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The Sustainability of Teak Forest Management in Cepu, Central Java, Indonesia: A Soil Resources Point of View

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ABSTRACT

Indonesia has been known as one of the major teak producers in the world. However, lately the quantity and quality of Indonesian teak has been getting worst. It was thought that the decrease in the quantity and quality of the Indonesian teak was caused by the improper growth of the tree due to decreasing soil quality as a result of accelerated soil erosion. To test this hypothesis, field experiments were done in the Cepu teak plantation, Central Java. With the existing forest management, the average soil erosion rate is 20.6 t/ha/year, far higher than the permissible soil erosion of 15 t/ha/year. If this rate is allowed to proceed continuously, the soil will be unproductive for the next 100 years. With the existing management, the harvesting of teak trees should be done for those over 60 years old; harvesting younger trees would speed up land degradation. Improving intercrop trees, shrubs, and cover crops growth as well as maintenance of the forest litter in the teak forests are absolutely essential. Planting spice crops under teak trees could help maintain the coverage of the forest floor, and hence promote sustainable teak forest production.

KEY WORDS: teak sustainable production, forest soil, soil erosion, land degradation.

1. INTRODUCTION

Indonesia is one of the major teak producers in the world. Indonesian teak has been recognized as the best quality for years; however, lately both the quantity and quality of teak exported from Indonesia has drastically decreased. Observations of the teak forests have shown that there are a lot of teak trees which have improper growth. The trees do not grow straight and posses little stems with a lot of branches. This is one of the symptoms of teak trees grown on degraded land with poor soil quality (1). In the past this phenomenon was uncommon, because the soil for teak forest production was of very good quality.

It had been widely understood that soil erosion from forest land was negligible, with a C factor (of USLE) of less than 0.01. This is true for natural closed system forests; with good land coverage, either due to trees, cover crops, or litter coverage, soil detachment due to rainfall will be negligible. Decomposed plant material from the forest's trees will improve soil aggregation and increase soil porosity. The improvement of these physical properties will increase the resistance of the soil to erosion; however, a higher value had been suggested for forests in poorer condition; i.e., C = 0.03 for forests without ground floor cover crops but with forest litters and $C \geq 0.5$ for forests without ground floor cover crops and forest litters (2). The C value for tree plantations, such as teak forests, depends on the management system employed; but it will not be less than 0.2 (3).

The origin of the teak tree in Indonesia is still debatable. Some scientists suggest that the teak tree is an indigenous species in Indonesia, but others suggest that this tree originates from India and has been brought to Indonesia by Hindu settlers. But all agree that the teak tree has been recognized as noble trees from as early as the year 400 AD. However, the modern teak forest management system only started in the 17th century, when Indonesia was colonized by the Dutch (4). The modern management system understands the role of the natural forest system to maintain soil productivity; therefore, teak forests are arranged in such a way that the ecosystem is close to that of a natural forest. To obtain these conditions, in addition to teak trees, there are many other trees that are planted in teak forests. These include high tree species, such as *Swietenia mahagony Jacq., Dalbergia latifolia, and Callopyllum inophyllum,* which are called intercrop trees; and shrub trees, such as *leucaena* and *caliandra,* which are usually planted following the contour lines. On the forest floor there are wild weeds and other cover crops. With this arrangement, there exists a multi-strata plant arrangement capable of decreasing the erosive energy of rainfall detachment. With the occurrence of cover crops and wild weeds and the existence of litter on surface of the forest floor, a decrease in surface water runoff and an improvement of the soil's physical properties had been shown by many researchers (5). The existence of other crops beneath the teak tree is also

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beneficial in increasing soil fertility. Planting of *leucaena* as an intercrop in teak plantations, for example, has been known for a long time as a practice able to increase nitrogen content and tree growth (6)

During the Dutch colonial periods and in the early days of Indonesian independence, this system was strictly controlled so the degradation of teak forest land could be minimized. The assumption of a low rate of soil and land degradation in forest land has continued until today, and this has caused studies on soil and land degradation for forest soil to be limited (7; 8; 9). At the moment, however, soil and land degradation in teak forest systems is not an uncommon phenomenon (10).

