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Study of Runoff Farming System to Improve Dryland Cropping Index in Indonesia

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***Abstract*— A barrier to productivity on dryland is limited availability of water during dry season. Heavy rainfall at most in the dryland farming in Indonesia causes high runoff that occurred during precipitations. The huge potential of runoff can certainly be utilized as alternative water sources in the dry season to improve cropping index. The research purposes were to assess the potential of runoff farming system in improving the cropping index on dryland with wet climate. The study was conducted through observation field conditions, rainfall analysis, potential runoff analysis, crop water requirements analysis and water balance analysis in the dryland area. The result of the study indicated that peak of rainfall-runoff started in last decade of December until March. However, entering the second growing season, rainfall occurs until April only. It's implied that during the second growing season has led to a lack of water supply in the peak phase of crop water needs. Rainfall-runoff analysis indicates that surface runoff potential as an alternative source of irrigation in the dryland farming if managed well, one of which uses runoff farming system. With harvest runoff and store it for irrigation in dry season could increase the cropping index. The significant finding of this research was base on supply and demand water analysis shows that to increase cropping index of food crop in dryland with wet climate needed of catchment and cultivation area ratio (CCA ratio) equal to 6.2, to the form of catchment area was arable land with multi-cropping pattern and varies slope.**

***Keywords*— rainwater harvesting; rainfall-runoff relationship; runoff harvesting; sustainable agriculture**

I. INTRODUCTION

Indonesia has the potential for vast dryland, reaching 148 million hectares; dry land suitable for agriculture is only about 76.22 million ha (52%), mostly is found in the lowlands (70.71 million ha or 93%) and the rest is in the highlands. Dryland for agricultural cultivation is spread in Sumatra, Java, Kalimantan, Bali and Nusa Tenggara, Sulawesi, Maluku and Papua [1], [2]. There are several obstacles facing the development of dryland farming [1]. The availability of water which is highly depended on rainfall and long dry season are among others.

Based on climatic conditions, dry land in Indonesia is divided into two types, dryland with wet climate (annual rainfall more than 1500 mm/year) and dryland with a dry climate (annual rainfall less than 1500 mm/year) [3]. Wet climate regions mostly found in Sumatra, Kalimantan, Java, Maluku and Papua, while the dry areas spread across parts of northern Aceh, parts of East Java, Palu, Bali, Nusa Tenggara, Maluku, and Merauke. The amount of rainfall in dryland region wet climate resulted in high runoff [4], [5]. Besides influenced by high rainfall, runoff on dryland is also influenced by way of farming and topographic condition that causes most of the rainwater flowing into surface streams [6]–[9]. Moreover, in some regions, it is found that steep dryland slopes that are susceptible to erosion planted with seasonal crops and land cultivation are in line with a slope which may increase surface runoff.

Agricultural cultivation on dryland is very susceptible to water shortages. To overcome this problem required additional water supply through irrigation. Irrigation is one of the important factors in food production and can be defined as a unit that is composed of various components, on efforts to supply, the distribution, management, and regulation of water to increase agricultural production [10]–[15]. Therefore, the management of available water resources is essential to meet the needs of irrigation water in the cultivation process. Moreover, according to Dwiratna [16] suggested that there was shift the early start of the rainy season between one to two weeks as a result of climate change.

Runoff farming system has not been widely applied in dryland farming Indonesia, especially in the dryland farming with a wet climate. An effort to overcome this problem is to manage runoff, especially during the wet season to meet the needs of water in the dry season. When the rainwater in the form of surface runoff are harvested and then directed to the agricultural area, this technique is called with runoff farming [17]. Runoff farming system proved able to improve agricultural production in dryland with the arid climate. However, there has been no application of runoff farming systems in dryland farming with wet climates. Therefore, this research aimed to assess whether the runoff farming system is capable of increasing the cropping index on dryland with wet climate. Therefore, this research aimed to assess whether the potential of runoff farming system by increasing the cropping index on dryland with wet climate.

II. MATERIALS AND METHODS

The experiment was conducted in Jatinangor, Sumedang Regency, West Java Indonesia. Field research was conducted in Padjadjaran University field research and study. Based on the position of the river area, the location of the study is in the Citarum upstream region or belong to the subzone Citarik, as can be seen in Fig. 1. The research covers an area of 2,144 hectares with undulating topography. Land cover that exists today in the form of annual vegetation areas in the form of rubbers, coconut and seasonal crops such as maize, cassava, and sweet potatoes.

