In August, the increase in $\delta^{18}$O was much smaller than in May and June, while the slope of EL was largest, although evapotranspiration determined by eddy correlation was relatively similar (3–5 mm day$^{-1}$ for all months). Comparing the condition of plant growth in these months, the values of LAI in the paddy field were 0.05, 0.73, and 5.16 m$^2$ m$^{-2}$, respectively. The much larger LAI in August than in the other months implies that active transpiration and the depression of evaporative loss by the grown rice canopy would occur. Under such conditions, transpiration from the rice canopy must be predominant. By transpiration, indeed, isotope fractionation occurs between the water in a leaf and the transpired vapor, but the isotopically enriched leaf water is never brought back to the ponded water. Consequently, the isotope composition of paddy water in August changed little in contrast to May and June, when significant evaporation considerably advanced the isotopic enrichment.

## Conclusions and future studies

As a result of this study, it was suggested that isotopic enrichment of paddy water is closely related to direct evaporation of ponded water, rather than the total evapotranspiration from the paddy field. This supports the possibility to separate evaporation and transpiration using the isotope hydrological approach, usually impossible by micrometeorological measurements. For more detailed and quantitative analysis, we conducted intensive field observations of water balance and the collection of water samples in the same paddy field during rice cultivation in 2004. Based on the data, we intend to examine the relationship among the isotope composition of paddy water, the components of water balance, and the stage of rice growth more precisely, and to construct an isotope hydrological model that can calculate the ratio of evaporation vs transpiration from a paddy field, considering the influences of rainfall and relatively complex irrigation management.

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## Notes

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# Erosion control by *sawah* in comparison to other land-use systems

Fahmuddin Agus and Irawan

*Sawah*, also known as a paddy field, has been sustainably producing rice, the staple food for most Indonesians, for hundreds or perhaps even thousands of years. Its other functions, especially in producing environmental services, are indispensable, yet have not been recognized or are ignored by most stakeholders.

Sawah areas are characterized by high population density and perfectly flat plots. The sawah plot size is usually small, especially on sloping land. As such, sawah farming has low efficiency, resulting in low profitability. Low-incentive sawah farming results in accelerating conversion of sawah to nonagricultural uses.

This study evaluated the environmental functions, especially soil loss and water-retaining capacity, of sawah relative to other land uses in Java in 2001. The results are important for advocating internalization of environmental services produced by sawah in national land-use-related policies, such that the existence of sawah with its multifunctionality can be maintained.

## Objective

The objectives of this study were to assess soil loss and water retention capacity (as an indicator of flood mitigation function) of sawah relative to that of other land-use systems.

## Materials and methods

### Location

Erosion from sawah was measured in Ungaran (07°20′S; 110°E), Central Java Province. The soil subgroup in the sawah area was classified as Typic Tropaquepts. A water retention study was conducted in the Upper Citarum Watershed (6°40′30″–7°15′00″S; 107°30′00″–107°55′00″E), West Java

Province. The dominant soil groups in the watershed are Eutrudepts, Dystrudepts, and Hapludalfs in uplands and Endoaquepts and Dystrudepts in lowlands (sawah).

### Erosion and sedimentation

For sawah, soil loss was measured in two rice seasons from 18 plots of terraced sawahs, ranging in area from 12 to 360 m$^2$, with a total area of 2,515 m$^2$. The macro slope of these terraces is 22%. The average elevation difference between plots was 73 cm.

V-notch weirs were installed at the outlets of selected plots to determine water level and discharge from the irrigation canal to the upper sawah plot, from one sawah to consecutive lower ones, and from the lowest sawah to the stream. Sediment concentrations were determined from water samples by the gravimetric technique.

For the upland farming systems, sediment yield data were obtained from the literature.

### Water retention capacity

Water retention capacity (WRC) is watershed capacity to absorb and hold (rain) water temporarily such that the portion of water does not flow as direct runoff (Nishio 1999). This includes water intercepted by plants' canopy, ponded on soil surface, absorbed by soil pores, and additional water that could be stored by paddy fields and dams.

