Indonesian Journal of Agricultural Science 11(2), 2010: 57-64

SEDIMENT TRAPPING BY TERRACED PADDY FIELD ON SLOPPING AGRICULTURAL LAND

Sukristiyonubowo[a], D. Gabriels[b], and M. Verloo[c]

[a]*Indonesian Soil Research Institute, Jalan Ir. H. Juanda No. 98, Bogor 16123, Indonesia*
Phone +62 251 8336757, Facs. +62 251 8321608, E-mail: balittanah@litbang.deptan.go.id
[b]*Department of Soil Management and Soil Care, Faculty of Bio Sciences Engineering, Ghent University, Coupure Links 653 Ghent-9000, Belgium*
[c]*Department of Applied Analytical and Physical Chemistry, Faculty of Bio Sciences Engineering, Ghent University, Coupure Links 653 Ghent-9000, Belgium*
Corresponding Author: Phone +62 899 5293743, Facs. +62 251 8321608, E-mail: Sukristiyonubowo@yahoo.com

Submitted 13 August 2009; Accepted 11 July 2010

ABSTRACT

Terraced paddy field is not only important for rural food security, but also for trapping sediment in the slopping land. The aims of this research were to quantify the amount of incoming and outgoing sediments and to study sediment movement behavior during harrowing and fertilizing under traditional irrigation of terraced paddy field system. This study was carried out at Keji Village, Semarang District, Central Java during two cropping seasons, a wet season 2003/04 and a dry season 2004. A paddy field with eight terraces was selected. The terraces were flat, different in size and descending to the river. Sediment samples were taken at harrowing and fertilizing activities. The results indicated that at harrowing, outgoing sediment was higher than incoming both during the wet and the dry seasons. About 0.53 and 0.27 t ha^{-1} day^{-1} of soil were eroded during harrowing in the wet and the dry seasons, respectively. However, a week before and after fertilizing, both in the wet and the dry seasons, the amounts of incoming sediment were higher than the outgoing one. In the wet season, the amounts of incoming sediments were three to four times higher than the outgoing one, both a week before and after fertilizing. During the wet season, about 0.31 and 0.34 t ha^{-1} day^{-1} of sediment was yielded a week before and after fertilizing, respectively. During the dry season, the incoming sediments were ten times higher than the outgoing one. On an average the sediment yields were about 0.07 and 0.08 t ha^{-1} day^{-1} a week before and after fertilizing, respectively. Terraces having greater areas deposited more sediment than those with smaller sizes. During a week before and after first fertilizing, the total amounts of incoming sediments were 6.44 and 1.19 t ha^{-1} for the wet and dry seasons, while that of outgoing sediments were 1.89 and 0.14 t ha^{-1} for the wet and dry seasons, respectively. This indicates that terraced paddy fields are not only producing rice, but also providing environmental service in term of sediment trapping. This external service minimizes sedimentation in the downstream.

[***Keywords***: Sedimentation, harrowing, fertilising, terraced paddy field, sediment trapping]

INTRODUCTION

In Indonesia, paddy fields are not only producing rice, but also a source of employment and income for most villagers. Recently, Agus *et al.* (2006) suggested that terraced paddy fields also have environmental functions such as sedimentation reduction. Increasing land demand for housing, industrial areas, roads, and other infrastructures in Indonesia resulted in shrinking of paddy field areas to cultivate rice and at the same time, the environmental services that they provide also decrease.

It is estimated that about 15-20% of Indonesian paddy fields are on slopping areas. Improving land management of terraced paddy fields does not only contribute to food security and increase farmers' income, but also creates a better environment.

Transplanting is the most common planting system in paddy field during which soft and muddy soil structure is desirable. The dispersed soil structure is easily flowing with water during this period. However, during most time of growing season, the soil particles are settled and water flowing from the terraced paddy field is not loaded with soil particles.

Water is usually added starting from land preparation to generative phase and is stopped when rice is entering ripening stage. About 45-50% of diverted fresh water is allocated to irrigate rice (Bouman and Tuong 2001; Cabangon *et al.* 2002; Kukal and Sidhu 2004). More than half of the water input to produce rice is allocated to land preparation. The water required for land preparation is about 150-200 mm, but it can increase up to 650-900 mm (De Datta 1981; Bhuiyan *et al.* 1994). In terraced paddy field systems, during harrowing the water input is about 95-112 mm (Sukristiyonubowo *et al.* 2003, 2004).

