The water balance on sloping land in rainfed lowland rice ecosystem

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Abstract

Quantifying water losses in paddy fields assists estimation of water availability in rainfed lowland rice ecosystem. There is, however, no definite method for determining the water losses, and little information is available on water balance in different toposequence positions of a sloped rainfed lowland. Therefore, the aim of this work was to quantify percolation and the lateral water flow with special reference to the toposequential variation. Data used for the analysis was collected in Laos and northeast Thailand. Percolation and water tables were measured on a daily basis. The percolator is a steel cylindrical tube with a lid to prevent water loss from evapotranspiration. The water table meter is a short PVC tube for determination of perched water table and a long PVC tube for groundwater table, and the side is perforated with 5-mm diameter holes at 20-mm distance. Percolation rate was determined using linear regression analysis of cumulative percolation. Assuming that the total amount of evaporation and transpiration was equivalent to potential evapotranspiration, the lateral water flow was estimated using the water balance equation. Our results are in agreement with the previously reported findings, and the methodology of estimating water balance components appears reasonably acceptable. With regard to the toposequential variation, the higher position in the topoesquence, the greater potential of the water losses because of higher percolation and lateral flow rates.

Media summary

Water losses from sloped lowland rice ecosystem has been quantified to assist estimation of plant water availability in the Mekong region.

Key Words

Percolation, Rice, Toposequence, Water table

Introduction

Quantifying the water budget in lowland rice fields is helpful for understanding plant water availability and its modeling. In general, the water balance equation represents the relationships among rainfall, runoff, percolation, seepage, evaporation and transpiration. Rainfall is measured at fields or nearby weather stations, while runoff may be estimated from bund height, rainfall and runoff from the neighboring fields. There is no definite method for determining percolation, seepage, evaporation and transpiration. Evaporation or/and transpiration can be measured and determined using micro-lysimeters, or evapotranspiration may be estimated from potential evapotranspiration or pan evaporation (Bouman et al., 1994; Fukai et al., 2000). Therefore, if the change in free water level is known, the total amount of percolation and seepage can be determined. If percolation is independently determined, seepage can be then computed. With respect to environmental resource use, low availability of resources, such as rainwater and soil nutrients, limits lowland rice production (Fukai et al., 1998). The availability may be different from position to position in the toposequence of the lowland environments (Homma et al., 2001). The objective of this paper was, therefore, to quantify percolation rate and the lateral water flow

(seepage) using the water balance equation with reference to the toposequential variation of sloped lowlands.

Materials and methods

Field experiments

Field experiments were carried out under rainfed conditions in Laos and Thailand during crop growing seasons (June–December). In Laos, the experiments were conducted at Sonkhon (16?11′N, 105?19′E) in Savannakhet during the 2001 and 2002 seasons. In Thailand, the experiments were conducted at Chum Phae (16?32′N, 102?7′E), Khon Kaen (16?25′N, 102?48′E)/Ta Pra (16?19′N, 102?49′E), Phimai (15?14′N, 102?28′E), Surin (14?54′N, 103?30′E) and Ubon Ratchathani (15?19′N, 104?40′E), which are located in the northeast, during the 2000 season. The experimental treatments were three (top, middle and bottom) positions of the toposequence for Laos and four cultural practices, including cultivar, direct seeding/transplanting, and fertilizer application, for Thailand. In addition, Khon Kaen/Ta Pra had two (high and low) toposequential position treatments.