With an increasing population, the requirement for timber and agricultural land has increased very rapidly, and has made the system difficult to effectively maintain. The increase in timber demand, both for housing and energy has caused excessive illegal logging which has not only resulted in the damage of teak trees, but has also destroyed the intercrop trees and shrubs. Excessive animal grazing and forest fires have depressed cover crops and forest litters, and hence exposed soil surfaces to destructive energy such as rainfall detachment and surface runoff water. These phenomena have caused the soil to be more susceptible to the degradation processes due to soil erosion. The teak forest soil is becoming thinner exposing stone and/or gravel. Field observation on teak forest land at Cepu, Central Java, Indonesia, has shown that most of the soil has an effective depth of less than 50 cm. If this phenomenon is allowed to proceed continuously, the teak trees will grow more and more poorly, and it is feared that Indonesia will no longer be able to produce teak wood.

Lately, sustainable forest management has been one of the most important issues in forest product trading, and many criteria for sustainable management have been developed (11; 12; 13; 14; 15). So far, there are no common definitions, criteria, or indicators, each one being applicable to specific local needs and situations (15). However, none of them have taken soil loss into consideration. In actual fact, the growth of the tree is completely controlled by the soil condition and soil fertility status.

The aim of the experiments described here is to study the 'soil loss by erosion' rate in the teak forest with the existing management system. Soil loss will influence soil productivity, and hence the sustainability of crop production. It is proposed that soil erosion rate should be taken into consideration in developing indicators and criteria for sustainable forest management. The experiment also explored the possibility of improving the crop management system to obtain sustainable teak production. The management system tested in this study tries to find the way to maintain forest floor coverage. Planting crops which have an economic value, such as spice and medicine crops, can be expected to encourage the farmers surrounding the teak forest to look after these cover crops. If this expectation can be realized, then the soil erosion in the teak forest can be minimized.

2. MATERIALS AND METHODS

Study location

Three years of experiments were done in the teak forest managed by PT Perum Perhutani, at Pasar Sore, which belongs to Cepu Administration Unit, Central Java, Indonesia. The soil belongs to Vertisols with surface land varying from about 3% to 36%. The climate has distinct wet and dry months, and the rainy season usually starts in November and ends in March; although in some cases there was still rain in April or May. The average annual rainfall is about 1800 mm with a variation of 1,500 to 2,000 mm.

All the measurements were done in a small watershed of about 1,385 ha. The teak forest condition, except for that of 5 years of age, had almost no intercrop trees and no shrubs with a clean forest floor (no cover crops, no weeds and no forest litter) due to excessive grazing and annual fires. The experiments were carried out from November 2003, to July 2007. Two types of experiments were established, plot size experiments and mini watershed experiments.

Experimental procedure

Plot experiments were done to study the erosion rate for different ages of teak tree and the effect of crop management on soil erosion. The plots of 20 m (length) and 8 m (width) were set up in teak plantation sectors of: (a) one year, (b) 5 years, (c) 10 years, (d) 30 years, and (e) 60 years old. Each age category was situated on slopes of: (a) 8 %, (b) 12 %, (c) 18 %, (d) 24 % or (e) 36 %. To collect the surface water runoff and eroded soil, collectors made from oil drums were constructed at the bottom end of the plot. The recorded rainfall data showed that the maximum daily rainfall was 90 mm. With the assumption that 20 % of the rain becomes surface runoff, the collectors were built to be capable of collecting about 3000 liters of surface runoff water.

The eroded soil and the surface water run off were measured on every rain day. The eroded soil was calculated by multiplying the sediment concentration in the runoff water by the volume of runoff water, and the data was presented on an oven dried base.

Rain erosivity, R, is calculated by the formula developed by Bols (16) as presented in equation (1):

$$R = 0.119\,(Rm)^{1.21}(Rd)^{0.47}(R24)^{0.53} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

In which: Rm is monthly rainfall (cm),

Rd is the number of rain days in that month, and

R24 is the maximum rainfall during 24 hours in that month.

Soil erodibility, K, is calculated with the "Soil Erodibility Nomograph" developed by Wischemeier et al. (17); and permissible erosion limit, Ep, was calculated using the method developed by Hammer (18):

Ep = d X fd/RL ……………………………………..……….…… (2)

In which: d is the measured effective depth (mm),

fd (=0.8) is a depth factor depending on the soil sub-order, and

RL is resources life

To calculate the soil erodibility index, K, soil structure was determined by field observation and soil texture by pipette methods. Soil organic matter was determined by the Walkley and Black methods, and soil permeability was measured with a permeater.

Plot experiments were also set up with applications of a management system that would encourage the farmers to maintain the coverage of the forest floor by planting economic cover crops under the teak trees. The crops planted were: (a) *Vetivera zizanoides*, (b) *Bachiaria sp*, (c) *Centrocema pubescens,* (d) *Curcuma domestica*, and (e) *Kamferia galanga*. These crops have a high economic value and can be harvested by the surrounding farmers; hence, it is expected that farmers will look after these crops, and the forest floor will avoid being damaged by animal grazing or forest fires.

