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Rainfall-Runoff Harvesting for Controlling Erosion and Sustaining Upland Agriculture Development

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ABSTRACT

In a tropical climate, some main constraints for the upland agriculture development are: (1) a very low productivity of the soil, probably due to uncertain water supply (2) the soil erosion rate, responsible for more than tolerable soil losses, caused by intensive rainfalls along with poor soil-conservation practices. In Java, several studies (Citanduy, West Java, Jratunseluna, Central Java and Brantas, East Java) have been conducted in order to cope with this problem. These projects focussed on the application of soil conservation practices. As first results, erosion rates decreased, but available water for agriculture could not be significantly increased. Further results are still expected.

Using these first data, we assumed that the approach has to change from soil erosion protection to run-off control through rainfall-runoff harvesting. Thus, rainfall-runoff harvesting research has been carried out, aimed at improving land productivity and strengthening sustainability.

Our study site is located on the Kali Garang watershed, Semarang, Indonesia, where yearly average rainfall is 4 000 mm (falling from October to March), slopes vary between 15 and 60% and mean land tenure is less than 0.3 hectare. Such conditions make it difficult for decision makers to set up strategies to improve farmers' income and to maintain sustainable agriculture development. The results of this study show that, by rainfall-runoff harvesting using small reservoirs, planting intensity can be raised to twice as much as than before, crops composition can be enriched with high value crops such as: chili, onions or water melon. Besides, reservoirs can be used to water animals and fresh water fishery, thus improving directly farmers' income, along with soil conservation practices. Furthermore, through rainfall-runoff harvesting, critical land can be rehabilitated. The result at this work suggests the uses of the watershed are as the planning unit. Basing efforts on the watershed, it is possible to evaluate the effects of rainfall-runoff harvesting not only on productivity and sustainability, but also on flood control during the wet season, as well as drought protection during the dry season. This is an important part in promoting sustainable upland agriculture development, especially in the developed and developing countries for the future.

INTRODUCTION

In tropical regions such as Indonesia, some current problems of upland agriculture development are: high runoff and erosion rates, low productivity of the soil, high agriculture risks due to climatic hazards and farmer's low average income. This marginal condition makes difficult the promotion, adoption and development of soil conservation technologies. Consequently, soils tend to degrade, causing low fertility and all the more with an over-exploitation of natural resources for agriculture production.

Many efforts have been made by the Government of Indonesia in order to develop upland agriculture, through several development projects on various watersheds including Citanduy (West Java, 1981-1985), Jratunseluna (Central Java) and Brantas (East Java, 1985-1990). The World Bank supported these projects. In the Citanduy project, soil conservation techniques have been introduced (such as terracing, mulching, contour hedgerow etc), along with credits, regular monitoring, and intensification of food crops production (Saragih et al., 1981). During the project, most of this program was running well. At the time, it was thought that farmers adopted these techniques of soil conservation.

Unfortunately, final results of such projects are generally under those expected, because once it has ended, most of the farmers return to their previous agricultural practices. Terrace improvements are not carried on, even if people know that it can limit erosion. Most of the terraces constructed during the project are not well managed, and some places are abandoned. Another project planned to re-green several critical watersheds. This included reforestation upstream of the watershed. Unfortunately the same results of this project also had difficulties. These project were proposed (i) to decrease erosion rate, (ii) to stock water in order to increase its availability and (iii) finally to improve soil productivity and farmers income. On the whole, the results were not as good as expected.

Based on several limitations of the former projects, we tried to find answers for why soil conservation and farming

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system technology as introduced did not work? According to the evaluation carried out by the World Bank (Perez and Sumarjo Gatot, 1996) there are several factors influencing the success of the development upland agriculture: (i) low water availability (ii) market oriented commodities and (iii) small size of land tenure. Even if a terracing program can successfully control erosion, it cannot directly provide water. Thus, during the dry season farmers cannot plant high value crops, because water is not sufficiently available. With state-planned food crops, this strategy promotes low income for the farmers, because selling prices are totally under control of the government. The situation would be different if the farmer would be allowed to select high-value varieties. During the dry season, if water is sufficiently available, farmers can grow horticultural crops in order to get more benefits, given that at this time, prices for such varieties are very profitable. Concerning land tenure, the government has to make a decision to find out solutions for this problem. Land reformation could be one of them.

According to the preceding experience, we set up a new approach based on alternative strategies aiming at changing : (i) from soil erosion control to runoff control through rainfall and runoff harvesting (ii) from food crop oriented to high value added commodities. Within these approaches, evaluation of the program can be easily carried out.