Erosion including from sloping land has been identified as a serious environmental problem requiring expanded research (Lal *et al.* 1998; Agus and Sukristiyonubowo 2002; Duque *et al.* 2002; Phommassack *et al.* 2002; Sojka *et al.* 1992; Toan *et al.* 2002; Agus *et al.* 2003; Sukristiyonubowo *et al.* 2003). The terrace and dyke architecture of paddy fields on sloping areas potentially trap most of sediments. Therefore, it is interesting to study incoming and outgoing sediments in the wetland rice farming systems. Tarigan and Sinukaban (2001) reported that besides land preparation, important activities such as weeding and fertilizing should also be taken into account to determine in and out flowing sediments from terraced paddy field.

The land preparation, usually called puddling, generally consists of land soaking, ploughing, and harrowing. The intensity of puddling varies among farmers and villages. In traditional rice growing areas, like in Keji Village, Semarang District, Central Java, two ploughings and one harrowing under submerged condition are carried out. Ploughing is usually done by hoe and harrowing by using animal drawn harrow. Puddling breaks down and dispersed soil aggregates into micro-aggregates and individual particles resulting in soft muddy conditions before transplanting takes place. The aims of puddling are to reduce the loss of water and nutrients through excessive percolation, to control weeds, to soften the soil, to create land levelling, to uniform water depth, and to facilitate transplanting. The effect of puddling on soil physical and chemical properties as well as on rice yield has been studied and reported, although the effect of puddling on rice yield is still unclear (Adachi 1990; Cabangon and Tuong 2000; Kirchhof *et al.* 2000; Kukal and Aggarwal 2003; Kukal and Sidhu 2004; Sharma *et al.* 2005). During harrowing, the main inlet and main outlet (outlet of the last terrace) are opened causing removal of soil particles and nutrients from the paddy field. During the rice growing period, water is allowed to go in and out through inlet and outlet systems. This also allows transporting of sediments and nutrients.

The objectives of this research were to quantify incoming and outgoing sediments and to study sediment movement at harrowing and fertilizing in a terraced paddy field under traditional irrigation system. It was hypothesized that terraced paddy fields function as sediment trap, and thus reducing the net sediment outflow to the downstream.

MATERIALS AND METHODS

The experiment was conducted at a terraced paddy field located in the valley bottom of the Babon meso catchment in Keji Village, Ungaran Subdistrict, Semarang District, Central Java. Eight terraces were selected for this study. The terraces were flat, different in size, and descending to the river (Fig. 1). The total area is about 904 m^2. Outlets with a V-notch weir were placed on each successive terrace arranged alternately on the left, centre and right descending to the river (Fig. 2).

Land use in the immediate upper slope of this experiment site was rambutan (*Nephelium lappaceum*) and clove (*Eugenia aromatica*) plantations. During the experiment, encroachments of cassava farming were taking place in the floor of rambutan plantation causing about 20% of rambutan floor relatively free from understory vegetation. This caused a greater exposure of the rambutan floor to through fall and canopy drops. This exposed area may have been the major source of sediment load of the experimental paddy field inlet.

Water velocity, water discharge, and sediment concentration in irrigation water and runoff water were

Fig. 1. General view of terraced paddy field systems in Keji Village, Semarang District, Central Java (T1-T8 indicate the studied terraces).

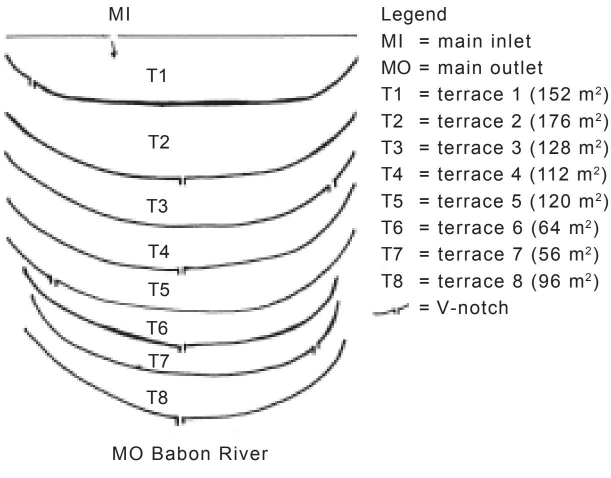

Fig. 2. Scheme of placing 90° V-notch in every terrace of paddy field systems in Keji Village, Semarang District, Central Java.

measured for the wet season (WS) 2003/04 and the dry season (DS) 2004 during harrowing and fertilizing activities (Tarigan and Sinukaban 2001; Sukristiyonubowo *et al.* 2003, 2004). The ploughing, harrowing, irrigation, drainage, and fertilizing were fully based on farmers' practices. The only intervention was placing a 90° V-notch weir at every terrace's outlet to accurately measure water discharge and to facilitate sampling of sediment runoff.