Measurements

Percolation was measured using the percolator, a steel cylindrical tube 400 mm in length and 200 mm in diameter with a lid to prevent evaporation and rainfall. The percolator was installed in the topsoil slightly penetrating to the hardpan, so the meter could measure the vertical water movement through the hardpan. Perched water table was measured using a PVC tube with a cylinder diameter of 100 to 150 mm and a depth of 350 mm. Similarly, groundwater table was measured using a 1000 to 1500 mm long PVC tube with a cylinder diameter of 25 mm. The side below 100 mm and 500 mm from the top of the perched water and groundwater tubes, respectively, has systematically designed holes with 5 mm in diameter. The design of the holes is a lozenge shape-systematic pattern, and the diagonal holes are vertically 20 mm and horizontally 40 mm apart. The perched water table meter was set at the hardpan surface, while the hole part of the groundwater table meter was installed in the subsoil. The schematic diagrams of the tubes are shown in Figure 1. All measurements were taken on a daily basis.
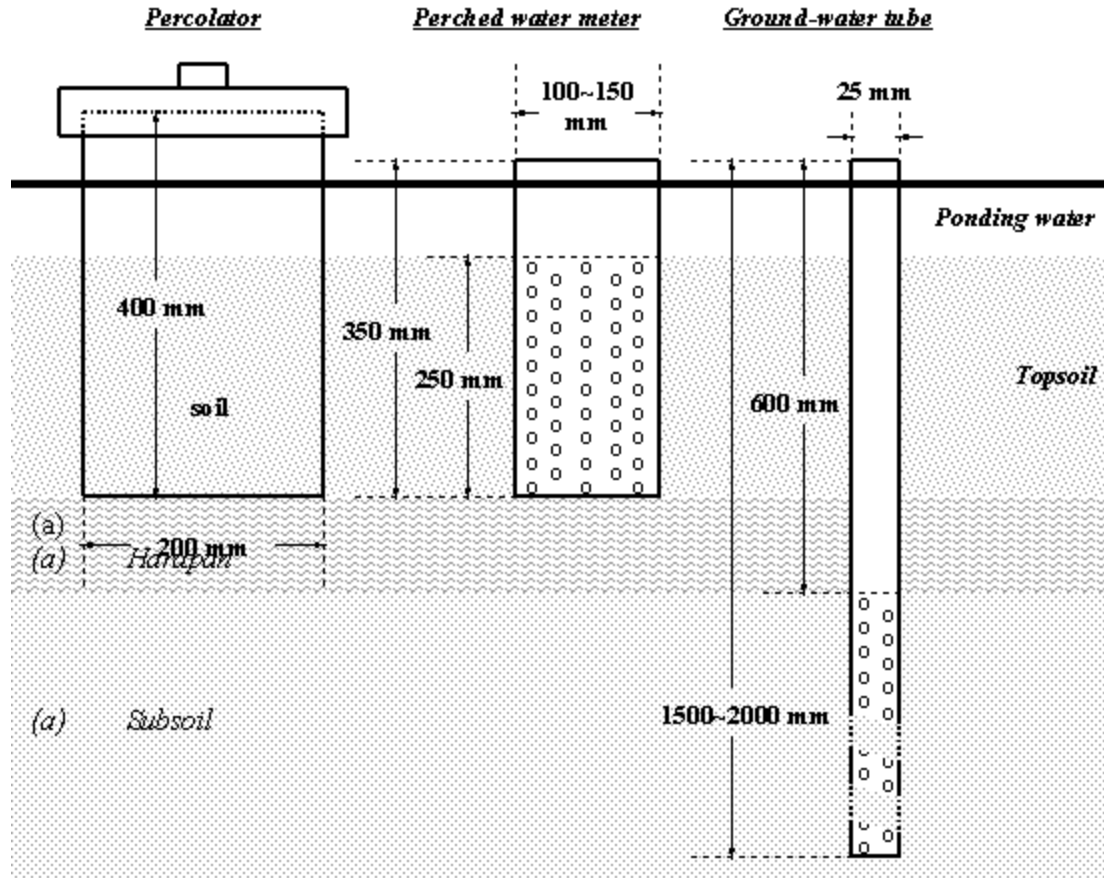
Figure 1. Schematic diagrams of the percolator, the perched water table meter, and the groundwater table meter.