Rainfall and runoff harvesting technologies have been applied in several regions through out Indonesia, especially for improving farming system by selecting and cultivating highly valuable varieties. Unfortunately, these technologies are only applied in regions with low annual rainfalls. During the dry season, farmers plant horticultural varieties such as watermelon, onion, chili, tomato or even ginger to replace rice, because the available water is not sufficient for this cereal. Using small reservoirs for collecting rainfall, farmers can also grow fresh water fish and part of this water can be used to waters animals. With sufficient water, farmers can develop forages on the terrace, in order to develop animal husbandry. If this system can be fully applied, sustainable development could be achieved for upland agriculture.

Inversely, in the region with high annual rainfall such as Kali Garang watershed (2 500 mm/year), farmers do not consider rainfall and runoff water collection as a priority. They think that water will be available at any time. That is not really true: as possible global climatic changes appear, such as EL NINO, farmers have to cope with the consequences on the local scale, even within the equatorial wet area. In this case, rainfall and runoff harvesting can play an important role to solve the problems of water deficit during the dry season and excess water during the wet season.

Despite the high density of population in most of the watersheds of Java (about 1 000 inhabitants/km^2) and a rapid development of the housing areas, this region remains a major area for agriculture. One can notice an increasing diversification of the farming system, influenced by the urban demand, and an increasing rate of the non-rice products within the farmer’s operation (agroforestry gardens, animal breeding, off-farm employment).

The objectives of this study are: (i) how to determine the volume of the rainfall and runoff that should be harvested (ii) how to improve efficient water use on the field level (iii) which type of culture should be grown to improve the farmers’ income and sustaining the development of upland agriculture?

MATERIAL AND METHODS

Presentation of the experimental site

This study was conducted in the Kali Garang watershed, located in Central Java, Indonesia. This watershed stretches from the summit of the Mount Ungaran (2,050 m) to the Java Sea's border. The outlet is located in the city of Semarang (the capital of the province of Central Java), from this benchmark the total area of the watershed is nearly 220 km^2. Three tributaries contribute to the Kali Garang river: Kali Kreo (West), Kali Kripik (Middle) and upper Kali Garang (East). Three different landform units can be described:

1) The highlands with elevation between 2,050 and 400 m, correspond to the steep slope (slope ranging from 15 to 40%) of Mount Ungaran, an ancient volcano dated from Pleistocene. The geological substratum is mainly constituted with basaltic lava. Forest and estate crops cover this region.
2) The intermediate plateau (between 400 and 50 m) corresponds to a hilly region, where the geological substratum is volcanic breccia, tuff and sandstone. The hydrological network concentrates into three tributaries winding in narrow canyons. The rivers’ beds are littered with stones carried by flash floods. A mosaic of agroforestry gardens, settlements and rice fields forms the landscape.
3) The coastal plain corresponds to a ten-kilometers wide area leading to the seashore. This swampy alluvial plain is now widely built up, except for fishery and ponds areas.

Yearly annual rainfall is about 4,000 mm in the Ungaran mountain and 2,000 mm downstream According to their relief, we can distinguish three kinds of landscape in Kali Garang watershed: (i) mountainous region, with an altitude between 400 and 2,050 m, land with slopes from 15 to 40% and where land use is dominated by forest and estate crops (ii) plateau region with an altitude of 50 to 400 m, land slope 8-25% and used for settlement, estate crops, upland farming system and low-land rice fields (iii) plain region with altitude less than 50 m, slope land less than 8% mostly used for settlement.

METHODOLOGY

Three steps were carried out in order to apply rainfall-runoff harvesting i.e. (i) theoretical approach (ii) application of the method and (iii) result validation. Theoretical approach consists in identifying the problem, then expressing it according to the existing theory. In the case of rainfall-runoff harvesting the general approach is presented on Fig. 1.

Three methods (flood control, water balance and crops composition) have been used in this research in order to set a rainfall-runoff harvesting in the field. In order to get a

