CONTRIBUTION OF EVAPOTRANSPIRATION REDUCTION DURING SPRINKLER IRRIGATION TO APPLICATION EFFICIENCY

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ABSTRACT

The effect of reduced corn evapotranspiration (ET) during solid-set sprinkler irrigation on application efficiency was analysed on two subplots. During each irrigation event, one subplot was irrigated (*moist* treatment) while the other was not (*dry* treatment). ET (weighing lysimeter) and transpiration (heat balance method) rates were determined at each subplot before, during and after the irrigations. During daytime irrigations, there was a significant decrease in ET (32-55 %) and transpiration (58 %) for the *moist* treatment. After the irrigations (1 to 2 h), ET significantly increased (34 %) and transpiration decreased (20 %). Gross wind drift and evaporation losses (WDEL_g) were found to be 19.3 % of the applied water. Taking into account the ET changes during and after the irrigations, net sprinkler

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evaporation losses (SEL_n) were 14.4 to 17.5 % of the applied water. During night time irrigations, changes in ET and transpiration were almost negligible, and SEL_n were slightly greater than $WDEL_g$ (9.5 % and 8.1 %, respectively, of applied water). SEL_n was mainly function of wind speed. Reduced ET and transpiration during daytime irrigations moderately increased solid-set sprinkler application efficiency.

KEYWORDS

Transpiration, Corn, Sprinkler irrigation, Water losses, Application efficiency

INTRODUCTION

During sprinkler irrigation a fraction of the water emitted by the sprinkler nozzles is evaporated before reaching the soil. These sprinkler evaporation losses (SEL) can be divided in wind drift and evaporation losses ($WDEL$) and interception losses (IL).

$$SEL = WDEL + IL \quad (1)$$

$WDEL$ occur during the trajectory of water droplets from the sprinkler nozzle to the surface being irrigated. Although some of these losses drift out of the irrigated area, it can be assumed that all this water is finally lost to evaporation. IL occur when droplets reaching crop leaves and stems evaporate before reaching the soil surface. These two variables can be expressed in mm or, more commonly, as a percentage of the applied irrigation water.

Several researchers have focused on measuring $WDEL$. Different values and predictive equations have been obtained depending upon factors such as sprinkler spacing, operating pressure, nozzle diameter, and, particularly, meteorological conditions (wind speed, water vapor pressure deficit and temperature). Values of $WDEL$ have been reported in the literature as high as 30 to 50% of the applied water (Playán et al., 2005, and references therein). Regarding IL , the water storage capacity of a crop is a function of its architecture. For corn, this storage capacity has been quantified between 0.4 and 2.7 mm (Norman and Campbell, 1983; Steiner et al., 1983a). With typical solid-set sprinkler irrigation depths ranging between 10 and 50 mm, IL is quantitatively smaller than $WDEL$, particularly for long irrigation events.

1 As a consequence of water lost to evaporation, during sprinkler irrigation crop
2 microclimate is modified: water vapor pressure deficit (VPD) and air temperature
3 decrease (Robinson, 1970; Steiner et al., 1983b; Tolk et al., 1995). The decrease in
4 air temperature could reduce crop heat stress (Tolk et al., 1995; Saadia et al., 1996).
5 The decrease in VPD would result in a certain reduction of the crop transpiration rate
6 (T), leading to the conservation of soil water, which would otherwise be depleted by
7 the crop (Mc Naughton, 1981; Steiner et al., 1983a). The effect of sprinkler irrigation
8 on soil evaporation (E) is not easy to assess *a priori*. The increase in soil water and
9 the presence of ponded water over the soil will result in an increased potential for
10 evaporation. However, the reduction in the evaporative demand of the air will induce
11 a decrease in the evaporation flux. In any case, the contribution of soil evaporation to
12 crop evapotranspiration ($ET = E + T$) in fully developed canopies is low.

13 McNaughton (1981) argued that any reduction in crop ET from a wetted area
14 as compared with a dry area (i.e. an area not being irrigated at the same time but
15 kept in the same conditions, including water availability) can be subtracted from the
16 gross irrigation water losses, resulting in the net irrigation water losses. Burt et al.
17 (1997) presented a classification of all possible sinks of irrigation water as a function
18 of their consumptive and beneficial nature. Sprinkler evaporation losses (including
19 both WDEL and IL) were classified as consumptive, non-beneficial. However,
20 according to McNaughton (1981), the part of SEL replacing crop ET should be
21 regarded as consumptive and beneficial. This leads to the introduction of gross and
22 net sprinkler evaporation losses (SEL_g and SEL_n). Eq. (1) holds for both gross and
23 net losses. Consideration of net evaporation losses instead of gross evaporation
24 losses results in an increase of application efficiency for a given application depth.
25 This should be taken into account when elaborating irrigation schedules.

26 Several studies have analyzed the differences in ET rates between wet and
27 dry surfaces just after irrigation events, but not during the events themselves.
28 McMillan and Burgy (1960), Frost (1963), and Seginer (1967) reported similar ET
29 rates for both wet and dry crops (with non-limiting soil water). Waggoner et al. (1969),
30 during typical summertime conditions in Connecticut (USA), found short-term ET
31 rates of wet corn canopies to be more than double that of dry corn canopies. This
32 difference only lasted for about 15 minutes, after which the ET rates became similar

for both canopies. To our knowledge, the only previous works where ET or transpiration have been measured during a sprinkler irrigation event are those of Frost and Schwalen (1960), Sternberg (1967) and Tolk et al. (1995). Frost and Schwalen (1960), using weighing lysimeters, found that dry-leaf evapotranspiration equaled or exceeded wet-leaf evapotranspiration under similar atmospheric conditions. Sternberg (1967) used weighing lysimeters to study rye grass ET during and after sprinkler irrigation and reported that ET was almost suppressed during irrigation and was decreased by about 33 % after irrigation, as compared with that of a non irrigated lysimeter. Tolk et al. (1995) reported a reduction of transpiration of about 36-41 % during two daytime irrigation events applied to corn using a lateral move sprinkler irrigation system in Texas (USA). Tolk et al. (1995) used an energy balance based method to quantify evaporation rates and net irrigation water depth. What these authors called interception losses were likely reflecting total SEL rather than IL because the energy balance as applied by Tolk et al. (1995) would not allow separating WDEL from IL.

The aim of this work is to quantify gross and net SEL and the reduction in transpiration and evapotranspiration during both daytime and night time solid-set sprinkler irrigation of corn (*Zea mays* L.). The main goal is to study how much of SEL contributed to meet crop water requirements and whether this possible contribution occurred during daytime and night time irrigation events.

MATERIAL AND METHODS

General characteristics of the experiments

Experiments were conducted during 2005 and 2006 at a 2.0 ha field plot located in Montañana (Zaragoza, NE Spain). Geographical coordinates are 41°43' N latitude and 0°49' W longitude, and elevation is 225 m above sea level. Long-term weather records in the area show that mean annual precipitation is 330 mm, average annual temperature is 15 °C and average annual wind speed (2 m above ground) is 2.4 m s⁻¹. Wind direction is variable but the most frequent wind directions are northwest and southeast. Plot soil is classified as Typic Xerofluvent, sandy loam, mixed (calcareous), mesic (Soil Survey Staff, 1999).