Land Preparation

In the WS 2003/04, harrowing was carried out on 27 December 2003 and in the DS 2004 on 8 May 2004 using a harrow drawn by two heads of buffaloes. The works started one day after the second ploughing, from 07:00 to 14:30 beginning at the top terrace. In the first ploughing, the surface soils for planting areas as well as the dykes were cleaned from the weed. Rice stubbles were ploughed under during ploughing. The second ploughing was mainly done for breaking down soil clods. Harrowing was done under submerged condition to break soil clods into smaller aggregates and then into muddy structure, create land levelling and finally to facilitate transplanting. The two-time ploughing and one harrowing significantly puddles the soils, but this does not happen during fertilizing.

Sampling at Land Preparation

Irrigation water and suspended sediments were sampled at every terrace starting from the main inlet to the main outlet. Samples were collected every 30 minutes starting when the first runoff sediment passed the V-notch of the first terrace's outlet and ending when the color of outgoing water was almost the same as the color of incoming water passing the inlet. This was done continually and simultaneously from the second to the last terrace, where the sediment runoff entered to the river. At each sampling time, two 600-ml plastic bottles were filled with the sediment laden runoff water.

Sampling at Fertilizing

During rice growing period, fertilizers have been applied two times, at 21 and 35 days after transplanting. Urea of 50 kg ha^{-1} season^{-1} and 33% of previous season rice straw production was applied. One day before fertilizing, the water was drained from the field by closing the main inlet and opening the main outlet. Two days after fertilizing, both the main inlet and main outlet were opened for a week. Afterwards, the main outlet was closed to increase the water level to about 5-7 cm of each terrace. Then incoming water was stopped by closing the main inlet.

Monitoring of sediment at fertilizing time was conducted during a week before and a week after fertilizing and done only during first fertilizing. Irrigation and runoff water of each terrace were sampled three times a day at 08:00, 12:00, and 16:00 o'clock for six days. These interval times coincided with the daily water level monitoring of canals and main river for hydrological purposes. Water samples were also collected in two 600-ml plastic bottles.

Measurement of Discharge

To estimate the amounts of incoming and outgoing sediments in each terrace, water discharge has to be known. At harrowing, water discharges of the main inlet and outlet of each terrace were measured every 30 minutes and at fertilizing three times daily at 08:00, 12:00, and 16:00 o'clock after sampling both irrigation water and runoff sediment.

For measuring the discharge of the main inlet, floating method with stopwatch was used. According to WMO (1994), measurement of discharge by the floating method is applied when the use of a current meter is impossible because of unsuitable water velocity or canal depths, presence of material in suspension, and when discharge measurement must be made in a very short time. In this experiment, the cross section of the canal was 150 cm wide x 60 cm deep. Discharge was calculated as follows (Sukristiyonubowo 2007, 2008):

$$Q = \frac{L \times W \times H}{t} \quad \text{.......................................} \quad (1)$$

Notes:

Q = discharge (m^3 second^{-1})

L = length or distance (m) of the float travelling during time

W = canal width (m)

H = water level (m)

t = time (second)

$$\text{as } \frac{L}{t} \text{ is velocity (V) ....} \quad (2)$$

W x H is the cross section of the canal (a) .... (3)

$$Q = V \times a \quad \text{..............................} \quad (4)$$

Discharges into other terraces including main outlet were determined by the bucket method. Eight buckets of 11-liter capacity were used. The volume of each bucket was calibrated before being used. In the bucket method, the time required by the runoff to reach 11-liter volumes was recorded. Every measurement was replicated three times. The discharge rate was calculated by dividing the volume of water in the bucket with the time to reach the volume.

Determining Sediment Yield

Net sediment yield was calculated as the differences between sediment inputs and outputs. When the difference between incoming and outgoing sediments is positive (+) it means the sediment is deposited, however, when the difference is negative (-), it means the sediment is transported to the lower terraces. Sediment concentration is determined in the laboratory, according to Ceisiolka and Rose (1998) as follow:

$$\text{Sediment concentration (s)} = \frac{\text{oven dry mass sediment}}{\text{volume of sediment + water}} \quad \text{... (5)}$$

Total incoming or outgoing water or volume (A) = Q x t .... (6)

Where Q is discharge (m^3 $second^{-1}$) and t is time (second)

From the equations 5 and 6, suspended load or soil loss is calculated.
Suspended load or soil loss (S) = A x s .... (7)

Notes:
S = soil loss (kg)
A = volume (m^3)
s = sediment concentration ($g\ l^{-1}$)

RESULTS AND DISCUSSION

Incoming and Outgoing Sediments at Land Preparation

Data of incoming and outgoing sediments indicated that at land preparation, especially at harrowing, the incoming sediment was lower than the outgoing one both during the wet and dry seasons. It means that during these activities, sediments from the paddy field were carried by runoff to the river. The travelling distance from one terrace to another combined with the water discharge greatly affected the amount of soil loss. About 0.53 and 0.27 t ha^{-1} day^{-1} of soils were eroded during harrowing in the WS 2003/04 and DS 2004, respectively (Fig. 3).