Soil erosion is a process in which the soil is removed from one site and deposited in another place. In a limited plot size experiment, the soil is removed from plot and deposited outside of the plot but still in the watershed. Thus soil erosion from the watershed is more complicated than that from a plot size experiment; therefore, the result of a plot size experiment cannot be directly applied to a real field scale Noordwijk et al.(19). To obtain an area for study of which the result can be used for calculating the erosion from the whole field, erosion measurement was done in mini watersheds with sizes of: (a) 0.5 ha, (b) 1.0 ha, (c) 6.6 ha, (d) 50 ha, (e) 100.0 ha, (f) 391.7 ha, (g) 500.0 ha and (h) 1384.3 ha. The eroded soil was measured at the outlet of the watershed, and calculated using equation (3):

E = SL x Q ………..………………..…………………..…. (3)

In which: SL is sediment load (kg/m^3), and

Q is discharge (m^3/sec.), which is calculated by equation (4)

Q = A x V …………………………....…………………….………….. (4)

In which: A is the area of wet perimeter and,

V is flow velocity.

3. RESULTS AND DISCUSSION

Rain erosivity, soil erodilibity and permissible erosion limit

The rain erosivity index, R, during the experiment, calculated with Bols' formula (16), is presented in Table 1. Except in 2002, the annual rain erosivity index is not much different compared to the mean ten years' rain erosivity index.

The erosive rain mostly occurs in November and December. This is the beginning of the rainy season in which teak forest land is in the condition of favoring soil erosion. Teak trees usually shed most of their leaves during the dry season, so if there is rain fall there is no rain interception; hence, almost all of this erosive rain energy will detach the soil. At this time the soil is very susceptible to erosion, because the forest floor is relative clean from the forest litter due to forest fires which occur almost annually.

Table 1 Rain Erosivity Index, R, in experimental site calculated by Bols' (16) Formula

Months	Mean 10 years (1990-2000)	2001	2002	2003	2004	2005
January	147	139	118	286	250	165
February	254	101	82	104	254	348
March	125	392	127	144	211	198
April	76	204	55	195	32	78
May	40	1	38	58	39	25
June	0	47	0	75	12	15
July	62	43	1	25	7	10
August	65	0	0	2	0	0
Sept	178	66	0	66	1	0
October	145	159	2	159	33	65
November	245	251	202	359	332	53
December	257	154	333	140	288	88
Total	1594	1557	826	1613	1459	1045

The data given in Table 2 shows that the soil erodibility index, K, decreases as the teak trees grow older. Soil index, K, decreased from 0.32 for 3 years old trees to 0.24 for 30 years old trees, after which soil index erodibility did not change as the trees growing older. The decrease in soil erodibility index with increasing teak ages was simply due to the increase of soil organic matter which will improve soil physical properties. Mapa (20) observed an increase in soil porosity, which was then followed by the increase in water retention and infiltration in the reforested teak trees. Increasing the amount of soil organic matter will also increase the soil aggregate stability, as soil organic matter is an important agent for cementation (21).

Table 2 Soil erodibility index, K, and soil organic matter content, and soil permeability as influenced by the age of teak tree

Teak tree age (years)	Erodibility index, K	C-organic (%)	Permeability cm/hour
3	0,32	1.92	1.24
10	0.30	2.34	1.21
20	0.27	2.38	1.38
30	0.24	2.67	2.25
50	0.24	3.25	2.54
60	0.23	3.20	2.65

The results is Table 2 also shows that a decrease in soil erodibility index was followed by an increase of soil permeability.

In forest soil, the buildup of soil organic matter will occur much faster than in agricultural soil. Therefore, the Resources Life (RL) suggested that for calculating permissible erosion limit was 300 years. The calculated permissible erosion limit, Ep, decreases with increasing the slope of the land. At a slope of 8 %, with the effective depth of 50 cm and soil bulk density of 1.28 Mgm^3, the permissible erosion limit, Ep, is 17.1 t/ha/year, and at a slope of 12 %, 18 %, 24 %, and 36 % Ep is 17.1 t/ha, 15.3 t/ha, 14.9 t/ha, and 13.3 t/ha/year respectively.

