Hydrological Processes of Coconut Palm Plantation: Rainwater uptake, Return to the Atmosphere, and The Moisture Conservation

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Balai Penelitian Tanaman Kelapa dan Palma Lain

ABSTRACT

The hydrological processes of coconut palm plantation are briefly reviewed in order to describe their role to provide sustainable way to improve coconut productivity. This review is based upon two distinct influence of coconut plantation on hydrological processes: the impact of coconut palm physiology on rainwater uptake and return to the atmosphere, and the moisture conservation to control runoff. To fully understand relationship between rainfall and coconut plantation, the interception, stemflow, and throughfall patterns are reviewed. Evapotranspiration is used as the indicators to describe potential changes in storage. Insufficient moisture in the soil will reduce nutrient absorption resulting in poor growth in young palms and low nut production. Therefore, some practices are introduced in this paper to maximize the volume of rainwater to be absorbed into the soil sub layers without allowing it to run-off the coconut plantation land.

Keywords : Hydrological processes, coconut palm plantation, rainwater uptake

ABSTRAK

Proses Hidrologi Pertanaman Kelapa: Pengambilan Air Hujan, Pengembalian ke Atmosfir, dan Konservasi Kelembaban

Proses hidrologi dari pertanaman kelapa direview untuk menggambarkan perannya dalam mendukung peningkatan produktivitas kelapa yang berkelanjutan. Review ini dibuat berdasarkan dua pengaruh berbeda dari pertanaman kelapa terhadap proses hidrologi, sebagai berikut: Penggaruh fisiologi kelapa terhadap pengambilan air hujan dan pengembalian ke atmosfer, dan konservasi kelembaban untuk mengatur limpasan permukaan. Untuk dapat mengerti hubungan curah hujan dengan pertanaman kelapa, intersepsi, aliran batang, dan curahan langsung direview. Evapotranspirasi digunakan sebagai indikator untuk menjelaskan potensi perubahan air yang tersimpan. Kelembaban tanah yang rendah akan mengurangi absorbsi nutrient yang menyebabkan buruknya pertumbuhan pada kelapa muda dan produksi kelapa menjadi rendah. Oleh karena itu, beberapa metode lapang diperkenalkan dalam tulisan ini ditujukan untuk memaksimumkan volume curah hujan yang terabsorbsi ke dalam sub lapisan tanah tanpa membiarkannya menjadi limpasan permukaan dan keluar area pertanaman kelapa.

Kata kunci : Proses hidrologi, pertanaman kelapa, pengambilan air hujan

INTRODUCTION

The Coconut Palm (*Cocos nucifera*) is a member of the Family *Arecaceae* (palm family). It is the only species in the genus *Cocos*, and is a large palm, growing to 30 m tall, with pinnate leaves 4-6 m long, pinnae 60-90 cm long; old leaves break away cleanly leaving the trunk smooth (Wikipedia, 2008). Coconut palm is one of the ten most useful trees in the world, providing food for millions of people, especially in the tropics (Duke, 1983). Water is an essential component for the vegetative growth and nut production of coconut palm. Water affect almost all processes inside plant, cell metabolic activity, and the growth has a strong relationship with the soil water content. To maintain the vital plant metabolic processes, soil water has many functions, such as: to dissolve and transfer the soil organic matter, as the source of hydrogen, to control of temperature and humidity, and leaching the toxic material of soil (Kramer in Pritchett, 1979). Pritchett (1979) describe that the rich mineral soil will not be productive without water availability while the sandy poor soil could supports plant productivity if it occurs with sufficient water capacity. Therefore, knowledge of hydrological processes in coconut plantation becomes important as its role as a sustainable ways to improve the productivity.

Coconut palm plantation

The coconut palm, *Cocos nucifera* L., was first grown as a plantation crop in the 1840's (Child, 1974). Coconut plantations were established throughout the tropics, wherever conditions were suitable, and often where they were not (Harries, 1978). Large production areas, in particular, are found along the coastal regions in the wet tropical areas of Asia in the Philippines, Indonesia, India, Sri Lanka and Malaysia. In these countries millions of people make a living from the coconut palm and its many products (Anonym, 1999).

