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Ecosystem Water Storage in a Teak Plantation under the Doi Tung Reforestation Royal Project, Chiang Rai Province, Northern Thailand

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ABSTRACT

The water storage in an ecosystem of a 22-year-old teak (*Tectona grandis* L.f.) plantation under the Doi Tung Reforestation Royal Project in Chiang Rai province was studied using five sample plots, each of size 40×40 m. The plots were arranged randomly within areas of altitude ranging from 515 and 704 m m.s.l. All individuals of teak and successional species of height ≥1.5 m were measured for stem girth at 1.3 m above ground (gbh) and total tree height. The mean densities of teak and successional species were calculated to be 85±48.73 and 23±38.38 trees plot^{-1}, respectively. The average stem gbh and height were: 63.87±7.85 cm and 16.62±3.12 m, respectively. The successional species in the five plots varied between 1 and 13 species. The average biomass of teak and successional species was 42.24±0.65 Mg plot^{-1} (264.0 ±103.42 Mg ha^{-1}), and contained average water amount of 47.72±20.93 m^3 plot^{-1} (298.25±130.82 m^3 ha^{-1}). The maximum capacity of water storage in 2-m soil depth in the plantation was 1,133.57±117.28 m^3 plot^{-1} (7,084.81± 733.0 m^3 ha^{-1}), whereas the water storage in the rainy season (on 17thAugust 2013) was 758.38±101.50 m^3 plot^{-1} (4739.85±634.41 m^3 ha^{-1}, or 66.90% of the maximum storage). The maximum water storage in the stand ecosystem (plant biomass and 2 m soil depth) was evaluated to 1,181.29 m^3 plot^{-1} (7,383.06 m^3 ha^{-1}), while the water storage on 17th August 2013 was 806.10 m^3 plot^{-1} (5,038.13 m^3 ha^{-1}, 68.24%). The percentage of water storage in plant biomass was only 4.04-5.92%, and the remainder 94.08-95.96% was in the soil. The water storage in the teak plantation implied its ecological roles, its importance for restoring the watershed environment, and the indirect benefits to highland and lower land communities since the water storage capacity can reduce the streamflow and flash flooding.

Keywords: Ecosystem water storage, Doi Tung Reforestation Royal Project, Teak plantation

INTRODUCTION

Massive flooding in 2011 caused tremendous devastation in Thailand. Much agricultural wealth was lost, especially rice, fruit orchards, pastures and fresh-water fishery. Many industrial factories and houses in low lying areas, particularly Bangkok and the surrounding areas, were flooded for a few months. Urgent integrated water management was planned by the government. One significant cause of the flooding was the deforestation in the watershed areas in the northern and northeastern regions of the country. It is considered that an important functional role of the forest ecosystem is the hydrologic cycle. Input of water into the ecosystem through precipitation especially rainfall provides more water than the vegetation can use or soils can store. The excess water contributes to stream flow, which provides for irrigation and urban needs, far from the source of precipitation. The forest vegetation is a major factor in the hydrologic cycle. Before rainfall reaches the soil, water is intercepted and evaporated from the surface of vegetation and the litter layer. The rate at which water infiltrates into the soil, runs off surface, or percolates through to the water table is affected by the density and depth of roots and organic residue incorporated into the soil. The hydrologic cycle through forest ecosystem has been described by many scientists (Landberg and Gower, 1997; Waring and Running, 1998; Kimmins, 2004; Chang, 2006).

Most literature on the hydrologic cycle in forests focused on inputs of precipitation into forest ecosystem, and movement of water through many processes, particularly interception-evaporation by forest canopy, throughfall, stemflow, uptake by roots, transpiration, water flow through vegetation, evaporation from soil, infiltration into soil, drainage and runoff, and stream flow. *Withawatchutikul et al*. (2011) reported that amounts of annual rainfall and streamflow of various forest types in Chiang Mai province were greatly different. The good montane forest received annual rainfall of 2,142.0 mm and had high streamflow of 1,382.8 mm (64.56%). The disturbed montane forest obtained annual rainfall of 2,127.4 mm and had lower stream flow, 415.99 mm (19.55%). The annual rainfall in mixed-deciduous forest was 1,660.5 mm with the streamflow 479.61 mm (28.88%) while the dry dipterocarp forest had annual rainfall of 1,734.3 mm and streamflow of 124.45 mm (7.18%). The differences between annual rainfall and streamflow in these forests were 759.20, 1711.41, 1180.89 and 1609.85 mm, respectively. These amounts were stored in forest biomass and soil, and losses were through transpiration and evaporation.

