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Continuous variation of wind drift and evaporation losses under a linear move irrigation system

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ABSTRACT

The traditional catch-can technique for measuring water depth application under sprinkler irrigation systems has the limitation of being unable to monitor the continuous variation of wind drift and evaporation losses (WDEL) under changing weather conditions. Such information is essential to better manage the agricultural water by improving the global water application uniformity under moving irrigation machines. Three parallel, long, impermeable water collection strips were constructed underneath a stationary linear move irrigation system to address this issue. The sprinkler discharge efficiency (SDE $\approx$ 1-WDEL) was monitored over 5-min intervals (SDE_{5min}) during Apr-Aug of 2014-on a bare experimental plot. Experiments were conducted on a discrete basis for about 1040 h total in order to collect more than 11,600 SDE_{5min} data points. It was found that the SDE_{5min} is very dynamic and can experience abrupt changes up to 16.5% as a result of sudden changes in wind speed and direction. The maximum and minimum observed SDE_{5min} during the study period were 97.5 and 73.6%, respectively. The difference between maximum and minimum SDE_{5min} during a day/night cycle was controlled by solar radiation and maximum wind speed. The average hourly SDE (SDE_{hr}) for data collected at predawn, morning, afternoon, and evening were 89.5, 87.7, 86.9 and 88.8%, respectively. Overall, the daily SDE was mainly controlled by air temperature and varied between 81.8 and 91.8%, indicating that ~8–18% of the daily applied water was lost on average. A multiple linear regression model was developed to help predict the SDE_{hr} as a function of weather parameters. The model indicated wind speed, temperature and relative humidity as the best explanatory variables and predicted the SDE_{hr} with an absolute error just over 4%. Because the difference between maximum and minimum SDE_{hr} over a full experimental day could be as high as 22%, this magnitude of error was considered to be acceptable for wind drift and evaporation loss estimation.

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1. Introduction

Agricultural water scarcity and food demand are both increasing as a result of population and economic growth (Gheysari et al., 2015). Consequently, there is a mounting pressure on irrigation systems to apply water more efficiently to ensure water resources availability and sustainability (e.g., Eisenhauer et al., 2011). Among alternative irrigation systems, the sprinkler method is often a preferred option to address these objectives because it has the potential to attain high water application efficiencies (Clemmens and Dedrick, 1994; McLean et al., 2000; Uddin et al., 2013). Investigating the factors that control the efficiency of pressurized irrigation systems is, therefore, important to develop new water conservation strategies (Tarjuelo et al., 2000).

Center pivots are the most popular sprinkler method in the U.S., and constitute almost 84% of the total surface area irrigated by pressurized irrigation systems (Evans and King, 2012). They are currently used to irrigate more than 12.5 million ha around the globe (Spears, 2003) and are steadily replacing traditional flood irrigation and other types of pressurized irrigation systems. This growth is mainly due to the significant advantages of the system, notably the ability to apply water on a regular and consistent basis, irrigating larger fields, having low labor and energy costs, and being adaptable to variable management objectives (Keller and Bliesner, 1990; Kincaid et al., 1996; Peters and Evett, 2007; Sadeghi and Peters, 2013).

Despite the aforementioned benefits, the global water application uniformity under center pivots is not consistent and varies across time and space (Evans et al., 1998; Ocampo et al., 2003).

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This is because the sprinkler discharge efficiency (SDE) is mostly a function of wind drift and evaporation losses (WDEL), SDE ≈ 1-WDEL. SDE is the amount of water that makes it to the surface for soil storage (and perhaps runoff) divided by the amount of water that leaves the sprinkler nozzles, (Harrison, 1993). Center pivot irrigation systems experience a wide variety of changing weather and microclimate conditions over a full rotation time period that often takes 1½ to 4 days. As a result, different parts of the field may receive different amounts of water, rendering a poor uniformity on a large spatial scale. In an attempt to mitigate these effects, growers often start the pivots at times inconvenient to them so that the system does not irrigate the same area of the field at approximately same times of day. They also deliberately over-irrigate some areas of the field in order to ensure that the entire field is adequately covered. On a large scale, this might result in several disadvantages, including an overall loss in yield and crop quality (Ortiz et al., 2010), more energy consumption, an increase in the risk of potential runoff, nutrient leaching, and soil loss (Santos et al., 2003; Luz and Heermann, 2005). These translate into additional expenses for growers as well as crop damage and environmental degradation.