In Indonesia, tall coconut plantation covers areas of 3.550.380 ha while the hybrid coconut plantation cover 164.509 ha. In general, tall coconut is usually cultivated by smallholders while only a small area of hybrid coconut cultivated by smallhoders as well as by the government. Hybrid coconut is intensively cultivated by the private estate crop. Most of tall coconut cultivation located in Riau and North Sulawesi, 465.38 and 289.792 ha, respectively. North Sulawesi has the highest productivity of tall coconut with 1.04 ton/ha of copra production. The biggest productive areas of hybrid coconut can be found in Lampung, South Sulawesi, and West Java, with the production of 15.626 ton, 18.956 ton, and 8.155 ton, respectively. The highest productivity of hybrid coconut is produced by South Sulawesi, with 1.37 ton copra/ha (Directorate General of Estate Crops 1997 in Abdurahman and Mulyani, 2003). According to Kumajas and Tuerah (2006), in South Minahasa, one of the factors that cause the low productivity of the coconut plantation is the lack of coconut farmers’ knowledge of managing the coconut farm enterprise. Consequently, the farmers are not able to determine an effective pattern for their own enterprises. To meet this, farmers should be prepared with knowledges in term of cultivation, farm management, quality of products, and marketing.

Hydrological Processes of coconut palm plantation

A. Rainwater uptake, storage and return to the atmosphere

Rainfall interception

Rainfall interception is a part of rainfall per storm retained by the canopy and litter and evaporated without adding to moisture in the mineral soil (Helvey and Patric in Swank 1968). In vegetated regions, plant surfaces are one of the first resistances rainfall encounters in its journey through the hydrologic cycle. The term interception is applied to this phenomenon and includes all processes that affect the catchment, storage, and disposition of precipitation on plant and litter surfaces (Swank, 1968). An assessment of land covers interception has been done in various locations (Table. 1). In this paper, the interception pattern of coconut will be further reviewed to examine its role as one of hydrological processes of coconut palm plantation.

Table 1. Percent of land covers interception in various locations
Tabel 1. Persentase intersepsi curah hujan dari beberapa tipe penutupan lahan di berbagai lokasi.

Land Cover *Penutupan lahan*	Location *Lokasi*	Rainfall (mm) *Curah hujan*	Interception (%) *Intersepsi*	Year *Tahun*	Source *Sumber*
Hardwood *Tanaman berkayu keras*	Canada *Kanada*	213,8	19,3	1995	Caryle-Moses & Price (1999)
Agroforestry *Agroforestri*	Kenya	1583	10,4	1994	Jacson (2000)
Corn, Rice, Casava *Jagung, padi, ubi kayu*	West Java *Jawa Barat*	1577	18	1995	Dirk & Bruijnzeel (2001)
Corn, Casava *Jagung, ubi kayu*	West Java *Jawa Barat*	1642	8	1999	
Nature Forest *Hutan alam*	Kalimantan	2199	11,4	1999	Asdak (1998)
Afforestation Area *Area penanaman hutan*	Kalimantan	3563	6,2	1993-1994	
Wheat *Gandum*	-	-	7	1994-1995	Lull (1964)
Nature Forest *Hutan alam*	West Java *Jawa Barat*	-	21	1980-1981	Calder (1986)
Coconut and Grassland *Kelapa dan rerumputan*	Philippines *Pilipina*	1635	14,8	1981	Rogelio (1982)
Coconut with land zones *Kelapa degnan zona-zona pertanaman*	Philippines *Pilipina*	1635	24,6	1981	
Coconut and pineapple *Kelapa dan nanas*	Philippines *Pilipina*	1635	-	1981	

Source: Modified from Iqbal (2006).
Sumber : Modifikasi dari Iqbal (2006).

Another studied of interception pattern from coconut plantation at different age classes in La Union, Philippines by Egidio (1983) shows that there was no significant difference in interception loss produced by the various coconuts at different age classes. The older and taller coconut trees with greater number of spirally drooping leaves intercepted greater amount of rainfall that later evaporated, while younger trees intercepted less amount of rainfall, of which a greater amount reached the ground for soil moisture recharge.

This brief examination of the interception loss process in coconut plantation implies that manipulation of coconut-based cropping systems can substantially alter amounts of rainfall reaching the coconut floor. The amount of interception loss from coconut-based cropping plantation (Coconut with land zones) is the highest obtained among other land covers in Table 1. Thus, interception is a major hydrologic process which alters the quantity, timing, and areal distribution of water input and output on coconut plantation area.

