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Water balance in artificial on-farm agricultural water reservoirs for the irrigation of intensive greenhouse crops

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ABSTRACT

The intensive-cropping system used in southeastern Spain is one of the most productive of the European Union. It is based on the efficient use of irrigation water using localised irrigation systems with water obtained mostly from small artificial on-farm agricultural water reservoirs (AWRs) that meet the evapotranspiration demands of the intensive greenhouse crops.

Several public and private initiatives have attempted to optimise the distribution of the water from wells and desalinating plants to avoid losses in the delivery network. However, the AWR water loss to evaporation could be dramatically reduced with the use of plastic shade materials. In addition, simple water-collection devices for capturing rainwater from the greenhouse roofs, which are currently used in more than half of the greenhouses of the study zone, recirculate water to the irrigation AWRs, significantly improving the water balance of the system.

The present work provides a monthly balance of the water deficit that could be overcome in an AWR over an irrigation season considering the rainwater directly received by the AWR, the losses due to direct evaporation from the AWR, and the water demand that must be met to provide sufficient irrigation. These water balances were compared with those that would occur if the AWR had been covered with shading material to reduce direct evaporation and if the rainwater from the greenhouse roofs had been collected in the AWR. When applying both of these management approaches, the annual water deficit decreased by 53.02%

1. Introduction

The southeastern coast of Spain has the world's greatest concentration of intensive cultivations protected by plastic (Castilla and Hernández, 2005; Meneses and Castilla, 2009). The success of the horticultural production of these low-cost structures is due to the protection that the crops receive from the plastic cover and the highly efficient use of irrigation water (Bonachela et al., 2006), a scarce resource in this arid zone.

Most greenhouses have a regulated drip-irrigation system fed that is by small artificial on-farm agricultural water reservoirs (AWRs). Therefore, the water needed by the crops is delivered by wells or by an external supply. The ratio of the surface area of the open water bodies to the surface area of the greenhouses is nearly 0.8% (Carvajal et al., 2006).

The monthly balance of water in each AWR is defined by the difference between the volume that is collected by direct precipitation on its open surface and the water lost to evaporation and the flow extracted to meet the water demand of the crops. In most months, the balance is negative; this constitutes a water deficit that must be offset by the farmer to maintain the water volume stored in the AWR.

The local mean precipitation is approximately 250 mm/yr, and rainfall is concentrated around a small number of events in the spring months. Because this period does not always coincide with the highest water demand by the crops, reservoir regulation becomes especially important.

The monthly deficit of an AWR can be reduced by modifying two of its components: reducing direct evaporation and augmenting the water collected in the AWR from nearby greenhouse roofs. Many greenhouses fail to practice either of these measures. In fact, less than half of the greenhouses of the area have a conduit system connecting their roofs to the AWR (Sanjuan and Garzón, 2002), despite the fact that the direct release of water without authorisation is prohibited. In addition, the regulations of the main local towns with high concentrations of greenhouses require these structures to have the elements necessary to collect and store rainwater and condensation for irrigation, and the release of these waters onto public and adjacent roads is prohibited. In most cases where there are downspouts on the greenhouses, the water is recycled to the

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Fig. 1. Study area. Red dots indicate the available weather stations and the black rectangle represents the limits of the satellite image acquired. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

AWR (Sanjuan and Garzón, 2002). Farmers who have no such rainwater recirculation system spend significant amounts of money to guarantee that their water supply is adequately provisioned. The economic effects and the technical efficiency of rainfall harvesting systems for extensive crops have been studied in semiarid regions (He et al., 2007; Wang et al., 2009).

Few of these AWRs were found to have covers, perhaps due to a lack of knowledge concerning the quantity of water that can be lost to evaporation and because of the absence of regulations mandating the use of such covers. Several studies have been conducted examining the reduction in evaporation (Martínez Álvarez et al., 2006a, 2006b; Li et al., 2013), the water quality (Maestre-Valero et al., 2011, 2013) and the economics (Martínez-Álvarez et al., 2009) of shading-covers in open bodies of water.

The aim of this work was to assess the irrigation-water balance in a pilot zone of greenhouses in a 7 km^2 area of SE Spain; each of the balance components was estimated, and the impact of the installation of rainwater-collection systems from the greenhouse roofs and the use of shading material to reduce evaporation from the AWRs was assessed.

