Land Management for Controlling Soil Erosion at Microcatchment Scale in Indonesia

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Introduction

Background and Statement of the Problem

Erosion is widely considered as the major cause of soil degradation. In the past, most erosion studies have been conducted at plot scale. These provide valuable data to compare erosion rates between different land management systems and soil types, but the measurement can not be directly extrapolated to catchment scale. Most of the plots have 22 m length and 9% slope, which is similar to the traditional plots used in the formulation of the Universal Soil Loss Equation (USLE). Errors in the estimation of erosion rates may occur if this approach is implemented at the catchment scale because: (a) artificial border in the plot scale blocks run-in soil particles and aggregates from the upper slope, and (b) there is no single slope in nature (catchment scale) and hardly uniform. Many of the studies have proven that this approach tends to overestimate rates of soil loss if the measurement is extrapolated to catchment scale.

Profitable land management techniques need to be introduced to increase quality and quantity of crop yields and the income of farmers and sustain the land resource base. Innovative technologies need to be implemented to have sustainable agricultural systems. Research on the micro catchment scale (Craswell *et al*, 1998) can help develop such technologies, which are able to reduce environmental damage and bring benefits to farmers (Garrity and Agus, 1999).

In the recent decades, many effective land management strategies have been developed to reduce erosion, but their adoption has been considerably limited. This was mainly because of the limited consideration of the farmers' socio-economic condition and the dynamics of on-going social changes. For this reason, the Indonesian Center for Soil and Agroclimate Research and Development (CSARD) collaborated with the International Water Management Institute (IWMI) to conduct soil erosion research under the Management of Soil Erosion Consortium (MSEC).

The first phase of this project showed erosion rates of 20 t $ha^{-1}yr^{-1}$ under multiple cropping system of food crops, 1.9 t ha^{-1} yr^{-1} under rambutan crops, and 1.7 t ha^{-1} yr^{-1} under the combination of rambutan and shrub, respectively (Agus *et al,* 2002). From their study at plot scale under similar climatic condition and soil types, Haryati *et al* (1995) reported a value of soil loss which was three times higher. This indicates that the measurement of soil loss at the plot scale cannot simply be extrapolated to catchment scale.

Results of the first phase of the project showed that the soil loss through erosion under Tegalan based cropping system exceeded the tolerable soil loss of 2 to 11 ton $ha^{-1}yr^{-1}$ for agricultural lands (El-Swaify, 1989). Under this condition, conservation measures have to be introduced for agricultural sustainability. Improving soil fertility is a great concern for the local farmers who apply fertilizers, lime and soil amendment like organic matter, even if the amount and kind are not those recommended. In contrast, most of the local farmers are not enthusiastic in applying conservation technologies to reduce erosion and increase land productivity. The reason is that the introduced conservation measures are considerably expensive and have not given real benefit to farmers.

As soil is lost through erosion, the contained nutrients are also lost. The analysis showed that 21.53 kg N, 5.82 kg P, and 9.02 kg K were lost per hectare per year from the

Tegalan microcatchment. From the Rambutan and the mixed rambutan and shrub microcatchemnts, 9.24 kg N, 0.21 kg P, and 5.97 kg K and 0.89 kg N, 0.89 kg P, and 1.11kg K were lost per hectare per year, respectively. These nutrients lost can reduce income of farmers from Rp 14,600 to Rp 205,400 ha^{-1} yr^{-1} (Agus and Sukristiyonubowo, 2001).

After more than two rainy seasons of observation, it has been shown that land management system determines the amount of erosion. Paddy field system had the lowest erosion and it can even deposit sediment coming from the upper area. Perennial tree system is very effective as long as there is good litter cover on the ground. When the tree floor is intensively cultivated, erosion increases. Intensive annual crop system had the highest erosion compared to tree and paddy rice systems. Modification of the intensive annual crop farming in the steep slope land with fodder grass has been observed to reduce erosion significantly even a few months after planting the grass. This could be attributed to the combined effect of the no tillage system and improved filtration of sediment by the grass.

The promising observations described above need to be further validated and therefore the project has continued to monitor the dynamics of land management to gain insights on the effects of various land uses and its changes on runoff and erosion processes and nutrient balances. A model would be useful to predict erosion rate at the micro catchment scale.

Immediate Objectives

1. To study the effects of land management systems on water and sediment yields at micro catchment scale;
2. To study nutrient balance under different land use systems;
3. To validate the GUEST model for predicting runoff and erosion.

Long Term Objectives

1. To improve land management systems for icreased productivity and conservation of natural resources;
2. To validate prediction model of erosion and runoff suitable for typical Indonesian catchments.

Scope of Work

The research in 2003 was focused on three major activities. These are related to: 1) land management systems, runoff and erosion, 2) nutrient balance in paddy fields, and 3) validation of soil erosion prediction model.

The *first activity* on the dynamics of land management systems and its effects on erosion and runoff at micro catchment scale is aimed to study the effects of various land use systems, changes in land management practices and the size of micro catchment on surface runoff and erosion. In the first phase of the project and in the current study, much attention has been paid to the surface hydrological response and behavior of solute balance with less attention to solute transport by flow. So far, the 2002 results show that fodder grass planting, in combination with cattle fattening of only one head of cattle per family, contributed to an increase in farm income by 60% for the Ungaran (Central Java) upland farmers where farming is a part time job. With population density of about 1000 persons per km^2, there is not much room for the farmers to expand their animal production, but for many farmers, there is potential to raise two to three heads of cattle per family and this promises a significant increase in their income. While capital is problematic for most farmers in the area, they prefer profit sharing more than availing of credit.

The *second activity* was focused on the nutrient balance under various land use systems and land management practices aimed at monitoring the nutrient dynamics as affected by the land management system. In the first phase of the project and the current year of 2003, the study was focused on the N, P and K balance under the rice–based cropping systems. Nutrient inputs were accounted from the fertilizer application, irrigation and recycled rice straw. Nutrient losses were related to erosion and crop removal at harvest. The change of nutrient in the soil and transported sediment by water has not yet been considered.

The 2002 results show that the main nutrient output from paddy field system is through harvest with N and P mainly in the rice grain and K in the rice straw. Therefore, recycling of rice straw can significantly alleviate the need for K fertilizer. Nutrient loss through erosion from paddy field is negligible.

The *third activity* was focused on the validation of the GUEST model for runoff and erosion prediction. The 2002 activity was mainly focused on data collection. Rainfall, runoff and erosion and factors such as soil physical and chemical properties, land use and soil cover data have been gathered. Rainfall and runoff event data such as time to peak, sediment yield (both suspended and bed load) have also been gathered. However, to run and validate the model, more comprehensive data are still required. This validated model is used to support policy makers in their planning and development programs.

Materials and Methods

Study Site

This long-term (intended for 10 years) watershed scale research was started in late 1999 at the upper Babon Catchment (about 285 ha area; 07^{o}20'S 110^{o}E), within the Kali Garang Watershed (220 km^2) in Central Java Province. Babon catchment is located about 3 km west of Ungaran, the capital of Semarang district, and about 20 km south of Semarang, the capital of the province. The study has been set up involving three micro catchments (MC): Tegalan (1.1 ha), Kalisidi (13 ha), and Rambutan (0.9 ha). The Tegalan MC is planted to upland annual crops with cassava as the main crop. Rambutan MC has wild grasses and rambutan as the main vegetation, while Kalisidi MC has Rambutan as the main crop. Characteristics of these MCs are described in Table 1 (Agus *et al*, 2002).

Data Collection and Analysis

The initial hydrological data were recorded in January 2000 after the complete identification and characterization of the catchment (mostly literature study) and the micro catchments, installation of V-notch weirs and sediment traps, automatic water level recorders (AWLR), and automatic weather station and manual rain gauges. Data on hydrology and nutrient concentration in soil, plant and water have been continuously collected until 2003. These were analyzed to evaluate the effects of land use and land management practices on runoff and erosion processes at micro catchment scale.

The activities undertaken were built on the past activities and include:

a. The dynamics of land management systems and its effects on erosion and runoff at micro catchment scale;
b. Nutrient balance under different land use systems;
c. Validation of soil erosion and runoff prediction model using GUEST (*Griffith University Erosion System Template*).

Table 1. Characteristics of catchment used in the study

Catchment	Area (ha)	Runoff coeff. (%) [1)]	Soils	Land use/Farming system	Dominant slope (%)
Tegalan	1.1	5	Andic Eutropepts	Cassava, maize, some trees in 2000 and 2001 and fodder grass covering about 60% area starting in December 2001	45 – 47(46)
Rambutan	0.9	1	Andic Dystropepts	95% Rambutan, 5% Shrub	22 – 55(40)
Kalisidi	13.0	14	Andic Dystropepts	100% Rambutan, lower catchment encroached for annual crops	22 – 55(37)
Babon	285.0		Typic Tropaquepts	All above + Rice field of about 17 ha	0 – 55(30)

1) Based on March 2000 to February 2001measurement

Effect of land management systems on erosion and runoff

The research was initiated with the construction of gauging station with sediment trap at each microcatchment to observe soil loss (bed load and suspended load), construction of small station at canals to monitor water level and suspended load, and biophysical and socioeconomic characterization of the site. To monitor discharge, each MC was equipped with V-notch gauging weir with both Automatic Water Level Recorder (AWLR, Orphimedes) and staff gauge for manual observation. The AWLR was set to record water level at one- or five- minute interval. The reading of the staff gauges was conducted three times daily at 08:00, 12:00 and 16:00.

Total soil loss or sediment yield is defined as sum of bed load and suspended load which are both measured every rainfall event. After taking sample for nutrient analysis, bed load from each trap was calculated separately. Sediment yield was estimated on a weight basis.

As rainfall-runoff relationship is very important in predicting soil loss at the catchment scale, rainfall was measured using the network of rain gauges within the catchment. Theoretically, the number of gauges required depends on the expected variability of precipitation over the catchment (WMO, 1994). In this research, seven manual rain gauges and one automatic climatic station were installed to observe daily rainfall over the catchment. The Thiessen Polygon Method was used to calculate the average precipitation over a specific area. In this procedure, lines are drawn between adjacent stations on a map. The perpendicular bisectors of these lines form a pattern of polygon with one station in each polygon.

The Tegalan and Kalisidi microcatchments are undergoing changes in land management systems. In the Tegalan microcatchment, 12 farmers introduced (with facilitation by researchers and extension workers) improved management system in the form of fodder grass planting and cattle fattening. The grass serves as catchment filter for sediments and as animal feed. This grass species has been tried in earlier conservation projects but monitoring the effects on erosion and runoff is limited. The participatory approach was employed with the farmers involved in the planning and implementation of the research. The empowerment of the group to be a dynamic and productive entity has

been enhanced through field visits and group discussion. Monthly meetings were conducted to address problems met and become more familiar with the introduced technology.

Nutrient balance in paddy fields

To assess nutrient balance within each microcatchment (Tegalan, Rambutan and Kalisidi) and under the terraced paddy field, nutrient gains and losses or nutrient inputs and outputs were monitored. The study has been limited to assess the NPK balance only. NPK inputs include those contributed from fertilizers, irrigation water, sediment inflow, rainfall, and crop residues. The outputs include NPK concentration in sediment outflow, harvested rice grains and straw. The basic approach to evaluate nutrient balance is described in Figure 1 and Tables 2 and 3. Also in the year of 2002/2003, contribution from rainfall was taken into account. Rainfall was sampled once per month from all rain gauges.

The study on nutrient balance and land management was conducted in the terraced paddy fields. The terraced paddy fields for lowland rice production cover about 17 ha in the valley of the Babon catchment. In general, farmers cultivate rice twice a year. The first cropping season starts in October-November and ends in February-March; the second season starts in March-April and ends in June-July. IR-64 is the common variety planted at a spacing of 25 cm x 25 cm.

The study was started during the dry season of 2001. During this time, rice yields (rice grains and rice straw production) were measured from a 1 x 1 m plot in the farmers' fields, repeated three times for each terrace. Beginning the rainy season of 2001/2002, a simple treatment was introduced. The farmers' practice where only 50 kg ha^{-1} of Urea is applied was compared with the 'improved technology' where as high as100 kg ha^{-1} $season^{-1}$ each of Urea, TSP, and KCl as recommended by the Food Crop Institute at District Level is used. The fertilizers were spread on the soil surface during the application.

The rainy season cropping in 2001/2002 started in October to November and ended the following February to March. The second cropping started in March/April until June/July 2002. High yielding rice variety of IR-64 was planted with spacing of about 25 cm x 25 cm. Six farmers were involved in this study with three of them representing each treatment.

The number of participating farmers increased to 10 in the rainy season 2002/2003 and to 12 in the 2003 dry season. Rice was planted in late December 2002 until January 2003. It was about two months delay compared with that in 2001/2002. The results in the rainy season 2002/2003 were discussed with the farmers coming up with the idea to modify the treatment for the dry season 2003. The treatments in the rainy season 2002/2003 included the recycling of 67% of the rice straw. This time, four treatments were done: (1) pure farmers' practice as control; (2) farmers' practice + recycled rice straw; (3) improved technology; and (4) improved technology + recycled rice straw.

Soil erosion was monitored from land preparation (plowing, harrowing, and puddling) to rice harvest. The measurement of suspended sediments was taken from the main outlet (the last terrace before the runoff goes out to the river) and the main inlet. The discharge at the main outlet was determined using tipping bucket method. An 11-liter bucket was used to measure discharge and to collect sediment samples. The relationship between the water level and discharge at the inlet (where the water from the canal enters the first terrace) was determined as the product of water velocity (measured using the float method) and the cross sectional area of the flowing water at the gauge.

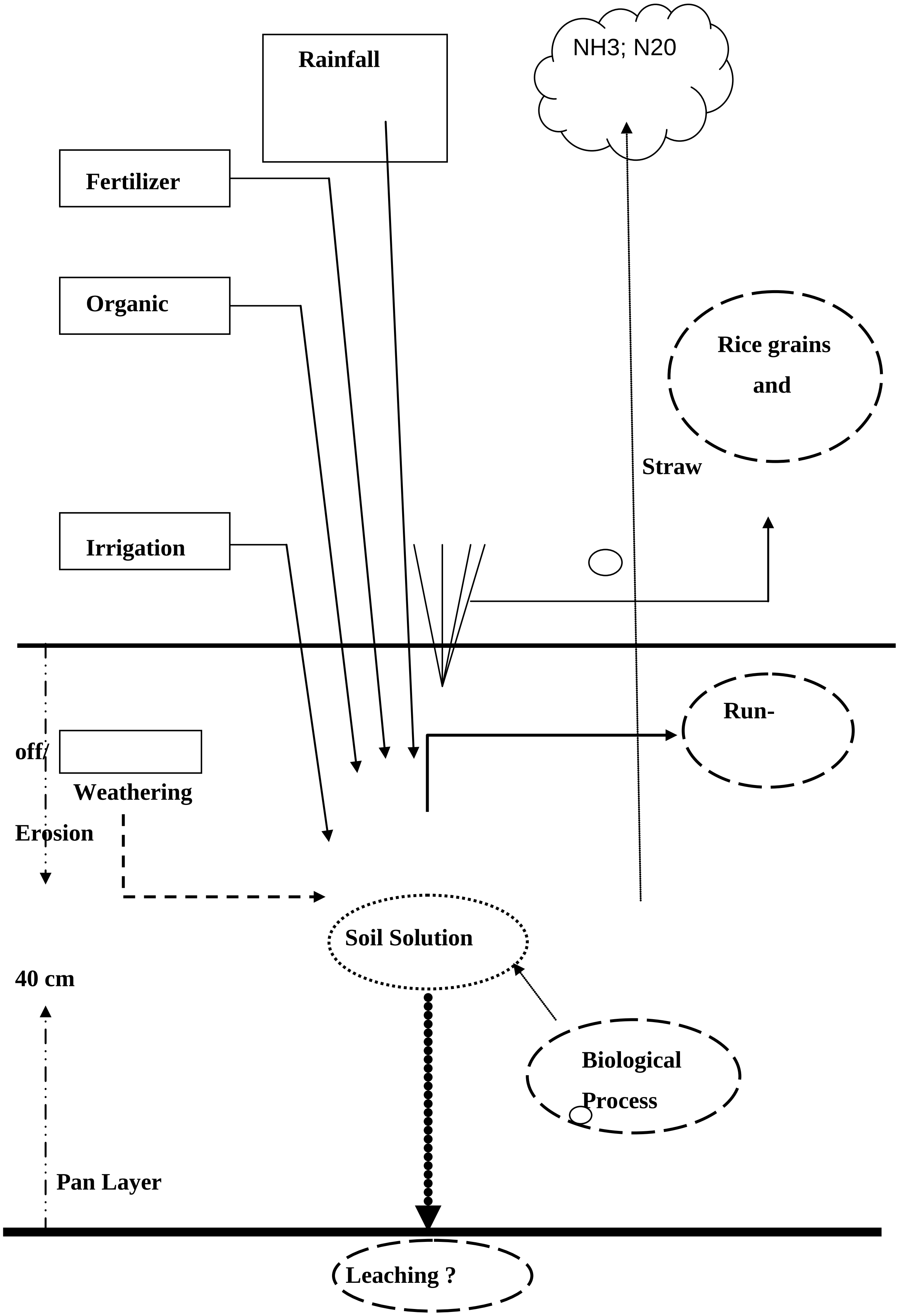


Figure 1. Basic approach for assessing nutrient balances in terraced paddy field

Table 2. Data collected and methods for the INPUTS unit in the assessment of N, P, and K balances at terraced paddy field system

Input data	Code and Nutrients	Data required/collected	Method of quantification
Mineral Fertilizers	IN-1: N, P, and K	• Type of fertilizer applied • Amount of fertilizer Applied • Nutrient content in fertilizer	• Field measurement • Field measurement • Laboratory analysis
Organic Fertilizer	IN-2: N, P, and K	• Amount of rice straw remain in the field • Amount of rice straw recycled • Nutrient content in rice straw that remain in the field • Nutrient content in recycled rice straw	• Field measurement • Field measurement • Laboratory analysis • Laboratory analysis
Irrigation	IN-3: N, P, and K	• Water level • Discharge • Nutrient concentration in water	• Field measurement • Field measurement • Laboratory analysis
Rainfall	IN-4: N, P, and K	• Daily, monthly and annual rainfall • Nutrient content in rainfall • N, P, and K deposition in rainfall	• Field measurement / record • Laboratory analysis • Study literature (for checking)
B N F	IN-5: N Only		• Secondary data/Study literature

During land preparation, suspended samples were collected every 10 minutes, starting from the first runoff at the V-notch of the main outlet to the stage when the color of suspension became nearly the same as the incoming water through inlet. These samples were taken to determine sediment concentration. To determine nutrient content in the run off water during land preparation, samples and discharge measurement were taken every 30 minutes. The incoming nutrients from the canal were sampled and monitored three times a day at 08:00, 12:00 and 16:00 o'clock.

