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Research Paper

Novel approach to evaluate the dynamic variation of wind drift and evaporation losses under moving irrigation systems

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The increased need for water and food security requires the development of new approaches to save water through irrigation management strategies, particularly for center pivot irrigation. To do so entails monitoring of the dynamic variation in wind drift and evaporation losses (WDELs) of irrigation systems under different weather conditions and for relatively long time periods. The historical catch can method has limited our ability to address this goal. Here, a new and easy-to implement methodology, called the strip test, was developed and validated against the catch can technique. Our results showed strong agreement between the catch can method and the strip test for determining the average water application efficiency (WAE ≈ 1-WDEL). Because the strip test method was measured for shorter intervals compared to the catch can method, the variables influencing WAE were able to be compared during each test. WAE had a large variance over time, which was controlled, in part, by wind speed (>4 m s^{-1}). Site-specific characterisation of WDEL is needed to apply this technique. Once applied, it can provide a better understanding of WAE behaviour over the time, and enhance the capability of predicting results for the optimising water use in sprinkler irrigation.

1. Introduction

In many areas of the world, 70–80 % of available fresh water is currently used in agriculture (Hoekstra & Chapagain, 2007). However, it is expected that as population and economy grow, a larger fraction of available water will be required for non-agricultural purposes, e.g., urban and industrial applications (Boserup, 2005). Also, climate change has already limited water resources for many regions of the world (Bandyopadhayay, Bhadra, Raghuwanshi, & Singh, 2009; Li et al. 2007; McVicar et al., 2007), which has a negative feedback to future agricultural sustainability and food security (Gheysari et al., 2015; Rockström et al., 2009). Optimising

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Nomenclature

T	Temperature (°C)
j	An index representing the tip number within each 5-min interval
WAE	water application efficiency
L	total distance between the first and the last row of cans (m)
WDEL	wind drift and evaporation loss
m	the total number of tips over 5-min for strips B
WAE_{can}	WAE from the catch can method
n	the total number of tips over 5-min for strips A
WAE_{Strip}	WAE from the strip method
p	the total number of tips over 5-min for strips C
z_i	The catch can irrigation depth after taking evaporation into account (m)
q_{av}	average sprinkler discharge (m^3 min^{-1})
α	Tipping bucket calibration coefficient
$q_{A,j}$	the flow rate for strips A after the j^{th} tip (m^3 min^{-1})
β	Strip width (m)
$q_{B,j}$	the flow rate for strips B after the j^{th} tip (m^3 min^{-1})
Δt	time difference between two consecutive tips
$q_{C,j}$	the flow rate for strips C after the j^{th} tip (m^3 min^{-1})
λ	sprinkler head spacing (m)
RH	relative humidity

agronomic water use efficiency through new irrigation management approaches is one way to mitigate this negative feedback, while at the same time, maximizing economic returns (Delirhasannia, Sadraddini, Nazemi, Farsadizadeh, & Playán, 2010; Evans & Sadler, 2008; Montazar & Behbahani, 2007).