The result also suggests that the total soil loss in WS 2003/04 was two times higher than that of DS 2004. High rainfall that occurred in the middle of harrowing caused splash erosion, both at planting areas and dykes, resulting in more soil dispersion and a higher amount of eroded soil in the runoff water.

Interestingly, every terrace showed a different behavior in transporting and redeposition of sediments (Fig. 4 and 5). Other scientists provided confirmation that the amount of sediments and nutrient movements from agricultural fields are influenced by climate, soil, topography, catchment size, land use, and management practices (Lal *et al*. 1998; Agus *et al.* 2003).

The first terrace (T1) and the last terrace (T8) are most susceptible to soil loss both in wet and dry seasons. However, in the WS 2003/04, T4 presented the high soil loss. This may be explained by (1) the harrowing was started at T1; (2) during harrowing, the water discharges of the main inlet and outlet of T1 were the highest causing more sediment runoff; (3) for T1 the total incoming sediment was smaller than outgoing; and (4) for T8 the incoming runoff sediment from T7 was re-dispersed during harrowing and directly went to the river along with the sediment of T8.

In case of terrace 4, the high soil loss during the WS 2003/04 may be explained by the intensity and duration of high rain events (about 54.0 and 59.6 mm in about 20 minutes, respectively) taking place during harrowing. These events caused splash erosion to bare lands both at planting areas and dyke thus causing more eroded soil in the runoff sediment. In

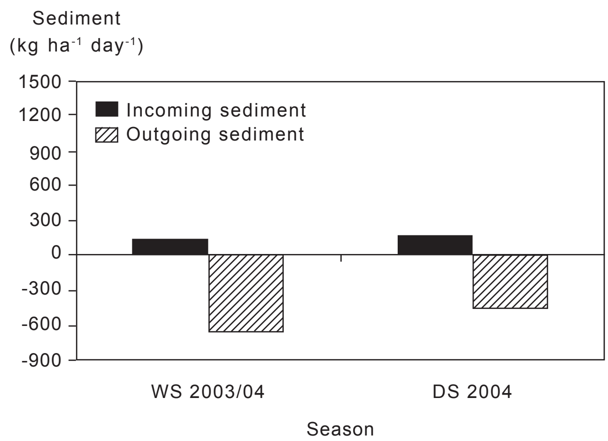

Fig. 3. Incoming and outgoing sediments in a terraced paddy field under traditional irrigation systems at harrowing, Keji Village, Semarang Distric, Central Java, wet season (WS) 2003/04 and dry season (DS) 2004.

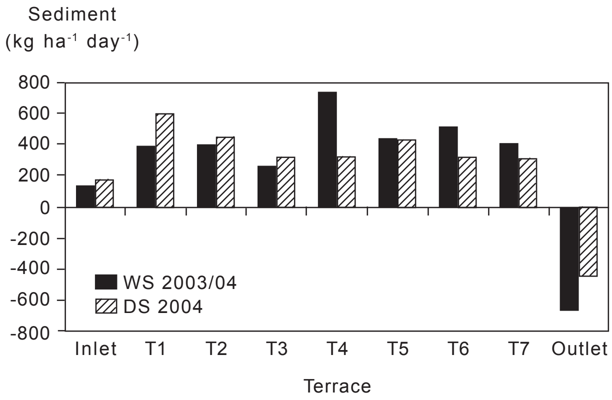

Fig. 4. Incoming and outgoing sediments in each terrace of paddy field system at harrowing, Keji Village, Semarang Distric, Central Java, wet season DS 2003/04 and dry season DS 2004.