For the first and the second fertilizer application, inflowing and outgoing sediments were sampled three times a day at 08.00, 12.00, and 16.00 o'clock a week before and after the fertilizers were applied. During these periods, the farmers open both inlet and outlet. When the fertilizers were added, both were closed for two days.

In the initial study, nutrient balance at teraced paddy field was calculated as the difference between inputs and outputs. The changes of nutrient in the soil were not taken into consideration. Nutrient inputs were accounted from the fertilizer addition, irrigation, and recycled rice straw, while nutrient losses were calculated from erosion and crop removal. In 2003, contribution from rainfall was included in the system.

Table 3. Data collected and method for OUTPUT unit in the assessment of N, P, and K balances at terraced paddy field system

Output data	Code and Nutrients	Data required/collected	Method of quantification
Harvested Product	OUT-1: N, P, and K	• Rice grain yield • Nutrient content in rice grain	• Field measurement • Laboratory analysis
Crop residues	OUT-2: N, P, and K	• Rice straw production • Amount of recycled rice straw • Amount of rice straw for feeding • Nutrient content in rice straw	• Field measurement • Field measurement • Field measurement • Laboratory analysis
Erosion	OUT-3: N, P, and K	• Water level • Discharge of outlet • Nutrient concentration in suspended sediment • Sediment concentration • Soil and nutrient losses	• Field measurement • Field measurement • Laboratory analysis • Laboratory analysis • Estimation based on field measurement : • Soil loss = q x sediment concentration • Nutrient loss = soil loss x nutrient concentration in sediment
Denitrification	Out-4: N only	• Annual rainfall • N in applied fertilizer • N recycled rice straw • Denitrification	• Field measurement • Laboratory analysis • Laboratory analysis • Estimation/transfer function
Leaching	OUT-5: N and K		• Secondary data/ Study literature. It may be neglected since there is pan layer that water can not pass through
Volatilization	OUT-6: N only		• Secondary data/Study literature.

Validation of runoff and soil erosion prediction model

The GUEST (Griffith University Erosion System Template) model of erosion prediction has been validated since the first phase of the project. Further refinement is still done in the current study. SIG software to run the model is PCRaster version 2.0, which is able to operate mathematical analysis based on the spatial and temporal variation of the data used. It can also be used to run dynamic and cartographic models.

Spatial, tabular, and time series data were used as inputs. Spatial data consist of digital elevation model (DEM), soil maps, land use maps, rainfall station distribution maps, and site of monitoring station maps. Slope range (class), cropping pattern,

infiltration capacity (based on the soil types, land use, cropping pattern and slope ranges), Manning's coefficient (based on land use) and land cover (based on land use and slope ranges) are included in tabular data. Time series data includes rainfall intensity at 5-sec interval (Paningbatan, 2001).

Model validation was done through a comparison between the predicted and measured erosion. Parameters that were compared are discharge and total sediment. Paired data (discharge and runoff for the same point in time) was tested by t-test. Measured and calculated values are significantly different if t-calculated is higher than t-table at $\alpha = 0.05$. The model was also tested by plotting the predicted (Y) and measured (X) values and comparing it with the 1:1 line to evaluate the distribution of the data. Predicted is different from measured value if data plotted are far from the 1:1 line.

Results and Discussions

Land Management Systems, Runoff and Erosion

Rainfall – runoff – erosion relationship

The relationships between rainfall, runoff and erosion were analyzed for the different microcatchments to assess any effect of land management systems. The relationship was discussed using not only the 2003 data, but also the data from previous years (2001 – 2002) to evaluate the temporal variability particularly the effect of the introduced soil conservation measure using grass on runoff and erosion.

The rainfall distribution showed variability within the catchment. It was higher in the northern part of the catchment than in the southern portion although the difference was not significant (Figure 2). The average rainfall during October 2002 to April 2003 was 3020 mm

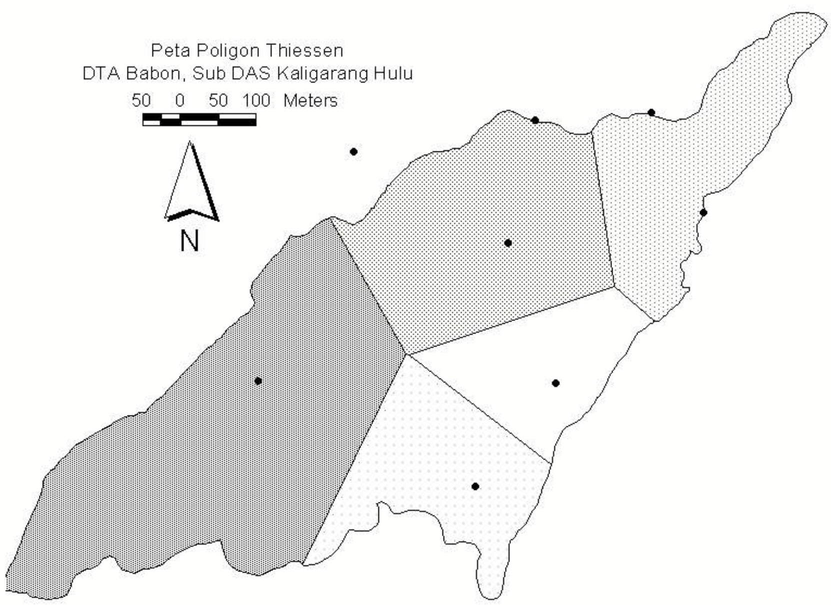


Figure 2. Polygon of Thiessen in Babon catchment, upper Kaligarang sub catchment

with the maximum of 151.2 mm in an event that occurred in January. It was observed that 10 mm of rain yielded runoff and soil loss in all microcatchments. With a measured rainfall of 35.4 mm, the Tegalan microcatchment produced 0.83 mm of runoff and 0.036 t ha^{-1} of soil loss. The maximum runoff of 2.52 mm occurred during an event with 93.9 mm of rainfall producing a total soil loss of 0.17 t ha^{-1}. The relationships between rainfall, runoff and erosion under Tegalan cropping system are shown in Figures 3, 4, and 5.

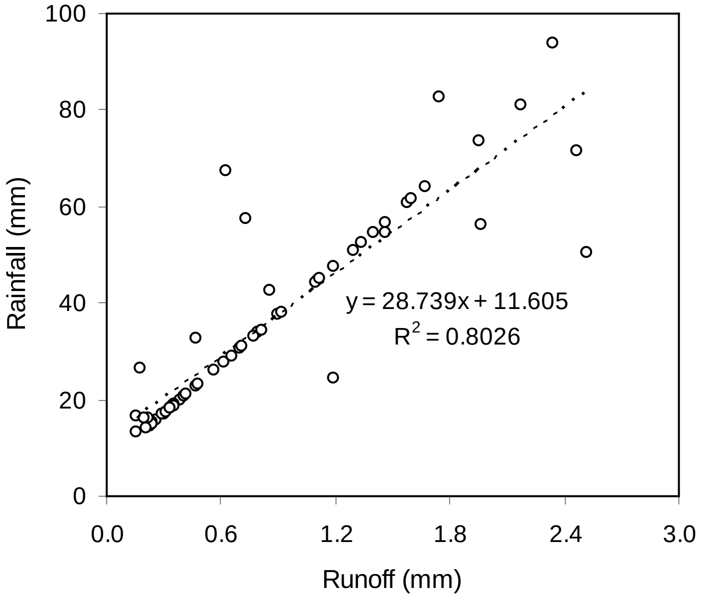


Figure 3. Relationship between rainfall and runoff in Tegalan microcatchment during wet season 2002/2003

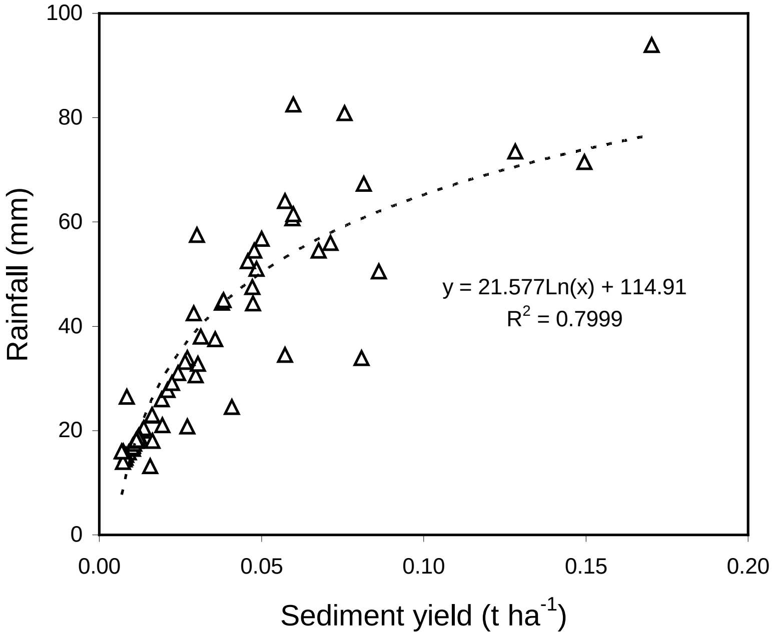


Figure 4. Relationship between rainfall and erosion in Tegalan microcatchment during wet season 2002/2003

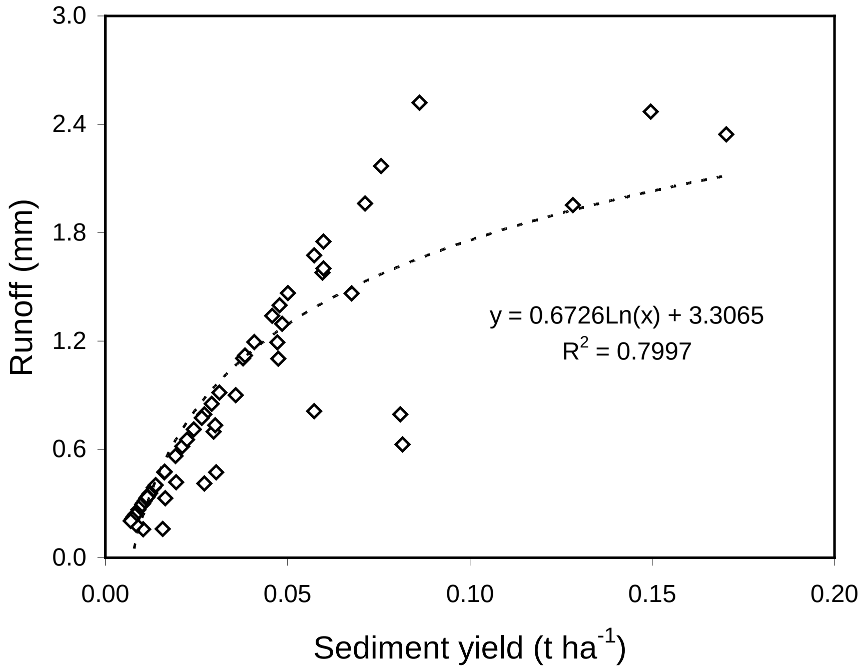


Figure 5. Relationship between runoff and erosion in Tegalan microcatchment during wet season 2002/2003

Under the Rambutan based cropping system, runoff and erosion were lower compared with those under Tegalan system (seasonal based cropping system). With 44.5 mm of rainfall, a runoff of 0.04 mm was produced with a soil loss of 0.00006 t ha^{-1}. The maximum rainfall of 104.8 mm yielded 0.17 mm of runoff and soil loss of 0.00026 t ha^{-1}. The relationships between rainfall, runoff and erosion under Rambutan cropping system are depicted in Figures 6, 7, and 8.

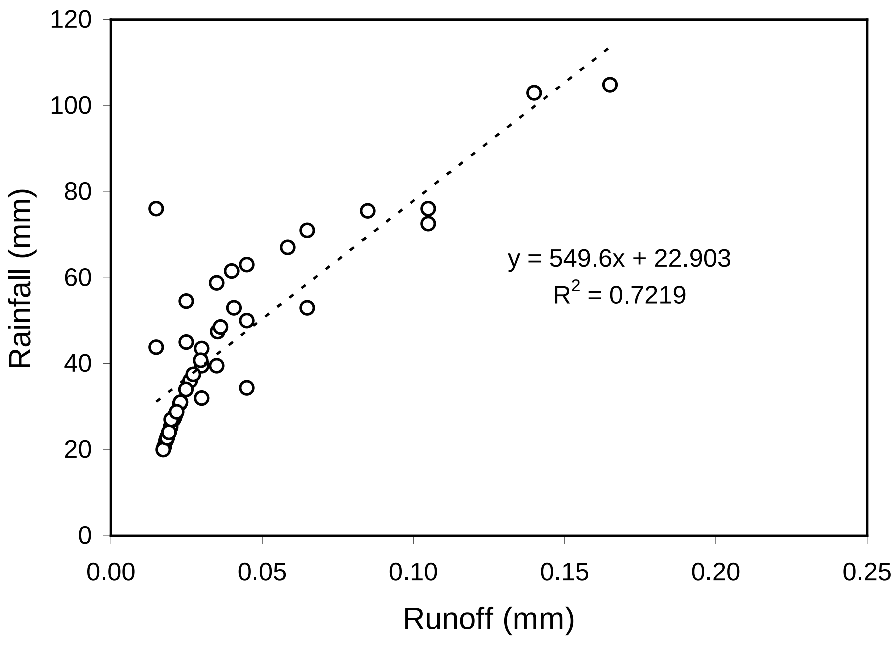


Figure 6. Relationship between rainfall and runoff in Rambutan microcatchment during wet season 2002/2003

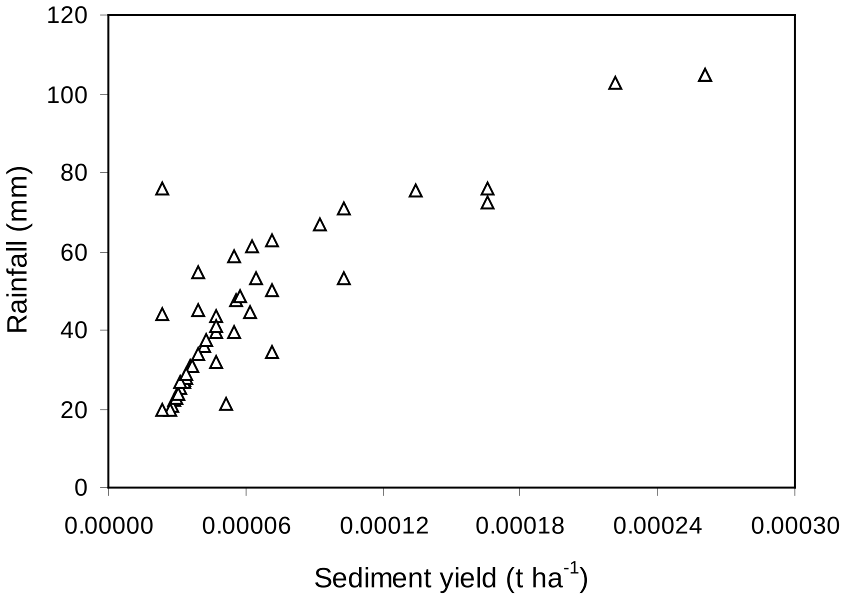


Figure 7. Relationship between rainfall and erosion in Rambutan microcatchment during wet season 2002/2003

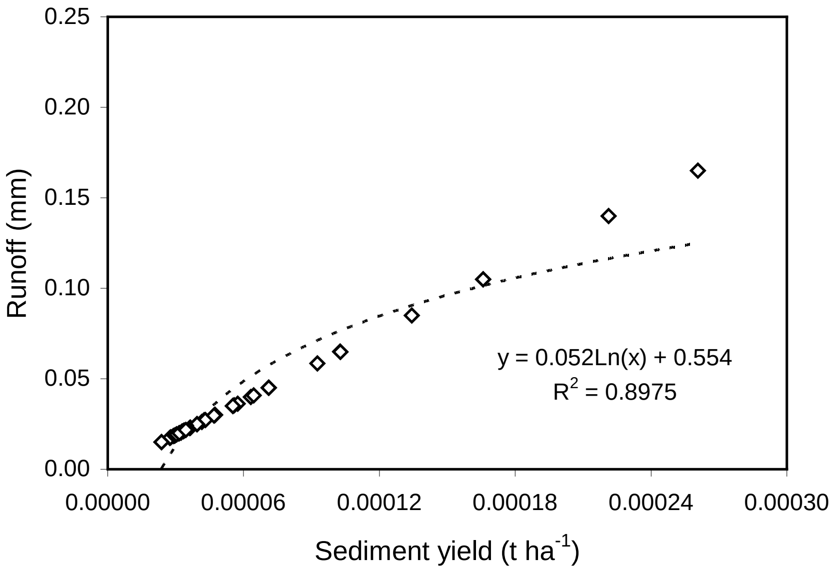


Figure 8. Relationship between runoff and erosion in Rambutan microcatchment during wet season 2002/2003

In the Kalisidi microcatchment, the rainfall of 42.2 mm generated a runoff 1.6 mm and total soil loss of 0.029 t ha^{-1}. This is almost similar to those observed in the Tegalan microcatchment. The maximum rainfall of 110.5 mm generated runoff of 51.0 mm and erosion of 0.93 t ha^{-1}. This supports the earlier findings of Agus *et al* (2002) that catchment size showed some effect on the measured runoff and erosion. The relationships between rainfall, runoff and erosion in Kalisidi micro catchment are depicted in Figures 9, 10, and 11.