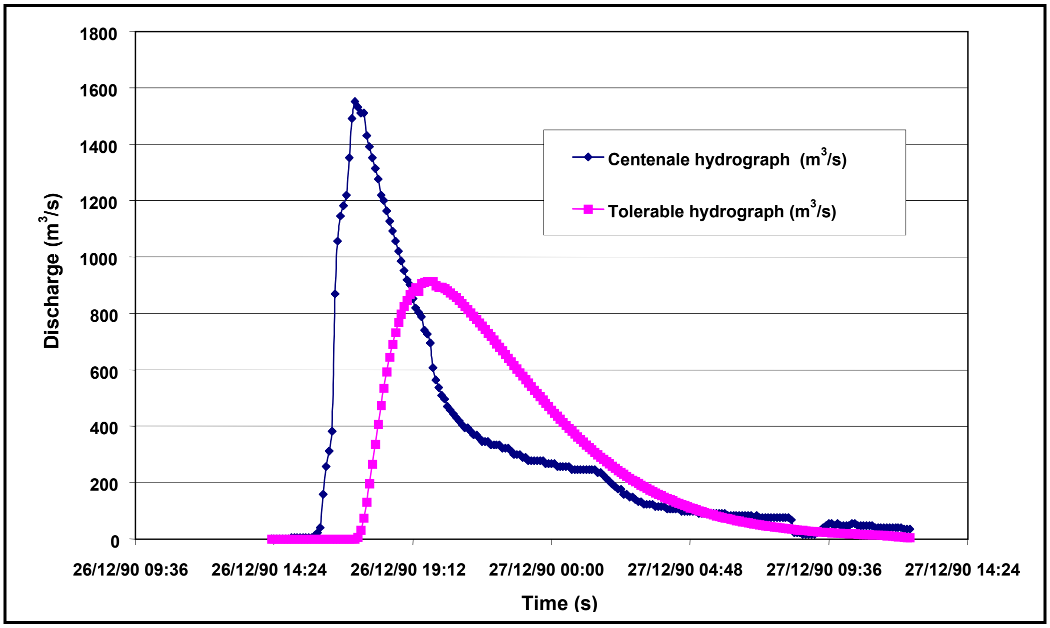

Figure 1. Flood routing through rainfall-runoff harvesting for diminishing flood risk in the rainy season and the water stress in the dry season.

significant result, a small basin (about 3.4 hectare) has been used for testing rainfall and runoff harvesting. According to daily water balance and hydrograph measurement in thebasin total (Kali Garang) show that runoff coefficient in this basin around 0,4-0,5. That mean, most of rainfall is transferred directly to the runoff and discharge. Only about 10% of rainfall recharge to soil. Physical and chemical of representative soil samples are taken in order to characterize soil fertility status of the study area. pH meter (1:5), Kjeldahl, HCl 25% and Ammonium Acetate had been used for determining respectively for pH, Nitrogen, P_2O_5 and cation exchangeable capacity (CEC). For physical characteristics of soil, we use Walkley-Black for organic matter content and membrane pressure apparatus for total drainage pores, drainage pores and water availability.

Flood control

For decreasing flood risks during the wet season (to decrease a maximum peak of discharge and increase the time to peak of discharge) and to manage water stress during the dry season, flood control has been introduced as the first step of this research (Figure 1). Water volumes that have to be collected are computed, based on a subtraction between the maximum of the centennial hydrograph (in this case) and the tolerable hydrograph (based on the river capacity).

Using data computation of the rainfall and runoff harvesting, we determined a site for collecting water. The experimental probability density function (*pdf*) of the drainage network was used as a guide. The collecting reservoir is located in the drainage network on a first order branch, according to Strahler classification (Strahler, 1964). Still, in order to increase the efficiency of flood control, we propose to set first the rainfall-runoff collecting equipment in the area, which corresponds to the peak of the probability density function of hydraulic length (Sumarjo Gatot, 1999). The others advantage of rainfall and runoff harvesting are: water flow velocity can be decreased and promote diminishing of erosion rate. So siltation problem can be controlled.

Water balance

In order to get efficient water use, we propose here a simple relation of the water balance or equilibrium between rainfall as the input variable and drainage, runoff and evapotranspiration as the output variable. Mathematically, this relation can be expressed:

$$P = S + D + RO + ETR$$

Or we can express as:

$$RO = P - S - D - ETR \qquad (1)$$

where: P is the rainfall volume, measured directly using rain gauge (mm), S is water stock in the soil measured through *pF* apparatus (mm), D is water volume drainage by soil (mm), RO is runoff (mm), calculated from hydrograph measurement and *ETR (mm)* is the real evapotranspiration and assume related to water required by crops according to their characteristics, we can estimate the maximum crop water consumption using Pan Class A, and crop coefficient can be computed as follow:

$$ETM = Kc.ETP \ (2)$$

where: *ETM* is the maximum crop water consumption, *Kc* is the crop coefficient and *ETP* is the evaporation from Pan Class A. Moreover the real Evapotranspiration (*ETR*) is modeled according to Eagleman (1971) approach, which has been modified by Forest and Reyniers (1986) as expressed:

$$ETR / ETM = a + b(Hr)^1 + c(Hr)^2 + d(Hr)^3 \qquad (3)$$

with:

$$a = -0.050 + 0.732 / ETP$$
$$b = 4.97 - 0.661.ETP$$
$$c = -8.57 + 1.56.ETP$$
$$d = 4.53 - 0.880.ETP$$

Hr is the relative humidity of soil and can be computed using the equation :

$$HR = (HM - HPF) / (HCC - HPF)$$

where :HM is the soil moisture content measured, HCC is the soil moisture content at the field capacity, HPF is the soil moisture content at the wilting point. The value of *ETR/ETM* varies from 0-1.