Few data are available on the potential of water storage in forest biomass and soil of different forest types. Brady and Weil (2010) described that the data on maximum retentive capacities within the average depth of soils in a watershed are useful in predicting how much rain water can be stored in the soil temporarily and possibly avoiding downstream floods. Nowadays, flooding and drought have become serious problems in Thailand. Reforestation in shifting cultivation areas on the highland watershed is very important to restore the watershed functions of the hydrologic cycle (Landberg and Gower, 1997; Waring and Running, 1998; Kimmins, 2004; Chang, 2006). The roles of forest plantations on the hydrologic cycle are significant to watershed functions.

The Doi Tung Development Project was established in 1988 by Her Royal Highness the Princess Mother (HRH the Princess Mother)'s initiative. The project area is located in Chiang Rai province including two districts, Mae Fah Luang and Mae Sai. It covers 93,515 rai (149.624 km^2) in an altitude ranging from about 400 to 1,500 m m.s.l. The areas are the head watershed supplying water to many streams which are beneficial to 27 villages of hill tribes: Akha, Shan, Lahu, Yunanese Chinese, Lua, Tai Lu, Lisu, Hmong, Karen and Mien, as well as local Thais in lower land communities. The hill tribes receive more income from the labour wage, agriculture products, handicraft and commerce during the project implementation.

Reforestation was one important activity of the project, aimed to improve the watershed environment. It was initiated in 1989 as part of the implementation of the rehabilitation plantations to celebrate the 90th year of Somdet Phra Srinagarindra Boromarajajonani Her Royal Highness the Princess Mother (HRH the Princess Mother). The plantation area had a total area of 10,532 rai (1,685.12 ha). Many tree species were selected for planting in the areas. *Pinus kesiya* was planted in areas above 950 m m.s.l., whereas the low lying areas were planted with teak (*Tectona grandis* L.f.). Other species were planted in the remaining smaller areas.

The research objective is to assess the potential amount of water storage in the ecosystem (plant biomass and soil) of a 22-year-old teak plantation under the implementation of the rehabilitation plantation to celebrate the 90th year of Somdet Phra Srinagarindra Boromarajajonani, Her Royal Highness the Princess Mother (HRH the Princess Mother). The data were expected to provide an indication of the ecological benefit of the teak plantation. This research reported only the water storage in the rainy season (August). The seasonal changes, however, are not given herein.

MATERIALS AND METHODS

Tree and plot data

A field survey in a 22-year-old teak plantation was carried out using five sample plots, each of size 40×40 m^2. The plots were arranged using a random sampling design within a study area at an altitude ranging from 515 to 704 m m.s.l. In each plot, data were collected for all teak and successional tree species of height $\geq$1.5 m, including stem girth at breast height (gbh, 1.3 m above ground) and total height. All plots were measured for the slope gradient, slope aspect, altitude, and location using GPS.

Biomass estimation of standing trees

The biomass of teak allocated in stem, branch and leaf components in the trees were calculated using the allometric equations of teak plantations at Mae Moh district, Lampang province (Khamyong *et al*., 2012) as follows:

$$w_S \text{ (stem)} = 0.0420 (D^2H)^{0.9746} \quad (r^2 = 0.8926)$$
$$w_B \text{ (branch)} = 0.0177 (D^2H)^{0.9375} \quad (r^2 = 0.7040)$$
$$w_L \text{ (leaf)} = 0.0248 (D^2H)^{0.7594} \quad (r^2 = 0.7728)$$

where

D = diameter at breast height in centimeters

H = tree height in meters

The root biomass of teak was not investigated in this study. However, the root biomass of teak and biomass of successional tree species were calculated using the equations developed by Tsutsumi *et al.* (1983), which were derived for about fifty tree species in Thailand, as follows:

$$w_S \text{ (stem)} = 0.0509 (D^2H)^{0.919} \quad (r^2 = 0.9780)$$
$$w_B \text{(branch)} = 0.00893 (D^2H)^{0.977} \quad (r^2 = 0.8900)$$
$$w_L \text{ (leaf)} = 0.0140 (D^2H)^{0.669} \quad (r^2 = 0.9810)$$
$$w_R \text{ (root)} = 0.0313 (D^2H)^{0.805} \quad (r^2 = 0.7140)$$

where D and H are as defined earlier.

