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Overland water and salt flows in a set of rice paddies

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ABSTRACT

Cultivation of paddy rice in semiarid areas of the world faces problems related to water scarcity. This paper aims at characterizing water use in a set of paddies located in the central Ebro basin of Spain using experimentation and computer simulation. A commercial field with six interconnected paddies, with a total area of 5.31 ha, was instrumented to measure discharge and water quality at the inflow and at the runoff outlet. The soil was classified as a *Typic Calcixerept*, and was characterized by a mild salinity (2.5 dS m^{-1}) and an infiltration rate of 5.8 mm day^{-1}. The evolution of flow depth at all paddies was recorded. Data from the 2002 rice-growing season was elaborated using a mass balance approach to estimate the infiltration rate and the evolution of discharge between paddies. Seasonal crop evapotranspiration, estimated with the surface renewal method, was 731 mm (5.1 mm day^{-1}), very similar to that of other summer cereals grown in the area, like corn. The irrigation input was 1874 mm, deep percolation was 830 mm and surface runoff was 372 mm. Irrigation efficiency was estimated as 41%. The quality of surface runoff water was slightly degraded due to evapoconcentration and to the contact with the soil. During the period 2001–2003, the electrical conductivity of surface runoff water was 54% higher than that of irrigation water. However, the runoff water was suitable for irrigation. A mechanistic mass balance model of inter-paddy water flow permitted to conclude that improvements in irrigation efficiency cannot be easily obtained in the experimental conditions. Since deep percolation losses more than double surface runoff losses, a reduction in irrigation discharge would not have much room for efficiency improvement. Simulations also showed that rice irrigation performance was not negatively affected by the fluctuating inflow hydrograph. These hydrographs are typical of turnouts located at the tail end of tertiary irrigation ditches. In fact, these are the sites where rice has been historically cultivated in the study area, since local soils are often saline-sodic and can only grow paddy rice taking advantage of the low salinity of the irrigation water. The low infiltration rate characteristic of these saline-sodic soils (an experimental value of 3.2 mm day^{-1} was obtained) combined with a reduced irrigation discharge resulted in a simulated irrigation efficiency of 60%. Paddy rice irrigation efficiency can attain reasonable values in the local saline-sodic soils, where the infiltration rate is clearly smaller than the average daily rice evapotranspiration.

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1. Introduction

In water-scarce regions of the world rice cultivation is often criticised for using too much water. Tuong and Bhuiyan (1999) summarised the results of a number of researchers in which rice irrigation efficiency fluctuated between 22 and 61%. These results are in reasonable agreement with those of Clemmens and Dedrick (1994), who presented a pessimistic and an optimistic estimation of paddy rice efficiency, with respective values of 40 and 60%. According to these figures, it is clear that paddy rice ranks very low in the comparison of irrigated agricultural systems based on irrigation efficiency.

A number of authors (Keller et al., 1996; Perry, 1999) have emphasized the hydrologic implications of irrigation efficiency, particularly in what refers to upscaling. A common conclusion of these works is that low values of on-farm irrigation efficiency (Burt et al., 1997) may not be harmful to regional water availability if the quality and location of the return flows permit to reuse them. In fact, water reuse is a very common feature of rice-growing areas, in which water flows from paddy to paddy following intricate paths. Recently, Hafeez et al. (2007) presented data on an irrigated rice project in the Philippines. Water reuse at various levels resulted in a regional irrigation efficiency of 71%. The authors believed that achieving 80% efficiency would not require major improvements in irrigation management and structures. Similar conclusions can be drawn in the central Ebro basin of Spain when taking into account non-point source water reuse in the Flumen irrigation district (Nogués and Herrero, 2003). These regional figures should alleviate social pressure on rice cultivation in areas where return flows are reused.

