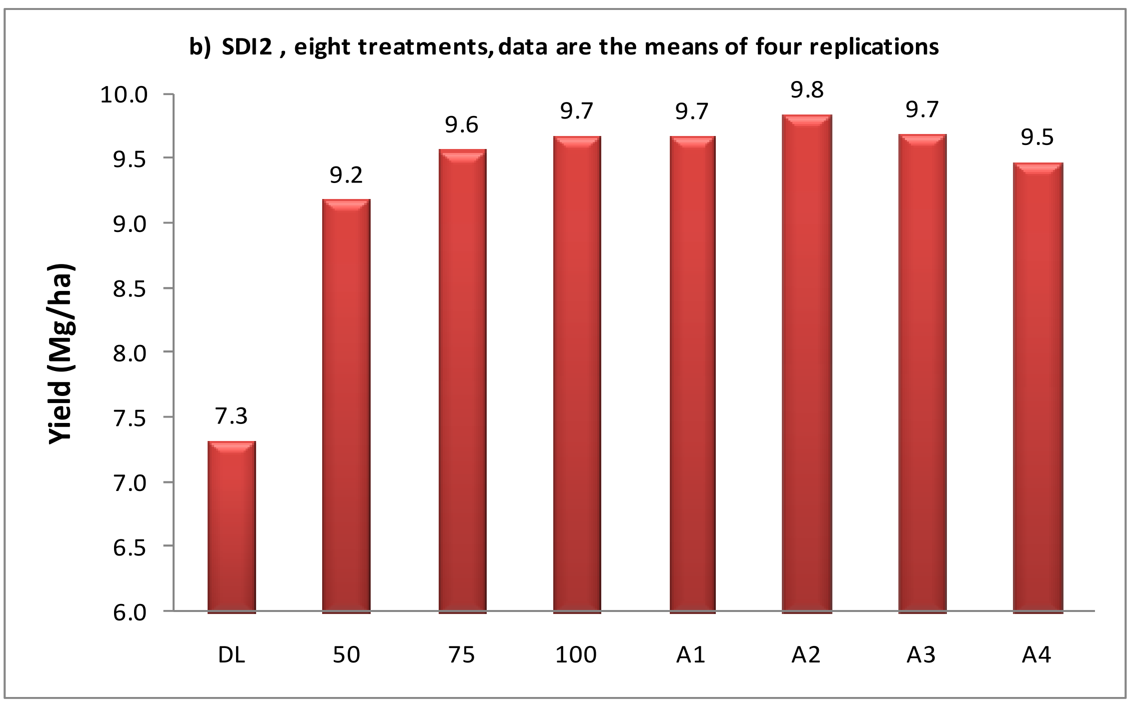


Figure 6. Mean yields for SDI1 and SDI2 in 2008.

Table 1. Irrigation treatments on SDI1 and SDI2 in 2007 and 2008.

SDI1

ID	Description of irrigation treatment
DL	Dryland or rainfed (no irrigation)
50	0.50 ET (meet 50% of evapotranspiration requirements) throughout the growing season
75	As 50, but 0.75 ET
100	As 50, but 1.00 ET (full irrigation)
B1	Start with no irrigation, 1.00 ET during two weeks starting at tasseling, then no more irrigation
B2	Start with 0.50 ET, 1.00 ET during two weeks starting at tasseling, then 0.50 ET
B3	As B2, but three weeks instead of two
B4	As B2, but four weeks instead of two
B5	As B2, but four weeks and 0.75 ET instead of 0.50 ET

nine treatments, eight replications, 72 plots

Plot size: 71.6 m by 9.1 m: 12 rows of corn per plot

SDI2

ID	Description of irrigation treatment
DL	Dryland or rainfed (no irrigation)
50	0.50 ET (meet 50% of evapotranspiration requirements) throughout the growing season
75	As 50, but 0.75 ET
100	As 50, but 1.00 ET (full irrigation)
A1	Start with 0.50 ET, 1.00 ET during two weeks starting at tasseling, then 0.50 ET
A2	As A1, but three weeks instead of two
A3	As A1, but four weeks instead of two
A4	As A1, but four weeks and 0.75 ET instead of 0.50 ET

eight treatments, four replications, 32 plots

Plot size: 38.1 m by 9.1 m: 12 rows of corn per plot

Table 2. Daily water applications on nine irrigation treatments, SDI1, 2007.

date	DL mm	50 mm	75 mm	100 mm	B1 mm	B2 mm	B3 mm	B4 mm	B5 mm
7/6/2007	20	20	19	19	20	20	20	20	20
7/18/2007	22	21	22	22	22	22	22	22	22
7/20/2007	0	0	0	13	13	13	13	13	13
7/23/2007	16	15	18	25	24	24	25	24	24
7/26/2007	0	0	12	16	16	16	16	16	16
7/27/2007	0	1	13	18	18	18	18	18	18
8/10/2007	0	0	0	21	0	0	14	21	21
8/13/2007	0	0	0	22	0	0	8	22	22
8/15/2007	0	0	20	11	0	7	7	11	11
8/17/2007	0	4	14	12	0	6	6	12	12
8/20/2007	0	9	15	20	0	10	10	10	15
8/22/2007	0	8	13	18	0	9	9	9	13
8/27/2007	0	8	12	17	0	9	8	8	19
9/7/2007	0	11	15	20	0	11	11	11	15
Total	**57**	**98**	**174**	**253**	**113**	**165**	**187**	**217**	**241**