Stemflow

Stemflow is a portion of gross rainfall which is caught on the canopy and reaches the litter or mineral soil by running down the stems (Helvey and Patric in Swank 1968). In coconut plantation, the pattern of stemflow has been investigated by Rogelio (1982) at different coconut-based cropping schemes for the period of one rainy season (June to December 1981). Of the 114 daily total rainfall recorded, 99 produced stemflow in the different cropping schemes. From 1635 mm of rainfall, for the pure coconut stand and coconut with land zones, stemflows are 96.82 and 91.66 mm. Egidio (1983) describe that there no significant variation in stemflow catch by the different age-classes coconut trees was apparent. The relationship of total rainfall to stemflow in all the treatments showed a direct trend.

Throughfall

Throughfall defined as a portion of gross rainfall which directly reaches the litter through spaces in the vegetative canopy and as drip from leaves, twigs, and stems (Helvey and Patric, 1965 *in* Swank, 1968). An investigation of throughfall at coconut-based cropping schemes by Rogelio (1982) reported that 99 throughfall occur from 114 daily total rainfall during the period of rainy season. For the pure coconut stand, out of the rainfall of 1.635 mm, 1.296 mm occurred as throughfall, and for coconut with land zones, 1.142 mm occur as throughfall. Another investigation of throughfall in coconut plantation by Egadio (1983) report that age class 10-15 years old produced throughfall about 0.069% of total rainfall. The throughfall catch variation among coconut tree age classes was not significant. There was a linear relationship between throughfall and total rainfall.

Evapotranspiration

The loss of water from a given area during a specified time by evaporation from the soil surface and by transpiration from plants is defined as evapotranspiration (ET) (Anonym, 2008). Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process (Anonym, 2007).

de Azevedo et al. (2006) conducted the field experiments to determine evapo-transpiration of a 6-year-old dwarf-green coconut. Three water levels were applied in plots with nine palms. The irrigation treatments denoted as T:50, T:100 and T:150 received 50, 100 and 150 L/plant/day, respectively. The actual evapotranspiration was obtained by the soil water balance (SWB) method. The application of the SWB resulted in mean daily evapo-transpiration values of 2.5; 2.9 and 3.2 mm/day for irrigation treatment of T:50, T:100 and T:150, respectively, while the cumulative evapotranspiration varied from 900 to 1100 mm as irrigation treatment increased from T:50 to T:150. Results also showed that evapotranspiration values were higher in the beginning and end of the year and lower in the middle of the experimental period. Evapotranspiration was strongly affected by irrigation water volume in coconut palms.

Study of evapotranspiration above and below coconut palm canopy on yearly time step by Rouspard et al. (2006) showed stand evapo-transpiration by eddy-covariance represented 40% of rainfall, indicating that water availability was close-to-optimum. Tree transpiration represented 68% of evapotranspiration, close to the 75% of soil coverage by palms. The inter-annual variability was low for potential evapotranspiration (ET_o). The seasonal variability was more pronounced, driven by radiation and vapour pressure deficit. Furthermore, Vincent et al. (2005) describe that coconut genotypes showed variation in transpiration rate (Table. 2) to response the conditions of high soil water deficit at all depths.

Table 2. Transpiration rate of coconut genotypes
Tabel 2. Laju transpirasi dari beberapa genotip kelapa

No.	Genotype *Genotip*	Transpiration Rate (Tr) (µ g cm^{-2}) *Laju transpirasi*
	TALLS (*Kelapa Dalam*)	
1.	East Cost Tall (ECT) *Dalam Pantai Timur*	2.15
2.	Laccadive Ordinary (LO) *Dalam Laccadive Ordinary*	2.96
3.	Andaman Ordinary (AO) *Dalam Andaman Ordinary*	2.20
4.	Philippines (PHL) *Dalam Pilipina*	3.10
5.	Cochin China (CC) *Dalam Cochin China*	3.06
	Mean (*Rata-rata*)	2.69
	DWARF (*Kelapa Genjah*)	
6.	Malayan Yellow Dwarf (MYD) *Genjah Kuning Malaya*	5.39
7.	Malayan Red Dwarf (MRD) *Genjah Merah Malaya*	5.34
8.	Ganga Bondam (GB) *Genjah Ganga Bondam*	4.40
9.	Chowghat Green Dwarf (CGD) *Genjah Hijau Chowghat*	5.40
10.	Ayiram Kachi (AY) *Genjah Ayiram Kachi*	5.61
	Mean (*Rata-rata*)	5.24
	HYBRIDS (*Kelapa Hibrida*)	
11.	VHC1(ECTxMGD)	3.88
12.	VHC2(ECTxMYD)	3.01
13.	WCTxMYD	3.94
14.	LOxCC	4.15
	Mean (*Rata-rata*)	3.74

Source: Vincent et al. (2005).
Sumber : Vincent et al. (2005).