The experimental plot was divided in two subplots of 1.0 ha each (Figure 1). Corn (*Zea mays* L.) cv. Pioneer PR34N43 was sown on 26 April, both years. Agronomical practices (fertilization and application of herbicides and insecticides) were the same on both subplots. Emergence was determined by counting the plants at four sampling spots on each subplot at 19 (2005) and 26 (2006) days after sowing (DAS). Emergence was 83,400 (2005) and 80,800 (2006) plants ha⁻¹.

A solid-set sprinkler system was installed at the experimental plot, with a square spacing of 15 m x 15 m (Figure 1). Sprinkler height was 2.2 m while wetted diameter varied between 15.1 to 15.3 mm depending upon irrigation pressure for a specific irrigation event. Sprinklers had two nozzles with diameters of 4.4 and 2.4 mm. Irrigation working pressure (P_a , kPa) was measured every 5 min during each irrigation event with two transducers (model 2200/2600, Gems Basingstoke, Hampshire, UK) placed at one sprinkler of each subplot. Recorded P_a values were used to compute the gross irrigation water depth emitted by sprinklers (I_g , mm) at each irrigation event using the Torricelli equation:

$$I_g = \frac{[0.00035 \cdot \pi \cdot c_d \cdot \sqrt{P_a} \cdot (d_1^2 + d_2^2)] I_t}{S_a} \quad (2)$$

where: c_d , discharge coefficient, 0.98 as determined experimentally; d_1 , large nozzle diameter, 4.4 mm; d_2 , small nozzle diameter, 2.4 mm; I_t , duration of irrigation event, s; P_a working pressure at the sprinkler nozzle; and S_a , surface area irrigated by a sprinkler (15 m x 15 m).

Irrigations were scheduled to meet the crop water requirements, which were computed weekly from reference evapotranspiration (ET_o) estimates, obtained at a standard automatic weather station located at an adjacent plot (grass weather station) using the FAO Penman-Monteith method (Allen et al., 1998), and from crop coefficients derived from relative cumulative degree-days (Martínez-Cob, 2007). Weekly crop water requirements were converted to weekly crop irrigation requirements (IR_w) using the following expression:

$$IR_w = \frac{ET_c - P_{ef}}{(1 - LF) EF_{apl}} \quad (3)$$

1 where: P_{ef} , effective precipitation (mm) estimated as 75 % of recorded precipitation;
2 LF, leaching fraction estimated as 0.15 during May, 0.1 during June and 0.05
3 afterwards; and EF_{apl} , water application efficiency estimated as 0.85.

4 Short and frequent irrigations were applied during the initial crop stages (May)
5 to favoring crop establishment. Later, the weekly crop irrigation requirements were
6 applied in three (rarely two) weekly irrigation events for each subplot. The duration of
7 the irrigation events was generally limited to 3 hours to avoid soil flooding. The
8 applied irrigation water depth in each irrigation event was the same at each subplot,
9 but irrigations were not simultaneous (Table 1). Generally, at the beginning and end
10 of the week, subplot A was irrigated on daytime periods and subplot B was irrigated
11 on night time periods the following day. At the middle of the week, subplot A was
12 irrigated on night time periods and subplot B on daytime periods the same day. Thus,
13 two irrigation treatments were considered: a) *moist* treatment; and b) *dry* treatment.
14 At each irrigation event, the subplot being irrigated was considered the *moist*
15 treatment, while the other subplot was considered the *dry* treatment. Each subplot
16 was considered alternatively under both irrigation treatments (Table 1). Most of the
17 daytime irrigations started at 13:00 to 14:30 Greenwich Meridian Time (GMT), while
18 most of the night time irrigations started at 2:00 to 3:30 GMT.

19 Water loss calculation

20 On 5 July (70 DAS) in 2005 and 1 June (36 DAS) in 2006, a matrix of 25
21 plastic catch cans (at a spacing of 3 m x 3 m) was arranged within four sprinklers at
22 each subplot (Figure 1) to measure gross wind drift and evaporation losses ($WDEL_g$)
23 as described by Playán et al. (2005). Catch cans were conical in its lower part and
24 cylindrical in its upper part. The lengths of these parts were 145 and 200 mm in 2005
25 and 2006, respectively, for the lower part, and 30 and 100 mm in 2005 and 2006,
26 respectively, for the upper part. The diameter of the upper part was 79 and 160 mm
27 in 2005 and 2006, respectively. The catch cans were marked in mm for direct
28 readout up to 40 and 45 mm in 2005 and 2006, respectively. Catch cans were placed
29 just above the crop canopy: they were moved up as the crop grew along the season.
30 Maximum catch can height was about 2.5 m, the maximum height reached by crop.
31 Just after each irrigation event the water depth collected in each catch can was
32 manually read and the average catch can collected water depth (l_{cc} , mm) was

calculated. These measurements were not taken during weekend irrigation events or when fertilizer or herbicides were applied during the irrigation. Then, $WDEL_g$, expressed in mm, was determined as:

$$WDEL_g = I_g - I_{cc} \quad (4)$$

and $WDEL_g$, expressed in percentage, was determined as:

$$WDEL_g = \frac{(I_g - I_{cc})}{I_g} 100 \quad (5)$$

A sap flow measurement system (Dynamax, Houston, Texas, USA) was installed in each subplot on 13 July (78 DAS) in 2005 and 30 June (65 DAS) in 2006 (Figure 1). Each system had a data logger and four sap gauges SGB19, appropriate for stems of 18-23 mm in diameter. Sap gauges were installed following Van Bavel (2005) at four representative corn plants in each subplot. They were removed and installed in other selected plants on 20 July, 3 and 17 August in 2005, and 14 and 28 July in 2006, to avoid damaging stems. The sap flow measurements allowed the calculation of corn transpiration rates based on the heat balance method (Baker and Van Bavel, 1987; Weibel and Boersma, 1995; Van Bavel, 2005). Transpiration rates ($g\ h^{-1}$) were determined for every plant every 15 min in 2005 and 20 min in 2006. At each subplot, the transpiration rates of the four plants were averaged to obtain 15-min (or 20-min) transpiration rates in $mm\ h^{-1}$ considering the corresponding measured average plant densities. Later, these values were composite into 1 h averages for the 2 h before and the 3 h after each irrigation event. Likewise, the average transpiration rate was calculated during the irrigation events for the whole duration at both subplots. The difference between transpiration rates at the *dry* (T_{DT}) and the *moist* (T_{MT}) treatments during the irrigation event would represent the contribution of WDEL to crop transpiration.