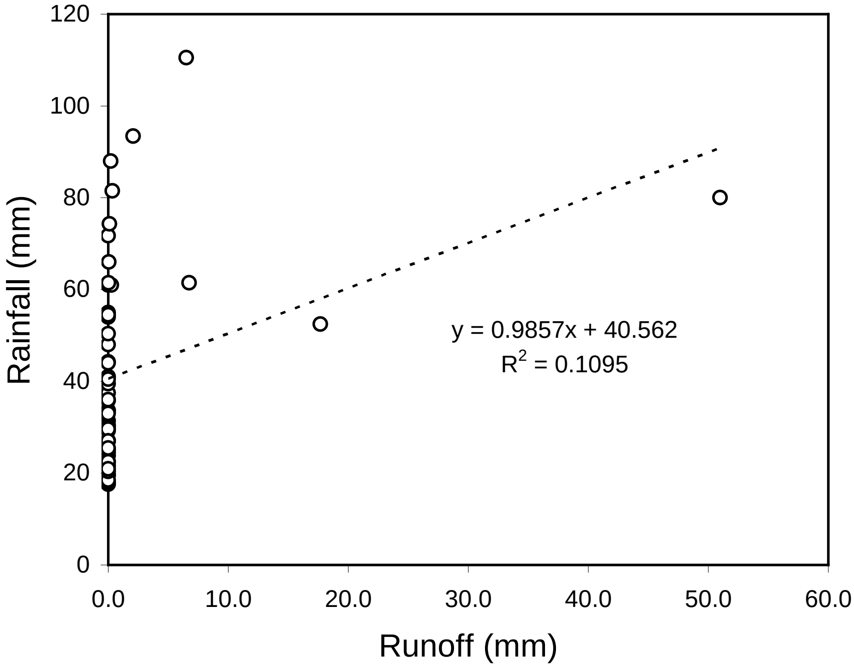


Figure 9. Relationship between rainfall and runoff in Kalisidi microcatchment during wet season 2002/2003

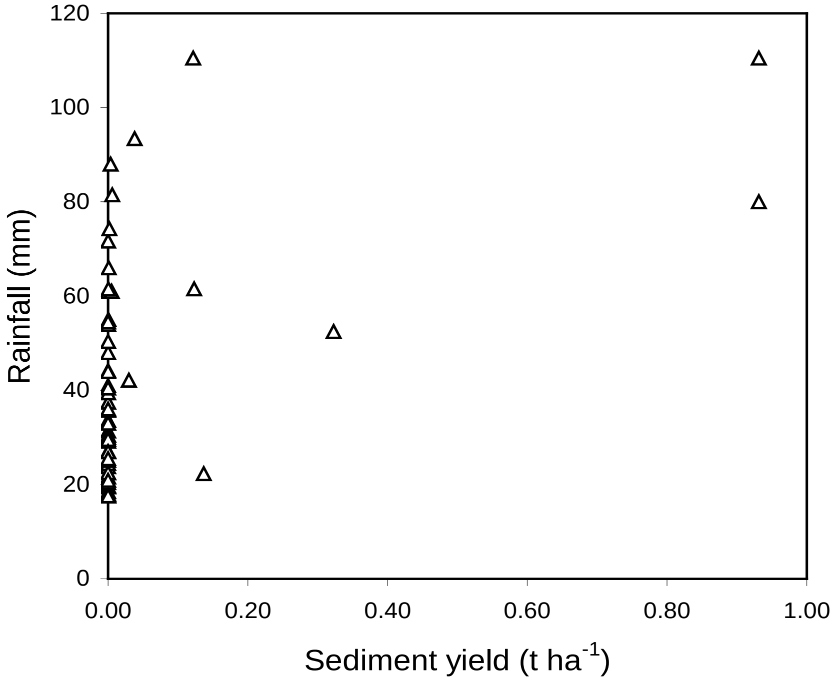


Figure 10. Relationship between rainfall and erosion in Kalisidi microcatchment during wet season 2002/2003

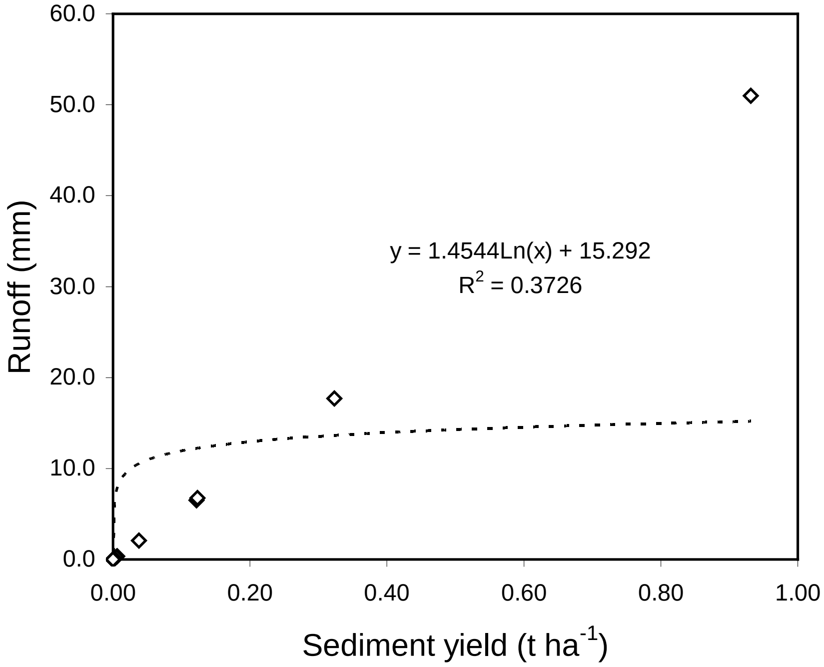


Figure 11. Relationship between runoff and erosion in Kalisidi microcatchment during wet season 2002/2003

The above results indicated that runoff and erosion occurred differently under different land use systems. This finding is similar to that observed by Agus *et al* (2002) and Vadari *et al* (2003). As the interception of rainfall is less, areas under seasonal crops show higher runoff than those under the tree based cropping system. Consequently, total soil loss was also be higher. In most cases, runoff was linearly correlated with rainfall. Total soil loss increased sharply at the beginning of the rainfall event, then increased gradually after some time creating a log-normal relationship.

As in previous results, runoff was generated largely from the Tegalan microcatchment, and it is much higher than that from the Rambutan and Kalisidi microcatchments. Figure 12 shows that there are two peaks of discharge from the Tegalan microcatchment during the storm event on January 1, 2003, a typical characteristic for this catchment. The hydrograph shows a sharp increase after the start of the storm to reach the peak indicating the dominance of quick flow. The flow then rapidly declined. In the Kalisidi microcatchment, flow gradually increased but then decreased sharply during the falling limb. There was no clear shape of the hydrograph from the Rambutan microcatchment. Characteristic of the rainstorm and corresponding runoff is presented in Table 4.

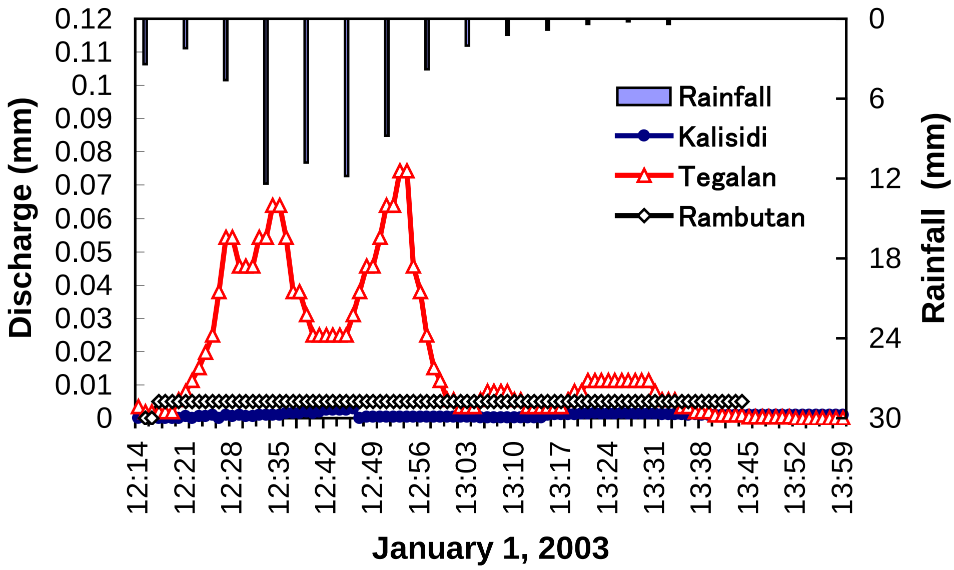


Figure 12. Effect of land use on hydrograph during the January 1, 2003 strom event

Table 4. Rainfall characteristics of the storm event on January1, 2003 with corresponding runoff

Rainstorm Characteristics	Value
Storm length (min)[a]	104
Total rainfall (mm)	62.8
Max intensity (mm.min^{-1})	12.4
Total runoff (mm.min^{-1})[b]	
• Tegalan	1.8
• Kalisidi	0.09
• Rambutan	-

a, b from 11:30 on August 21, 2001 (the storm started) to 15:30 on August 22, 2001 (the storm end) by excluding baseflow for the total runoff

In December 2001, conservation technology was introduced in the Tegalan microcatchment by planting Benggala grass (*Panicum maximum*) along the contour and some cultivated areas. The system reduced soil loss by up to 50% in a period of only one year. There was a reduction of as much as 90% in the second year (Figure 13). The reduction in soil loss was mainly in the reduction in the amount of bed load. Although not as high as in Tegalan microcatchment, soil loss also tended to decrease in Rambutan catchment. Soil loss in the Kalisidi microcatchment did not show any trend but varied from year to year. Moreover, suspended load was higher than the bed load.

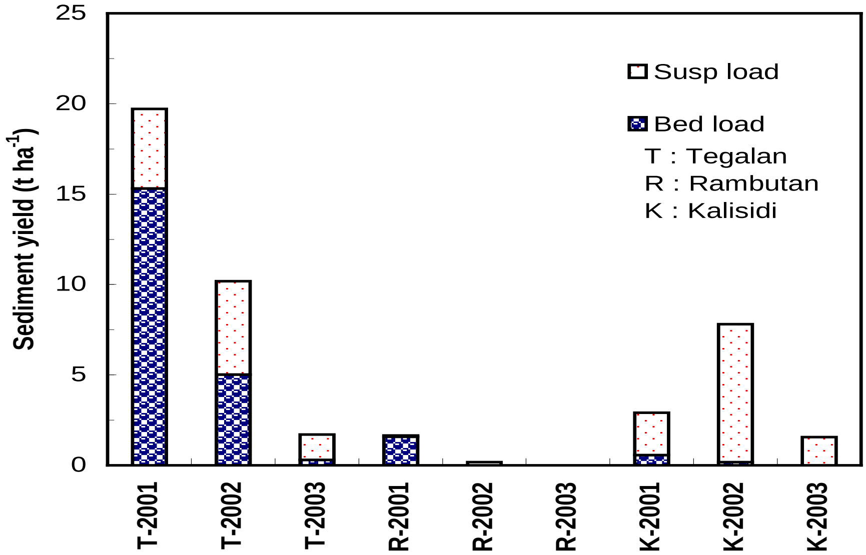


Figure 13. Temporal variation of total soil loss under different land use system

Alternative management system

There have been many technologies that have been introduced in soil conservation projects but adoption by farmers does not sustain because most of the introduced measures can not generate intrinsic rewards to farmers while external rewards or incentives are normally temporary at best. Mechanical and vegetative conservation measures are widely known but the implementation of those technologies is relatively limited. Bench terracing and planting grass as soil conservation measures are widely known to reduce erosion (Abujamin *et al*, 1983; Haryati *et al*, 1993). However, the adoption of such techniques may prove unsuccessful if farmers are not fully involved.

The participatory approach considers both the biophysical condition of the area and the socio-economic aspects of the farmers in the management of upland. Participatory research for development includes empowering farmers in (1) diagnosing the biophysical as well as socio-economic problems, (2) development of plans by blending farmer's solution with research based alternatives, (3) implementation, and (4) monitoring and evaluation. The farmers in general take the initiative while extension workers and researchers facilitate the process.

Planting grass for soil conservation in sloping uplands is known widely and almost every farming system technology package introduced in the uplands of Java has fodder grass and livestock components (Hermawan and Prasetyo, 1991; Prawiradiputra *et al*, 2000). The grasses reduce runoff and serve as filters of eroded soil, while the cattle component serves as an income source.

During the late rainy season of 2001, the integration of fodder grass planting and cattle fattening was introduced as an alternative option to the conventional intensive annual crop cultivation in the Tegalan microcatchment. The selection of the best bet option was based on lessons learned from elsewhere in Indonesia, that farmers' adoption of alternative technologies is determined by the economic contribution of the measure to the household economy. Farmers are attracted to a practice only if the practice promises direct economic benefits and this consideration must be put forward in the participatory technology selection.

Benggala grass (*Panicum maximum*) introduced and planted in some of the bench terrace risers and in the small portions of the microcachments has decreased soil erosion. After the second year of implementation (2002) erosion decreased by almost 50% and by more than 90% in the third year (Figure 12). The sharp reduction in soil loss was mainly caused by the decrease in bed load rather than in suspended load.

The scarcity of the fodder this year did not affect the farmers. During this dry season, only two out of 12 farmers went outside the village to source out the rice straw. In the previous year, during the peak of the dry season in July - August 2002, the farmers had to travel as far as 25 km out of Keji village to get 240 kg rice straw.

Fodder given to the cattle was mostly natural grass and the approximate daily fodder requirement for 13 cattle raised by 12 farmers was 300 to 450 kg. The grass was collected from their upland farms and paddy fields and from the estate land or common land. The introduced grass yielded only 570 kg and this was good for only two days. The rice straw as fodder given to the cattle accounted to 15% (100 kg), 5% of introduced grass, and the rest from common grass or other forages.

The income of the farmers who raised cattle this year was less than last year. On the average, the farmers earned an income of US$ 9.52/month in 2002, but only US$ 3.57/month in 2003. The lower benefit was primarily because of the lower price of the animal in 2003. In 2002, the cattle were sold during the Idul Qurban (Sacrifice Moslem Celebration) time when the demand was high. This lower income did not dampen the enthusiasm of the farmers. They still want to continue this cattle fattening activity. In one meeting, one solution proposed was to sell meat instead of live animal.

Based on the study, at least four heads of cattle for each farmer would be needed for increased income, but this alternative might not be suitable due to shortage of fodder or farmers' lack of capital. Figure 14 shows a scenario of the fodder required for raising one and two heads of cattle. The analysis was based on the assumption that the initial weight of the cattle is 200 kg, daily weight gain is 0.4 kg, and daily fodder requirement is 20 kg (20% of cattle weight). This also assumed that the fodder will be supplied from natural grass, introduced grass and rice straw. The introduced grass has an average yield of 570 kg/month based on production in 2003 harvested twice a month from 1000 m^2 upland. The rice straw is assumed at 240 kg collected twice a year in March and August after paddy field harvest. The natural grass collected daily, usually by women, from the surrounding areas (common land, estate crops land, and paddy field ricers) is 30 kg.

Raising one cattle will cause no problem for the farmers as the required fodder can be obtained by just collecting natural grass for up to 11 months of raising the cattle. At that time, the animal will have reached the weight of 332 kg (weight gain of 132 kg). Also, he would have earned a gross profit of about US$ 232 in 11 months or a monthly income of US$ 21 (carcass weight is 45 % of total weight, carcass price is US$ 1.55/kg, 1 US$=Rp 8,400). This figure agrees with the earlier report of US$ 15.44 – 21.13 additional expected income based on four heads of cattle (Project Completion Report of Phase I, 2003).

For two heads of cattle, the farmers would require minimum effort to find grass in five months and after seven months the effort increases over time to find more grass or collecting rice straw from his village or outside Keji village. After five months the expected gross income will be US $ 362.70, but thereafter, the effort increases but the profit decreases. To manage the increasing demand for fodder, expanding the area of the grass or the use of rice straw may be further studied

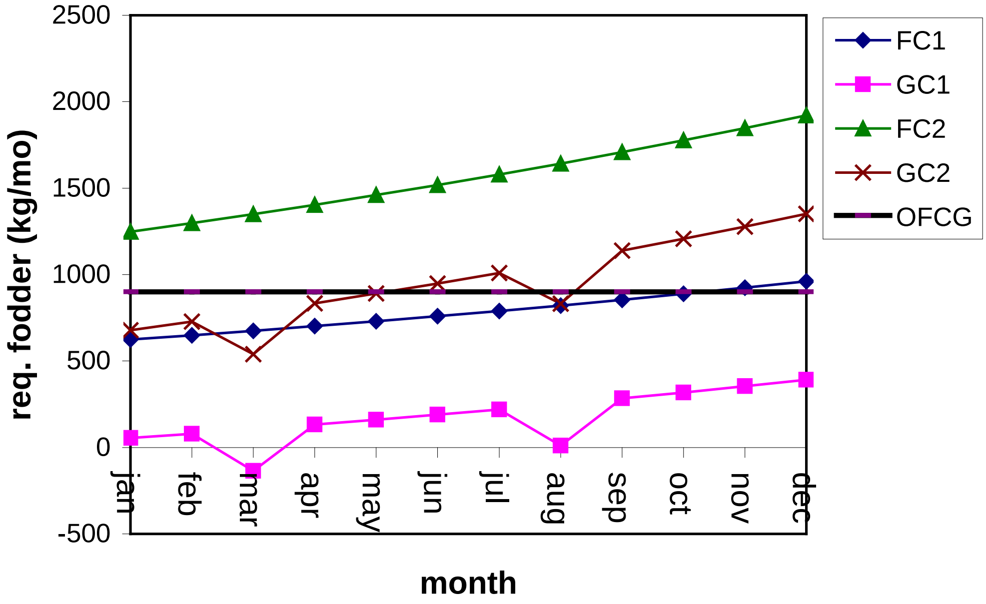


Figure 14. Fodder and grass required for raising one and two heads of cattle (FC1= monthly weight of fodder required for one head; GC1=monthly weight of field grass required for head; FC2=monthly weight of fodder required for two heads; GC2=monthly weight of field grass required for two heads; OFCG=optimal monthly weight of field grass collected by farmers)

Observations on the reaction of the participating farmers on the new management system revealed that their cooperation has been gradually established. This is further enhanced through regular meetings and visits to other cooperatives established by non-government organizations such as Trukajaya and Uswatun Khasanah. The meetings were conducted monthly and almost all of the participant farmers attended the 11 meetings in 2002.

Sediment and Nutrient Balance in Paddy Fields

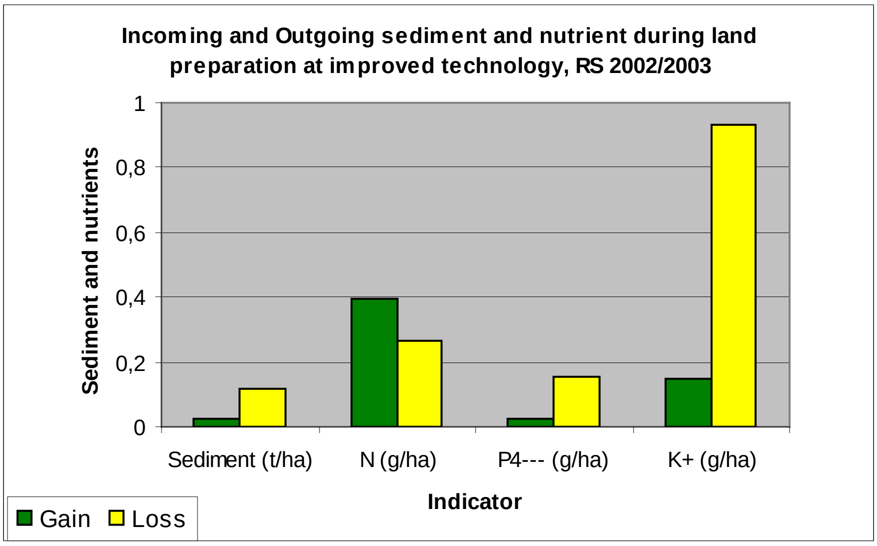
Sediment balance

Soil or sediments going in and out of the paddy fields were determined during land preparation and fertilizater application when the soil is greatly disturbed and the inlet and outlet are opened allowing entry and exit of sediments. Weeding, by hand or rotary weeder, was not done since the farmers did land preparation very well and kept the water at the desired level (about 5-7cm) resulting in less weeds during the rice growing period (personal communication with all farmers involved in this study, 2003). Similar result was also reported by Kukal and Aggarwal (2003), Sharma and De Datta (1996), and Adachi (1990) which showed that puddling reduces percolation loss of irrigation water, controls weeds and makes easy transplanting.