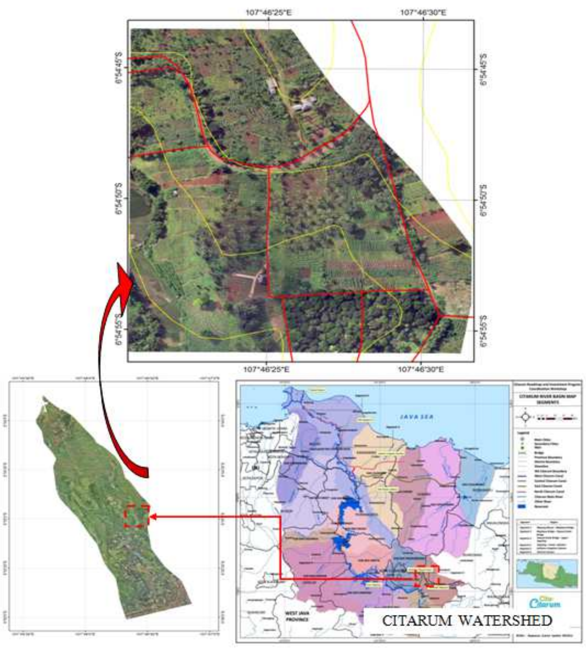

Fig. 1 Research location

Cropping index (IP) existing at the study site varies between 100% to 200% per year. Based on discussions with farmers in the research area, it was known that the availability of water into the biggest limiting factor in the cultivation of dryland agriculture. Therefore, they choose a mix of cropping systems. If sufficient water they prefer planting monoculture with a selection of sweet corn when water is available and sweet potatoes when the water decreases. Selection of both commodities because both of these commodities have a higher selling price compared to others.

A. *Runoff Farming System*

A runoff harvesting system for dryland farming consists of three zones area, namely, catchment area, cultivated area and reservoirs or storage zone as shown in Fig. 2.

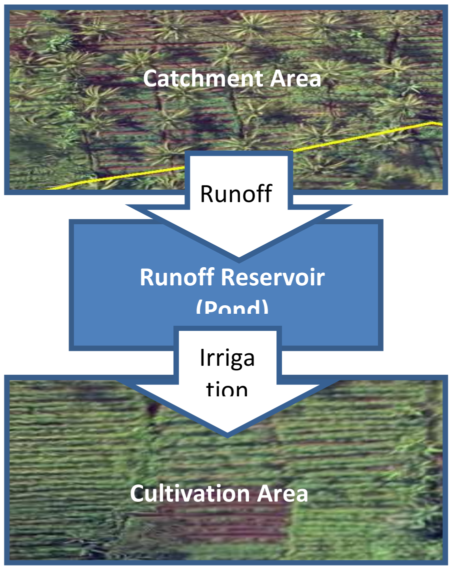

Fig. 2 Runoff farming system

The determination of catchment, storage, and cultivated location area must take into consideration the topography and direction of runoff. The catchment area is determined by the upstream area with a sharp slope (steep), while the cultivation area which will be used as the experiment is at a downstream location which has a relatively flat or sloping. Meanwhile, the water storage placed between the catchment area and the area of cultivation. Water reservoir used in this study a farm pond. Runoff that falls on the land surface raised toward the main channel, to then flowed into the farm pond.

Design of runoff farming system is doing based on the results of the data analysis of physical properties of soil, topography analysis and ratio analysis catchment area and the area of cultivation (ratio C: CA). To determine the ratio of C: CA, requires data water requirements, seasonal rainfall design, surface runoff coefficient and efficiency factors that are influenced by the rate of infiltration and percolation. The basic principle in determining the ratio of the catchment and cultivation area in dryland with a wet climate is as follows:

- Water is needed in cultivation area (CA) = Water harvested in the catchment area (C)
- Water is needed in cultivation area (CA) = [water requirement] × A_{CA} (m²)
- Water requirement = total of water deficit values in water balance analysis.
- Water harvested in the catchment area (C) = runoff coefficient x rainfall design x efficiency factor x A_C (m²)
- Thus, the ratio of the water catchment area and the area of cultivation is calculated by the following equation:

$$\frac{C}{CA} = \frac{Water\ Needs}{Runoff\ Coefficient \times Rainfall\ Design \times Eff.Factor} \quad (1)$$

Overall the research method used is a combination of survey methods, observation methods, and descriptiveanalytical methods. Methods survey was conducted to identify data of rainfall and climatology from the nearest observation station. Monthly rainfall data used is the data series from 1994 to 2012, derived from SPMA Pedca climatological stations and Jatiroke rainfall stations. While climatological data used in the form of data of temperature, humidity, wind speed, solar radiation from 1994 to 2012 were taken from Bandung and SPMA Pedca climatology stations.