A weighing lysimeter was located at the centre of each subplot (Figure 1). Each lysimeter had an effective surface area of $6.26\ m^2$ ($2.72\ m \times 2.30\ m$) and a depth of 1.7 m. Both lysimeters were made of stainless steel with a thickness of 6 mm. A more detailed description of the lysimeters is presented in Martínez-Cob (2001). Lysimeters recorded 5-min evapotranspiration (ET) rates that were composite into 1-h totals from the 2 h before to the 3 h after each irrigation event. During the

irrigation event itself, 5-min ET rates recorded at the *dry* treatment lysimeter (ET_{DT}) were summed up and later transformed to $mm\ h^{-1}$. However, it was not possible to measure ET rates at the *moist* treatment lysimeter (ET_{MT}) due to its gain of mass because of the applied irrigation water. Thus, the (ET_{MT}) rates were indirectly determined as:

$$ET_{MT_di} = T_{MT_di} + (ET_{MT} - T_{MT})_{ai} \quad (6)$$

where: ET_{MT_di} and T_{MT_di} , estimated ET and measured transpiration rates at the *moist* treatment during the irrigation event itself; and $(ET_{MT} - T_{MT})_{ai}$, difference between measured ET and transpiration rates at the *moist* treatment after the irrigation event. All terms of Eq. (6) are expressed in $mm\ h^{-1}$. To apply Eq. (6), only ET_{MT} and T_{MT} rates during 1 h after the irrigation event were considered. This estimation of ET in the *moist* treatment is based on the assumptions that: a) evaporation rates during the irrigation event and during 1 h after the irrigation event are similar; this assumption would be supported to some extent by the fact that average pan evaporation estimated from ET_o estimates at the weather grass station during the daytime irrigation events included in this study ($0.83\ mm\ h^{-1}$) was quite similar to average pan evaporation estimated for 1 h after those irrigations ($0.84\ mm\ h^{-1}$); b) most evaporation would be due to intercepted water by plants and soil surface; and c) soil evaporation was negligible during the experiment since corn was effectively covering the ground. In this study, the above mentioned assumptions (particularly the first one) and thus the estimated ET_{MT_di} values should be taken as rough approximations of the true ET_{MT} rates during the irrigation event itself. This is particularly true since the time span from the beginning of the irrigation event to the end of the 1 h period after the irrigation was limited to 4 h. For irrigations lasting more time, the first assumption mentioned above may not be adequate. Likewise, the assumption of similarity of evaporation rates at the beginning and after the night time irrigation events would be more questionable because most of these events ended near sunrise. However, to support to some extent the above assumptions, it could be expected that evaporation rates of intercepted water during the irrigation event would generally be lower than after the irrigation. This is due to the sharp decrease of VPD observed, leading to a lower water vapor gradient between the evaporating surface and the atmosphere layer next to it.

Only in 2005, a second approach was used to determine ET rates at the *moist* treatment during the irrigation events (ET_{MT_di}):

$$ET_{MT_di} = \frac{I_{lcc} - I_{lys}}{t} \quad (7)$$

where: I_{lcc} , water depth applied to the lysimeter during the irrigation event, mm; I_{lys} , water depth recorded at the lysimeter during the irrigation event, mm; t , duration of the irrigation event, h. I_{lcc} was determined as the average water depth collected in 16 catch cans, similar to those used in 2005 for measurement of $WDEL_g$, located just around the lysimeter since 2 June (37 DAS). The I_{lys} was determined as the gain in mass by the lysimeter during the irrigation event divided by its effective surface area (Martínez-Cob, 2001). Uncertainty of Eq. (7) arises from the different resolution of the catch cans and the lysimeter, about 0.5 and 0.05 mm, respectively. Eq. (7) was only used for the irrigation events in which $WDEL_g$ were also measured.

In this work, it was hypothesized that the difference between ET_{DT} and ET_{MT} during the irrigation event (di) can only respond to the contribution of $WDEL$ to crop ET following McNaughton (1981). Therefore:

$$WDEL_n = WDEL_g - (ET_{DT} - ET_{MT})_{di} \quad (8)$$

At the end of the irrigation event, the plants in the *moist* treatment lysimeter are covered by the gross crop interception losses. After the irrigation event (ai), and during the time it takes for this water to evaporate, the following equation holds:

$$IL_n = (ET_{MT} - ET_{DT})_{ai} \quad (9)$$

Consequently, the differences between ET recorded at the *moist* and *dry* treatment lysimeters after irrigation were used to determine the net interception water losses at each irrigation event. Please note that the procedures used in this research did not permit to determine IL_g . The net interception losses (IL_n) would be the result of IL_g and the transpiration reduction after the irrigation event. Values of $WDEL_n$ and IL_n were used to determine SEL_n applying Eq. (1).

Eq. (1), and Eqs. (4) to (9) were only applied on the periods of July and August (2005 and 2006) for which the sap flow measurement device was in operation. Therefore, these equations were not applied to the irrigation events of May and June.

Prediction of net sprinkler evaporation losses

Several multiple linear regressions were tested using a backward stepwise regression procedure to develop a predictive equation for SEL_n , ET reduction and IL_n (all expressed in $mm\ h^{-1}$) as a function of several meteorological variables: vapor pressure deficit (VPD), wind speed (U), solar radiation (R_{sol}), and air temperature (T_{air}). Values of SEL_n , estimated when ET_{MT_di} was calculated using Eq. (6), were used for the regression. These values were expressed in $mm\ h^{-1}$ to avoid problems of serial autocorrelation in the residuals, problems that were observed when performing the regressions using SEL_n expressed as percent of applied water. The meteorological variables used were averages of recorded values at the grass weather station for the irrigation events listed in Tables 7 and 8.

RESULTS AND DISCUSSION

General characteristics of the experiments

There were some differences between the meteorological conditions of both years (Table 2). During the studied period, the air temperature in 2006 was greater than in 2005, particularly during night time irrigation events. Thus, the cumulative degree-days necessary for crop physiological maturity was reached earlier in 2006 (September 17) than in 2005 (September 27). Average solar radiation and ET_o were greater in 2006 for the daytime irrigation events. Wind speed was slightly greater in 2005 than in 2006, particularly during daytime irrigation events. Vapor pressure deficit was greater in 2005 for the daytime irrigation events and in 2006 for the night time irrigation events (Table 2). $WDEL_g$ are highly affected by meteorological conditions, particularly wind speed and vapor pressure deficit (Playán et al., 2005, and references therein). The observed differences in meteorological conditions during the irrigation events could explain some of the differences found for $WDEL_g$ between 2005 and 2006.

During the whole irrigation season, 736 and 688 mm in 2005 and 2006, respectively, of irrigation water were applied to subplot A. For subplot B, these figures were 778 and 708 mm in 2005 and 2006, respectively. The small difference between subplots was due to a slight difference in the operating pressure recorded at

the two subplots. The number of irrigation hours was very close, 91.7 and 92.7 h in 2005 and 2006, respectively, in subplot A, and 91.8 and 93.3 h in 2005 and 2006, respectively, in subplot B.

The general characteristics of the daytime and night time irrigation events during the recording periods of sap flow measurements are listed in Tables 3 and 4, respectively. Both transpiration and evapotranspiration rates were available before (2 h), during and after (3 h) for almost every irrigation event. $WDEL_g$ were available in a lower number of irrigation events, since the water collected in the catch cans was not measured during the weekend irrigations or during the irrigations in which fertilizer and pesticides were applied.