Soil erosion

The data given in Table 3 shows that, for all land slopes, soil erosion in older teak tree areas is lower than soil erosion in younger teak tree areas. Soil erosion in one year old teak tree areas varies from 31.55 t/ha (at 8 % slope) to 88.21 t/ha (at 36 % slope). The rate of soil erosion is a function of land slope, with which the soil erosion rate increases with increasing land slope (Table 3). As a consequence, at a steep slope the remaining soil should be less, or in other words shallow. Since soil depth is one of the factors which determines permissible erosion limit (see equation 2), it is reasonable that soil on steep slopes has lower permissible soil erosion compared to that on the lower slope.

The decrease in soil erosion with the growing of the teak tree is, in part, caused by the decreasing soil erodibility index (see Table 2) and the lowering of rainfall detachment due to the increase of land surface cover. The lower erosion in the older teak tree areas is also caused by the increasing soil water infiltration (20), which will decrease the velocity and volume of surface water runoff. The increase of erosion with increasing land slope was a consequence of increasing volume and velocity of the surface water runoff (22).

The high soil erosion rate in one year old teak tree areas is also caused by soil disturbance during land preparation for the annual crop which is intercropped within the teak tree areas. In Java, replanting of the teak forest is done by farmers surrounding the forest using the “tumpang sari” system. In this system, farmers are allowed to plant food crops between the teak trees (up to 3 years old); the teak forest management can save the replanting cost, and at the same time the farmers surrounding the forest, who usually have no farmland, can grow the food crops.

Table 3 Erosion rate from teak forest of different age and land slope

Teak tree ages (years)	Soil loss at slope of (t/ha/year)				
	8 %	12 %	18 %	24 %	36 %
1+)	31.55	44.23	72.56	75.70	88.21
5	28.38	39.45	62.71	66.8	78.39
10	24.86	34.20	52.25	57.2	67.64
20	19.07	25.69	36.27	42.00	50.30
30	14.63	19.30	25.18	30.01	37.49
40	11.22	14.50	17.48	22.60	27.92
50	8.61	10.89	12.13	16.57	20.78
60	6.61	8.18	8.42	12.16	15.47
70	7.01	8.15	6.85	11.9	11.52

+) Means of three years (e.g. For 1 year old is means of 1, 2, and 3 years old)

To understand the relationship between teak tree ages (Tn) and soil erosion (En), the soil erosion data in Table 3 was plotted against the teak tree ages, which resulted in an exponential equation of:

$$En = a + e^{bn} \quad \text{……. ………..………………………………. (5)}$$

In which: En is soil erosion of the teak plantation at n years old, and
a and b are constant coefficients obtained from measurement.

The resulting a and b coefficients, and the coefficient of determination, R, for each land slope are presented in Table 4. With these equations, it can be calculated that soil erosion in a teak tree plantation will be nearly constant for teak trees at more than 40 years old and a low slope (8%), and teak trees at 60 years old for steeper land slopes.

Table 4 The value of a and b coefficients and coefficient of determination, R, equation (5) for each land slope.

Teak tree ages (years)	**The value of**		
	a	**B**	**R**
8	32.96	-0.029	0.83
12	45.52	-0.028	0.79
18	75.26	-0.036	0.93
24	78.08	-0.031	0.88
36	90.85	-0.029	0.86

To understand the relationship between land slope (S) with the soil erosion (E) at different teak tree ages (Tn), soil erosion was plotted against plant age and slope, with the resulting equation (eq. 6):

$$En = 33.36 - 0.71\ Tm + 1.11\ S \quad \text{..…………... (6)}$$

This equation indicates that soil erosion decreases with increasing teak tree ages by a factor of 0.71 and increases with increasing land slope by a factor of 1.11.

From a soil resources point of view, a sustainable production can be obtained if the soil loss is less than or equal to the permissible erosion limit; hence, it is important to know the erosion rate from the field. To calculate the soil erosion from the whole field, the mean soil erosion at any teak tree area was plotted against plant age (data in Table 3), and the resulting equation is:

$$\overline{En} = 22.93\ e^{-0.03\ n} \quad \text{……………………………..…………. (7)}$$

In which: $\overline{En}$ is the mean soil erosion at year n (t/ha)
n is plant age (years)