This formula includes two assumptions, (i) water absorption in the soil is represented by *ETR/ETM* ratio, which depends on the soil moisture content in the soil and (ii) evapotranspiration (*ETP*). *Hr* is determined by iteration and takes into account roots water absorption by roots growth of roots follows the movement of moisture and is limited by water stock (*RU*). RU is directly determined from the water content and takes into account the soil depth where roots can absorb water.

Concerning water from rainfall and runoff harvesting, the variation of water volume (*dV*) in the reservoir within time can be expressed as (Indarto, 1998):

$$\frac{dV}{dt} = (K_r.P.A_b + P.A_r - Ir.A_i - ETP.A_r - In.A_r).dt \qquad (4)$$

where:K_r is a runoff coefficient, A_b is the catchment area (m^2), I_r is water used for irrigation (*m*), A_i is irrigated area (m^2), In is the infiltration in the reservoir (*m*).

Using this relation we can predict how long water in the reservoir can be used for irrigation. Rainfall and runoff harvesting can determine quantitatively from the existing runoff volume according to equation 1. Theoretically, it could be difficult to harvest all of runoff in the first year. So, in the beginning only about 10% of rainfall and runoff will be harvested. Three small reservoirs are used in rainfall and runoff harvesting. The capacities of reservoir respectively are: 225 m^3 in the lower part; 125 m^3 in the middle part and 100 m^3 in the upper part. The cross section site for representing of rainfall and runoff harvesting and their application presented Fig. 2.

Crops composition and production

Base on the runoff harvesting and water balance, we can determine the total amount of supplement water available for agriculture and the existing water deficit. In order to increase water use efficiency, supplementary traditional irrigation applies while ETR/ETM (equation 3) inferior 0.8, mainly in the critical period of crop (for example: flowering and fruit formation are critical period for Chili). Using these data, we can determine the crop composition based on crop water requirement, the market demand and available technology for the farmer. Crop production will be used as an indicator of the influence of rainfall and runoff harvesting for sustaining upland agricultural development. Several high value crops base on regional market demand such as: chili, ginger and forage, were selected and planted besides maize as the main crop in order to increase farmers income. So the treatment consist of two types:

1. *Influence of irrigation supplementary from runoff harvesting to maize yield and theirs components).*
   A. Maize (green manure, marce-ear and grain maize) before runoff harvesting (no supplementary irrigation)
   B. Maize (green manure, marce-ear and grain maize) after runoff harvesting (with supplementary irrigation taking into account ETA/ETC value superior 0.8). To reach ETA/ETC 0.8, we use daily water balance and take into account soil, climate and plant characteristic as describing on the equation 3.
2. *Application of irrigation supplementary from runoff harvesting in diversification of high value commodities cultivation.*

This irrigation application targeted to increase the diversification of high value commodities that can be planted in the upland. We suppose that if soil productivity is improved with rainfall and runoff harvesting, the farmers will be capable of supplying their family needs and maintain soil. So increasing the amount of high value commodities can be cultivated, means rainfall and runoff harvesting can achieve agricultural sustainable development.

RESULT AND DISCUSSION

This preliminary result was obtained the first year of the project (1998/1999). This part deals with: (i) soil physical and chemical characteristics (ii) crop and reservoir water balance and (iii) crops production before and after rainfall and runoff harvesting.

Physical characteristics of soil in the site

Table 1 shows that total drainage pores of soil in the study area increase along with the soil depth. This fact is probably due to the influence of intensive agriculture activities. This drop let assume that agriculture on this site is non-sustainable. From our own experience on soils cleared from tropical forest, where organic matter is first abundant, food crops can first grow excellently without any fertilizer. After five years still, as organic matter drops drastically, crops cannot grow, even with high fertilizer inputs (Sumarjo Gatot et al., 1987). Another influence of organic matter contents is the relatively high total drainage, due to the pores, as most of them are low drainage capacity pores. This is why water supply from soil to the plant is limited. In other words, soil tends to supply water with less efficiency.