For the daytime irrigation events listed in Table 3, subplots A and B were the *moist* treatment 19 and 9 times, respectively. Average duration of these daytime irrigation events was 2.7 h, and average irrigation pressure was 348 kPa (CV=12.0 %). In average, 8.1 mm h^{-1} were applied at each irrigation event (CV=6.1 %). For the night time irrigation events, subplots A and B were the *moist* treatment 11 and 13 times, respectively. Average duration of these night time irrigation events was 2.6 h, and average irrigation pressure was 349 kPa (CV=14.6 %). In average, 8.1 mm h^{-1} were applied at each irrigation event (CV=7.6 %).

Sprinkler irrigation effects on crop transpiration

The time evolution of 15 or 20 min transpiration rates recorded from 2 h before and until 3 h after two daytime and two night time irrigation events is shown in Figure 2. These results are representative of those observed in the rest of irrigation events. Error bars representing the corresponding standard deviations are also depicted in Figure 2 to show the variability of the measurements. During daytime irrigation events, transpiration rates before irrigation were similar in both treatments. As soon as irrigation started, the transpiration rate of the *moist* treatment sharply decreased and this low transpiration rate continued up to the end of the irrigation event. Once the irrigation event finished, the transpiration rate of the *moist* treatment progressively increased until matching that of the *dry* treatment. In 65 % of the irrigation events the matching occurred in the following hour to the end of irrigation. Only in 5 % of the irrigation events the matching of transpiration rates was delayed until 2 h after the end of the irrigation. Tolk et al. (1995) reported negligible changes

1 of corn transpiration rates during two irrigation events under a low energy precision
2 application (LEPA) irrigation system, but a high reduction of transpiration rates during
3 other two irrigation events under a lateral move (impact sprinklers) irrigation system.
4 For these latter irrigation events, Tolk et al. (1995) reported a longer duration of the
5 recovery time of transpiration rates than observed in this study. This difference could
6 be due to the differences in irrigated area and in irrigation system between both
7 research works.

8 During night time irrigation events, differences between the *moist* and the *dry*
9 treatments were not relevant. Even if the transpiration rate of the *moist* treatment
10 also decreased during night time irrigation (Figure 2) compared with the *dry*
11 treatment, this decrease was quite small, likely due to the almost null transpiration
12 rates typical of night time periods. Moreover, measurement errors of the sap flow
13 equipment used in this work usually become more important under these conditions
14 (Van Bavel, 2005). Consequently, the recovery of the transpiration rates after night
15 time irrigation could not be properly appreciated.

16 In both daytime and night time irrigations there was a certain delay between
17 the beginning of the irrigation and the decrease in transpiration. This delay seems to
18 be related to the time required to modify the conditions of the canopy and the
19 surrounding air after the beginning of the irrigation event. A similar delay occurred
20 after the end of the irrigation event.

21 The average corn transpiration rates before (1-2 h), during, and after (1-3 h)
22 each daytime sprinkler irrigation event are shown in Figure 3 for the *moist* and the
23 *dry* treatments. There were not significant differences ($\alpha = 0.95$) between treatments
24 before irrigation started (Table 5). However, during the irrigation event itself,
25 transpiration rates at the *moist* treatment were significantly ($\alpha = 0.95$) lower than
26 those at the *dry* treatment (Figure 3, Table 5). Average total transpiration at the *moist*
27 treatment during irrigation events was 0.86 mm, about 58 % lower than average total
28 transpiration at the *dry* treatment, 2.03 mm. This transpiration reduction during
29 irrigation was similar to that reported by Tolk et al. (1995) after analyzing two daytime
30 corn irrigation events in Texas using a lateral move sprinkler irrigation system. Both
31 sources of experimental data show that transpiration is highly but not completely
32 reduced during irrigation, as predicted by simulation models in previous works

(Thompson et al., 1993). After daytime irrigation events, there were significant differences ($\alpha = 0.95$) between both treatments only during the first hour (Figure 3, Table 5). Average total transpiration at the *moist* treatment 1 h after irrigation was 0.48 mm, about 20 % lower than that observed at the *dry* treatment, 0.60 mm. These figures were also similar to those reported by Tolk et al. (1995) after irrigation.

In general, during the nighttime irrigation events results were qualitatively similar to those observed during daytime irrigation events (Table 5). However, differences between treatments were quantitatively much lower. Thus, during nighttime irrigation, average total transpiration at the *moist* treatment was 73 % lower than that at the *dry* treatment, but in both treatments transpiration rates were almost negligible, 0.04 versus 0.15 mm. After irrigation, differences between both treatments were significant during two hours. The accuracy of transpiration rates using sap gages based on the heat balance method decreases when transpiration approaches zero (Van Bavel, 2005). In such conditions, the assumption of null heat storage at the stem tissues is somewhat questionable (Baker and Nieber, 1989; Groot and King, 1992; Grimes et al., 1995; Weibel and Boersma, 1995). Thus, the results listed in Table 5 for nighttime irrigation events should be taken with caution.

Sprinkler irrigation effects on crop evapotranspiration

Transpiration rates were measured in this work when the crop was at full cover. At this stage, transpiration is the main component of evapotranspiration (ET) and soil evaporation is generally low. Thus, the reduction of transpiration during sprinkler irrigation should also imply a subsequent reduction of ET rates.

The average corn ET rates, before (1-2 h), during (using Eq. (6)), and after (1-3 h) each daytime sprinkler irrigation event are shown in Figure 4 for the *moist* and the *dry* treatments. As observed for transpiration, there were not significant differences ($\alpha = 0.95$) in ET rates between the two treatments before irrigation started (Table 6). However, during the irrigation events, ET rates at the *moist* treatment were significantly lower than those at the *dry* treatment (Figure 4, Table 6). The *moist* ET rates were not negligible, opposite to that reported by Sternberg (1967). During the irrigation events, the average total ET at the *moist* treatment was 1.35 mm, which was about 32 % lower than the average total ET at the *dry* treatment, 1.99 mm. This

1 reduction of ET during irrigation was 50 % lower than that observed for transpiration
2 (Table 5). During the irrigation event, some of the water intercepted by the plants can
3 evaporate, which could explain the difference found between the reduction of both
4 variables (ET and T) in the *moist* treatment.

5 In 2005, the average total ET at the *moist* treatment for the daytime irrigation
6 events for which Eq. (7) was applied was 0.80 mm, about 55 % lower than the
7 average total ET at the *dry* treatment, 1.81 mm. Calculation with Eq. (6) for those
8 daytime irrigation events led to an average total ET at the *moist* treatment of 1.23
9 mm, about 32 % less than that average at the *dry* treatment. Then, the two
10 approaches, Eqs. (6) and (7), led to different values of ET at the *moist* treatment
11 during the irrigation. The reasons for this discrepancy are related with the uncertainty
12 of Eq. (7) due to the different resolution of the catch cans and the lysimeter, and with
13 the assumptions of Eq. (6), particularly the similarity of evaporation rates during the
14 irrigation events and during the first hour after the irrigation. During the irrigation
15 event the reduction of vapor pressure deficit is much greater than immediately
16 afterwards (Tolk et al., 1995). As a consequence, the evaporation rate of intercepted
17 water during the irrigation event should be lower than after the irrigation event.
18 Therefore, the *true* ET rates during the irrigation at the *moist* treatment should be
19 expected to be within those computed with Eqs. (6) and (7). In other words, the
20 results of this work have shown that sprinkler irrigation reduced the ET during the
21 daytime irrigation events in a range of 32 to 55 %.