The model given in equation (7) is obtained from the plot size experiment. As discussed before, a calculation of the erosion rate from the whole field by using the data obtained from the plot size will result in an overestimation of the soil erosion rate. Therefore the experiment here was also intended to study the minimum plot or mini watershed size at which the data can be used for calibrating the experimental result to the whole field scale. With the assumption that the plot and all watersheds in which the measurements were done have the same characteristics, soil erosion data obtained from the mini watershed experiments (+ plot size experiment of 30 year old teak tree at a slope of 8 %) were plotted against the area (A), and the resulting equation is (equation 8):

$$\overline{Ew} = 7.66\ e^{-0.15A} \quad \text{………………………………………………….. (8)}$$

In which: $\overline{Ew}$ is the mean soil erosion at watershed scale (t/ha)
A is the area of the watershed

By using equation (8), it was found that the minimum watershed area that can be used to calculate the erosion rate of the whole field scale was about 20 ha. Based on equation (8), with a value for A of 20 ha, equation (7) was reformulated resulting in equation (9):

$$EN = 22.27\ e^{0.01n} \quad \text{…….…………..……………………………… (9)}$$

Where EN is soil erosion rate for teak tree at age of n years at field scale

The cumulative soil erosion to that year, (CEN), was obtained by using integration of equation (9). The average annual soil erosion was obtained by dividing the cumulative erosion by the total number of years. Then, by applying the lowest permissible soil erosion (13 t/ha/year), it is suggested that with the existing management, in order to obtain sustainable teak production (from a soil resources point of view), the teak trees should be harvested at no less than 60 years of age. Harvesting of the teak tree at less than 60 years of ages will result in unsustainable teak production because the effective depth of the soil will decrease continuously.

Lately with the increasing timber demand and in order to increase the cash flow and efficiency of teak growing, Perum Perhutani, as the management of the teak forest in Java, intends to shorten the life cycle of the teak trees. By planting fast growing teak species followed by improvement of crop management, it is expected that the teak tree can be harvested at less than 20 years old. This policy implies that in order to obtain sustainable teak production, proper crop management which yields an erosion rate low enough that the actual soil erosion is less than the permissible erosion limit is essential.

A simple method to select crop management is to apply the Universal Soil Loss Equation (USLE), with which we can determine the crop management (23; 24):

$$Ep \leq RKLSCP \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

In which: Ep is the permissible erosion limit
R is Rain erosivity index
K is Soil erodibility index
LS is slope factor

In addition to experimental results, the values of the Crop and Management factor (CP) used for this purpose was also obtained from the literature, and is presented in Table 5.

Table 5 The value of crop and management (CP) factor for cropping management in teak forest

Crop under teak tree	CP
Teak tree, one year old, monoculture[1)]	0.90
Teak tree, one year, intercrop with maize[1)]	0.56
Teak tree, 10 year, no cover crop, no litter[1)]	0.56
Teak tree, 50 year, no cover crop, no litter[1)]	0.42
Teak tree, Vetivera + Centrocema[1)]	0,03
Teak tree, Bachiaria spp. + Centrocema[1)]	0,03
Teak tree, Cucurma + Centrocema[1)]	0.14
Teak tree, Kaemferia + Centrocema[1)]	0.06
Teak tree, taungya system[2)]	0.17
Teak tree + mahagony, good land coverage[2)]	0.04

Sources : [1)] experimental results, [2)] Wiersum (2)

For example, if the Teak Forest Management is willing to harvest their teak trees at 20 years old, with the average permissible erosion limit of 15 t/ha/year, rain erosivity index, R, of 1350 (Table 1), soil erodibility index, K, of 0.24 (Table 2), and LS factor of 1.22 (means slope 12 % and slope length 20 m), the crop management employed should have a value of:

$$Ep \leq RKLSCP$$
$$15 < 1350*0.24*1.22*CP,$$
$$CP \leq 0.04$$

From the data given in Table 5, the Teak Forest management has a choice to employ crop management of teak trees with cover crops of Vetivera + Centrocema, teak trees with cover crops of Bachiaria + Centrocema, or teak trees + mahogany with good land coverage. With this crop management, it is expected that soil erosion rates will less than 15.0 t/ha/year, and the sustainable teak production can be achieved.

4. CONCLUSION

With the existing forest management, the average soil erosion rate in teak plantation of Cepu area is 20.6 t/ha/year. This is far higher than the permissible soil erosion of 15 t/ha/year. If this rate proceed continuously, the soil will be unproductive for the next 100 years. With the existing management, the harvesting of teak trees should be done for those over 60 years old; harvesting younger trees would speed up land degradation. Improving intercrop trees, shrubs, and cover crops growth as well as maintenance of the forest litter in the teak forests are absolutely essential. Planting spice crops under teak trees could help maintain the coverage of the forest floor, and hence promote sustainable teak forest production.

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