Paddy fields surrounded by dikes temporarily store water at times of heavy rain, and discharge it gradually into downstream rivers and surrounding areas. In this way, they function as mini dams and thus hold water in the plots which would otherwise flow directly downstream, which might in turn contribute to flooding.

Upland fields, on the other hand, store rainwater temporarily in the porous soil layer as well as intercept rainwater in the plant canopy. Some temporary ponding of water occurs on the soil surface because of its roughness.

To understand the contribution of each land use, the WRC of each land use was assessed separately. For sawah, WRC was estimated by the difference between dike height (which is normally 12–15 cm) and normal water level (usually 0.05 m). For the upland systems, WRC was assessed by summing the canopy interception, soil surface ponding capacity, and soil pore absorption capacity, using the equation

$$WRC = (TPS - FC)*AZ + PC + IC$$

where TPS is the percentage of total soil pore space, FC is the percentage of soil water content at field capacity, AZ is the depth of absorption zone or rooting zone, PC is surface ponding capacity, and IC is plant canopy interception capacity.

## Results

### Erosion and sedimentation

Table 1 summarizes the measurement of sediment transport. The two-season data show that there was a net sediment gain in paddy fields as high as 2.0 t ha$^{-1}$ in the first season and 5.4 t ha$^{-1}$ in the second season. Sediment output from the plots is relatively high during the plowing and puddling periods but the sediment transported from one plot is mostly deposited in the next few lower plots and thus the net output of sediment at the end of the terraces is very low (about 2.2 t ha$^{-1}$ y$^{-1}$ during the two seasons). In comparison, sediment output was 10–20 t ha$^{-1}$ y$^{-1}$ from a 1.1-ha catchment planted to annual upland crops at a nearby location (Agus et al 2003). Similar research results in Indonesia (van Dijk 2002) suggested that sediment transported from rainforest and logged pine plantation forest is very low (3–7 t ha$^{-1}$ y$^{-1}$) compared to upland agricultural land uses, such as multistrata agriculture (10–12 t ha$^{-1}$ y$^{-1}$), annual crop-based agriculture on bench terraces (19–25 t ha$^{-1}$ y$^{-1}$), and vegetables on steep slopes with terraces (42–75 t ha$^{-1}$ y$^{-1}$). Therefore, it can be stated that the function of sawah in reducing soil erosion and sedimentation is more effective than, or at least is as effective as, forest.

**Table 1. Amount of sediment entering and leaving 18 plots of terraced sawah.**

| Variable | Rice season | |
|---|---|---|
| | First[a] | Second[b] |
| Total sediment entering sawah from irrigation canal (t ha$^{-1}$) | 3.4 | 6.2 |
| Sediment yield from sawah (t ha$^{-1}$) | 1.4 | 0.8 |
| Sediment yield from sawah during tillage (t ha$^{-1}$) | 0.7 | 0.6 |
| Net sediment deposition (t ha$^{-1}$) | 2.0 | 5.4 |

[a]31 Oct. 2001 to 31 Jan. 2002. [b]16 Mar. 2002 to 1 July 2002.

### Water retention capacity

The water retention capacity of different land uses at Citarum Watershed, West Java, is presented in Figure 1. The data show that forest and mixed cropping (tree-based multistrata system) in this study area had a WRC of about 0.15 and 0.09 m, respectively. Meanwhile, the WRC of paddy field, annual upland, and housing and industrial areas was 0.08, 0.06, and 0.02 m, respectively. This means that during and shortly after heavy rain 1 ha of forest and sawah can store, respectively, about 1,500 and 800 m$^3$ of water before runoff takes place. The capacity of sawah to retain water is much higher than that of annual upland and housing and industrial areas of 600 and 200 m$^3$ ha$^{-1}$. Therefore, it can be stated that, if more sawah and upland agricultural lands are converted to housing and industrial development, the same amount of rainfall will cause greater runoff, and will finally cause a higher chance of flood.