22 Contrary to what was observed during the irrigation event, ET was significantly
23 ($\alpha = 0.95$) greater for the *moist* treatment during the following 2 h after the irrigation
24 event (Figure 4, Table 6). It should be noted that the average difference for the 2h-
25 after-irrigation case, although significant (Table 6), was close to the sensitivity of the
26 lysimeter (Martínez-Cob, 2001). Average total ET at the *moist* treatment 1 and 2 h
27 after irrigation was about 35 % and 21 % greater, respectively, than the
28 corresponding average total ET at the *dry* treatment. In 32 % of the daytime irrigation
29 events, the ET was similar for both treatments within 40 minutes after the end of the
30 irrigation. This percent was 64 % within the first hour after the irrigation. Only in 19 %
31 of the irrigation events, there was some difference in ET between treatments after
32 100 minutes since the end of irrigation. Greater ET for the *moist* treatment during 1-2

h after irrigation reflects the balance between increased evaporation due to interception losses (IL_n) and reduced transpiration for a short period just after irrigation. Other authors have also reported increased ET rates after irrigation for the *moist* treatment, although this difference only lasted for a shorter period of time (Waggoner et al., 1969; Tolk et al., 1995).

In general, during the nighttime the results were qualitatively similar to those observed during daytime irrigation events although quantitatively smaller (Table 6). During the irrigation itself, average total ET at the *moist* treatment was greater than at the *dry* treatment. During the nighttime irrigation, the microclimatic changes, reduction of air temperature and vapor pressure deficit (data not shown) and the reduction of transpiration rates (Table 5), were relatively small. Thus, this transpiration reduction would not compensate the increase of evaporation of intercepted water in the crop canopy which led to greater ET rates at the *moist* treatment during nighttime irrigation events. After irrigation, differences between both treatments were significant for the 2 h period but not for the 1 and 3 h periods (Table 6). However, these differences were small and within the sensitivity of the lysimeter, so they should be considered negligible.

The results observed in this study for ET are different than those reported by Sternberg (1967). This author reported that ET during the irrigation in the moist treatment was almost completely suppressed and that ET after the irrigation was lower at the *moist* treatment. Sternberg (1967) assumed that ET was almost suppressed as the difference between water depth collected in a semicircular trough surrounding the lysimeter and the net weight gain of the lysimeter was almost zero. For his study, Sternberg (1967) compared total ET about 7-8 h after the irrigation in both treatments, while in this study the comparison was limited to 3 h after the irrigation. Likewise, Sternberg (1967) reported that ET prior to irrigation was greater at the non irrigated lysimeter, likely due to the instrumentation placed surrounding the irrigated lysimeter to catch the applied water. This author always used the same lysimeter as moist treatment for the corresponding comparisons. So the combined effects of these factors would explain the differences between his study and ours. In addition, this study has shown that ET is not completely suppressed during the

irrigation because the measured transpiration, the main component of ET, decreased but not cancelled out (Table 5, Figures 2 and 3).

The reduction of ET during the irrigation event found in our study agrees with that reported by Frost and Schwalen (1960). However, in our study the reduction in ET ranged from 32 % to 55%, while Frost and Schwalen only reported a reduction lower than 20%. The difference of crop height between corn and the short crops used by Frost and Schwalen (1960) could partially explain the differences.

Determination of net sprinkler evaporation losses

A balance of sprinkler evaporation losses was calculated for the irrigation events for which $WDEL_g$, ET and transpiration measurements were available (Table 7). For daytime irrigation events, computed $WDEL_n$ were smaller than $WDEL_g$ as the difference $ET_{DT}-ET_{MT}$ was greater than 0 (Table 6). However, for night time irrigation events, the opposite occurred. To estimate IL_n for daytime and night time irrigation events, Eq. (9) was applied for the 2 h period after the irrigation. For night time irrigation events, IL_n could have been considered as negligible (as previously discussed). However, in order to be consistent with the calculations performed for daytime periods, it was decided to account for IL_n even for the two hours period after the end of the irrigation. Finally, the sprinkler evaporation losses (SEL) were determined using Eq. (1).

During the daytime irrigation events (both years) used for the balance, 343 mm of gross irrigation water (I_g) were applied (Table 7). Measured $WDEL_g$ added up to 66.2 mm, 19.3 % of total applied water. As previously discussed, $WDEL_g$ partially satisfy crop water requirements due to the reduction of ET during irrigation ($ET_{DT}-ET_{MT}$). This reduction amounted to a total of 9.7 mm, 2.8 % of applied water. Thus, if this ET reduction is subtracted from $WDEL_g$, it results in $WDEL_n$ of 56.5 mm, 16.4 % of applied water. Net interception losses during 2 h after irrigation (3.6 mm, 1.0 % of applied water) must be added to $WDEL_n$, resulting in total net sprinkler evaporation losses (SEL_n) of 60.1 mm, 17.5 % of applied water when using Eq. (6) for estimation of ET_{MT_di} . Thus, SEL_n was 6.1 mm less than $WDEL_g$, i.e. SEL_n was 9.2 % less than $WDEL_g$ for the daytime irrigation events of both years. This difference between $WDEL_g$ and SEL_n should be considered as moderate as it only represented 1.8 % of applied water. Net interception losses after the irrigation were quite small. This result

1 is expected for herbaceous crops in which the ratio of canopy to aerodynamic
2 resistances is also low, so that the reduction of transpiration almost cancels out the
3 increased evaporation of intercepted water (Monteith, 1981; Steiner et al., 1983a).
4 Interception losses depend more on crop architecture than on microclimatic changes
5 during the irrigation (Norman and Campbell, 1983; Steiner et al., 1983a).

6 Would the $WDEL_n$ for the daytime irrigations of 2005 listed in Table 7 have
7 been computed using the ET_{MT_di} values determined by Eq. (7), the estimated SEL_n
8 would have been 30.0 mm (14.4 % of applied water). $WDEL_g$ for daytime irrigation
9 events in 2005 was 37.8 mm (18.2 % of applied water). Then, SEL_n would have been
10 7.8 mm less than $WDEL_g$, i.e. SEL_n would have been 20.6 % less than $WDEL_g$. SEL_n
11 for daytime irrigation events in 2005 when using Eq. (6) to compute ET_{MT_di} was 33.7
12 mm (16.2 % of applied water), 4.1 mm (10.8 %) less than $WDEL_g$ (Table 7). Thus,
13 during the daytime irrigation events in 2005, the estimated difference between
14 $WDEL_g$ and SEL_n was about 90 % greater when using Eq. (7) than Eq. (6) for
15 determination of ET_{MT_di} . Although this difference seemed to be quite high, it should
16 still be considered as moderate since the difference between $WDEL_g$ and SEL_n for
17 the daytime irrigation events of 2005 only amounted to 1.7 % of applied water, from
18 2.0 % when using Eq. (6) to 3.7 % when using Eq. (7) (Table 7).