During land preparation, in both the farmers' practice and improved technology, the incoming sediment was lower than that flowing out. About 106 to 118 kg of sediment per hectare was eroded from the field while only 8 to 24 kg ha^{-1} came in from the irrigation water, respectively (Figure 15a and b). This finding is similar to that found by Tarigan and Sinukaban (2001) in Way Besay Watershed Lampung. They concluded that the sediment loss under terrace paddy field mainly occurred during land preparation. Meanwhile during fertilization period, the data indicated that a week before and after the first fertilization, inflowing sediment was higher than outgoing sediment (Figure 16a and

b). It means that incoming sediment through irrigation water was deposited in the field. Total sediment deposited varied from about 76 to 281 and 4 to 147 kg day^{-1} ha^{-1}

(a)



(b)

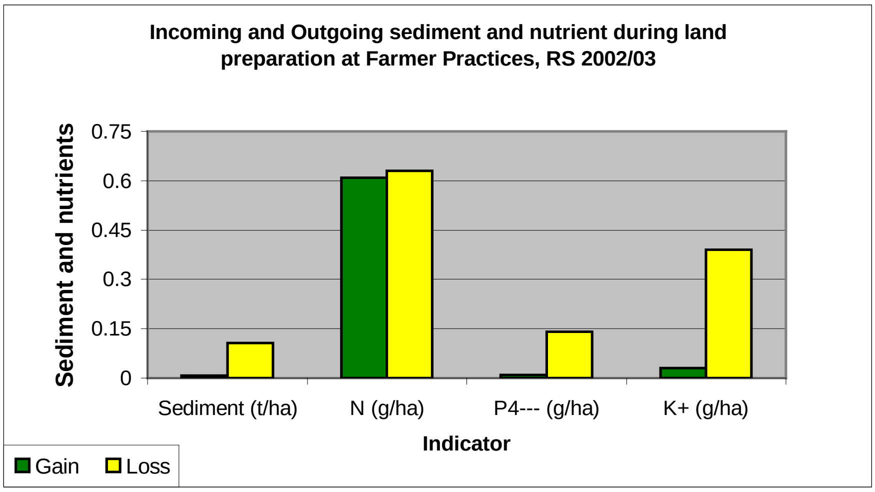
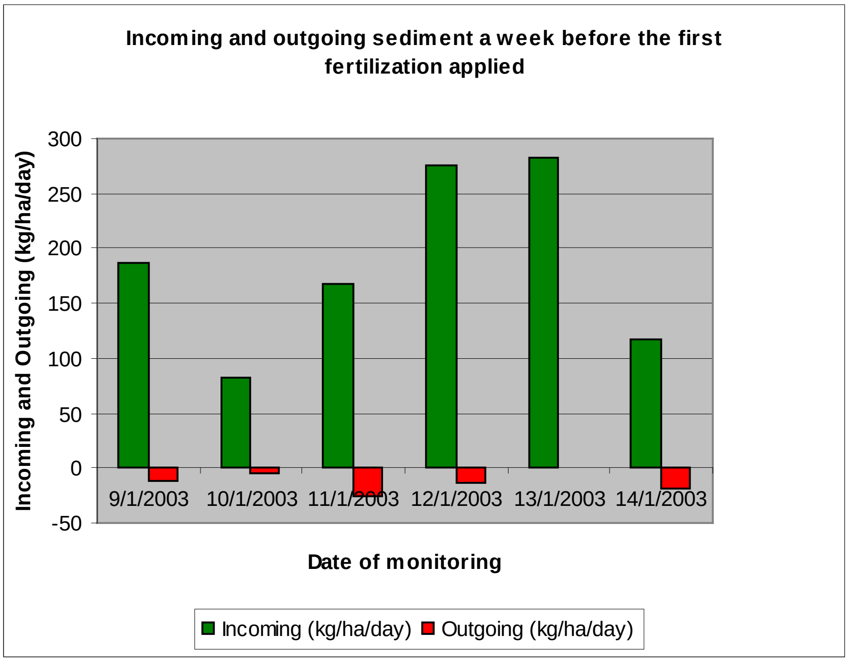


Figure 15. Incoming and outgoing sediment during land preparation under improved technology (a) and farmers practices (b)

observed a week before and after fertilizer application, respectively. These amounts of sediment deposited per day depended on the activities upstream, stream bank erosion, and other biophysical conditions upstream. Many scientists reported that nutrient movement in agricultural fields is influenced by climate, soil, topography, land use, and management practices (Agus *et al*, 2003; Lal, 1998; Powlson, 1998). These data suggests that terraced paddy field system plays an important role in controlling erosion at catchment scale and can minimize the negative impact downstream. From both activities, it can be concluded that during rainy season 2002/2003, about 1385 kg ha^{-1} $season^{-1}$ sediment were deposited and distributed along the terraces. Therefore, it is also interesting to study the deposition rate of sediment in each terrace.

(a)



(b)

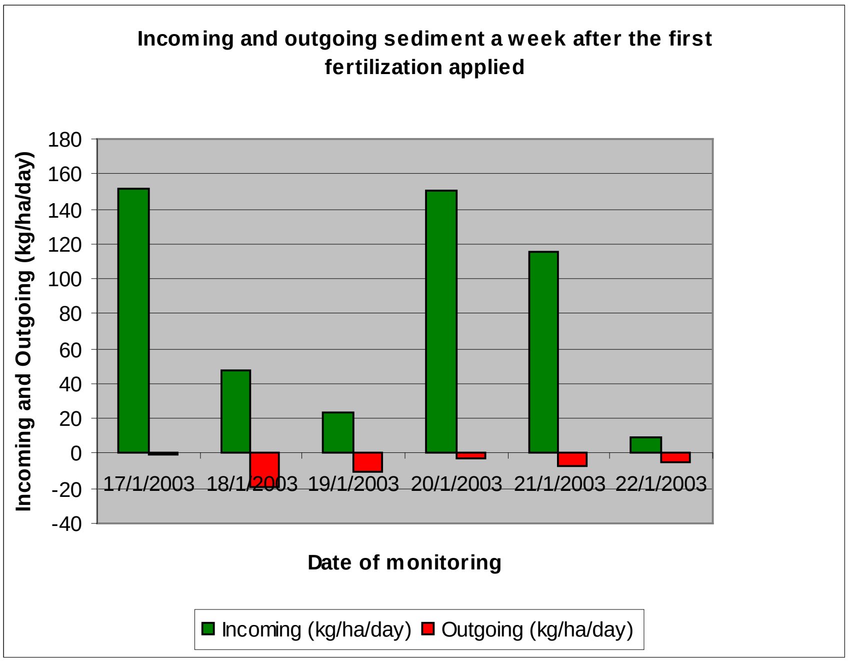


Figure 16. Incoming and outgoing sediment a week (a) before and (b) after the first fertilizer application

Nutrient balance

The measured discharge at the canal and at the gate (inlet, outlet) during land preparation is presented in Table 5. In general, the discharge at the gate was higher in the morning than in the afternoon. It varied among farmers depending on the soil condition (wetness), slope position, puddling depth, the number of terraces, the size of each terrace,

and the discharge at the canal. The average discharge at the inlet was 3.06, 3.44, and 2.05 l sec^{-1} measured in the morning, mid-day, and afternoon, respectively. The corresponding values at the outlet were 0.84, 1.29, and 0.92 l sec^{-1} The discharge at the inlet was significantly different from the discharge at the outlet during land preparation and fertilizer application. During land preparation, more water was required to saturate the soil for easy puddling and transplanting. On the other hand, a week before and after fertilization, water was mainly used to maintain a certain level of about 5-7 cm for normal rice growth and weed control.

Table 5. Mean discharge of canals and inlet and outlet during land preparation and fertilizer application in the rainy season of 2002/2003 in terraced paddy filed, Babon catchment

Location	Discharge (l sec^{-1})			Range		
	08:00	12:00	16:00	08:00	12:00	16:00
Canal - SS 1	351.7	373.1	395.3			
Canal - SJ 1	357.1	406.6	481.2			
Canal - SK 1	607.5	767.1	733.2			
INLET (Land Prep)	3.06	3.44	2.05	1.40 - 3.71	1.47 - 4.83	0.86 - 3.42
OUTLET (Land Prep)	0.87	1.29	0.92	0.65 - 0.98	0.68 - 2.31	0.49 - 1.66
INLET (wbf)*	4.52		4.57			
OUTLET (wbf)**	0.29		0.29			
INLET (waf)	3.28		2.80			
OUTLET (waf)	0.40		0.40			

WBF: Week Before Fertilization; WAF: Week After Fertilization; SS1: *Saluran Sawah* 1; SJ1: *Saluran nJaru* 1; SK1: *Saluran Kemloso* 1

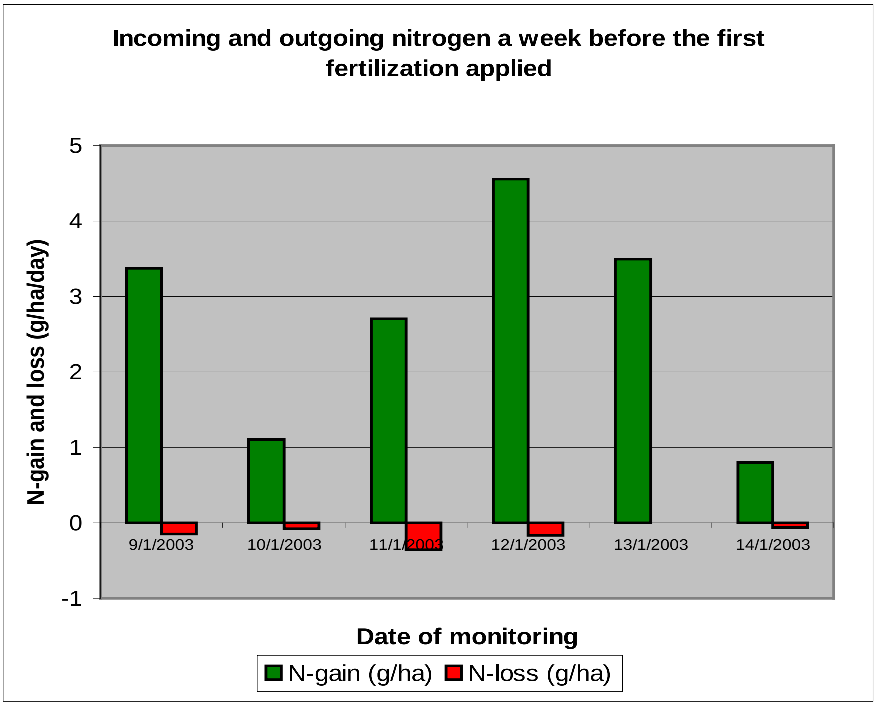
The contribution of irrigation water to the nutrient input was mainly during land preparation and fertilizater application when incoming and outgoing nutrients through water and sediment were greatly dynamic even if both the inlet and outlet are closed during fertilizer application. Less water passes through the inlet and outlet during other stages of the rice growth meaning that less nutrient movement also takes place.

The data showed that the outgoing nutrients via runoff sediment were higher than the incoming nutrients from irrigation water, as the outgoing sediment was also higher (Figure 15). It is interesting to note that the K loss was higher in the improved technology treatment than in the farmer practices. During these activities, 0.36 and 0.79 K^+ g ha^{-1} was lost from the field. For phosphate the loss was almost the same, about 0.13 $P0_4^{3-}$. In the case of nitrogen, contribution of incoming sediment was higher than losses through outgoing sediment (erosion). This is because nitrogen may not be bound in the fine materials (eroded soil) as P and K. In addition, contribution of rainfall, decomposed organic matter and leaching of nitrate from upstream may enrich the irrigation water. The net gain of nitrogen from the incoming sediment during land preparation was 0.13 N g ha^{-1}, which was very small. The study on N and P transport by surface runoff reported by Ng Kee Kwong *et al* (2002) showed insignificant level of N and P moving from the plot and subcatchments during runoff event. Less than 1 kg total P was lost and about 2 to7 kg N ha^{-1} was transported by surface runoff. These values were agronomically not important. Douglas *et al* (1998), Albert *et al* (1978), and Kissel *et al* (1976) reported similar results.

A week before and after the first fertilizer application, the incoming nutrients were higher than outflowing nutrients, meaning that during these periods the soil was enriched by nutrients from deposited sediment (Figures 17, 18, and 19). The total nutrient inputs from irrigation water a week before and after fertilization activities were 17.8 N, 2.4

PO4, and 3.1 K g ha^{-1}. These values were small and may not potentially contribute to soil fertility improvement.

(a)



(b)

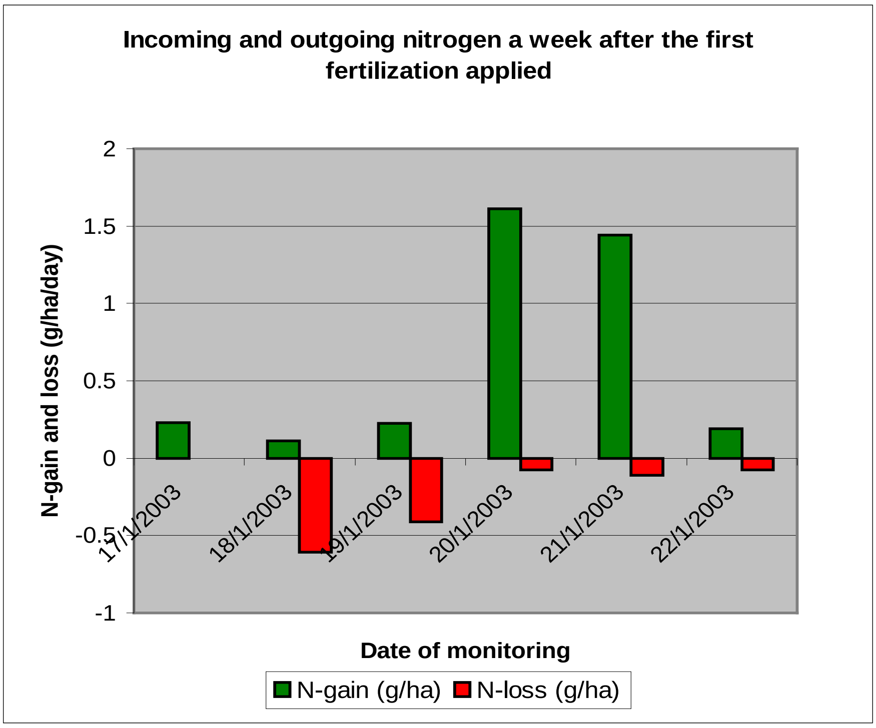
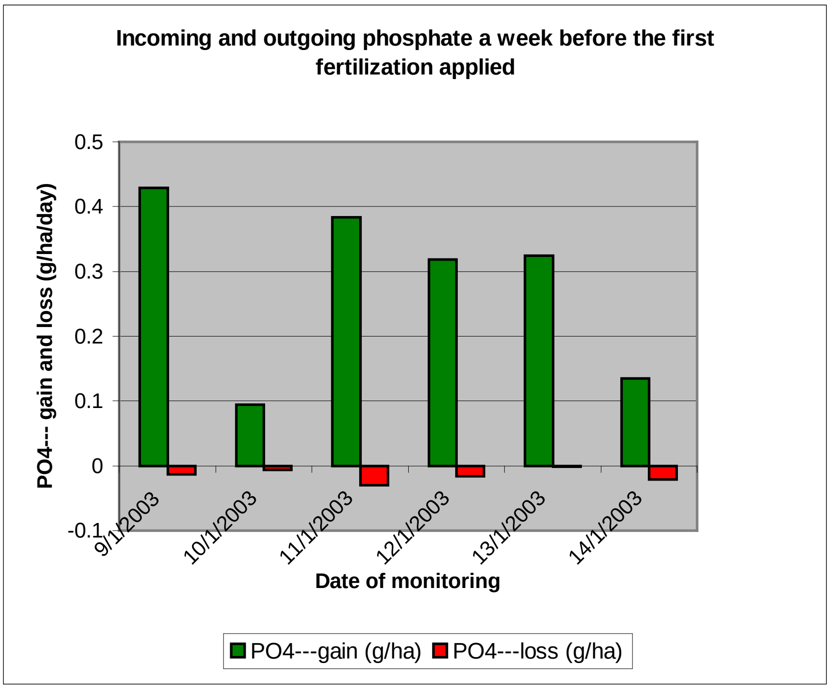


Figure 17. Incoming and outgoing nitrogen a week (a) before and (b) after the first fertilization applied in Babon catchment (terraced paddy field)

(a)



(b)