Chemical characteristics of soil in the site studied

From a chemical point of view, soil fertility is very low, as shown in Table 2. This fact is similar to the soil physical properties. Low *pH*, *N*, *Mg*, *K*, *CEC* and *BS* indicate that upland agriculture practice was unsustainable and promoted a decrease in soil chemical additions. Farmers, focusing on improving production, tend to exploit the soil with very limited application of the soil conservation principles. This situation is probably due to the limitation of skills, manpower, and capital in farmers' families.

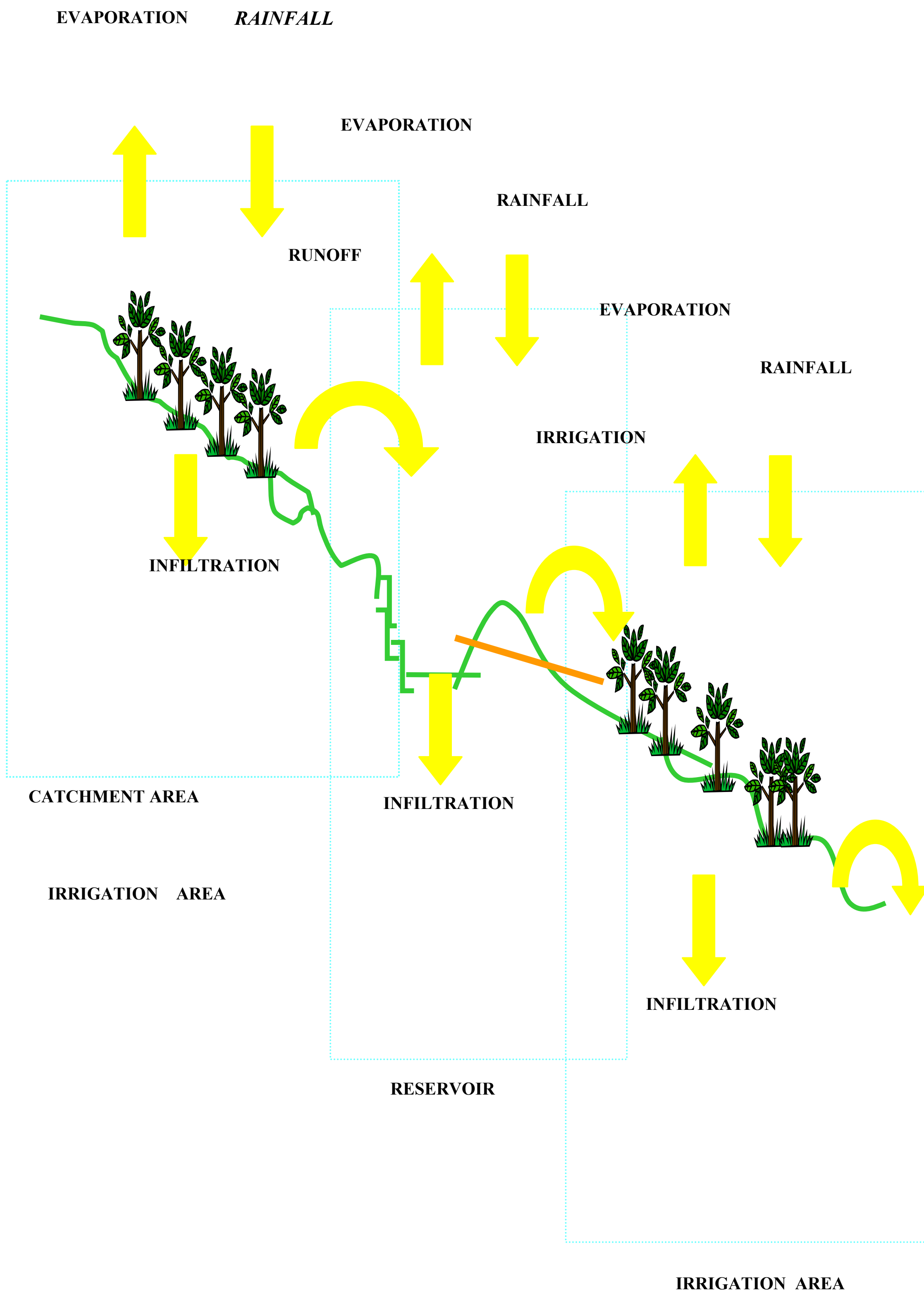

Figure 2. The cross-section of rainfall and runoff harvesting of site study.