Water storage in plant biomass

The collection of fresh leaf, branch, stem and root samples of teak was taken at one time in the rainy season, on 17thAugust 2013. The samples were gathered from three individuals of teak in the plantation. They were put in plastic bags, and carried to a laboratory. They were oven-dried at 80^{o} C until they reached a constant weight, and then the moisture content was determined. As for the succession tree species, the mean water content studied by Seeloy-ounkeaw *et al*. (2012) was used to calculate the biomass water storage. The average water content in stem, branch, leaf, and root organs of 13 dominant tree species were reported to be 79.48$\pm$4.42, 102.49$\pm$19.50, 112.11$\pm$23.01 and 80.01$\pm$21.03% dry weight, respectively.

Maximum capacity and water storage in soil

A soil pit, 1.5 x 2 x 2 m in size, was made in a selected plot of teak plantation. Soil samples were collected using a 100 cm^3 corer from 13 layers at the depths of 0-5, 5-10, 10-20, 20-30, 30-40, 40-60, 60-80, 80-100, 100-120, 120-140, 140-160, 160-180 and 180-200 cm. Two replications of the soil samples were gathered in both sides of the pit, in areas about 1.5 m apart from the left and the right. The samples of the two replications were used to determine the maximum water holding capacities and moisture content on 17th August 2013 in a laboratory. The maximum water holding capacity was determined from the field capacity (FC) (Brady and Weil, 2010). Water was added into the soil sample within 100 cm^3 corer until it was completely saturated with water, and allowed to drain out of the macropores. The soil was then said to be at field capacity, and it was later measured for the moisture content by volume. The FC was calculated using the equation, FC = Vw/Vt, where Vw was the water volume, and Vt was the total soil volume. Then, the amount of water storage per unit area in each soil layer was determined, and the total amount within 2 m soil depth per unit area was calculated.

RESULTS AND DISCUSSION

Tree girth, height and density

Table 1 shows tree girth, height and density in five sample plots in the teak plantation. The mean density of teak and succession tree species were 85±48.7 and 23±38.4 trees plot^{-1}, respectively. The mean stem girth at breast height (gbh) and height of teak were 63.87±7.85 cm and 16.62±3.12 m, respectively. The teak density greatly varied among the plots due to the different tree survival rates. Since the sampling sites were situated in mountainous areas, differences in the physiographic factors, particularly slope gradient, aspect, and altitude, might have had an effect on the teak growth. The plant succession in teak plantation also varied among the sample plots. Good succession was observed in Plot 1, and it was poorer in the other plots. The common succession species were *Lithocarpus grandifolius* (D. Don) Bigwood, *Cratoxylum formosum* (Jack) Dyer subsp. *pruniflorum* (Kurz) Gogel., *Aporosa villosa* (Wall. ex Lindl.) Baill., *Dalbergia cultrata* Graham ex Benth. and *Phyllanthus emblica* L.

Table 1 Tree densities of teak and successional species, and tree girth and height of teak in the five sample plots (S.D. stands for standard deviation).

Plot no.	Tree density (trees plot^{-1})		Stem gbh (teak) (cm)	Tree height (teak) (m)
	Teak	Other species		
1	146	91	51.73±16.56	16.05±8.45
2	78	10	66.62±21.65	13.66±2.47
3	77	7	65.44±20.21	13.39±1.56
4	115	1	73.18±20.84	20.09±2.28
5	110	4	62.36±18.11	19.40+3.12
Mean±S.D.	85±48.73	23±38.38	63.87±7.85	16.62±3.12

Plant biomass and water storage

Table 2 shows the biomass of teak and succession species in five sample plots of the 22-year-old plantation. The biomass varied between 27.06 and 68.42 Mg plot^{-1}, and averaged 42.24±0.65 Mg plot^{-1} (or 264.0±103.42 Mg ha^{-1}). The average biomass allocated in stem, branch, leaf and root were 28.45±0.45 (67.35%), 8.50±0.13 (20.12%), 2.11±0.04 (5.00%), and 3.18±0.35 (7.53%) Mg plot^{-1}, respectively. The biomass of succession species in these plots varied from 0.27 to 18.23 Mg plot^{-1} (0.40-53.76% of the total stand biomass). It was highest in Plot 1.