19 During the night time irrigation events, 259.9 mm of water were applied. The
20 $WDEL_g$ and $WDEL_n$ amounted 8.1 and 9.0 % of total applied water, respectively
21 (Table 8). Adding the IL_n , the estimated SEL_n was 9.5 % of the applied water. During
22 the night time irrigation events $WDEL_g$ were lower than during daytime irrigation
23 events as expected due to lower wind speed, air temperature and VPD. The ET for
24 the *moist* treatment increased instead of being reduced because transpiration
25 reduction was almost negligible but there was evaporation of intercepted water
26 during the irrigation (Table 6). Thus, net sprinkler evaporation losses were slightly
27 greater than $WDEL_g$ for night time irrigation events. So, WDEL of night time sprinkler
28 irrigation did not contribute to satisfy crop water requirements as opposed to daytime
29 sprinkler irrigation.

30 In any case, the contribution of the reduction of ET during daytime irrigation
31 events to satisfy crop water requirements was only moderate in the conditions of this
32 experiment: the difference between $WDEL_g$ and SEL_n was only 1.8 to 3.7 % of

applied water, depending on the approach to estimate ET_{MT_di} . Would the reduction of transpiration during daytime irrigations have been considered for the balance of water losses of Table 7 instead of the reduction of ET, as performed by Tolk et al. (1995), the difference between $WDEL_g$ and SEL_n would have been almost 5.0 % of the applied water. This figure is closer (but still lower) to that reported by Tolk et al., (1995), who only used transpiration reduction for the calculation of SEL_n . In addition, Tolk et al. (1995) used an irrigation pressure (225 kPa) lower than that used in this work. Greater irrigation pressures produce smaller droplets that are more prone to be evaporated or drifted on their way from the sprinkler to the crop. Two factors could explain the relatively low observed contribution of $WDEL_g$ to meet corn water requirements: i) the assumption that evaporation rates of intercepted water after the irrigation event are similar to those during the irrigation; and ii) the reported uncertainties of Eq. (7). As stated previously, during irrigation, the air VPD decreased sharply because of air humidification as reported by other authors (Steiner et al., 1983a, b; Tolk et al., 1995). Then it could be expected that evaporation rates of intercepted water during the irrigation are somewhat smaller and thus the ET values computed using Eq. (6) would have been somewhat greater. Nevertheless, the results of this study suggest that there is a reduction of ET during daytime irrigations leading to SEL_n values lower than $WDEL_g$. Several other factors may affect the difference between these two variables; for instance, pressure and irrigation spacing.

Prediction of net sprinkler evaporation losses

The wind speed (U , in $m\ s^{-1}$) was the only meteorological variable found to have a significant effect on SEL_n (in $mm\ h^{-1}$) (Figure 5). The following regression equations were finally selected, through a backward stepwise procedure, as the most adequate (slopes and intercepts were statistically significant, p-values lower than 0.01):

All irrigation events	$SEL_n = 0.3964 + 0.3087 U$	$R^2 = 0.74$
Daytime irrigation events	$SEL_n = 0.5482 + 0.2660 U$	$R^2 = 0.65$
Night time irrigation events	$SEL_n = 0.1025 + 0.5292 U$	$R^2 = 0.80$

The reduction of ET, estimated using Eq. (6), had a weak to moderate positive correlation with average water vapor deficit (VPD) recorded at the grass weather

station during the irrigation events. This agrees with the following observation made in this study: the reduction of air temperature, VPD, canopy temperature and transpiration at the MT were only related to the average VPD recorded at the grass weather station (data not shown). On the other hand, the IL_n did not show a significant correlation with any of the recorded meteorological variables. This agrees with previous studies where interception losses depended mostly on crop architecture (Norman and Campbell, 1983; Steiner et al., 1983a). The $WDEL_g$ recorded in this study showed a significant correlation with the average wind speed and VPD recorded at the weather grass station, although the highest correlation was with wind speed. Therefore, this circumstance and the moderate difference (expressed as percent of applied water) between $WDEL_g$ and SEL_n , when using Eq. (6) (Tables 7 and 8), would explain why SEL_n only showed a significant correlation with average wind speed but not with VPD. For conditions similar to those of this study, the regression equation obtained for all irrigation events to predict SEL_n as function of wind speed would be recommended.

CONCLUSIONS

Transpiration and evapotranspiration (ET) rates during daytime solid-set sprinkler irrigation events significantly ($\alpha=0.95$) decreased for the *moist* treatment as compared with the *dry* treatment. This decrease was about 58 % for transpiration and between 32 and 55 % for ET, depending on the approach to determine ET during the irrigation events at the *moist* treatment. Transpiration rates recovered within the next two hours after irrigation. The ET rates for the *moist* treatment were significantly greater than those for the *dry* treatment during two hours after the irrigation, reflecting losses of intercepted water. During the nighttime irrigation events transpiration was reduced but ET was increased.

The decrease of ET rates during daytime irrigation lead to lower net wind drift and evaporation losses ($WDEL_n$) than gross WDEL ($WDEL_g$): the difference between these two variables was 14.7 % [if using Eq. (6) for both years] to 25.1 % [if using Eq. (7) for 2005] of $WDEL_g$, although this difference only represented 2.8 % [if using Eq. (6)] to 4.6 % [(if using Eq. (7))] of applied water. If interception losses (about 1.0 %) are accounted for, total net sprinkler evaporation losses (SEL_n) for daytime irrigation

were lower than $WDEL_g$ by about 1.8 % to 3.7 % of applied water. For night time irrigation events, however, SEL_n were greater than $WDEL_g$, about 0.9 % of applied water, because of an increase of ET rates during the irrigation event due to evaporation of intercepted water. An equation was developed to predict SEL_n for corn irrigated with solid-set sprinkler irrigation as function of wind speed for all irrigation events that explained 74% of the experimental variability.

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13 **ACKNOWLEDGEMENTS**

14 This work was supported by grant AGL-2004-06675-CO3-02 (PN I+D+I,
15 Ministerio de Educación y Ciencia of Spain). The authors express their gratitude to
16 Miguel Izquierdo, Jesús Gaudó, Daniel Mayoral, José Manuel Acín and Pilar
17 Paniagua for field assistance and to Sai Gonuguntla (Dynamax Inc.) for technical
18 assistance in sap flow measurement implementation.

1 Table 1. General scheme of weekly irrigation events.

Period	Daytime irrigations (Start time: 13:00 to 14:30 ^a)		Nighttime irrigations (Start time: 2:00 to 3:30 ^a)	
	Moist treatment (MT)	Dry treatment (DT)	Moist treatment (MT)	Dry treatment (DT)
Beginning of the week	Subplot A	Subplot B	Subplot B	Subplot A
Middle of the week	Subplot B	Subplot A	Subplot A	Subplot B
Weekend	Subplot A	Subplot B	Subplot B	Subplot A

2 ^a Greenwich Meridian Time.

