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Water use efficiency of corn among the irrigation districts across the Duero river basin (Spain): Estimation of local crop coefficients by satellite images

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ABSTRACT

Irrigation in the Duero river basin accounts for 75% of total water resources. Nevertheless, irrigation in this area is paramount to maintain agricultural production. Within this context, this paper is aimed at assessing the water use efficiency (WUE), for the major crop (corn), among four irrigation districts (IDs) from 2014 to 2017. Since the WUE indicators base upon crop water requirements, these were calculated by estimating the reference evapotranspiration and the local crop coefficients Kc. First, they were estimated by satellite images and then, compared with the recommendation from the Regional Irrigation Advisory Service. Finally, the gross irrigation requirements were compared with the irrigation supply.

WUE indicators varied among IDs depending upon the hydrologic year, the water available for irrigation (superficial and subsurface water), and the corn sowing date. Usually, the IDs performed deficit irrigation in the dry years, and either full irrigation or over irrigation in the wet years. The rainfall only fulfilled less than 10% of corn requirements. Small differences in Kc were observed within municipalities (in each ID) and/or among IDs. The pattern of the Kc fitted curves varied among IDs and was affected by sowing dates.

Although, the local Kc values were close to the general coefficients recommended by the Irrigation Advisory Service, they affected the determination of gross irrigation requirements which were significant different among IDs. Moreover, it was observed that the FAO recommendation for the duration of the corn growth stages fitted better the estimated Kc than the one from the Advisory Center.

The gross irrigation requirements were similar among IDs and years, varying between 6476 and 7646 m^3/ha. The local Kc estimation could help irrigation managers to adapt the irrigation supply to the actual corn needs.

1. Introduction

According to FAO (2017), the earth`s population could reach 10 billion of habitants by 2050 which will boost agricultural demand for staple foods. In addition, the effect of climate change could affect food production worldwide. Irrigated agriculture provides higher crop yield than rain fed agriculture. However, its average water consumption is about 75% in a world where not only water is scarce but it is also foreseen the scarcity will continue in the future. Likewise at global scale, the crop yield for major crops such as maize, rice, and wheat are levelled off since 1990´s. Within this context, the high water consumption in the agricultural sector highlights the need to adopt joint strategies aimed at achieving proper water use efficiency. Moreover, the sector would be affected by the reduction on water supply, and this might have a negative impact on the National gross income.

Water resources can be assessed at field scheme or regional scale by means of water use efficiency WUE indicators (Bos, 1997; Clemmens and Molden, 2007; Droogers and Kite, 1999; Droogers et al., 2000;

Abbreviations: ARIS, annual relative irrigation supply; ARWS, annual relative water supply; CTZ, irrigation district Canal Toro Zamora; CV, coefficient of variation; CVG, irrigation district Canal Villagonzalo; Ea, irrigation efficiency; ET, crop water requirement or crop evapotranspiration; ETo, reference evapotranspiration; GIR, gross irrigation requirements; i, year; ID, irrigation districts; IWS, irrigation water supply; Kc, crop coefficient; Kc_{ini}, initial Crop coefficient; Kc_{mid}, mid-season crop coefficient; Kc_{end}, end Crop coefficient; Kcb, basal crop coefficient; $Kc_{satellite}$, crop coefficient from satellite images; Kc_{ITACYL}, crop coefficient (ITACyL); Ke, evaporation coefficient for soil bare fraction; N, number of satellital images; NI, near-infrared regions; NIR, net irrigation requirements; NDVI, normalized difference vegetation index; P, precipitation; Pe, effective precipitation; RRedspectral, reflectance; RMSE, root mean square error; RRS, relative rainfall supply; SGVT, irrigation district Canal Simancas, Geria and Villamarciel de Tordesillas; S2A, sentinel 2A; S2B, sentinel 2B; T, temperature; VC, irrigation district Villalar de los Comuneros Sector I; WUE, water use efficiency

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Kassam et al., 2007). They also have been applied to propose measures to increase water use efficiency (Vazifedoust et al., 2008).

In Spain, irrigated agriculture is performed within the irrigation district ID where agricultural producers are associated for the management of the irrigation system. The WUE indicators have been applied to assess the irrigation performance and suggest criteria for irrigation management. Lorite et al. (2004a, 2004b), Moreno-Pérez and Roldán-Cañas (2013) and, Andrés and Cuchí (2014) have characterized water use in several IDs in the Guadalquivir river basin, and showed the effect of crop, soil texture and irrigation method on irrigation management. Salvador et al. (2011), evaluated the irrigation performance, and its variability, between irrigation systems and crops in the Ebro river basin. Naroua et al. (2014) assess the irrigation strategy of farmer`s in the Adaja irrigation district (Castilla and León region).

Most of the studies cited above highlighted the benefits of a proper estimation of crop coefficient Kc to determine crop water requirements and thus, to ensure an adequate irrigation supply. Guerra et al. (2016) have presented several procedures to estimate Kc through different methodologies such us: soil water balance (Allen et al., 1998; Sun et al., 2006) or remote sensing and geographic information systems (Battude et al., 2017; Calera et al., 2004, 2017; Casa et al., 2009; Consoli and Barbagallo, 2012; Gontia and Tiwari, 2010; Melton et al., 2012; Pôças et al., 2015; Roerink et al., 1997; Zohrab Samani et al., 2009). Other studies (Marques et al., 2005; Lu et al., 2017) have shown the implication of the Kc estimation not only in the determination of irrigation supply but in optimizing water productivity.