The average water content in stem, branch, leaf and root of teak on 17th August 2013 were measured to 97.29, 177.53, 181.58 and 97.33% by dry weight, respectively. These values were used for calculation of water storage in the teak biomass. In Table 3, the total water storages in plant biomass in five plots of the teak plantation varied from 31.44 to 80.50 m^3 plot^{-1} (average: 47.72±20.93 m^3 plot^{-1} or 298.25±103.82 m^3 ha^{-1}). The average amounts of biomass water stored in stem, branch, leaf and root components were in the following order: 26.99±11.69, 14.19±6.63, 3.75±1.79, and 2.79±0.91 m^3 plot^{-1}. The amounts of water storage in biomass of the succession species varied between 0.26 and 43.16% of the total stand. It was the highest in Plot 1, and the lowest in Plot 4.

Table 2 Biomass allocated in various organs of tree species in the five sample plots.

Sample plot no..	Tree species	Biomass amounts (Mg plot^{-1})				
		Stem	Branch	Leaf	Root	Total
1	Teak	10.51	3.17	0.91	1.09	15.68
	Others	11.79	3.53	0.34	2.57	18.23
	Total	**22.30**	**6.70**	**1.25**	**3.66**	**33.91**
2	Teak	18.68	5.62	1.57	1.90	27.77
	Others	3.81	1.18	0.09	0.76	5.84
	Total	**22.49**	**6.80**	**1.66**	**2.66**	**33.61**
3	Teak	17.18	5.18	1.47	1.77	25.60
	Others	0.94	0.28	0.03	0.22	1.46
	Total	**18.12**	**5.46**	**1.50**	**1.99**	**27.06**
4	Teak	46.59	13.76	3.51	4.28	68.15
	Others	0.17	0.05	0.01	0.04	0.27
	Total	**46.76**	**13.81**	**3.52**	**4.32**	**68.42**
5	Teak	32.05	9.58	2.60	3.15	47.38
	Others	0.54	0.16	0.02	0.12	0.83
	Total	**32.59**	**9.74**	**2.62**	**3.27**	**48.21**
Mean (Mg plot^{-1})		28.45$\pm$0.45	8.50$\pm$0.13	2.11$\pm$0.04	3.18$\pm$0.35	42.24$\pm$0.65
Mean (Mg ha^{-1})		177.81$\pm$72.13	53.14$\pm$20.99	13.19$\pm$5.90	19.87$\pm$5.62	264.00$\pm$103.42

Table 3 Biomass water storage in various organs of tree species in the five sample plots.

Sample plot no.	Tree species	Water storage in plant biomass (m^{3}plot^{-1})					
		Stem	Branch	Leaf	Root	Total	%
1	Teak	10.23	5.63	1.65	1.06	18.57	56.84
	Others	9.12	3.20	0.34	1.44	14.10	43.16
	Total	**19.34**	**8.82**	**1.99**	**2.51**	**32.67**	**100**
2	Teak	18.17	9.98	2.85	1.85	32.85	87.88
	Others	2.95	1.07	0.09	0.43	4.53	12.12
	Total	**21.12**	**11.05**	**2.94**	**2.28**	**37.38**	**100**
3	Teak	16.71	9.20	2.67	1.72	30.30	96.39
	Others	0.73	0.25	0.03	0.12	1.13	3.61
	Total	**17.44**	**9.45**	**2.70**	**1.85**	**31.44**	**100**
4	Teak	45.33	24.43	6.37	4.17	80.29	99.74
	Others	0.13	0.05	0.01	0.02	0.21	0.26
	Total	**45.46**	**24.47**	**6.38**	**4.19**	**80.50**	**100**
5	Teak	31.18	17.01	4.72	3.07	55.98	98.85
	Others	0.42	0.14	0.02	0.07	0.65	1.15
	Total	**31.60**	**17.15**	**4.74**	**3.13**	**56.63**	**100**
Mean (m^3 plot^{-1})		26.99$\pm$11.69	14.19$\pm$6.63	3.75$\pm$1.79	2.79$\pm$0.91	47.72$\pm$20.93	
Mean (m^3 ha^{-1})		168.69$\pm$73.06	88.69$\pm$41.41	23.44$\pm$11.16	17.44$\pm$5.67	298.25$\pm$130.82	