In addition, the amount of water that plants transpire varies greatly geographically and over time. There are a number of factors that determine transpiration rates (Leopold *et al.*, 1960):

- Temperature: Transpiration rates go up as the temperature goes up, especially during the growing season, when the air is warmer due to stronger sunlight and warmer air masses. Higher temperatures cause the plant cells which control the openings (stoma) where water is released to the atmosphere to open, whereas colder temperatures cause the openings to close.
- Relative humidity: As the relative humidity of the air surrounding the plant rises the transpiration rate falls. It is easier for water to evaporate into dryer air than into more saturated air.
- Wind and air movement: Increased movement of the air around a plant will result in a higher transpiration rate. This is somewhat related to the relative humidity of the air, in that as water transpires from a leaf, the water saturates the air surrounding the leaf. If there is no wind, the air around the leaf may not move very much, raising the humidity of the air around the leaf. Wind will move the air around, with the result that the more saturated air close to the leaf is replaced by drier air.
- Soil-moisture availability: When moisture is lacking, plants can begin to senesce (premature ageing, which can result in leaf loss) and transpire less water.
- Type of plant: Plants transpire water at different rates. Some plants which grow in arid regions, such as cacti and succulents, conserve precious water by transpiring less water than other plants.

Finally, the examples above describe that measurements of evapo-transpiration in coconut plantation would be useful indicators of potential changes in storage. Evapotranspiration following an inverse trend to water yield, transpiration is at its peak when water yield is reduced.

B. Moisture conservation

According to Appuhamy (2008), to ensure the availability of water throughout the year for growth and nut production, conservation of water in coconut plantations should be implemented. Nutrients in the soil are absorbed by root only if they are dissolved. Insufficient moisture in the soil will reduce nutrient absorption resulting in poor growth in young palms and low nut production. Clay and organic matters hold the water in the soil. Higher content of organic matter in the soil increases the moisture holding capacity. Much of the organic matter is present in the topsoil. If soil erosion is prevalent in coconut lands, the water holding capacity of the soil is reduced. Bare soils in coconut plantations result in heavy erosion due to runoff. Continuous soil erosion finally results in barren land where coconut cultivation is no longer profitable. Therefore practices have to be adopted in coconut plantations to maximize the volume of rainwater to be absorbed into the soil sub layers without allowing it to run-off the land. Appuhamy (2008) introduced some practices and their explanations that could effectively increases productivity of the coconut plantation land, as follows:

1. Establishment of cover crops

The growing of cover crops in coconut plantations is now becoming more and more popular in coconut growing countries (Anonym, 2000). Any crop intended to prevent soil erosion is generally known as a cover crop. One of the most effective method of conserving soil and moisture in coconut plantations is the establishment of a leguminous cover crop.

Benefits of cover crop

- Cover cropping in coconut land is the best method to control surface run off and soil erosion due to complete live cover formed on the soil surface.
- They are always fast-growing creepers capable to cover the soil in a short period of time, thereby controlling weeds.
- Nitrogen fixing bacteria live in the nodules of the roots of these leguminous plants and are capable of transforming atmospheric nitrogen into nitrogenous compounds, which the plant can utilize.
- It enhances infiltration rate of rainwater into the soil during rain thereby increases water holding capacity of coconut growing soils.
- It reduces leaching of nutrients and soil temperature
- Cover crop improves the physical, chemical and biological properties of soils in coconut lands.
- Cover crops are shade tolerant surface rooters and do not compete for moisture in coconut plantations
- It dries up during the drought period and regenerates during rains and produce seeds
- It completely changes the micro climate in the coconut land

The following legume creepers are recommended grow as cover crops in coconut lands: *Calapogonium muconoides*, *Pueraria phaseoloides*, *Centrosema pubescens*. After the establishment, it should be managed well in order to obtain the expected benefits. If the growth of cover crop is thick, light harrowing should be done once or twice a year. Ploughing of alternative rows of coconut will increase humus content of soil. Ploughing should be carried out during rainy weather. In addition, the study of interactions between cacao (*Theobroma cacao*) and coconut (*Cocos nucifera*) in Lampung, Indonesia by Mialet-Serra et al. (2001) report that when coconut palms were aged five years or over, coconut and cacao growth were satisfactory under virtually normal environmental conditions; death rates remained reasonable and yield percentages differed little from those of the monocultures for each crop. So, coconut farmers could also consider any other cover crops as profitable intercrop system to be adopted.

