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Scale effects on water use and water productivity in a rice-based irrigation system (UPRIIS) in the Philippines

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ABSTRACT

Between 25% and 85% of water inputs to rice fields are lost by seepage and percolation. These losses can be reused downstream and do not necessarily lead to true water depletion at the irrigation system level. Because of this potential for reuse, the general efficiency of water use can increase with increasing spatial scale. To test this hypothesis, a multi-scale water accounting study was undertaken in District I of the rice-based Upper Pampanga River Integrated Irrigation System (UPRIIS) in the Philippines. Daily measurements of all surface water inflows and outflows, rainfall, evapotranspiration, and amounts of water internally reused through check dams and shallow pumping were summed into seasonal totals for 10 spatial scale units ranging from 1500 ha to 18,000 ha.

The amount of net surface water input (rainfall plus irrigation) per unit area decreased and the process fraction, depleted fraction, water productivity, and amount of water reuse increased with increasing spatial scale. In total, 57% of all available surface water was reused by check dams and 17% by pumping. The amount of water pumped from the groundwater was 30% of the amount of percolation from rice fields. Because of the reuse of water, the water performance indicators at the district level were quite high: the depleted fraction of available water was 71%, the process fraction of depleted water was 80% (close to the 75% area covered by rice), water productivity with respect to available water was 0.45 kg grain m^{-3} water, and water productivity with respect to evapotranspiration was 0.8 kg grain m^{-3} water. Water use in the district can be reduced by cutting down the $49 \times 10^6\ m^3$ uncommitted outflows. The depleted fraction of available water can be increased to 80% or more by a combination of adopting alternate wetting and drying (AWD) and increased pumping to capture percolating water. Water productivity with respect to available water can be increased to 0.83 kg grain m^{-3} water by a combination of reduced land preparation time, adoption of AWD, and increased fertilizer N use to increase yields.

1. Introduction

Rice is eaten by about three billion people and is the most common staple food in Asia (Maclean et al., 2002). Some 75% of the world's annual rice production is harvested from 79 million ha of irrigated lowland rice, mainly in Asia, where it accounts for 40–46% of the net irrigated area of all crops (Dawe, 2005). Because of its large area, and because rice

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receives relatively much water, Bouman et al. (2006) estimated that 34–43% of the world's irrigation water is used to irrigate rice. However, water resources are getting increasingly scarce and rice is a main target for water-saving initiatives (Rijsberman, 2006).

Total seasonal water input to rice fields (rainfall plus irrigation) is up to two to three times more than for other cereals (Tuong et al., 2005). It varies from as little as 400 mm in heavy clay soils with shallow groundwater tables to more than 2000 mm in coarse-textured soils with deep groundwater tables (Bouman and Tuong, 2001; Cabangon et al., 2004). Around 1300–1500 mm is a typical value for irrigated rice in Asia. Because of these large water inputs, the water productivity of rice with respect to water inputs is quite low: the average reported value for rice at the field level of 0.4 kg grain m^{-3} water is about two times smaller than that of wheat (Tuong et al., 2005). The large water inputs are mostly caused by surface drainage and seepage and percolation flows from the continuously ponded fields into the groundwater, creeks, and drains. Seepage and percolation flows account for about 25–50% of all water inputs in heavy soils with shallow (20–50 cm depth) groundwater tables (Cabangon et al., 2004; Dong et al., 2004), to 50–85% in coarse-textured soils with groundwater tables of 1.5 m depth or more (Sharma et al., 2002; Choudhury et al., 2007). Therefore, most water-saving technologies developed at the field level aim to reduce seepage and percolation flows (Bouman and Tuong, 2001; Tuong et al., 2005). However, though these flows are losses at the field level, they can be captured and reused downstream and do not necessarily lead to true water depletion at the irrigation system level. Therefore, it has been argued that the efficiency of water use and the water productivity of rice may increase with increasing spatial scale and may be much higher at the irrigation system level than at the individual field level (Tuong et al., 2005). To test this hypothesis, water flows within an irrigation system would need to be tracked at different spatial scales. Also, the water flows would need to be separated into reusable flows and real depletion flows (such as evapotranspiration), and amounts of water reuse would need to be estimated. Loeve et al. (2004) measured water flows at "micro" and "meso" scales in the 467,000 ha Zanghe Irrigation System (ZIS), in Hubei Province, China, in which 27% of the area was cropped with lowland rice. The micro-scales consisted of small sets of farmers' fields that were together less than 1 ha, and the meso scales were areas within the irrigation system of 287 ha and 606 ha. Water inflows were also available for main canal command areas of 28,000–196,000 ha and for the whole irrigation system. Water productivity decreased from micro to meso scale, but increased from meso scale to canal command area and to the whole irrigation system. The number of scale levels at which detailed flow measurements were made, however, was not large enough to make solid conclusions on the relationship between scale and water productivity and other water use parameters. In this paper, we present results for a multi-scale study on water use in a rice-based surface irrigation system in the Philippines. Using the water accounting principles of Molden (1997) and Molden and Sakthivadivel (1999), and computing internal water flows, we calculated water productivity and various water use indicators for 10 different spatial scale levels. We also estimated formal and informal water reuse through surveys and actual water flow measurements. The ultimate aim was to test the hypothesis that the efficiency of water use and water productivity of rice increases with increasing spatial scale because of the reuse of seepage, percolation, and drainage water. We also used the water performance indicators to suggest where improvements in water management in the system could be made.