It should be possible to adjust pivot speed in response to changing SDE under different weather conditions to reduce temporal and spatial variability. For this purpose, estimates of SDEs (or subsequently WDELs) must be determined over short- and long-sampling periods that span the microclimate (5–60-min) diurnal (24-h), and synoptic (several days) controls. Catch-can based studies (Kohl et al., 1987; Abo-Ghobar, 1992; Faci et al., 2001; Ocampo et al., 2003; Playán et al., 2005; Silva, 2006; Ortiz et al., 2009) conducted over the past 30 years have made it clear that WDELs of center pivots might vary from 0 to 36% (Table 1) depending on the system's design characteristics (nozzle pressure, size, height and type) and weather parameters (wind speed and direction, temperature, vapor pressure deficit etc.). In addition, these studies have shown that the magnitude of WDELs is different during day and night. For example, Hermsmeier (1973) reported that evaporation during daytime hours is 3–4 times the evaporation of nighttime hours during July and August in the Imperial Valley, California (Desert climate). Playán et al. (2005) found that WDELs were twice as high during the day compared to night under the semi-arid meteorological conditions of Zaragoza, Spain. For the same region, Ortiz et al. (2009) reported that WDELs can be reduced up to 75% if using rotating spray plate sprinklers (RSPS) at 1 m height in night irrigation events, as opposed to fixed spray plate sprinklers (FSPS) at 2.5 m height in daytime irrigations.

Despite their merits, the aforementioned catch can based studies do not provide any information about how the SDE (or subsequently WDELs) changes over day-night cycles under different weather conditions. This is mainly because the catch can method is cumbersome and time consuming (Uddin et al., 2010) and only allows discrete data points that represent a specific time span, making it very difficult to collect adequate data points over long periods of time. This can be verified from the data presented in Table 1, wherein the maximum number of catch can experiments conducted to evaluate WDELs under moving irrigation machines has never exceeded 52. Additionally, even if enough data could be collected, the catch can test would be unable to reflect the dynamic variation of SDE. For example, more than a 30-min sprinkler run time is needed, and only a single data point is provided at the end of the experiment (Sadeghi et al., 2015).

The lack of adequate data by catch cans also makes it difficult for scientists to justify their findings. For example, Ocampo et al. (2003) found a non-significant difference between their observed WDELs during predawn, morning, afternoon and evening and related this anomaly to the insufficient initial collected data (i.e., 8 experiments only, Table 1). Another case is a recent study conducted by King et al. (2012) who proposed a methodology for measuring WDELs from center pivot sprinklers using a combination of applied water collectors, bromide tracer, and air samplers. These authors observed two unexpected high volume balance errors in their experiments and reported that more tests in higher wind speeds are needed to determine or at least eliminate the cause of this anomaly.

Recently, Sadeghi et al. (2015) proposed a new methodology called the "strip method" in order to measure the dynamic variation of the SDE over long sampling periods and short timing intervals. They successfully validated the technique against catch can measurements and concluded that it worked well even under very hot or windy weather conditions. According to this methodology, the water is captured by long collection strips that are perpendicular to the mainline and is oriented toward the outlets where its outflow is continuously measured by tipping buckets flow gauges (Figs. 1 and 2).

The objective of this study is to use the strip method to (i) continuously monitor the SDE for a stationary linear move irrigation system during a full growing season (no canopy present) under

Table 1
Range of measured wind drift and evaporative loss by the catch can test for center pivot and experimental irrigation machines.

Investigator(s)	Location	Climate	Experimental System(s)	WDEL range (%)	Number of experiments	Best explanatory factor(s)
Abo-Ghobar (1992)	Saudi Arabia	Desert	three low-pressure center-pivots	15–36	3	Nozzle height
Kohl et al. (1987)	Brookings, South Dakota, USA	Cool and wet	a 121 m line source equipped with spray nozzle sprinklers	0.4–1.5	9	Wind speed, nozzle height
Ocampo et al. (2003)	Georgia, USA	Humid	Four center pivots	0–22	8	Relative humidity
Playán et al. (2004)	Zaragoza, Spain	Semi-arid	a static experimental irrigation machine	0.3–8.3	39	Wind speed
Playán et al. (2005)	Zaragoza, Spain	Semi-arid	a static experimental irrigation machine	4.3–14.7	52	Wind Speed
Ortiz et al. (2009)	Albacete, Spain	Cold semi-arid	Center pivot	3.3–13.7	47	Wind Speed
Steiner et al. (1983)	Southwestern Kansas, USA	Semi-arid	Center pivot	<15	39	VPD, Temp, Wind
Faci et al. (2001)	Zaragoza, Spain	Semi-arid	A single spray sprinkler	1–30	nr[b]	nozzle diameter, wind speed, and air temperature
Silva (2006)	Alentejo region, Portugal	Mediterranean	a 30 m long experimental center-pivot	5.8–36.4	10	nr
McLean et al. (2000)[a]	Manitoba, Canada	Cold semi-arid	four different center pivot systems equipped with impact and micro jet sprinklers	<3%		nr

[a] Only evaporation losses were evaluated.
[b] Not reported.