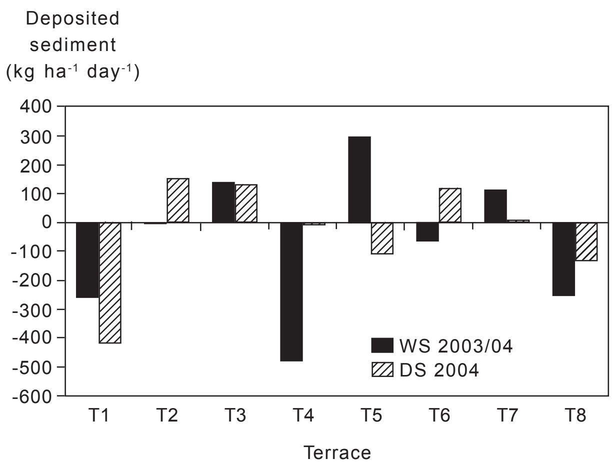

Fig. 5. Deposited (+) and transported (-) sediments in every terrace of paddy field system at harrowing, Keji Village, Semarang Distric, Central Java, wet season (WS) 2003/04 and the dry season (DS) 2004.

addition, the high rainfall also increased the discharge of T4, from 0.49 to 2.93 liters second^{-1} and sediment concentration from 190 to 495 mg liter^{-1}, respectively. For T1, T2 and T3, the impact was minimal because the sediment was already settled and pounding water had reached about 4 cm layer; thick enough to protect the puddled soil from rain drop impact.

Incoming and Outgoing Sediments During Fertilizing

Different from the measurement at harrowing, fertilizing was carried out without any significant disturbance to the soil. The rainfall, fertilizer application, and activities done upstream dominantly influenced the amount of incoming and outgoing sediments. During the monitoring period, precipitation was very high (152 mm), resulting in increased water velocity, discharge, erosions (splash, farm road and dyke erosions), and sediment movement. Hence, in WS 2003/04, incoming sediment was higher than outgoing one both during a week before and after fertilizing. On average, incoming sediments were three to four times higher than the outgoing. About 0.31 and 0.34 t ha^{-1} day^{-1} sediments were deposited on the terraced paddy field from the incoming sediment loads of 0.41 and 0.51 t ha^{-1} day^{-1} (Fig. 6 and 7).

Sediment transport is closely related to the rainfall intensity. When the rain occurred upstream, the incoming sediment load (measured at the main inlet) also increased. When the rain happened on the site, the outgoing sediment load (measured at the main outlet) increased, but when the rain fell both upstream and on the site, both the incoming and outgoing sediment loads increased. The relationship between rainfall and sediment transport may be expressed as $Y = 26.548 + 0.059 X + 0.011 X^2$ ($r^2 = 0.962$), where X is rainfall in mm and Y is outgoing sediment in kg ha^{-1} day^{-1}.

A similar deposition pattern was shown in the DS 2004 both during a week before and after fertilizing. The amounts of incoming sediments were ten times higher than outgoing. On average, the sediment amounts deposited were about 0.07 and 0.08 t ha^{-1} day^{-1}, from the average incoming sediment loads of 0.08 and 0.09 t ha^{-1} day^{-1} (Fig. 8 and 9).

The sediment movement behavior in every terrace, during a week before and after fertilizing, showed

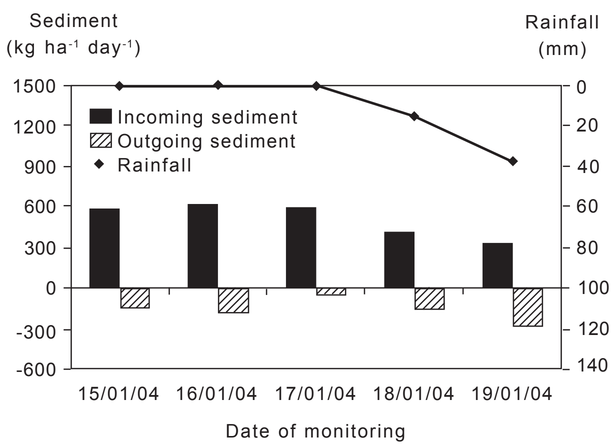

Fig. 6. Incoming and outgoing sediments in the terraced paddy field system during a week before first fertilizing, Keji Village, Semarang Distric, Central Java, wet season 2003/04.

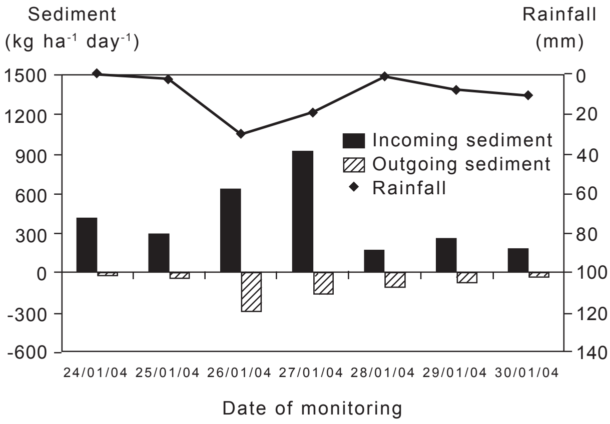

Fig. 7. Incoming and outgoing sediments in the terraced paddy field system during a week after the first fertilizing, Keji Village, Semarang Distric, Central Java, wet season 2003/04.