2. Burial of coconut husks in pits

Burying coconut husks in pits is one of the best methods to harvest rainwater in close proximity to coconut palm. Coconut husk acts like a sponge and can absorb and retain six times their weight of water, which can be utilized by the palm during dry periods. Husks have manorial and other properties. The main constituent of husk is potash. On an average, about 100,000 husks contain potash equivalent to one metric ton of Muriate of Potash. This potash is in a readily available form. Although all types of soil benefit from this cultural practice, husk burial is particularly effective on lateritic gravel and cinnamon sandy soil, but it is not suitable for waterlogged lands with poor drainage. The beneficial effects of husk burying last for about 4 – 5 years. Husk pits of the size 8ft long, 4ft wide and 3ft deep (8 ft. x 4 ft. x 3 ft.) are arranged alternately between palms along the row is the best method recommended for coconut lands.

3. Mulching on the manure circle

Mulching is the practice of covering the surface of the soil with a layer of vegetable waste material, with a view to keeping the surface layers at a more even temperature, more premeable to water and for reducing weed growth (Anonym, 2000). The effective root zone of the coconut palm greatest concentration of roots is found in the top one meter of soil and within a radius of 2m from the bole. Knowledge of the distribution of active root zone in the soil is important in order to understand the effects of fertilizer application and moisture conservation and other cultural practices should be carried out in this region to obtain the best results. Mulching is low cost and important agricultural practice in soil and moisture conservation and should be carried out throughout the year. In mulching layers of organic materials are placed on the manure circle up to a distance of 1.75 meters (6 ft) from the base of the palm. Mulch on the manure circle protects the effective root zone of a palm from direct expose from solar radiation resulting in low temperature in the root zone even in dry periods. It also reduces soil and nutrient erosion, enhances water infiltration during rain and controls the growth of weeds on the manure circle. One of the most common practices is to use coconut fronds, weed trash and lopping of trees as mulch. Other material, which can be used effectively as mulch, is coconut husk. One or two layers of husk could be used to cover the manure circle.

4. Deep planting of seedlings

Deep planting could be practiced to harvest rainwater in areas with well-drain soils. With the growth of seedlings, deep manure circle should be given a shape of a funnel to collect rainwater. The funnel shaped soil preparation not only collects rainwater in the effective root zone but also reduce nutrient loss due to runoff. The funnel shaped structure could be enlarged and maintained even up to mature stage of palms. The concave surface of manure circle of mature palm brings about number of benefits. It collects canopy and stem flows of water during rain and allows plant nutrients and fertilizer applied get into the effective root zone of the palm.

5. Contour drains and bunds

Contour drains are essential in sloping lands to control surface runoff. This is one of the best ways to enhance the rainwater infiltration rate in shallow gravels soils, which are subjected to water stress even in a short dry spell. Contour drains should be laid carefully on the contour to reduce soil erosion, surface runoff and increase moisture conservation. When contour drains are opened excavated soil is placed above the drain in order to form a continuous soil bund across the slope.

6. Construction of water reservoirs along water streams in coconut plantations

In rainy season runoff water in sloping coconut plantations are naturally collected and flows out of the estate through lower areas forming water streams. Mostly in these steams, water flow could be seen only in rainy periods and they dry up in dry periods. Considerable amount of rainwater received by the plantation area is moved out of the plantation area through these water steams. With the construction of soil dams across these steams at different elevations with over flow floes a large capacity of rainwater could be harvested in water reservoirs. Rainwater thus collected in reservoirs at different elevation along the stream leads to uplift the ground water table which intern has beneficial effect on the nut production. At the end of stream, a large deepened water reservoir could be excavated to collect more water for irrigation. Traditionally these ponds were called as "Pathaha" and used to provide water for estate cattle and goads. The pond constructed in this manner could be used effectively as water sources for irrigation.

ENDINGS

1. Hydrological processes in coconut plantation becomes important as a sustainable ways to improve the crop productivity.
2. Interception pattern of coconut plantation depends mainly on coconut-based cropping systems.
3. The relationship of total rainfall to stemflow showed a direct trend.
4. There was a linear relationship between throughfall and total rain-fall.
5. Measurements of evapotranspiration in coconut plantation would be useful indicators of potential changes in storage.
6. Insufficient moisture in the soil will reduce nutrient absorption resulting in poor growth in young palms and low nut production.

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