Calculations

Assuming that all transpiration water comes from soils above the hardpan because most of the root system exists in the topsoil layer, the lateral water flow (seepage), L, on the i-th day is given by:

$$L_i = \left(S_{i-1} - S_i\right) + R_i - E_i - T_i - P_i - O_i$$

where S is free water level, R is rainfall, E is evaporation, T is transpiration, P is percolation rate through the hardpan, and O is surface drainage/runoff. For each experiment, L was computed daily during three months of August, September and October, and the computation was carried out during time with standing water in the field. The period of estimation did not include any days on which flood occurred, so O was assumed to be nil. The total amount of E and T is assumed to be equal to potential evapotranspiration (PET). PET was calculated using weather data for the 2000 season at Khon Kean, Thailand, and this was used for the study area in northeast Thailand. P was determined during a period before standing water disappeared, using linear regression analysis of cumulative percolation. Figure 2 shows an example of the linear regression. Then, P was assumed to be constant during the three months for each experiment.
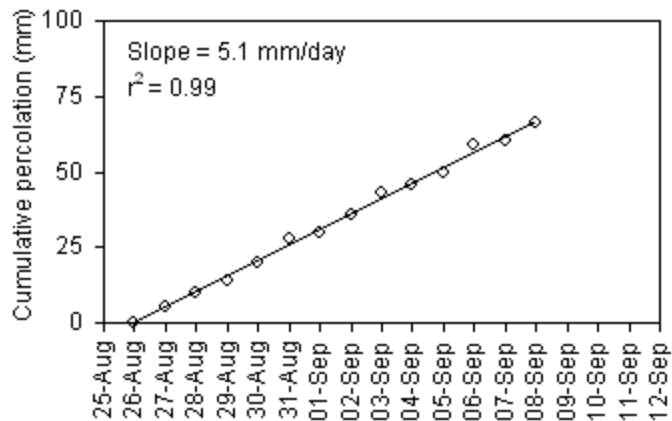
Figure 2. An example of the linear regression analysis for cumulative percolation loss (Ubon Ratchathani, Thailand).

Results and discussion

Water tables

Paddy fields can be classified into two types with respect to water availability. Some paddy fields have only one water table, while others have separate perched water and groundwater tables. For Sonkhon, Laos, as shown in Figure3, the field had both perched water and groundwater tables during the 2001 season. By contrast, readings of the perched water table meter mostly overlapped those of the groundwater table meter during the 2002 season, suggesting that there was continuous free water through soil profile. In Thailand, both perched water and groundwater tables were observed at most of the Ubon Ratchathani fields during the season, while the other four locations (Chum Phae, Khon Kaen/Ta Pra, Phimai and Surin) had mostly no perched water.
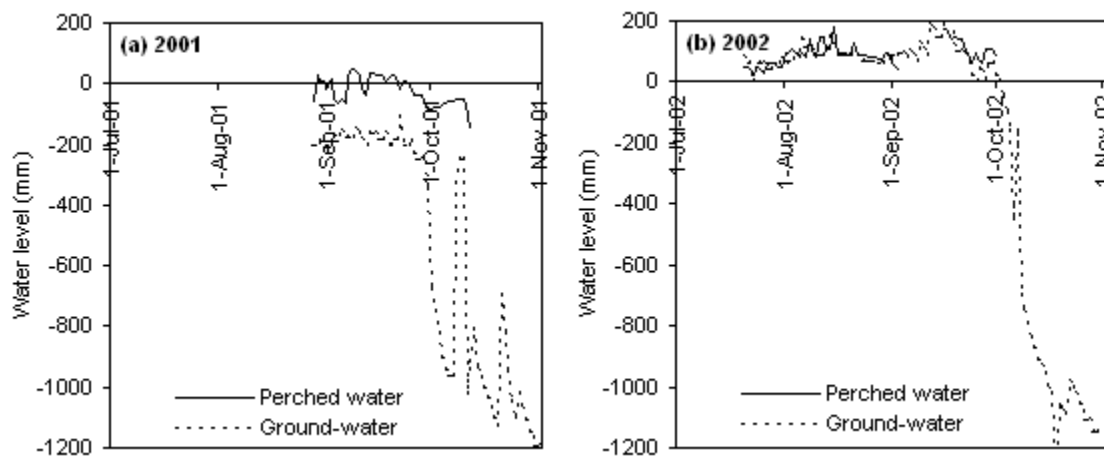
Figure 3. Examples of perched water and groundwater levels at Sonkhon, Laos.