The Kc estimation requires to measure crop-specific parameters such as leaf area index and albedo. Since their calculation is complex in local conditions, without specific instruments, their values frequently are selected from the FAO-56 table.

Nowadays, the remote sensing technology can estimate Kc from the multispectral images sent by sensors on board spacecraft, airborne or on land (Calera et al., 2004; Glenn et al., 2011).

In general, satellite-based ET, focusing on vegetation indices, or ground-based energy balance methods are time consuming, and require a learned skill sets (Allen et al., 2011). Although the last are simpler, both of them estimate Kc coefficients though the general vegetation indices which correspond to vegetation cover, leaf area, and transpiration (Glenn et al., 2008).

The Normalized Difference Vegetation Index (NDVI) is a common index estimated from two shortwave bands typically measured by satellites: the red band (~0.6–0.7 m) and the near infrared band (~0.7–1.3 m) (Allen et al., 2011).

The crop coefficient Kc can be estimated from the so-called dual crop coefficient as:

$$Kc = Kcb + Ke \quad (1)$$

Where: Kcb is the basal crop coefficient, that refers to the transpiration of the plant (ratio between the crop transpiration without water stress and ETo), and Ke considers the evaporation from the bare soil fraction.

The lineal relation between Kcb and NDVI is accurate since it doesn't include soil evapotranspiration (Glenn et al., 2008; Gonzalez-Dugo et al., 2009; Vanino et al., 2015). Bausch and Neale (1987) reported one of the first studies to set up a relationship between the reflected canopy radiation and NDVI. They calculated Kcb corn coefficients from NDVI in EEUU.

Tucker et al. (1979), monitored corn and soybean development with hand-held radiometer spectral data. Later, Bausch (1993) assessed the soil background effects on reflectance-based crop coefficients for corn and Neale et al. (1989) developed a reflectance based crop coefficients. The remote sensing techniques have improved faster and have been applied mainly to the estimation of crop coefficients in crops with high economic value such as vineyards (Vanino et al., 2015). A complete review of Remote Sensing for Crop Water Management in Mediterranean regions can be found in Calera et al. (2017).

In Spain, the Irrigation Advisory Services recommend Kc coefficients for corn in the irrigation districts across the country. In some regions, these coefficients came from FAO datasets (for initial stage = 0.3, for mid-season = 1.2 and for end-season = 0.6-0.35). In others such as in the Castilla La Mancha (Central Spain), they recommended:0.4, 1.15 and 0.6 for each stage, respectively. In the Andalucia region (South Spain), recommended 0.3, 1.15 and [0.6–0.35] for each stage, respectively and (Villalobos and Fereres, 2002). Likewise, Calera et al. (2004) monitored barley and corn growth, at field scale from remote sensing data in the Castilla La Mancha region, and Cuesta et al. (2005) proposed and validated a methodology to estimate the Kc in different herbaceous crops, including corn. Their results were compared with the recommendations given by the Irrigation advisory Services. Calera et al. (2017) have described the procedure to determine Kc coefficient in Spain trough the SPIDERWEBGIS open software, based on remote sensing, which has processed satellite image since 2014. However, in the Castilla and Leon region, the Kc coefficients are not yet been adapted to their local environment and there is a need for their estimation to determine a proper crop water requirements and irrigation supply. Hence, this work seeks to fill this gap and provide tools and suggestions for better irrigation and water application in the study area.

2. Objectives

The main objective of this study is the estimation and evaluation of the irrigation water use efficiency WUE of the major crop (corn) among the Spanish irrigation districts in the Duero river basin (Castilla and León region). It used the common water efficiency indicators but the crop needs are estimated by local Kc coefficients determined by satellite images considering different scales: field plots, municipality and irrigation district. Moreover, the spatial Kc variability among scales is assessed. Finally, the Kc coefficients are compared with the actual coefficients recommended by the Irrigation Advisory Services for Castilla and León (ITACyL), in order to advise local stakeholders to improve corn irrigation management in the region.

3. Materials and methods

3.1. Description of the study area

The study focuses on four irrigation districts IDs: Canal Simancas, Geria and Villamarciel of Tordesillas SGVT (616 ha of irrigation), Canal Toro Zamora CTZ (6962 ha of irrigation), Canal Villagonzalo CVG (4100 ha of irrigation) and Villalar of Comuneros VC (296 ha of irrigation). They locate across the basin of the Duero river basin (Castilla and León region) in the northwestern Spain as it is shown in Fig. 1.

According to the information of the last four years, corn (Zea mays L.) is one of the major crops cultivated in the IDs and is irrigated during the summer months to fulfil its high water requirements. The area devoted to this crop in each irrigation district is: SGVT 590 ha (95%); CTZ, 2781 ha (40%); CVG, 2413 ha (59%) and VC, 15 ha (5%). Sprinkler irrigation is used in the 31% and 47% of the area in CTZ and CVG, respectively but unfortunately the other two IDs did not bring this information.

The area has a continental Mediterranean climate with long and cold winters (average temperatures between 3 and 6 °C), and short and hot summers (average temperature from 19 to 22 °C). Likewise, rainfall is scarce, about a 450–500 mm/year (average) more accentuated at the low lands areas (Nafría et al., 2013).

Regarding to the information published by ITACYL (2017), the most frequent soil textures at each irrigation district location are: SGVT loamy clay sand and loamy sand; CTZ loamy clay sand; CVG loamy sand, loam or sandy loam, and VC loamy clay sand or sandy loam.

Even though, the Duero river basin is the second largest in Spain, the climate variability, especially precipitation, exhibited in the last