Agricultural Water Management 171 (2016) 108–119

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Water balance implications of switching from continuous submergence to flush irrigation in a rice-growing district

Sandra Cesari de Maria[a,*], Michele Rienzner[a], Arianna Facchi[a], Enrico Antonio Chiaradia[a], Marco Romani[b], Claudio Gandolfi[a]

[a] Department of Agricultural and Environmental Sciences (DiSAA), Universitá degli Studi di Milano, 20133 Milan, Italy
[b] Centro Ricerche sul Riso, Ente Nazionale Risi (ENR), 27030, Castello d'Agogna (PV), Italy

ARTICLE INFO

Article history:
Received 8 August 2015
Received in revised form 22 March 2016
Accepted 24 March 2016

Keywords:
Rice irrigation
Shallow groundwater
Irrigation district
SWAP model
Scenario analysis

ABSTRACT

Studies conducted at the field scale report significant reductions in the irrigation requirements of rice when continuous submergence (CS) is replaced by less water-demanding regimes such as flush-irrigation (FI, i.e. intermittent irrigations of rice growing in non-submerged soils). However, the effects of their extensive application in paddy areas with shallow groundwater is much less studied. We present a scenario analysis investigating the impacts on irrigation requirements induced by a shift from CS to FI in an irrigation district of Northern Italy where rice is the main crop, followed by maize and poplar. The area is characterised by a shallow water Table whose depth fluctuates between two meters (in winter) and less than 1 m (in summer). We applied a three-stage procedure, where we first analysed present state conditions using the SWAP (Soil, Water, Atmosphere, Plant) model to simulate irrigation deliveries and percolation fluxes. Then, we calibrated an empirical relationship between estimated percolation fluxes and measured depths to groundwater. Finally, we applied this relationship, in combination with the SWAP model, to predict the variation of district irrigation requirements due to a widespread shift from CS to FI. Results show that neglecting the feedback between groundwater recharge due to irrigation and groundwater depth led to overestimating the reduction of irrigation requirements of rice, which decreased from around 80% when no feedback was considered to around 60% when it was accounted for. Moreover, increased groundwater depths resulted in higher irrigation requirements for maize with an estimated growth of more than 50% due to the need of shortening the irrigation turn. These results demonstrate the importance of considering the impacts on the hydrological processes at larger scales when planning the conversion of CS into more efficient field irrigation methods.

1. Introduction

The method of flush irrigation, in which rice is irrigated as an upland crop such as wheat or maize, has been tested in different environments (e.g. Belder et al., 2007; Bouman et al., 2005, 2007; Feng et al., 2007; Govindarajan et al., 2008; Kato et al., 2009; Tabbal et al., 2002; Xue et al., 2008). Various authors report that flush irrigation (FI) of rice can reduce irrigation water deliveries by up to 60%, compared to continuous submergence (CS), albeit with a yield loss of 10% to 30% (Borrell et al., 1997; Bouman et al., 2005; Tabbal et al., 2002). However, most research on alternative irrigation techniques, to date, has been limited to individual field experiments and there is still the need to assess the large-scale and long-term impacts of flush irrigation (see, e.g., Guerra et al., 1998; Humphreys et al., 2005). One open issue, in particular, refers to the role of the feedback effects on rice irrigation requirement due to the likely increase of groundwater depth when a large-scale shift from CS to FI takes place. Indeed, Belder et al. (2005) and Cabangon et al. (2004) observed that groundwater depths remained very shallow in various field experiments, while it can be expected that the large-scale adoption of FI or of similar techniques will lead to an increase in groundwater depth, due to reduced recharge (Belder et al., 2004; Mishra et al., 1990). This, in turn, will increase percolation and limit root uptake from groundwater, thus limiting the ultimate reduction in irrigation requirements (Belder et al., 2007; Tabbal et al., 2002). Furthermore, negative impacts on ecosystem services are expected

* Corresponding author.
E-mail addresses: sandra.cesari@unimi.it (S. Cesari de Maria), michele.rienzner@unimi.it (M. Rienzner), arianna.facchi@unimi.it (A. Facchi), enrico.chiaradia@unimi.it (E.A. Chiaradia), m.romani@enterisi.it (M. Romani), claudio.gandolfi@unimi.it (C. Gandolfi).