Former projects focusing on soil conservation incentives and credits proved to be of no use to sustain upland agriculture. Past experience shows that these programs work only as long the project can be funded and supervised: farmers usually do not carry on new practices on their own. In order to find out a solution to this problem, we worked with farmers in a region with well-distributed rainfall. These farmers can increase their income through increasing planting intensity and/or introducing crops with higher economic value. Generally with a good income, soil conservation practices can be financed.

Crops and reservoir waters balance

Fig. 3 shows that runoff and drainage volume tends to increase along with rainfall. Moreover, if the rainy events are successive, soil moisture contents saturate and the next rainfall directly goes to instant runoff (Horton, 1945). Under this condition, rainfall can spark flooding problems, especially if excess rainfall is too high for the channel capacity, as happened in the basin studied in December 1990. In order to manage flood risk, rainfall-runoff-

Table 1. Soil physical characteristics of the studied site

Symbol	Depth (cm)	Organic matter content (%C)	Bulk density (gr/cm^3)	Total drainage pores (% vol)	Drainage pores (%) *Rapid pF2.54*	Drainage pores (%) *Slow p//f4 2*	Water available pores (% vol)
(1)	(2)	(3)	(4)	(5)	*(6)*	*(7)*	(8) = (6) - (7)
PS1	0-20	0.40	1.23	53.60	39.9	27.5	12.4
PS2	20-40	0.51	1.17	55.80	43.3	30.7	12.6
PS3	40-60	0.47	1.10	58.50	46.5	30.7	15.8
PS4	60-80	0.42	1.07	59.60	46.4	30.4	16.0
PS5	80-100	0.39	1.11	58.10	46.4	29.9	16.5

Table 2. Soil chemical characteristics of the site studied

Symbol	Depth	pH (1:5 H_2O)	N Kjeldal	P_2O_5 HCl 25%	Cathion exchangeable capacity (CEC) *(NH4-Acetat, pH7)*						
					Ca	mg	K	Na	Total	CEC	BS
	cm		------------------------------------			*mg 100 g^{-1}*				------------------------------------	*%*
PS1	0-20	3.8	0.13	78	1.97	0.48	0.20	0.04	2.69	7.34	37
PS2	20-40	4.2	0.07	73	3.18	0.83	0.17	0.03	4.21	7.37	57
PS3	40-60	4.3	0.08	70	4.68	1.03	0.08	0.06	5.85	7.53	70
PS4	60-80	4.6	0.06	61	4.14	0.76	0.06	0.06	5.02	7.31	69
PS5	80-100	4.7	0.06	56	4.37	0.84	0.04	0.04	5.40	7.82	69

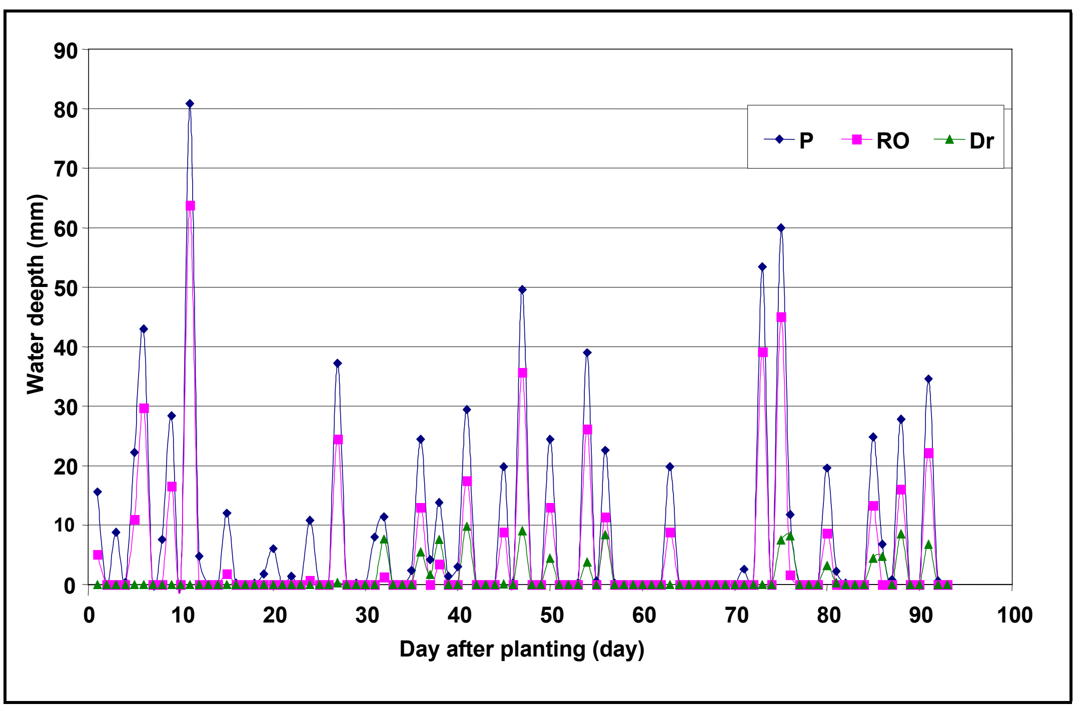

Figure 3. Comparison between rainfall depth, runoff and drainage of the site studied