2. Materials and methods

2.1. Study area

Our study area was District I of the 102,000 ha Upper Pampanga River Integrated Irrigation System (UPRIIS) in Central Luzon, Philippines (Fig. 1). UPRIIS is owned and operated by the National Irrigation Administration (NIA) of the Philippines with the main purpose of providing irrigation water to rice fields. District I has a total area of 28,205 ha, including rice fields (dominant land use), upland crops, vegetables, roads, settlements, and water bodies. The district is bounded by the Talavera River to the east and the Ilog Baliwag River to the west, and consists of an upper part, called the Talavera River Irrigation System-Lower (TRISL), and a lower part, called the Santo Domingo Area (SDA). Water is supplied by Diversion Canal No. 1, which gets its water from the Pantabangan reservoir, and the TRIS main canal, which gets its water from the Talavera River through a run-off-the-river diversion dam. The major direction of water flow is from northeast to southwest, though locally, water flows in various directions according to topography. The TRIS main canal first supplies water to an irrigation system north of, and contiguous to, District I, called TRIS-Upper. The area is quite flat, with elevations of around 20 m above sea level. Soils are Vertisols, Entisols, and Inceptisols, and have typically silty clay, silty clay loam, clay loam, and clay textures. The climate is characterized by two pronounced seasons, dry from November to April and wet for the rest of the year. The

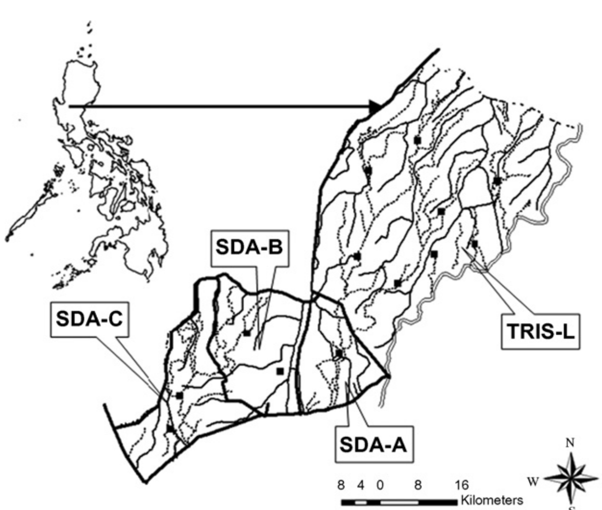

Fig. 1 – Location map of District I, UPRIIS, and the spatial units of the case study. The dots indicate the location of check dams for reuse of surface drainage water.