3

- 1 Table 2. Average meteorological conditions recorded at the grass weather station
- 2 during the irrigation events listed in Tables 3 and 4.

Period	Year	Air temperature (°C)	Vapor pressure deficit (kPa)	Wind speed (m s ⁻¹)	Solar radiation (W m ⁻²)	ET _o (mm h ⁻¹)
Daytime	2005	30.4	3.06	3.1	549	0.54
	2006	30.8	2.94	2.9	765	0.68
Nighttime	2005	16.8	0.35	1.1	4	0.00
	2006	19.2	0.53	1.2	2	0.00

3

1 Table 3. General characteristics of the daytime irrigation events applied during the
2 recording periods of sap flow measurements in the 2005 and 2006 experiments.

Year	Date	Irrigated subplot	Starting time ^a	Duration (h)	Pressure (kPa)	Applied water (mm)
2005	14-Jul	B	14:05	2.33	388	19.9
	16-Jul	A	14:05	3.25	367	27.0
	18-Jul	A	14:25	2.58	360	21.2
	21-Jul	B	14:00	3.00	395	25.8
	23-Jul	A	13:50	3.17	370	26.4
	25-Jul	A	14:05	2.67	369	22.2
	29-Jul	B	12:25	2.67	399	23.1
	30-Jul	A	14:05	2.67	373	22.3
	01-Aug	A	14:05	2.75	373	23.0
	02-Aug	B	12:25	2.00	404	17.4
	06-Aug	A	14:05	2.25	375	18.9
	08-Aug	A	14:05	2.58	371	21.5
	11-Aug	B	14:05	2.58	398	22.3
	13-Aug	A	14:05	2.58	373	21.6
	15-Aug	A	14:05	2.17	372	18.1
	18-Aug	B	14:05	2.17	398	18.7
	22-Aug	A	14:05	2.00	376	16.8
2006	03-Jul	B	13:00	2.67	335	21.1
	06-Jul	B	10:20	2.92	310	22.2
	07-Jul	A	09:10	3.33	293	24.7
	15-Jul	A	12:50	3.17	296	23.6
	17-Jul	A	13:00	3.00	291	22.2
	22-Jul	A	13:00	3.00	292	22.2
	24-Jul	A	13:00	3.00	292	22.2
	29-Jul	B	13:00	2.50	298	18.7
	31-Jul	A	11:30	3.00	297	22.4
	05-Aug	A	13:00	2.58	297	19.3
	07-Aug	A	13:00	3.00	296	22.4

3 ^a Greenwich Meridian Time.

1 Table 4. General characteristics of the nighttime irrigation events applied during the
2 recording periods of sap flow measurements in the 2005 and 2006 experiments.

Year	Date	Irrigated subplot	Starting time ^a	Duration (h)	Pressure (kPa)	Applied water (mm)
2005	14-Jul	A	02:00	3.25	370	27.1
	19-Jul	B	02:15	3.00	399	25.9
	24-Jul	B	02:15	3.00	400	26.0
	26-Jul	B	02:35	2.67	400	23.1
	29-Jul	A	02:35	2.67	373	22.3
	31-Jul	B	02:35	2.67	403	23.2
	04-Aug	A	02:45	2.50	379	21.1
	11-Aug	A	02:40	2.58	372	21.6
	14-Aug	B	02:40	2.58	398	22.3
	16-Aug	B	03:05	2.17	398	18.7
	18-Aug	A	03:05	2.17	375	18.2
	23-Aug	B	03:15	2.00	403	17.4
	25-Aug	A	03:15	2.00	378	16.8
2006	02-Jul	B	02:00	3.00	374	25.1
	04-Jul	A	02:20	2.67	318	20.6
	09-Jul	B	03:45	1.25	211	7.9
	13-Jul	A	01:50	3.17	303	23.9
	16-Jul	B	01:50	3.17	309	24.1
	25-Jul	B	02:00	3.00	303	22.6
	27-Jul	A	02:15	2.75	301	20.7
	30-Jul	A	02:30	2.50	301	18.8
	01-Aug	B	02:00	3.00	305	22.7
	03-Aug	A	02:25	2.58	301	19.4
	06-Aug	B	02:25	2.58	307	19.6

3 ^a Greenwich Meridian Time.

1 Table 5. Average total transpiration of *moist* (T_{MT}) and *dry* (T_{DT}) treatments during
2 July and August (2005 and 2006), and average differences between them (T_{DT} -
3 T_{MT}) during, 1 to 2 h before and 1 to 3 h after the irrigation events. N, sample size.

Period		Daytime irrigation				Nighttime irrigation			
		N	T_{MT} (mm)	T_{DT} (mm)	$T_{DT}-T_{MT}$ (mm)	N	T_{MT} (mm)	T_{DT} (mm)	$T_{DT}-T_{MT}$ (mm)
Before	1 h	21	0.84	0.85	0.01 ^{ns}	21	0.13	0.09	-0.05 ^s
	2 h	22	0.82	0.84	0.03 ^{ns}	21	0.13	0.08	-0.05 ^s
During		21	0.86	2.03	1.23 ^s	21	0.04	0.15	0.12 ^s
After	1 h	22	0.48	0.60	0.10 ^s	21	0.03	0.12	0.09 ^s
	2 h	22	0.46	0.47	-0.02 ^{ns}	21	0.22	0.29	0.07 ^s
	3 h	22	0.34	0.36	-0.01 ^{ns}	21	0.39	0.38	0.00 ^{ns}

4 ^s significantly different than 0 ($\alpha = 0.95$).

5 ^{ns} not significantly different than 0 ($\alpha = 0.95$).

6

1 Table 6. Average total evapotranspiration of *moist* [ET_{MT} , Eq. (7)] and *dry* (ET_{DT})
2 treatments during July and August (2005 and 2006), and average differences
3 between them ($ET_{DT}-ET_{MT}$) during, 1 to 2 h before and 1 to 3 h after the irrigation
4 events. N, sample size.

Period		Daytime irrigation				Nighttime irrigation			
		N	ET_{MT} (mm)	ET_{DT} (mm)	$ET_{DT}-ET_{MT}$ (mm)	N	ET_{MT} (mm)	ET_{DT} (mm)	$ET_{DT}-ET_{MT}$ (mm)
Before	1 h	26	0.86	0.82	-0.05 ^{ns}	23	0.04	0.04	-0.01 ^{ns}
	2 h	26	0.88	0.86	-0.02 ^{ns}	24	0.07	0.05	-0.02 ^{ns}
During		26	1.35	1.99	0.63 ^{s, a}	23	0.28	0.07	-0.21 ^{s, a}
After	1 h	26	0.66	0.49	-0.17 ^{s, b}	23	0.09	0.06	-0.03 ^{ns, b}
	2 h	26	0.40	0.33	-0.07 ^{s, b}	24	0.15	0.11	-0.04 ^{s, b}
	3 h	26	0.24	0.23	-0.00 ^{ns}	24	0.31	0.28	-0.03 ^{ns}

5 ^s significantly different than 0 ($\alpha = 0.95$).