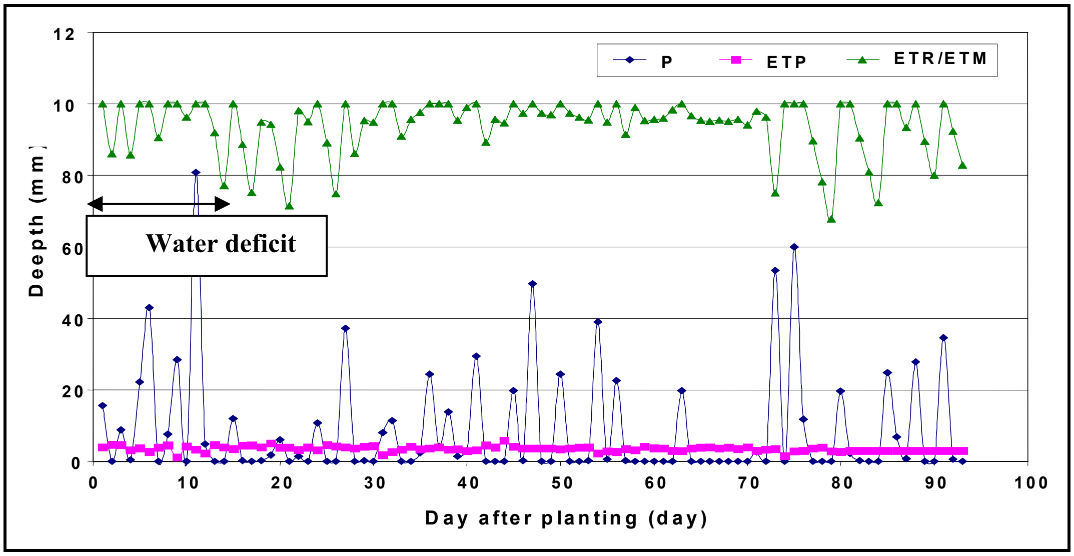

Figure 4. Rainfall, ETP and RTR/ETM of the site studied

Table 3. Comparison between maize production and theirs components before and after treatment in the site studied, in the dry weight.

Maize components	A. Before treatment (ton ha^{-1})				B. After treatment (ton ha^{-1})			
	I	II	III	average	I	II	III	average
Green manure	1.61	1.25	1.32	**1.39**	2.34	2.34	2.71	**2.46**
Marce-ear	3.60	4.28	4.01	**3.96**	3.99	3.48	3.89	**3.78**
Grain maize	1.70	2.12	1.87	**1.89**	3.30	2.93	3.17	**3.13**

Table 4. Crops production after rainfall and runoff harvesting.

Commodities	Production (ton ha^{-1})			
	I	II	III	average
Grain maize	3.30	2.93	3.17	**3.13**
Chili (Class A)	10.32	15.99	15.03	**13.78**
Chili (Class B)	2.81	3.09	2.19	**2.69**
Ginger	38.00	45.20	78.00	**53.73**

A and B respectively correspond to the first and second quality

harvesting techniques have to be introduced. Thus, rainfall and runoff volumes can be collected and distributed during periods with low rainfalls. Consequently, the maximum peak discharge can be decreased and time to peak discharge can be prolonged (Rodriguez-Iturbe et al., 1979).

Even though this research was conducted in the wet season of 1998, we had several days without any rainfall (day 62 to 70). Other problem faced in the beginning of planting (Day 12 to 26) that rainfall depth is not sufficient to compensate evaporation and crop transpiration. The ETA/ETC value decreases to less than 0.8 and in this stage, crop water stress arises and supplementary irrigation has to be applied. That means that water stress problems possibly happened during this period. Using additional irrigation, the *ETR/ETM* ratio can be raised as shown in the Fig. 3. With *ETR/ETM* values reaching to 80%, water will be sufficient to support plant growth and development. Regarding to high agriculture risk (water stress) in the upland agriculture development, climate characteristics have to be taking into account.