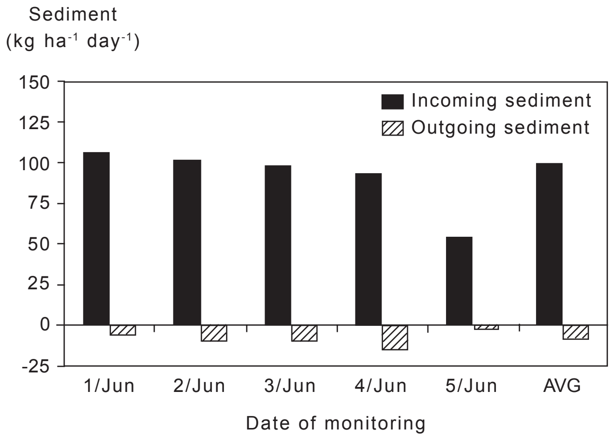

Fig. 8. Incoming and outgoing sediments in the terraced paddy field system during a week before the first fertilizing, Keji Village, Semarang Distric, Central Java, dry season 2004.

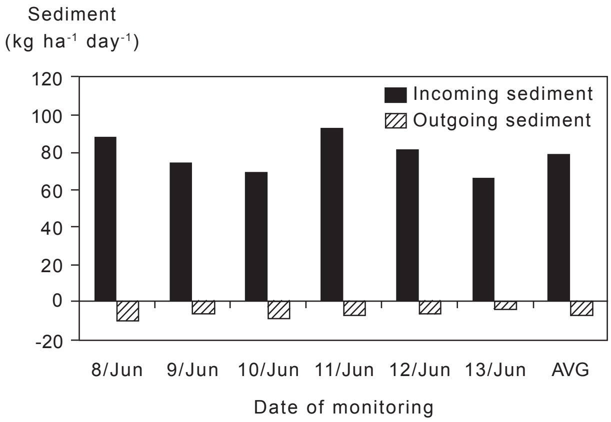

Fig. 9. Incoming and outgoing sediments in the terraced paddy field system during a week after the first fertilizing, Keji Village, Semarang Distric, Central Java, dry season 2004.

great differences in sediment deposition compared to at the harrowing. Terraces with greater sizes had less impact from rainfall resulting in less sediment transported and more sediment deposited (Fig. 10 and 11).

Compared to the WS 2003/04, in the DS 2004 the re-deposited sediment in each terrace was completely different both during a week before and after fertilizing. During the DS 2004, sediments were transported and trapped proportionally in every terrace. Runoff sediment was not observed, yielding in positive balance of sediment in every terrace (Fig. 10).

From the results a week before and after fertilizing, we conclude that a terraced paddy field system reduced the negative impact of erosion by trapping

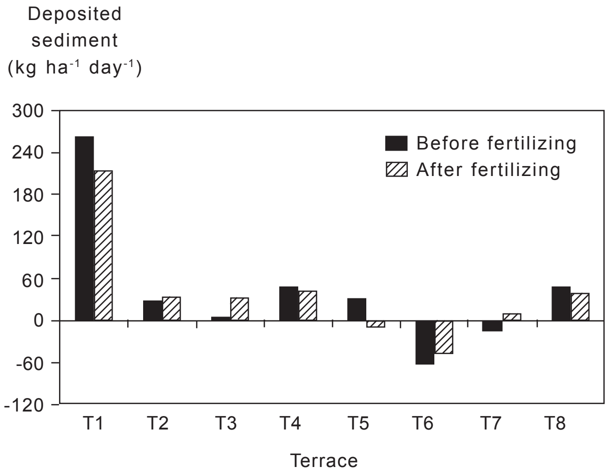

Fig. 10. Average deposited (+) and transported (-) sediments from each terrace of paddy field system measured during a week before and after the first fertilizing, Keji Village, Semarang Distric, Central Java, wet season 2003/04.