6 ^{ns} not significantly different than 0 ($\alpha = 0.95$).

7 ^a $ET_{DT}-ET_{MT} = WDEL_g - WDEL_n$.

8 ^b $ET_{DT}-ET_{MT} = -IL_n$.

9

1 Table 7. Balance of sprinkler evaporation losses during and after daytime irrigation
2 events.

Date	I_g (mm)	During		1-2 h after		WDEL (mm)		IL_n (mm)	SEL_n (mm)
		ET_{MT} (mm)	ET_{DT} (mm)	ET_{MT} (mm)	ET_{DT} (mm)	Gross	Net		
14-Jul-2005	19.9	1.1	2.5	1.2	1.5	4.0	2.6	-0.3	2.4
18-Jul-2005	21.2	1.4	1.8	0.9	0.5	4.5	4.1	0.4	4.5
21-Jul-2005	25.8	1.6	2.1	0.7	0.6	4.0	3.5	0.1	3.5
25-Jul-2005	22.2	1.7	2.1	0.8	0.5	2.0	1.6	0.4	2.0
29-Jul-2005	23.1	0.9	2.8	1.5	1.7	3.4	1.5	-0.2	1.3
02-Aug-2005	17.4	1.4	1.8	1.6	1.5	3.6	3.2	0.1	3.3
08-Aug-2005	21.6	0.9	1.1	0.8	0.5	3.8	3.5	0.2	3.8
11-Aug-2005	22.3	1.0	1.8	1.1	0.9	5.9	5.1	0.1	5.2
15-Aug-2005	18.1	1.4	1.4	1.2	0.7	2.1	2.1	0.5	2.5
22-Aug-2005	16.8	1.0	0.9	1.1	0.6	4.6	4.7	0.5	5.3
SUM (2005)	208.3	12.5	18.4	10.8	9.0	37.8	31.9	1.8	33.7
03-Jul-2006	21.2	2.2	2.0	0.8	0.9	2.3	2.5	-0.1	2.4
07-Jul-2006	24.7	2.0	1.7	1.8	1.5	5.6	5.9	0.3	6.1
17-Jul-2006	22.2	0.9	2.4	0.6	0.1	3.6	2.1	0.5	2.6
24-Jul-2006	22.2	1.1	1.8	1.0	0.5	4.1	3.4	0.5	4.0
31-Jul-2006	22.4	2.0	2.7	1.4	1.2	4.4	3.7	0.2	3.9
07-Aug-2006	22.4	0.7	2.2	1.3	0.9	8.4	6.9	0.4	7.3
SUM (2006)	135.0	8.9	12.8	6.9	5.1	28.4	24.5	1.8	26.4
SUM (Both years)	343.3	21.4	31.2	17.7	14.1	66.2	56.5	3.6	60.1

3
4 Note: I_g , applied water; ET_{MT} , evapotranspiration at the *moist* treatment, Eq. (7);
5 ET_{DT} , evapotranspiration at the *dry* treatment; WDEL, wind drift and evaporation
6 losses; IL_n , interception losses, Eq. (10); SEL_n , net sprinkler evaporation losses.

1 Table 8. Balance of sprinkler evaporation losses during and after nighttime irrigation
2 events.

Date	I_g (mm)	During		1-2 h after		WDEL (mm)		IL_n (mm)	SEL_n (mm)
		ET_{MT} (mm)	ET_{DT} (mm)	ET_{MT} (mm)	ET_{DT} (mm)	Gross	Net		
14-Jul-2005	27.1	0.1	0.0	0.2	0.2	1.2	1.3	0.1	1.4
19-Jul-2005	26.0	0.7	0.0	0.5	0.3	2.9	3.6	0.2	3.8
26-Jul-2005	23.1	0.3	0.0	0.2	0.1	2.3	2.6	0.1	2.7
29-Jul-2005	22.3	0.1	0.0	0.3	0.2	-0.2	-0.1	0.1	0.0
04-Aug-2005	21.1	0.5	0.1	0.4	0.2	1.2	1.6	0.2	1.8
11-Aug-2005	21.6	0.0	0.1	0.1	0.0	0.8	0.7	0.1	0.8
23-Aug-2005	17.4	0.4	0.0	0.4	0.1	2.2	2.5	0.2	2.8
25-Aug-2005	16.8	0.0	0.0	0.1	0.1	0.3	0.4	0.0	0.3
SUM (2005)	175.3	2.2	0.2	2.1	1.2	10.7	12.6	1.0	13.6
04-Jul-2006	20.6	0.2	0.1	0.3	0.1	1.3	1.4	0.2	1.6
13-Jul-2006	23.9	0.3	0.2	0.3	0.2	4.0	4.1	0.1	4.3
27-Jul-2006	20.7	0.0	0.1	0.2	0.1	1.5	1.4	0.0	1.5
03-Aug-2006	19.4	0.4	0.1	0.3	0.3	3.6	3.8	0.0	3.8
SUM (2006)	84.6	0.9	0.4	1.1	0.7	10.4	10.6	0.3	11.2
SUM (Both years)	259.9	3.1	0.6	3.2	1.9	21.0	23.5	1.3	24.8

3
4 Note: I_g , applied water; ET_{MT} , evapotranspiration at the *moist* treatment, Eq. (7);
5 ET_{DT} , evapotranspiration at the *dry* treatment; WDEL, wind drift and evaporation
6 losses; IL , interception losses, Eq. (10); SEL_n , net sprinkler evaporation losses.

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8

Figure 1. Scheme of the experimental plot. WDEL, location of measurement of wind drift and evaporation losses; Tr, sap flow gages; Lys, weighing lysimeters; Met, automatic meteorological stations; Pres, irrigation pressure transducers; Sp, sprinklers; ICH, irrigation control hut; Cc, catch cans.

Figure 2. Corn transpiration rates every 15-20 minutes from 2 hours before the irrigation until 3 hours after the end of the irrigation in two daytime and two nighttime sprinkler irrigation events. MT, *moist* treatment; DT, *dry* treatment. Error bars represent the corresponding standard deviations.

1

2 Figure 3. Average corn transpiration rates 1-2 h before, during, and 1-3 h after
 3 daytime sprinkler irrigation events at the *moist* treatment (MT) versus the
 4 corresponding rates recorded at the *dry* treatment (DT).

1

2 Figure 4. Average corn evapotranspiration (ET) rates, 1-2 h before, during [using Eq.
 3 (7)], and 1-3 h after daytime sprinkler irrigation events at the *moist* treatment (MT)
 4 versus the corresponding rates recorded at the *dry* treatment (DT).

Figure 5. Net sprinkler evaporation losses (SEL_n), calculated using Eq. (7) to estimate ET at the moist treatment during the daytime and nighttime sprinkler irrigation events, versus average wind speed (U). The regression equation fitted for the “all irrigation events” case is shown.