Maximum capacity and water storage in soil

The maximum capacity of soil water storage and soil moisture content in the rainy season (on 17th August 2013) within 2 m soil depth in the teak plantation were investigated. Some physical properties, including bulk densities and gravel content along the soil profile, are given in Table 4. The bulk densities of soil were moderately low throughout the soil profiles. There were small fractions of gravel in the upper 100-cm depth, and somewhat increased in the deeper horizons.

As shown in Table 4, the field capacities of water varied along the soil profile. The high relative value in surface soil might be influenced by the high content of organic matter, whereas the high capacities in subsoils were caused by the high clay accumulation.

S shown in Figure 1, the mean maximum capacity of water storage within 2-m depth of soil profile was 1,133.57$\pm$117.28 m^3 $plot^{-1}$ (or 7,084.81$\pm$733.0 m^3 ha^{-1}). In the middle of the rainy season (on 17th August 2013), the mean water storage in the 2-m soil depth was 758.38$\pm$101.50 m^3 $plot^{-1}$ (or 4,739.85$\pm$634.41 m^3 ha^{-1}). The water storage in soil on this day was 66.90% of the maximum water storage. The soil water storage capacity was 375.19 m^3 $plot^{-1}$ (2344.96 m^3 ha^{-1}).

Table 4 Bulk densities, gravel contents, field capacities, water content on 17th August 2013, maximum capacities of water storage, and water storage on 17th August 2013 along soil profiles in the teak plantation.

Depth	Bulk density	Gravel	F.C.	Water content	Maximum water storage		Water storage on 17th August 2013	
(cm)	(Mg m^{-3})	(% by weight)	(% by volume)	(% by volume)	(m^3 ha^{-1})	($m^3 plot^{-1}$)	(m^3 ha^{-1})	($m^3 plot^{-1}$)
0-5	1.23±0.18, ML	4.50±2.54	46.18±6.90	38.99±3.25	230.89±34.47	36.94±5.51	194.95±16.26	31.19±2.60
5-10	1.24±0.08, ML	5.79±3.29	39.74±13.18	26.95±5.47	198.69±65.88	31.79±10.54	134.75±27.37	21.56±4.38
10-20	1.30±0.04, ML	7.85±3.01	39.91±4.43	30.50±4.61	399.12±44.31	63.86±7.09	305.02±46.09	48.81±7.37
20-30	1.33±0.06, ML	12.65±3.92	26.26±5.83	17.46±6.40	262.59±58.32	42.01±9.33	174.61±64.02	27.94±10.24
30-40	1.37±0.04, ML	9.28±5.10	32.55±10.62	24.51±10.39	325.51±106.17	52.08±16.98	245.10±103.94	39.22±16.63
40-60	1.38±0.08, ML	7.12±3.26	33.90±7.94	25.54±7.59	677.98±158.81	108.47±25.41	510.85±151.76	81.73±24.28
60-80	1.36±0.07, ML	5.48±0.95	39.34±5.82	29.59±6.37	786.89±116.32	125.90±18.61	591.90±127.46	94.70±20.39
80-100	1.42±0.01, ML	7.87±1.86	36.80±6.13	26.16±7.13	735.93±122.53	117.75±19.60	523.21±142.47	83.71±22.80
100-120	1.25±0.12, ML	21.58±5.30	32.30±6.35	19.80±7.19	645.91±127.02	103.35±20.32	396.09±143.78	63.38±23.00
120-140	1.19±0.16, L	22.60±5.77	39.06±4.55	25.87±2.41	781.18±90.94	124.99±14.55	517.30±48.14	82.77±7.70
140-160	1.07±0.19, L	28.05±9.78	35.40±6.94	22.84±5.27	707.94±138.67	113.27±22.18	456.83±105.30	73.09±16.85
160-180	1.26±0.06, ML	21.87±10.17	35.14±10.43	20.81±8.77	702.71±208.57	112.44±33.37	416.20±175.26	66.59±28.04
180-200	1.25±0.10, ML	22.67±12.17	31.47±7.14	13.65±6.94	629.47±142.81	100.72±22.85	273.05±138.70	43.69±22.19
				Total	**7,084.81± 733.0**	**1,133.57±117.28**	**4,739.85±634.41**	**758.38±101.50**