Center pivot irrigation systems currently irrigate more than 12.5 million ha around the globe (Spears, 2003; Sadeghi & Peters, 2013), and they are steadily replacing traditional flood irrigation and other types of sprinkler irrigation. The key advantage of center pivots is their ability to apply water on a regular and consistent basis (Peters & Evett, 2007). In addition, pivots can easily irrigate large fields with relatively low labour and energy costs, and they are also adaptable to different and changing management objectives (Keller & Bliesner, 1990; Kincaid, Salomon, & Oliphant, 1996). Despite these advantages, center pivot systems are unable to irrigate the whole circle in a perfectly uniform manner. The 'global' water application uniformity is dependent on the water application efficiency (WAE), *i.e.*, the amount of water that reaches the soil surface for storage divided by the amount of water that leaves the sprinkler nozzles for any given area (Harrison, 1993; ANSI 1995). It is generally recognised that typical center pivots will have an average WAE of 80–85% (Musick, Pringle, & Walker, 1988; Neibling, Shewmaker, & Falen, 2009). The temporal WAE is, however, not necessarily within this range and mostly depends on wind drift and evaporation losses (WDELs, where WAE ≈ 1-WDELs), *i.e.*, spray losses (Ortiz, Tarjuelo, & Juan, 2009; Schneider, 2000) that occur during the irrigation event. The most rapid center pivots complete a full rotation in ~1½ days, but 2-to-4 days per rotation is typical. Over this time period a wide range in weather (synoptic), diurnal, and microclimate conditions occurs. On a large scale, this contributes to poor application uniformity under center pivots, as well as inaccurate estimates of actual water application depths. A grower using an irrigation system with inconsistent uniformity must then apply additional water in order to adequately irrigate the entire field, often applying water when and where it is not needed. Overwatering some areas increases the risk of potential runoff, nutrient leaching and soil loss (Bauder, Andales, & Waskom, 2008; Santos, Reis, Martins, Castanheira, & Serralheiro, 2003). Non-uniform watering will also result in non-uniform plant growth reducing overall yield and producing a loss of quality (Ortiz, Juan, & Tarjuelo, 2010).

Finding practical solutions to reduce the temporal variation in center pivot water application efficiency is clearly needed. Catch-can based studies have been conducted in the past to measure the WAE of pressurised irrigation systems (Abo-Ghobar, 1992; Bavi, Kashkuli, Boroomand, Naseri, & Albaji, 2009; Christiansen, 1942; Faci, Salvador, Playán, & Sourell, 2001; Frost & Schwalen, 1955; George, 1955; King, Dungan, & Bjorneberg, 2012; Kohl, Kohl, & DeBoer, 1987; Kraus, 1966; McLean, Ranjan, & Klassen, 2000; Musick et al., 1988; Ocampo, Thomas, Hook, & Harrison, 2003; Ortiz et al., 2009; Playán et al., 2005; Robinson, 1973; Seginer, Kantz, & Nir, 1991; Silva, 2006; Sternburg, 1967; Tarjuelo, Montero, Carrion, Honrubia, & Calvo, 1999; Yazar, 1984). The testing usually involved the placement of multiple catch cans in a networked pattern and estimating the amount of water being delivered to the cans (assuming spatial independence of the measurements, Loescher, Powers, & Oberbauer, 2002). Although the catch-can test is a standardised international test (ISO 11545) that is quick and suitable for discretely evaluating system performance during the growing season, it cannot be used to measure the continuous variation of the WAE due to (i) its lack of spatial representation, *i.e.,* n-size sampling theory (Loescher, Ayres, Duffy, Luo, & Brunke, 2014), (ii) its inability to reflect the dynamic variation of WAE, *i.e.*, more than 30-min is needed and only a single data point is provided at the end of the experiment, (iii) low catch efficiency occuring under windy conditions (Hendawi, Molle, Folton, & Granier, 2005; Kohl, 1972; Livingston, Loftis, & Duke, 1985; Marek, Schneider, Baker, & Popham, 1985) and; (iv) it is a cumbersome and time-consuming technique (Sadeghi & Peters, 2012; Uddin, Smith, Hancock, & Foley, 2010). For example, recent catch can based studies carried out by Playán et al. (2005) and Ortiz et al. (2009) used only 52 and 47 irrigation tests to evaluate WDELs under a center pivot irrigation.

Optimising irrigation WAE requires a new approach to advance our understanding of the abiotic controls on the continuous variation of WDELs under different weather conditions. As such, estimates of WAE (and subsequently WDELs) must be determined over both short- and long-sampling periods that span the microclimate (5–60-min) diurnal (24-h), and synoptic (several days) controls. Using a larger catchment area can also be measured more frequently and be a possible solution to achieve this goal, *i.e.*, collector strips. This method has been previously used to evaluate the uniformity of spray distribution from nozzles in laboratory conditions (rf. Sayinci & Bastaban, 2011) as well as estimating surface runoff and/or