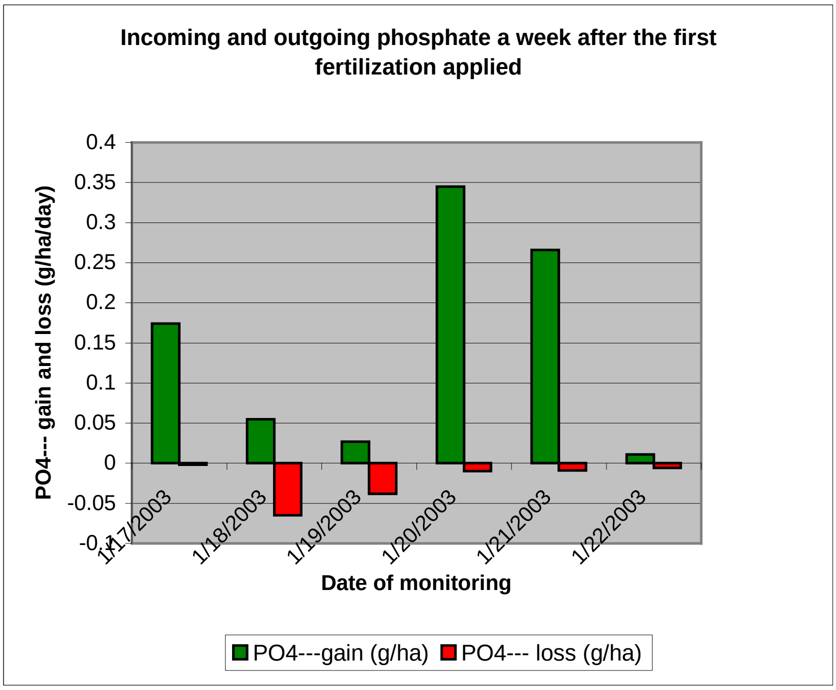
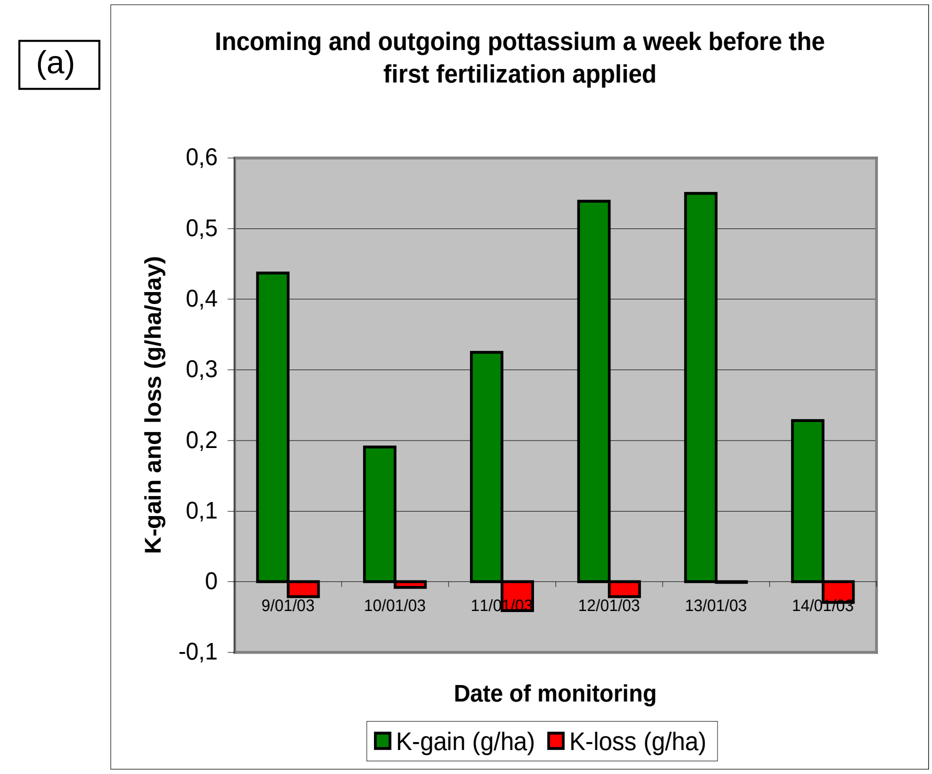


Figure 18. Incoming and outgoing P a week before (a) and after (b) the first fertilizers were applied in Babon catchment (terraced paddy field)



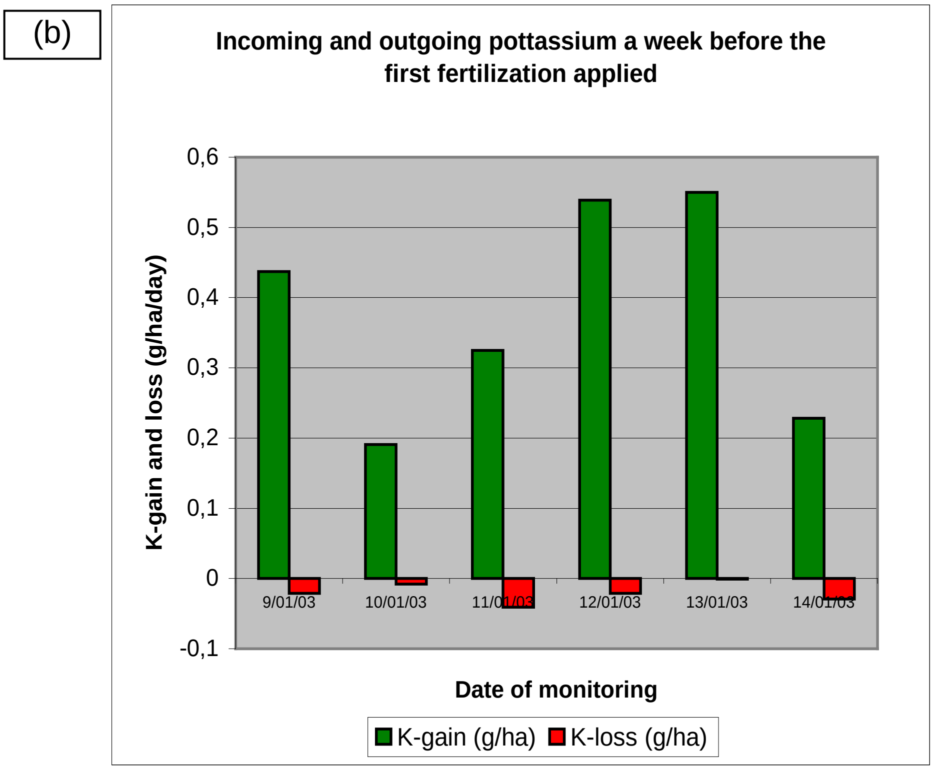


Figure 19. Incoming and outgoing K a week before (a) and after (b) the first fertilizers were applied in Babon catchment (terraced paddy field)

Rainy season 2002/2003 occurred from end of October 2002 to April 2003 (Figure 20). The annual rainfall was 2231 mm with monthly maximum of 533.1 mm occurring in January 2003. This rainfall amount was lower by 905 mm from the rainfall in 2001/2002. Total nutrient gain from the rainfall was about 8.53 N, 1.09 P, and 3.65 K kg ha^{-1} yr^{-1}. These values were considered low. Poss and Saragoni (1992) obtained the same result from samples collected in Togo, getting values of 4.4 $N0_3$, 1.1 $P0_4$, and 4.1 K kg ha^{-1} yr^{-1}. Schuman and Burwell (1974) recorded a value of 7.26 kg N ha^{-1} yr^{-1} from an average precipitation of 926 mm. These are lower compared to the nitrogen content measured in Belgium of about 25 kg N yr^{-1} (Demyttenaere, 1991). Lefroy and Konboon (1999) also measured low nutrient content in rainfall.

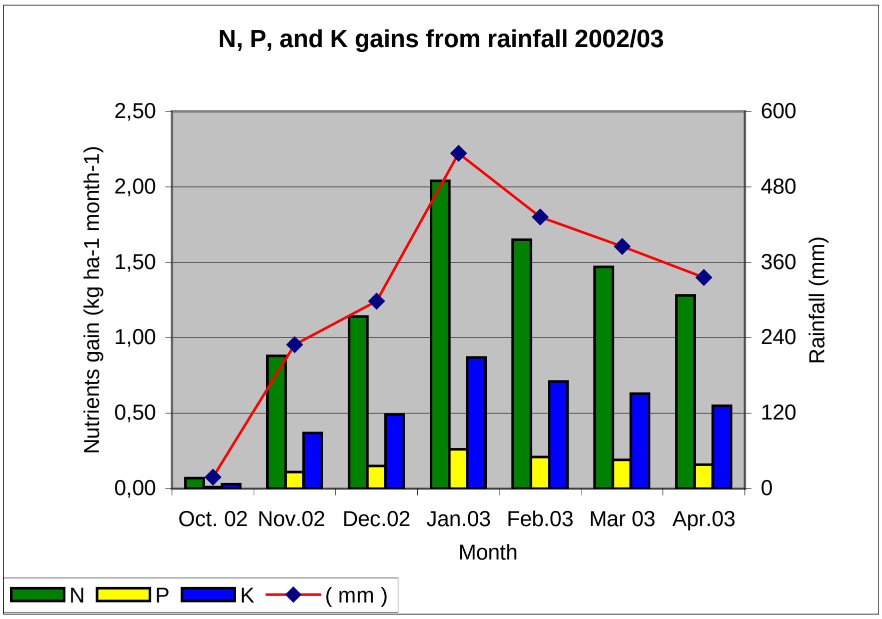


Figure 20. Monthly rainfall and its contribution to nutrient inputs

Rice was harvested by cutting the straw at 10 to 15 cm above the ground. The stem and roots remained in the field, and therefore considered an input. The total rice residues and their contribution to input are presented in Table 6. The data indicated that rice residues are rich in N and K and these have potential to increase soil fertility, although they are low in P.

Table 6. Rice residues and their contribution to N, P, K input in rainy season 2002/2003

Treatment	Rice residues (t ha^{-1})	INPUT (kg ha^{-1} $season^{-1}$)		
		N	P	K
Farmer Practices	5.26	137.3	3.9	106.3
Improved Technology	8.51	222.1	6.4	171.9

The total nutrient gains from rice residues were 137, 4, and 106 kg ha^{-1} $season^{-1}$ of N, P, and K respectively under the farmers' practice, and 222, 6, and 172 kg ha^{-1} $season^{-1}$ of N, P, and K respectively under the improved technology. Rice residues and nutrients were higher in the improved technology than in the farmers' practice. This can be attributed to higher fertilizer rates in the improved technology. This finding is similar to

that reported by many authors (De Datta, 1981; De Datta *et al*, 1991; Yoshida, 1981; Sukristiyonubowo *et al*, 2003).

Loss of nutrient by crop removal through harvest was high especially for N and K, which are mainly contained in the rice straw. Among the nutrients studied, nitrogen loss was highest and contained in the rice grain. Loss of nutrient under the improved technology was considerably higher than that under the farmers' practice (Table 7). Similar results were obtained in the first year study as reported by Sukristiyonubowo *et al* (2003). The result suggests that rice straw can be a potential nutrient source for improving soil fertility. Recycling of rice straw either for organic fertilizer source or fodder source for cattle will be tested in Suruhan Village.

Table 7. Nutrients losses through harvest in terraced paddy field during rainy season 2002/2003

Loss (kg $ha^{-1}season^{-1}$)			Rice straw		Rice grain	Loss (kg $ha^{-1}season^{-1}$)		
K	P	N	(t ha^{-1})	Treatment	(t ha^{-1})	N	P	K
204.9	8.4	281.7	9.85	Farm Prac	4.79	127.9	11.7	14.8
233.0	14.9	333.0	10.80	Imp Tech	5.85	168.1	15.6	19.7

It is interesting to note that the yield of rice under the farmers' practice showed a declining trend while it was increasing under the improved technology (Figure 21). From simple correlation analysis, an increase of 0.20 t ha^{-1} in the yield of rice is expected every cropping while a decrease of 0.25 t ha^{-1} is expected every cropping in the farmers' practice. This correlation is represented in the equation, Y= 0.5074 Ln (x) + 5.2109, for improved technology, and Y=0.6134Ln(x) - 5.1163 for the farmers' practice.

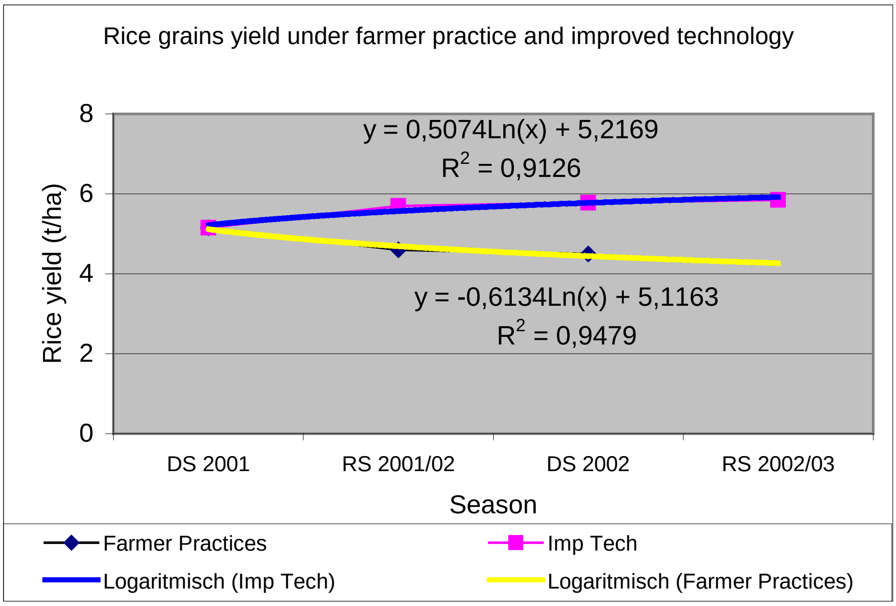


Figure 21. Rice grains yield under farmer practices and improved technology in terraced paddy field

The N, P, and K balances during the rainy season cropping 2002/2003 are presented in Table 8. The results showed that crop residues under both the farmers' practice and the improved technology provided the biggest contribution to the input.

Under the farmers' practice, 78-98% of the nutrient gain was contributed by the crop residues. Under the improved technology, crop residues contributed 23-85% of the nutrient gain.

Crop removal is also the major cause of nutrient loss in the paddy fields. Nutrient loss through erosion is almost nil. Recycling rice straw can therefore be a good management practice. It will be beneficial to leave more rice straw in the field, say, by cutting the rice straw higher from the ground during harvest.

Table 8 also shows a negative balance for all nutrients under both the farmers' practice and the improved technology indicating the urgent need to improve management to address further nutrient depletion. This observation is similar to that from the first year data. Nitrogen showed the highest negative balance of -241 and -219 N kg $ha^{-1}season^{-1}$ under the farmers' practice and the improved technology, respectively. For P, a negative balance of -15 and -3 kg ha^{-1} $season^{-1}$ under the farmers' practice and the improved technology, respectively, was observed. The corresponding balance for K was -56 and -32 kg ha^{-1} $season^{-1}$.

Table 8. N, P, and K balances at terraced paddy field system for rainy season 2002/2003

Parameter	Nutrient Balance (kg ha^{-1} $season^{-1}$)					
	Farmer Practices			Improved Technology		
	N	P	K	N	P	K
Gains:						
1. Fertilizer	22.50	-	-	45.00	20.00	25.72
	*(14%)**			*(15%)*	*(73%)*	*(13%)*
2. Irrigation	0.02	0.002	0.003	0.02	0.002	0.003
3. Rainfall	8.53	1.09	3.65	8.53	1.09	3.65
4. Crop Residues	137.30	3.90	160.30	228.10	6.40	189.80
	(81%)	*(78%)*	*(98%)*	*(81%)*	*(23%)*	*(85%)*
Total Gains	168.35	4.99	163.95	279.65	27.49	220.17
Losses:						
1. Removal by harvest						
• Rice grains	127.90	11.70	14.80	168.10	15.60	19.70
	(31%)	*(58%)*	*(6.7%)*	*(33.9%)*	*(51%)*	*(7.8%)*
• Rice straws	281.70	8.40	204.90	330.10	14.90	233.00
	(69%)	*(42%)*	*(93%)*	*(66%)*	*(49%)*	*(92%)*
2. Soil Loss						
• Run off sediment	0.00	0.00	0.00	0.00	0.00	0.00
• Bed load	-	-	-	-	-	-
Total Losses	409.60	20.10	219.70	498.20	30.50	252.70
Balance	-241.25	-15.11	-55.75	-218.55	-3.01	-32.53

*Values in bracket are the percentage of the total nutrient gain or loss

Scenarios to support higher production

The high negative balance of all three major nutrients, especially under the farmers' practice, points to the need to immediately address the problem of nutrient depletion. Integrated nutrient management, with due consideration of managing inputs and outputs of nutsrients must be looked at. The results taken from two years of study indicated that rice grain and straw represent about 66-74% of total rice biomass and contain an equivalent amount of 69-75% N, 83-84%P and 58-60% K. Rice straw alone therefore contains about 46-52% N, 35-40% P, and 54-55% K. Rice straw management like recycling it back to the rice paddies appears to be a potential strategy to look at.

Recycling about 67% of the total harvested straw provides about 94, 2.8, and 68.3 kg ha^{-1} $season^{-1}$ of N, P, and K, respectively, under the farmers' practice, and 110, 4.9, and 77.6 kg ha^{-1} $season^{-1}$ under the improved technology. This would result in the nutrient balance of -133, -10, and +80 kg ha^{-1} $season^{-1}$ of N, P, and K, respecticvely, in the farmers' practice. The corresponding balance in the improved technology is -4, +7, and +104 kg ha^{-1} $season^{-1}$ of N, P, and K, respectively (Table 9).

Table 9. Expected nutrient balance for lowland rice with 67% of rice straw produced per year recycled

Treatment	Nutrient balance (kg ha^{-1} $season^{-1)}$ N	P	K
1. Rice straw is used for feeding:			
▪ Farmer Practices	- 241	- 15	- 56
▪ Improved Technology	- 219	- 3	- 32
2. 33% of rice straw recycled:			
▪ Farmer Practices	- 133	- 9	+ 81
▪ Improved Technology	- 4	+ 7	+ 104

Validation of Soil Erosion Prediction Model

Digital elevation model (DEM) was developed based on the topographic map by converting the vector format into raster using grid tools analysis. The vector format was converted into triangulated irregular network (TIN) using 3D and spatial analysis from the Arc View 3.1. The result was exported into ASCII format, which was used as the spatial data input for PCRaster. Before converting into raster format, *clone.map* was created from the available spatial data. The overall procedure is shown in Figure 22.

DEM maps of Tegalan, Rambutan and Kalisidi are presented in Figures 23, 24, and 25 respectively. These maps were used to create the slope map and the local drain direction (LDD) map, which is the flowpath of the surface runoff. Using these maps, the sediment that is transported from one raster to the other raster was calculated, while the flow path was used to calculate runoff and sediment within the raster. LDD map was created using operational commands of PCRaster as follow:

PCRCalc LDD.map = lddcreate(DEM.map,1,1e35,1e35,1e35)

In Tegalan microcatchment, slopes ranged from 40 to 60 percent with some parts about 90 percent. The Rambutan microcatchment has gentle slope near the ridge with dominant slope of 40 to 60 percent at the middle and lower slope. The Kalisidi microcatchment has steeper slopes of 50 to 70 percent, especially near the natural creecks. The LDD map of Tegalan, Rambutan and Kalisidi microcatchments showed that the flow to the outlet was as the original.

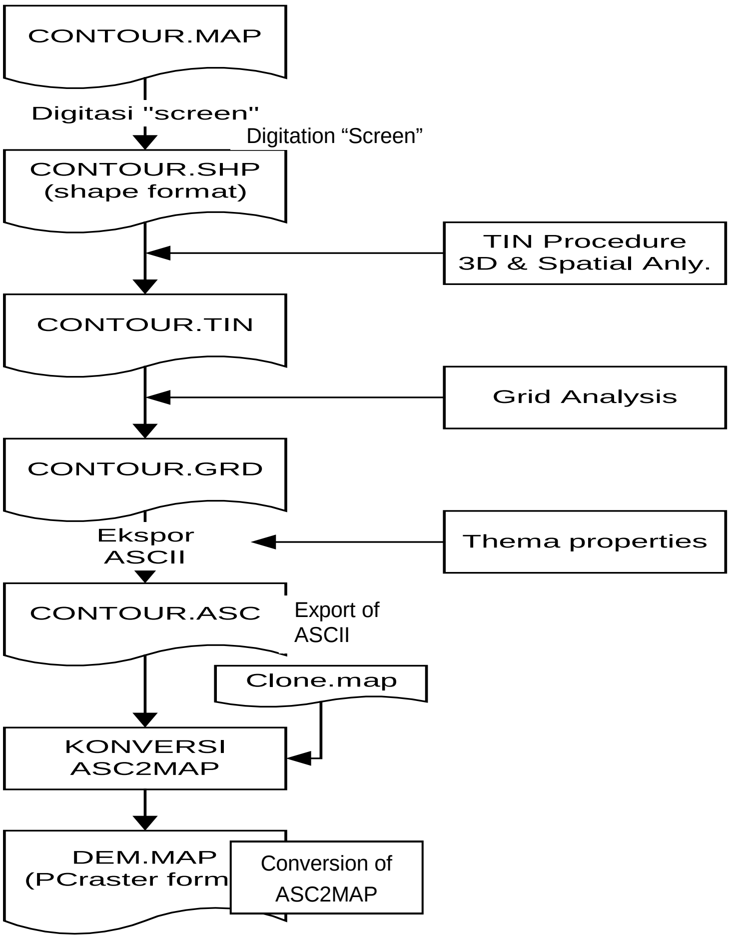


Figure 22. Flowchart explaining the process of data conversion of the contour in the digital elevation model in the model of MSEC-1 (Paningbatan, 2001; ICRAF, 2001; Eiumnoh, 2002).