Crop production

Influence of irrigation supplementary from runoff harvesting to maize yield and theirs components

Before rainfall and runoff harvesting introduced, only food crops (maize, soybean etc) can be cultivated. For comparing the effect of rainfall and runoff harvesting, we took two steps: (i) to compare the production for the same commodity (Table 3) and (ii) to demonstrate the number of high value commodities that can be planted (Table 4).

Table 3 shows that green manure and grain maize production increased after rainfall-runoff harvesting. This increase is probably due to the continuity of water supply during the growth and development period. On the plot without rainfall-runoff harvesting water, supply tends to vary according to the rainfall. A problem arises if water is not sufficient in critical periods, such as flowering. In this case, additional irrigation has to be poured in to support the plant. An interesting result was that if water supply was not sufficient, the dry weight of marce-ear tends to increase, but it was the contrary for maize with sufficient water supply. The increase of grain maize production (about 65%) through rainfall and runoff harvesting, can be used to justify the application of water management in the upland agriculture, and its development can play an important role for sustainability in the future.

Application of irrigation supplementary from runoff harvesting in diversification of high value commodities cultivation

Table 4 shows that rainfall and runoff harvesting practices can improve crops composition planted. That is a second advantage for sustaining upland agriculture and development. Diversification of commodities that can be cultivated promotes intensification of the upland agriculture development and increasing short-term, medium-term and long-term income. At the develop country with small land tenure (less than 0.25 ha) such as Indonesia, increasing soil and crops productivities will play an important role in promoting batter sources income (Perez et al., 1997). Supplied with sufficient water on the upland agriculture, farmers can improve their income through a combination of high value crops such as chili, onion, watermelon or tomato. Moreover, they are developing fruit crops (durian, rambutan, mango, pineapple) thus bettering again their income. A combination of food crop (maize) and cash crops (chili and ginger) in the upland agriculture indicate a potentiality of upland agriculture development in the future. This result promote farmers in this surrounding area adopt this technology through constructing small reservoir in theirs own land for developing a high value added crops. Mostly they collaborate with their group to accelerate the reservoir construction.

Usually most of price of agriculture products are fluctuated depend on the equilibrium between demand and supply. In fact farmers could not bargain the price. So with several commodity can be planted, farmers can decrease price risk while supply of product bigger than demand. That is another advantage with rainfall and runoff harvesting.

CONCLUSION

Water stress even in the wet season is one of constrain in developing sustainable upland agriculture in Indonesia and probably in most of developing country around the world. Moreover, high population pressure and limited soil and water conservation practices promote soil degradation and decreasing crops production. Daily water balance and runoff computation base on hydrograph measurement can be used as a tool for determining the period of water stress and the volume of rainfall and runoff should be harvested. The results show that through water harvesting, production of maize and high value added crops could be increased. Taking into account of increasing value added of water harvesting, irrigation supplementary (traditional or modern technology) and selection of high value added crops have to be conducted. For augmenting water use efficiency, water satisfaction index (ETA/ETC) superior 0.8 can be used, as a tool for determining the quantity of water should be irrigated.

Concerning the application of rainfall-runoff harvesting in the watershed according to our approach, rainfall and runoff are collected using small reservoirs not only to decrease climate and flood risks, but in addition, collected water can be used to improve crops composition especially with high value commodities such as: ginger, chili, water melon and fresh water fisheries. Moreover increasing of the amount of crops that can be cultivated means diversification of income for short-term, medium-term and long-term can be conducted. Besides diminishing water flow velocity, rainfall and runoff harvesting can promote rehabilitation of degraded land through increasing water available for agriculture practices. Small size reservoir is promoted to develop the upland agriculture development, because the existing land tenure actually less than 0.3 hectares one part and for managing this reservoir easily in another part.

Good results can be achieved through rainfall runoff harvesting in the watershed. The site that recommended for rainfall and runoff harvesting is upstream area, where the probability density function of hydraulic lengths is high. That means that water will be equally distributed spatially and does not concentrate in the same places (Rodriguez et al, 1995).

Increasing short-term, medium-term and long-term farmers incomes through diversification of high value commodities can be planted using irrigation supplementary probably become one of a strategic approach should be conducted. Decreasing water flow velocity will be decreasing soil erosion. The result at this work suggests the uses of the watershed are as the planning unit Moreover, it is necessary to the farmers, to show the practice of rainfall-runoff harvesting functions, and its several advantages for sustaining upland agriculture and development. For disseminating the results of this research, field trials should be conducted in a several type of soil and climate of upland agriculture areas.

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