Notes: L = low, ML = moderately low; according to Nongkarn (1986) mentioned by Anongrak (2003)

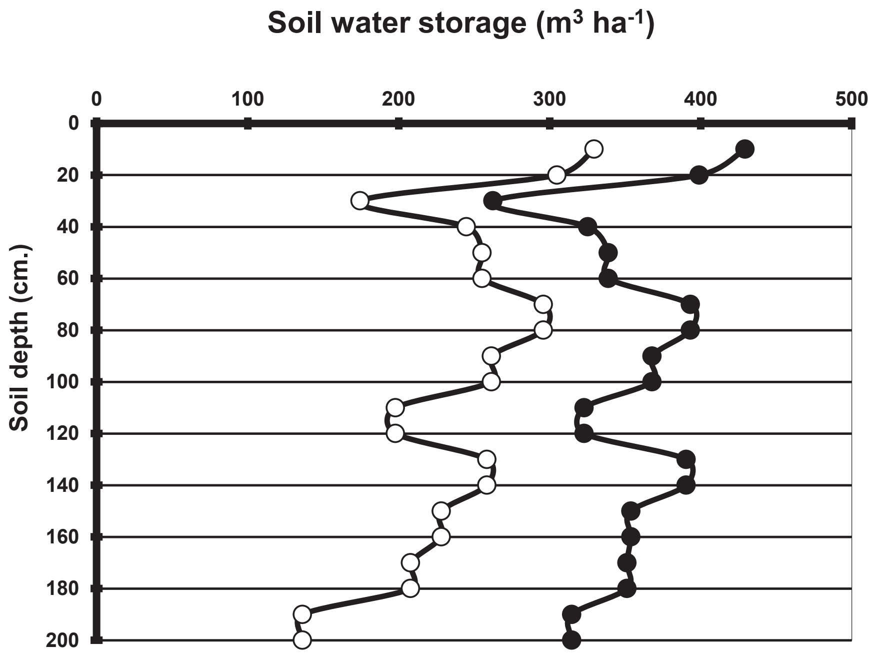

Figure 1 Amounts of water storage along a soil profile in 22-year-old teak plantation. (● = maximum water storage, ○ = water storage on 17th August 2013)

Ecosystem water storage

The water storage in the teak plantation ecosystem includes mainly two components: plant biomass and soil system. It was found that the average amount of water stored in biomass of all teak and succession species was 47.72$\pm$20.93 m^3 $plot^{-1}$ (or 298.25$\pm$103.82 m^3 ha^{-1}). The maximum capacity of water storage in the soil profile within 2-m depth was 1,133.57$\pm$117.28 m^3 $plot^{-1}$ (or 7,084.81$\pm$733.0 m^3 ha^{-1}). Therefore, the total amount of ecosystem water storage (plant biomass and 2-m soil depth) in the teak plantation was 1,181.29 m^3 $plot^{-1}$ (7,383.06 m^3 ha^{-1}). The storage in plant biomass was only 4.04% of the total amount in the stand ecosystem, and the remaining 95.96% were in the soil.

In the rainy season (on 17th August 2013), the amount of water storage within 2-m soil depth was measured to 758.38$\pm$101.50 m^3 $plot^{-1}$ (or 4,739.85$\pm$634.41 m^3 ha^{-1}). Thus, the total amount of ecosystem water storage (plant biomass and soil) in the teak plantation on this day was 806.10 m^3 $plot^{-1}$ (5,038.13 Mg ha^{-1}). The water storage in plant biomass was 5.92% of the total stand ecosystem, and the remaining 94.08% was in the soil. The data indicated a low percentage of water storage in plant biomass of the teak plantation compared to that in the soil.