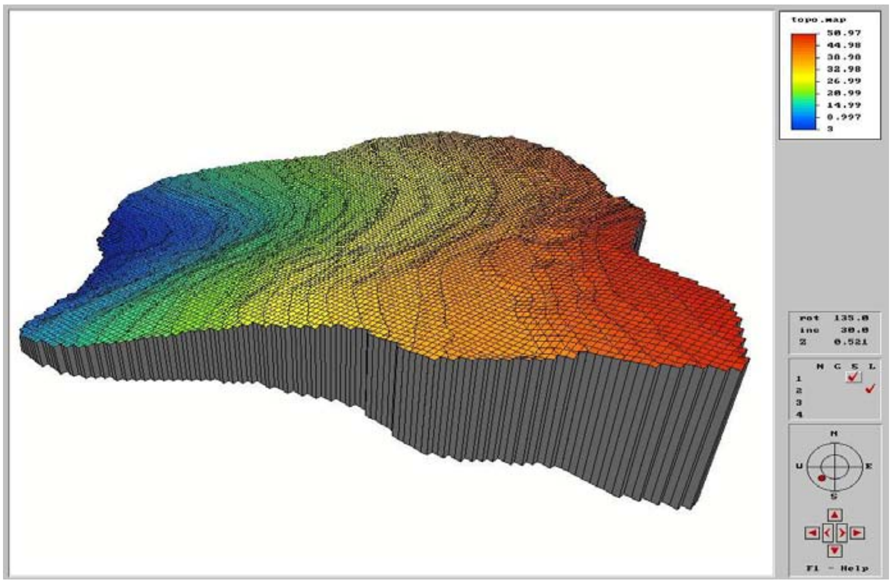


Figure 23. DEM map of Tegalan micro catchment with the raster size of 1 x 1 m (not in the scale)

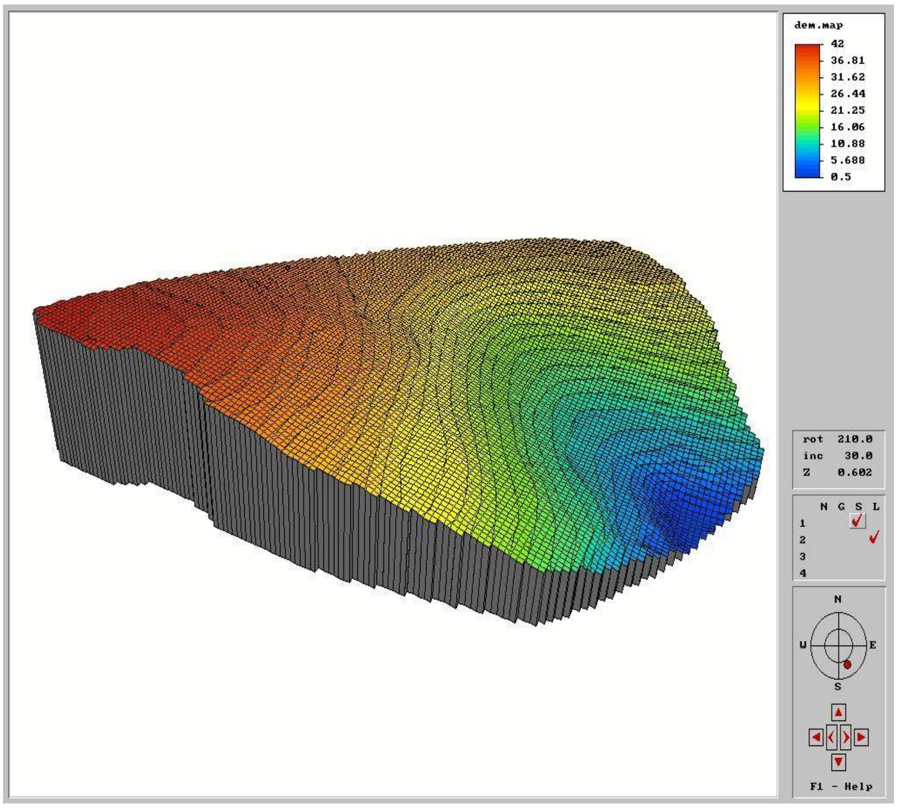


Figure 24. DEM map of Rambutan micro catchment with the raster size of 1 x 1 m (not in the scale)

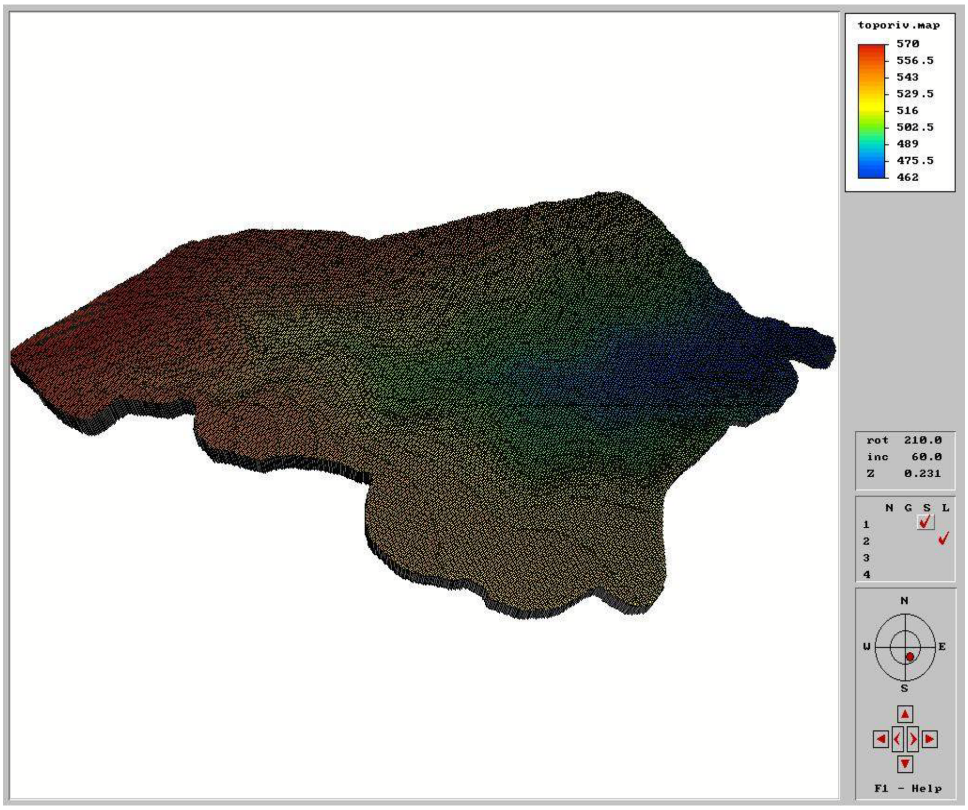


Figure 25. DEM map of Kalisidi micro catchment with the raster size of 1 x 1 m (not in the scale)

Soil maps were created by converting analog soil map into digital (raster) format using extention facility of grid tools analysis from the ArcView 3.1 without TIN procedure. The result was exported as the ASCII format, and used for spatial data entry from PCRaster using clone.map created from previous spatial data. The overall procedure to create soil map is depicted in Figure 26.

The created soil maps of Tegalan, Rambutan, and Kalisidi are presented in Figure 27, 28, and 29. These maps were used to create Sed-den and Sed-vel maps, which present the density of the sediment particle and the flow velocity of the soil particle, respectively. These two parameters are affected by soil types. The soils of Rambutan and Kalisidi are dominated by Andic Dystropepts, while Andic Eutropepts dominate in Tegalan. These maps were used for further calculation, where the entry of spatial data is done using a command of LookUp from PCRaster as follow:

PCRCalc Sedden.map = lookupscalar(Density.tbl,Soil.map)
PCRCalc Sedvel.map = lookupscalar(Velocity.tbl, Soil.map)

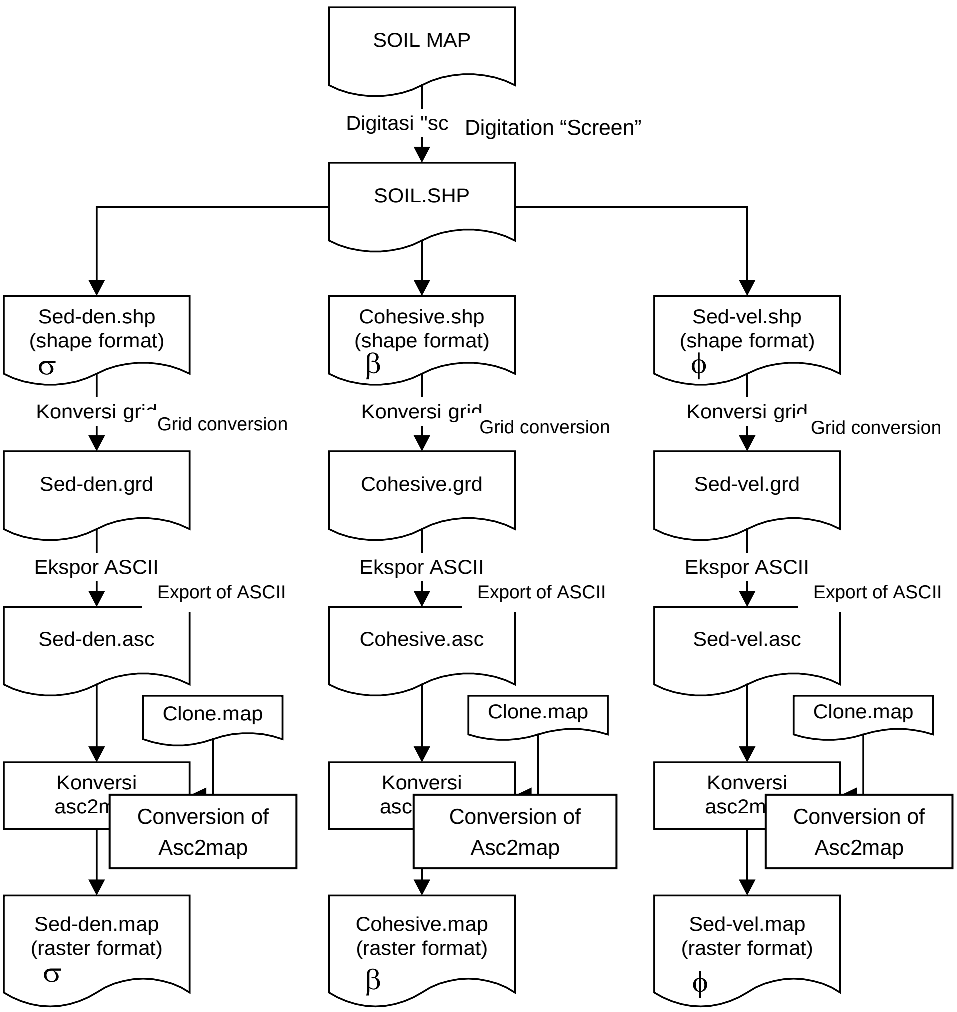


Figure 26. Flowchart explaining procedure to convert analog soil data into digital soil data (ICRAF, 2001; Eiumnoh, 2002)

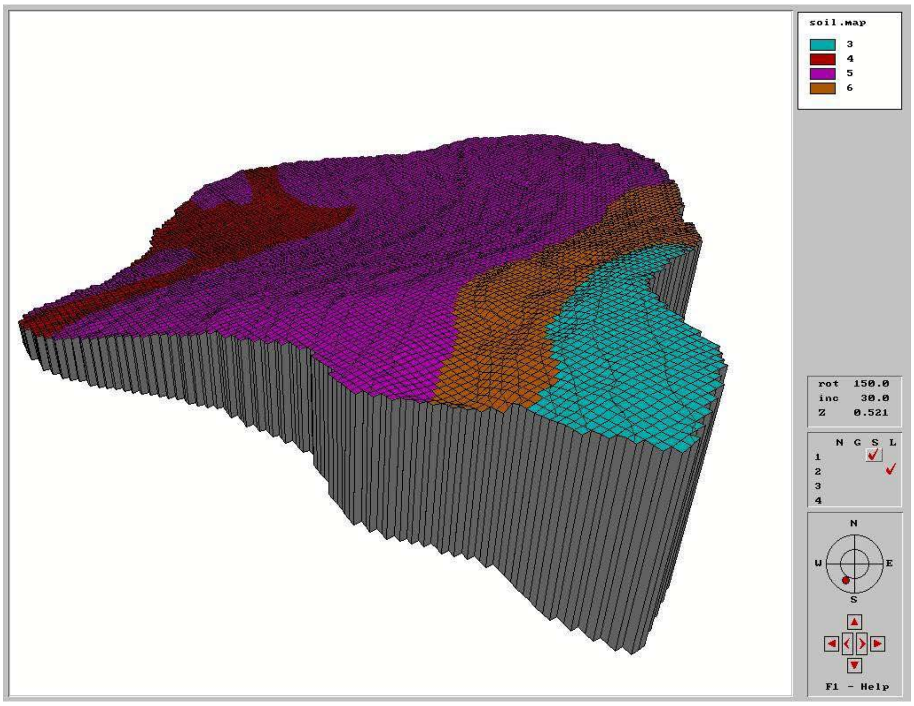


Figure 27. Soil map of Tegalan micro catchment with the raster size of 1 x 1 m (not in the scale)

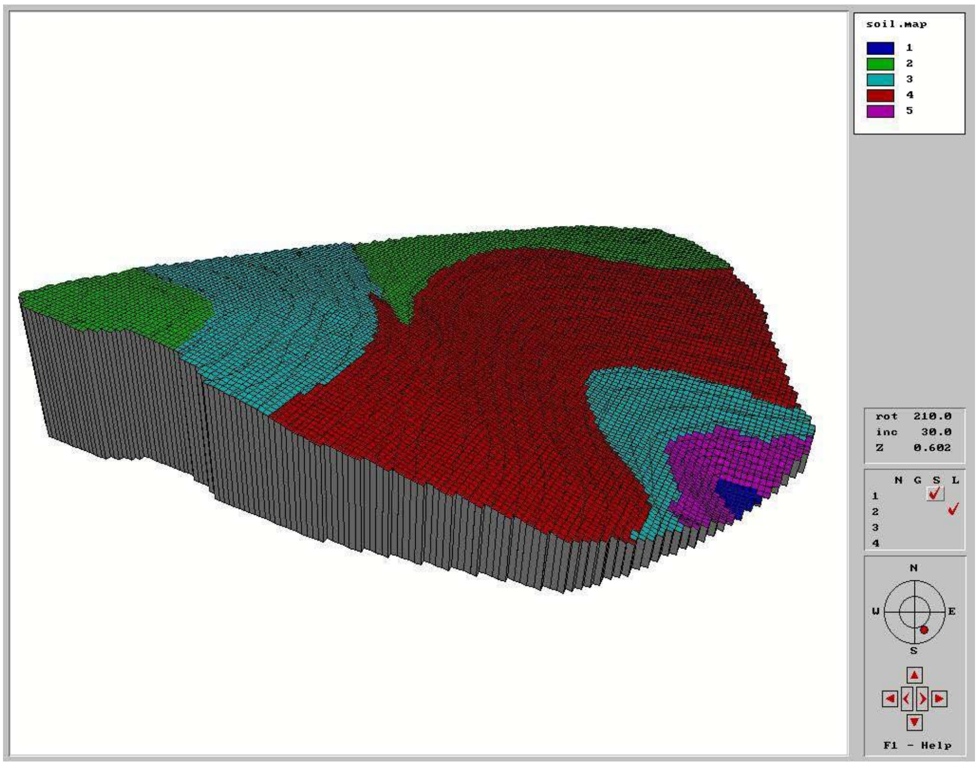


Figure 28. Soil map of Rambutan micro catchment with the raster size of 1 x 1 m (not in the scale)

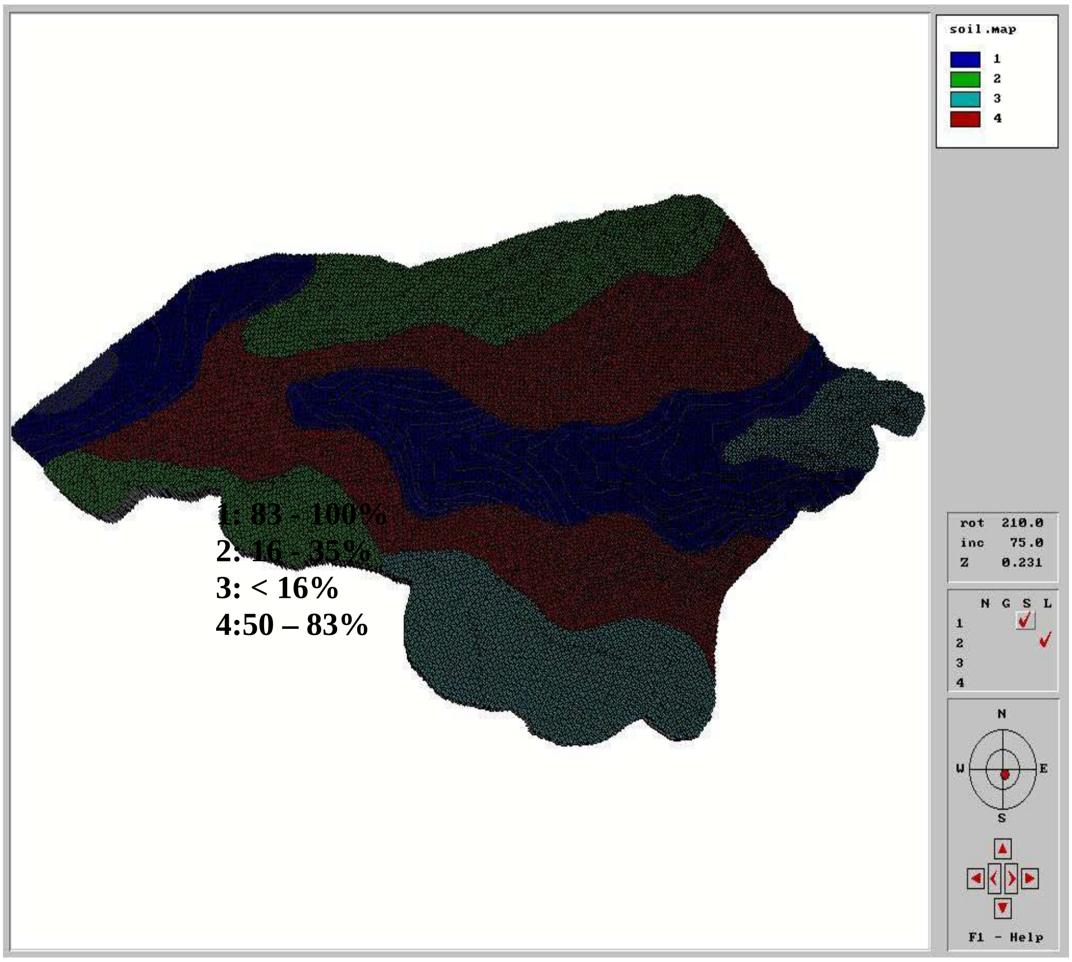


Figure 29. Soil map of Kalisidi micro catchment with the raster size of 1 x 1 m (not in the scale)

Both density and flow velocity of the particle are based on the soil texture *i.e* clay loam and the particle size (2680). Since there was no study on these parameters in Indonesia, the values were adopted from ACIAR project. The produced soil maps were also used to create erodibility map. Like the Sed-den and Sed-vel maps, which are interconnected spatial data, they were used for further calculation. The next step was to create a Beta map, which was done according to the following command:

PCRCalc Beta.map = lookupscalar(Cohesive.tbl,Soil.map)

ACIARs' parameter of cohesiveness was also adopted to create tabular data, which were used in the model. The value of 0.50 was used for parameter of particle size. The tabular data was formatted into ASCII structure named sedden.tbl, sedvel.tbl, dan cohesive.tbl (Rose *et al*, 1997; Eiumnoh *et al*, 2001).