The reduction of on-farm water use presents advantages over return flow reuse. These are related to the conservation of water quantity (keeping irrigation water at the system source; controlling water table rise) and quality conservation (avoiding the pollution present in runoff and percolation water). This is the reason why a number of techniques have been proposed to improve on-farm rice irrigation efficiency, such as soil puddling (Kukal and Aggarwal, 2002), intermittent ponding (Belder et al., 2004), soil suitability assessment (Beecher et al., 2002) and nonsubmerged sprinkler irrigation (McCauley, 1990).

The central Ebro Valley of Spain has an irrigated area of about half a million hectares. The area cropped to rice fluctuates every year, but rarely exceeds 20,000 ha. Rice is not particularly important in the region from a water use perspective, but it occupies its own niche: it is the only cropping alternative for saline-sodic soils. The vertical saturated hydraulic conductivity of these soils is usually very low, due to: (1) a degraded structure; (2) the frequent alternating millimetric layers of silt and sodic clay of the underlying Holocene sediments; and (3) soil tillage, puddling with the rice straw to produce an impervious soil pan. As a consequence, rice irrigation can attain reasonable efficiencies. In these crop conditions, soil salinity does not pose a limitation to rice growth and yield due to the permanent flooding with fresh water. Saline-sodic soils are often located in poorly drained, low geomorphic positions. Rice is cultivated every year in these soils. In the years when rice is particularly profitable, the crop can also be found in non saline-sodic soils occupying higher geomorphic positions. Rice farms in the area often occupy between 3 and 10 ha, and are typically divided into a number of paddies, with 0.5–2 ha each. The set of paddies has a canal turnout and a runoff disposal point, and water continuously flows between paddies during the crop season. Rainfall usually represents a small fraction of the seasonal water input.

The objectives of this paper are: (1) to assess water use in a set of rice paddies in the central Ebro basin, estimating all terms of the hydrologic balance as well as irrigation performance; (2) to evaluate the quality of irrigation and surface runoff waters; (3) to assess the influence of soil infiltration on irrigation performance; and (4) to identify better performing irrigation management techniques, capable of reducing surface runoff.

2. Materials and methods

2.1. *The experimental field*

A commercial rice field located in *Albero Bajo* (Huesca, Ebro valley, Spain) was evaluated in 2002 for irrigation performance and during 2001, 2002 and 2003 for irrigation and runoff water quality. The coordinates of the field are 41°59′53″N and 0°24′34″W. The total field area was 5.31 ha, divided into six paddies with areas ranging between 0.58 and 1.39 ha (Table 1, Fig. 1). A topographic survey revealed that the difference in elevation between the highest and the lowest paddies was 4.26 m. The standard deviation of soil surface elevation (Playán et al., 1996) for each paddy ranged between 0.010 and 0.021 m, indicating that the field had been laser-levelled in recent years. Rice was grown annually in the field since 1996,

Table 1 – Main characteristics of the paddies: area (m^2), average soil surface elevation (m, referenced to paddy 6), standard deviation of soil surface elevation (SDe, m), number of EMI readings, and statistics of the ECe 0–50 cm estimates

Paddy #	Area (m^2)	Elevation (m)	SDe (m)	EMI readings	ECe 0–50 cm estimates				
					Mean (dS m^{-1})	Median (dS m^{-1})	Min. (dS m^{-1})	Max. (dS m^{-1})	C.V. (%)
1	7,973	4.26	0.021	17	1.53	1.43	1.07	2.09	22.2
2	10,004	2.57	0.010	20	1.32	1.26	0.92	2.05	24.2
3	5,844	1.62	0.019	10	1.44	1.43	1.05	1.71	16.0
4	7,188	0.99	0.020	15	1.86	1.69	1.15	3.40	37.1
5	8,240	0.26	0.019	21	4.68	4.31	2.49	9.86	46.2
6	13,866	0.00	0.014	18	3.31	2.69	2.10	8.56	48.6
All	53,115	–	0.017	101	2.50	1.96	0.92	9.86	71.6