Percolation rate

In Thailand, Ubon Rachathani and Chum Phae had the highest and lowest mean values of percolation rate, respectively, as shown in Table 1a. Khon Kaen/Ta Pra had high variation in percolation rate although the mean value was very similar to those for the other two locations (Phimai and Surin). The

mean values for Chum Phae, Khon Kaen/Ta Pra, Phimai and Surin ranged between 0.6 and 1.9 mm/day in agreement with the range (0.0 and 1.5 mm/day) estimated by Fukai et al. (1995) for the same areas: 1.5, 1.0, 1.5 and 0.0 mm/day for Chum Phae, Khon Kaen/Ta Pra, Phimai and Surin, respectively. The mean value for Ubon Ratchathani was a half the value (6.0 mm/day) for the same area reported by Fukai et al. (1995); however, this high value was similar to the maximum value determined in this study (5.1 mm/day). Percolation rates at three (top, middle and bottom) positions of the toposequence for Sonkhon, Laos were 3.3, 2.6 and 1.9 mm/day, respectively. Thus, the higher position in the topoesquence, the greater percolation loss, which may be related to its lighter soil texture.

Table 1. Percolation and lateral water flow (mm/day) for the Thailand experiments.

Location	(a) Percolation				(b) Lateral water flow			
	Min	Max	Mean	SD	Min	Max	Mean	SD
Chum Phae	0.5	0.8	0.6	0.2	-38.4	52.8	0.8	9.8
Khon Kaen/Ta Pra	0.5	3.3	1.7	1.4	-73.1	46.8	-0.1	16.2
Phimai	1.2	2.7	1.9	0.8	-71.3	20.8	-3.5	11.9
Surin	1.2	2.0	1.6	0.3	-151.7	113.0	1.9	28.2
Ubon Ratchathani	1.4	5.1	3.0	1.6	-50.3	69.6	2.2	19.1

Lateral water flow

The lateral water flow for five locations of Thailand is presented in Table 1b. Mean values indicate that Chum Phae, Surin and Ubon Ratchathani had net water loss/outflow (positive values); in contrast, Khon Kaen/Ta Pra and Phimai had net water gain/inflow (negative values). The means and standard deviations ranged between –3.5 and 2.2 mm/day and between 9.8 and 28.2 mm/day, respectively. The high standard deviation indicates high variation in the lateral water movement during the season, as lateral flow rate varied greatly with rainfall events. The averaged maximum value for the five locations was very high (60 mm/day). Similarly, the high value of the lateral water outflow was reported by Tuong et al. (1994); they referred to the lateral water outflow as the under-bund percolation loss. Concerning the toposequential variation, means ? standard deviations for high and low positions of the toposequence at Khon Kaen/Ta Pra were –0.9 ? 9.8 mm/day and –4.0 ? 17.6 mm/day, respectively. Although the standard deviation is high, the mean values imply that the low position have high potential of the lateral water inflow.

Conclusion

In this paper, a method of quantifying components of the water balance in sloped paddy fields was described. Percolation rate determined in this study agrees with the previously reported values. The maximum values of the lateral water flow were very high, and a similar result was previously reported. With reference to the toposequential variation, the higher the position on the sloped land, the greater the potential of the water losses. In other words, there is high water availability at the lower positions. In fact, this has been observed at paddy fields on sloped land.

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