B. Design Rainfall

Historical rainfall data used in the analysis of the design rainfall with a probability of 80%, using the equation below [18], [19]. Previous rainfall data sorted from the smallest to the largest.

$$P(\%) = \frac{m-0.375}{N+0.25} \; x \; 100 \quad (2)$$

where:

P = probability of rainfall data (%)
m = Ranking of rainfall data
N = Total amount of rainfall data is used

Rainfall was analyzed in the form of annual data and seasonal rainfall (wet monthly rainfall based on Oldeman climate classification system, more than 200 mm per month).

C. Runoff Coefficient

Field observations are used to analyze the value of runoff coefficient through direct measurement using a plot of runoff. Plots of runoff measurements were made by local conditions, as can be seen in Table 1.

TABLE I
SURFACE RUNOFF PLOT MEASUREMENT

Plot	Crop Pattern	Plot Area	Slope (%)
Plot 1	Rubber	88	12
Plot 2	Cassava, Corn, Red Bean	88	21
Plot 3	Sweet Potato, Cassava	66	20
Plot 4	Sweet Potato, Red Bean, Cassava	66	22
Plot 5	Cassava, Corn, Red Bean, Peanut	66	10

Observation of surface runoff whenever rain events. The data observed in the form of runoff volume, daily rainfall data, and severe soil erosion. Once data was captured, then the value of the runoff coefficient (C) was calculated by the following equation [20]:

$$C = \frac{Total\ Runoff\ (mm)}{Total\ Rainfall\ (mm)} \quad (3)$$

D. Water Balance Analysis

Soil water balance analysis was conducted to determine the condition of water surpluses and deficits in the research field, so it can determine when crops require irrigation. Dwiratna [21] state water balance calculation field contains six major components, namely precipitation, potential evapotranspiration, actual evapotranspiration, soil water availability and surface runoff (surplus and deficit), which is expressed by the following equation:

$$\mathrm{R = Q + ET \pm \Delta S} \quad (4)$$

where *R* is rainfall; Q is the runoff; ET is evapotranspiration and ΔS are the storage of water in the soil, aquifers or reservoirs.

Analysis of water balance with Thornthwaite - Matter method is done by using crop evapotranspiration (ETC) value in the calculation of actual evapotranspiration (ETA) in the field rather than using of potential evapotranspiration (ETP). Crop evapotranspiration value is calculated using the formula below [22]:

$$\mathrm{ETC} = ETP \; x \; Kc \quad (5)$$

where Kc is the crop coefficient values according to the selected cropping pattern. In this study, the selected cropping pattern is sweet corn - sweet corn - sweet potato because it has a higher economic value than other cropping patterns[1]. Potential evapotranspiration (ETP) can be obtained by several different methods of calculation. However, the calculation of the ETP using Penman-Monteith method is the best estimate evapotranspiration recommended by FAO[22]. The potential evapotranspiration calculated using CROPWAT v.8 software [23].

E. Irrigation Management on Runoff Farming System

Runoff harvesting carried out during the rainy season. Filling runoff reservoirs observed every day. After the rains stopped, the runoff that is collected was used as a source of irrigation water during the dry season. Determination of irrigation water requirements and irrigation scheduling based on the analysis of plant water balance with a certain interval of water provision. Irrigation water requirements and irrigation scheduling were determined based on the analysis of water balance with a specified interval of water provision. The cropping pattern used was cropping patterns developed in locations based on the results of the identification of the location and the condition. Provision of irrigation water done when the water deficit in the soil, the water supply intervals performed regularly at intervals of 2 days.

III. RESULT AND DISCUSSION

A. Soil Physic Characteristics

Testing of soil physical properties is essential to know in designing runoff farming system. Analysis of the soil used in the analysis of soil water balance to predict some water requirements and irrigation scheduling. Soil texture in the research location is clay with soil water content in field capacity condition (pF 2.54) is 33.65 % and 20% in permanent wilting point condition (pF 4.2).