Similar procedure was done to create land use maps. The overall procedure is presented in Figure 30. The land use map of Tegalan, Rambutan and Kalisidi microcatchments are presented in Figures 31, 32, and 33.

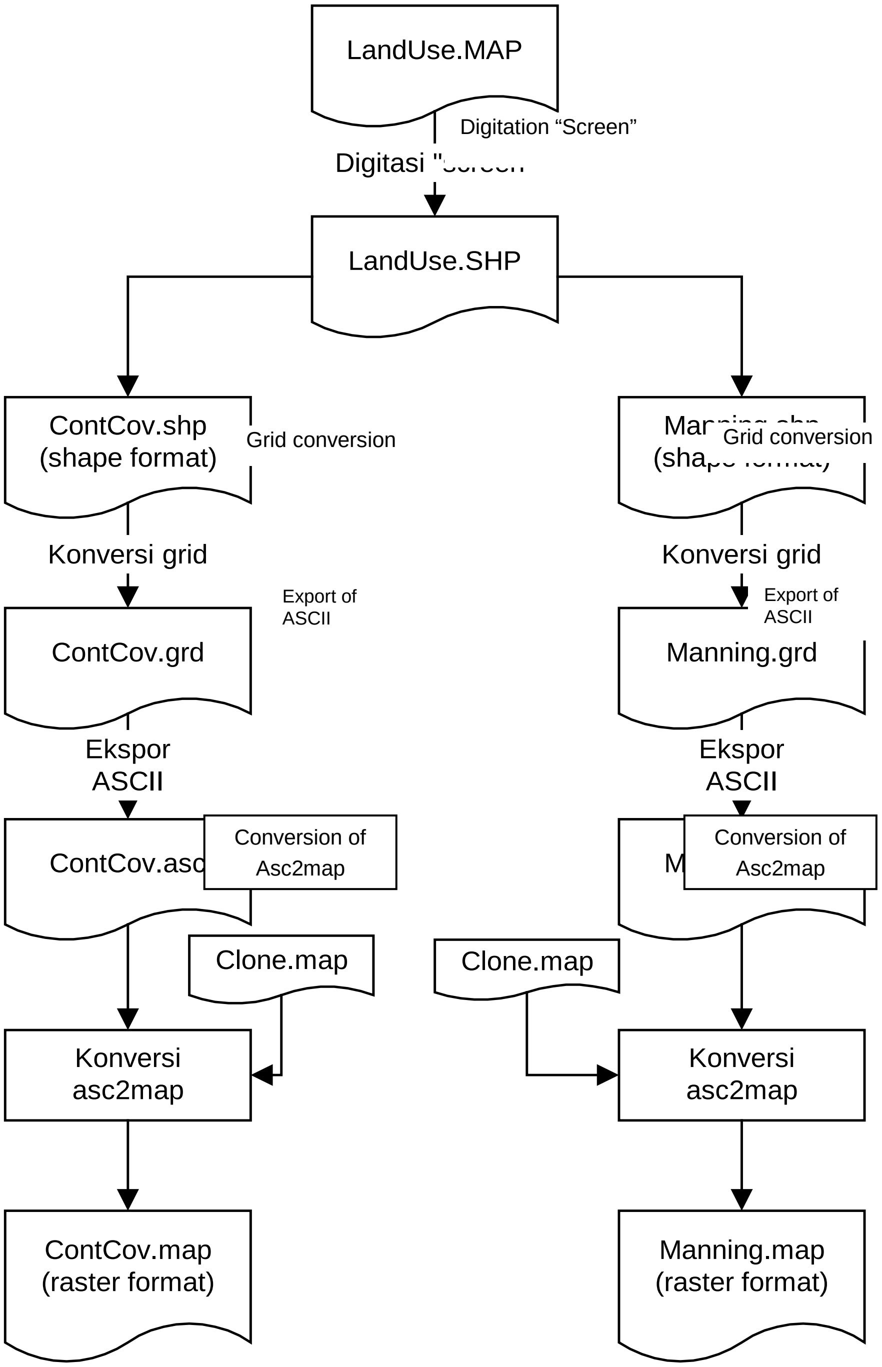


Figure 30. Flowchart explaining the procedure to covert analog land use data into digital land use data (Paningbatan, 2001; ICRAF, 2001; Eiumnoh 2002)

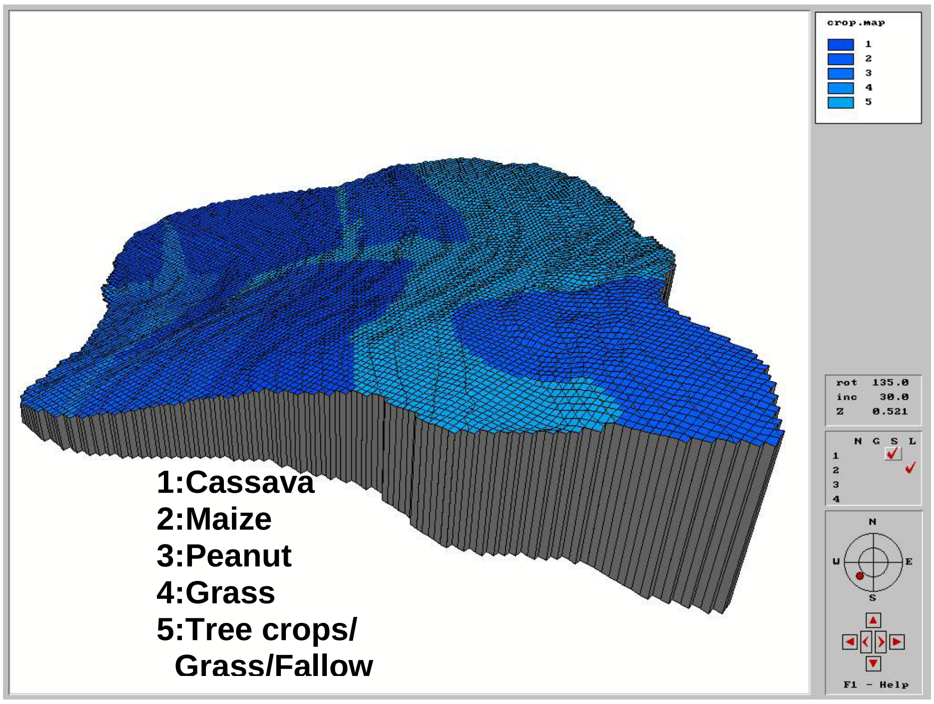


Figure 31. Land use of Tegalan micro catchment with the raster size of 1 x 1 m (not in the scale)

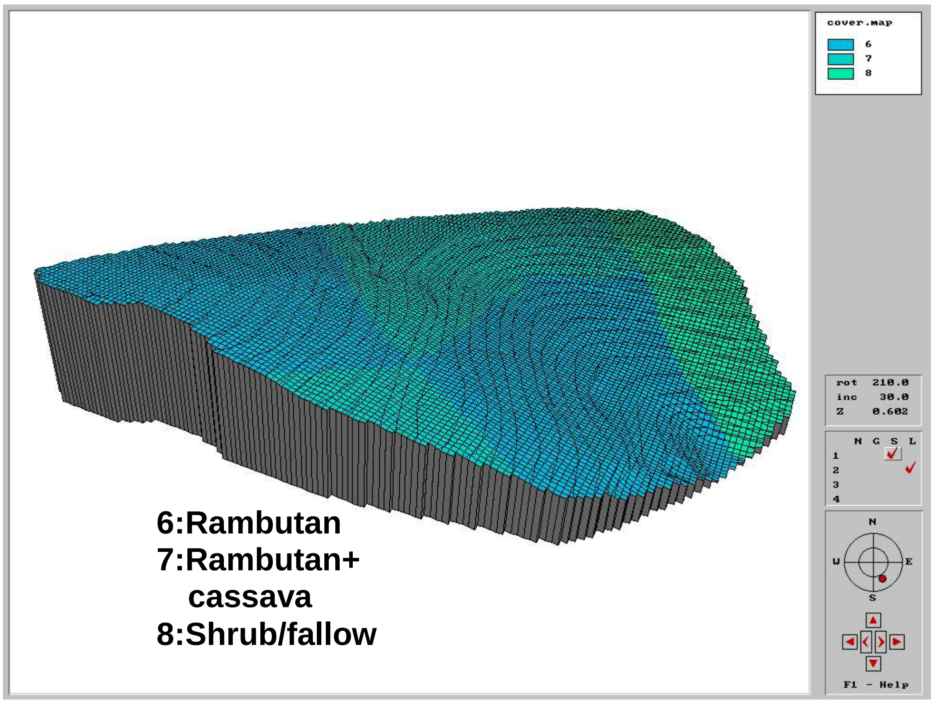


Figure 32. Land use of Rambutan micro catchment with the raster size of 1 x 1 m (not in the scale)

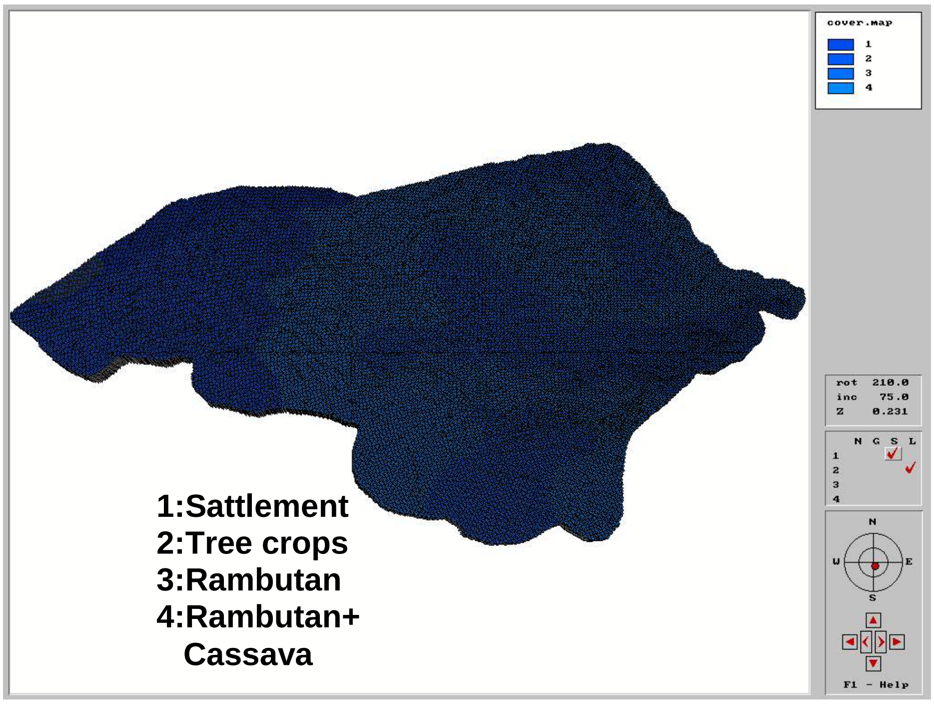


Figure 33. Land use of Kalisidi micro catchment with the raster size of 1 x 1 m (not in the scale)

In Tegalan microcatchment, cassava, corn, and peanut were dominant, with a few tree crops like coffee, rambutan and durian. The surface of the ground was covered by grass and shrub. In both Rambutan and Kalisidi microcatchments, rambutan was the main vegetation. About 25 – 30 % of the Rambutan microcatchment was fallow. Beside rambutan, part of the Kalisidi microcatchment was covered with cassava and used for traditional estate and settlement.

The Mannings'roughness constant and the contact cover maps are created using the land cover map. These maps were used for further calculation on which the spatial values have been entered using a command of LookUp from PCRaster as follow:

PCRCalc Manning.map = lookupscalar(Manning.tbl,Crop.map)
PCRCalc Contcov.map = lookupscalar(Contcov.tbl, Crop.map)

The Manning Table and Contact Cover values were related to the existing crops when rainstorm and erosion occurred. These values were published by the ACIAR project and used in this study. Theses values were derived from the studies done in Malaysia, Thailand, Philippines, Northern Australia. Values for Indonesia were based on ICRAF project in Lampung under coffee based cropping system (ICRAF 2001, Rose, *et.al.*, 1985, dan Rose, *et.al.*, 1997; Eiumnoh, *et.al*, 2001). These maps were, then, used to define runoff and transport capacity of sediment and deposition through the flowpath.

Rainfall was recorded in six minute interval using automatic weather station and converted into hour data to define intensity in mm per hour. The first step was to save the data in Raind.tss file, then the Raind.tss file was freated by coding 1 or 0 every rainfall event. The third step was to create the dune.tss file after converting the unit of time from minute to second (6 x 60 = 360) (Paningbatan, 2001; and Eiumnoh, 2002). Those files were made in ASCII format like what was done for tabular data required in the PCRaster to run the model. The model is valid for a single rainfall event.

This model was run using the command of Model.mod. The model deals with the dynamic process that corresponds to the timestep. The number of timestep was the same as the rainfall data input. Automatic calculation used batch file (1run.bat), which consisted of command of PCRCalc –f Model.mod.

As mentioned in the previous discussion, two peaks of discharge were also predicted for the Tegalan microcatchment (Figure 34). The rising limb of the hydrograph was almost similar to the falling limb, indicating the dominance of quick flows. The predicted flow during the rising limb increased sharply, while the measured one increased gently suggesting that the flow response to rainfall occurred later than the predicted response. This provides insight that Hortonian overland flow seems to occur in the field suggesting that the infiltration parameter need to be incorporated in the model as done in the MSEC 2 or PCARES models.

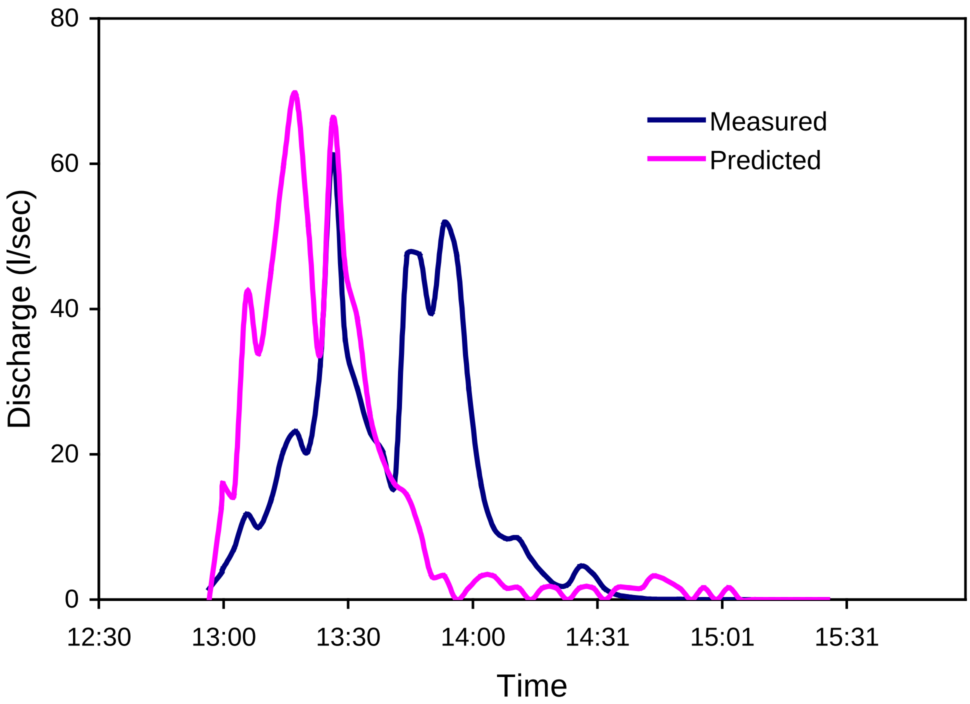


Figure 34. Comparison between predicted and measured runoff for Tegalan microcatchment on January 15, 2003 event

There was a close relationship between predicted and measured runoff with a coefficient of determination (R^2) of 0.72 (Figure 35). This means that about 30 percent of the predicted value still needs to be accounted for. Hydrologically, the model has not yet correctly predicted the time to peak, but able to predict volume of runoff as a response to rainfall.