The teak plantation with a total area of 3600 rai (576 ha) could store a maximum amount of water in the ecosystem (2-m soil depth) of 4,252,644 m^3, and the total water storage on 17th August 2013 (rainy season) was 2,901,960 m^3, that is, it could store more rain water amounting to 1,350,684 m^3. In general, the ecosystem water storage varied with time of the year.

The mean stem gbh and height of teak in the 22-year-old plantation at the Doi Tung area were 63.87±7.85 cm and 16.62±3.12 m, respectively. The growth rate of teak in this area was identified as intermediate. The teak plantations at the Doi Tung areas are underlain by granite rock with very steep slopes, and the growth varies greatly with different topographic conditions. The Silvicultural Division, Royal Forest Department (1993) described that in the intermediate site of teak plantation, the teak trees in the 22-year-old stand were 57.06 cm gbh and 16.94 m height. In the good site, the trees were 78.79 cm of gbh and 28.92 m height. However, the objective of teak plantation at the Doi Tung areas is for ecological restoration, but not for economic purposes.

A forest plantation ecosystem can store water in three components: forest biomass, organic layers on forest floor and soil system. However, many tropical natural forests and plantation forests usually do not have organic layers on forest floor due to forest fire and rapid litter decomposition. In plant biomass, the water was stored in different organs, including stem, branch, leaf and root. The amount of water storage varies among tree species, and even the same species the storage is different among tree sizes and ages. In soil, the water storage depends on soil texture, organic matter content and soil depth. Soil water retention improves with increase in organic matter increases, as does infiltration rate and water holding capacity (Brady and Weil, 2010). According to Waring and Runing (1998), a forest ecosystem is important for energy balance. The energy exchange between vegetation and the environment involves a number of processes. Water stored in plants and soil can absorb heat energy during daytime, and cool down through evaporation and transpiration. The heat transfer is re-radiation, convection and wind removal. In this study, the amount of water stored in teak biomass of the 22-year-old plantation was 47.72 m^3 $plot^{-1}$ (or 298.25 m^3 ha^{-1}). No data are available for the water storage in plant biomass of forest vegetation.

Plant succession usually occurs in forest plantations, and the stands will usually develop to climax forest. Pornleesangsuwan *et al.* (2012) found that plant succession in the pine plantations involved 72 broad-leaved tree species which also existed in the nearby fragmented lower montane forests. In this study, successional tree species played an important role in biomass water storage in the teak stand. Plant succession was good in Plot 1, and resulted in a high contribution of the successional species to water storage of 43.16% of the total stand. The contribution was lower in the stands where plant succession was poor. Before planting teak, the plantation areas were open land, and used for shifting cultivation. Some areas had no trees before teak plantation, and thus, the teak stand had poor plant succession, whereas other sites might have had living stumps which sprouted or trees that acted as seed sources in the teak stands.

In general, the water storage in soil varies with time, day or month. It is high in rainy season and very low in dry season. In this study, the water storage in soil profile within 2-m depth on 17th August 2013 in the teak plantation accounted for 66.90% of the maximum storage. The storages in forest biomass was only 5.92% of the total stand ecosystem, and the remaining 94.08% was in the soil. The percentage of water storage in the plant biomass was much lower than that in the soil. *Withawatchutikul et al.* (2011) reported that water storage in forest soils were different among the forests. The montane forest (150-cm soil depth), moist evergreen forest (100-cm), dry evergreen forest (70-cm), mixed-deciduous forest (60-cm) and dry dipterocarp forest (30-cm) could store water volume of 9475.5, 4782.0, 3184.3, 2611.8 and 1441.5 m^3 ha^{-1}, respectively. The soil depth is an important factor affecting the amount of soil water storage.

CONCLUSION

The ecological roles of the 22-year-old teak plantation on water storage are summarized as follows:

1. The water storage was occurred mainly in two components: plant biomass of teak and successional tree species, and soil system. The maximum capacity of ecosystem water storage (plant biomass and 2-m soil depth) in the teak plantation was 7,383.06 m^3 ha^{-1}.

2. A small percentage of water storage occurred in the plant biomass, and the remainder was in the soil. As for maximum capacity, the water storage in plant biomass was only 4.04% of the total stand ecosystem, and the remaining 95.96% was in the soil.

3. The successional tree species in the teak plantation had an important role on the water storage. The contribution of successional species in the teak stand to water storage in biomass increased in the stand with good plant succession.

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