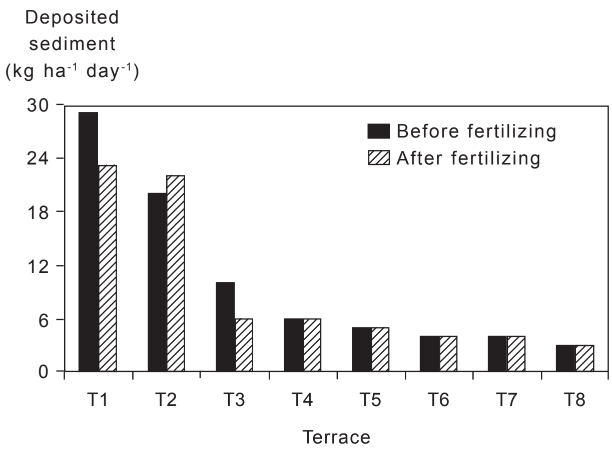

Fig. 11. Average deposited (+) sediments into each terrace of paddy field system during a week before and after the first fertilizing, Keji Village, Semarang Distric, Central Java, dry season 2004.

sediments. The sediment transported and trapped to every terrace indicated the way terracing system minimized the downstream effect. The amounts of sediments moved and deposited in each terrace depend on rainfall, size and position of terraces, travelling distance, and activities carried out upstream. The total sediments deposited during a week before and after fertilizing were 4.5 and 1.1 t ha^{-1} for the WS 2003/04 and DS 2004, respectively.

CONCLUSION

Harrowing of terraced rice field both in the WS 2003/04 and DS 2004 increased sediment transport. On the contrary, during a week before and after fertilizing, sediments were deposited in every terrace. In the wet season, the amounts of mean incoming sediments were three to four times higher than the outgoing both during a week before and after fertilizing. Meanwhile, during the dry season the incoming sediments were ten times higher than the outgoing. On average, the sediments deposited were 0.07-0.08 t ha^{-1} day^{-1} from the incoming sediment loads of 0.08-0.09 t ha^{-1} day^{-1} measured during a week before and after fertilizing.

Every terrace presented different behaviors in transporting and trapping the sediments. The larger the terraces the more sediments are deposited. The longer the distance from the outlet, the less sediment transported. Thus, terraced paddy fields are effective in reducing sediment outflow to downstream areas. As the erosion mostly occurs during harrowing and tillage, we recommend that water input be reduced during these operations to reduce the amount of sediments transported to the downstream.

REFERENCES

Adachi, K. 1990. Effect of rice-soil puddling on water percolation. p. 146-151. *In* Proceedings of the Transactions of the 14th International Congress on Soil Science Vol. I. ISSS, Kyoto, Japan.

Agus, F. and Sukristiyonubowo. 2002. Nutrient loss and on site cost of soil erosion under different land use systems in South East Asia. *In* Integrated Catchment Management for Land and Water Conservation and Sustainable Agricultural Production in Asia. CD-ROM. IWMI, Colombo, Sri Lanka.

Agus, F., T. Vadari, R.L.Watung, Sukristiyonubowo, and C. Valentin. 2003. Effects of land use and management systems on water and sediment yields: Evaluation from several microcatchments in Southeast Asia. p. 135-149. *In* A.R. Maglinao, C. Valentin, and F.P. de Vries (Eds.). From Soil Research to Land and Water Management: Harmonising people and nature. Proceedings of the IWMI-ADB Project Annual Meeting and 7th MSEC Assembly.

Agus, F., U. Kurnia, and A.R. Nurmanaf (Eds.). 2006. Proceeding of National Seminar on the Multifunction of Sawah. Pusat Penelitian dan Pengembangan Tanah dan Agroklimat, Bogor, Indonesia. 147 pp. (in Indonesian).

Bhuiyan, S.I., M.A. Sattar, and D.F. Tabbal. 1994. Wet seeded rice: water use efficiency, productivity and constraints to wider adoption. Paper presented at the International Workshop on Constraints, Opportunities, and Innovations for Wet Seeded, 31 May-3 June 1994, Rice, Bangkok. 19 pp.

Bouman, B.A.M. and T.P. Tuong. 2001. Field water management to save water and increase its productivity in irrigated lowland rice. Agric. Water Mgmt. 49: 11-30.

Cabangon, R.J. and T.P. Tuong. 2000. Management of cracked soils for water saving during land preparation for rice cultivation. Soil Tillage Res. 56: 105-116.

Cabangon, R.J., T.P. Tuong, and N.B. Abdullah. 2002. Comparing water input and water productivity of transplanted and direct-seeded rice production systems. Agric. Water Mgmt. 57: 11-31.

Ceisiolka, C.A.A. and C.W. Rose. 1998. The measurement of soil erosion. p. 287-302. *In* Soil Erosion at Multiple Scale. Principles and Methods for Assessing Causes and Impacts. CABI Publishing in Association with IBSRAM.