B. Climatological Data and Potential Evapotranspiration

Climatological data were used in this study includes the data of temperature, humidity, wind speed, and solar radiation. The data used were obtained from the nearest climatological station is Station SPMK Pedca from 1994 to 2012, as can be seen in Table 2.

Potential evapotranspiration in research area was calculated using Penman-Monteith method based on climatological data in Table 3. This method is the most recommended method for the analysis of crop water requirement for considering the factors of temperature, wind speed, humidity and solar radiation [22], [23]. The results of the analysis of potential evapotranspiration in the area of research can be seen in Fig. 3.

TABLE II
CLIMATOLOGICAL DATA AVERAGE BETWEEN 1994 - 2012

Month	Temperature (^oC)	Humidity (%)	Wind Speed (km/day)	Solar Radiation (%)
January	24.3	80.4	164	45.9
February	24.1	80.9	167	48.7
March	24.3	80.4	140	50.9
April	24.4	80.7	114	57.4
May	24.4	79.0	119	61.2
June	24.0	76.6	118	64.9
July	23.8	75.0	132	70.7
August	23.9	70.6	135	74.4
September	24.4	70.8	157	69.4
October	24.5	76.4	148	57.2
November	24.4	81.1	129	45.9
December	24.3	80.5	148	51.1

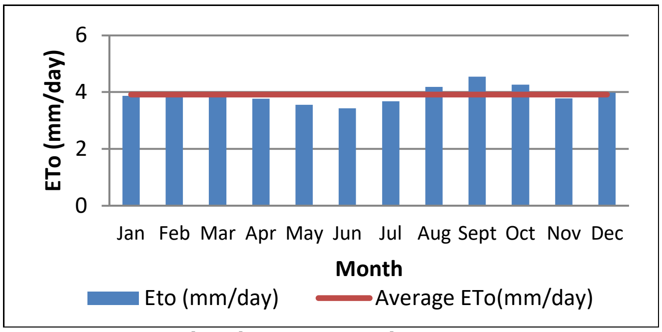

Fig. 3 Daily and average potential evapotranspiration

Fig. 3 shows that the average value of daily evapotranspiration in the research area reached 3,91 mm / day. Based on its monthly distribution, potential evapotranspiration in August, September, and October was above the average value. While the smallest potential evapotranspiration occurred in June at 3,43 mm / day.

C. Area Rainfall and Design Rainfall

Rainfall is the main parameter to be considered in the planning runoff farming system. Rainfall is an important factor in addition to the characteristics of the area of water catchment areas that determine the production of water runoff [18]–[20], [24], [25]. Analysis of rainfall area was done by using Thiessen Polygon Method. From the calculation, it can be said that the method of polygons gives the figure an annual rainfall average is more accurate than the method of Arithmetic, but not as complex as using Isohyet [26].

Based on the area rainfall analysis, it's known that annual rainfall in the research study of 1879.69 mm. Distribution graph monthly rainfall data in Jatinangor region can be seen in Fig. 4. It is known that the study site had five wet months (> 200 mm / month), which occurred in November and March, and four months of dry (<100 mm / month), which occurs in May through September. So based on the climate classification Oldeman, research sites included into climate type C3.

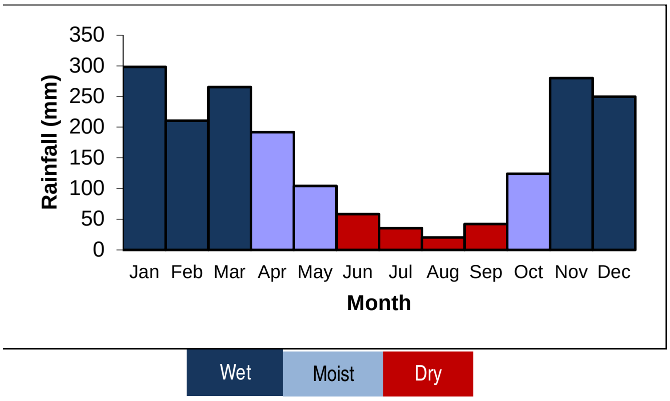

Fig. 4 Monthly rainfall distribution

The quantity of rain which is used as a basis for designing runoff farming systems commonly referred to as "design rainfall." In this case, the design rainfall is defined as the amount of rain in the catchment area which will result in surface runoff water to meet the water needs of plants. If the actual rainfall that occurred under design rainfall, the water needs cannot be met. Conversely, if the actual rainfall exceeds the design rainfall excess water runoff that occurs can destroy the infrastructure that was built in runoff water harvesting system [18]–[20].