Table 3. Daily water applications on eight irrigation treatments, SDI2, 2007.

date	DL mm	50 mm	75 mm	100 mm	A1 mm	A2 mm	A3 mm	A4 mm
7/6/2007	18	18	18	18	18	18	18	18
7/18/2007	11	11	11	11	11	11	11	11
7/20/2007	0	0	10	23	23	23	23	23
7/23/2007	12	12	18	23	23	23	23	23
7/26/2007	0	4	13	17	17	17	17	17
7/27/2007	0	8	13	18	18	18	18	18
8/10/2007	0	0	0	15	0	15	15	15
8/13/2007	0	0	17	24	0	9	24	24
8/15/2007	0	0	12	15	7	0	0	15
8/17/2007	0	3	9	26	6	0	11	12
8/20/2007	0	10	15	20	10	20	10	12
8/22/2007	0	7	19	13	9	0	9	18
8/27/2007	0	7	7	22	8	0	8	9
9/7/2007	0	10	15	20	10	10	10	15
Total	**41**	**90**	**177**	**264**	**158**	**164**	**196**	**231**

Table 4. Daily water applications on nine irrigation treatments, SDI1, 2008.

date	DL mm	50 mm	75 mm	100 mm	B1 mm	B2 mm	B3 mm	B4 mm	B5 mm
7/23/2008	0	7	10	14	15	14	14	14	14
7/25/2008	0	8	11	15	15	15	15	15	15
7/28/2008	0	0	2	6	6	6	6	6	6
7/30/2008	0	3	10	14	14	14	14	14	14
8/1/2008	0	9	14	20	20	20	20	20	20
8/4/2008	0	0	1	8	8	8	8	8	8
8/6/2008	0	0	10	12	0	6	14	12	14
8/8/2008	0	4	6	8	0	4	8	8	8
8/11/2008	0	5	7	9	0	5	9	9	9
8/20/2008	0	0	0	13	0	0	0	7	10
8/22/2008	0	0	12	16	0	0	0	8	12
8/25/2008	0	4	13	17	0	4	4	8	12
8/27/2008	0	8	12	16	0	8	8	8	12
8/29/2008	0	7	11	14	0	7	7	7	11
9/2/2008	0	20	28	39	0	20	20	20	29
Total	**0**	**74**	**147**	**223**	**78**	**131**	**148**	**165**	**194**

Table 5. Daily water applications on eight irrigation treatments, SDI2, 2008.

date	DL mm	50 mm	75 mm	100 mm	A1 mm	A2 mm	A3 mm	A4 mm
7/23/2008	0	7	2	14	15	15	15	15
7/25/2008	0	8	16	16	16	16	16	16
7/28/2008	0	0	6	6	6	6	6	6
7/30/2008	0	2	10	13	14	13	13	13
8/1/2008	0	10	15	20	20	20	20	20
8/4/2008	0	0	1	9	8	7	7	7
8/6/2008	0	0	9	13	6	13	13	13
8/8/2008	0	4	6	8	4	8	8	8
8/11/2008	0	5	7	10	5	9	9	9
8/20/2008	0	0	0	13	0	0	6	9
8/22/2008	0	0	12	15	0	0	8	12
8/25/2008	0	4	12	17	4	4	8	12
8/27/2008	0	8	12	15	8	8	8	12
8/29/2008	0	7	11	14	7	7	7	11
9/2/2008	0	20	29	38	20	20	20	29
Total	**0**	**74**	**149**	**221**	**134**	**147**	**166**	**194**

Table 6. Observed corn growth stages and events

	Growth stage/event
2007	
5/14	Plant corn variety Kaystar 890
5/21	Emergence
7/15	Tasseling
7/31	Fully silked, some pollen
8/6	Pollination complete, silks brown
8/23	Beginning dent
9/12	Past ¾ milk line, but no black layer yet, little liquid in kernels
10/2	Physiological maturity (black layer)
11/6	Harvest SDI1
11/7	Harvest SDI2
2008	
5/21	Plant corn variety Pannar KX 890 Bt
6/1	Emergence
7/29	Tasseling
8/6	Pollination starting
8/20	Milk stage (r3), between blister (r2) and dough (r4)
9/4	Beginning dent
9/24	No black layer yet, close to ½ milk line
10/13	Physiological maturity (black layer)
11/19-20	Harvest SDI2
11/24-25	Harvest SDI1