De Datta, S.K. 1981. Principles and Practices of Rice Production. John Wiley, New York.

Duque Sr, C.M., R.O. Ilao, L.E. Tiongco, R.S. Quita, N.V. Carpina, B. Santos, and T. de Guzman. 2002. Management of soil erosion consortium: An innovative approach to sustainable land management in the Philippines. MSEC-Philippines Annual Report. *In* Integrated Catchment Management for Land and Water Conservation and Sustainable Agricultural Production in Asia. CD-ROM. IWMI, Colombo, Sri Lanka.

Kirchhof, G., S. Priyono, W.H. Utomo, T. Adisarwanto, E.V. Dacanay, and H.B. So. 2000. The effect of soil puddling on the soil physical properties and the growth of rice and post-rice crops. Soil Tillage Res. 56: 37-50.

Kukal, S.S. and G.C. Aggarwal. 2003. Puddling depth and intensity effects in rice-wheat system on a sandy loam soil. I. Development of subsurface compaction. Soil Tillage Res. 72: 1-8.

Kukal, S.S. and A.S. Sidhu. 2004. Percolation losses of water in relation to pre-puddling tillage and puddling intensity in a puddle sandy loam rice (*Oryza sativa* L.) field. Soil Tillage Res. 78: 1-8.

Lal, R., F.P. Miller, and T.J. Logan. 1998. Are intensive agricultural practices environmentally and ethically sound? J. Agric. Ethics 1: 193-210.

Phommassack, T., A. Chanthavongsa, C. Sihavong, C. Thonglatsamy, C. Valentine, A. deRouw, P. Marchand, and V. Chaplot. 2002. An innovative approach to sustainable land management in Lao PDR. MSEC-Lao PDR Annual Report. *In* Integrated Catchment Management for Land and Water Conservation and Sustainable Agricultural Production in Asia. CD-ROM. IWMI, Colombo, Sri Lanka.

Sharma, P., R.P. Tripathi, and S. Singh. 2005. Tillage effects on soil physical properties and performance of rice-wheat-cropping system under shallow water table conditions of Tarai, Northern India. Eur. J. Agron. 23: 327-335.

Sojka, R.E., D.L. Carter, and M.J. Brown. 1992. Inhoff cone determination of sediment in irrigation runoff. Soil Sci. Soc. Am. J. 56(3): 884-890.

Sukristiyonubowo, R.L. Watung, T. Vadari, and F. Agus. 2003. Nutrient loss and the on-site cost of soil erosion under different land use systems. p. 151-164. *In* A.R. Maglinao, C. Valentin, and F.P. de Vries. From Soil Research to Land and Water

Management: Harmonising people and nature. Proceedings of the International Water Management Institute-ADB Project Annual Meeting and 7th MSEC Assembly.

Sukristiyonubowo, F. Agus, D. Gabriel, and M. Verloo. 2004. Sediment and nutrient balance under traditional irrigation at terraced paddy field systems. Paper presented at Second International Symposium on Land Use Change and Soil and Water Processes in Tropical Mountain Environments, 14-17 December 2004, Luang Phrabang, Lao PDR.

Sukristiyonubowo. 2007. Nutrient Balances in Terraced Paddy Field under Traditional Irrigation in Indonesia. PhD thesis. Faculty of Bioscience Engineering, Ghent University, Ghent, Belgium. 184 pp.

Sukristiyonubowo. 2008. Mobilitas sedimen dan hara pada sistem sawah berteras dengan irigasi tradisional. Jurnal Tanah dan Iklim 28: 39-54.

Tarigan, S.D. and N. Sinukaban. 2001. Peran sawah sebagai filter sedimen: Studi kasus di DAS Way Besai, Lampung. hlm. 29-37. Prosiding Seminar Nasional Multifungsi Lahan Sawah, Bogor, 1 Mei 2001. Pusat Penelitian dan Pengembangan Tanah dan Agroklimat, Bogor.

Toan, T.D., T. Phien, D.D. Phai, and L. Nguyen. 2002. Managing soil erosion for sustainable agriculture in Dong Cao Catchment. MSEC-Vietnam Annual Report. *In* Integrated Catchment Management for Land and Water Conservation and Sustainable Agricultural Production in Asia. CD-ROM. IWMI, Colombo, Sri Lanka.

WMO (World Meteorological Organisation). 1994. Guide to Hydrological Practices. Data acquisition and processing, analysis, forecasting and other applications. 5th edtion. WMO-No.168. 735 pp.