http://dx.doi.org/10.1016/j.agwat.2016.03.018
0378-3774/

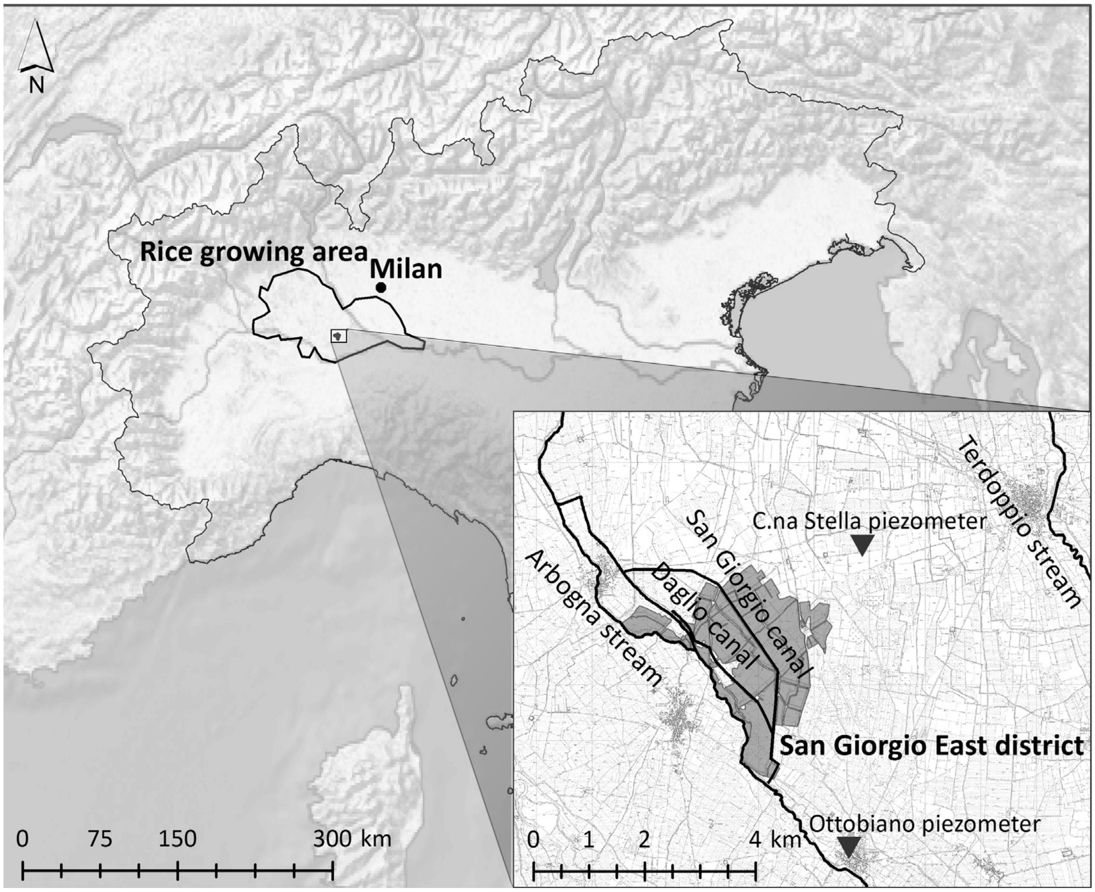

Fig. 1. Pilot study area of the San Giorgio East district (Italy) with location of the main streams and piezometers .

since flooded rice paddies play a key role in sustaining a rich biodiversity, including unique and threatened species (Fernando et al., 2005). In addition to that, also negative impacts on groundwater dependent ecosystems can be expected due to the reduction of percolation fluxes.

The rice area covering about 200,000 ha in the Western Po Valley, Italy, is a typical case of a historical rice district where the pressure to shifting from CS to alternative water management practices has been increasing during recent years (ENR, 2013). Rice in the area has been traditionally grown in bunded fields, that are kept flooded from April to September. The agricultural practice consists of broadcasting pre-germinated seeds over submerged, levelled fields and then maintaining a ponded water depth of about 100 mm for most of the growing season. Currently, the seasonal irrigation depth averages approximately 3000 mm (INEA, 2013), but it is quite variable in the area, depending on soil characteristics and groundwater depth. The long-term persistence of a traditional rice cropping system in much of the area has created a very characteristic agro-environment, that has been included in the European ecological network NATURA 2000 and in the official list of the European Special Protected Areas (HABITAT Directive, 92/43/EEC). Moreover, the continuous submergence practice is a key factor in the recharge of the phreatic aquifer, which is very shallow over most of the area and feeds many semi-natural springs, called “fontanili”, that form a longitudinal strip of groundwater-dependent ecosystems across the area.

The increasing competition for water is motivating the adoption of less water-demanding regimes. Delayed flooding after dry-seeding has increased in recent years in the eastern portion of the area (ENR, 2013). So, too, has the interest in flush irrigation, given its potential to strongly decrease irrigation requirements, contributing to reducing pressures on riverine environments due to abstractions for irrigation, consistent with the objectives of the EU Water Framework Directive (2000/60/EC). On the other hand, however, there is a concern that the widespread adoption of flush irrigation may alter the hydrological regime of surface and groundwater, while having a smaller effect than expected on the total irrigation requirements and especially on the peak irrigation demand.

In this paper, we present a procedure to account for the feedbacks between irrigation deliveries and fluctuations in groundwater depth and we illustrate the results of its application to the analysis of a scenario of shift from CS to FI rice in a pilot agricultural district within the western Po Valley rice area.

2. Material and methods

2.1. Pilot study area and data collection

The study area is the San Giorgio East district, which comprises about 500 ha located at the centre of the western Po Valley rice area, about 45 km southwest of the city of Milan (northern Italy). The district is bounded to the west and east by two small streams, Arbogna and Terdoppio, respectively (Fig. 1) and is characterised by nearly homogeneous soils and an average slope of about 1‰. The local climate is humid subtropical (Cfa) according to the Köppen climate classification (Köppen, 1936), with average temperature of 20 °C and cumulated rainfall depth of about 360 mm during the agricultural season (April-September, average over the period 1993–2013). The main soil type of the area is Argic Udipsamments mixed mesic (ERSAL, 1993; USDA, 1975), with a high percentage of