For agriculture, which used the design rainfall is the rainfall with a probability of 80% is exceeded. Analysis carried out on the design rainfall annual rainfall and rainfall seasonally. Seasonal rainfall period used was the monthly rainfall and November to March. Based on the analysis of rainfall region, it was known that between November to March was the month in the wet climate classification Oldeman (monthly rainfall average of more than 200 mm) as shown in Fig. 4. The results of analysis of the design rainfall for annual and seasonal rainfall can be seen in Table 3.

Table 3 shows that the annual rainfall analysis gives design rainfall higher than the seasonal rainfall in all probability value. Based on Table 4 in mind that the 80% probability value is between 15th and 16th with a value of 1533 mm of annual rainfall and rainfall of 964 mm for seasonally. Runoff reservoir will be filled during the period of seasonal rains than in other times of the year. The use of annual rainfall in the analysis of the draft would give the design runoff harvesting building above the forecast. Therefore, the rainfall data used in the analysis of the design rainfall is seasonal rainfall data, the monthly rainfall runoff that allows the case to fill the reservoir.

D. Runoff Coefficient

In the design of runoff farming system, one of the important parameters that must be known is the coefficient of runoff. Runoff coefficient or often abbreviated as C is a number that indicates the ratio between the amount of runoff against the amount of rainfall. This coefficient value is determined by many factors, including the infiltration or the percentage of impermeable soil, slope, ground cover plants and the intensity of the rain. This coefficient also depends on the nature and condition of the soil. The coefficient of runoff will determine the number of the potential flow of runoff that may occur in a catchment area.

TABLE III
RANKING AND PROBABILITY OF ANNUAL AND SEASONAL RAINFALL IN JATINANGOR, WEST JAVA

Year	AR (mm)	Rank (m)	Prob (%)	Year	SR (mm)	Rank (m)	Prob (%)
2010	3380	1	3	2010	2174	1	3
1998	2788	2	8	2005	1835	2	8
2005	2492	3	13	1998	1731	3	13
2001	2454	4	18	1994	1562	4	18
1996	1993	5	23	2012	1441	5	23
1994	1934	6	28	1996	1425	6	28
1995	1925	7	33	2003	1401	7	33
2012	1902	8	38	2008	1370	8	38
1999	1857	9	43	1999	1357	9	43
2000	1835	10	48	2004	1354	10	48
2009	1825	11	52	2009	1353	11	52
2003	1806	12	57	2001	1327	12	57
2004	1719	13	62	2002	1281	13	62
2008	1702	14	67	1995	1122	14	67
2002	1633	15	72	1997	1084	15	72
1997	1467	16	77	2000	934	16	77
2011	1232	17	82	2011	833	17	82
2006	895	18	87	2006	605	18	87
2007	875	19	92	2007	585	19	92

Note: AR (Annual Rainfall); SR (Seasonal Rainfall); Prob (Probability)

Runoff coefficient is done by directly measuring the flow of surface runoff and precipitation that falls on the demonstration runoff. Measurements of surface runoff water at each rainfall event that causes the flow of runoff; during the rainy season. Observations lasted from the beginning of the rainy season in November 2013 to April 2014. Observations in the field show that by the time the rainfall depth increased will rise the surface flow. The amount of daily rainfall affects the amount of runoff that occurs in the area where the higher rainfall will cause the volume of runoff are greater. Water runoff that occurs in five plots used indicates that surface runoff is also influenced by cropland cover and slope as can be seen in Fig. 5.

Fig. 5 shows that the flow of runoff follows the pattern of rainfall, at which time the precipitation increases, surface runoff that occurs also increases. Runoff rate differences that happen in each plot were tested showed that surface runoff is also influenced by the slope of the land and vegetation cover. The smallest number of surface runoff occurred at Plot 1, wherein the ground cover in the form of stands of rubber trees that belong to the category of forest plants. This is consistent with the theoretical statement that the coefficient of runoff in the small forest plants or other words the volume of rain which accommodated almost entirely for infiltration.