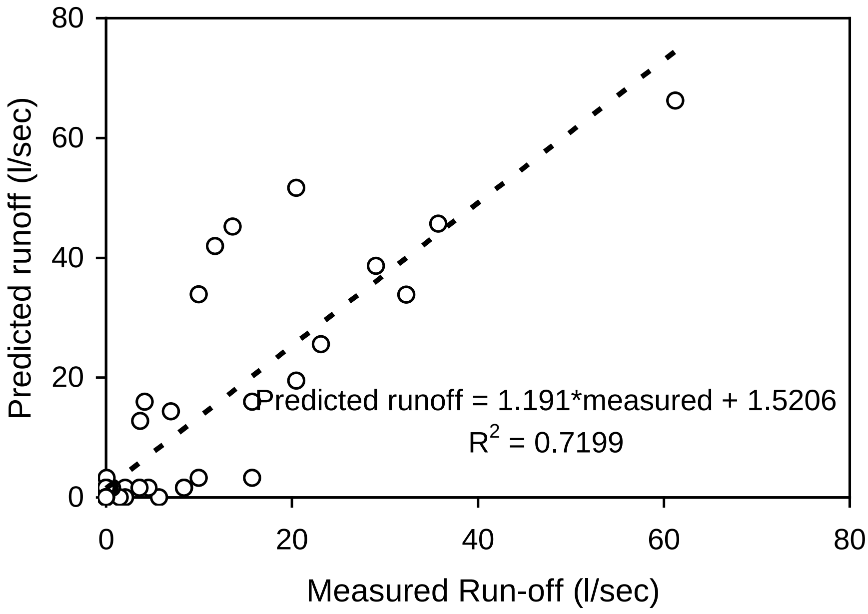


Figure 35. Relationship between predicted and measured of runoff for Tegalan microcatchment

Compared with Tegalan microcatchment, the predicted runoff in Rambutan microcatchment occurred much earlier than the measured one, although the hydrographs were similar (Figure 36). This shows that the lag time was longer meaning that much rainfall infiltrated and time to peak was longer. The predicted runoff occurred just at the same time as the rainfall. The regression analysis showed a lower correlation of 0.40 (Figure 37). During the rainfall event, the ground floor of the Rambutan microcatchment was covered by about 30% of grass and shrub, which facilitated infiltration and reduced the surface runoff.

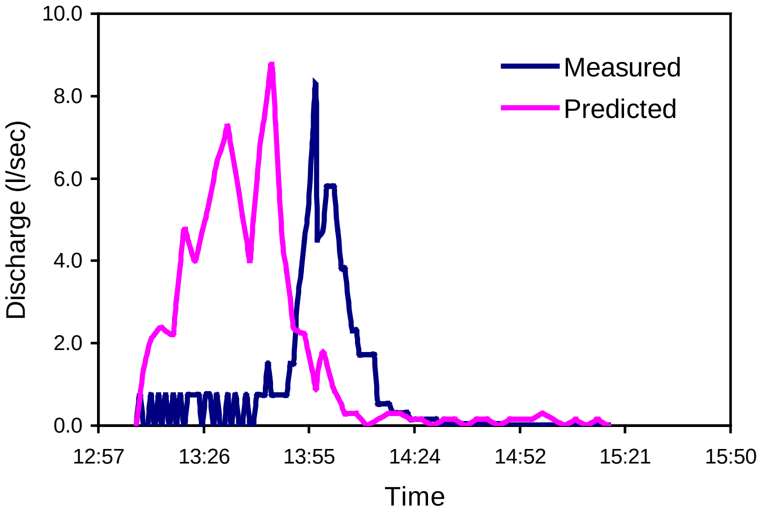


Figure 36. Comparison between predicted and measured runoff for Rambutan microcatchment on January 15, 2003 event

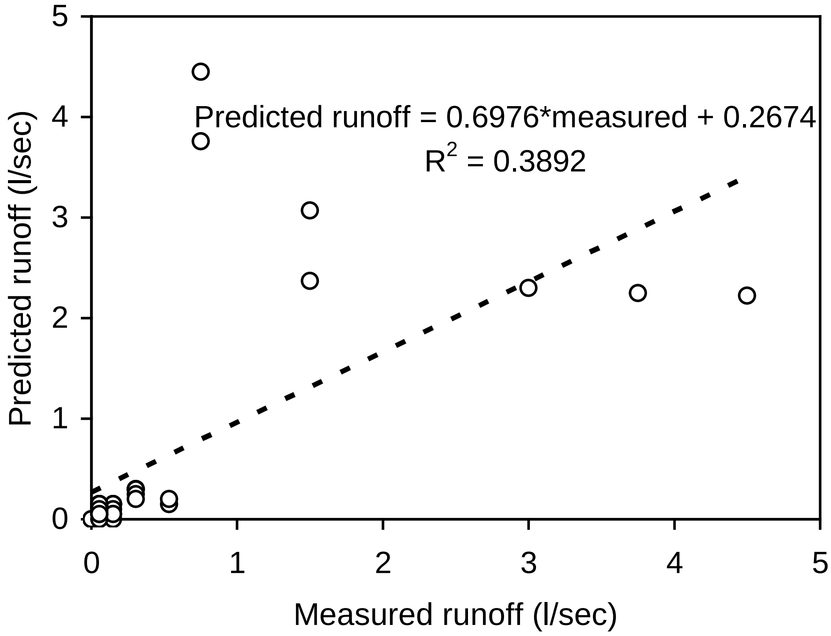


Figure 37. Relationship between predicted and measured of runoff for Rambutan microcatchment

Although it has similar land use as the Rambutan microcatchment, the Kalisidi microcatchment showed better prediction of runoff with a correlation value of 0.72 (Figures 38 and 39). Similar to the Tegalan and Rambutan microcatchments, the predicted flow occurred earlier than the measured one although the lag time was shorter. There was lag time between rainfall event and generated runoff and the pattern of hydrograph indicated that the flow increased sharper than the predicted one. The different in the surface roughness is one of the key factors influencing the surface runoff.

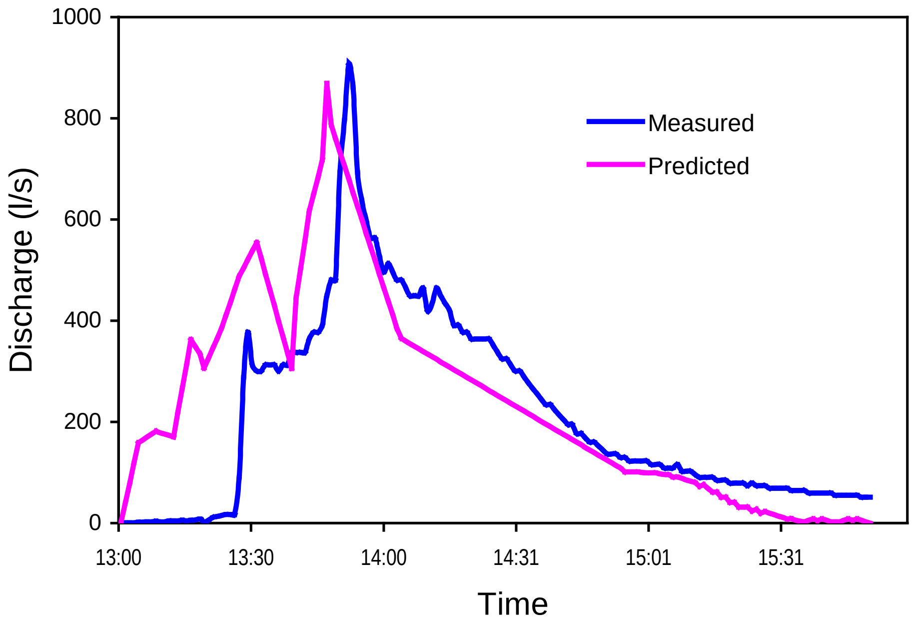


Figure 38. Comparison between predicted and measured runoff for Kalisidi microcatchment on January 15, 2003 event

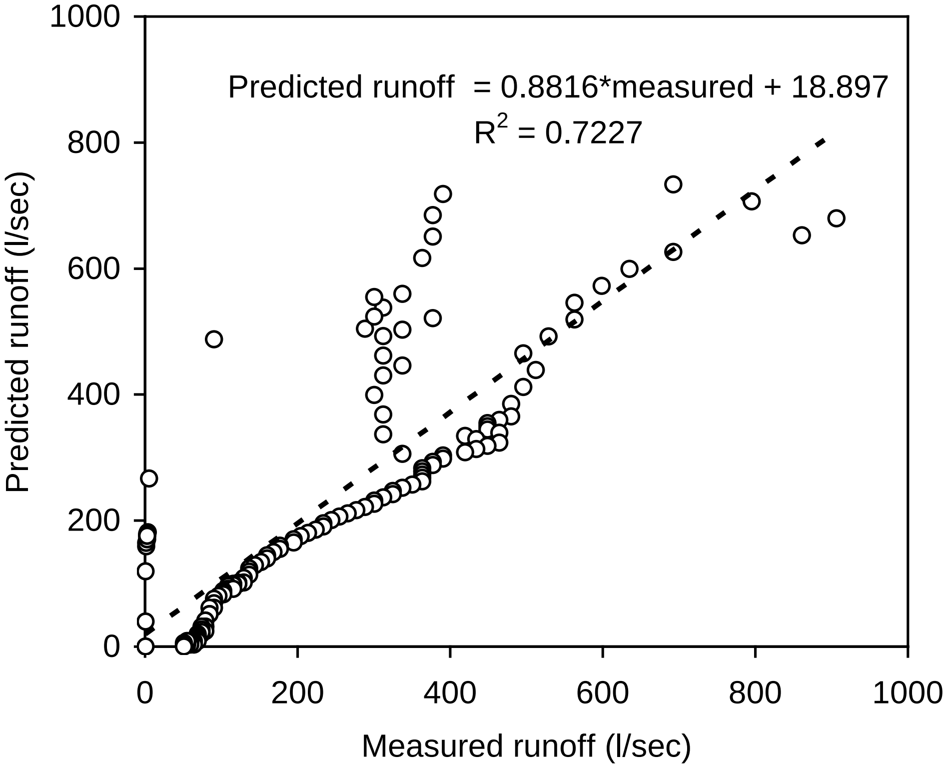


Figure 39. Relationship between predicted and measured runoff for Kalisidi microcatchment

Conclusions and Recommendations

Conclusions

1. The upland soil is more susceptible to surface runoff and erosion when it is used for seasonal crops compared to perennial crops. As far as controlling surface runoff and soil loss is concerned, tree crop provides significant contribution. If the cultivation of seasonal crops is selected to be an alternative, conservation measures have to be introduced to avoid land degradation. The use of Benggala grass (*Panicum maximum*) for erosion control resulted in 50% lower sediment yields in the first year and almost 90% in the second year. Integrated grass planting and cattle fattening promises sustainable conservation farming system that reduces soil erosion and increases farmer's income.
2. Loss of N, P and K through runoff, sediment transport and crop harvest has been noticed to be high. Most of N and K losses are concentrated in the transported sediment, while that of P was in the surface runoff.
3. Under the terraced paddy field, the lost of sediment and nutrient was high during land preparation. It is recommended to recycle rice straw as much as 67% of the total straw produced during the year.
4. The farmers' practice in which only 50 kg urea ha^{-1} cropping $season^{-1}$ was applied, needs to be improved. Application of 100 kg each of Urea, TSP and KCl ha^{-1} cropping $season^{-1}$ has been tested and gave no response to crop yield. Perhaps, the additional fertilizer or readjustement of the composition of the three fertilizers is required and it needs further study to test the effects.
5. Validation model of GUEST on the surface runoff has come up with the results, which showed different coefficient of determination (R^2) among the land use systems. The

R^2 values of Tegalan, Rambutan and Kalisidi were 0.72; 0.39; and 0.72, respectively. In all land use systems, predicted values showed typical pattern where the flow occurred earlier than the measured one. This suggests that, for application in Indonesia, GUEST model need to be refined by including a parameter of infiltration rate. The processes have explained that Hortonian overland flow occurred in the catchment studied.

Recommendation

So far, the study has been focused on the surface runoff and erosion with respect to the rainfall event. Stream flow is hydrologically not only the result of surface flow but also subsurface flow. Understanding the dynamic behavior of the rainfall – runoff relationship will be more comprehensive if it deals with subsurface flow. The dynamic change in nutrient status in the soil has not been much considered in the present study concerning the nutrient balance.

The future study may cover some topics as follow:

- Linking hydrology and biogeochemical processes
- Hydrologic pathways and erosion processes
- Community-led of soil and water conservation measures

References

Agus, F., T. Vadari, Sukristiyonubowo, B. Hermianto, J.P. Bricquet , and A. Maglinao. 2002. Catchment size and land management systems affect water and sediment yields. Proceedings of 12th ISCO Conference 26-30 May 2002, Beijing, China. pp. 469-475.

Agus, F. and Sukristiyonubowo. 2001. Nutrient loss and on site cost of soil erosion under different land use systems in South East Asia. cross-country analysis. Paper presented at MSEC Assembly, Hanoi 10-15 December 2001. 15p.

Craswell, E.T., C.Niamskul, and F.W.T. Penning de Vriest, 1998. Catchment approach to combating soil erosion in Asia-the Managing Soil Erosion Consortium. p 161-173. *In* F.W.T. Penning de Vries, F. Agus, and J. Kerr eds.: Soil Erosion At Multiple Scale: Principles and Methods for Assessing Causes and Impacts. CABI Publishing in Association with IBSRAM.

El-Swaify, S.A. 1989. Monitoring of weather, runoff, and soil loss. p 163-178. *In* Soil Management and Smallholder Development In The Pacific Islands. IBSRAM Proceedings No.8. Thailand.

Garrity, D.P., and F. Agus. 1999. Natural resource management on a watershed scale: What can agroforestry contribute? pp. 165-193 *In* Lal, R. (ed.) Integrated Watershed Management in the Global Ecosystem, CRC Press, Washington, D.C.

Haryati, U., Haryono, and Abdurachman, A. 1995. Pengendalian erosi dan aliran permukaan serta produksi tanaman pangan dengan berbagai teknik konservasi pada tanah Typic Eutropepts di Ungaran, Jawa Tengah. Pemberitaan Tanah dan Pupuk 13: 40-50.

Herschy, Reginald W. 1985. Stream flow measurement. Elsevier Applied Science Publishers, England. 553 p.

Hashim, G.M.; K.J.Caughlan; and J.K. Syers. 1998. On-site nutrient depletion: An effect and a cause of soil erosion. In Soil Erosion At Multiple Scale. Principles and Methods for Assessing Causes and Impacts. CABI Publishing in Association with IBSRAM: 207-222

Lefroy, R.D.B.; and J. Konboon. 1999. Studying nutrient flows to assess sustainability and identify areas of nutrient depletion and imbalance: an example for rainfed rice

systems in Northeast Thailand. In Rainfed Lowland Rice: Advances in Nutrient Management Research. Edited by Ladha et al. IRRI: 77-93

Paningbatan, E. 1995. The ASIALAND management of sloping lands network: Soil erosion under different soil conservation practices. pp 109-126. In International Workshop on Conservation Farming for Sloping Uplands in Southeast Asia: Challenges, Opportunities, and Prospects. IBSRAM Proceedings No 14. Bangkok.

Santoso, D.; IG.P. Wigena; Z. Eusof; and X.H. Chen. 1995. The ASIALAND management of sloping lands network: Nutrient balance study on sloping lands. In: International Workshop on Conservation Farming for Sloping Uplands in Southeast Asia: Challenges, Opportunities, and Prospects. IBSRAM Proceedings No 14. Bangkok, pp 93-108

Sheldrick, W.F.; J.Keith Syers; and John Lingard. 2003. Soil nutrient audits for China to estimate nutrient balance and output/input relationships. Agriculture, Ecosystems and Environment. 94: 341-354

Smaaling, E.M.A.; J.J. Stoorvogel; and P.N. Wiindmeijer. 1993. Calculating soil nutrient balances in Africa at different scles II. District scale. Fertilizer Research (35) 3: 237-250

Stoorvogel, J.J.; E.M.A Smaaling; and B.H.Janssen. 1993. Calculating soil nutrient balances in Africa at different scales. I. Supra-national scale. Fertilizer Research (35) 3: 227-236

Sukristiyonubowo; Robert L. Watung; and F. Agus. 2003. Nutrient balance under terraced paddy field system at Babon Catchment Indonesia. Paper presented at MSEC Assembly held in Vientiane, Lao PDR.

Sukristiyonubowo; Tagus Vadari; Robert LW; Sidik HT, and Fahmuddin Agus. 2002. Impact assessment of MSEC Project in Indonesia. Paper presented at training on Impact Assessment organized by IWMI, Bangkok, Thailand.

Tarigan, S.D. and N. Sinukaban. 2001. The role of paddy fields as sediment filter: Case study in Way Besai Watershed, Lampung. Prosiding Seminar Nasional Multifungsi Lahan Sawah. Bogor 1 May 2001: 29-37.

Uexkull, H.R. von. 1989. Nutrient cycling. In : Soil Management and Smallholder Development in the Pacific Islands. IBSRAM Proceedings 8: 121-132.

Institution and Capacity Building

The MSEC project in Indonesia has not only contributed to scientific research, but also given opportunities to the team members to interact with the regional scientific community and learn more about advanced research methodologies through the training, workshops and others. The list of students involved in Indonesian MSEC project is also given below.

Training, Workshops, and Seminars on 2003

Place/Date	Name	Activity/Seminar attended/Paper presented
Los banos, Philippines, July 20-30, 2003	Kasdi Subagyono	International Training-Workshop on Impact Assessment and Process Documentation
Bangkok, Thailand, October 6-10, 2003	Kasdi Subagyono Tagus Vadari	Training-Workshop on Data Management and Interpretation
Bogor, Indonesia, November 1-3, 2003	J.P. Bricquet Tagus Vadari Kasdi Subagyono	Hydras 3/Minimum Data Set of Indonesia

Students doing research in MSEC project site on 2003

I	a. Name of Student	Mr. Tagus Vadari
	b. Degree sought	MS
	c. University Affiliation	Bogor Agricultural University, Indonesia
	d. University Supervisor	Dr. Hidayat Pawitan
	e. Thesis Research Title	Micro-catchment scale Erosion Modeling (tentative)
	f. Duration of Program	Jan. 2002-October 2004
	g. Source of funding support	Personal
II	a. Name of Student	Mr. Sukristiyonubowo
	b. Degree sought	PhD
	c. University Affiliation	University of Ghent, Belgium
	d. University Supervisor	Prof. Dr. Ir. M. Verloo
	e. Thesis Research Title	Nutrient Balance under Different Land Use Systems at Babon Meso Catchment
	f. Duration of Program	2002 - 2005
	g. Source of funding support	Government of Indonesia
III	a. Name of Student	Mrs. Rohlini
	b. Degree sought	PhD
	c. University Affiliation	AIT - Bangkok
	d. University Supervisor	Prof. Dr. Apisit Eiumnoh
	e. Thesis Research Title	USLE Aided Development of Improved Land management Systems
	f. Duration of Program	2002 – 2004?
	g. Source of funding support	Government of Indonesia
IV	a. Name of Student	Mr. Yusrial
	b. Degree sought	MS
	c. University Affiliation	Gajahmada University, Yogyakarta, Indonesia
	d. University Supervisor	
	e. Thesis Research Title	Spatial and temporal variation in infiltration capacity of Babon catchment, Central Java
	f. Duration of Program	Jan. 2002-April 2003
	g. Source of funding support	Government of Indonesia

Financial Status

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