In addition, a calculation was made to determine the AWRs depth that would be needed to preserve the regulatory capacity of the AWRs after the installation of the rainwater-collection systems and the reduction of direct evaporation.

2. Study area

Almería is the province with the largest surface area (269.58 km^2) covered by greenhouses in Spain, (Meneses and Castilla, 2009). For this study, a rectangular zone of 6425 × 3240 m^2 near Campohermoso (which belongs to Campo de Níjar) was chosen as representative of this cropping system (Fig. 1).

The study area has a total greenhouse surface area of 7.07 km^2; the surface area of the AWRs was 58,012 m^2 (Carvajal et al., 2010).

Because the size of the chosen representative zone was not very large, the spatial variability of certain climatic variables was not very high. Nevertheless, the surface size from which the spatial variability of the climatic variables was considered was not pre-established. A general methodology for larger zones was applied in this paper. The obtained surfaces by interpolation can be used to any zone in the province, or even to the whole province, taking into account that the data source is well distributed through the province. The influence of certain independent variables was also studied.

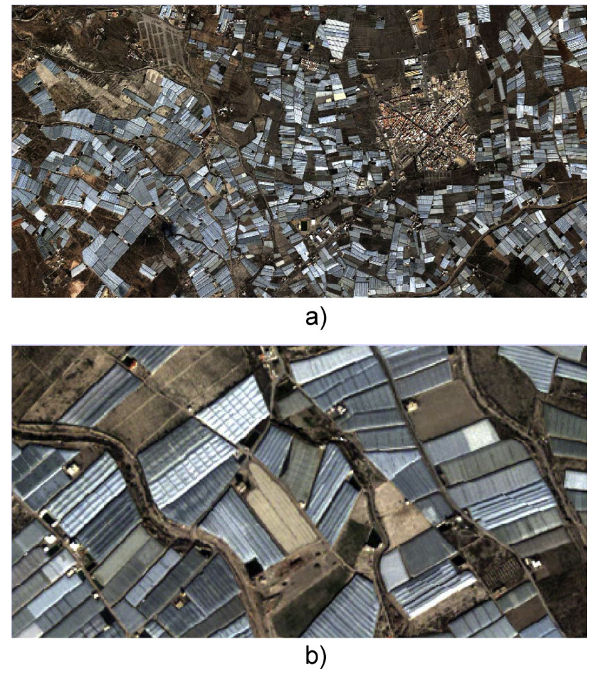

Fig. 2. Sample plot of an intensive agriculture system in Almería (Spain): (a) QuickBird image on December 2004, (b) detail of the image showing open water bodies corresponding to the AWR.

3. AWRs detection

From a high-resolution QuickBird satellite image registered in 2004, a cut-out of the study area composed of three channels of the visible spectrum and the nearby infrared band was made. The spatial resolution and range of this image was 2.5 m per pixel and 16 bit per pixel, respectively.

In addition to the prior radiometric corrections known as dark offset subtraction and non-uniformity correction that were made to the basic QuickBird images, two more pretreatments were applied to detect the AWRs and greenhouses and make surface measurements: orthorectification and atmospheric correction. For the orientation of the sensor, Toutin's model was applied (Toutin, 2002) using 10 control points of land measured with a GPS in differential mode to obtain a mean quadratic transformation error of close to 0.72 m. Fig. 2 shows the satellite image reprojected onto the UTM reference system containing the greenhouse distribution.

The best atmospheric correction treatment for greenhouse detection was based on the conclusions drawn in previous studies (Carvajal et al., 2010); in other words, the top-of-atmosphere transformation method was applied with statistically unpurified training sites.

In this phase, the well-known supervised method of image classification based on artificial neural networks was applied to detect the AWRs (Carvajal et al., 2010; Tsoukalas and Uhring, 1997).

The neurons used are clustered in functional units or levels. In this application, a specific neural network was designed (Carvajal et al., 2006) at three levels in which inlet-level neurons constitute four channels in the multi-spectral satellite image, the outlet level neurons are detected classes, and the hidden level is composed of operational neurons. The back-propagation method was used to train our neural network.