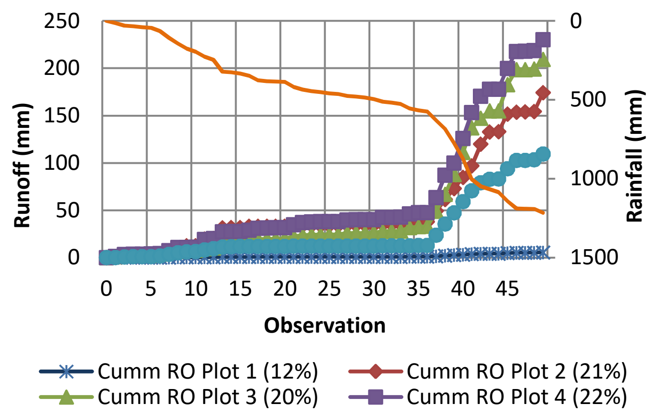

Fig. 5 Runoff cumulation on different catchment condition

TABLE IV
RUNOFF COEFFICIENT FOR DIFFERENT CROPPING PATTERN

Plot	Cropping Pattern	Slope (%)	Runoff Coefficient
Plot 1	Rubber	12	0.001
Plot 2	Cassava, Corn, Red Bean	21	0.13
Plot 3	Sweet Potato, Cassava	20	0.12
Plot 4	Sweet Potato, Red Bean, Cassava	22	0.15
Plot 5	Cassava, Corn, Red Bean, Peanut	10	0.09
Average Runoff Coefficient			**0.10**

Plots 4 and plot 5 show different surface runoff rates that are affected by the slope of the land even though the both of plots have the relatively similar land cover, i.e., intercropping of seasonal crops. Plot 4 which has the highest slope of land (22%) resulted in the higher surface runoff than the other three plots. While plot 5 has a smaller surface runoff flow, this is because the slope of the land on the plot is relatively sloping, i.e., by 10%. The coefficient of runoff in the five plots that were attempted is shown in Table 4.

From Table 4 mentioned above is known that the coefficient of runoff on perennial crops (rubber) most small compared with the runoff coefficient of land with vegetation cover in the form of seasonal plants. In the forest area, almost all precipitation that falls on top of it will be absorbed into the soil. Unlike the land cover in the form of seasonal crops, less than 20% of rainwater that falls on it will be turned into a stream runoff.

E. Water Requirement Analysis

Identify the required amount of water into one of the parameters that must be known in designing the runoff harvesting systems for agriculture. Value needs of water used in the planning of runoff farming system are the total value of water deficit in the water balance analysis. Analysis of water balance in the cropping pattern of sweet corn - sweet corn - sweet potato can be seen in Fig. 6 below.

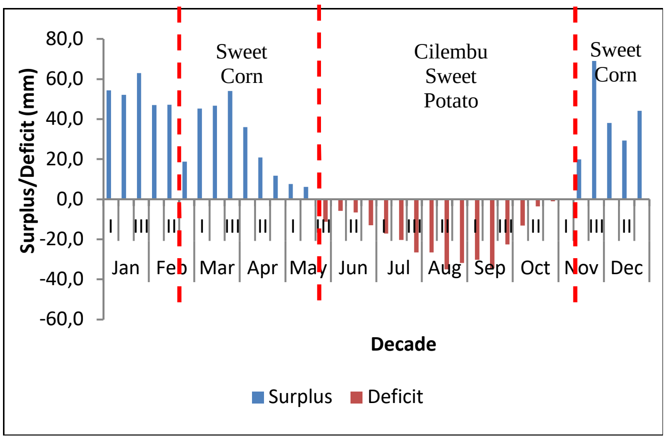

Fig. 6 Water balance analysis

Fig. 6 above shows that the deficit in the third decade of May until the third decade of October. Total deficits amounted to 299.3 mm, the value of the deficit is the value of water needs to be met in the runoff farming systems.

F. Catchment and Cultivation Area (CCA) Ratio

When designing a water harvesting system, the size of the catchment area needs to be calculated or estimated accurately to ensure that enough water runoff that can be harvested to meet the needs of plants in cultivation. Relations between the two land area is expressed as a ratio of C: CA, which is the ratio between the area-catch (C) and the area of cultivation (CA). The parameters used in determining the ratio of the C: CA is the need for water, the design rainfall, surface runoff coefficient and the efficiency factor.