Similar research in Japan showed that the average WRC for forest, sawah, orchard, grassland, and dry cropland was 0.18, 0.15, 0.11, 0.02, and 0.04 m, respectively (Nishio 1999).

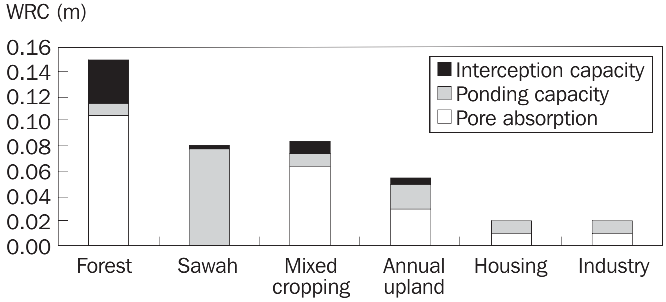

**Fig. 1. Water retention capacity (WRC) of sawah and other land-use systems.**

## Conclusions

Sawah is superior in controlling erosion to other land uses. Erosion mainly happens in sawah during and shortly after tillage operations.

The capacity of sawah to retain water during and shortly after rainfall is comparable with that of the tree-based mixed cropping system and significantly higher than that of annual crop-based and housing and industrial areas. Policy measures should be implemented to maintain the existence of sawah considering the significant environmental services it can offer, in addition to its tangible role as a rice producer.

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# Wrap-up of Session 12

Although it is recognized that the cultivation of paddy rice sustains soil fertility, there is a large area whose fertility of soil is still low. Therefore, it is necessary to increase both the sustainability and productivity of these soils urgently. One of the main themes of the conference is "the development of sustainable rice cultivation based on environment and food security." In this session, this theme was discussed from the viewpoint of soil and water conservation.

Participants entered into "the world of paddy soils" with the presentation of Prof. K. Kyuma (Japan). His keynote lecture was "Paddy soils around the world." Based on his more than 40 years' experience in the field of paddy soil science, he emphasized the importance of diversity of paddy soil and its environment.

Diversity and sustainability of paddy soils were discussed by N. Ngoc Hung (Vietnam), K. Naklang (Thailand), and T. Wakatsuki (Japan). N. Ngoc Hung reported on the current status of soil fertility in the Mekong Delta of Vietnam. He pointed out some problems in fertility such as nitrogen (N) loss through ammonium volatilization. In contrast to the relatively fertile Mekong Delta, the paddy soils in northeastern Thailand are very infertile. K. Naklang introduced her long-term field trials, and discussed the effect of organic matter application on the improvement of soil fertility. T. Wakatsuki reported that the area with lowland rice farming has increased in West Africa. He predicted that a Green Revolution with paddy rice farming would take place in this area with the proper integration of forestry, upland farming, and lowland rice farming.

To optimize fertilizer management in such diverse paddy soils, C. Witt (Singapore) proposed an effective and site-specific management of nutrients on the basis of his field trials with fertilizer application.

Recently in China, rice yield has increased dramatically with the increase in fertilizer application. However, the amount of application for rice exceeds the requirement. As a result of this imbalance, N pollution is becoming a serious environmental problem. J. Zhu (China) evaluated the environmental impact of N loss under the wheat-rice system in the region around Taihu Lake. To solve this problem, it is necessary to increase the recovery of N from fertilizer urgently. M. Saigusa (Japan) reported that the application of polyolefin-coated urea, which was used as a controlled-availability fertilizer (CAF), improved N recovery. The invention of CAF now enables a *co-situs* application (contact application of fertilizer with plant roots) and that is improving the efficiency of fertilizer, environmental loading from fertilizer, and so on. W. Bowen (Bangladesh) also reported a good recovery of N from fertilizer with the deep placement of supergranule urea for lowland rice in Bangladesh.

D. Olk (USA) indicated that the yield decline caused by intensive rice cropping under continuously flooded conditions was