Water requirement is taken from the total deficit in the water balance analysis of plants, which amounted to 299.3 mm. Design rainfall value used was the seasonal rainfall data as described in Section 4.1, which amounted to 837 mm. Meanwhile, surface runoff coefficient values used in this analysis was the average runoff coefficient, that was equal to 0.1. Factors efficiency was the efficiency of runoff that is used by the plant. Most of the flow of runoff harvested cannot be used by plants as missing. Water loss occurs due to infiltration, evaporation, filling the ground and percolation basin. This value varies between 0.5 to 0.75. Reddy et al. [19] state that for the type of runoff water harvesting system macro-catchment typically use the value of efficiency factor of 0.5, while for micro-catchment amounting to 0.75. Based on the parameters defined above parameters, found that the value of the ratio of C: CA is at 6.2. This figure means that to meet the water needs of cultivated land 1000 m^2 requires a catchment area covering 6200 m^2.

G. Irrigation Management on Runoff Farming System

One method of irrigation scheduling is to use fix interval method. On Fixed interval irrigation scheduling, water was provided at an interval of fixed and does not depend on the state of water in the root zone. In this study, irrigation water is given at intervals of 2-day at each stage of growth. The reason for using the 2-day interval is by the opinion of Dwiratna [16] which states that for seasonal crops, the maximum limit of irrigation interval is two days in dry conditions without rain. Besides that, the ability of soil to hold water is usually only two days, and after that, the plants will wither. The results of water demand calculation and scheduling can be seen in Table 5.

TABLE V
IRRIGATION SCHEDULING WITH 2 DAYS INTERVAL

Decade	Irrigation Need (mm)	Irrigation Frequency	Irrigation Per Application*		Total Irrigtaion Per Decade*	
			mm	liter	mm	liter
May 3	11	6	2	11	11	67
June 1	6	5	1	7	6	35
June 2	7	5	1	8	7	39
June 3	13	5	3	16	13	78
July 1	17	5	3	21	17	103
July 2	20	5	4	24	20	122
July 3	27	5	5	32	27	159
August 1	27	5	5	32	27	159
August 2	35	6	6	35	35	210
August 3	32	5	6	38	32	191
September 1	30	5	6	36	30	182
September 2	35	5	7	41	35	207
September 3	23	5	5	27	23	136
October 1	13	5	3	16	13	79
October 2	4	5	1	4	4	22
TOTAL	**298**	**77.0**	**58**	**349**	**298**	**1789**

Note : * the amount of irrigation water requirement shown is some water needs for a mound with dimensions of 10 m length x 0.6 m width.

Initial Phase | Mid-Season Phase
Development Phase | Late-Season Phase

Table 5 shows that the crop water requirements to be met reach a peak during the mid-season phase that falls in the second decade of July to the first decade of September (the coefficient of the plant reaching the value of 1.15). From Table 6 it was known that the amount of water required in the initial phase was 17 mm, for the development phase of 37mm, the mid-season phase of 171 mm and the late-season phase of 74 mm. Table 5 below presents the cilembu sweet potato yield.

Based on Table 6, it is known that the addition of irrigation water based on the analysis of the water balance of the crop with a 2-day interval obtained cilembu sweet potato yield with the average weight of sweet potato harvest per bunds of 7,720 kg or equivalent to 12.87 tons per hectare. The range of cilembu sweet potato yield in Pamulihan and Jatinangor sub-districts in March 2015 (rainy season cultivation) ranged from 12.4 to 12.9 tons/ha. The management of surface runoff water in dryland can increase the intensity of crops with the production equivalent to production in the rainy season (water sufficient). Compared with the condition, the implementation of the runoff farming system proved to increase the intensity of cropping index up to 3, and also able to increase the water productivity of dryland.

TABLE VI
THE YIELD OF CILEMBU SWEET POTATO

Bunds	**Classification of Cilembu Sweet Potato Yield**			**Total Yield (kg /Bund)**
	I	**II**	**III**	
1	1,512	2,975	4,250	8,737
2	1,319	2,505	2,190	6,014
3	1,264	3,218	3,101	7,583
4	1,853	2,729	3,963	8,545
Average	1,487	2,857	3,376	7,720

IV. CONCLUSIONS

It is concluded that surface runoff on dryland could be harvested and used as irrigation resources to increased dryland cropping index to 300% with CCA ratio of 6.2 for cropping pattern sweet corn- sweet corn – sweet potato. Irrigation scheduling application with two days interval on runoff farming system could produce sweet potatoes yield to 12,87 ton/ha, that is same as the average production of sweet potatoes that cultivated during the rainy season.

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